Aspects of the Ecology of Sandy Beaches along Durban's Urbanised Coastline

By

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Preface

This work described in this thesis was conducted while at the School of Biological and Conservation Sciences, University of KwaZulu-Natal, and was part of a pilot internship programme with the eThekwini Municipality under the supervision of Professor David S Schoeman, Dr. Albertus J Smit and Dr. Debra Roberts.

This study represents original work by the author and has not been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others, it is duly acknowledged in the text.

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Urban sandy beaches are the primary focus of numerous pressures. Among these are the disruption of sand budgets because of an increasing demand for coastal infrastructure, pollution from landward sources, and recreation and the associated stressors such as trampling and off-road vehicles. More recently, climate change and the manifestations thereof, such as sea-level rise and increased storminess have added to the suite of threats to sandy beach ecosystems. Despite being important natural and economic resources these urban systems have not received adequate research attention and, consequently, the management of sandy beaches has been based on ecologically unsustainably principles.

The aims of this study were to provide baseline biodiversity information of urban beaches along the Durban coastline, South Africa, as a step toward the application of improved ecological management procedures for metropolitan beach ecosystems. Macro- and meiofaunal communities of 15 representative beaches along the Durban coastline were quantitatively surveyed using standard sandy beach sampling protocols.

This study showed that Durban's beaches, despite being highly urbanised, harbour rich and abundant faunal communities. This is contrary to previous findings that reported a paucity of life on Durban beaches. A total of 23 macrofauna taxa were identified, with the dissipative Battery Beach having highest diversity with 13 macrofaunal species. La Lucia, a reflective beach, had the highest macrofaunal abundance and was the second most diverse beach, thus departing from global trends that report a poor macrofaunal community of reflective beaches. Twenty higher-level meiofauna taxa were recorded in this study and it was found that meiofauna abundance showed a significant and positive relationship with beach width. Because of the coarse taxonomic resolution, meiofauna diversity may likely be much greater than that recorded in this study.

The conventional view that sandy beaches are resilient to exploitation was questioned when it was found that meiofauna assemblages were significantly and negatively impacted by stormwater outlets on two of the sampled beaches, possibly through freshwater intrusion or erosional effects. This raises questions regarding the functioning of beach ecosystems, and the services they provide, when faced with anthropogenic stressors that impact faunal communities.

This snapshot survey of aspects of the ecology of Durban’s sandy beaches has provided much needed baseline data for this coastline. These data will be used in conjunction with other available data toward the development of a fine scale systematic conservation plan for Durban to enable the prioritisation of conservation and management efforts. The use of these data will also facilitate the development of guidelines for the integrated ecological management of urban sandy beach ecosystems.

Acknowledgements

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To my supervisor, Prof. Dave Schoeman, for knowing exactly what each of his students needs. Thank you for giving me the space to feel my way around this project, for many inspirational discussions and for all the advice and encouragement. I would also like to thank my co-supervisors, Dr. AJ Smit for always being my champion, especially during the difficult teething stages of the project and then at the end during the stress of completion, and Dr. Debra Roberts for being open-minded about sandy beach research.

To all those that painstakingly helped me move tons of sand off the beach, my deepest gratitude. Micole Moses for never saying no, Christopher Jones for the comic relief, Nasreen Khan Vermeulen for always being so enthusiastic, Elizabeth Plumb for your motivational talks, and Nichola van Os for your optimism. Thanks also to Santhiska Pather, Nelson Miranda, Justin Lock, Abdullah Vermeulen, Timothy Wiggill, Sean O’Donoghue, Kirby Waddington, Keren Worlock, Kendyl Le Roux, Robin Beard, Christina Francis, Chirag Patel, Lyle Ground, Nicholas Molver and Kamini Govender. I am extremely grateful for all your efforts in the field.

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Lastly, this thesis is dedicated to my family, especially to my mum, who taught me to think and to dream.

Chapter 1 – A review of the pertinent sandy beach literature

O investigator do not flatter yourself that you know the things nature performs for herself – Leonardo da Vinci (1452 – 1519)

Abstract

This review will discuss the pertinent sandy beach literature thus far, together with core elements of beach ecology, and then place these in the context of the aims and objectives of this study. The focus of this literature review is the physical characteristics of sandy beach ecosystems, the macro- and meiobenthos of sandy beaches and the physical environment as determinants of invertebrate community structure on beaches.

1.1. Introduction

Sandy beaches comprise two-thirds of the world's tropical and temperate coastlines (McLachlan and Brown, 2006), but remain one of the most neglected fields of scientific study. Most people regard beaches at worst as piles of sand, devoid of life, and at best as marine deserts. This is a direct consequence of studies of their ecology being grossly under-represented in the scientific literature (Fairweather, 1990). Ecological research on beaches has lagged behind that of other coastal ecosystems such as rocky shores, estuaries and coral reefs. This has been explained in terms of the nature of the environment (dynamic and physically rigorous) and of the organisms themselves (inconspicuous due to their fossorial lifestyles or small size).

A recent study documents possible evidence for life's origin on beaches approximately 4.3 billion years ago. The hypothesis broadly states that beach sand contained vital elements that linked abiotic and biotic systems on Earth (Adam, 2007). Today, life persists on beaches; in fact, beaches teem with life, both macro- and microscopic, and these organisms impart many important goods and services. Apart from being popular venues for recreation and possessing great aesthetic appeal (Parsons and Powell, 2001), beaches play an important role in storm protection (buffer areas), with the beach face absorbing and dissipating the destructive energy of waves (Bird, 1993; McLachlan and Brown, 2006). Dunes on the beach backshore also naturally protect coasts, and in many areas where structural development has been located on the beach or in vegetated dunes and impinged on their protective capacity, storms have resulted in severe devastation (Bird, 1993). Moreover, as the interface between the marine and terrestrial environments, sandy beach ecosystems interact with both sea and land, making them crucial links in the coastal zone (e.g., McLachlan and Erasmus, 1983; Schlacher *et al*., 2006). Beaches are thus important not only because they may be the site for life's origin or because of their high socio-economic value, but also because detailed knowledge of these systems is fundamental to the understanding of coastal processes as a whole.

Beach ecosystems are, however, under threat. Exponential human population growth and the concomitant increase in the demand for coastal infrastructure result in the excavation of sandy beach and dune systems in favour of development (Nordstrom, 2000; Scapini, 2000). Further human impacts include pollution (Brown, 1983; Watling, 1983; de la Huz *et al*., 2005; Ramirez *et al*., 2005), resource exploitation (Schoeman *et al*., 2000; McLachlan *et al*., 2006), tourism related activities such as access by off-road vehicles (Hill *et al*., 1988; Williams *et al*., 2004; Neves and Bemvenuti, 2006) and trampling (Fanini *et al*., 2005; Gheskiere *et al*., 2005) and beach nourishment (Gorzelany and Nelson, 1987; Nelson, 1993; Peterson *et al*., 2000; Fanini *et al*., 2009).

Globally, such inappropriate developments are particularly prevalent along urban coasts. Development along South Africa's shores is extensive, particularly along the country's fastest growing urban centre, Durban in KwaZulu-Natal. Unfortunately, this trend coincides with global warming which not only results in sea-level rise, but also an increase in the frequency and severity of storms (IPCC Fourth Assessment Report, 2007). Individually, sea-level rise and increased storminess will act to accelerate the rate of beach erosion (Feagin *et al*., 2005; Cowell *et al*., 2006), but what is often overlooked is that an interaction between these processes might have catastrophic consequences along developed shorelines (Nordstrom, 2000; Slott *et al*., 2006). Beach ecosystems are thus forced into a "coastal squeeze", infringed on the terrestrial and seaward sides by rapid urbanisation and sea level rise due to global warming, respectively. When the beach is lost, not only are coastal properties threatened, but biotic communities resident on the beach disappear with unknown consequences for coastal ecosystem function. The real question is whether the loss of beaches will have ecological consequences. The problem is that the processes underlying these ecosystem services have seldom been studied in detail anywhere in the world.

Prior to 1941, most of the work conducted on sandy beaches was of a taxonomic nature as many scientists strove to identify new species in the marine environment. The earliest ecological study of a sandy beach was conducted in 1941 (Pearse *et al*., 1942), but it was only in the early 1980s that beach ecology began to develop a sound body of theory to steer sandy beach research (Defeo and McLachlan, 2005) culminating in the first sandy beach symposium in 1983 (McLachlan and Erasmus, 1983). This was the first international gathering of beach scientists and encouraged a multidisciplinary approach to the study of beach ecosystems. Over the past two decades comparatively more research has been conducted on sandy beaches resulting in them being recognised as viable marine ecosystems and no longer a "scientific no-man's land" (McLachlan and Erasmus, 1983). While South Africa has in many ways been at the forefront of sandy beach research, the majority of studies have been focused on beaches on the south and west coasts of the country. The east coast, and particularly the Durban shores, has received little attention from beach ecologists. This review will discuss the pertinent sandy beach literature thus far, together with core elements of beach ecology, and then place these in the context of the aims and objectives of this study.

1.2. The physical environment

There exists a lack of consensus on the term "beach". The diverse working definitions employed are dependent to some degree on a researcher's disciplinary bias. Social, economic or legislative studies (e.g., West, 1984) have taken the beach to be the visible body of sand between the high and low water marks. Ecological studies (e.g., Chapman, 1983) may define beaches in terms of processes such as water dynamics, sediment transportation and energy dissipation (Bally, 1986). Beaches have often been depicted as a prism of sand that is modified by wave action at various timescales (e.g., Bascom, 1964; McLachlan *et al.*, 1981b; Short and Wright, 1983). The concept of a "sand prism" has been expanded by various authors who have defined diverse terrestrial and marine boundaries. The landward boundary has included the upper limit of the swash zone (Short and Wright, 1983), the drift line excluding the dunes (McLachlan, 1983) and the incipient foredune (Chapman, 1983). On the seaward side, the limit has been considered the outer extent of surf circulation cells (McLachlan, 1983), the depth at modal wave base (Short and Wright, 1983) and the zone stable enough to include bioturbation (Chapman, 1983).

In more recent years, authors have come to refer to the "littoral active zone" – a combination of the surf zone, intertidal beach, dune system, and in some instances, river mouths and estuaries (McLachlan and Brown, 2006). Sediment dynamics is one of the defining characteristics of sandy shores; accordingly, the littoral active zone, which refers to the zone of sand that is continually reworked by wind or wave action, encompasses all the elements of this system. Sediment transport by wave action may extend well into the surf zone. On the other hand, aeolian or wind driven sediment transport has the capacity to move sand to fully vegetated dunes. This is a process driven definition in which the sand beach is seen as a geomorphic system (Tinley, 1985), wherein changes to any one part of the system would result in changes to other parts. This study is focused on the intertidal sandy beach – that part of the littoral active zone alternately covered and uncovered by tides. Implicit in this definition is the exclusion of muddy beaches (intertidal sand flats near estuaries), along with gravel, pebble, cobble and boulder beaches (Table 1.1) and inclusion of any beach consisting of sediment with a median grain size of between 53 μm and 2000 μm.

Table 1.1. Grain-size characteristics according to the Wentworth scale (Gray, 1981)

Grain size (mm)	Phi (Φ) scale	Type of sediment
256	-8	cobble
64	-6	
16	-4	pebble
4	-2	
2	-1	granule
1	0	very coarse sand
0.5	1	coarse sand
0.25	2	medium sand
0.125	3	fine sand
0.0625	4	very fine sand
0.031	5	coarse silt
0.0039	8	silt
0.002	9	
0.00006	14	clay

Sandy beaches are not homogeneous piles of sand but cover a range of types called beach morphodynamic states, defined by wave climate, tidal regimes and sediment granulometry (McLachlan and Brown, 2006 and the references therein). Moreover, unlike rocky shores where distributional gradients (both physical and biological) are manifested perpendicular to the shore, on sandy beaches, there are three important gradients: the alongshore gradient (parallel to the shore), across-shore gradient (perpendicular to the shore) and the depth gradient.

1.2.1. The makings of a beach: wave action, sedimentology, beach slope and tides

Wave action has been referred to by some authors as a “super parameter” that is a primary determinant of beach morphodynamic type (McLachlan, 1983). Wave climate affects both the size and shape of the beach, sediment distribution and size, as well as moisture and oxygen content of the sand. Studies refer to exposed and sheltered beaches as well as high or low energy beaches, based largely on the wave action of the respective sandy shores. Until McLachlan (1980) developed a rating system that unified classification of beaches from different parts of the world (Table 1.2 and 1.3), many of these terms were subjective.

Together with wave action, an additional physical character of sandy beaches that requires attention is the sediment itself. Rivers may transport sand and gravel to the marine environment and dune sand may enter the intertidal by wind or waves. In addition, beach sand is composed of shell fragments and other biogenic debris transported to the beach from both marine and terrestrial environments (Swart, 1983). The sediment particle size that occurs on sandy beaches is determined by the sources of beach material and the wave energy of the beach (McLachlan, 2001), with highest grain sizes corresponding to beaches with greatest wave action. Wave action is also responsible for sorting of beach sediments on a gradient perpendicular to the shore in a similar manner, with coarser sediments occurring on the part of the beach on which waves break. On a typical sandy beach, this occurs low on the shore (Swart, 1983) as the denser particles settle out of the water column resulting in finer sediment particles being carried to areas higher on the shore by swash or wind action.

The above two parameters, wave action and sediment grain size, work together with tidal regimes to define beach slope which is an overall indicator of beach state (Defeo and McLachlan, 2005). Beaches can either be macrotidal (a spring tidal range of > 4 m) or microtidal (spring tidal range < 2 m). Wide beaches with flat slopes occur when there is a combination of high wave action, large tidal regimes and small grain size. Conversely, narrow, steeply sloped beaches occur in microtidal conditions with low wave energy and coarse sand (e.g., Rodil and Lastra, 2004).

The interaction between waves, sediment and tides has repeatedly been found to be the primary driver of beach type (e.g. Bascom, 1980; McLachlan, 1996; McLachlan, 2001; Short, 2006). A few of the secondary drivers of beach type include local bathymetry, coastal topography, the source of beach sediments, estuarine mouth dynamics, the impacts of storms and more recently, climate change effects such as sea level rise.

The parameters discussed above account for the dynamic nature of beaches, whereby a storm may alter the slope and sediment distribution of a beach thus changing the morphodynamic type. Similarly, wind and wave climate can act to increase the temporal variability of beach morphodynamic type. Coastal squeeze and sea level rise also contribute to the changes in beaches.

Table 1.2. Rating scheme for assessing beaches in terms of the degree of exposure (McLachlan, 1980)

Parameter	Rating					Score
Wave action	practically absent					0
	variable, light to moderate, wave height seldom exceeds 0.5 m					1
	continuous, moderate, wave height seldom exceeds 1 m					2
	continuous, heavy, wave height mostly exceeds 1 m					3
	continuous, extreme, wave height never less than 1.5 m					4
Surf zone width	very wide, waves first break on bars					0
	moderate, waves usually break 50 – 150 m from shore					1
	narrow, large waves break on beach					2
% very fine sand (63 – 125 μm)	> 5%					0
	1 – 5%					1
	< 5%					2
Depth of the reducing layers	0 – 10 cm					0
	10 – 25 cm					1
	25 – 30 cm					2
	50 – 80 cm					3
	> 80 cm					4
Stable macrofauna burrows	present					0
	absent					1
Median particle diameter[1] (μm)	Slope of the intertidal zone					
	> 1/10	1/10 – 1/15	1/15 – 1/25	1/25 – 1/50	< 1/50	
> 710 (> 0.5 Φ)	5	6	7	7	7	
500 – 710 (1.0 – 0.5 Φ)	4	5	6	7	7	
350 – 450 (1.5 – 1.0 Φ)	3	4	5	6	7	
250 – 350 (2.0 – 1.5 Φ)	2	3	4	5	6	
180 – 250 (2.5 – 2.0 Φ)	1	2	3	4	5	
180 (> 2.5 Φ)	0	0	1	2	3	
Sum of the scores obtained above	*Highest exposure*					20
	Lowest exposure					0

[1] Refer to Table 1.1 for detail regarding sediment classification

Unlike deep sea, coral reef and rocky shore environments, wherein biological interactions such as competition and predation play a major role in structuring biotic communities, sandy beaches are physically controlled systems (McLachlan, 1993; Moreno *et al*., 2006) and the physical environment is a primary determinant of biological diversity and ecosystem function.

Table 1.3. Categories of exposure of sandy beaches according to the total score obtained from Table 1.2 (McLachlan, 1980)

Score	Beach type	Description
1 – 5	Very sheltered	Virtually no wave action; shallow reduced layers; abundant macrofaunal burrows
6 – 10	Sheltered	Little wave action; reduced layers present; usually some macrofauna burrows
11 – 15	Exposed	Moderate to heavy wave action; reduced layers deep if present; usually no macrofauna burrows
16 – 20	Very exposed	Heavy wave action; no reduced layers; macrofauna only tough motile forms

1.3. The fauna of sandy beaches

The most notable aspect of sandy beaches is the mobility of the substratum, devoid of surfaces for the physical attachment of organisms. It is a rigorous environment wherein organisms must be either rapid burrowers or small enough to live between sand grains such that the effect of wave and tidal action is negligible. This mobile substratum confers a three dimensionality to the intertidal sandy beach, similar to that of the open ocean pelagos, and provides two sub-habitats for faunal and microalgal populations. These are 1) the sand surface and upper layer of sediment where macrofaunal forms abide, and 2) the interstitial systems between individual sand grains in which meiofauna and microfauna can be found (McLachlan, 1983).

Most of the ecological work on sandy beaches has been focused on macrofauna (Figure 1.1). The macrofauna of sandy beaches are usually defined as those organisms larger than 1 mm, i.e. animals that are retained in a 1000 μm mesh (McLachlan, 1983). This is different to estuarine environments where the lower limit for macrofauna is usually 500 µm. Dominant sandy beach macrofauna are polychaetes, molluscs (clams and gastropod snails) and crustaceans (isopods, amphipods, anomurans and decapods); however most of the major invertebrate taxa are represented on sandy soft-substrata.

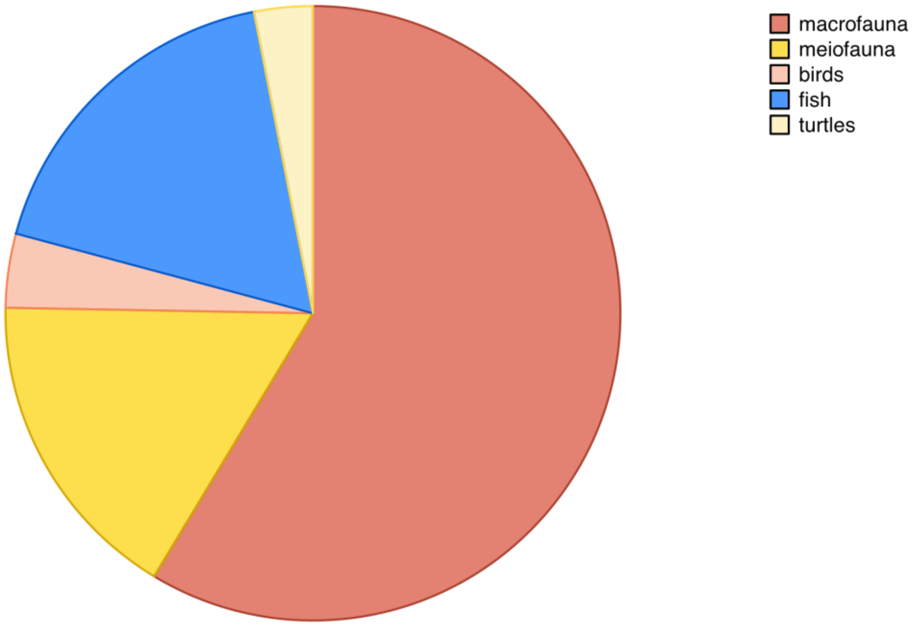

Figure 1.1. Relative number of studies conducted on sandy beach fauna. Results obtained from searching scientific databases and plotting the number of "hits" each group displayed. Only studies of the ecology of each group of taxa were taken into consideration i.e., physiology and systematics were excluded.

To overcome the rigorous physical stress brought upon by continual wave action and tidal cycles, sandy beach macrofauna have evolved certain adaptations that can be either behavioural or physiological. Most are rapid burrowers that reduce the effects of wave action by digging into the sand e.g. the mole crab, *Emerita austroafricana* (Hippidae). Others like the plough snail *Bullia natalensis* (Nassariidae) migrate up and down the beach with the tide, scavenging on dead or dying animals on the beach (McLachlan, 1988). Sandy beach macrofauna of the top shore, on the other hand, are air-breathers e.g. ghost crabs of the genus *Ocypode* that remain in burrows, only emerging at low tide (McLachlan, 1988).

Unlike macrofauna, the meiofauna (derived from the greek *meio* meaning "smaller") of sandy beaches have not been as extensively studied. This may be due to their small size, i.e. animals that pass through a 1 mm sieve but are retained by a mesh size of 0.045 mm (Dye and Fustenburg, 1988; Higgins and Thiel, 1988). It is a term that is used exclusively for the benthos, the planktonic organisms being treated as a separate category. The dominant groups of beach meiofauna are nematodes and harpacticoid copepods, with turbellarians, ostracods, kinorhynchs, tardigrades and mystocarids also occurring but in smaller numbers (Brown and McLachlan, 1990). Meiofauna may be either temporary (larval forms of macrofauna) or permanent interstitial forms (McLachlan, 1983).

In addition to those organisms that inhabit the sediment – the benthic fauna and flora – sandy beaches also play host to zooplankton (Clutter, 1926; Moran, 1972; Youngbluth, 1979), fish (Steele, 1968; Beyst, 2001; Selleslagh and Amara, 2008), and birds (Dugan, 2003; Hubbard and Dugan, 2003) and in some parts of the world, reptiles (Mazaris *et al*., 2006) and mammals as well. The dominant zooplankton of sandy beaches are epibenthic mysids of the genus *Mesopodopsis* and *Gastrosaccus* (Moran, 1972; Clutter, 1976), but copepods also occur in the surf zones of beaches (Youngbluth, 1979). Estuaries are known to be important nursery grounds for several fish species (Wallace and van der Elst, 1975) but because beaches are such physically demanding environments, their function as nurseries for juvenile fishes has often been overlooked. Studies have, however, shown that many fish species may use beaches as sites of recruitment, growth and feeding of juveniles (Steele, 1968; Lockwood, 1974; Beyst, 2001; Suda *et al*., 2002). The more charismatic or iconic members of coastal food webs, birds and turtles, are also found to use dunes on the beach backshore as nesting grounds (Dugan, 2003; Hubbard and Dugan, 2003). This study is focused on the zoobenthos of sandy beaches, specifically meio- and macrofauna, and further discussion will focus on these groups of organisms.

1.4. The physical environment as a determinant of sandy beach community structure

Many studies have provided evidence for a strong relationship between beach type and biodiversity (e.g. McLachlan, 1980; McLachlan, 1990; Defeo and McLachlan, 2005). An extensive body of literature exists on the development of beach classifications schemes. With regard to macrofauna, crustaceans tend to be most abundant on exposed beaches and polychaetes dominate the most sheltered conditions (Dexter 1983, Defeo and McLachlan, 2005) (Figure 1.2).

Short (1996) developed an index for microtidal beaches, recognising that beach types exist on a continuum of morphodynamics, from reflective through intermediate to dissipative. This index of beach type is called Dean's parameter (Ω) and is given by:

$$\Omega = \frac{Hb}{Ws.T}$$

where *Hb* is the modal breaker height (m), *Ws* is sand fall velocity or sediment sinking rate ($m.s^{-1}$) and *T* is modal wave period (s). Dean's parameter is a dimensionless measure of where a given beach lies on a scale form reflective to dissipative. It is essentially a measure of how much the wave energy of a beach can erode sand (Defeo and McLachlan, 2005). Dissipative beaches are erosional, losing sand due to wave action, and reflective beach states are accretional, in that wave action transports sand landward. If $\Omega < 2$, beaches are classified as reflective and if $\Omega > 5$ they are dissipative. A $2 < \Omega < 5$ means a beach is intermediate and can be intermediate-reflective or intermediate-dissipative depending on which state it most closely resembles (Figure 1.1)

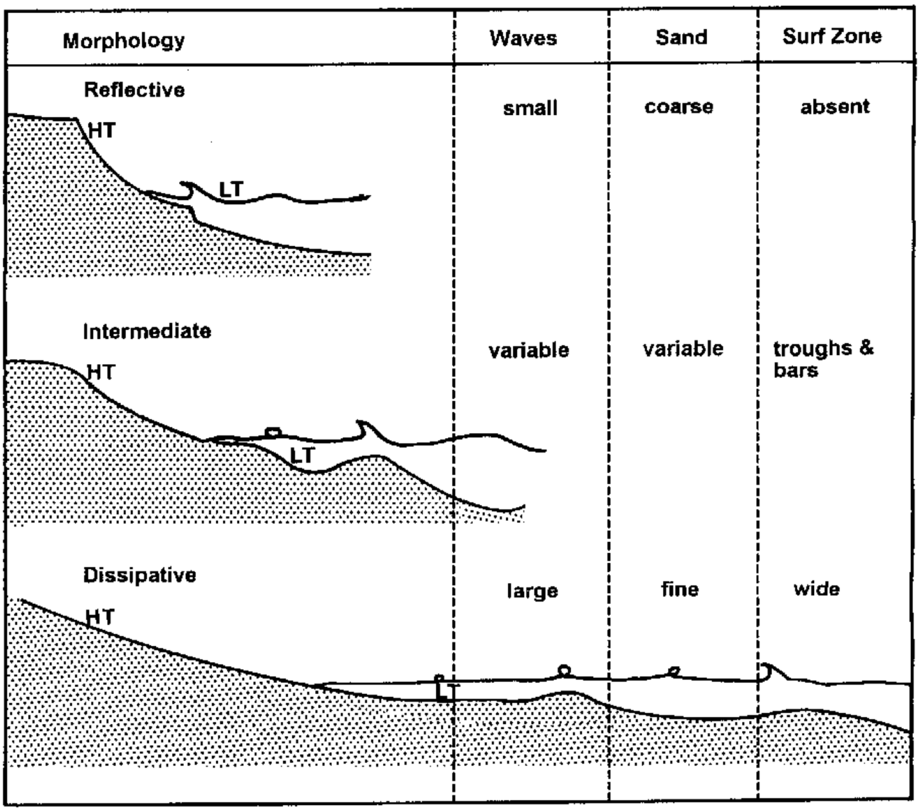

Figure 1.2. Diagrammatic representation of beach morphodynamic states under microtidal conditions (HT – high tide, LT – low tide) (source: McLachlan, 2001)

A shortfall of Dean's parameter is that it is an index concerned only with microtidal beaches; thus, it does not incorporate tidal regimes. The relative tide range (*RTR*) is a measure of the relative importance of waves and tides in determining beach morphodynamic type. *RTR* is given by:

$$RTR = TR/Hb$$

where *TR* is the spring tidal range (m). Dean's parameter and *RTR* were combined by McLachlan and Dorvlo (2005) to give a composite index of each type – the beach index (*BI*):

$$BI = \log 10\left(\frac{Mz.TR}{S}\right)$$

Here, *Mz* represents the mean grain size in Φ units (+1 to avoid negative numbers), *TR* is the spring tidal range (m) and *S* is the beach face slope.

The use of beach classification equations has been met with scepticism from certain authors (e.g., Jackson, 2005). In many cases it was found that a marked difference existed between actual beach morphology and that which was predicted by beach state models. This was attributed this to underlying geological factors (Jackson, 2005). Such parameters, though useful in standardising beach classification schemes, must thus be used with caution.

Physical characteristics of beaches can be used as a proxy for biological community structure. In addition to exposure ratings, macrofauna community structure has been found to be correlated with Dean's Parameter as well as with the beach state index (e.g., Colombini, 2005; Lastra, 2006). In general, species richness increases linearly from reflective to dissipative beach states and species abundance increases exponentially over the same range (Hacking, 1998; Defeo *et al*, 2001). This trend of greater richness and abundance on wider, flatter beaches has been found to be a global occurrence, evidenced by studies conducted in Australia (e.g., Dexter, 1983), New Zealand, Chile (e.g., Jaramillo and McLachlan, 1993), Uruguay (Defeo *et al.*, 1992;

Gimenez and Yannicelli, 2000), Spain (Rodil and Lastra, 2004), India, Mexico (Dexter, 1976) and Oman, to name a few.

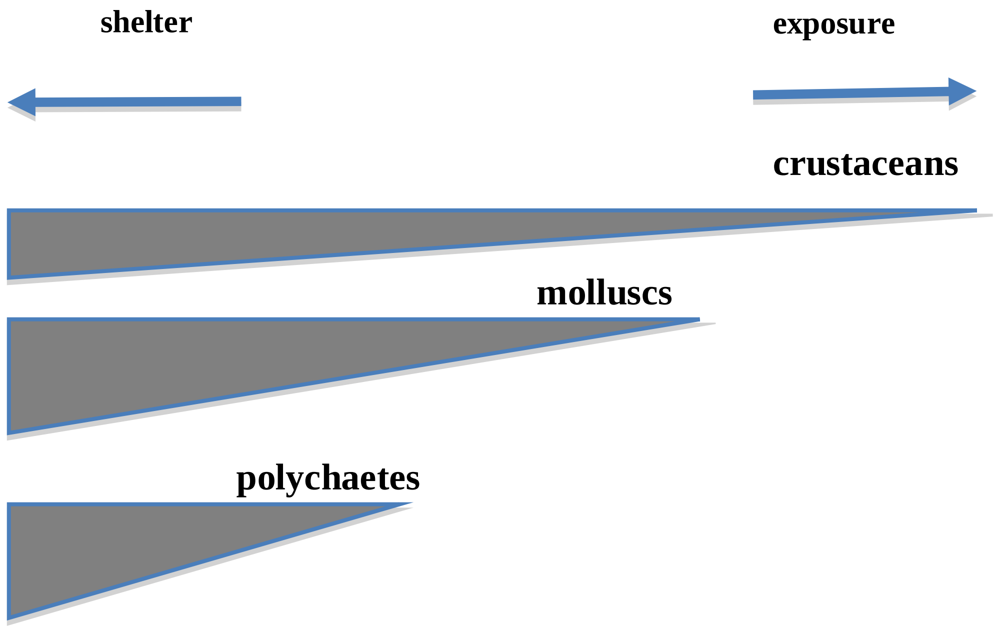

Figure 1.3. Macrofaunal responses to sandy beach exposure gradients (source: McLachlan, 1983)

Reflective beaches may have no macrofaunal organisms or harbour one or two species of supralittoral forms, while dissipative beaches may have as many as 40 different taxa (McLachlan, 1993). Meiofauna patterns in relation to beach parameters and composite beach indices have in some instances been found to show opposite trends in comparison to the macrofauna. Causative explanations for the spatial variations in sandy beach communities have been explored by many authors (e.g., Arntz *et al*, 1987; Defeo *et al*, 2001). McLachlan (1993) defined the “swash exclusion hypothesis” which was a refinement of his earlier suggestion that the swash climate of a beach together with sediment particle diameter were the primary determinants controlling macrofauna distribution patterns on sandy beaches. Swash climate is in simple terms a manifestation of wave and tidal action – the movement of water over the beach face as experienced by intertidal fauna (McLachlan, 2001). In this manner, a harsh swash climate may be responsible for excluding certain species (McLachlan, 1993, 2001) in the intertidal zone, as it creates turbulence that may increase the chances of organisms being stranded on areas of the beach they are not adapted to cope in (McLachlan, 2001; Defeo and McLachlan, 2005).

The mechanisms governing spatial distribution of organisms across the continuum of beach morphodynamic types needs further investigation. Studies have indicated that beach community structure may involve more than the physical environment. For example, Incera *et al*. (2003) found that the biochemical composition of sediment organic matter may play a role in shaping the distribution and abundance of organisms on sandy beaches. Moreover, in a study to determine if biotic interactions play a part in the distribution of the cirolanid isopods *Excirolana armata* and *Excirolana braziliensis*, Defeo *et al* (1997) provided evidence that interspecific interactions cannot be overlooked as determinants of community structure and distribution on beaches. Nevertheless, it is the aforementioned indices based on physical beach parameters that have been found repeatedly to explain beach biodiversity structure on local and global scales. While biological explanations should not be overlooked, these effects may be mostly negligible on sandy beaches, or may in fact be ultimately linked to physical parameters.

1.5. This study

Approximately 70 % of South Africa's coastline consists of sandy beaches, and many pioneering ecological studies of beaches have been conducted along this coast. Figure 1.4 is a summary of ecological sandy beach studies conducted along the South African coast.

South Africa has in many ways been at the forefront of sandy beach research except that most studies have been concentrated on the south and west coasts of the country. The east coast is conspicuously absent from the peer-reviewed literature (Figure 1.3). This is despite the fact that 79 % of KwaZulu-Natal's coastline is composed of sandy soft substrata. In addition, of the few ecological beach studies conducted along the east coast, two were in the Maputoland Reserve of northern KwaZulu-Natal and the other on the Transkei coast. No published records exist of urbanised beaches within KwaZulu-Natal, like those of one of the province's fastest growing urban centres – Durban. Bally (1981) reviewed intertidal sandy beach work conducted on South African sandy shores and both he and Dye *et al*. (1981) have recorded the paucity of knowledge on Durban sandy beaches. Nearly three decades later, Durban beaches remain unchartered territory in terms of ecological beach research.

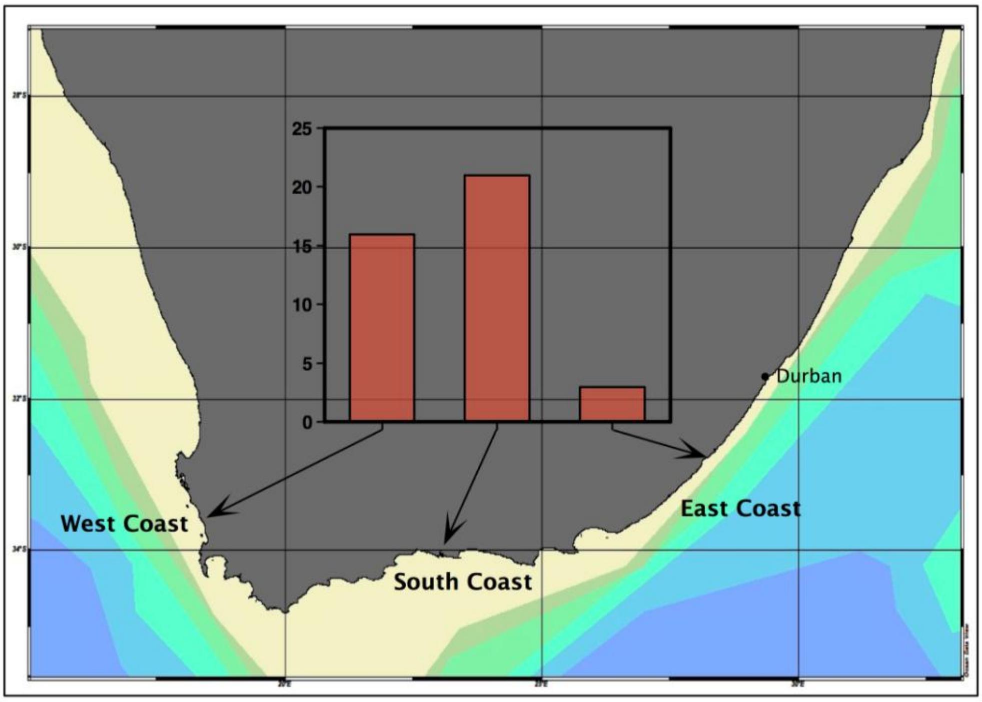

Figure 1.4. A summary of the number of peer-reviewed scientific publications from research conducted along the South African coastline. This chart was constructed by searching scientific databases such as Scirus and ISI Web of Knowledge using keywords relating to the ecology of sandy beaches.

Beaches are regular tourism hotspots due to their recreational and aesthetic attributes. Durban's beaches are particularly popular because the region as a whole is climatically favourable. Studies have shown that tourism related activities might negatively impact the beach environment (Gheskiere *et al*., 2005b). In addition to tourism, the migration of people to coastal areas has resulted in an expansion of coastal cities and a subsequent exacerbation of coastal development. Inappropriate developments are prevalent along all urban coasts and are now expanding along the Durban coastline. Unfortunately, this trend coincides with global warming, which not only results in sea-level rise, but also an increase in frequency and severity of storms

(IPCC Fourth Assessment Report, 2007). What is often overlooked is that an interaction between these processes might have catastrophic consequences along developed shorelines (Slott *et al*., 2006) not only in economical terms, but ecologically as well (Arntz, 1987).

These factors are thought to have already caused considerable degradation of the intertidal zone in terms of biodiversity and ecosystem services. Without baseline information, the validity of this premise is difficult to assess, impeding the establishment of appropriate management strategies to protect coastal processes. Due to the dearth of information pertaining to Durban's sandy beaches, there exists a need for baseline ecological data, without which meaningful predictions cannot be made regarding the extent to which factors such as global climate change and prolific coastal development actually serve to alter an ecosystem. Sandy beaches are the most extended intertidal system along the Durban coastline, and understanding the responses of beach ecosystems to anthropogenic perturbations is essential for appropriate management.

1.5.1. Aims and objectives

The purpose of this study was to revise and update knowledge of Durban's intertidal sandy beaches, given the paucity of information available. The research aimed to investigate aspects of the macro- and meiofaunal communities of Durban's sandy beach ecosystems and to identify the spatial determinants of beach biodiversity.

To this end, objectives of this study were:

- To describe the composition (diversity and abundance) of macrofauna of intertidal sandy beaches along the Durban coastline;
- To describe meiofaunal community structure of a range of Durban sandy beaches in relation to beach morphodynamic type, proximity to a nutrient point (estuary mouth, storm- or wastewater) and degree of urbanisation.

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Chapter 2 – Intertidal sandy beach macrofauna of the central Durban area

"To see a world in a grain of sand" – William Blake (Auguries of Innocence)

Abstract

Five sandy beaches situated along the Durban coastline, in South Africa, were sampled for macrofauna using standard beach sampling protocol. This was a pilot study with the aim of providing necessary ecological data on the ecology of macrofauna on highly urbanised sandy beaches given the paucity of available information. The objectives were threefold: 1) to quantify the macrofaunal abundance, diversity and biomass of the selected beaches, 2) to examine zonation patterns of macrofauna across the intertidal and 3) to test the hypothesis that Durban's urbanised beaches have significantly different macrofauna communities than less urbanised KZN beaches. This study showed that Durban's beaches, despite being highly urbanised, harbour rich and abundant faunal communities. This is contrary to previous findings that reported a paucity of life on Durban beaches. A total of 23 macrofauna taxa were identified, with the dissipative Battery Beach having highest diversity with 13 macrofaunal species. La Lucia, a reflective beach, had the highest macrofaunal abundance and was the second most diverse beach, thus departing from global trends that report a poor macrofaunal community of reflective beaches. The zonation of macrofaunal organisms generally showed similarities to that found elsewhere in South Africa and globally. Significant differences existed between Durban's urbanised beaches and beaches within marine reserves. This was attributed to differences in the degree of urbanization of the beaches that were compared or location along the coastline. The findings of this study provided a baseline upon which further research can be undertaken.

2.1. Introduction

Sandy beaches are dynamic soft bottom habitats (McLachlan *et al*., 1996) and are the most extended intertidal system of the world's coastlines. Because of the nature of the environment – physically demanding and uniform in appearance – the common perception of beaches has been that they are "marine deserts" (McLachlan and Erasmus, 1983) or worse, that beaches are "piles of sand." Consequently, these ecosystems are thought to be resilient to exploitation with the management of sandy beaches based largely on ecologically unsustainable principals. However, intertidal sandy beaches harbour a diverse and unique marine fauna (Rodil *et al*., 2006), and as the interface between terrestrial and marine environments, beaches are a crucial link in the coastal zone (Schlacher, 2007).

Approximately 70 % of the South African coast is comprised of sandy soft substrata (Fleischack, 1985). Durban, located on the east coast of South Africa in the KwaZulu-Natal (KZN) province, is one of the country's fastest growing urban centres.

In addition, the city is the largest municipal region on the east coast of Africa (Roberts, 2005), and encompasses an area of ~2,292 km^2 with a population of approximately 3.5 million people (Community Survey, 2007). The Durban coastline is dominated by sandy beaches, which are not only sought after by tourists, but are also an important recreational resource for the local population (Allen and Brennan, 2004; Mather, 2007). In economic terms, tourism is the fastest growing industry in the world (World Tourism Organisation, 2001), and Durban's beaches, with favourable climatic conditions, serve as a drawcard for coastal recreation (Maharaj *et al*., 2006). What is often overlooked are the ecological value of sandy beaches and the intrinsic link between socio-economic and ecological principals.

Beaches are faced with escalating pressures that threaten to destroy the ecological integrity of these systems (Schlacher *et al*., 2006, 2008). In addition to tourism and recreation, exponential human population growth has resulted in the expansion of cities and a subsequent exacerbation of habitat transformation in favour of human developments. This is prevalent along all urban coasts and is now expanding along the Durban coastline. These modifications to the natural environment are known to cause stress to coastal systems through contamination and disturbance (Lindergarth and Hoskin, 2001) and by reducing the recovery potential of ecosystems (Lotze, 2006). A further pressure to beaches is global warming, which not only results in sea-level rise, but also an increase in frequency and severity of storms (IPCC Fourth Assessment Report, 2007) that in some cases result in extensive beach erosion (Zhang *et al*., 2001). These factors are thought to have already caused considerable degradation to the intertidal zone in terms of biodiversity (Gheskiere *et al*., 2005b; Davenport and Davenport, 2006; Veloso *et al*. 2006). However, without baseline information, the validity of this premise is difficult to assess, impeding the establishment of appropriate management strategies to protect coastal processes. Furthermore, with the enhanced rates of species extinction through anthropogenic impacts, there exists an urgent need for a documentation of all extant species (May, 1988) for an improved understanding of how ecosystems are being altered.

Despite this, even the most general information on the beach biodiversity along the Durban coast in scarce compared to other parts of South Africa, where rigorous beach programmes have been conducted. This study comprised a survey of the macrofauna of five beaches along Durban's urbanised coastline as a step toward a more detailed understanding of the ecology of urban beaches. The available information on benthic macrofauna of sandy beaches in the study regions is particularly scant, consisting of a small number of dissertations (e.g. Fleischack, 1985; Sinclair–Hannocks, 1994) and species lists based on casual observations. No published records exist on macrofaunal community structure as a whole, although the ecology or ecophysiology of individual species has received some attention (e.g. Dye *et al.*, 1981). Furthermore, some reports of certain aspects of the benthos can be found in the “grey” literature.

Benthic macrofauna are one of the most important components of aquatic ecosystems. Studies have shown that these organisms can be used as ecological indicators of environmental pollution (e.g. Gray, 1979; Nahmani *et al*., 2006), by exhibiting qualitative and quantitative changes when exposed to pollution in the form of organic matter, oil, and industrial or agricultural waste. Macrofauna also form key trophic links in marine systems and play an important role in energy transfer in benthic systems and bentho-pelagic coupling (e.g., Asmus and Asmus, 1985). On sandy beaches, macrofaunal crustaceans (e.g., *Emerita* spp.) and molluscs (e.g., *Bullia* spp.) are an important food component for shore- and seabirds, surf zone fish and marine mammals (Lasiak, 1983; Dugan, 2003). Many bird species use beaches as nesting and breeding sites (Dugan, 2003) and the importance of the surf zone of beaches as sites of recruitment, growth and feeding of juvenile fish has repeatedly been demonstrated (Steele, 1968; Lockwood, 1974; Beyst, 2001). Invertebrate macrofauna, particularly the filter-feeding functional group, also play a significant role in nutrient cycling and organic matter mineralisation. The majority of the macrofauna species on sandy beaches are comprised of filter feeders (Lewin and Norris, 1970; McLachlan, 1977) and are involved in the large-scale degradation and assimilation of dissolved and particulate organic matter to their inorganic constituents (McLachlan, 1983; Hubbard and Dugan, 2003).

For these reasons, thorough quantitative descriptions of macrofauna communities within benthic marine systems are necessary because these permit an understanding of ecosystems as a whole (James and Fairweather, 1996; Pennifold and Davis, 2001). This research thus aimed to describe Durban’s sandy beach macrofaunal communities given the lack of available information. The objectives were to provide baseline data on macrofauna abundance, species richness and biomass of selected Durban beaches and to examine zonation patterns of macrofauna across the sandy shores. This study also tested the hypothesis that macrofauna communities of Durban’s urbanised beaches were significantly different from those of protected or less urbanised KZN beaches.

2.2. Materials and methods

2.2.1 Study area

Fifteen beaches were initially chosen for this study based on anthropogenic impacts and physical/chemical differences. However, logistical constraints made sampling so many beaches impossible. Instead, five representative sandy beaches within Durban along the central KwaZulu-Natal coast (South Africa) were sampled in the October and November 2007. Each beach was sampled once. These were La Lucia, Thekwini, Battery, uShaka and Garvies, from north to south (Figure 2.1). Thekwini, Battery and uShaka, together with several closely situated "pocket" beaches make up what has come to be called the Durban beachfront. The beaches were chosen because they exhibited different morphodynamic types and were representative of the northern, southern and central Durban coastline. These beaches are characterised by high levels of development and recreation. La Lucia, situated to the north of the beachfront beaches, is backed by residential properties and has several stormwater outlets along its length.

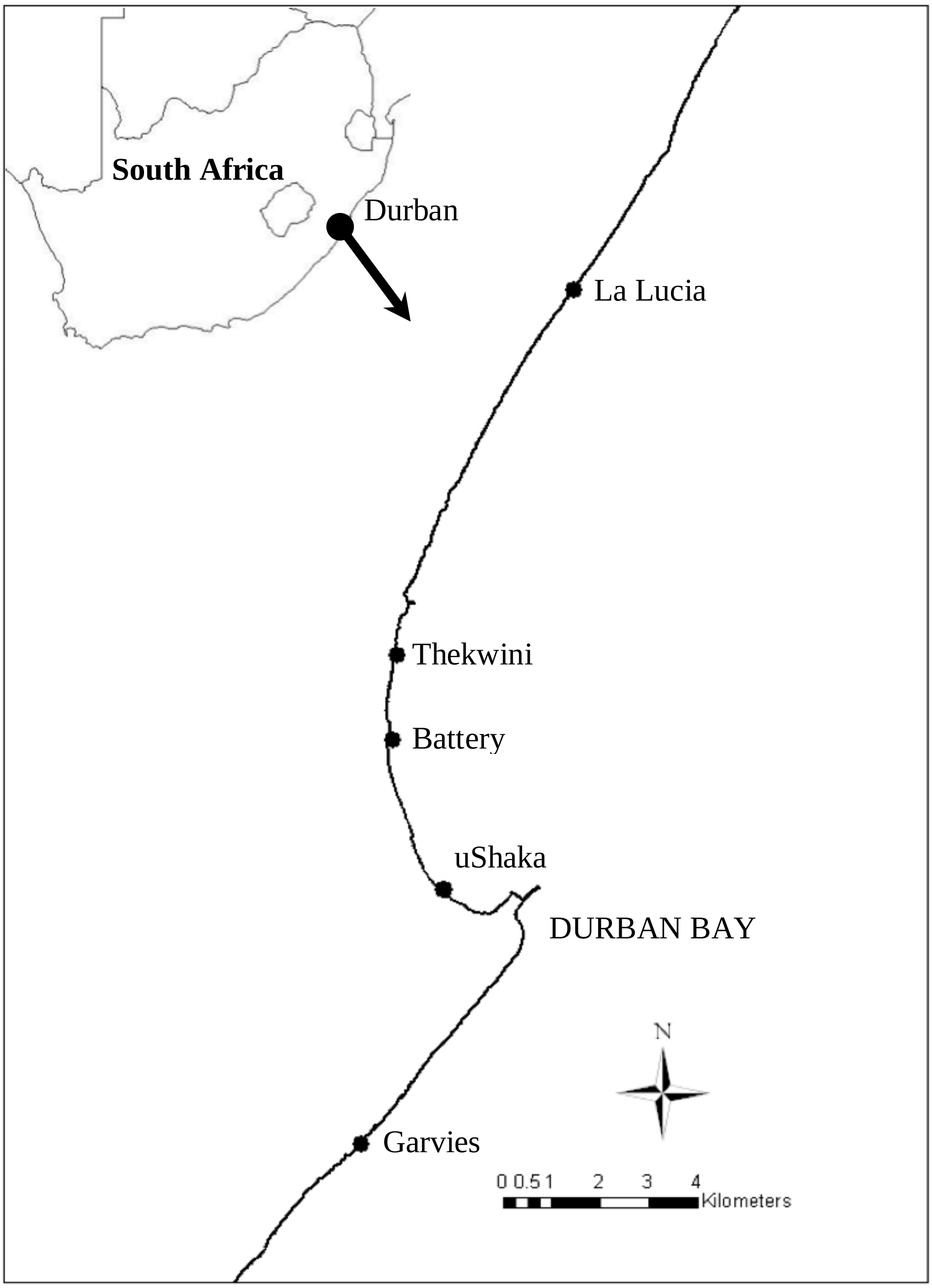

Figure 2.1. Beaches sampled for macrofauna along the Durban coastline

Garvies, to the south, is a sand beach adjoining a rocky shore. Although not as intensely frequented or developed as the beachfront beaches, both La Lucia and Garvies are popular angling sites. In addition, Garvies plays host to snorkelers and SCUBA divers. In the studied area, the mean spring tidal excursions ranged from 1 to 2 m, averaging a moderate to low range of 1.7 m along the coast. The coast is classified as subtropical

(Brown and Jarman, 1978) and is influenced by the warm southwest flowing Agulhas Current.

Data for KwaZulu-Natal beaches situated outside Durban were obtained from Nel and Bezuidenhout (2008) for north coast beaches, and Harris *et al*. (in prep.) for beaches south of Durban. These data were used to compare macrofaunal community structure of Durban's urbanised beaches with those of protected or less urbanised beaches.

2.2.2. Sampling design

Sampling was carried out during spring low tides under conditions of low to moderate ocean swell (1 – 1.5 m) using a random stratified sampling design. This design resulted in the entire along-shore length of each beach being taken into account when designating sampling stations. This is contrary to the protocol used in many sandy beach studies that are focused on a smaller, central region within a beach. Studies that concentrate on haphazardly or randomly selected sections of beaches may potentially result in an under-representation of beach faunal communities, due to the inherent patchiness of benthic organisms (Bally, 1983a; McLachlan, 1988).

At each beach, five transects were laid out perpendicular to the shore from the low tide mark to just above the drift line (the upper limit of the swash during the previous high tide). The position of individual transects was assigned randomly along the beach. Within each transect, 10 sampling levels were marked at equal vertical intervals, determined by differences in elevation between the low water spring (LWS – level 1) and the drift line (level 9). Level 10 was situated landward of the drift line.

At each level, five sediment cores (which were subsequently pooled) were taken using a hand-held, cylindrical, stainless steel corer (surface area = 0.0254 m^2) inserted to a depth of 25 – 30 cm for the collection of macrofauna. Studies have shown that macrofaunal organisms on beaches occur within the first 15 cm of sediment. Most researchers, however, collect samples from a depth 20 – 30 cm to account for vertical migrations of macrofauna (McLachlan and Brown, 2006).

At uShaka, Thekwini and Battery Beach, the pooled sediment from each level was washed through a sieve bag with a mesh size defining the lower limit for macrofauna (1000 μm in this study) in the swash zone of the respective beaches. This allowed for the removal of excess sediment prior to the collection of macrofauna. The macrofauna remaining in the bag were stored in labelled honey jars and fixed in a ~5 % formalin solution. At Garvies and La Lucia, the sediment was coarse and did not pass through the macrofauna sieves. At these beaches, sediment cores were deposited into labelled plastic bags and taken to the laboratory for extraction of macrofauna through manual elutriation. Elutriation entails submerging the sediment cores containing macrofauna in water, stirring rapidly and then decanting the water through a sieve with the appropriate mesh size. Elutriation is based on the fact that macrofauna are less dense than sediment and will remain suspended in the water while the sediment settles, thus allowing for extraction of organisms from sediment. Larger animals are removed by then sieving the remaining sediment through a mesh with an aperture size of 2 mm.

A preliminary study to determine the number of decants required to remove at least 95 % of organisms from sediment with varying grain size was carried out for both live and preserved animals. This entailed adding a known number of macrofaunal specimens to coarse and fine sediment of the same volume (4 L) in a 10 L plastic bucket. In the field, the experiment was carried out with the crustacean *Emerita austroafricana* and the molluscs *Bullia natalensis* and *Tellina* sp. Sufficient water was added to facilitate stirring and elutriation. Preserved specimens included a variety of polychaete, mollusc and crustacean species. It was found that three and four iterations of stirring and decanting were required to remove 95 % of all macrofauna from coarse and fine sand respectively (Table 2.1). This was unexpected as it was thought that live animals would burrow into sediment, making it more difficult to remove them. However, upon agitation of the water, live animals tended to float to the surface, facilitating their extraction from sediment. For the purposes of this study, it was concluded that five stir and decants would be sufficient to remove 100 % of macrofauna from beach sediments in most cases.

Table 2.1. Percent specimens extracted after individual stir and decants reported in mean ± SD ($n = 5$) for different grades of sand (MD_{50} = median grain size)

Number of decants	MD_{50} = 1015.7 µm		MD_{50} = 311.8 µm		MD_{50} = 1015.7 µm		MD_{50} = 311.8 µm	
	Preserved specimens - % extracted	cumulative %	Preserved specimens - % extracted	cumulative %	Live specimens - % extracted	cumulative %	Live specimens - % extracted	cumulative %
1	67.0 ± 0.8	67	73.2 ± 1.4	73.2	85.2 ± 0.5	85.2	76.3 ± 1.2	76.3
2	21.8 ± 1.7	88.8	22.4 ± 0.9	95.65	13.6 ± 1.7	98.8	23.6 ± 0.2	99.9
3	5.9 ± 1.4	94.7	3.8 ± 0.5	99.5	1.2 ± 0.3	100	0.1 ± 0.1	100
4	3.3 ± 1.3	98.1	0.4 ± 0.1	99.9				
5	1.4 ± 0.6	99.3	0.1 ± 0.1	100				
6	0.6 ± 0.1	99.9						
sum	100	100	100	100	100	100	100	100

A total area of 6.34 m^2 was sampled per beach, well within the recommended sample area for sandy beach macrofaunal community studies (Schoeman *et al*., 2003). A separate sediment core (internal diameter of 2 cm) was taken to the same depth for sediment granulometry. Beach slope was measured and number of effluent line passes was recorded by counting the number of times the swash reached or crossed the effluent line over a five-minute period. This was replicated at each transect along the beach.

Macrofauna were identified to the lowest possible taxonomic level and counted. Animals were oven-dried in an air circulating oven at 60°C to determine biomass. Sediment cores were dried at 60°C for 24 hours and the sand passed through nested sieves set at half Φ intervals to obtain sediment grain size characteristics.

2.2.3. Data analysis

Macrofauna abundance from each sandy beach was standardised to number of individuals per linear meter of transect:

$$\sum \text{individuals per species} \times \text{length of transect/total sample area}$$

Sediment grain size parameters and physical descriptions were computed using GRADISTAT Version 4.0 (Blott, 2000). Wave height and period data were obtained from WindGuru (www.windguru.cz/int/historie) because it was not feasible to measure these parameters in the field. WindGuru, however, does not have wave data for individual beaches. For this reason, the wave heights and wave periods were averaged over the entire sampling period. These parameters were used in the calculation of Dean's parameter according to the equation:

$$\Omega = \frac{Hb}{Ws.T}$$

where Hb is the modal breaker height (m), Ws is sand fall velocity (m.s^{-1}) (using conversion factors obtained from Gibbs *et al.* (1971) and T is modal wave period (s). A further parameter that was calculated was the Beach Index (BI):

$$BI = \log 10\left(\frac{Mz.TR}{S}\right)$$

Here, Mz represents the mean grain size in Φ units (+ 1 to avoid negative numbers), TR is the spring tidal range (m) and S is the beach face slope.

Kite diagrams were constructed to describe potential zonation patterns of macrofauna of the sampled sandy beaches using species abundance (individuals.m^{-1}). For the elucidation of groups with distinct community structure among all the sampled beaches (i.e., including those beaches outside Durban), hierarchical agglomerative clustering using the Bray Curtis similarity measure (group-average linking) was performed and dendrograms constructed. Groups of samples with a high level of similarity were designated visually. The data were subsequently subjected to non-metric multidimensional scaling (MDS) ordinations, with the Bray-Curtis similarity index. The stress value (S) was used as a measure of the goodness-of-fit of the MDS ordination where $S < 0.2$ indicates a good ordination in which the chances of misinterpretation of data are very slight (Clark and Warwick, 1994). Pairwise analysis of similarities (ANOSIM) were undertaken to test the null hypothesis that there were no differences in the macrofaunal communities between the groups obtained using the Bray-Curtis index (Fig. 10). The R significance is close to zero if the null hypothesis is accepted; if approximately one it implies the least similarity between pairs (Clark, 1993). The above multivariate analyses were performed using square-root transformed data to balance the contribution of dominant species (Clark and Warwick, 1994). The suite of statistical programs and data visualisation software utilised consisted of PRIMER V.6 (Plymouth

Routines in Multivariate Ecological Research), devised by Clarke and Warwick (1994), Prism Version 5.0 a and Aabel 2.

2.3. Results

2.3.1. Physical characteristics of Durban beaches under study

Table 2.2. Physical characteristics of the five Durban beaches

Beach	MD_{50} (μm)	Sorting coefficient (μm)	Overall textural group	1/slope	Beach width (m)	Beach index	Dean's parameter (Ω)	Beach classification	Effluent line passes (min^{-1})
La Lucia	1015.7	518.5	Poorly sorted, very coarse sand	8.1	45.0	1.2	1.6	Reflective	4.68
Thekwini	496.3	294.1	Moderately sorted, medium sand	33.3	69.3	2	4.9	Intermediate dissipative	0.6
Battery	311.8	124.7	Moderately well sorted, medium sand	66.6	82	2.5	9.5	Dissipative	0.48
uShaka	463.4	298.1	Moderately sorted, medium sand	38.5	56.7	2.1	5.1	Intermediate dissipative	0.6
Garvies	709.5	362	Moderately sorted, coarse sand	28.6	38.4	1.8	2.1	Intermediate reflective	0.72

La Lucia had the most dynamic swash environment, experiencing 4.7 effluent line passes per minute, and Battery the least rigorous with 0.48 effluent line passes per minute (Table 2.2). The 20-point exposure scale for beaches developed by McLachlan (1980) (Chapter 1, Table 1.2) defined La Lucia and Bluff as exposed, Battery as sheltered, and uShaka and Thekwini as sheltered.

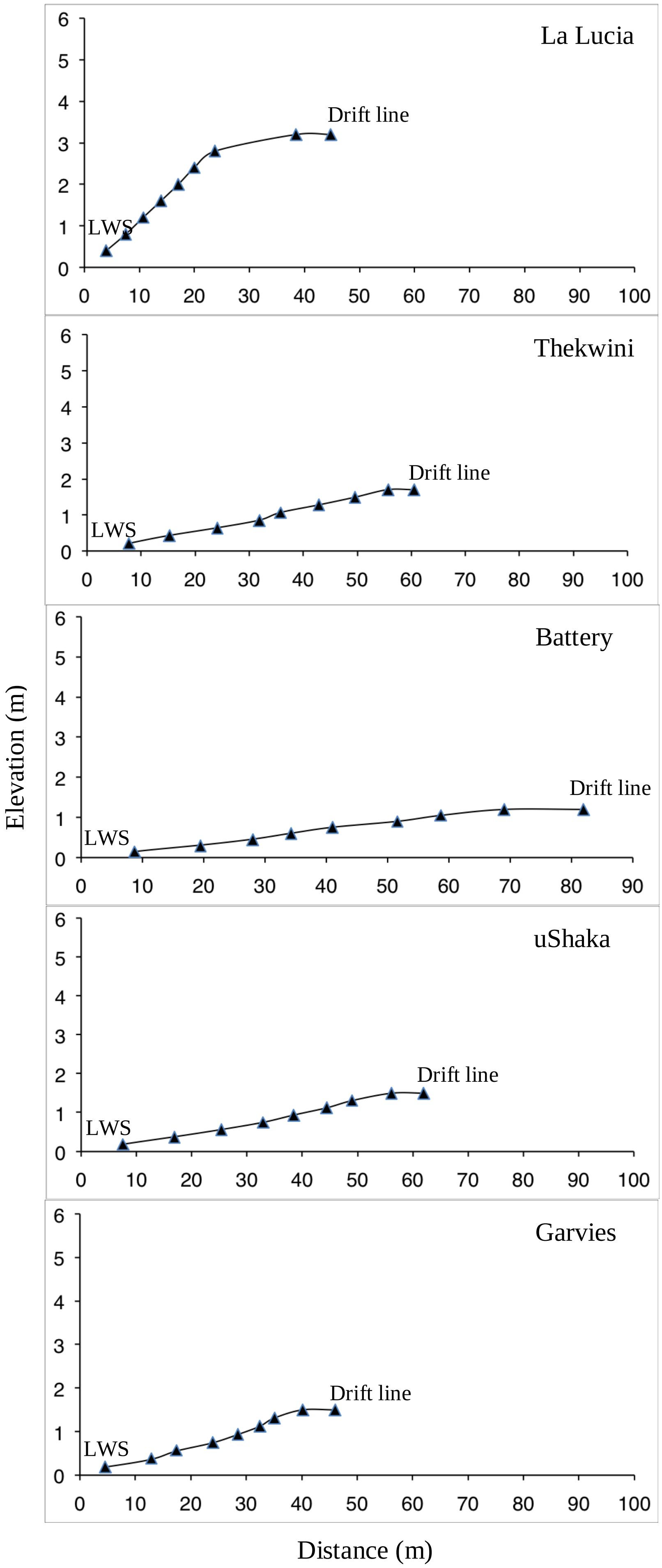

Figure 2.2. Beach face morphology of the sampled beaches. Triangles denote sampling levels.

The slope of the intertidal ranged from 1/8.1 to 1/66.6 with La Lucia exhibiting the steepest slope and Battery the flattest. The beach face morphology is shown in Figure 2.2. The width of the intertidal ranged from 44 to 82 m and median grain size (MD_{50}) from 311.8 to 1015.7 μm (Table 2.2). La Lucia and Bluff were characterised by coarse sand and the remaining three beaches all had medium sand. Beach sediments were poorly sorted (La Lucia), moderately sorted (eThewini, uShaka, Bluff) or moderately well sorted (Battery Beach).

2.3.2. Biological characteristics of Durban beaches

The dominant macrofauna were crustaceans, polychaetes and molluscs (Table 5). The most widely distributed crustaceans were the anomuran, *Emerita austroafricana*, and the isopods *Eurydice longicornis* and *Excirolana natalensis*. Amphipods were also recorded but were restricted to Battery and Thekwini beaches. A total of five polychaete families were recorded and La Lucia displayed the richest polychaete assemblage (Table 5). Molluscs were represented by bivalves (*Tellina* sp. and *Donax madagascarensis*) and a gastropod (*Bullia natalensis*).

Table 2.3. Macrofauna diversity, abundance and biomass of the selected Durban beaches. (*H'* is the Shannon-Weiner diversity index)

Beach	Diversity (no. of species)*	Abundance (ind.m^{-1})*	Biomass (g. m^{-1}) **	H'
La Lucia	11	401514.9	116.5	1.1
Thekwini	10	1157.2	73.1	1.7
Battery	13	2311.5	109.5	2.1
uShaka	10	2894.1	193.8	2.1
Garvies	6	61951.0	32.8	1.2

***** values are exclusive of copepods, nematodes and molluscs spat

** values are exclusive of copepods, nematodes, mollusc spat and organisms too small that their weights were negligible

Overall, a total of 21 species (excluding nematodes, copepods and mollusc spat) were collected on the beaches, with six to 13 taxa per beach (Table 2.3 and 2.4). Total macrofauna abundance ranged from 1157.2 – 410514.9 ind.m^{-1} (Table 2.3). Highest macrofauna abundance was recorded at La Lucia and lowest at Thekwini, while species richness peaked at Battery Beach. Garvies was the least diverse of all the studied beaches (Table 2.3). At La Lucia, polychaetes were responsible for the high abundance values, while crustaceans dominated the other beaches (Table 2.4). The range of macrofauna biomass was from 32.8 –193.8 g.m^{-1}. Biomass was greatest at uShaka and least at Garvies (Table 2.3). The polychaetes, *Pisionidens indica* and *Pisionidens africana*, made up the bulk of the biomass (60 % and 22 %, respectively) at La Lucia and crustaceans accounted for most of the biomass at the rest of the beaches.

Table 2.4. Complete species list and abundance (individuals.m^{-1}) of individual species per beach

Taxa	La Lucia (ind.m^{-1})	Garvies (ind.m^{-1})	Thekwini (ind.m^{-1})	uShaka (ind.m^{-1})	Battery Beach (ind.m^{-1})
Crustacea					
Anomura					
Emerita austroafricana (Hippidae)	97.1		251.1	455.5	155.0
Isopoda					
Eurydice longicornis (Cirolanidae)	82.2		218.3	535.9	529.4
Excirolana natalensis (Cirolanidae)		438.4	10.9	8.9	64.6
Amphipoda					
Mandibulophoxus stimpsoni (Phoxocephalidae)			76.4		116.2
Urothoe grimaldi (Haustoridae)					25.8
Mysideacea					
Gastrosaccus bispinosa (Mysidae, Gastrosaccinae)				35.7	477.8
Polychaeta					
Scolelepis squamata (Spionidae)				1268.4	206.6
Glycera tridactyla (Glyceridae)				8.9	167.9
Glycera natalensis (Glyceridae)	177.2	4444.7	43.7	187.6	
Glycera sp. 1 (Glyceridae)	177.0		43.7		142.0
Pisionidens indica (Pisionidae)	7986.5		10.9	80.4	142.0
Pisione africana (Pisionidae)	14377.3	19759.4			
Saccocirrus sp. (Saccocirridae)	93064.7				
Lumbrinereis coccinea (Eunicidae)					25.8
Polygordius sp. (Polygordiidae)	256836.9				
Mollusca					
Bivalvia					
Donax madagascarensis (Donacidae)				71.5	
Donax spat (Donacidae)	176.5		272.9	116.1	219.5
Tellina sp. 1 (Tellinidae)			54.6	26.8	
Tellina spat (Tellinidae)			152.8	98.3	
Gastropoda					
Bullia natalensis (Nassariidae)			21.8		38.7
Insecta					
Anurida maritima (Neanuridae)	9403.9	27191.4			
Coleoptera 1	7.1				
Coleoptera 2	7.1	30.2			
Nematoda	19121.1	1668			
Unidentified eggs	99.2				25.8
Calanoid copepods			32.7		1330.1

At uShaka, adult mole crabs (*E. austroafricana*) accounted for 86.3 % of the total biomass, followed by the polychaete *Scolelepis squamata*. The molluscs collected at Battery were juveniles and did not contribute significantly to overall biomass (0.1%). *Emerita austroafricana* also contributed most to total biomass at Thekwini and Battery (87.9 % and 66.1 %). At Battery, mysids and cirolanid isopods made up 5.5 % and 6.1 % of total biomass and the gastropod, *Bullia natalensis*, was second only to mole crabs, making up 13 % of the biomass recorded for the beach.

Macrofauna zonation is illustrated in Figure 2.3. For the purposes of this study, sampling levels 1 – 3 will be referred to as ‘low-shore’, levels 4 – 7 as ‘mid-shore’ and levels 8 – 10 as ‘high-shore’. No data on moisture content are available, precluding the designation of zones according to Salvat’s (1964) physical zonation scheme. However, sampling levels 1 – 3 represent that region of the intertidal that was continually wetted by wave or swash action during the spring low tide. Level 8 comprised sand that was semi-dry and levels 9 and 10 were characterised by dry sand. Levels 4 – 7 were still moist from being submerged during the previous high tide, but neither as saturated nor dry as the physical environment of the low- and high-shore, respectively.

The distribution of the same species on different beaches was generally dissimilar (Figures 2.3 a – e). The exceptions were the polychaete *Pisione africana*, which consistently occurred at greatest abundance at the low-shore region (Figures 2.3 a and b); the isopod *Excirolana natalensis*, which could be found in the mid-shore region of all beaches (Figures 2.3 b – e), the insect, *Anurida maritima*, with abundance peaking in the middle of the intertidal (Figures 2.3 a and b) and several species of glycerid polychaetes. *Glycera natalensis* was most abundant at the low-shore wherever present (Figures 2.3 a – e). A glycerid that could not be identified (*Glycera* sp.1) was found to occur at the mid-shore levels of Thekwini (Figure 2.3 c) and Battery (Figure 2.3 e) and *Glycera tridactyla* found on sampling levels 7 and 8 (Figures 2.3 d). Molluscs were found near the low water mark on some beaches (Figures 2.3 c and d) but were most abundant at the high water mark at Battery (Figure 2.3 e).

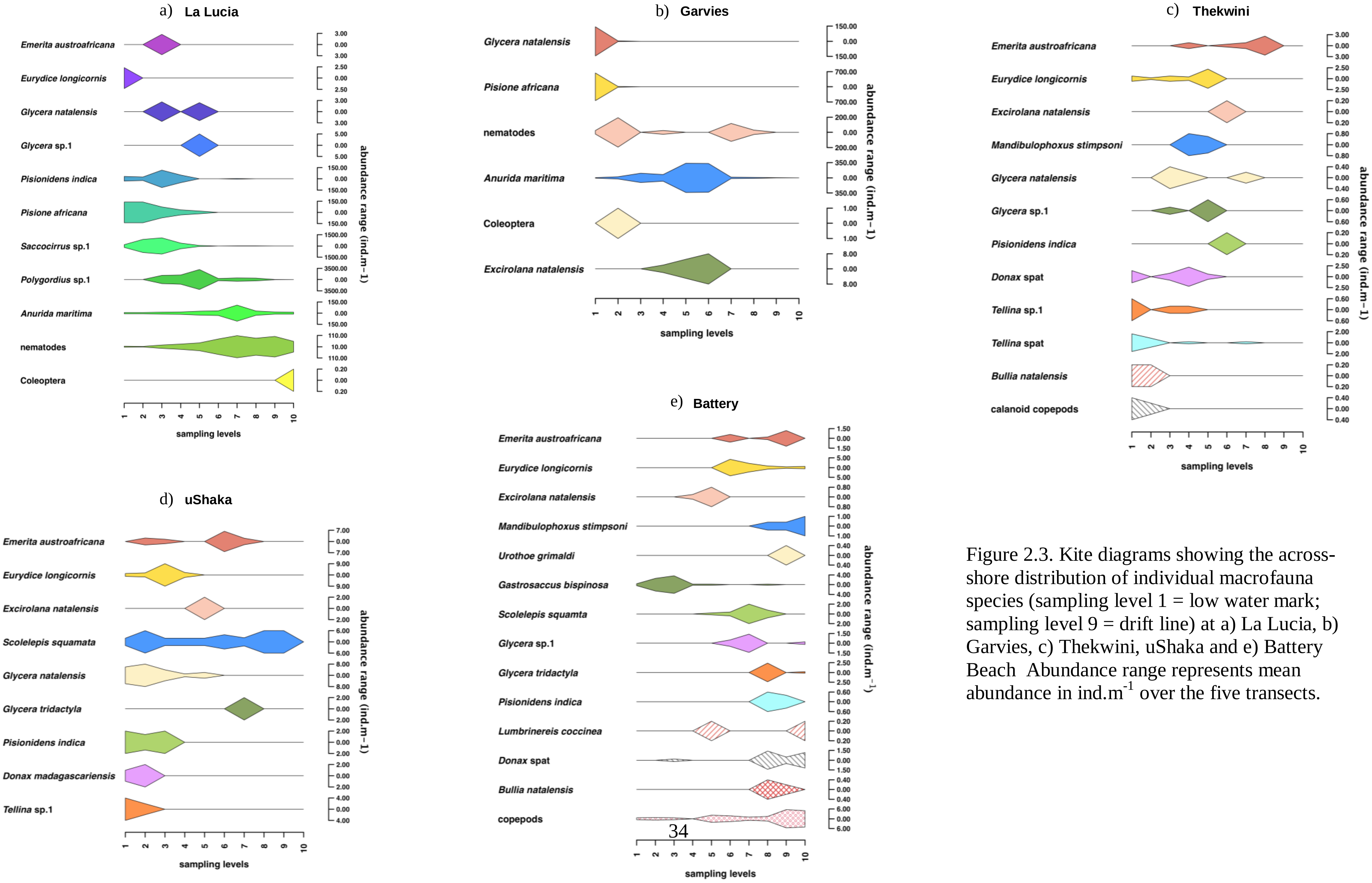

Figure 2.3. Kite diagrams showing the across-shore distribution of individual macrofauna species (sampling level 1 = low water mark; sampling level 9 = drift line) at a) La Lucia, b) Garvies, c) Thekwini, uShaka and e) Battery Beach Abundance range represents mean abundance in ind.m^{-1} over the five transects.

2.3.3. Comparison between macroinfauna between Durban's urbanized beaches and less urbanised or protected beaches in KwaZulu-Natal

Beaches situated outside of Durban sampled by Nel and Bezuidenhout (2008) and Harris *et al*. (in prep.), were either intermediate or reflective and no fully dissipative beaches were sampled. The reflective beaches were not as steep as La Lucia (Table 2.5) and none of the beaches sampled were as wide as Battery (Table 2.5).

Table 2.5. Selected physical characteristics of the beaches sampled by Nel and Bezuidenhout (2008) and Harris *et al*. (in prep.)

Beach	Grain size category	Sorting	1/slope	Width	Beach index	Beach state
Island Rock	medium-fine	well sorted	19	48	2	intermediate
Sodwana	medium-fine	well sorted	31	72	2.3	intermediate
Cape Vidal	medium-coarse	well sorted	22	43	2	intermediate
Mapelane	coarse	well sorted	14	32	1.6	reflective
Umlalazi	medium-coarse	well sorted	26	62	2	reflective
Port Shepstone	very coarse	poorly sorted	12	55	1.4	reflective
Southbroom	medium-fine	medium sorted	24	63	2.1	intermediate
Trafalgar	medium-fine	well sorted	31	75	2.2	intermediate

Examination of the cluster analysis and MDS ordinations suggested associations of beaches with generally similar morphodynamic characteristics and location along the coast. Four groups were delineated at the 40 – 45 % similarity level (Figure 2.4) using cluster analysis. The beaches located within marine reserves on the north coast (Island Rock, Mapelane, Sodwana, Cape Vidal, Umlalazi) grouped together (Group III) and this affinity was also seen for the reserve beaches of the KZN south coast (Southbroom and Trafalgar, Group I). The beachfront beaches (Battery, uShaka and Thekwini) formed a group at the 60 % similarity level (Group II), with uShaka and Battery being more similar to each other than to Thekwini (Figure 2.4). Port Shepstone, La Lucia and Bluff formed the last group (Group IV).

The results if the non-metric multidimensional scaling showed a similar picture (Figure 2.5). The low stress value ($S = 0.09$) is indicative of a good ordination, meaning that the plot is an adequate representation of the data. The MDS plot also shows groupings based primarily on morphodynamic characteristics (Figure 2.5).

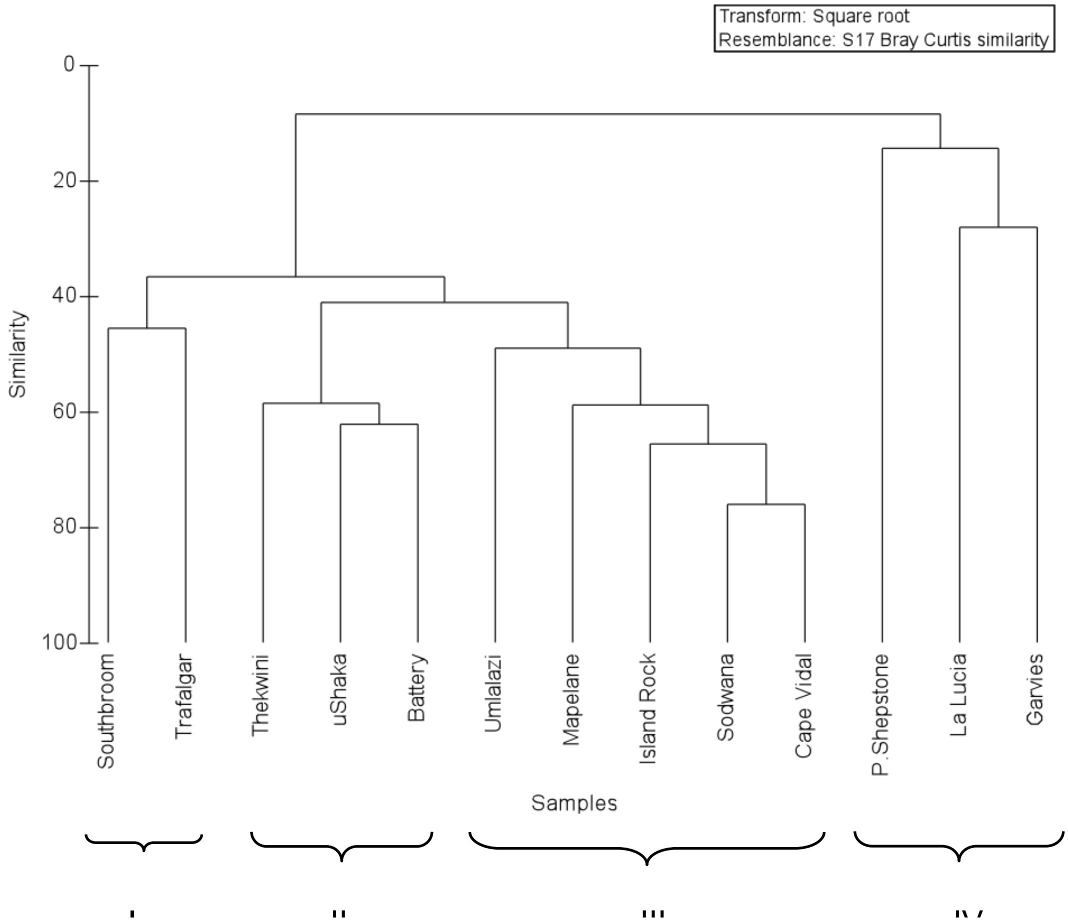

Figure 2.4. Dendrogram showing groupings of beaches along KZN. Five groups were distinguished at the ~ 40 % similarity level

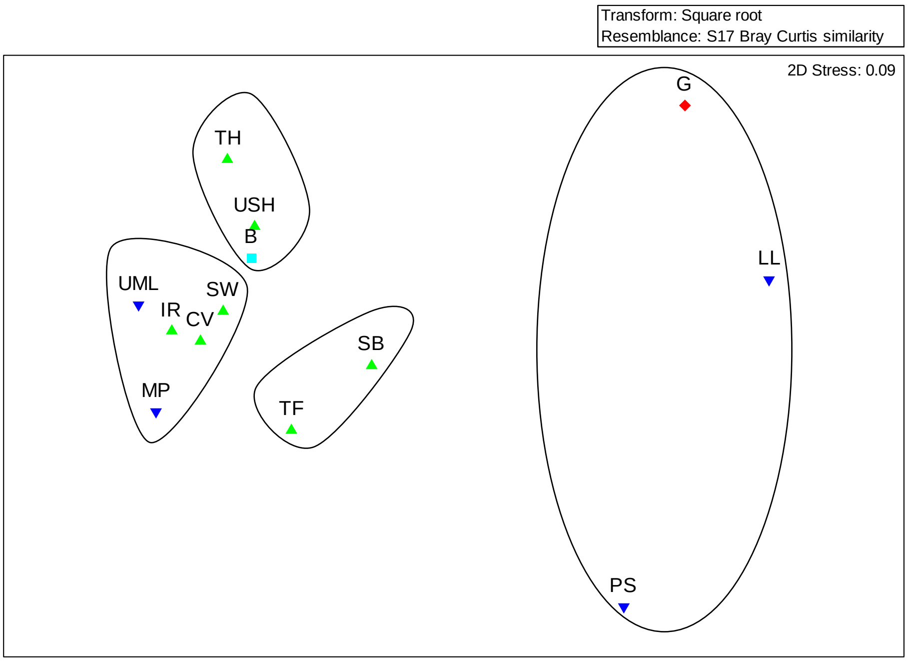

Figure 2.5. MDS ordinations with the Bray-Curtis similarity index using species abundance data. (SB: Southbroom, TF: Trafalgar, TH: Thekwini, USH: uShaka, B: Battery, UML: Umlalazi, MP: Mapalane, IR: Island Rock, SW: Sodwana, CV: Cape Vidal, PS: Port Shepstone, LL: La Lucia, G: Garvies.

Results of the ANOSIM to test for differences between the groups obtained using the Bray-Curtis index indicated that significant differences existed between Group I and III (R = 0.873; p = 0.048), Group II and III (R = 0.764; p = 0.018) and Group III and IV (R = 0.0.928; p = 0.018) (Table 2.6, Figure 2.5).

Table 2.6. Results of the ANOSIM test for significant differences between groups. Reported values are *R* – significance. Asterisks denote significant differences between groups

	II	III	IV
I	0.917	0.873*	0.333
II		0.764*	0.741
III			0.928*

2.4. Discussion

2.4.1 Macrofauna community structure of Durban beaches

Durban's beaches are not uniform in appearance and show a range of morphodynamic types from reflective, through intermediate, to dissipative. A dissipative beach is one in which the energy of incoming waves is dissipated in a wide surf zone instead of being reflected off the beach face, as in reflective beaches (see Chapter 1 for a detailed description of the different beach types). Intermediate beaches lie in the middle of the continuum of beach morphodynamics and exhibit physical characteristics of dissipative and reflective beaches. The beachfront beaches – Thekwini, Battery and uShaka – are gently sloped with moderately sorted, medium sand. Battery's flatter slope, finer sand and wide surf zone represent the dissipative beach state, while Thekwini and uShaka are both intermediate-dissipative beaches. La Lucia, to the north, is at the opposite end of the scale, where poorly sorted, coarse sands, steep slopes and a narrow surf zone define the reflective character of this beach. Garvies to the south was also found to have coarse sands and steep slopes and was classified as intermediate-reflective. These findings are in agreement with earlier studies of the physical character of Durban's beaches (Davies, 1972; Dye *et al*. 1981; Sinclair-Hannocks, 1994) that noted the variability in beach morphodynamics along the coast.

Since as early as the1900s, central Durban beaches (or beachfront beaches) began to experience severe erosion. This was principally due to the construction of harbour breakwaters (Fleischack, 1985). Several expensive programmes to counteract the loss of sand by beaches were initiated by local municipal authorities. Rigorous sand pumping schemes to offset the deleterious effects of beach erosion were undertaken (Fleischack, 1985) and are currently, still ongoing. Because the sand pumped onto these beaches is typically medium to fine grained, the nourished beaches may have changed considerably from their natural state, resulting in them becoming more comparable through time. This would account for the similar morphodynamic character of the three beachfront beaches. In addition, these beaches are more sheltered than other beaches in Durban, due to the bay configuration (Figure 1).

Previous studies of macrofauna on Durban's beaches were rudimentary and fragmented. One found only a single species of crustacean after sampling three beaches (Sinclair-Hannocks, 1994) and another concluded that Durban's beaches lacked the typical sandy beach macrofauna (Dye *et al.*, 1981). This study showed, to the contrary, that the beaches, despite being highly urbanised, have rich and abundant macrofaunal communities. The discrepancy between results of earlier work and those of the present study may be due to potentially inadequate sampling protocols employed by previous authors. Sinclair-Hannocks (1994) sampled macrofauna to a depth of five centimetres which is insufficient to adequately represent rapidly burrowing macrofaunal organisms that may attain depths of ~25 cm (Schlacher *et al.*, 2008). Similarly, the studies of Dye *et al.* (1981) formed part of a baseline survey of sandy beach benthic communities along the entire South African coastline, with the proviso that the findings were based on limited fieldwork. The present work satisfied all the recommendations for ecological surveys of sandy beach macrofauna in terms of total area sampled, depth of coring and equipment used (Schoeman *et al.*, 2003; McLachlan and Brown, 2006; Schlacher *et al.*, 2008)

Species richness typically increases from temperate to tropical environments (Soares, 2003; McLachlan and Dorvlo, 2005). Species richness of subtropical east coast Durban beaches was found to be comparable to that of beaches on the warm-temperate south coast of South Africa, where authors have noted seven to 13 species per beach (McLachlan, 1977a; Wooldridge *et al.*, 1981; Wendt and McLachlan, 1985) but lower to that of than cool-temperate west coast beaches, where macrofaunal diversity of up to 23 taxa were recorded (Bally 1983, 1987). The higher diversity of temperate west coast beaches may be due to the fact that several beaches sampled by Bally (1987) were receiving an energy subsidy in the form of kelp wrack. Kelp gets stranded along the drift line of these beaches and attracts air-breathing herbivorous arthropods and their predators, thus increasing species diversity at the high tide mark (Tarr, 1983; Bally, 1987; Dugan *et al.*, 2003). Algal wrack is uncommon on Durban beaches and may only occur in limited quantities on beaches that are situated near rocky reefs. Further, the increased demand of Durban beaches as recreational resources has resulted in beach grooming programmes being initiated by local municipal authorities. Beach grooming not only removes materials of anthropogenic origin, but also organic material, food resources and potential habitat associated with natural wrack (Dugan *et al.*, 2003; Gheskiere *et al.*, 2006).

On sandy beaches, the bulk of the biomass is made up of molluscs; biomass has been shown increase from tropical to temperate latitudes (Willig *et al.* 2003; McLachlan and Dorvlo, 2005). Molluscs are generally dominant on temperate beaches, attaining larger sizes and greater numbers than on tropical and sub-tropical beaches (Dugan *et al.* 2003). Durban's beaches show a poor representation of this phylum. Biomass was generally lower than reported on the south and west coasts of the country (Wendt and McLachlan, 1985; Bally, 1987) and the paucity of molluscs on the sampled beaches beaches may thus account for the low biomass recorded. Macrofauna abundance of Durban's beaches was similar to that for beaches in other parts of South Africa (Wooldridge *et al.* 1981; Wendt and McLachlan, 1977a; Bally, 1987). A comparison of the biotic characteristics of the beaches sampled in this study with those in other geographical areas shows lower species diversity than subtropical beaches on the coast of Oman (McLachlan *et al.* 1998), beaches along the coast of Spain (Rodil *et al.*, 2006) (McLachlan *et al.*, 1998) and of the Californian coastline (Dugan *et al.* 2000). Chilean beaches have comparable species richness (four to 14) (Jaramillo, 1987; Jaramillo and McLachlan, 1993) to Durban's beaches.

The beach morphodynamic model states that species richness and abundance increases from reflective, through intermediate to dissipative beach states (e.g. McLachlan, 1981). This trend was not observed in this study. While diversity was highest at the dissipative Battery Beach, most interesting, perhaps, was the high abundance and diversity of macrofauna recorded for the reflective La Lucia Beach. Studies of reflective beaches in South Africa and worldwide have consistently shown that reflective beaches have impoverished macrofaunal diversity, abundance and biomass (Gauld and Buchanan, 1956; Dye *et al.*, 1981; McLachlan, 1985; Defeo *et al.*, 1992). This has been explained in terms of the "swash exclusion hypothesis" (McLachlan, 2001). The swash climate of a beach, together with sediment particle diameter, is the primary determinant of macrofauna distribution patterns on sandy beaches. Swash climate is in simple terms a manifestation of wave and tidal action – the movement of water over the beach face as experienced by benthic fauna (McLachlan, 2001). In this manner, a harsh swash climate may be responsible for excluding certain species (McLachlan, 1993, 2001) from the intertidal zone as it creates turbulence that may increase the chances of organisms being stranded on areas of the beach they are not adapted to survive in (McLachlan, 2001; Defeo and McLachlan, 2005). Dissipative beaches have a benign swash environment compared to that experienced on reflective beaches (McLachlan, 2001). In general, macrofauna abundance of greater than 100 000 ind.m^{-1} is considered very high and less than 1000 ind.m^{-1}, very low (McLachlan *et al*., 1996). La Lucia, despite being a reflective beach, displayed abundance values of 401 514.9 ind.m^{-1}, which is unprecedented for a beach with this morphodynamic type. Of the five beaches sampled, macrofauna species richness at La Lucia was second only to Battery, and uShaka alone displayed a higher biomass than La Lucia. Further, most of the organisms found at La Lucia were polychaetes, which typically dominate dissipative beaches. Their fragile forms preclude them from inhabiting very coarse sediment because this makes burrowing difficult (McLachlan and Brown, 2006). Further studies are required to determine the cause of the anomalously high macrofauna abundance and richness on this reflective beach.

A possibility is that the values recorded were a coincidence brought upon by sampling during a spawning event. Most polychaete species exhibit mass spawning episodes that are triggered by various factors including temperature and seasonality and often and combination or lunar and diel rhythms (e.g., Dorresteijn and Westheide, 1999). Assuming that sampling did coincide with spawning, the polychaetes collected during the survey would possibly remain in the environment for a short period of time until the harsh conditions would result in them failing to establish viable populations. In this event, if sampled again, the beach may harbour only a few polychaete species that occur in lower abundance. A further possibility is that the large interstitial spaces between the coarse grained sands enables polychaetes to live between sand grains as opposed to burrowing into the sediment. This brings into question the validity of including these organisms as macrofauna. At La Lucia, the polychaetes responsible for the high abundance were *Polygordius* sp. (Polygordiidae) and *Saccocirrus* sp. (Saccocirridae), comprising 64 % and 23 % of the total abundance, respectively. In addition, *Pisionidens indica* and *Pisione africana* (Pisionidae) contributed most to overall biomass (60 % and 12.5 %, respectively). Neither *Saccocirrus* spp. nor *Polygordius* spp. appeared in the polychaete identification guide utilised in this study (Day, 1967) and were instead found in the meiofauna guide (Higgins and Theil, 1988). Both *P. indica* and *P. africana* also generally form part of the meiobenthos (Higgins and Theil, 1988). On coarser beaches, meiobenthos may attain larger sizes due to the larger interstitial spaces available for occupation (McLachlan, 1983). In this manner, typical meiobenthic organisms may be retained in macrofauna sieves.

Delimiting what constitutes macrofauna, meiofauna and microfauna is an ongoing debate. Traditionally, these groups are defined by size (Mare, 1942) and many authors have stressed the importance of retaining size limits to standardise methods (Dahl, 1976; Theil, 1983). If defined by their behaviour or the actual habitat they occupy within the benthos, a different picture may emerge. For example, assuming meiofauna are defined, not by size, but by the fact that they are interstitial organisms (Boaden, 1962), and macrofauna by their burrowing lifestyle (Zinn, 1968), the abundance values obtained for La Lucia may conform to global trends – a macrofaunal species poor reflective beach. Laboratory microcosm studies are required to determine if the polychaetes found at La Lucia were in fact meiofauna that progress through the interstitial pore system without shifting sediments, and not macrofauna, that actively displace sediments by ingesting or moving particles aside.

2.4.2. Distribution of macrofauna across the intertidal

Zonation schemes based on biological (Dahl, 1952; Trevallion *et al.*, 1970) and physical (Salvat, 1964) characteristics have been proposed for sandy intertidal habitats (see detailed discussion in Chapter 1). Unlike rocky shores, however, where distinct biological zones exist, sandy beach zonation has often been considered an "artificial division of a continuum" (Degraer *et al.*, 1999; Rodil *et al.*, 2006). The kite diagrams depicting macrofauna zonation along Durban sandy beaches were thus intended to illustrate the distribution of species at different tidal levels and not distinct zonation patterns. Tidal migratory *Emerita austroafricana*, *Donax madagascarensis*, *Tellina* sp. and *Bullia natalensis* were variable in their distribution across the intertidal. *Donax* spat and juvenile *E. austroafricana* were frequently found on the high shore, while adults were found to occur on the low shore region of the beach (Figures 2.3 b - d). This is in agreement with previous studies that suggested that the occurrence of juveniles of these species on higher levels of a beach is possibly a behavioural adaptation to escape from predation by fish in the surf zone (McLachlan, 1988). An alternative explanation is that the smaller organisms are more susceptible to being displaced by wave or tidal action, thus being transported passively across the intertidal.

In a summary of the zonation of intertidal macrofauna along the South African coast, McLachlan (1981) found the mid-shore to be typified by cirolanid isopods, *E. natalensis* and *Eurydice longicornis*, the high-shore to be dominated by ocypodid crabs, oniscoid isopods and talitrid amphipods, and the low shore to play host to a variety of species including mysids, bivalves, gastropods, anomurans, and polychaetes. Macrofauna of Durban beaches do not follow precisely these distribution patterns. The distribution of the cirolanid isopod, *Excirolana natalensis*, on the mid-shore of Durban beaches was in agreement with studies conducted in South Africa (Bally, 1983; McLachlan, 1980; McLachlan *et al*., 1981) and other parts of the world (Gianuca, 1983; Defeo *et al*., 1992). The mysid, *Gastrosaccus bispinosa*, also conformed to regional (Brown, 1964; Bally, 1983; McLachlan, 1980) and global trends (Tarr, 1985). The mid-shore region of Durban beaches played host to a variety of polychaete species such as the spionid *Scolelepis squamata*, which was recorded on a similar tidal levels by other authors (Pichon, 1967; Tarr *et al*., 1985). Amphipods *Mandibulophoxus stimpsoni* (Phoxocephalidae) and *Urothoe grimaldi* (Haustoridae) have typically been recorded on the low shore of beaches (Bally, 1983; Dexter, 1984; Tarr *et al*., 1985) but were found to be concentrated on the mid- and high-shore levels of Durban beaches. The characteristic high-shore species recorded by other authors were not found on beaches in this study. The absence of a well-developed supralittoral community is thought to occur as a result of poorly developed drift lines (McLachlan, 1980). The absence of algal wrack along the drift line precludes the occupation of air-breathing arthropods (Bally, 1987; Dugan *et al*., 2003), which might explain why the high-shore of Durban beaches have such sparse macrofauna assemblages. However, the sampling technique and equipment may have influenced these results. Certain supralittoral forms, like the ghost crab *Ocypode ryderi*, may be too fast or burrow too quickly to be adequately sampled.

Snapshot sampling surveys may, however, not provide an accurate picture of macrofauna zonation across a sandy shore. This is because instantaneous sampling methods cannot account for temporal migrations of species (Brazeiro and Defeo, 1996). These may be short-term migrations in response to temperature or food availability (McLachlan, 1983, Jaramillo, 1987) or longer-term seasonal migrations related to reproductive behaviour, escaping from predators or decreasing competition (McGwynne and McLachlan, 1985). Detailed studies that take these factors into account are thus required to accurately depict zonation patterns across Durban’s sandy beaches.

2.4.3. Comparison between the macrofauna of Durban’s urbanised beaches and less urbanised or protected beaches in KwaZulu-Natal

The lack of historical data on Durban sandy beach macrofauna hinders the ability to evaluate how these communities may have changed with an increase in urbanisation. For this reason, the only alternative was to compare these beaches with protected beaches along the same stretch of coastline. Significant differences existed between Durban’s urbanised beaches and beaches within marine reserves, thus the outlined hypothesis is accepted. These differences may, however, not necessarily be attributable to anthropogenic impacts and may be an artefact brought upon by beaches grouping according to similar morphodynamic type or location along the coast. The latter was seen with the affinity of the north coast reserve beaches with each other, the south coast reserve beaches grouping together and the central Durban beaches forming another group. Groupings based on location along the coast may imply that macrofauna communities of beaches in close proximity may share similar larval stock. Larval dispersal and connectivity among sandy beaches is largely an unexplored field of research. The delineation of beaches based purely on physical structures such as the presence of piers or other man-made landmarks or headlands is often used in sandy beach research but the question of where one beach ends and another begins is a matter of contention. Beaches are thus in many ways similar to the open ocean pelagos in the sense that they are highly spatially connected, and the differentiation of one beach from the next is a rich avenue of research when factors such a larval dispersal are taken into consideration. While the groupings of beaches based on this factor may be likely, it does not account for the final group obtained that comprised of La Lucia (a beach located on the north coast of Durban), Garvies (a beach located on the south coast of Durban) and Port Shepstone (a beach located outside Durban, on the south coast of KZN). This may instead be attributed to beach morphodynamics, as these three beaches were of the reflective or intermediate-reflective type.

Studies have demonstrated that macrofaunal communities do differ between urban and protected beaches, usually attributing the differences to one or two species that do not tolerate high levels of disturbances (Veloso *et al.*, 2006). The number and frequency of bathers on Durban beaches reaches maximum levels during the holiday season (June/July and December/January). This is particularly so for the beachfront beaches that are inundated with bathers to such an extent that it is difficult to find a patch of unoccupied sand. The data for this study were collected during the off-peak season where the number of bathers was negligible and the beaches were thus only minimally disturbed. *In situ* experiments and mesocosm laboratory are needed to detect the impact of human disturbance on sandy beaches.

2.4.4. Conclusions

The bulk of the Durban coastline is made up of beaches of coarse sand and steep slopes (Harris *et al.*, in prep.), representing reflective or intermediate-reflective beaches. The central Durban beaches (beachfront beaches or bay beaches) with fine sand may be havens for many species despite being highly urbanised. These beaches are, however, artificially dissipative, a state brought upon by years of nourishment activities. Beach nourishment has been shown to have detrimental effects on sandy beach communities. Battery Beach, with its high species richness is a prime example of this type of diversity. In general, dissipative beaches are considered sources in terms of macrofauna populations, and reflective beaches, as sinks (Defeo and McLachlan, 2005). Durban's beachfront beaches, despite their high degree of anthropogenic impact, may thus play an important role in seeding macrofaunal populations to adjacent sandy beaches along the coast. It is thus necessary that these beaches receive special attention with regard to management and conservation. In addition, the high abundance and diversity of the typical reflective beach of La Lucia need further investigation to determine casual processes, possibly with replicate reflective beaches along the coast to determine if other reflective beaches in Durban have equally rich and abundant macrofauna communities.

This study has provided basic information of macrofauna communities along the Durban coastline, however, the absence of long-term, ecological monitoring of sandy beach ecosystems represents a dire problem for the appropriate assessment of urban beaches. Sandy beaches are dynamic environments and the macrofauna communities are equally dynamic. Community structure may change temporally and spatially in response to tidal cycles, seasons and storm surges, to name a few. For this reason, it is inadvisable to base management and conservation strategies on snapshot surveys of sandy beaches, although this is often the only information available to legislative authorities. It is imperative that studies take into account the inherent variability of populations and this further emphasises the need for long-term monitoring. This study thus forms the basis for proposing and testing further hypotheses, some of which have already been outlined above.

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Chapter 3 – Meiofaunal distribution and abundance along Durban beaches

Equipped with his five senses, man explores the universe around him and calls the adventure Science. -
Edwin Powell Hubble

3.1. Introduction

Benthic organisms play a crucial role in processes such as nutrient cycling, pollution remediation and energy transfer in marine sediments, and an understanding of these organisms' ecology is important and challenging (e.g., Snelgrove, 1998). On sandy beaches, most of the research has been concentrated on macrofauna and the physical (e.g., McLachlan, 1996; Bayed, 2003), biological (Defeo *et al*., 1997; Incera *et al*., 2003) and anthropogenic drivers of macrofaunal community structure (e.g., Peterson *et al*., 2000; Lecari and Defeo, 2003). Surf zone fish (Lasiak, 1983; Beyst *et al*. 2001) and birds (Dugan et al., 2003; Cornelius *et al*. 2001) that use beaches as sites for recruitment or nesting, respectively, have also received some attention from beach ecologists. Sandy beach microfauna and meiofauna, on the other hand, have in many ways been neglected despite being among the most diverse and abundant sandy littoral groups. Indeed, in terms of sandy beach ecological research, there appears to be an inverse relationship between the size of an organism (and its ecological importance) and number of studies conducted on it.

Meiofauna (derived from the greek *meio* meaning 'smaller) is a term used exclusively for the benthos with planktonic organisms being treated as a separate category. They are metazoans that pass through a macrofauna sieve (screen size – 1 mm) but that are no smaller than 38 μm (Dye and Fustenburg, 1988; Higgins and Thiel, 1988), and that possess special adaptations to exploit the interstitial matrix between sand grains. Meiofauna are, phyletically, the most diverse of all marine biota (Kennedy and Jacoby, 1999), represented by 23 phyla, and also occur in abundances that exceed many other marine groups of organisms.

Despite their small size, meiofauna are functionally an extremely important group of organisms, perhaps even more so than the larger macrobenthos. As trophic links, they transfer energy from the microbial/algal community to macrofauna and fish predators and, as agents of bioturbation, meiofauna increase the availability of detritus to detritivorous consumers (Tenore *et al*. 1977, Briggs *et al*. 1979). Further, they play an important role in the mineralisation of organic matter (e.g., Hubas *et al*., 2006, 2007) and in nutrient cycling in marine ecosystems (McLachlan, 1983). Meiofauna have also been shown to play a role in structuring macrofaunal communities (Watzin, 1983). Macrofauna recruits often form part of the temporary meiofauna (Palmer, 1988) and in this manner permanent meiofauna may alter their densities through selective predation by certain meiofaunal groups. Their small size, relatively fast generation times and fast metabolic rates make meiofauna good indicators of environmental disturbance (Heip *et al*, 1988; Hooge *et al*., 1999). Studies have shown qualitative and quantitative changes to meiofauna communities in response to environmental pollution, both organic and inorganic (e.g., McLachlan, 1977; Moore *et al*., 1987; Marin *et al*., 2008). In addition, being among the first metazoans to colonise areas of disturbance, meiofauna are fundamental to ecosystem resilience (Chandler and Fleeger, 1983).

An understanding of these organisms is thus important for the understanding of whole ecosystems and the interconnectedness between systems. On sandy beaches, the meiofauna community is often more abundant and diverse than the macrofaunal communities, but in general, more work has been conducted on the latter group. This may be explained in terms of the small size of meiofauna and their taxonomic complexity, where identification to species level (where even possible) is extremely time consuming. Meiofauna of Durban beaches have been poorly documented in the published scientific literature, although several studies in the “grey” literature do exist. These are mainly in the form of environmental impact assessment reports using BACI (Before After Control Impact) surveys to determine the effects of anthropogenic influences on ecosystems (e.g., Blair *et al*., 2004).

The present chapter reports on a survey of meiofauna of beaches along the Durban coastline and provides a baseline for future investigations. Given the importance of sandy beaches and their fauna, baseline data on the descriptions of the biotic communities and associated ecosystem processes are fundamental to the proposition of applicable and sustainable management policies. The aim of this chapter was thus to provide much needed baseline data on the meiofauna assemblages of Durban’s sandy beaches. The objectives were to: 1) describe meiofauna community structure in terms of abundance and species richness in relation to beach morphodynamics and anthropogenic impact, and 2) evaluate changes in meiofauna community structure on a gradient away from a nutrient point i.e., an estuary mouth or storm- or wastewater outlet. This study tested the hypothesis that beaches near an estuary or other nutrient point would have different meiofauna community structure to beaches located further away from point sources.

3.2. Materials and methods

3.2.1. Study area

Fifteen beaches located within Durban, along the central KwaZulu-Natal coast were sampled between October and November 2007. These beaches were chosen based on anthropogenic impacts, physical/chemical differences, proximity to a nutrient point and presence/absence of a rocky reef. Helicopter footage from aerial surveys and field observations was used to categorise beaches along the coast based on above-mentioned criteria (Table 1). This approach enabled the selection of beaches that were representative of Durban sandy beaches. The final choice involved 15 beaches within the eThekwini Municipality (Table 1). From north to south these are: Umdloti Estuary Beach; Umdloti Main Beach; Umhlanga Estuary Beach; Umhlanga Main Beach; La Lucia; Beachwood Mangroves; Thekwini Beach; Battery Beach; North Beach; uShaka; Garvies; Isipingo; Toti Main Beach; Toti Estuary Beach; Karridene Estuary Beach (Table 1).

In the studied area, the mean spring tidal excursions ranged from 1 to 2 m, averaging a moderate to low range of 1.7 m along the coast. The coast is classified as subtropical (Brown and Jarman, 1978) and is influenced by the warm southwest flowing Agulhas Current.

3.2.2. Sampling design

Sampling was carried out during spring low tides under conditions of low to moderate ocean swells (1 – 1.5 m) using a random stratified sampling design. Positioning of transects and levels were carried out exactly like in ‘Chapter 2’. Please refer to Chapter 2 for details.

Table 3.1. Categorisation of beaches along the Durban coastline from examination of aerial footage. Bold font represents beaches sampled in this study.

Beach	Dunes[1]	Rocks	Reefs	Frequented[2]	Developed[3]	Nutrient point	Notes
Laguna Beach	1	-	-	4	4	Estuary	Popular angling beach.
Beachwood Mangroves	**4**	**-**	**-**	**1**	**1**	**Estuary**	**Lies within a marine reserve protecting the mangrove ecosystem. Limited access.**
Broadway Beach	2	-	-	3	3		At the end of Beachwood Mangroves. ORV access point. Golf course.
Beachwood Country Club	2	-	-	3	4		ORV access.
Garvies	**2**	*****	*****	**3**	**2**		
Virginia Beach	3	-	-	2	4		Virginia airport. Golf course.
Glenashley	1	-	-	4	5	Outfall	High levels of residential development with houses on the dunes and virtually on the beach. There exists a small area of dune vegetation.
La Lucia	**2**	**-**	**-**	**3**	**5**	**Outfall**	**Intermittent hard structures. Development on dunes and beach. Signs of beach driving from footage.**
Umhlanga (Lighthouse Beach)	0	*	*	4	5		Several hard structures on beach e.g., pier.
Umhlanga (Main Beach)	**0**	*****	**-**	**5**	**5**	**Outfall**	
Umhlanga (Bronze Beach)	3	*	*	4	3	Outfall	
Umhlanga Estuary Beach	**4**	**-**	**-**	**2**	**2**	**Estuary**	**Agricultural land. Limited access beach.**
Umdloti (Main Beach)	**0**	*****	*****	**5**	**5**	**Outfall**	
Umdloti Estuary Beach	**4**	**-**	**-**	**1**	**2**	**Estuary**	**Limited access.**
Vetches Beach	1	*	*	3	4		
Bells/uShaka Beach	**1**	**-**	**-**	**4**	**5**		**Some dune vegetation between two walls. Frequented mostly during holiday seasons.**
Addington Beach	0	-	-	5	5	Outfall	
South Beach	0	-	-	5	5		
Dairy Beach	0	-	-	5	5		Signs of beach driving. Cleaning operations

Beach	Dunes[1]	Rocks	Reefs	Frequented[2]	Developed[3]	Nutrient point	Notes
North Beach	**0**	**-**	**-**	**5**	**5**		
Bay of Plenty	0	-	-	5	5		
Thekwini	**2**	**-**	**-**	**3**	**4**		
Isipingo Beach	**2**	*****	*****	**4**	**3**		**Popular angling beach.**
Toti Main Beach	**0**	*****	*****		**5**		**Development almost directly on beach. Beach severely eroded.**
Toti Estuary Beach	**0**	**-**	**-**	**5**	**5**	**Toti estuary**	**Launch site for boats.**
Battery Beach 1	**1**	**-**	**-**	**3**	**5**		
Battery Beach 2	**1**	**-**		**5**	**4**		
Dunes Beach	2	-	-	3	4		Development behind dunes quite extensive. Tractors on beach, signs of beach driving further along beach.
Karridene Beach	**4**	**-**	**-**	**2**	**2**	**Mzimbazi estuary**	

1) Rated from 0 to 5, with 0 being a complete absence of intact dunes and five being extensive dune and coastal forest

2) Rated from 0 to 5, with 0 being a no access beach and 5 being a popular recreational hotspot (many of people all year round)

3) Rated from 0 to 5, with 0 being no development on the beach and surrounding area and 5 meaning extensive development on beach i.e. highest degree of urbanization

* Indicates the presence of reef/rocks

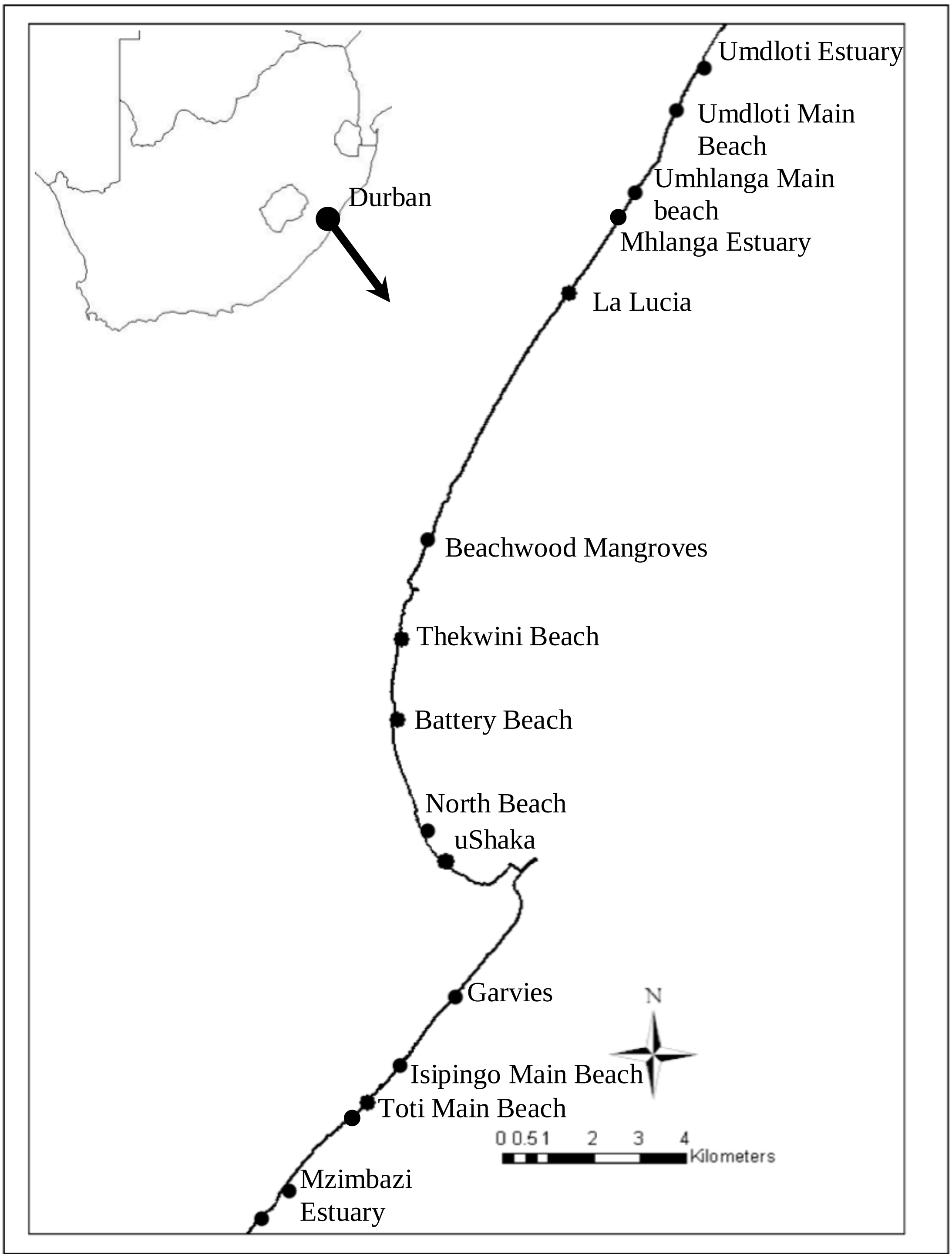

Figure 3.1. Beaches sampled for meiofauna along the Durban coastline.

At each beach, five transects were laid out perpendicular to the shore from the low tide mark to just above the drift line (the upper limit of the swash during the previous high tide). The position of individual transects was assigned randomly along the beach. Within each transect, 10 sampling levels were marked at equal vertical intervals, determined by differences in elevation between the low water spring (LWS – level 1) and the drift line (level 9). Level 10 was situated just landward the drift line.

On beaches situated near a nutrient point source such as an estuary (Mdloti Estuary Beach, Mhlanga Estuary Beach, Toti Estuary Beach and Mzimbazi Estuary Beach) or stormwater outlet (La Lucia and Umdloti Main Beach), transect 1 (T 1) was situated nearest to the estuary/stormwater outlet and the other four transects were situated on an alongshore gradient away from this point such that transect 5 (T 5) was furthest away from the nutrient point.

At each sampling level within a transect, three sediment cores (which were subsequently pooled) were taken using a hand-held, cylindrical, PVC corer (internal diameter = 5.5 cm) inserted to a depth of 25 – 30 cm for the collection of meiofauna. In estuarine meiofauna studies, it has been found that meiofauna are concentrated within the top 2 cm of sediment. This may due to the compaction of the fine sediment grains that prevent interstitial organisms from attaining greater depths. On exposed, microtidal sandy beaches, sediment grain sizes are often larger than that of estuaries, resulting in larger interstitial spaces. Meiofauna may thus attain greater depths. Studies of meiofauna on sandy beaches have taken cores to a depth of 10 cm (e.g., Moreno *et al.*, 2006) and 5 cm (Gheskiere *et al.*, 2006). McLachlan (1977) sampled meiofauna to a depth of 90 cm and sectioned cores to determine if a vertical gradient of meiofauna existed on beach. It was found maximum meiofauna abundance in the top 15 cm of sediment. Durban beaches are in general characterised by coarser grained sand. It was thus decided that meiofauna should be collected to a greater depth; however further studies are required to test how far into beach sediments meiofaunal communities can still be detected.

Sediment cores were deposited into labelled plastic bags and taken to the laboratory for extraction of meiofauna. The large sample sizes precluded the use of Ludox (Burgess *et al.*, 2001) or an Oostenbrink (Fricke, 1979) to extract meiofauna from sediments. Instead, meiofauna was extracted from sediment through manual elutriation. Elutriation entails submerging the sediment cores containing meiofauna in water, stirring rapidly and then decanting the water through a sieve with the appropriate mesh size. Elutriation is based on the fact that the organisms are less dense than sediment and will remain suspended in the water while the sediment settles, thus allowing for extraction of organisms from sediment.

A preliminary study (Chapter 2) to determine the number of decants required to remove at least 95 % of organisms from sediment with varying grain size was carried out. A known number of meiofaunal specimens were added to coarse and fine sediment of the same volume (4 L) in a 10 L plastic bucket. Sufficient water was added to facilitate stirring. For the purposes of this study, it was concluded that five stir and decants would be sufficient to remove 100 % of all groups of meiofauna from beach sediments in most cases. (detailed procedure in Chapter 2).

A separate sediment core (internal diameter = 2 cm) was taken to the same depth for sediment granulometry. Beach slope was measured and number of effluent line passes was recorded by counting the number of times the swash reached or crossed the effluent line over a five-minute period. This was replicated at each transect along the beach.

Due to the taxonomic complexity of meiofauna, organisms were identified to broad functional groups and counted. Sediment cores were dried at 60°C for 24 hours and the sand passed through nested sieves set at half ϕ intervals to obtain sediment grain size characteristics.

3.2.3. Data analysis

Meiofaunal abundance from each sandy beach was standardised to number of individuals per linear meter of transect:

$$\sum \text{individuals per species} \times \text{total sample area/length of transect}$$

Sediment grain size parameters and physical descriptions were computed using GRADISTAT Version 4.0 (Blott, 2000). Wave height and period data were obtained from WindGuru (www.windguru.cz/int/historie) because it was not feasible to measure these parameters in the field. WindGuru, however, does not have wave data for individual beaches. For this reason, the wave heights and wave periods were averaged over the entire sampling period. These parameters were used in the calculation of Dean’s parameter according to the equation:

$$\Omega = \frac{Hb}{Ws.T}$$

where *Hb* is the modal breaker height (m), *Ws* is sand fall velocity ($\mathrm{m.s^{-1}}$) (using conversion factors obtained from Gibbs *et al*, 1971) and *T* is modal wave period (s). A further parameter that was calculated was the Beach Index (*BI*):

$$BI = \log 10\left(\frac{Mz.TR}{S}\right)$$

Here, *Mz* represents the mean grain size in φ units (+ 1 to avoid negative numbers), *TR* is the spring tidal range (m) and *S* is the beach face slope.

The relationship between environmental variables (as well as composite beach indices such as Dean's parameter and the Beach Index) and total meiofaunal abundance was examined through linear regression analyses. To test the hypothesis that meiofauna abundance differed significantly among transects sampled along a gradient away from a nutrient point source, the six "impacted" beaches were treated as replicates and a one-way analysis of variance (ANOVA) was carried out between transects. Add sentence on normality etc. Further, for each individual beach, stations within transects were treated as replicates and differences among transects within a beach were tested using one-way ANOVAs. When the null hypothesis of no difference was rejected at a probability $p < 0.05$, pair-wise multiple comparisons were evaluated using the Tukey *post-hoc* test. For beaches where statistically significant differences ($p < 0.05$) were found, individual transects were compared with those of "non-impacted" beaches using *t*-tests, with "treated" referring to beaches with a nutrient point source and "control" referring to a beach without a nutrient point source. Transects were consistently sampled with Transect 1 being the southernmost transect and Transect 5, the northernmost.

The suite of statistical programs and data visualisation software utilised consisted of Prism Version 5.0a and Aabel 2.

3.3. Results

3.3.1. Physical characteristics of the investigated beaches

Table 3.2: Physical characteristics of the studied beaches. Beaches are listed from north to south along the coastline.

Beach	MD_{50} (μm)	Sorting coefficient (μm)	Overall textural group	1/slope	Beach width (m)	Beach index	Dean's parameter (Ω)	Beach classification	Effluent line passes (min^{-1})
Mdloti Estuary beach	997.7	468.2	Moderately sorted, very coarse sand	10.1	48	1.2	1.7	Reflective	5.10
Umdloti Main Beach	964.3	379.8	Moderately sorted, very coarse sand	11.8	39.2	1.3	1.8	Reflective	4.32
Mhlanga estuary Beach	769.8	385.2	Moderately sorted, coarse sand	17.2	55	1.4	2.3	Intermediate-reflective	2.0
Umhlanga Main Beach	539.1	301.2	Moderately sorted, medium sand	32.1	30.0	1.8	4.7	Intermediate-dissipative	0.7
La Lucia	1015.7	518.5	Poorly sorted, very coarse sand	8.1	45.01	1.2	1.6	Reflective	4.68
Beachwood Mangroves	712.4	348.1	Moderately well sorted, coarse sand	25.1	62	1.7	2.2	Intermediate-reflective	1.0
Thekwini	496.3	294.1	Moderately sorted, medium sand	33.3	69.32	2	4.9	Intermediate-dissipative	0.6
Battery	311.8	124.7	Moderately well sorted, medium sand	66.6	82	2.5	9.5	Dissipative	0.48
North Beach	429.7	264.5	Moderately sorted, medium sand	38.7	56	2.2	6.2	Intermediate-dissipative	0.6
uShaka	463.4	298.1	Moderately sorted, medium sand	38.5	56.72	2.1	5.1	Intermediate-dissipative	0.6
Garvies	709.5	362	Moderately sorted, coarse sand	28.6	38.4	1.8	2.1	Intermediate - reflective	0.72
Isipingo Main Beach	756.4	376	Moderately sorted, coarse sand	24.3	36	1.7	2.4	Intermediate-reflective	0.72
Toti Main Beach	543.4	254.8	Moderately sorted, medium sand	42.1	30	1.9	5.4	Intermediate-dissipative	1.0
Toti Estuary Beach	775.3	398.2	Moderately sorted, coarse sand	28.0	45	1.8	2.3	Intermediate-reflective	1.0
Mdloti Estuary Beach	586.2	232.5	Moderately sorted, medium sand	35.8	64	2.2	6.3	Intermediate-dissipative	0.5

The slope of the intertidal ranged from 1/8.1 to 1/66.6 with La Lucia exhibiting the steepest slope and Battery, the flattest. The width of the intertidal ranged from 39.2 to 82 m and median grain size (MD_{50}) from 311.8 to 1015.7 μm (Table 4). Mdloti Estuary Beach, Umdloti Main Beach, Umhlanga Estuary Beach, La Lucia, Bluff, Isipingo and Toti Estuary Beach were all characterised by coarse sand and the remaining beaches had medium sand. Beach sediments were poorly sorted (La Lucia), moderately sorted (Umdloti Main Beach, Mdloti Main Beach, Umhlanga Estuary Beach, Thekwini, uShaka, Bluff, Toti Main Beach, Toti Estuary Beach, Isipingo) or moderately well sorted (Battery Beach). Mdloti Estuary Beach had the most dynamic swash environment, experiencing 5.1 effluent line passes per minute and Battery, the least rigorous with 0.48 effluent line passes per minute (Table 4). The composite beach indices also showed a large degree of variation, ranging from 1.2 to 2.5 for *BI* (Mdloti Estuary beach and Battery Beach, respectively) and 1.6 and 9.5 for the dimensional Dean's parameter (La Lucia and Battery, respectively).

3.3.2. Meiofauna communities of the Durban sandy beaches and the relationship between their distribution and community structure

Twenty higher-level taxa of meiofauna (one represented by larval stages – copepod nauplius larvae) were recorded in this investigation (Table 3). The most common taxa were Nematoda and Crustacea (comprising harpacticoid copepods, isopods and ostracods) accounting for 50 % and 33 % of total meiofauna abundance, respectively. Polychaeta, Protista, Insecta, and Mystacocarida were also frequently recorded in samples, comprising 3 %, 5.3 %, 2.8 % and 2.6 % of the total meiofauna abundance, respectively. Turbellaria, Gastrotricha, Oligochaeta, Ciliophora, Rotifera, Kynhorhincha and Mollusca were recorded in smaller abundance, together making up 2.7 % of total meiofauna abundance.

Highest taxonomic richness was recorded at Battery Beach and lowest at Toti estuary beach (Table 4), with values of 20 and six taxa, respectively (Table 4). Abundance of meiofauna ranged from 520 644.9 ind.m^{-1} to 7 492 227.7 ind.m^{-1} (Table 4). Meiofauna abundance was greatest at Thekwini beach and lowest at Toti Main Beach. Toti Estuary Beach displayed the highest nematode to copepod ratio, and North Beach, the lowest.

With regard to specific differences between meiofauna of beaches with different morphodynamic type, the results show that nematodes generally dominated dissipative (Battery Beach, with 60.5 ± 60.5 % nematodes) and intermediate-dissipative beaches

(North Beach, uShaka, Thekwini, Mzimbazi, Toti Main Beach and Umhlanga Main Beach with a nematode abundance of 64.1 ± 26.6 %) (Figure 3.2). Crustaceans, and polychaetes (in some instances) dominated reflective (La Lucia, Umdloti Main Beach and Mdloti Estuary Beach) and intermediate-reflective beaches (Toti Estuary Beach, Isipingo Beach, Garvies, Umhlanga Estuary Beach, Beachwood Mangroves) (Figure 3.2). At the dissipative Battery Beach crustaceans (21%) formed the next greatest contributor of total meiofaunal abundance. Intermediate dissipative beaches were generally dominated by nematodes, making up 64.1 ± 26.6 % of total abundance, while crustaceans generally dominated the intermediate reflective beaches (51.5 ± 40 %). A few exceptions were found and these were at the intermediate dissipative Toti Beach where polychaetes dominated meiofauna samples (45.7%) and at the intermediate reflective Toti estuary beach where nematodes (50.4%) and the “other” group of organisms (comprised of the abundant Protista, Insecta, Mystacocarida, Turbellaria, Gastritricha, Oligochaeta, Ciliophora, Rotifera, Kynhorhincha and Mollusca) accounted for 48.6%of the abundance. Crustaceans made up 80.9 ± 2.5 % of total abundance on the reflective beaches.

Table 3.3. Meiofauna taxa recorded from sandy beaches in the central Durban area. ME: Mdloti Estuary Beach, MA:Umdloti Main Beach, UMH: Umhlanga Main Beach, UME: Umhlanga Estuary Beach, LL: La Lucia, BM: Beachwood Mangroves, TH: Thekwini, BB: Battery Beach, NB: North Beach, USH: uShaka, GB: Garvies, IS: Isipingo Beach, T: Toti Main Beach, TE: Toti Estuary Beach, M: Mzimbazi Estuary Beach

Taxa	**ME**	**MA**	**UMH**	**UME**	**LL**	**BM**	**TH**	**BB**	**NB**	**USH**	**GB**	**IS**	**T**	**TE**	**M**
Nematoda		C	AB	AB	C	VA	VA	VA	VA	VA	C	C	C	AB	VA
Turbellaria															
Turbellaria sp.1															AB
Catenulida sp.1															C
Kynhorhyncha						C	C	C	C	C					
Copepoda															
Harpacticoid copepoda sp.1	C	C	AB		C	C		AB	AB	AB	C				AB
Harpacticoid copepoda sp.2	R	R	C	R	R							R	C	R	C
Harpacticoid copepoda sp.3	C	C		AB	AB	AB	AB	AB	AB	AB	AB	C	C	R	C
Copepod nauplius larvae	AB	AB		C	AB	C	C	C	R	R	AB		R		R
Ostracoda															
Ostracoda (*Phylomedes* sp.)	VA	VA		VA	VA						VA	VA			
Ostracoda sp.1	AB	AB		AB	AB										
Cumacea sp.1															AB
Isopoda								R							
Mystococarida	R	R	C		R	AB		AB	C	AB					AB
Mollusca	C	C	C		C	R	C	C	C	C	C	C	C	AB	C
Rotifera						R		C	C						
Ciliophora															
Ciliophora sp.1								C	C	C					
Ciliophora sp.2															C
Gastrotricha	R	R		R	R	AB	C	AB	AB	AB					AB

Oligochaeta	R	R	C		R	C	C	C	AB	R	R	R	R		R
Polychaeta															
Polygordius sp. (Polygordiidae)	C	AB			AB						AB	AB	AB		
Scolelepis squamata (Spionidae)								R							
Saccocirrus sp. (Saccocirridae)	C	C			C	C					C	R	C		
Pisione africana (Pisionidae)						C	C	C	C	C					
Pisionidens indica (Pisionidae)	C	C		C	C	AB					C	R			
Protodrillidae sp.1								C							C
Hesionidae sp.1									R	C					R
unidentified polychaete sp.1											C				R
unidentified polychaete sp.2															R
Halacaroidea															
Anomalohalacarus sp.1	R	VR		R	R						VR				
Scaptognathus sp.1						C		C	AB	C					
Insecta															
Anurida maritima (Neonuridae)	AB	AB	AB		C						AB	AB	C	R	
Coleoptera (Phreatodytidae)						C		C							
Coleoptera sp.1														R	
Foraminifera	C	C	C	C	C	AB	C	AB	C	C	R	AB	R		
Sarcomastigophora	VR	VR	R	VR	VR	AB		C	C						
centric diatom	C	C	C	AB	C	C	AB	AB	AB	AB		C	C		
dinoflaggelate						R	C			R					

VA	very abundant	> 1 000 000	C	common	10 000 – 100 000	VR	very rare	< 1000
AB	abundant	100 000 – 10 000 000	R	rare	1000 - 10 000			

Table 3.4. Meiofauna diversity and abundance of selected Durban beaches

Beach	Diversity (no. of species)	Abundance (ind.m^{-1})	nematode/copepod ratio
Mdloti estuary beach	19	5 282 029.9	2.81
Mdloti main beach	19	6 214 905.7	4.48
Umhlanga main beach	10	1 381 706.4	6.59
Mlanga estuary beach	12	3 419 760.0	7.98
La Lucia	19	5 695 974.8	2.04
Beachwood mangroves	19	3 471 504.2	3.06
Thekwini	11	7 492 227.7	0.71
Battery Beach	20	6 446 881.1	0.40
North Beach	17	6 596 561.8	0.21
Ushaka	16	6 796 649.4	1.30
Garvies	14	2 949 699.7	2.20
Isipingo	12	2 362 448.6	16.56
Toti main beach	11	520 644.9	52.95
Toti estuary beach	6	884 122.0	0.71
Mzimbazi estuary beach	17	6 170 352.6	0.34

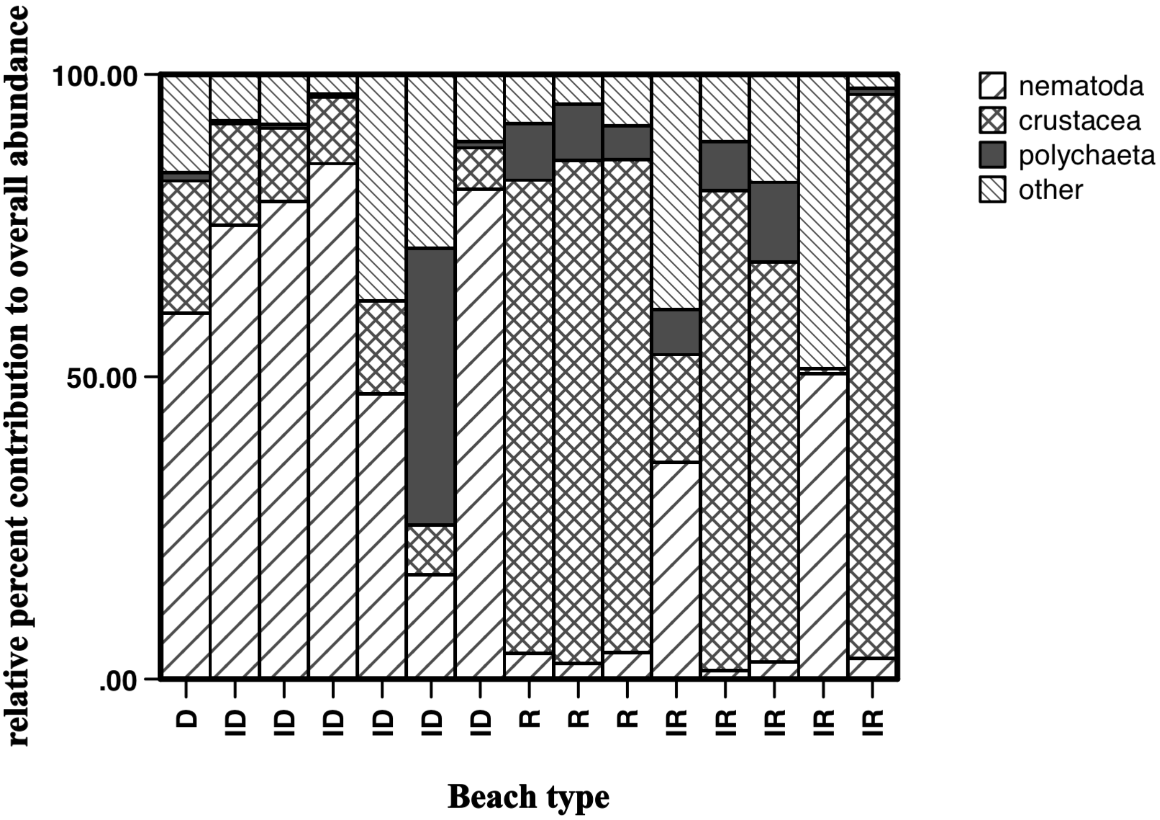

Figure 3.2. Dominant taxa present on beaches with differing morphodynamic type (D – dissipative; ID – intermediate-dissipative; R – reflective; IR – intermediate-reflective).

Regressions of environmental parameters (slope, median grain size, effluent line passes and beach width) including composite beach indices (*BI* and Ω) showed no significant relationship between total meiofaunal abundance and sediment grain size ($p = 0.450$), total meiofaunal abundance and beach slope ($p = 0.700$), total meiofaunal abundance and effluent line passes ($p = 0.610$), total meiofaunal abundance and *BI* ($p = 0.359$) or total meiofaunal abundance and Ω ($p = 0.164$) (Figure 4). A significant positive relationship was found between total meiofaunal abundance and beach width ($p = 0.024$) (Figure 3.3).

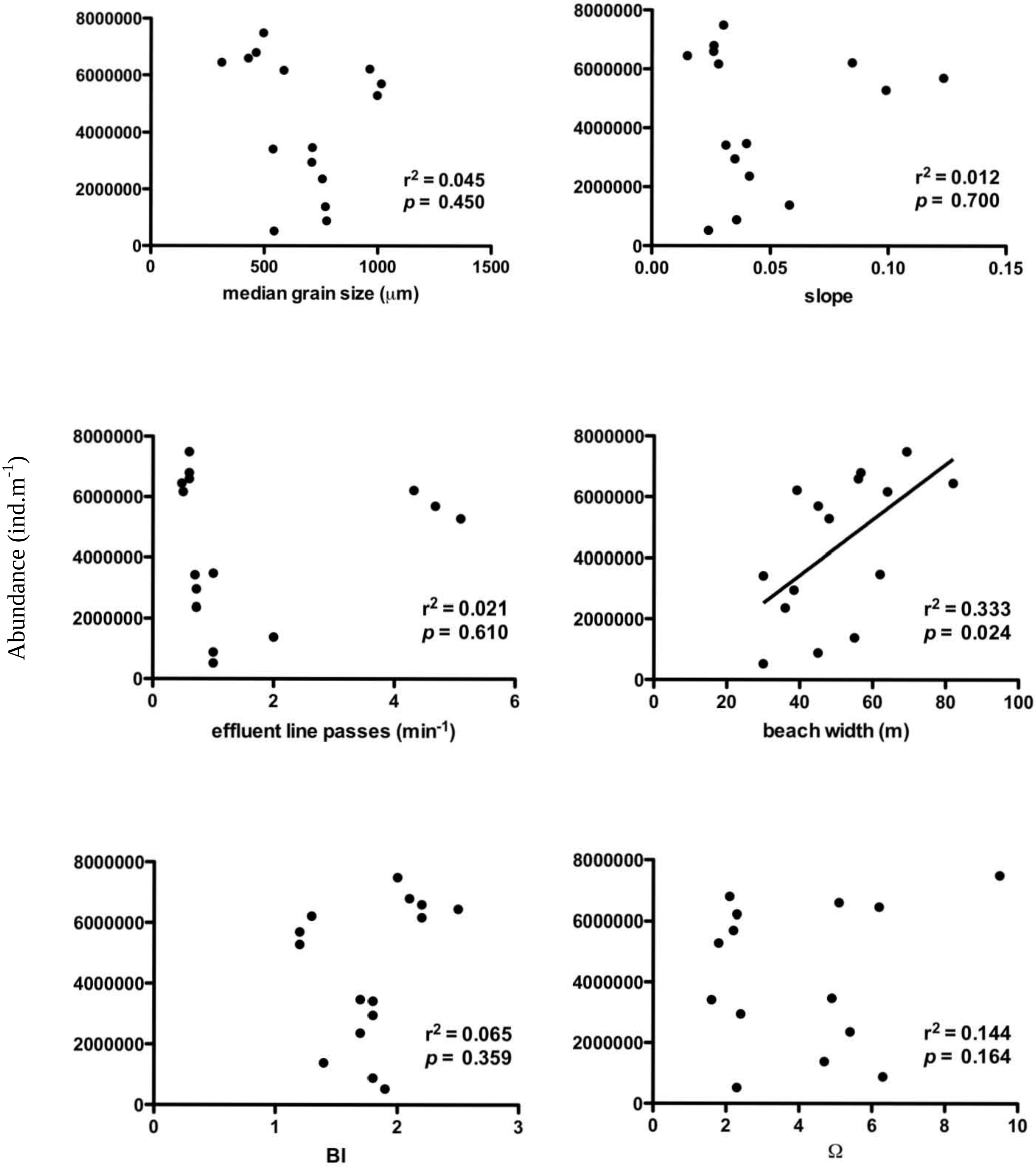

Figure 3.3. a-f. Linear regression analysis of total abundance versus selected environmental variables, i.e., median grain size, slope, effluent line passes, beach width, beach index and Dean's parameter. Trend lines indicate significant relationships ($p < 0.05$).

3.3.3. Effect of a nutrient point source on meiofauna community structure

To test the potential impact of a nutrient point (estuary mouth, storm- or wastewater outlet) on meiofauna assemblages on sandy beaches, sampling was conducted on transects located at intervals away from these nutrient point sources on certain beaches. When using beaches as replicates, no significant differences were found among transects (ANOVA, $p = 0.0856$) and the null hypothesis of no difference was not rejected (Figure 5).

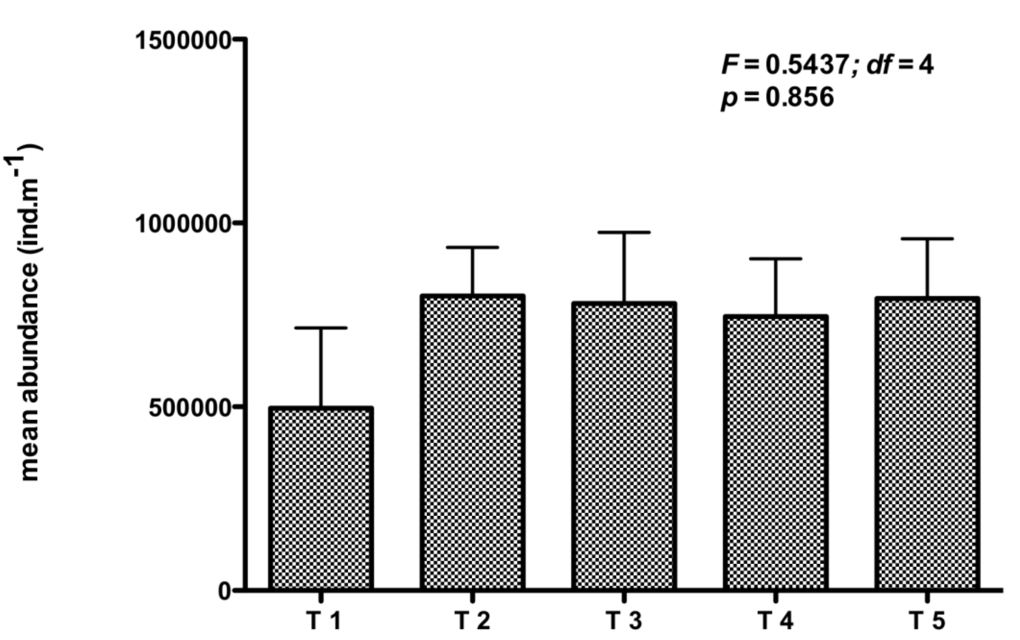

Figure 3.4. Differences in meiofauna assemblages at intervals away from a nutrient point source. T 1 is the transect closest to the nutrient point and T 5 the furthest. Abundances are given as mean ± S.D. of six beaches

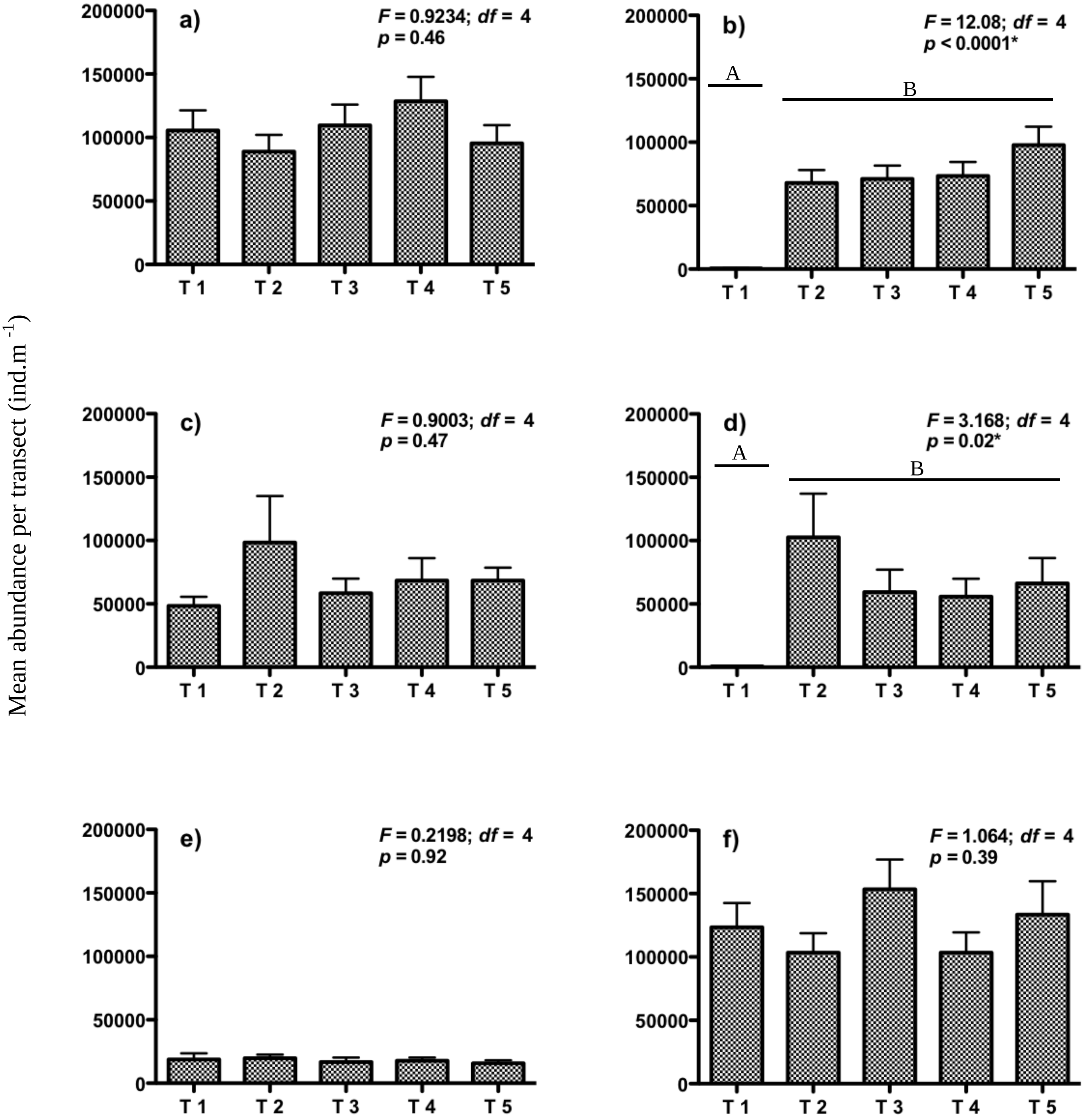

Figure 3.5. Differences in meiofauna assemblages at intervals away from a nutrient point on individual beaches, a) Mdloti Estuary Beach, b) Umdloti Main Beach, c) Mlanga Estuary Beach, d) La Lucia, e) Toti Estuary Beach and f) Mzimbazi Estuary Beach. T 1 is closest to the nutrient point and T 5 the furthest. Abundances are given as mean ± S.D. of 6 beaches. Capitalised letters indicates significant differences, where 'A' is significantly different from'B'.

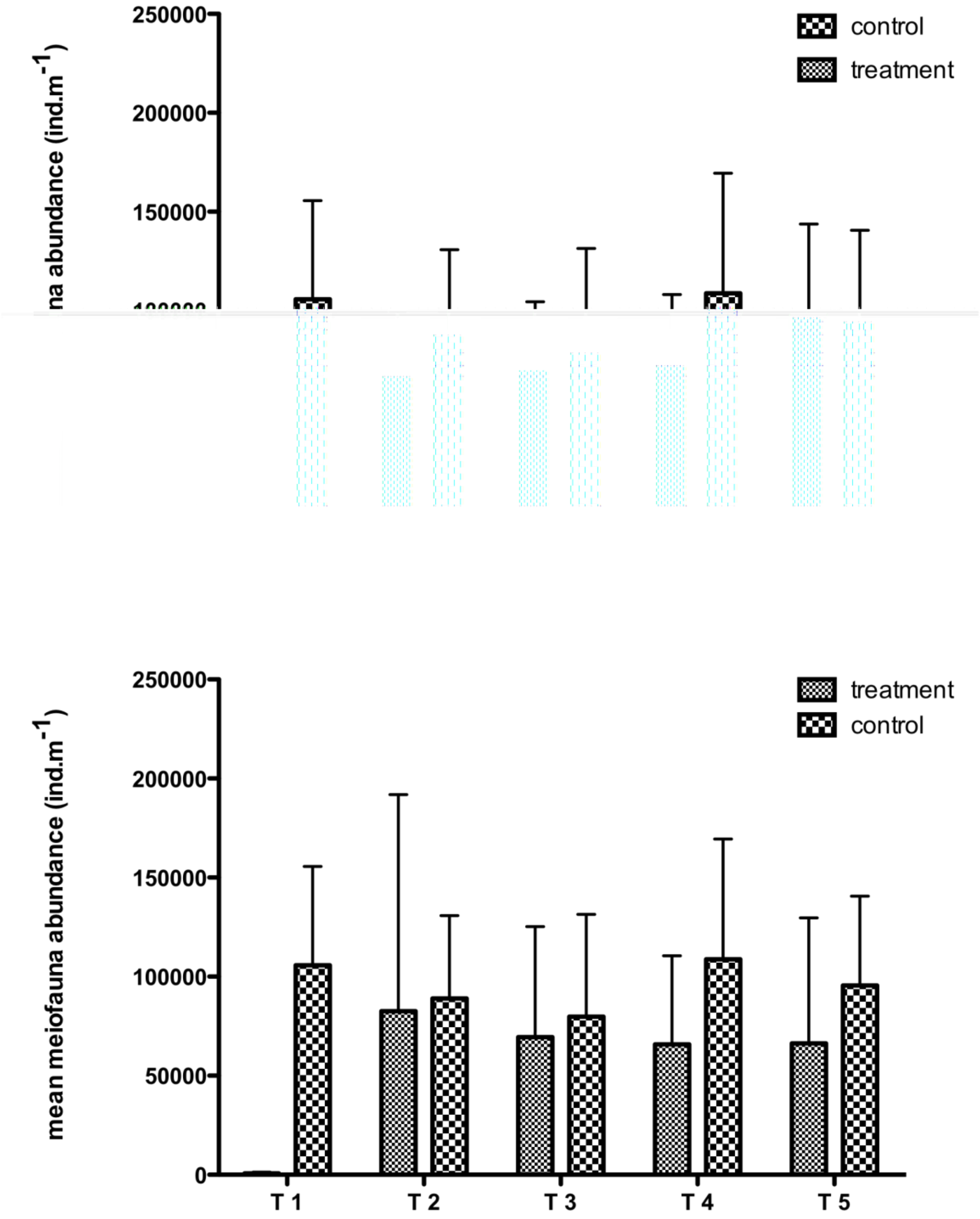

Figure 3.6. Comparison between transects of impacted (beaches with a nutrient point) and a control beach (beach without a nutrient point), a) Umdloti main beach and b) La Lucia. T 1 is the transect closest to the nutrient point and T 5 the furthest. Abundances are given as mean ± S.D. of six beaches. Asterisks denote significance ($p < 0.05$)

Each beach was then treated as an entity, with stations within transects as replicates (Figure 6 a – f). ANOVA results indicating no significant difference among transects within a beach were obtained for four of the impacted beaches. These were Mdloti Estuary Beach (p = 0.46, Figure 3.5, a), Mhlanga Estuary Beach (p = 0.47, Figure 3.5, c), Toti Estuary Beach (p = 0.92, Figure 3.5, d) and Mzimbazi estuary beach (p = 0.39, Figure 3.5, f). Significant differences were found at Umdloti Main Beach and La Lucia ($p < 0.05$, Figure 3.5, b and d, respectively). The transect closest to the stormwater outlets on these beaches was significantly depleted in meiofauna, compared to transects further away. Examining these two beaches more closely, through a comparison with a non-impacted beach, showed that the transects adjacent to stormwater outlets had significantly lower total meiofauna abundances ($p < 0.05$) than the corresponding transect on the ‘control’ or non-impacted beach (Figure 3.6 a and b).

3.4. Discussion

3.4.1 The physical character of Durban sandy beaches

Beaches along the Durban coastline exhibited a large degree of variability with respect to environmental variables and composite beach indices. The sandy beaches selected for this study were representative of those within Durban, comprising beaches across the continuum of morphodynamic states (dissipative, intermediate-dissipative, intermediate-reflective and reflective; see Chapter 1 for a detailed discussion on beach type). Inclusive of this were beaches adjacent to rocky shores, estuary mouths and storm- or wastewater outlets. The findings are in agreement with those of earlier studies related to the physical nature of Durban beaches that demonstrated a tendency for central Durban beaches (Thekwini, Battery, North beach, uShaka) to be composed of finer sand and flatter slopes which became coarser and steeper as one progresses toward the more exposed shores of the south coast of Durban (Garvies, Isipingo, Toti Estuary Beach). Beaches on the north coast also typically have coarser sand and steeper slopes (Mdloti Estuary Beach, Umdloti Main Beach, Mhlanga Estuary Beach, La Lucia, Beachwood Mangroves).

The exceptions in this study were Toti Main Beach and Umhlanga Main Beach, both with finer sand than that which characterises their location along the coast (south and north, respectively). This may have been due to recent storm events that scoured away a large portion of these beaches. Both beaches are highly developed as well as recreational hotspots, with bathers frequenting the beach not only during peak holiday seasons but throughout the year. During the storm events, much of each beach was eroded away, decreasing the beach width substantially, and threatening coastal properties lying in close proximity to the beach. Mechanisms were thus put into place to counteract this loss of sand. Rigorous sand pumping schemes to offset the deleterious effects of beach erosion were undertaken by the local municipal authority. The sand pumped onto both beaches were medium to fine-grained, resulting in a change to the overall morphological character of these beaches, causing Toti main beach and Umhlanga main beach to resemble more closely the central Durban beaches. Central Durban beaches (or beachfront beaches as they are commonly referred to have a long history of beach nourishment, beginning as early as the 1990s and resulting in them becoming very similar with regard to beach morphodynamic state, as evidenced in this study.

3.4.2. Meiofauna communities of the Durban sandy beaches and the relationship between distribution and environmental parameters

Studies of the meiofauna of Durban beaches are conspicuously absent from the scientific literature, but several unpublished reports do exist. These are usually in the form of impact assessment reports that look at localised meiofauna community responses to pollution (e.g., Blair *et al*., 2005). What is lacking is an overall description of meiofauna community structure on a larger ecological scale. This study aimed to remedy this and to provide much needed baseline data for beaches along the Dubran coastline.

Durban beaches have rich and abundant meiofauna communities, more diverse and numerous than that of the macrobenthos. This is in agreement with meiofauna studies conducted both in estuaries (e.g., Coull, 1990) and sandy beaches (e.g., McLachlan, 1983) that have repeatedly shown that meiofauna, despite their small size, are a biologically diverse component of the benthos, often occurring in numbers several orders of magnitude greater than that of the macrofauna, and exhibiting a diversity that may be underrepresented due to the taxonomic complexity of these organisms.

Most of the research on sandy beaches focuses on the physical nature of these environments (e.g., McLachlan, 1977; Bayed, 2003; Rodil et al., 2004). Studies have demonstrated that meiofauna community structure is closely related to exposure and sediment granulometry (Eleftheriou and Nicholson, 1975; Fricke and Flemming, 1983). Estuarine habitats were thought to harbour more abundant meiofauna communities (Coull, 1988), however, highest meiofauna abundances have been recorded for intermediate beaches, where the optimal balance exists between organic input and sediment oxygenation (Weiser, 1959; McIntyre and Murison, 1973). Both these factors are closely related to grain size characteristics, with finer, more compacted sediment being less oxygenated and richer in organic matter than coarser sediments. This trend was observed in the present study, with the intermediate-dissipative beaches, such as Thekwini, uShaka and North beach, generally having the most abundant meiofaunal communities. Reflective beaches sampled in this study also exhibited very high abundance values, which is uncharacteristic for this beach type.

McIntyre (1971) and McLachlan et al. (1981) found that the relationship between meiofauna abundance and beach morphodynamic characteristics is generally opposite to that of the larger macrobenthos. Macrofauna communities typically increase in community diversity, abundance and biomass from reflective beaches to dissipative beaches (e.g. McLachlan, 1990; Jaramillo et al., 1995). Rodriguez et al. (2003) noted an exponential increase in meiofauna biomass and species richness from exposed to very exposed beaches and a linear increase in species richness with sediment grain size. In this study, statistical analyses showed no clear relationship between grain size parameters and meiofauna distribution (Figure 4). This was also true for beach slope, effluent line dynamics and the composite beach indices, Beach Index (*BI*) and Dean's parameter (Ω). These findings are in agreement with those of others that also found no significant effects of these physical parameters on meiofauna abundance (Rodriguez et al., 2003). Only beach width was found to significantly correlate with meiofauna distribution along Durban sandy beaches, with communities becoming more abundant with an increase in beach width (Figure 4 d). This suggests that other factors such as bacterial densities, chlorophyll-*a* or dissolved organic matter concentrations (McLachlan, 1985) may have played a greater role in determining meiofauna distributions. However, these parameters were not measured in this study. Interestingly, meiofauna samples collected in this study also contained significant quantities of large centric diatom and dinoflagellate species. These are not a component of meiofauna but were included in the analyses due to their occurrence in such high abundances. Durban beaches have long been considered poor in terms of primary productivity, but as evidenced by these high abundances of photosynthetic organisms, beaches may in fact be exactly like the semi-closed ecosystems proposed by McLachlan (1980), not relying entirely on allochthonous input of both terriginous and marine origin to sustain production.

In general, nematodes and harpacticoid copepods dominate benthic meiofauna communities, comprising more than half of the total meiofauna abundance (Harris, 1972; Radziejewska and Stankowska-Radziun, 1979; Rodriguez et al., 2003). Durban beaches follow this trend, for the most part, although annelids (both polychaetes and oligochaetes) also occurred in considerable abundances and were the third-largest group of organisms encountered. Mystococarids, turbellarians, kynorhynchs, gastrotrichs, oligochaetes, isopods, rotifers, ciliophorans, halacaroids and insects are also common members of the meiobenthos in marine habitats (Higgins and Theil, 1988; Rodriguez et al., 2003) and were recorded for Durban sandy beach meiofauna.

3.4.3. Differences in meiofauna community structure on a gradient away from a nutrient point

To test the potential impact of a nutrient point (estuary mouth or storm- or wastewater outlet) on meiofauna assemblages on sandy beaches, sampling was conducted on transects located on a gradient away from these nutrient point sources on certain beaches. It was predicted that there would be changes in meiofauna assemblages closer to the nutrient point due to increased nutrient loading (as would be the case with an estuary). Lercari and Defeo (2006) showed that estuarine discharges might act as an aggregate factor influencing macrofaunal communities by altering sediment and salinity characteristics of the nearshore beach environment. The results of this study showed no significant differences in meiofaunal assemblages between Durban beaches close to an estuary mouth and those located further away. A possible explanation for this is the fact the at the time sampling, the mouths of the estuaries were closed, precluding the intrusion of estuarine-derived water (and the associated nutrients) to the beach. A further explanation may be that the distances of transects from the estuary mouth may not have been sufficiently large to adequately detect changes in meiofauna community structure along the prescribed gradient.

While sampling beach meiofauna transects at intervals away from stormwater outfalls at two of the beaches (La Lucia and Umdloti main beach), it was found that in both cases, the abundance of meiofauna was two orders of magnitude lower close to the outfall than it was further away. Localised freshwater discharges have been shown to produce changes in both habitat and resident fauna (e.g., Irlandi et al., 1997) in the marine environment. One possible explanation for the trend observed at the stormwater beaches could be that the marine meiofauna of sandy beaches are not tolerant to the freshwater being released by the stormwater outfall and were thus eliminated from the immediate environment. However, if this was the case, organisms more tolerant should recolonise the existing niches and thus does not account for the drastic reduction in meiofauna abundance at these sites. A further possibility is that discharges from the stormwater outlets onto a beach not only eroded away copious amounts of sediment (personal observation) but resident biotic communities as well. Discharges may be too frequent for organisms to colonise and establish viable populations on the disturbed portion of the beach, thus accounting for the extremely low meiofauna abundances recorded on transects closest to the stormwater outlets of both beaches. Durban experiences summer rainfall and during the period of sampling, discharges from the stormwater outlet may likely have been high. Evidence for this has been shown in estuarine systems, where immediately following a breaching event, both pelagic and benthic diversity of the system decreases (Begg, 1984a and b).

Nematode/copepod ratios were calculated for all the beaches sampled for meiofauna, to determine if the results would reflect the degree of anthropogenic impact on the investigated beaches. Copepods are generally more sensitive to oxygen depletion or anoxia than nematodes (Elmgren, 1975; Murrrell and Fleeger, 1989, Moodley *et al.*, 2000) and their numbers tend to diminish in systems exposed to such disturbances. Therefore, a higher nematode/copepod ratio should indicate a more disturbed system (Table 3.4). The results of this study with regard to the nematode/copepod ratio are inconclusive. Some of the least disturbed beaches exhibited the highest nematode/copepod ratios (e.g., Mloti Estuary Beach and Umhlanga Estuary Beach). These are beaches that have limited access, comparatively little development on the beach backshore, and retain relatively intact dunes. On the other hand, beaches that experience high levels of disturbance displayed nematode/copepod ratios that were uncommonly low (e.g., uShaka and North Beach). The highest ratio was recorded at Toti main beach and was an order of magnitude greater than those recorded at the other Durban beaches. Toti main beach was also the site displaying the lowest meiofauna abundance. As previously mentioned, a possible explanation for this may be the beach nourishment scheme that was initiated after a severe storm devastated the coastline. Several studies have investigated the effect of beach nourishment that is used to combat beach erosion (e.g. Nelson, 1993; Fanini et al., 2009) but these were focused on macrofauna. These studies showed that certain organisms may be sensitive to nourishment because this activity alters habitat characteristics such as grain size and sediment quality (Fanini et al., 2009). Unfortunately, no similar investigations on meiofauna have been conducted yet, but the findings here suggest that beach nourishment may in fact be an important feature affecting meiofauna of sandy beaches.

3.4.4. Conclusions

This baseline study of the meiofauna of Durban beaches provided much needed information on benthic assemblages of sandy beaches along the coast. Durban beaches have rich and abundant meiofauna communities and may be even more so when examined at a higher taxonomic resolution. Due to the taxonomic complexities of meiofauna, this study grouped organisms into very broad categories. However, each category may contain several different species, genera, and even families. For example, one study found up to 55 different species of nematodes on the strandline of a Belgian beach (Gheskiere et al., 2006). For this reason, the taxonomic richness reported in this study is likely a gross under-representation of meiofauna species richness along the Durban coast. There is a dire need for taxonomic related studies, aimed purely at the identification of meiofauna species along beaches not only in South Africa, but worldwide. It is a very likely possibility that such studies will yield numerous new meiofaunal species new to science and endemic to the KwaZulu-Natal or South African coastline.

Unlike macrofauna that reproduce seasonally, meiofauna exhibit continuous reproduction (McLachlan, 1977) and assemblages may thus not change considerably with time. Because this study was a snapshot survey of beaches along the coastline, it is, however, necessary that it be followed by further surveys to determine if temporal variations of communities occur.

With respect to the effect of stormwater outfalls on biotic assemblages the findings of this study are very important for the management of sandy beach ecosystems. Further hypothesis-driven research is required to determine the causative effects of these results. It is often argued that beaches are resilient to exploitation and do not require special consideration with regard to conservation because of their inherent variability and dynamic nature. This study has demonstrated, to the contrary, that anthropogenic disturbances can severely impact sandy beaches, to the detriment of the functioning of the ecosystem.

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Chapter 4 – General discussion and synthesis

We are at the very beginning of time for the human race. It is not unreasonable that we grapple with problems. But there are tens of thousands of years in the future. Our responsibility is to do what we can, learn what we can, improve the solutions, and pass them on – Richard Feynman

Abstract

In this chapter the findings of the research outlined in this thesis is collated and questions and hypotheses arising from the research are elaborated upon.. The threats to sandy beach ecosystems are reviewed and discussed in terms of the management of beaches. The applicability of the findings of this study is discussed and management interventions for beaches are proposed. Questions and hypotheses arising from the research conducted are elaborated upon.

4.1. Introduction

The United Nations Millennium Ecosystem Assessment was the largest study done of ecosystems around the world, involving 1300 scientists from 71 countries. The Millennium Ecosystem Assessment Report, published in March 2005, stated that 60 percent of the ecosystem services that support life on Earth are being degraded and warned that, "Any progress achieved in addressing the goals of poverty and hunger eradication, improved health, and environmental protection is unlikely to be sustained if most of the (biodiversity and corresponding) ecosystem services on which humanity relies continue to be degraded" (Millennium Ecosystem Assessment Report, 2005).

This was reiterated in the Millennium Development Goals of the United Nations Millennium Project (Millennium Project, 2009). Eight broad goals were proposed through extensive discussions by a worldwide network of participants from academia, UN agencies, international financial institutions, nongovernmental organisations, donor agencies, and the private sector. These goals were as follows:

- Eradicate extreme poverty and hunger;
- Achieve universal primary education;
- Promote gender equality and empower women;
- Reduce child mortality;
- Improve maternal health;
- Combat HIV/AIDS, malaria, and other diseases;
- Develop a global partnership for development and most important

importantly for the purposes of this discussion;

- **Ensure environmental sustainability,** the target here to significantly reverse the loss of environmental resources by 2015, to ensure the provision of crucial ecosystem services (such as the provision of clean water) to humankind.

The above goals were stated as being the ‘fulcrum’ on which development policy of the international political system is based because of the comprehensive, time-bound and quantifiable targets upon which it founded (Millennium Project, 2009). More importantly, the Millennium Ecosystem Assessment and the Millennium Development Goals brought to the fore the importance of preserving the valuable services provided by the natural ecosystems of the world for policy makers.

4.2. Sandy beach ecosystems and their importance

As far as ecosystems go, sandy beaches have been neglected in terms of scientific research and management. This is despite the fact the beaches dominate the world’s temperate and tropical coastlines (Bascom, 1980; McLachlan, 1983). Beaches are prime areas of recreation, but more importantly possess a unique biodiversity that provides numerous ecosystem services that are, for the most part, overlooked. For example, beaches play a central role in storm protection (buffer areas), with the beach face absorbing and dissipating the destructive energy of waves (Bird, 1993; McLachlan and Brown, 2006). Coastlines of the world are also naturally protected by dunes on the beach backshore, and in many areas where structural development has been located on the beach or in vegetated dunes, storms have resulted in severe devastation (Bird, 1993). When the beach is lost, not only are coastal properties threatened or the natural aesthetic value of the coastline degraded, but biotic communities resident on the beach disappear with unknown consequences for coastal ecosystem function and the un-quantified services people derive from this functioning, such as water purification through filtration.

Technically, beaches may be considered low diversity environments; nevertheless they are composed of unique biotic assemblages. In addition, they are integral components of coastal food webs upon which many charismatic or iconic members of higher trophic levels (birds, fish and turtles) depend. Studies have shown that many fish species may use beaches as sites of recruitment, growth and feeding of juveniles (Steele, 1976; Beyst, 2001). Estuaries are known to be important nursery grounds for several fish species (Wallace and van der Elst, 1975) but because oceanic beaches are such physically demanding environments, their function as nurseries for juvenile fishes have often been overlooked.

Sandy beach fauna and flora also contribute directly by providing essential services such as biofiltration and the recycling of nutrients (Dye, 1981; McLachlan and Brown, 2006). What this means is that beaches probably function as nesting or nursery grounds, pantries, and biological filters for coastal water bodies, ensuring that these water bodies are clean. The problem is that the processes underlying these ecosystem services have seldom been studied in any detail anywhere in the world, and studies of KwaZulu-Natal beaches are particularly prominent by their absence from the peer-reviewed scientific literature making the management and conservation of these crucial ecosystems a very difficult task.

4.3.This study

The research outlined in this dissertation aimed to revise and update knowledge of intertidal sandy beaches within the eThekwini Municipality. The eThekwini Municipality is one of five local municipalities governing the province of KwaZulu-Natal, the others being the uMkhanyakude District, uThungulu District, Ilembe District and Ugu District. The eThekwini Municipality governs the coastal city of Durban, which, despite being the fastest growing city in South Africa, not only boasts a wealth of inland biodiversity but also comprises rich coastal resources which include, rocky shores, mangrove forests, coral reefs, coastal forests, wetlands and sandy beaches.

Of these, the least studied are sandy beach ecosystems and as Schlacher et al. (2006) aptly pointed out, it is these neglected ecosystems that will ultimately “bear the brunt of change”. Anthropogenic factors influencing urban sandy beach systems are associated with infrastructural, commercial, industrial, and residential developments and networks (transportation, sewerage, drainage, power and communications). These usually manifest on the landward side of the beach but a further threat to beaches is that which encroaches on the seaward side – global climate change and the manifestations thereof. Increased storminess and sea level rise, together with exponential human population growth, which results in increased habitat transformation in favour of anthropogenic developments, have forced sandy beaches, especially urban beaches, into what has come to commonly be referred to as a “coastal squeeze”. What is often overlooked is that these processes might have catastrophic consequences along developed shorelines – like that of Durban – not only in economical terms, but ecologically as well (Arntz, 1987; Slott et al., 2006).

This study comprised the first truly ecological study of sandy beaches along the Durban coastline and has provided necessary data on aspects of the biodiversity of urban beaches. The hypotheses tested were largely exploratory and tested the existence of drivers of spatial patterns with regard to sandy beach macrofauna and meiofauna biodiversity along urbanised coasts. These findings will ultimately be used in the development of a management plan for Durban's beaches that takes into account not only beach biodiversity, but also ecosystem services.

In this section I will give a brief overview of the findings of this study, address the threats facing beaches, highlight several working hypotheses to address the causative reasons for the patterns attained in this study and discuss future research needs for sandy beach ecosystems.

4.4. Review of threats to sandy beaches

The major threats to sandy beaches fall into five broad categories: climate change, urban sprawl, pollution, resource exploitation, recreation and tourism (Figure 4.1). The influence of these threats, while being diverse and varied, can ultimately be reduced to the loss of ecosystems goods and services provided by these ecosystems due to biodiversity losses (Figure 4.1).

4.4.1. Climate change

One of the major problems facing sandy beaches is global change and the manifestation thereof, which include oceanographic changes (such as changes in temperature, ocean currents and ocean acidity), climate variability (changes in weather patterns, most notably, an increase in the frequency and severity of storms), and sea-level rise (Feagin et al., 2005; Cowell et al., 2006; Harley et al., 2006). The socio-economic consequences lie in the damage to property, infrastructure, interruption of economic activity and loss of human lives (Klein 2001). Coastal cities such as Durban are predicted to be most vulnerable, but once again, the cost to biodiversity is overlooked in favour of socio-economic implications. Sea level rise, increased storminess and changes to the ocean's physical and chemical oceanography will be detrimental to sandy beaches and resident faunal communities. Geographic distributions of species will most likely be impacted by changes in temperatures and many species that occur at their thermal tolerance limits may become locally extinct, as has been predicted for terrestrial species (Thuiller et al., 2006). An increase in temperature will likely impact Durban’s beach biodiversity through alterations in metabolic activity (and hence beach productivity), decomposition and nutrient cycling.

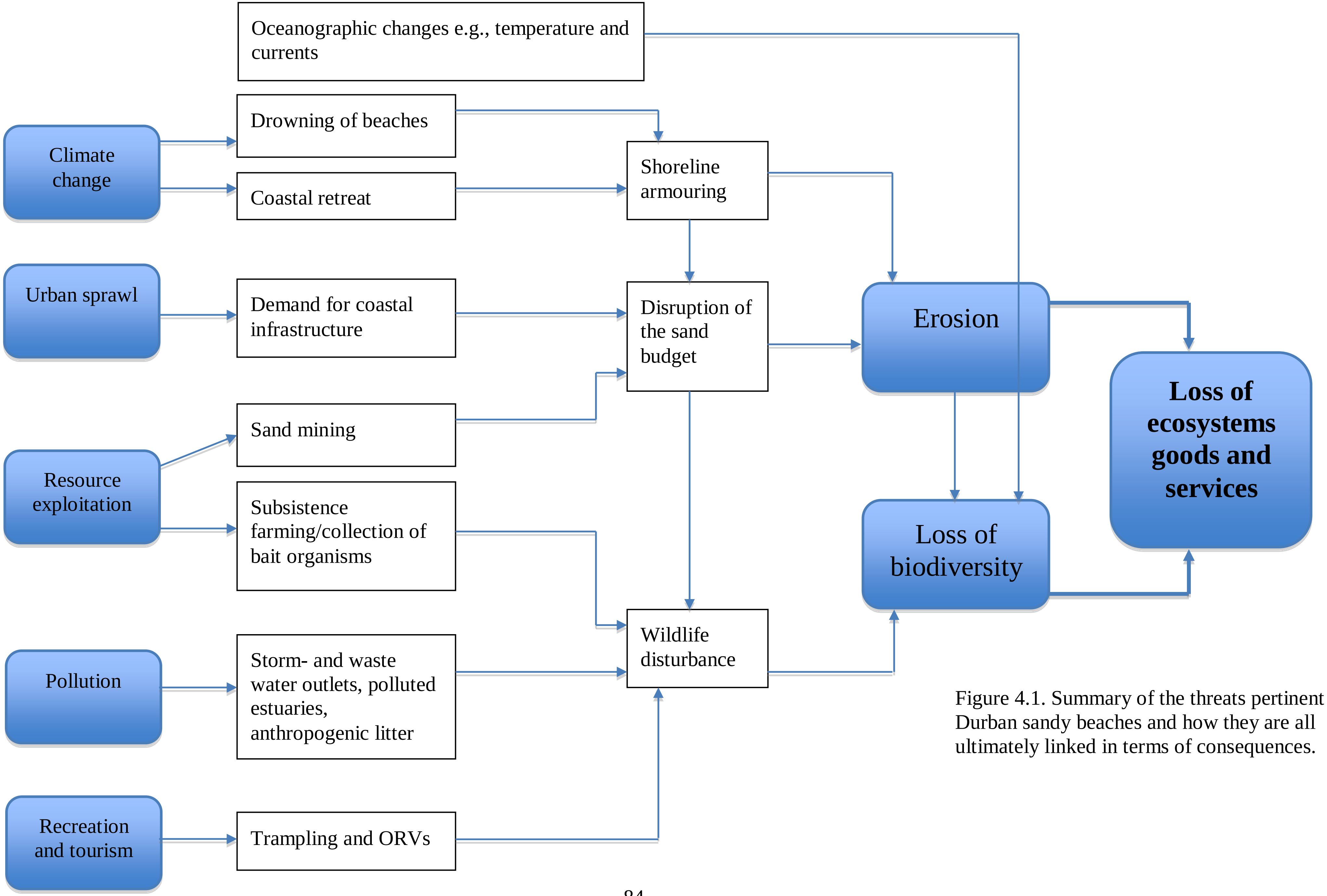

Figure 4.1. Summary of the threats pertinent to Durban sandy beaches and how they are all ultimately linked in terms of consequences.

A snapshot of the impact of sea level rise and increased storminess was seen in March 2008 when a combination of weather and astronomical events (cyclonic activity and extreme spring tides), resulted in the inundation of coastal areas on the east coast of South Africa (Figure 4.2). Durban was hit by soaring waves and extremely high tidal levels, which inundated coasts. Sandy beaches were the worst impacted ecosystem, suffering severe and exacerbated erosion. In some instances, whole sandy beaches were scoured away, leaving only rocky outcrops.

The impacts of these and similar storm events in other parts of the world showed that faunal abundances decrease immediately after a storm event but recover shortly afterward (e.g., Saloman and Naughton, 1977). One of the findings of the present study was a substantial decrease in meiofaunal abundance at one of the most impacted beaches, Toti Main Beach. During the March 2008 storm event most of this beach was scoured away by wave surges, resulting in significant damage to coastal infrastructure and a substantial decrease in the width of the beach. For several months following the storm event, even as sediment was slowly accreting on the beach, the high tides would encroach into the adjacent parking lots and beach restaurants. Causative effects for the decrease in meiofauna abundance cannot be determined with a snapshot survey; however, it is clear that the fauna of this beach, possibly due to an interruption of its sand budget, was severely impacted by the storm event.

Figure 4.2. Photo taken during the March 2008 storm event showing the inundation of coastal areas.

4.4.2. Urban sprawl

This is one of the single most detrimental anthropogenic activities to coasts worldwide. The removal of intact dune systems and beach backshores in favour of human developments (Figure 4.3) for industrial, residential or commercial use has been responsible for most of the problems facing sandy beach ecosystems today. Hard structures on the beach backshore prevent the natural migration of beach sediment. This migration is important in ensuring the maintenance of a beach's sand budget and the disruption of this is responsible for most of the erosion problems that beaches face.

Figure 4.3. Development along a Durban beach. Most of the coast experiences similar high levels of coastal development. (Photo: L. Harris)

Any hard structure on a beach will inevitably disrupt the sand transport (either along-shore or on/off shore) and lead to erosion. These structures usually take the form of harbours, breakwaters, jetties and groins, which deprive beaches that are "down drift" and result in sediment accumulation on 'updrift' beaches and towards the sea. Beach erosion caused by human activities, such as the construction of infrastructure in the form of piers and groynes, has received attention because it has threatened property not because of ecological implications. The construction of engineered structures with the intention of restoring the sand budget of a beach usually fails due to lack of implementation of sound designs. These hard engineering structures are usually designed with the intention of protecting coastal property and may become a more frequent feature of coastlines as the climate continues to change. The structures have repeatedly been shown to damage beach ecosystems instead of protecting them (e.g., Clark, 1983), for the reasons mentioned above.

The Durban coastline is one of the most transformed coastlines along South Africa. The continuing beach nourishment activities (see 4.2.6 below) have in some cases reduced the deleterious effects of erosion. However, the combined effects of a changing climate is going to excaserbate the effect of hard structures that have replaced natural dune systems and beaches that would normally migrate landward will face disappearance into the sea.

4.4.3. Resource exploitation

The fauna of beaches along the Durban coastline are not intensively harvested by subsistence farmers. Mole and ghost crabs (*Emerita austroafricana* and *Ocypode ryderi*) are sometimes used by anglers as bait, but the quantities being utilised are often negligible. The resource most exploited on sandy beaches is the sediment itself. Beaches are largely composed of sand transported to the shore by rivers (Swart, 1983).

Figure 4.4. Sand mining on the banks of the Lovu estuary on Durban’s south coast. Many similar illegal sand mining operations have been identified within Durban’s estuaries and rivers.

As the human population continues to expand and the demand for infrastructure grows, so too does the need for building materials. In Durban, the source of sediments to produce raw material for construction (bricks, cement etc.), has been the many river systems in the region (Begg, 1978). In recent years, this resource has become severely depleted because of over-exploitation (Figure 4.4). The unsustainable mining of sand has contributed to the disruption of the sand budget of beaches because sediment particles that would have otherwise been transported to the beach are now being mined out of the aquatic systems.

In addition, the construction of dams and other means of water abstraction from rivers further contribute to the disruption of the sand budget on beaches. Water abstraction decreases river flows, hindering the transport of sediment to the marine environment.

4.4.4. Pollution

Some of the sources of pollution to sandy beaches include oil pollution from tanker accidents (e.g., de la Huz et al., 2005); organic pollution from wastewater and sewage discharges (Gowen et al., 2000); the release of pathogens; eutrophication from rivers or stormwater outlets (Gowen et al., 2000); factory effluent discharging potentially toxic

In 2008, Durban beaches were at the centre of controversy regarding water quality and the safely of beaches for recreational use. This was due to high pathogen pollution concentrations, which resulted in many beaches failing South African and International Water Quality Guideline limits. The sources of pathogenic pollution are waste- and stormwater outfalls and rivers, and while it is well-documented that the pollution of coastal waters has important socio-economic consequences by negatively impacting public health and the tourism industry, the impact to beach biota is not well known. The present study demonstrated the potentially detrimental effect of stormwater outfalls (Figure 4.5) to beach meiofauna communities. Arguments against the need for specific conservation actions tailored to beaches often revolve around the perception that resident biological assemblages of these highly dynamic systems are simply insensitive to disturbances: when an entire beach can change shape in the course of a storm, how could a storm-water outfall have any significant impact? The answer to this question was unexpectedly provided while sampling beach meiofauna transects on gradients away from storm-water outfalls at two KwaZulu-Natal beaches. In both cases, the abundance of meiofauna was two orders of magnitude lower close to the outfall than it was further away. This demonstrated the need for a critical evaluation of the positioning of these outfalls on beaches.

Figure 4.5. Numerous storm- and wastewater outlets are scattered along Durban beaches. These hard structures not only release vast amounts of pollutants onto beaches, with potential detrimental effects to sandy beach organisms, but also promote beach erosion (Photo: L. Harris)

4.4.5. Recreation and tourism

Beaches are known to be a prime drawcard for tourism to region. The effects of tourism activities, such as trampling and the use of off-road vehicles (ORVs) have been found to negatively impact beach ecosystems (Neves and Benvenuti, 2006) but recent legislation, based on the findings of several scientific studies to the impacts of ORVs on sandy beach fauna have made the use of ORVs illegal on most beaches. This is because, even though beach organisms are characterised by their ability to burrow rapidly into the sediment, the use of ORVs on beaches resulted in organisms such as ghost crabs and clams being damaged (Figure 4.6)

The Durban coastline in particular is sort after by tourists, particular during holiday seasons, because the region as a whole is climatically favourable. This results in large numbers of people (tourists and locals) on Durban beaches during peak holiday season (Figure 4.6). The impact of these large quantities of people on beaches has not been quantified, but the disturbance to biotic communities through trampling and anthrogenic litter is very likely substantial.

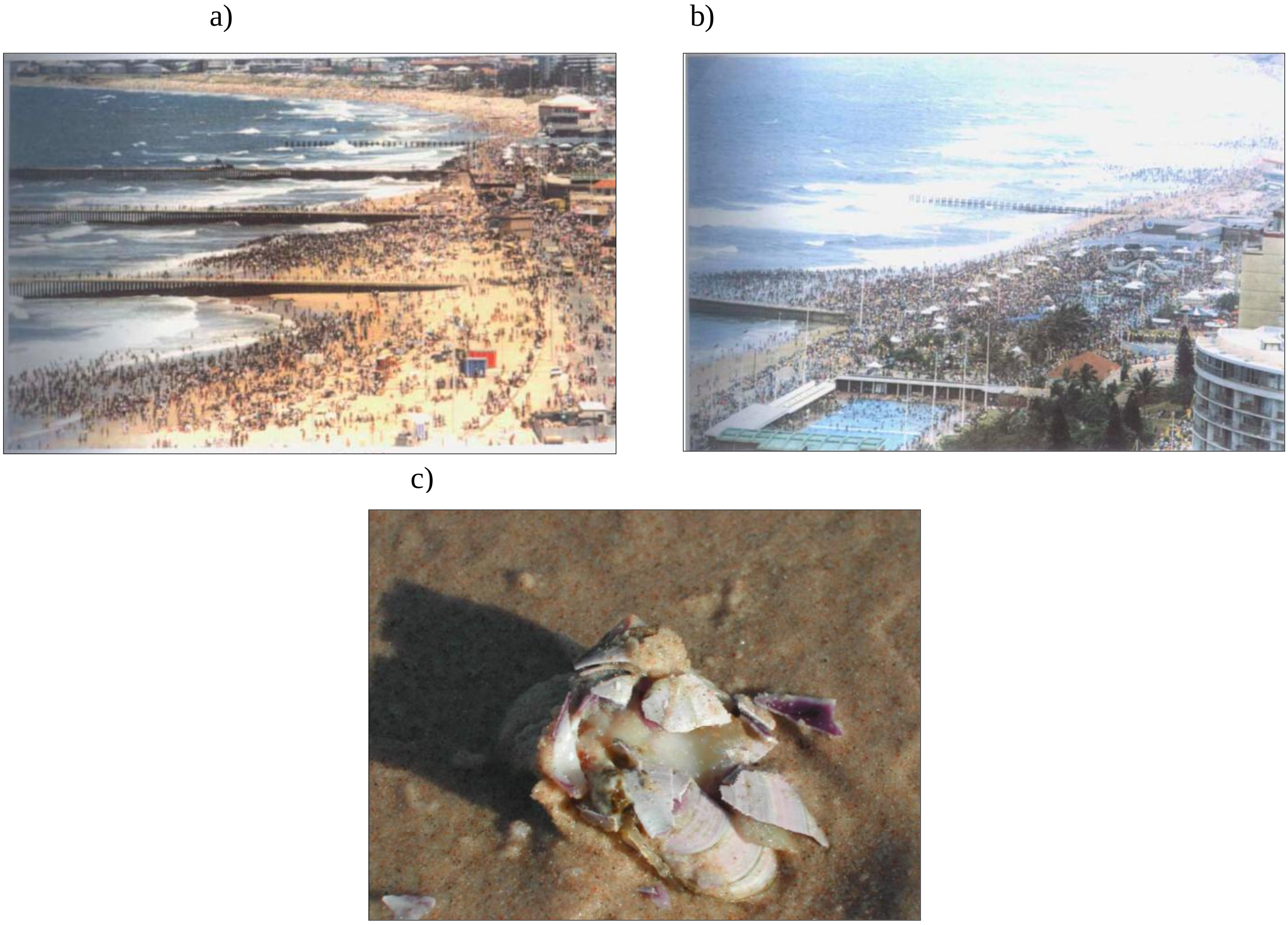

Figure 4.6. a) and b) Recreational beach use along the Durban “beachfront” (Sinclir-Hannocks, 1994). c) Damaged to beach clam, *Tellina* sp., after being driven over by an off-road vehicle illustrating a direct anthropogenic impact to beach organisms (Photo: from Schlacher et al., 2006).

4.4.6. Beach nourishment, erosion and loss of biodiversity

Climate change impacts, demand for coastal infrastructure due to an ever-growing human population and sand mining have all resulted in the disruption of sediment movement processes on beaches. For this reason, sandy beach erosion has become a persistent threat to sandy beaches. Many countries have over the last few decades employed soft engineering – the addition of large volumes of sand to sandy shores – to alleviate shoreline erosion. This has been thought of a preferred method to deal with problems of erosion, but the impact of beach nourishment to sandy beach biota has been thought of as secondary to the protection of shoreline property.

Since as early as the1900s, central Durban beaches (or beachfront beaches) began to experience severe erosion. This was principally due to the construction of harbour breakwaters (Fleischack, 1985). Several expensive programmes to counteract the loss of sand by beaches were undertaken by local municipal authorities. Rigorous sand pumping schemes to offset the deleterious effects of beach erosion were undertaken (Fleischack, 1985) and are ongoing. Because the sand pumped onto these beaches is typically medium to fine grained, the morphodynamic character of the nourished beaches may have changed considerably from their natural state, resulting in them becoming more comparable through time.

This study found that macrofauna may not be noticeably impacted by beach nourishment but a different picture emerged when the smaller meiofauna were examined. Nourishment after a severe storm caused large-scale erosion of the beach, which appeared to have resulted in depressed species richness and abundance of meiofauna as well as elevated nematode-copepod ratios, implying very high levels of disturbance. Meiofauna are sensitive to disturbance and in the event of a disturbance, the sensitive taxa (crustaceans) disappear from an ecosystem, leaving behind the more resilient nematodes. Because of the paucity of information about the ecosystem effects of these changes in community structure, one can only speculate as to the impact that such alterations would have. Meiofauna play a crucial role in nutrient cycling and organic matter mineralisation (Riera and Hubas, 2003). The contribution of specific meiofauna taxa in providing this ecosystem service has not been quantified. What is known, however, is that more biodiverse systems are better able to provide important services such as biofiltration and organic matter mineralisation (Worm et al., 2007), because of the combination of different ingestion, respiration and excretion activities if the diverse groups. When this biodiversity is lost, so too are the ecosystem services it provides.

4.5. Management of sandy beach ecosystems

According to the Integrated Coastal Management Bill for the Republic of South Africa (The Coastal Bill) coastal management refers to “(a) the regulation, management, protection, conservation and rehabilitation of the coastal environment; (b) the regulation and management of the use and development of the coastal zone and coastal resources and (c) monitoring and enforcing compliance with laws and policies that regulate human activities within the coastal zone.” Sandy beaches need to be managed in adherence with this definition and no longer should they be relegated to the scientific and managerial no-man’s land.

The overall health of marine natural resources would be improved by the implementation of an ecological oriented approach to assessing and managing coastal resources. The long-term sustainability of coastal marine resources can only be made possible through the use of scientifically derived options that inform the decisions of local, regional, national and international institutions.

Three main approaches have been used internationally to develop coastal zone management practices: i) administrative, based on existing administrative boundaries; ii) linear, based on arbitrary distances from a linear reference point; and iii) biophysical, based on biological and physical features. An ecological approach, based on system relationships, functions and processes, is unfortunately, not included in this classification,

In marine systems, particularly with sandy beaches, there exists a need to understand the linkages between and among systems. Sandy beaches, for example, as the interface between the marine a terrestrial environments, are vitally linked to both these systems. The sediment that makes up a sandy beach is made up of mostly terrigenous materials carried down to the beach by rivers on their way to the sea. The morphodynamic character of a beach is a function of many marine variables, such as wave and tidal regimes. For this reason, the linear demarcation of sandy beaches for management responsibility is inappropriate.

In recent years, a systems-based approach to the management of ecosystems had been adopted and the way forward for sandy beach management lies in applying the principals of such an approach. Recognising that the biotic and abiotic components of sandy beaches are linked by a network of processes within the coastal zone is the first step to understanding these dynamic systems. These processes relate not only to sediment and water movement and dynamics, but also energy flow and nutrient cycling. The research dichotomies that exist between sandy beaches and estuaries or sandy beaches and rocky shores, are artificial. This is because these marine sub-systems are ecologically and vitally linked to one another in the coastal zone. Activities such as sand-winning (i.e. the dredging and removal of sediment from river catchments) not only disrupts the naturally functioning of the river and estuary by disrupting hydrological flow rates and impacting food webs through siltation effects, but also has the potential to impact the sandy shoreline by disrupting the supply of sediment to the beach. These crucial linkages have not been adequately assessed anywhere in the world and it is this shortfall that needs immediate remedying. Instead of looking at the impact if sand mining just on the immediate environment (i.e., rivers and estuaries) we should look at the entire system to get an indication of the full extent of the impact.

The dynamic nature of sandy beach ecosystems requires that the management of these systems be proactive, flexible and continually updated. Rigid approaches are not conducive to the appropriate management of a system that is characterised by its dynamic nature. To achieve this, sandy beaches need to monitored on a long-term basis to capture the inherent variability in the resident biotic communities. A system of long-term ecological sandy beach monitoring does not exist anywhere in the world, mostly due to the lack of resources or misconceptions about the ecological importance of beaches. This is, however, critical if these systems are to be understood and thus appropriately and sustainably managed. The eThekwini Municipality together with Marine and Estuarine Research (MER) have undertaken the considerable task of updating the information on the rivers and estuaries within the city of Durban. The last such report was published by Begg (1978) and since then, the rivers and estuaries within the city have been severely impacted and have changed considerably. Unfortunately, beaches have never been considered a biodiversity resource within Durban and similar information on Durban beaches do not exist. It is now time to remedy this situation. This study has provided the first comprehensive baseline data of Durban beach communities and like the work being undertaken for estuaries within the region, a similar sandy beach undertaking must be a priority.

The lack of human and financial resources may make this impractical on a long-term basis, therefore, it would be useful to use the findings of snap-shot surveys like this one to get an indication of where research efforts should be concentrated. Regular surveys of beach morphodynamics would be a good place to start because it is far less labour intensive than full ecological surveys. The information from these surveys would show how beaches are physically changing (in terms of sediment grain size, width and profile) over time. In addition, course studies of beach meiofauna could be conducted on selected beaches to test specific hypotheses, This study demonstrated the usefulness of meiofauna as indicators of disturbance on sandy beaches. Unfortunately meiofauna are also resource intensive to survey. Nevertheless, if it a sufficient number of studies show how the determinants of a beach's profile (sediment grain size, wave action, etc.) determine meiofaunal diversity and abundance, these physical measures (which are easily obtained by two people armed with a theodolite and levelling staff) could be used as a proxy for the beach community's probably composition and function.

Both proactive and reactive management strategies will be required to adequately manage Durban's beaches. The baseline surveys and long-term monitoring (proactive) will give an indication of how communities are changing over time, but what is perhaps more important is making use of current and planned urban development to test specific hypotheses relating to how communities change when faced with urbanisation of the landscape (Figure 4.6).

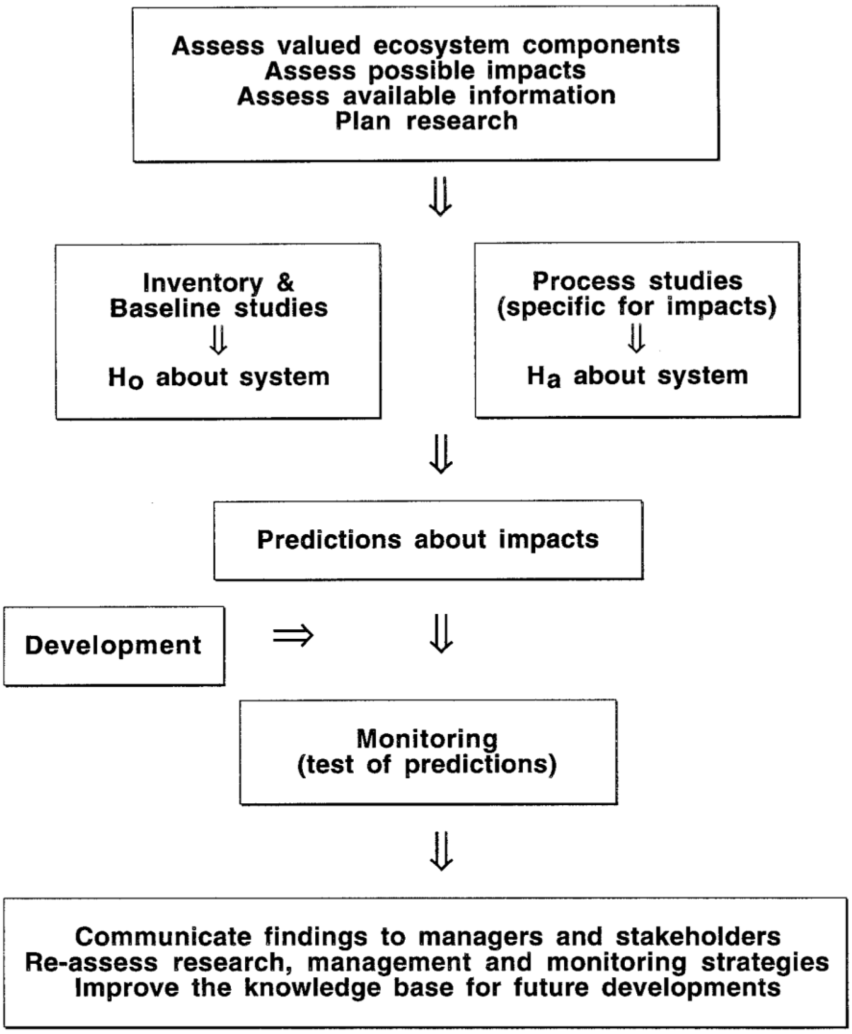

Figure 4.7. Flow chart of the steps involved in sustainable management of marine ecosystems (Fleischack, 1985).

4.6. Conclusions

Over the past millennium, the decline in marine biodiversity has accelerated at a rapid pace and this trend persists. Due to the vastness of the ocean and its taxonomic complexity, it is often difficult to explicate the effect of these losses on a global scale. In a recent paper, Worm et al. (2006) report on the continuing decline in our oceans bounty by providing evidence across temporal and spatial scales for the practical value of biodiversity. They emphasise the value of marine biodiversity in terms of ecosystem goods and services. [Worm et al. (2006).

It has long been acknowledged that biodiversity offers valuable societal benefits. Apart from providing food resources to the growing human population, marine ecosystems contribute several other services such as detoxification and flood control. However, the importance of biodiversity in delivering these tangible benefits to humans has not been tested on a global scale like the world ocean. Worm et al. (2006) show conclusively the positive correlation between biodiversity and ecosystem services. Their meta-analysis of published data revealed among other things that:

1) Decreased biodiversity reduces an ecosystems capacity for filtration and detoxification services;

2) Higher biodiversity promotes a greater resistance to disturbance and facilitates faster ecosystem recovery after disturbance;

3) Ecosystems with greater diversity have lower extinction rates.

Unfortunately, it is only in recent years that scientists and managers alike have come to recognise sandy beaches as a vital biodiversity resource. With the onset of global climate change and the manifestations thereof, the recognition of beaches as important systems is of utmost importance. Threats to sandy beaches, such as erosion, will only be exacerbated as managers are forced to make decisions regarding the armouring of shores against the potential rise in sea-levels and increased storminess.

Only scientifically-informed decisions will ensure the continued functioning of these important marine ecosystems. The major findings of the present study were as follows:

- Durban beaches are not uniform in appearance and are represented by beaches along the entire continuum of beach morphodynamics;

- In terms of both macro- and meiofauna, Durban beaches have rich and abundant communities, which differ on beaches of different morphodynamic type;

- Although more important in terms of biomass, sandy beach macrofauna are less diverse and abundant than meiofauna by several orders of magnitude;

- Beaches are not as resilient as is often assumed because of their inherent dynamism, but can be severely impacted by anthropogenic impacts;

- Sandy beach meiofauna are useful indicators of disturbance of beaches due to their fast generation times a and small size.

Questions that need to be addressed include:

- Do the macro- and meiofauna of Durban sandy beach exhibit temporal variations?

- What is the mechanism through which a stormwater outlet (or a polluted estuary) on a beach impacts the resident meiofauna communities?

- How diverse are the communities of meiofauna on Durban sandy beaches? Are there species here that are new to science?

- What are the short and long-term impacts of beach nourishment to sandy beach communities?

- Can conservation priority indices be applied to urban beaches and if so, what criteria be used to select beaches for conservation priority?

This study was the first step toward the appropriate assessment and management of urban sandy beaches, however, a lot of work is still required, from both scientists and managers to protect these previously neglected ecosystems. As Birch (1990) cautions, “If we plan remedial action with our eyes on political rather than ecological realities then very reasonably, very practically and very surely we will muddle our way to extinction”.

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