The Ecological Feasibility of Creating Estuarine Habitat in Durban Bay by a Basin Extension to the Little Lagoon

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Prepared for:
Paris Foolchard
Transnet Capital Projects
237 Mahatma Ghandi Road
Durban

Prepared by:
Coastal Systems Research Group
Ecosystem Services Competence Area
CSIR, PO Box 17001, Congella, 4013

Contact person:
Steven Weerts
Tel: +27 (0)31 242 2377
Fax: + 27 (0)31 261 2509
Email: sweerts@csir.co.za

Report authors:
Weerts SP, Pillay S, Rajkumar A, Newman BK

With inputs from:
Dr Alan Whitfield (South African Institute of Aquatic Biodiversity), Mr Roddy (CJ) Ward (botanical specialist), Mr David Allan (Durban Natural Science Museum) and Ms Fiona (CF) MacKay (Oceanographic Research Institute)

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Contents

1. Introduction

Durban Bay, on the KwaZulu-Natal coast, is one of only three estuarine bays (*sensu* Whitfield 1992) in South Africa. Development of the Port of Durban within the Bay has significantly altered the original estuarine system's morphology, hydrodynamics and immediate surroundings. Development of the city of Durban around the Bay and of the larger eThekwini municipal area has also significantly altered the Bay's hinterland, its catchments, and the quantity and quality of inflowing freshwaters. These alterations have unarguably had a marked impact on the ecology of the Bay.

Despite this Durban Bay (known also as the Bay of Natal or the Port of Durban) still has significant ecological value as an estuarine embayment (Forbes *et al*. 1996). It is important that this ecological value is maintained. A management dilemma is, therefore, presented by the seemingly disparate uses and requirements made of the system; to continue to function as a commercial port vital to the national economy and at the same time to supply ecological goods and services for the wider society. This dilemma is reflected in recent history, with various development proposals in the Port of Durban meeting strong public opposition on environmental grounds. Anthropogenic influences outside of the Bay continue to impact the system's ecological functioning, leading to public distress and anger; a major fish kill in the summer of 2007/8 being the best recent example.

The problem clearly requires the formulation of guiding principles on how best to manage Durban Bay, with agreement from all stakeholders. To this end the formulation of an Estuarine Management Plan (EMP) for Durban Bay was recently commissioned. The first phase of formulating this EMP has been completed and is documented in a Situational Assessment Report (SAR) (MER/ERM 2011).

In a recent meeting between Transnet Capital Projects (TCP), Transnet National Ports Authority (TNPA) and CSIR the need to address the ecological decline of the Bay proactively was discussed, especially in light of the economic drive for future development of the port. During the meeting the potential for creating estuarine habitat in the vicinity of the Little Lagoon in Durban Bay was raised. The CSIR was requested to investigate the viability and value of such a habitat creation exercise. This document reports on the findings of the investigation.

The work relied on a desktop analysis, but benefitted from the large amount of ecological work that has been conducted in the Bay in recent years. Several ecological specialists with direct working knowledge of the Bay, its biota, ecological value and the development pressures it faces were consulted and provided valuable input to the analysis; Dr Alan Whitfield (South African Institute of Aquatic Biodiversity), Mr Roddy (CJ) Ward (botanical specialist), Mr David Allan (Durban Natural Science Museum) and Ms Fiona (CF) MacKay (Oceanographic Research Institute).

2. The ecological importance of Durban Bay

2.1 The local context

The importance of estuaries and the ecological goods and services they provide to humans is now widely recognised. With the decline of these systems at all scales (worldwide, regional, national and local), both in terms of direct losses due to coastal development and indirect losses due to flow modifications and pollution, increasing obligation and public pressure is placed on relevant authorities, managers and users to manage these resources wisely for wider and greater societal benefit.

The above has high relevance in South Africa. The nursery function of estuaries for many species of fishes and crustaceans is often cited as the most important ecological value of these systems. In other regions of the world suitable nursery conditions for these species are also formed by shallow, turbid waters with variable salinity outside estuaries. This is not the case for South Africa, however, because alternative shallow, turbid and brackish waters that provide a nursery role do not exist on the country's narrow continental shelf (Blaber 1981).

Furthermore, many of South Africa's estuaries are in an impacted condition and a particularly high proportion of sub-tropical systems on the coast of KwaZulu-Natal are in a poor ecological condition (Figure 1, Van Niekerk and Turpie 2012). This places significant conservation importance on all estuarine habitats in KwaZulu-Natal, including Durban Bay and Richards Bay (Forbes *et al*. 1996, Weerts *et al*. 2003).

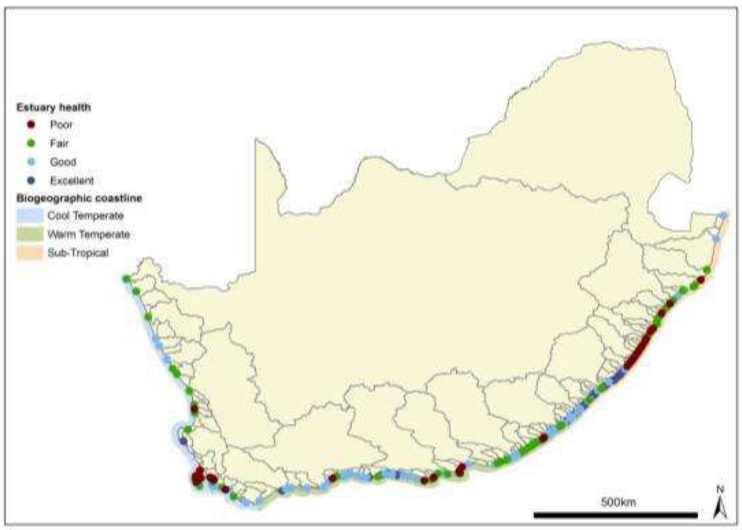

Figure 1: Health status of South Africa's estuaries (from Van Niekerk and Turpie 2012)

2.2 Trends in ecological state

While Durban Bay retains some ecological function it is undoubtedly in a markedly different condition from its original state. The estuarine bay has undergone significant alteration due to development in its basin and catchments, which has affected its natural functioning.

Prior to port and city development, Durban Bay was characterised by extensive mangrove swamps, intertidal and shallow subtidal mudflats, sandflats and seagrass beds surrounded by tidal and freshwater swamps. Port development began in earnest with construction of the north pier in 1854 (Begg 1978), although European settlement reliant on shipping trade was already permanently established thirty years earlier (Pearson 1995). The Bay has subsequently undergone extensive physical and bathymetric modification. These include a widening and deepening of the mouth to form the entrance channel, deepening of much of the water body for vessel navigation, hardening of much of the perimeter to form quay walls, and infilling of intertidal and shallow subtidal sand- and mudflats and mangroves for port and city infrastructure. Habitat losses (excluding surrounding freshwater swamps) are estimated at 57% of the

Bay area, 86% of tidal flats, 97% of mangroves and 96% of natural shoreline (Allan *et al*. 1999, see Figure 2).

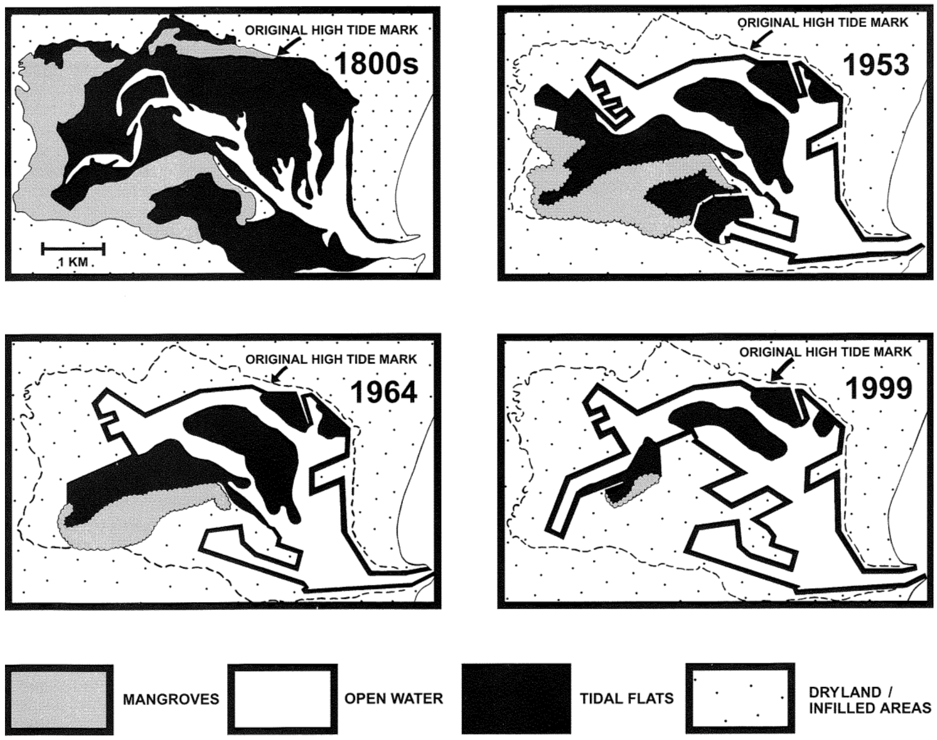

Figure 2: Habitat losses in Durban Bay (from Allan *et al*. 1999)

The full impact of these habitat losses on the system's biota cannot be quantified. No records of ecological surveys of the original Durban Bay exist. The earliest recorded surveys are from the early 1950's (Day and Morgans 1954), after the Bay had already undergone extensive modification due to port and city development. These surveys indicated that the system at that time, despite being in a modified state, was still remarkably productive and supported a diverse flora and fauna.

The subsequent 25 - 30 years, however, saw a marked degradation in the Bay's ecological state. The major causes for the ecological deterioration that occurred between ~1950 and ~1980 were identified by Begg (1978, 1984) as:

- Loss of "marginal" vegetation (this included primarily mangroves and *Zostera* seagrass),
- "Disruption" of suitable substrates as feeding grounds (referring to dredging impacts on sand and mud substrates, and loss of these shallow water habitats),
- Industrial pollution,
- Increased tidal exchange.

In the 30 years subsequent to Begg's (1978) synopsis on the state of Durban Bay further degradation and loss of ecosystem function has occurred. This has involved a reduction in species diversity caused by losses of sensitive species and/or reductions in their abundance. This is best documented in the analysis of the Bay's avifauna by Allan *et al*. (1999). A full analysis cannot be conducted across all biotic groups as available data were not always generated using consistent methods and/or effort. Nevertheless, monitoring and research consultancy reports as well as published scientific papers over the last 15 years are consistent in their opinion that the ecological health of the Bay is in a state of decline (Allan 2001; Forbes and Demetriades 2003; Forbes and Demetriades 2006a; Newman *et al*. 2008, MER/ERM 2011 and work cited therein).

The impact of loss of structural habitat (sandbanks and mudflats, mangroves and *Zostera*) was, in all likelihood, the predominant vector of ecosystem degradation between ~1950 and ~1980. Major port developments occurred during this period. Pollution undoubtedly played some role, with domestic and industrial effluent disposed from an outlet on North Pier at the port entrance until 1969. Potential impacts of this practise were mitigated by restricting disposal to outflowing tides and major pollution events were likely the result of spillages rather than persistent contaminant loading. An early (1972) fish kill in the Bay was reportedly the result of discharge of acidic effluent (Heydorn 1972, cited in Begg 1978).

Concomitant with urban development around the Bay and in its catchments, river and stormwater contamination became increasingly problematic to the point that Begg (1978, p. 247) described the Bay as functioning as a "giant stormwater sump for the city of Durban". Monitoring programmes conducted in the last decade all indicate degraded water and sediment quality in the Bay, most notably in the vicinity of river and stormwater inflows (Pillay and Newman 2007, James *et al*. 2008a,b, Deyzel *et al*. 2009).

Past port and city development has, therefore, already affected the significant majority of the original area of Durban Bay, through physical alteration and destruction of habitat. The rate of port expansion has decreased in recent years, largely constrained by the decreasing amount of space left to develop. Future port growth now relies on the expansion of quays and wharfs at the expense of open water and the little natural intertidal and subtidal habitat that remains. The surrounding urban population and city development, on the other hand, has continued to increase, with concomitant increases in pollutant loads to the port via river and stormwater inflows. This increasing pollution loading into a decreasing water area with reduced assimilative capacity through loss of natural habitat has reduced the ecological resilience of the Bay. Pollution impacts, such as fish kills experienced in 2007 (Weerts and Pillay 2008) are the result.

Durban Bay's remaining ecological value as a functional estuary is largely dependent on the remaining natural habitats and water quality that sustains aquatic life. Of concern is that this remaining ecological function hangs tentatively in the balance, and that the system has little resilience to even minor perturbation which might be brought about by further loss of estuarine habitat (to port and city development) and/or degradation of water and sediment quality (through port and catchment activities). This threatens the ecosystem services provided by the Bay to the wider society.

2.3 Ecosystem goods and services provided by Durban Bay

Ecosystem goods and services provided by Durban Bay have been the subject of investigation in recent years, largely in response to the need to assist and guide decision-making pertaining to various port development options. Table 1 represents a summary of the most recent thinking on ecosystem services provided, as presented in the Situation Assessment Report of the Estuarine Management Plan formulated for Durban Bay (MER/ERM 2011). This thinking stems largely from the ecosystem goods and services assessment conducted as part of the Transnet - eThekwini Municipality Planning Initiative (Mander *et al*. 2006). The reader is referred to these documents for a more detailed discussion but it is suffice to summarise here that all remaining natural habitats in Durban Bay play a role in providing diverse goods and services to society.

Table 1: Ecosystem goods and services provided by Durban Bay (from MER/ERM 2011).

Ecosystem goods and services or mitigation supplied by Durban Bay	Key habitats essential for delivery of goods and services
Atmospheric management	Sandbanks, water column
Climate management - cooling built up urban areas	Water body, sandbanks
Climate change - species diversity and links to different industries supported by these species as well as international obligations	All habitats
Waste dilution - waste entering the port from port activities and urban/industrial runoff is diluted by water volume and tidal exchange	Water column, sandbanks (current topography promotes rapid exchange)
Waste assimilation and disease risk management - waste and bacteriological contamination entering the port from port activities and urban/industrial runoff is absorbed and degraded	Sandbanks, water column, mangroves
Flood mitigation - receiving facility / shock absorber reducing flood damage	Water body
Mitigation of environmental impacts on adjacent smaller estuaries caused by droughts/floods, artificial mouth breachings and pollution events	Intertidal sandbanks, water column
Nursery for estuarine dependent crustaceans and fish - without estuarine systems these organisms cannot complete their life cycle	All habitats, especially intertidal sandbanks, mangroves and Little Lagoon
Essential habitat for aquatic birds - a local, regional and internationally important habitat for resident and migratory birds	Sandbanks, water surface, mangroves
Genetic, species and landscape conservation - conservation of national assets	All habitats, especially intertidal sandbanks
Landscape character - creates a sense of place for local residents and users of the Bay area	Water surface, sandbanks
Food production and supply	All habitats
Sport and outdoor recreational activities - swimming, canoeing, fishing, fly-fishing, sailing	Waterbody, sandbanks
Leisure activities - picnic and bird watching	Sandbanks, mangroves
Education activities	Mangroves, Little Lagoon, sandbanks
Research and knowledge creation	All habitats

2.4 Important habitats and species

A comprehensive review of the biological characteristics of Durban Bay has been made as part of the Situational Assessment for the EMP (MER/ERM 2011) and is not repeated here. In an ecological sense all species in Durban Bay are important. Complex physico-chemical, trophic and biotic linkages are the fabric of an estuarine ecosystem. Features of the biota that are particularly conspicuous, either as being of conservation significance, important as resources with societal use, dependant on the Bay, or playing a critical role in the system are highlighted below.

Mangroves, comprising three species, occur at Bayhead as a remnant of the original mangrove stands that once characterised Durban Bay. They are habitat forming, providing critical structure for several elements of the estuarine biota. They are also likely to play a role in the Bay's biogeochemistry and trophic dynamics.

Seagrass, *Zostera capensis*, was an additional botanic element of Durban Bay's biota that played a habitat forming role. The presence of this macrophyte in Mhlathuze Estuary has a significant influence on that system's fish diversity and role as a nursery (Weerts and Cyrus 2002). Prior to its loss from Durban Bay in the 1960's, *Zostera* undoubtedly had the same influence in Durban Bay.

Many species of waterbird make use of Durban Bay and have a high dependence on the habitats it offers, particularly as roosting and feeding areas (Allan *et al.* 1999, McInnes *et al*. 2005). Several of these species are migratory. It is widely regarded that suitable alternative habitat either does not exist or is generally fully utilised, so the reduction or loss of these habitats in Durban Bay will result in wider population losses.

Estuarine dependant fishes and crustaceans make use of Durban Bay. The spotted grunter (*Pomadasys commersonnii*) is arguably the most important of these from a fisheries resource point of view. Within the Bay this species is a favoured target for recreational anglers. Subsistence anglers also target the species, along with other estuarine dependant fishes. Several of these species are heavily exploited in coastal fisheries outside of Durban Bay, and the Bay plays an unquantified, but likely important role in sustaining these fisheries.

The sandprawn *Callianassa kraussi* is an important component of the Bay's invertebrate fauna. It is probably the reason that spotted grunter favour Durban Bay, as these prawns comprise an important component of their diet. The role of *Callianassa* as a bioturbator influencing sandbank structure and biological communities in Durban Bay has been highlighted in recent scientific literature (Pillay *et al*. 2007a,b; 2008). The mudprawn, *Upogebia africana*, also occurs in the Bay. Mudprawns are not limited to shallow banks. They also occur in deeper (and muddier) basins and channels (Weerts, per.obs) and are also likely to be an important food source for spotted grunter and other fishes.

Many of invertebrate, fish and bird species in the Bay have a high dependence on the systems sandbanks. Indeed, the importance of sandbank habitat in Durban Bay has been highlighted in many previous studies of the system. This is captured in the Situational Assessment Report for the Estuarine Management Plan for the Bay of Natal (MER/ERM 2011) which further points out that these sandbanks are the only sheltered, marine dominated, permanently tidal sandbank habitat in the central KwaZulu-Natal region. These sandbanks are the key ecological drivers of the Bay and are likely to provide ecosystem goods and services, such as those listed in Table 1 above, at scales and over areas disproportionate to their size and location.

The Little Lagoon, an area of shallow subtidal mudflat and sandbank opposite the Congella Basin has been found to be a biological "hot spot" within Durban Bay (Forbes and Demetriades 2003, Newman *et al*. 2008) and is an especially important habitat from benthic biodiversity and estuarine fish nursery perspectives. Shallow subtidal waters and sediment granulometry are probably the most important factors underpinning these biological features (Newman *et al*. 2008).

Habitat integrity, diversity and connectivity are the critical features of estuaries which underpin their resilience and their ability to provide ecosystem goods and services. From the above it is apparent that all remaining natural habitat in the Bay, as well as artificial deepwater basins and canals play a role in providing ecosystem goods and services to the wider society. Loss of any single habitat (even partial) will reduce the resilience of Durban Bay and, therefore, threaten its continued provision of the goods and services. There is strong public and scientific opinion that, as a system, Durban Bay is close to an ecological threshold, a point where any further small change (in terms of habitat loss or increase in pollutant loading) will lead to rapid and significant deterioration in its ecological function.

3. Proposed habitat creation in the Bay

3.1 Options for improving the ecological state of the Bay

From the above it is apparent that two broad options exist for improving the biological health (in terms of estuarine function) of Durban Bay. These are:

- Improve and/or increase natural estuarine habitats such as sandbanks, mangroves and seagrass,
- Improve water quality in the system.

The former is difficult in that available space to create new habitat is limited. Improving existing estuarine habitat involves manipulating ecological processes with uncertain results. Creation of one type of estuarine habitat (e.g. mangrove) at the expense of an already functional but different habitat (e.g. sandbank) can be achieved through human intervention, but involves difficult choices about the relative value of different habitat types. In KwaZulu-Natal, and indeed in South Africa, all estuarine habitats are valuable and the notion of creating one habitat at the expense of an existing one should be considered with extreme caution, if at all.

The latter, however, is even more difficult as water quality in the Bay is impacted primarily by poor water quality in inflowing rivers. Addressing the complexities of catchment management issues in the wider eThekwini are requires the co-ordinated attention of a multitude of organisations, authorities and communities. While this should be an objective of stakeholders (and the EMP) it is probably something that will only be addressed in the longer term, and it is certainly not something that is totally in the ambit of TNPA influence.

The single option available, therefore, is that consideration be given to creating estuarine habitat in areas of the Bay that are severely degraded, or have no or very limited estuarine function. Presently these are either deepwater areas (shipping channels or basins) or land adjacent to the Bay. Options for shallowing deepwater areas are extremely limited in the port for vessel traffic reasons. However, a currently unused piece of land immediately adjacent to Little Lagoon has been identified as potentially suitable for an estuarine habitat creation initiative in the Bay (Figure 3).

Figure 3: Durban Bay with unused land (potential habitat creation area) adjacent to the Little Lagoon indicated by arrow

3.2 Little Lagoon extension

The proposed creation of estuarine habitat via an extension of the Little Lagoon is presented conceptually in Figure 4. It comprises an excavated basin connected to the Little Lagoon via a relatively narrow mouth. Broadly, the intention will be to create habitat types with the highest potential ecological value for estuarine fauna. These are shallow subtidal habitat similar to that presently existing in the Little Lagoon (which is a demonstrated biodiversity and nursery hotspot) and, ideally, re-established seagrass *Zostera capensis*. Mangroves would be encouraged to establish along the eastern shoreline of this Little Lagoon extension basin for secondary reasons. There is potential to create valuable bird habitat (roosting and nesting) in the form of dead trees, islands and/or artificial platforms in shallow subtidal areas.

Should the initiative proceed, sizes and locations of the different habitats, and morphology and location of the mouth connecting the basin to Little Lagoon, are likely to be investigated more closely, incorporating hydrological and engineering considerations. Further detail and assessment of the viability and value of establishing such habitats, as well as a high level screening of potential terrestrial impacts and sediment quality considerations is given below.

Figure 4: Conceptual layout of estuarine habitat to be created as an extension of the Little Lagoon

4. The viability of habitat creation

An assessment of the potential for habitat restoration in Durban Bay was conducted as part of the Transnet - eThekwini Municipality Planning Initiative (TEMPI). This assessment noted that in Durban Bay options for estuarine habitat restoration were limited to "additional or rehabilitation of existing degraded estuarine habitats in presently non-functional areas" (Forbes and Demetriades 2006b, p. 15). The current proposal is in line with this finding. Although the authors of this report have deliberately avoided the term habitat "rehabilitation" in favour of habitat "creation", the proposed initiative does in fact represent reclamation of estuarine habitat as the land targeted for excavation is infill of part of the original Bay of Natal. Given the massive changes that have occurred in the Bay, rehabilitation to its original state is impossible and replication even of selected areas of habitat to a reference (pre-developed) state is highly unlikely. This should not, however, stop initiatives to improve the system through informed manipulation to maximise potential ecological benefits.

Valuable ecological habitats can be created by human intervention. Examples are given locally in Richards Bay, an industrial node some 200 km north of Durban that has been the focus of development since the 1970's. Thulazileka Pan was created as a result of earth moving involved in the development of the Port of Richards Bay, and developed into a productive water body that was one of KwaZulu-Natals premier spots for waterbirds. Pollution of groundwater and surface runoff, together with water level manipulation has since seen the system degrade, but this speaks to poor environmental management of a valuable, albeit manmade, natural resource. Tidal changes, also brought about by the development of the Port of Richards Bay, have seen proliferation of mangroves in the Mhlathuze Estuary to the point that over half of South

Africa's mangrove area now exists in this system. Although unintended, and a significant modification of the original estuarine lake, this estuary ranks amongst South Africa's most important systems in terms of its conservation status (Turpie *et al*. 2002).

4.1 Intertidal and shallow subtidal flats

The Little Lagoon extension basin will be as large as possible. The bulk of the proposed created habitat area will comprise shallow subtidal habitat (0.3 - 1 m below mean low water spring tide). Intertidal sandbanks will fringe the basin (where not colonised be mangroves). Consideration will be given to maximising shoreline length by engineering an irregular and convoluted basin perimeter. A narrow connection between the new basin and the existing Little Lagoon will enhance the sheltered nature of the new habitat by minimising wave intrusion. The basin will be separated from mudflats to the southwest and the Little Lagoon to the northeast by low sandbar to reduce wave fetch and create calm sheltered conditions most conducive to the successful establishment of *Zostera*. The southern bar will also protect the basin from potentially poor water quality and sediment inputs via the Silt Canal during floods.

While *Zostera* and mangroves would need to be transplanted into the newly created basin, recruitment and colonisation of tidal flats by microalgae, invertebrates, fishes and birds would occur naturally and follow broadly predictable ecological succession.

Growth of surface microalgae in these new habitats will stabilise sediments and provide the primary productivity driving faunal colonisation. Estuarine invertebrates, particularly those that inhabit tidal flats, play an important role in habitat function, as they aid in the breakdown and assimilation of organic matter into sediments and provide a key food source to fish and other invertebrates (French *et al*. 2004).

Tidal sand and mud flat creation and restoration initiatives have been undertaken and studied in other parts of the world; e.g. USA (Levin *et al*. 1996, Ray, 2000), UK (Evans *et al*. 1998), Japan (Lee *et al*. 1998; Ishii *et al*. 2008) and Australia (French *et al*. 2004). Studies investigating the colonisation of these habitats have found that in most cases the early stages are dominated by the presence of opportunistic organisms such as polychaetes, giving way to colonisation by tubiculous amphipods and followed by a more stable community (Zajac and Whitlatch, 1982b; French *et al*., 2004). The natural recruitment of estuarine benthic organisms and the structure of the benthic community that develops in a newly created or restored tidal flat is influenced by the many interrelated factors (Zajac and Whitlatch 1982a,b, French *et al*. 2004, Parker *et al.* 2004):

- Physical processes:
  - Hydrodynamic characteristics of created tidal flats determine the type of habitat that is created. Factors such as the slope of the tidal flat, site conditions of water depth and exposure during the tidal cycle, tidal currents, wave action and freshwater discharges are important drivers that influence the benthic species distribution and abundance in the created habitat.
  - Substrate characteristics such as elevation gradient, sediment erosional and depositional characteristics, sediment particle size and moisture content play important roles in colonisation of created tidal flats and the distribution of species. Invertebrate organisms have different physiological requirements and tolerances to environmental variables and therefore they may inhabit different gradient zones on the shoreline. Similarly, different behavioural and feeding processes dictate invertebrate sediment grain size preferences. The ability to create stable burrows in sediments and organic matter content, which is important to deposit

feeders, also influence invertebrate colonisation; whereas fine sediment particles that cause turbidity can obstruct the feeding and respiratory apparatus of many filter and suspension feeders.

- Chemical processes
  - Nutrients and physico-chemical parameters are also important influences on the distribution and abundance of tidal flat organisms. Excessive nutrient concentrations can cause eutrophication and have a negative impact on the diversity and abundance of invertebrate inhabitants. Estuarine invertebrates have different physiological requirements and tolerances to physico-chemical parameters so species diversity and distributions are also greatly affected by salinity variations, turbidity levels, temperature levels, organic content and anoxic sediment conditions.
- Ecological processes
  - Larval availability is a key biological factor influencing recruitment to newly available habitats. Many benthic species have pelagic larvae which are dispersed by water movements and will settle provided that the substrate is suitable.
  - Recruitment and colonisation of some species can occur via mobility of adults. Species with sedentary adult forms, however, are forced to rely on larval dispersal.
  - Once recruited to a new habitat levels of food resources are a key determinant of successful colonisation.
  - The presence of existing biota can also have a marked influence on the ability of some species to gain successfully a foothold in newly created habitat. Biological interactions can take the form of competition, predation and/or bioturbation.

Success in the development of benthic infaunal assemblages in created habitats has varied among habitats and different projects (Ray 2000). In most cases "success" is regarded as the establishment of a faunal community the closely resembles a reference habitat. Thus, while most studies indicate that benthic invertebrate communities can rapidly colonise constructed habitats (Kenworthy *et al*. 1980, Ray 2000, Craft and Sacco 2003), others suggest that it may take several years, even decades, for the establishment of benthic fauna similar to long established natural habitats (Ray 2000, Craft and Sacco 2003, French *et al*. 2004).

In the case of a Little Lagoon extension basin a benthic community exactly the same as that of Little Lagoon is unlikely to establish in the short term, if indeed ever. The basin will have a different hydrodynamic regime and, in all likelihood, a different water and sediment chemistry. However, there is a strong likelihood that in areas of suitable sediment and depth very diverse communities typical of South African estuaries will establish in a reasonably short period. In this respect muddy sand/sandy mud sediments are likely to be most favourable. Sediments in the created basin may need to be seeded with mud to create a suitable granulometry. Ishii *et al*. (2008) investigated the feasibility of improving benthic species richness and abundance by adding dredged spoil (as a source of silt and clay) to an artificial sandflat. Their results show that silt and clay, as well as organic content of the substrate promoted benthic community establishment, even though the potential for pollutant contamination is sometimes high in dredged sediments.

In the Durban Bay context, finer sediments would likely exclude dense colonisation of the created tidal flats by the sandprawn *Callianassa kraussi*. This is to be encouraged. Although an important source of food for sub-adult and adult spotted grunter, sandprawn are a significant bioturbator and turnover sediments to the detriment of diversity of smaller benthic species (Pillay *et al*. 2007a,b, 2008, Pillay and Branch 2011). Sandprawn can also eliminate transplanted *Zostera capensis* from natural habitats (Siebert and Branch 2007), something that is clearly undesirable in this habitat creation initiative (see below).

4.2 Seagrass habitats

Seagrasses are marine angiosperms (flowering plants) found in sheltered shallow subtidal and intertidal environments. They can grow into extensive beds (or "meadows") by vegetative reproduction. These seagrass beds provide important ecological functions (Hotaling *et al.* 2011). Seagrasses are often characterised by high invertebrate and fish diversity, offering food, shelter and essential nursery area to commercial and recreational fishery species (Pollard 1984 and references therein). Their high productivity, structural complexity and biodiversity have led some researchers to describe seagrass communities as the marine equivalent of tropical rainforests.

Seagrasses are subject to a number of biotic and abiotic stresses such as storms, grazing by herbivores, disease and anthropogenic threats due pollution, decreasing water clarity, excessive nutrients, sedimentation, and damage by boating (propeller scarring). The effect that these stresses have on seagrasses is dependent on both the nature and severity of the particular environmental challenge. If only leaves and above-ground vegetation are impacted, seagrasses are generally able to recover from damage within a few weeks. However, when roots and rhizomes are damaged the ability to produce new growth is severely impacted, and plants may never recover. As photosynthetic productivity is dependent on light, seagrasses may be damaged or killed by high turbidity caused by fine sediments or excessive phytoplankton growth. High turbidity and excessive dissolved macronutrients are, therefore, a severe threat to seagrasses in many parts of the world.

Zostera capensis is the predominant seagrass found in estuaries in South Africa. Originally found in several open estuaries in KwaZulu-Natal (Begg 1978), seagrass habitat in the province is now highly threatened. With prolonged drought, mouth closure and hypersalinity, *Zostera* has been lost from the St Lucia system in recent years and now occurs only in the Mhlathuze Estuary, and even this stand has been subject to losses caused by dredge spoil disposal (Cyrus *et al*. 2008). Other systems, including Durban Bay, have long since lost their populations of this valuable habitat forming species. Seagrass beds have been recognised as important habitats for juveniles of many fish species in South Africa (Beckley 1983, Whitfield *et al*. 1989, Weerts and Cyrus 2002) and the absence of this habitat from KwaZulu-Natal estuaries is a limiting factor to fish diversity.

The value of seagrass habitat and its loss from many systems worldwide has prompted a large body of research into seagrass habitat restoration (Short *et al.* 2002, Kemp *et al*. 2004, Katwijk *et al*. 2009, Hotaling *et al*. 2011). Seagrass transplantation projects in coastal environments have had mixed success. A large-scale seagrass transplant project in Florida's Biscayne Bay, USA was very successful with rapid expansion of vegetation and faunal colonisation rates (Yap 2000). In North Carolina, USA, transplanted seagrass habitat reached vegetation and faunal population levels that were similar to natural areas in less than 1.5 years (Kenworthy *et al*. 1980). Similar successes were found by Fonseca *et al*. (1982) in USA, Paling *et al*. (2001) in Western Australia, and Harrison (1990) in Canada. In coastal areas of England, however, large-scale transplantation trials have achieved little long-term success (Parker *et al*. 2004). The reasons for failures here were inappropriate site selection and high water motion, which combined with insufficient anchoring of the planted seagrass resulted in the removal of vegetation (Paling *et al*. 2001, Parker *et al*. 2004).

Differences in transplantation success have been found in closely related seagrass species. *Zostera nolti* was a more resilient transplant species than *Zostera marina* in a seagrass transplant programme in the Waden Sea (Katwijk *et al*. 2009). In South Africa, *Zostera capensis* was successfully established in the Mhlathuze Estuary after it was lost to port development in Richards Bay (Weerts 2002). In the Western Cape, transplants of this species were found to be excluded by bioturbation by sandprawn *Callianassa kraussi* (Siebert and Branch 2007). Other species that act as bioturbators to the detriment of seagrasses include rays (excavation), crabs (excavation and clipping), polychaetes (burial) and water birds (grazing) (Short *et al*. 2002).

Reasons for the loss of *Zostera capensis* from Durban Bay are not certain, but probably relate to fine sediments suspended by dredging activities reducing light penetration and possibly depositing over and smothering *Zostera* beds. Wind driven wave suspension of sediments and wave-chop breaking up leaf fronds might also have been contributing factors. Bioturbation appears unlikely given the original location of *Zostera* in the Bay and timing of it loss. Given this uncertainty the re-establishment of *Zostera capensis* in Durban Bay is by no means certain to be achieved by the proposed habitat creation initiative. However, if successful it will be of major ecological value.

Zostera for translocation to the Little Lagoon extension basin could be sourced from the Mhlathuze Estuary in Richards Bay. Plants from this environment will be adapted to similar subtropical conditions as the proposed translocation area and will, therefore, be better suited than plants from warm temperate or cool temperate estuaries of the Cape. As seagrasses are protected, permits will have to be sought from the relevant authorities (Ezemvelo KZN Wildlife) for the removal and translocation of *Zostera.*

4.3 Mangroves

Although mangroves are valuable components of the estuarine ecosystem the establishment of an additional mangrove stand to cover the proposed Little Lagoon extension basin is not encouraged. The main reason is that additional subtidal sand/mud flat and (potentially) new seagrass habitats are deemed more important than mangroves in the Durban Bay context. Mangroves are establishing naturally in several intertidal areas of the Bay away from the main Bayhead stand (although admittedly in small and isolated patches). Mangroves should be encouraged, by seeding with *Avicennia marina* propagules or saplings collected from elsewhere in the Bay, to establish in a narrow intertidal bank around the eastern perimeter of the Little Lagoon extension basin. These trees would function to create habitats for selected birds and aquatic invertebrates, but would primarily serve the purpose of creating a visual barrier to the artificial slope behind.

Three species are currently present in Durban Bay and it is possible that in the long-term some form of ecological succession of these species might occur along the shoreline of the proposed basin. The white mangrove (*Avicennia marina*, proposed here for initial colonisation) is a pioneer of estuarine habitat along the east coast of South Africa and establishes in well drained yet tidally influenced sandy areas. It is intolerant of excessive shading and will not establish under canopies of other mangroves. The white mangrove has a shallow root system from which small vertical roots (pneumatophores or pencil roots) extend above ground to absorb oxygen directly from the atmosphere.

White mangroves establish, or can be encouraged to establish quite easily on tidal estuarine banks. This leads to changes at the soil surface through the trapping of fine sediment and provision of organic material resulting in the development of surface scums of microorganisms (bacteria, fungi and algae), which together eventually stabilise the substrate and protect it from erosion.

The black mangrove (*Bruguiera gymnorrhiza)* is more tolerant of fine (muddy) sediment and shade. Propagules of this species often establish within stands of white mangrove as fine sediment and organic material accumulate, and may eventually out-compete the latter species. Where drainage is impeded or smothering by sediment occurs within stands of white mangrove, succession is accelerated since the black mangrove is more tolerant of inundation and sediment deposition.

Like the black mangrove, the red mangrove (*Rhizophora mucronta*) is also tolerant of shade and may also be successional to white mangrove. This species is more tolerant of basal inundation than black and white mangrove and stands may extend into shallow water. Trees of this species are anchored to the substrate by large numbers of prop roots borne around the trunk.

The planting of mangroves, particularly the genera *Rhizophora* and *Avicennia,* has been successful in many countries (Kairo *et al*. 2001). Cases of unsuccessful mangrove rehabilitation have mainly been the result poor site and species selection (Erftemeijer and Lewis 1999, Walters 2004, Primavera and Esteban 2008). In South Africa mangroves, particularly *Avicennia marina*, have proliferated in the Mhlathuze Estuary post port development at Richards Bay. They are also spreading naturally in Durban Bay, although constrained by the paucity of intertidal soft edge habitat to colonise. Through careful engineering of depth contours, mangrove distribution on the proposed created habitat can be manipulated, although this might require initial monitoring and intervention to ensure success.

4.4 Fish and bird habitat

The discussion above has focussed largely on the value and likelihood of successfully creating habitat that will be colonised by habitat forming species (seagrass and to a lesser extent mangroves), or species at the lower end of the estuarine trophic web (benthos). Successful establishment of these biota will result in profitable utilisation of the created habitat by higher trophic level organisms (fish and birds).

Fish especially will benefit from the creation of additional shallow subtidal habitat. Indeed the present configuration and bathymetry of Durban Bay, with a strong predominance of deepwater habitat or intertidal habitat, and limited shallow subtidal habitat, reduces its value as a fish nursery. Shallow water offers juvenile fishes protection from predation by piscivorous fishes (Blaber 1987, Ruiz *et al*. 1993). Such habitat is limited in Durban Bay at low tide, leaving juvenile fishes susceptible to predation.

In contrast to the case of estuarine fishes, intertidal habitat is more important than subtidal habitat for avifauna in Durban Bay (McInnes *et al*. 2005). Nevertheless several bird species will utilise the newly created basin and its benthic and fish productivity. Its value as a bird habitat could be significantly increased by providing roosting and nesting habitat, either artificially in the form of floating structures or as naturally engineered islands. Dead trees protruding from subtidal waters would also be utilised as foraging perches, roosts and nesting habitat. These should be kept low enough to the water surface so as not to be used as hunting perches for falcons that might otherwise prey on waterbirds.

4.5 The value of terrestrial habitat to be lost

Being dry land situated well above the high water mark the site identified for habitat creation obviously has no value as estuarine habitat. Even as a secondary terrestrial habitat (being infill), however, it might have some ecological significance. An assessment of this is clearly needed before sacrificing the area to excavation for creating of a subtidal basin. To this end a high level screening of potential terrestrial impacts was conducted. This screening was based largely on a field survey of the site, focussing on vegetation as a yardstick of ecological value. Faunal diversity of the site can quite safely be assumed to be poor. Evidence of molerat (*Cryptomys tottentotus*) burrow mounds and greater cane-rat (*Thryonomys swinderianus*) scat were noted during the field survey.

Field survey of the site identified for habitat creation

Site characteristics

A survey of the site was undertaken on 22nd May 2011 by the CSIR and Mr Roddy Ward, with the main aim of determining whether plant species of conservation significance are present and that might present a fatal flaw to the proposed habitat creation initiative. It was clear that terrestrial habitat at the site is secondary in nature, with plants having established on previously dumped soil. At least some of this is material has been dredged from the Bay, as evidenced by the abundant shell material at the top of the stockpile. The area proposed for habitat creation consists of a narrow intertidal sand bank along the western shore of Little Lagoon, rising steeply in a series of irregularly stepped terraces up to a final estimated height of approximately 20 m. It is likely that this topography was established through successive dumping of unwanted or stockpiled material. Excavation of the site for habitat creation will require the dumping and/or reuse of a large quantity of this material and chemical contamination of this soil has been investigated to assess these options (see below).

Botanical composition

The secondary nature of the plant community was clear, with many opportunistic indigenous and alien species having established in the area. It must be noted that, with plant succession, even secondary communities may become valuable as habitat or may include species of conservation value. However, in this instance it was clear that the site represented a disturbed environment that had not developed into what may be described as coastal scrub or woodland. It did nevertheless contain a few species worthy of conservation. For these species recommendations regarding relocation are made below. A full plant list for the area is given in Appendix 1.

The area was characterised by a ground layer of mainly hardy grasses, dominated by *Stenotaphrum secundatum*. Several alien species, including *Bidens pilosa*, *Tagetes minuta, Chromolaena odorata* and *Catharanthus roseus*, were common in this community, while a small population of one protected indigenous species of high conservation value, *Eulophia speciosa*, was present towards the upper reaches of the hillside. Relocation of this species to the entrance of the Bayhead Heritage Site is recommended. Another species that may be considered for relocation is *Asparagus densiflorus*, which occurs midway up the western slope.

The shrub community included several alien species that commonly occur in disturbed habitats, including *Tecoma stans*, *Ricinus communis*, *Sesbania sesban* and *Leucaena leucocephala*. A large stand of *Agave sisalana,* which is reproducing prolifically, occupied the lower reaches the southern end of the site. Indigenous species that are common in dune and coastal scrub included *Chrysanthemoides monilifera* and *Dodonaea angustifolia*. In this community the latter species are most worthy of relocation to the Heritage Site (landward of the mangroves).

The most common and reproductively prolific alien tree species present throughout the site was *Schinus terebinthifolius*. Originally planted as a wind break in KwaZulu-Natal this species has become a serious invader in the region. Other alien species noted were *Melia azedarach*, which is also highly invasive, and *Terminalia catappa*. Indigenous trees included *Brachylaena discolor*, a dune species that is locally common, *Dichrostachys cinerea*, *Ficus robusta*, *Barringtonia racemosa*, one specimen each of *Hibiscus tiliaceus* and *Phoenix reclinata*, and a sapling of *Sideroxylon inerme*. Consideration should be given to relocation of *B. racemosa, H. tiliaceus* and *P. reclinata*. The *S. inerme* sapling must, however, be relocated to the Heritage Site as this is a protected species.

Findings

It was determined through the field survey that the site proposed for estuarine habitat re-creation was a disturbed area supporting a secondary botanical community. With the exception of the presence of two protected species, which must be relocated to the Heritage Site, the area was considered to be of low conservation value in terms of its present terrestrial plant community. The proposed created estuarine habitat, in contrast, would be considered of high value should the envisaged habitats be successfully established. In conclusion, there appears to be no fatal flaw associated with sacrifice of this habitat.

4.6 Assessment of sediment contamination of material to be excavated

As noted above a large volume of material will need to be excavated for the proposed habitat creation. Ideally, this material will be suited for use as construction (e.g. fill) material and can be used by TNPA or sold for use in the local building industry. Alternatively it might find use as material to be used in Durban's sand bypass scheme. If no beneficial use for the overburden exists the material will have to be disposed of, most likely at a registered offshore dumpsite. An investigation of potential chemical contamination of this soil was conducted to assess these options.

Methods

Soil samples were collected at 10 stations. At each station any surface vegetation present was cleared and the upper few centimetres of soil collected using a scoop. The soil was stored in containers until return to the laboratory, where the soil was sieved through a 2 mm mesh size sieve (i.e. gravel free). The soil from all stations was then analysed for 13 major, minor and trace metals, and from 6 of the stations also for a suite of polycyclic aromatic hydrocarbons, organochlorine pesticides and polychlorinated biphenyls. Appropriate quality assurance and quality control procedures were followed in the field and laboratory.

Grain size and total organic content

Since the soil was sieved through a 2 mm mesh size sieve it is not possible to make any comment about the contribution of gravel to bulk sediment. The soil at all sites was dominated by sand (>90%), with the dominant grain size class either medium- or fine-grained sand (Table 2). Mud sized grains were poorly represented, comprising less than 10% of bulk sediment weight.

The total organic content of the sediment was low, ranging between 0.06 to 1.81% of bulk sediment weight. This said there is strong evidence that the total organic content of the soil is somewhat higher than can be expected for granulometrically equivalent sediment in Durban Bay, or offshore of Durban. This should be expected considering that the soil was covered by vegetation and fragments of the vegetation will almost certainly have been worked into the soil by insects (e.g. ants).

Table 2. Grain size class fractions and total organic content of soil collected at the potential habitat creation site. Mean grain size is also provided. VCS = very coarse-grained sand, CS = coarse-grained sand, MS = medium-grained sand, FS = fine-grained sand, VFS = very fine-grained sand, TOC = total organic content.

Station	Gravel (%)	VCS (%)	CS (%)	MS (%)	FS (%)	VFS (%)	Mud (%)	TOC (%)
LL 1	0.00	1.10	7.05	49.62	38.18	0.13	3.93	0.66
LL 2	0.00	1.98	15.16	30.04	51.39	0.18	1.25	0.34
LL 3	0.00	0.72	4.67	39.91	45.14	2.72	6.84	1.81
LL 4	0.00	4.81	10.81	36.00	35.62	3.19	9.57	1.54
LL 5	0.00	1.18	5.45	34.21	50.21	3.84	5.11	0.87
LL 6	0.00	1.72	6.60	41.99	44.84	2.68	2.17	0.16
LL 7	0.00	0.99	4.69	35.18	51.20	3.34	4.60	0.68
LL 8	0.00	0.90	6.15	42.31	46.57	3.64	0.43	0.06
LL 9	0.00	2.16	6.49	35.29	47.89	3.32	4.85	1.29
LL 10	0.01	5.98	11.53	32.54	36.48	3.72	9.75	0.94

Metals

Metal concentrations analysed in the soil samples are presented in Table 3. The concentrations were interpreted using baseline metal concentration models and baseline cadmium concentrations recently defined for Durban Bay by the Coastal Systems research group of the CSIR (all mercury concentrations are below the method detection limit and were not therefore interpreted). The baseline models compensate for the influence of sediment granulometry on the natural variation of metal concentrations in sediment/soil. This is a prerequisite for discriminating between natural metal concentrations and concentrations that are enhanced through anthropogenic contributions. Comparison of the metal concentrations showed that only a single arsenic concentration (at station LL9) is enriched, that is, exceeds the baseline concentration range for sediment in Durban Bay. However, the magnitude of enrichment is so low that it is impossible to determine whether this may in fact not simply reflect a limitation of the baseline model.

Table 3. Metal concentrations (mg.g^{-1} for aluminium and iron and µg.g^{-1} for all other metals) in soil samples. The Warning Level, Level I and Level II of the South African sediment quality guidelines for the identification of management options for material identified for dredging in South African coastal waters is also included. Concentrations below the method detection are indicated by the symbol < followed by the relevant detection limit.

Metal	Stations 1	2	3	4	5	6	7	8	9	10	Warning Level	Level I	Level II
Aluminium	3.91	2.62	4.00	4.71	4.64	3.42	3.71	3.49	5.61	6.82			
Iron	4.58	3.17	4.39	5.22	5.13	3.71	4.07	3.89	6.25	7.26			
Arsenic	4.03	3.99	2.78	2.30	3.56	3.44	3.65	2.48	6.42	2.14	42	57	93
Cadmium	0.072	0.040	0.049	0.024	0.050	0.092	0.042	<0.02	0.072	0.051	1.2	5.1	9.6
Cobalt	2.20	<1	1.74	2.48	2.33	1.10	2.59	1.55	3.35	4.16			
Copper	6.11	2.39	5.80	6.54	7.26	1.68	6.43	2.21	10.16	11.43	110	230	390
Chromium	15.66	5.42	13.72	11.78	16.16	8.28	13.02	6.40	17.26	18.28	250	260	370
Manganese	137.7	54.1	100.3	109.3	149.2	39.1	66.7	75.7	97.8	159.8			
Mercury	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.43	0.84	1.5
Nickel	2.51	0.96	2.93	2.67	2.64	1.31	2.40	1.41	3.40	4.97	88	140	370
Lead	4.56	<2.5	8.69	4.29	5.90	<2.5	5.54	<2.5	6.66	6.46	110	218	530
Vanadium	8.01	6.12	8.43	9.02	9.33	8.84	8.81	6.20	11.83	13.52			
Zinc	23.41	9.89	48.16	23.98	24.10	6.55	27.81	7.52	26.27	27.73	270	410	960

Organic chemicals

Of the organochlorine pesticides analysed only constituents of chlordane and DDT were present at concentrations exceeding the method detection limit, and then only in soil at station 10 (Table 4). One or more polycyclic aromatic hydrocarbon isomers were present at concentrations exceeding the method detection limit at all but station 6 (Table 5). All polychlorinated biphenyl congeners were present at concentrations below the method detection limit in soil at all stations (Table 6).

Batterman *et al*. (2008) recently reported the widespread existence of DDT (technical and derivatives) and chlordane metabolites in air samples collected in Durban. Recent monitoring by the CSIR (unpublished data) has also identified these pesticides in air samples. DDT and its metabolites were also recently detected in numerous (31 of 49) sediment samples, and chlordane in one sediment sample collected in estuaries and rivers in the Durban area by the Coastal Systems research group of the CSIR (unpublished data). The source of DDT and chlordane in the study area is thus probably atmospheric deposition rather than direct application considering that the use of these pesticides is banned under the conditions of the Stockholm Convention on Persistent Organic Pollutants with the exception of certain regulated uses. In South Africa, for example, DDT is still used for the control of malaria bearing mosquitoes.

The polycyclic aromatic hydrocarbons probably reflect a mix of atmospheric deposition (e.g. soot) and, at station 10, the dumping of waste materials. The isomer composition in soil at station 7 (Table 5) suggests that the polycyclic aromatic hydrocarbons were derived from bitumen/asphalt or possibly creosote, considering the representation of numerous five and six ring isomers. These isomers are usually absent or poorly represented in areas contaminated by oil. This suggests that although the soil samples were screened through a sieve a granule/fleck of tar or some other hydrocarbon dominated material was included in the sample.

Assessment of suitability for construction material or beach disposal

The soils to be removed, if accurately characterised by the surface samples collected here, are strongly dominated by medium- and fine-grained sands. At face value this material seems suited for use as fill material or for other application in the construction industry, although this needs a more qualified assessment from an engineer. Not reflected in the laboratory results is the fact that some contamination of the site with asbestos might be possible. From information the CSIR has been able to source, indications are that this contamination is very minor and of limited spatial extent. Nevertheless this warrants confirmation by TNPA and TCP prior to any earth moving operations. This almost certainly prohibits the use of the material on Durban beaches and most likely requires that special application be made to relevant environmental, labour and health departments before working these soils.

Assessment of suitability for offshore disposal

Soil and sediment quality guidelines are often used to assess the potential ecological significance of contaminant concentrations. Since soil from the study area will possibly be disposed at the openwater spoil disposal ground offshore of Durban, sediment rather than soil quality guidelines are used to assess the potential ecological significance of the chemical concentrations. Metal concentrations are evaluated against sediment quality guidelines recently derived by the Department of Environmental Affairs for the specific purpose of determining whether sediment identified for dredging in South African ports is of a suitable quality for unconfined openwater disposal. Three guidelines were defined, namely a Warning Level and the Level I and Level II (Table 3). The Warning Level is intended to provide a warning of incipient contamination, but is not used for decision-making. The Level I and Level II guidelines are used for decision-making. Concentrations of metals that fall between the Level I and Level II are cause for possible concern, with the degree of concern increasing as the concentration approaches the Level II. Depending on the concentration, additional testing may be required to determine whether the metal concentrations are likely to be toxic to aquatic organisms. Metal concentrations that exceed the Level II guideline are considered unsuitable for openwater disposal unless other evidence (e.g. results of toxicity testing) shows that the metals are present in a form that is not toxic to aquatic organisms. The concentrations of metals in the soil samples fall well below the sediment quality guidelines (Table 3).

Table 4. Concentrations ($\mu g.kg^{-1}$) of organochlorine pesticides in soil samples. The Effects Range Low and Effects Range Median of the Long *et al*. (1995) sediment quality guidelines are provided. Concentrations that exceed the Effects Range Low are highlighted in bold italics. Concentrations below the method detection are indicated by the symbol < followed by the relevant detection limit.

Chemical	Station						Effects Range Low	Effects Range Median
	1	3	4	6	7	10		
alpha-HCH	<1	<1	<1	<1	<1	<1		
beta-HCH	<1	<1	<1	<1	<1	<1		
gamma-HCH	<1	<1	<1	<1	<1	<1		
delta-HCH	<1	<1	<1	<1	<1	<1		
Hexachlorobenzene	<1	<1	<1	<1	<1	<1		
Heptachlor	<1	<1	<1	<1	<1	<1		
Heptachlor epoxide (cis)	<1	<1	<1	<1	<1	<1		
Heptachlor epoxide (trans)	<1	<1	<1	<1	<1	<1		
Hexachlorobutadiene	<1	<1	<1	<1	<1	<1		
Aldrin	<1	<1	<1	<1	<1	<1		
Dieldrin	<1	<1	<1	<1	<1	<1		
Endrin	<1	<1	<1	<1	<1	<1		
Isodrin	<1	<1	<1	<1	<1	<1		
Telodrin	<1	<1	<1	<1	<1	<1		
alpha-Endosulfan	<1	<1	<1	<1	<1	<1		
beta-Endosulfan	<1	<1	<1	<1	<1	<1		
alpha-Endosulfansulphate	<1	<1	<1	<1	<1	<1		
alpha-Chlordane	<1	<1	<1	<1	<1	1.4		
y-Chlordane	<1	<1	<1	<1	<1	1.2		
Chlordane (sum)	<2	<2	<2	<2	<2	2.6		
o,p'-DDT	<1	<1	<1	<1	<1	8.3		
o,p'-DDT	<1	<1	<1	<1	<1	16		
o,p'-DDE	<1	<1	<1	<1	<1	1.3		
o,p'-DDE	<1	<1	<1	<1	<1	2.2		
o,p'-DDD	<1	<1	<1	<1	<1	<1		
o,p'-DDD	<1	<1	<1	<1	<1	<1		
Sum HCH compounds	<4	<4	<4	<4	<4	<4		
DDT (sum)	<2	<2	<2	<2	<2	***24.3***	1.58	46.1
DDE (sum)	<2	<2	<2	<2	<2	***3.5***	2.2	27
DDD (sum)	<2	<2	<2	<2	<2	<2		
DDX (sum)	<6	<6	<6	<6	<6	27.8		

Since there are no South African sediment quality guidelines for organic chemicals the guidelines derived by Long *et al*. (1995) for application in North American coastal waters are used. The sediment quality guidelines comprise two guidelines, namely the Effects Range Low and Effects Range Median (Tables 3-4). The Effects Range Low represents the concentration below which adverse biological effects were rarely observed (10th percentile of effects) while the Effects Range Median represents the concentration above which adverse effects were frequently observed (50th percentile of effects). Concentrations that fall between the Effects Range Low and Effects Range Median represent concentrations where adverse biological effects should theoretically be observed with increasing frequency depending on where the concentration falls within this range.

Table 5. Concentrations (μg.kg^{-1}) of polycyclic aromatic hydrocarbons in soil samples. The Effects Range Low and Effects Range Median of the Long *et al*. (1995) sediment quality guidelines are provided. Concentrations that exceed the Effects Range Low are highlighted in bold italics. Concentrations below the method detection are indicated by the symbol < followed by the relevant detection limit.

Chemical	Station						Effects Range Low	Effects Range Median
	1	3	4	6	7	10		
Naphthalene	<10	<10	<10	<10	19	<10	160	2100
Acenaphthylene	<10	<10	<10	<10	<10	<10	44	640
Acenaphthene	<10	<10	<10	<10	***36***	<10	16	500
Fluorene	<10	<10	<10	<10	***26***	<10	19	540
Phenanthrene	16	17	12	<10	***480***	<10	240	1500
Anthracene	<10	<10	<10	<10	64	<10	85.3	1100
Low Molecular Weight isomers (sum)	<60	<60	<60	<60	***625***	<60	552	3160
Fluoranthene	20	21	22	<10	530	<10	600	5100
Pyrene	18	19	<10	<10	420	<10	665	2600
Benzo(a)anthracene	<10	12	<10	<10	200	<10	261	1600
Chrysene	18	21	<10	<10	220	<10	384	2400
Benzo(b)fluoranthene	23	25	25	<10	260	<10		
Benzo(k)fluoranthene	<10	<10	11	<10	94	<10		
Benzo(a)pyrene	<10	<10	<10	<10	160	<10	430	1600
Dibenzo(ah)anthracene	<10	<10	<10	<10	27	<10	63.4	260
Benzo(ghi)perylene	14	14	15	<10	120	11		
Indeno(123cd)pyrene	<10	<10	<10	<10	100	<10		
High Molecular Weight isomers (sum)	<100	112	<100	<100	***2131***	<100	1700	9600
Polycyclic aromatic hydrocarbons (sum)	<160	<160	<160	<160	2756	<160	4022	44793

The total DDT and DDE concentrations at station 10 exceed the Effects Range Low but not the Effects Range Median (Table 4). In other words, there is a possibility that these concentrations may be associated with adverse ecological effects to bottom-dwelling organisms if the sediment was in an aquatic system. The concentrations of three low molecular weight isomers and the sum of high molecular weight isomers exceed the Effects Range Low at station 7, but are well below the Effects Range Median (Table 5). Thus, there is a low possibility that the polycyclic aromatic hydrocarbons at this station may be associated with adverse effects to bottom-dwelling organisms.

The critical question based on the exceedances of sediment quality guidelines by concentrations of some organic chemicals in the soil is whether the concentrations are likely to cause significant toxic effects to bottom-dwelling organisms at the dredged spoil disposal ground (assuming that the chemicals are not significantly leached from the sediment during the descent of sediment to the seabed). This is a difficult question to answer but it is the professional opinion of the scientists that compiled this report that this is unlikely considering that contamination of the soil is extremely patchy (and thus of a small volume) and while some concentrations exceed sediment quality guidelines the magnitude of exceedance is not pronounced. Furthermore, the concentrations are typically well below the guidelines indicative of a high likelihood for adverse effects to bottom-dwelling organisms (i.e. the Effects Range Median).

Table 6. Concentrations (µg.kg^{-1}) of polychlorinated biphenyls in soil samples. The Effects Range Low and Effects Range Median of the Long *et al*. (1995) sediment quality guidelines are provided. Concentrations that exceed the Effects Range Low are highlighted in bold italics. Concentrations below the method detection are indicated by the symbol < followed by the relevant detection limit.

Chemical	Station						Effects Range Low	Effects Range Median
	1	3	4	6	7	10		
PCB28	<1	<1	<1	<1	<1	<1		
PCB52	<1	<1	<1	<1	<1	<1		
PCB101	<1	<1	<1	<1	<1	<1		
PCB118	<1	<1	<1	<1	<1	<1		
PCB138/163	<1	<1	<1	<1	<1	<1		
PCB153	<1	<1	<1	<1	<1	<1		
PCB180	<1	<1	<1	<1	<1	<1		
PCB (sum)	<1	<1	<1	<1	<1	<1	22.7	180

5. Conclusions

The notion of creating estuarine habitat as an extension basin to the Little Lagoon in Durban Bay, as described in this document, is an attractive option. The present initiative does not involve habitat creation at the expense of existing estuarine habitat, or even at the expense of functional terrestrial habitat, and should be actively pursued. The study team has a high level of confidence that the proposed habitat creation can be achieved, at least in terms of the tidal flats. If successfully implemented this has very definite ecological benefits. This development would almost double the size of Little Lagoon type habitat in the Bay, and if *Zostera* can be re-established would represent a small but significant step towards the system re-establishing some semblance of its former state. Ideally, options for similar habitat creation opportunities should be investigated. One such option is presented by currently unused land immediately south of the Bayhead mangroves, although botanical considerations would need to be carefully assessed here (apparently this site supports a small population of rare orchid).

Monitoring and management will undoubtedly be required in the implementation of this project, but these can be quite easily and cost-effectively achieved. The potential exists to link the newly created habitat with the existing Bayhead Heritage Site, and bird hides and ecowalks can be used by TNPA as part of its corporate social responsibility programme. The initiative would also provide excellent research opportunity and value, particularly to life sciences students at local institutions such as the University of KwaZulu-Natal.

The initiative also holds value as a potential offset measure for unavoidable habitat loss that might be incurred by future port development. The strength and acceptability of this habitat creation exercise as an offset measure will depend heavily on the type and amount of habitat that is potentially lost to new development. As indicated throughout this report the notion of replacing one functional habitat type with another in estuarine systems in KwaZulu-Natal should not be accepted at face value. Shallow subtidal habitat in Durban Bay, such as that potentially created by this project, is important and any increase in this habitat, even at the expense of intertidal habitat, will be beneficial to estuarine fishes and invertebrates. In the case of these biotic components such an offset might well be feasible. However very important elements of the Bay's existing avifauna would be negatively impacted by such a trade-off as intertidal area, rather than subtidal area is of more importance to the Bay's birdlife.

6. References

Allan D (2001). The waterbirds of Durban Bay, South Africa - a worst-case scenario of African coastal wetland destruction. Symposium S04: Wetlands and Waterfowl. Ostrich 72:S15: 71–87.

Allan DG, Sinclair JC and Rossouw J (1999). The waterbirds of Durban Bay: current status and historical trends. *Durban Museum Novitates* 24: 1–21.

Batterman SA, Chernyak SM, Gounden Y, Matooane M and Naidoo RN (2008). Organochlorine pesticides in ambient air in Durban, South Africa. *Science of the Total Environment* 397: 119–130.

Beckley LE (1983). The ichthyofauna associated with *Zostera capensis Setchell* in the Swartkops Estuary, South Africa. *South African Journal of Zoology* 18: 15–24.

Begg GW (1978). The Estuaries of Natal. Natal Town and Regional Planning Report 41: 1–657.

Begg GW (1984). The Estuaries of Natal (Part II). Natal Town and Regional Planning Report 55: 1–631.

Blaber SJM (1981). The zoogeographical affinities of estuarine fishes in south-east Africa. *South African Journal of Science* 77: 305–7.

Blaber SJM (1987). Factors affecting recruitment and survival of mugilids in estuaries and coastal waters of southeastern Africa. *American Fisheries Society Symposium* 1: 507–518.

Craft C and Sacco J (2003). Long-term succession of benthic infauna communities on constructed *Spartina alterniflora* marshes. *Marine Ecology Progress Series* 257: 45–58.

Cyrus DP, MacKay CF & Weerts SP (2008). Intrusion of beach-disposed dredger spoil into the Mhlathuze Estuary, South Africa, and its impact on *Zostera capensis*. *Southern African Journal of Aquatic Science* 33: 223–231.

Day JH and Morgans JFC (1956). The ecology of South African estuaries. Part 7: The biology of Durban Bay. *Annals of the Natal Museum* 13: 259–301.

Deyzel SHP, James NC and Paterson AW (2009). Confidential report on long-term ecological monitoring in the Port of Durban. July 2008 and January 2009. SAEON Unpublished Report.

Erftemeijer PLA and Lewis RR (1999). Planting mangroves on intertidal mudflats: habitat restoration or habitat conversion? Proceedings of the ECOTONE VIII Seminar "Enhancing Coastal Ecosystems Restoration for the 21st Century" Ranong Thailand 23-28 May 1999. Royal Forest Department of Thailand Bangkok Thailand: 156–165.

Evans PR, Ward RM, Bone M and Leakey M (1998). Creation of temperate-climate intertidal mudflats: factors affecting colonisation and use by benthic invertebrates and their bird predators. *Marine Pollution Bulletin* 37: 535–545.

Fonseca MS, Kenworthy WJ and Thayer GW (1982). A low cost transplanting procedure for sediment stabilisation and habitat development using eelgrass (*Zostera marina*). Wetlands 2: 138–151.

Forbes AT and Demetriades NT (2003). Ecology of the Little Lagoon area of Durban Bay. Report prepared for National Ports Authority Durban by Marine and Estuarine Research. 74 pp.

Forbes AT and Demetriades NT (2006a). Transnet-eThekwini Municipality Planning Initiative. Specialist Report - Environment. Report for Transnet-eThekwini Municipality Planning Initiative.

Forbes AT and Demetriades NT (2006b). Assessment of the potential for restoration of habitats in Durban Bay. In Forbes AT and Demetriades NT (2006). Specialist Ecological Reports July - November 2006. Report for Transnet-eThekwini Municipality Planning Initiative.

Forbes AT, Demetriades NT and Cyrus DP (1996). Biological significance of harbours as coastal habitats in KwaZulu-Natal, South Africa. *Aquatic Conservation*: *Marine and Freshwater Ecosystems* 6: 331–41

French K, Robertson S and O' Donell MA (2004). Different invertebrate infaunal assemblages of constructed and natural tidal flats in New South Wales Australia. *Estuarine Coastal and Shelf Science* 61: 173–183.

Harrison PG (1990). Variations in success of eelgrass transplants over a five-year period. *Environmental Conservation* 17(2): 157–163.

Hotaling AS, Lingle RB and Ankerson TT (2011). Comprehensive seagrass restoration planning in Southwest Florida: science law and management. *Sea Grant Law and Policy Journal* 4(1): 61–78.

Ishii R, Nakano Y, Nakai S, Nishijima W and Okada M (2008). Benthic ecosystem development in an artificial tidal flat constructed from dredged spoil. *Marine Pollution Bulletin* 12: 2059–2066.

James NC, Paterson AW and Deyzel SHP (2008a). Confidential report on long-term ecological monitoring in the Port of Durban. January and February 2008. SAEON Unpublished Report.

James NC, Paterson AW and Deyzel SHP(2008b). Confidential report on long-term ecological monitoring in the Port of Durban. July 2008. SAEON Unpublished Report.

Kairo GK, Dahdou-Guebas F, Bosire J and Koedam N (2001). Restoration and management of mangrove systems - a lesson learnt for and from the East African region. *South African Journal of Botany* 67: 383–389.

Katwijk MM, Bos AR, de Jonge VN, Hanssen L SAM, Hermus DCR and de Jong DJ (2009). Guidelines for seagrass restoration: importance of habitat selection and donor population spreading of risks and ecosystem engineering effects. *Marine Pollution Bulletin* 58: 179–188.

Kemp WM, Batuik R, Bartleson R, Bergstrom P, Carter V, Gallegos G, Hunley W, Karrh L, Koch E, Landwehr J, Moore K, Murray L, Naylor M, Rybicki N, Stevenson JC, Wilcox D (2004). Habitat requirements for submerged aquatic vegetation in Chesapeake Bay: Water quality light regime and physical-chemical factors. *Estuaries* 27: 363– 377.

Kenworthy WJ, Fonseca MS, Homziak J and Thayer GW (1980). Development of a transplanted seagrass (*Zostera marina* L.) meadow in Back Sound Carteret County North Carolina. In: Cole DP (ed) Proceedings of the 7th Annual Conference for Restoration and Creation of Wetlands. Hillsborough Community College Tampa FL. p 175–193.

Lee JG, Nishijima W, Mukai T, Takimoto K, Seiki T, Hiraoka K and Okada M (1998). Factors to determine the functions and structures in natural and constructed tidal flats. *Water Research* 32: 2601–2606.

Levin LA, Talley D and Thayer G (1996). Succession of macrobenthos in a created salt marsh. *Marine Ecology Progress Series* 141: 67–82.

Long ER, MacDonald DD, Smith SL and Calder FD (1995). Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management* 19: 81–97.

Mander M, Demetriades NT, Forbes AT and Allan D (2006). An Assessment Of The Ecosystem Benefits Supplied By Durban Bay And The Implications Of Port Development Options. Report for Transnet-Ethekwini Municipality Planning Initiative.

McInnes AM, Allan DG and Malan M (2005). Key sites for the conservation of waterbirds (Aves) in Durban Bay, South Africa. *Durban Museum Novitates* 30: 1–14.

MER/ERM 2011. Development of the Bay of Natal Estuarine Management Plan: Situation Assessment. Report prepared for eThekwini Municipality, Transnet National Ports Authority and the Department of Agriculture, Environmental Affairs and Rural Development.

Newman B, Weerts S, Porter S and Mackay F (2008). Specialist Studies for Transnet Capital Expansion Program Durban Bay. CSIR Report for Transnet Projects. Unpublished. 230 pp. incl. 17 Appendices.

Paling EI, Van Keulen M, Wheeler KD, Phillips J, Dyhrberg R, and Lord DA (2001). Improving mechanical seagrass transplantation. *Ecological Engineering* 18: 107–113.

Parker R, Bolam S, Foden J and Morris D (2004). Suitability Criteria for Habitat Creation Report I: reviews of present practices and scientific literature relevant to site selection criteria. R&D Technical Report FD1917TR1. Defra/Environment Agency Flood and Coastal Defence R&D Programme. Centre for Environment Fisheries and Aquaculture Science (CEFAS) Lowestoft Laboratory. Accessed from www.defra.gov.uk/environ/fcd/research on 24/05/2012.

Pearson T (1995). African Keyport: Story of the Port of Durban 29 Degrees 52Min South and 31 Degrees 02Min East. Accucut Books, Rossburgh. 281 pp.

Pillay D and Branch GM (2011). Bioengineering effects of burrowing thalassinidean shrimps on marine soft-bottom ecosystems. *Oceanography and Marine Biology: An Annual Review* 49: 137–192.

Pillay D, Branch GM and Forbes AT (2007a). The influence of bioturbation by the sandprawn *Callianassa kraussi* on feeding and survival of the bivalve *Eumarcia paupercula* and the gastropod *Nassarius kraussianus*. *Journal of Experimental Marine Biology and Ecology* 344: 1–9.

Pillay D, Branch GM and Forbes AT (2007b). Experimental evidence for the effects of the thalassinidean sandprawn Callianassa kraussi on macrobenthic communities. *Marine Biology* 152: 611–618.

Pillay D, Branch GM and Forbes AT (2008). Habitat change in an estuarine embayment: Anthropogenic influences and a regime shift in biotic interactions. *Marine Ecology Progress Series* 370: 19–31.

Pillay S and Newman BK (2007). Water Quality Monitoring Programme: Port of Durban 2007-2008. CSIR Report No. CSIR/NRE/PW/ER/2007/0117/C.

Pollard DA (1984). A review of the ecological studies on seagrass-fish communities, with particular reference to recent studies in Australia. *Aquatic Botany* 18: 3–42.

Primavera JH and Esteban JMA (2008). A review of mangrove restoration in the Philippines: success failures and future prospects. *Wetlands Ecology and Management* 16: 345–358.

Ray GL (2000). Infaunal assemblages on constructed intertidal mudflats at Jonesport Maine (USA). *Marine Pollution Bulletin* 40: 118–1200.

Ruiz GM, Hines AH and Posey MH (1993). Shallow water as a refuge habitat for fish and crustaceans in non-vegetated estuaries: an example from Chesapeake Bay. *Marine Ecology Progress Series* 99: 1–16.

Short FT, Burdick DM, Short CA, Davis RC and Morgan PA (2000). Developing success criteria for restored eelgrass salt marsh and mud flat habitats. *Ecological Engineering* 15: 239–252.

Short FT, Davis RC, Kopp BS, Short CA and Burdick DM (2002). Site selection model for optimal transplantation of eelgrass *Zostera marina* in the northeastern U.S. *Marine Ecology Progress Series* 227: 253–267.

Siebert T and Branch GM (2007). Influences of biological interactions on community structure within seagrass beds and sandprawn-dominated sandflats. *Journal of Experimental Marine Biology and Ecology* 340: 11–24.

Turpie JK, Adams JB, Joubert A, Harrison TD, Colloty BM, Maree RC, Whitfield AK, Wooldridge TH, Lamberth SJ, Taljaard S and Van Niekerk L (2002). Assessment of the conservation priority status of South African estuaries for use in management and water allocation. *Water SA* 28: 2: 191–206.

Van Niekerk L and Turpie JK (eds) (2012). South African National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component. CSIR Report Number CSIR/NRE/ECOS/ER/2011/0045/B.

Walters BB (2004). Local Management of Mangrove Forests in the Philippines: successful conservation or efficient resource exploitation? *Human Ecology* 32(2): 177–195.

Weerts SP (2002). Habitat utilisation by juvenile fishes in Mhlathuze Estuary and Richards Bay Harbour. MSc Thesis. University of Zululand, KwaDlangezwa.

Weerts SP and Cyrus DP (2002). Occurrence of young and small-sized fishes in different habitats within a subtropical South African estuary and adjacent harbour. *Marine and Freshwater Research* 53: 447–456.

Weerts SP and Pillay S (2008). Fish kills in Durban Bay, December 2007. CSIR Report No. CSIR/NRE/ECO/ER/2008/0015/C.

Weerts SP, Cilliers G and Cyrus DP (2003). Estuarine macrocrustacea of Richards Bay Harbour, South Africa, with particular reference to the penaeid prawns. *African Journal of Zoology* 38: 285–296.

Whitfield AK (1992). A characterization of southern African estuarine systems. *Southern African Journal of Aquatic Sciences* 18: 89–103.

Whitfield AK, Beckley LE, Bennett B, Branch GM, Kok HM, Potter IC and van der Elst RP (1989). Composition, species richness and similarity of ichthyofaunas in eelgrass *Zostera capensis* beds of southern Africa. *South African Journal of Marine Science* 8: 251–259.

Yap HT (2000). The case for restoration of tropical coastal ecosystems. *Ocean and Coastal Management* 43(8–9): 841–851.

Zajac RN and Whitlatch RB (1982a). Responses of estuarine infauna to disturbance. I. Spatial and temporal variation of recolonisation. *Marine Ecology Progress Series* 10: 1–14.

Zajac RN and Whitlatch RB (1982b). Responses of estuarine infauna to disturbance. II. Spatial and temporal variation of succession. *Marine Ecology Progress Series* 10: 15–27.

Appendix 1: Plant list compiled from a field survey (22nd May 2012)

MONOCOTYLEDONS	
FAMILY AND BOTANICAL NAME	**GROWTH FORM**
Poaceae	
Imperata cylindrica (L.) Raeusch.	Tufted grass – common, sandy coastal areas
Hyparrhenia sp. cf. *H. filipendula* (Hochst.) Stapf var. *filipendula*	Wiry tufted grass – common, thatching grass
Stenotaphrum secundatum (H.Walter) Kuntze	Creeping grass – common, coastal areas
Panicum maximum Jacq.	Robust tufted grass – disturbed places
Melinis repens (Willd.) Zizka subsp. *repens*	Short tufted grass
cf. *Pennisetum* sp. cf. *P. natalense* Stapf	Tufted grass
Cenchrus brownii Roem. & Schult. *	Tufted grass
Arundo donax L. *	Robust reed-like grass – disturbed places
Sporobolus virginicus (L.) Kunth	Hardy grass - coastal dunes and estuaries
Eragrostis ciliaris (L.) R.Br.	Hardy grass – disturbed places
Eragrostis curvula (Schrad.) Nees	Hardy grass – disturbed places
Cynodon dactylon (L.) Pers.	Short creeping grass – lawns, disturbed places
Chloris gayana Kunth	Tufted grass
Imperata cylindrica (L.) Raeusch.	Tufted grass – common on coastal sands
Cyperaceae	
Cyperus dubius Rottb.	Rhizomatous sedge
Cyperus esculentus L. var. *esculentus*	Rhizomatous sedge – common, weedy
Arecaceae	
Phoenix reclinata Jacq.	Palm – dune forest
Commelinaceae	
Commelina eckloniana Kunth	Prostrate herb
Asparagaceae	
Asparagus densiflorus (Kunth) Jessop	Herb - fine leaved multi-stemmed clumps
Agavaceae	
Agave sp. cf. *A. sisalana* Perrine	Robust succulent, rosette - invasive
Orchidaceae	
Eulophia speciosa (R.Br. ex Lindl.) Bolus	Herb, ground orchid – coastal dune scrub
DICOTYLEDONS	
Mesembryanthemaceae	
Carpobrotus dimidiatus (Haw.) L.Bolus	Creeping succulent - sand dunes
Caryophyllaceae	
Pollichia campestris Aiton	Spreading herb
Fabaceae	
Acacia robusta Burch. subsp. *clavigera* (E.Mey.) Brenan	Tree - locally common
Leucaena leucocephala (Lam.) De Wit *	Robust shrub - highly invasive
Senna bicapsularis (L.) Roxb. *	Shrub
Crotalaria lanceolata E.Mey. subsp. *lanceolata*	Herb
Tephrosia purpurea (L.) Pers. subsp. *canescens* (E.Mey.) Brummitt	herb
Sesbania bispinosa (Jacq.) W.Wight var. *bispinosa* *	Shrub - invasive
Desmodium incanum DC.	Herb – common disturbed places
Canavalia rosea (Sw.) DC	Creeping herb – common dune plant
Rhynchosia caribaea (Jacq.) DC.	Herb
Macroptilium atropurpureum (DC.) Urb. *	Herb
Meliaceae	
Melia azedarach L. *	Tree – highly invasive

Euphorbiaceae *Ricinus communis* L.var.*communis* * *Euphorbia hirta* L. * *Euphorbia kraussiana* Bernh. var. *kraussiana* *Euphorbia heterophylla* L.* *Euphorbia indica* Lam. *	 Shrub – highly invasive Creeping herb Creeping herb Herb/subshrub Creeping herb
Anacardiaceae *Schinus terebinthifolius* Raddi *	 Tree – highly invasive
Sapindaceae *Dodonaea viscosa* Jacq. var. *angustifolia* (L.f.) Benth.	 Shrub – dune scrub/forest
Tiliaceae *Triumfetta rhomboidea* Jacq. var.*rhomboidea*	 Small shrub
Malvaceae *Hibiscus tiliaceus* L. subsp. *tiliaceus*	 Tree – coastal and estuarine areas
Combretaceae *Terminalia catappa* L.*	 Tree
Sapotaceae *Sideroxylon inerme* L. subsp. *inerme*	 Tree – coastal and estuarine areas
Apocynaceae *Catharanthus roseus* (L.) G.Don * *Thevetia peruviana* (Pers.) K.Schum. *	 Herb – disturbed places Tree – becoming invasive
Convolvulaceae *Ipomoea pes-caprae* (L.) R.Br. subsp. *brasiliensis* (L.) Ooststr.	 Creeping Herb – sand dunes
Verbenaceae *Lantana camara* L. *	 Shrub – highly invasive
Bignoniaceae *Tecoma stans* (L.) Juss. ex Humb., Bonpl. & Kunth var. *stans**	 Shrub - invasive
Acanthaceae *Asystasia gangetica* (L.) T.Anderson subsp. *micrantha* (Nees) Ensermu.	 Prostrate herb
Cucurbitaceae *Coccinia palmata* (Sond.) Cogn.	 Climbing herb
Asteraceae *Chromolaena odorata* (L.) R.M.King & H.Rob. * *Conyza albida* Spreng. * *Conyza bonariensis* (L.) Cronquist * *Brachylaena discolor* DC. *Helichrysum asperum* (Thunb.) Hilliard & B.L.Burtt var. *asperum* *Helichrysum decorum* DC. *Ambrosia artemisiifolia* L. * *Bidens biternata* (Lour.) Merr. & Sherff * *Bidens pilosa* L. * *Tridax procumbens* L. * *Senecio chrysocoma* Meerb. *Chrysanthemoides monilifera* (L.) Norl. subsp. *rotundata* (DC.) Norl.	 Shrub – highly invasive Herb – common weed Herb – common weed Tree – common in coastal forest Herb Herb Herb Herb – common weed Herb – common weed Prostrate herb – common weed Herb Shrub – common in coastal areas

* indicated alien species