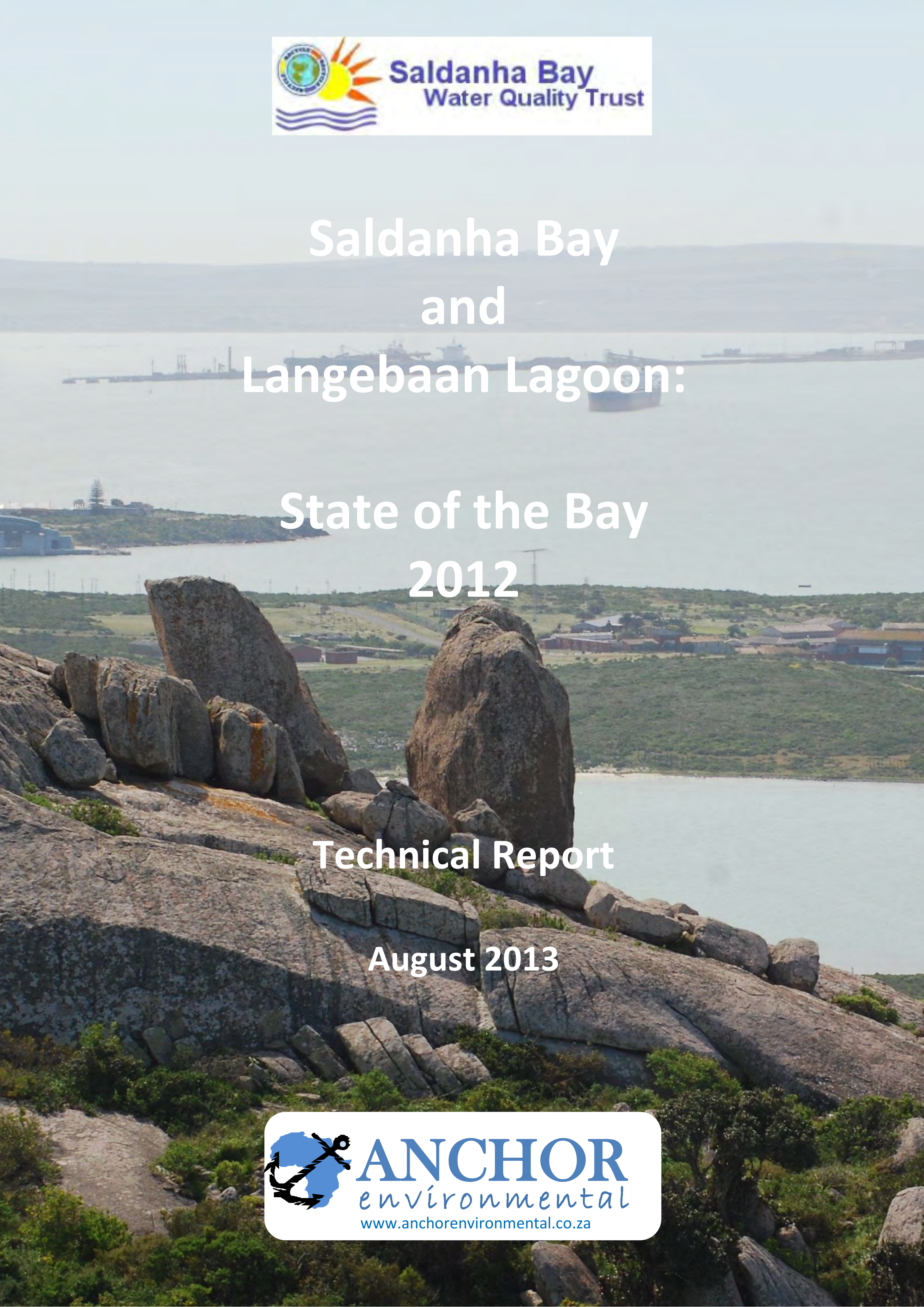


Saldanha Bay Water Quality Trust

Saldanha Bay and Langebaan Lagoon:

State of the Bay 2012

Technical Report

August 2013

ANCHOR environmental

www.anchorenvironmental.co.za

Saldanha Bay and Langebaan Lagoon

State of the Bay 2012

Technical Report

Prepared by:

Anchor Environmental Consultants

8 Steenberg House, Silverwood Close, Tokai 7945, South Africa

Prepared for:

Saldanha Bay Water Quality Trust

October 2013

Authors:

B.M. Clark, J. Turpie, C. Jurk, K. Hutchings, K. Tunley, A. Biccard, and N. Steffani

EXECUTIVE SUMMARY

Regular, long-term environmental monitoring is essential to identify and to enable proactive mitigation of negative human impacts on the environment (e.g. pollution), and in so doing maintain the beneficial value of an area for all users. This is particularly pertinent for an area such as Saldanha Bay and Langebaan Lagoon, which serves as a major industrial node and port while at the same time supporting important tourism and fishing industries. The development of the Saldanha Bay port has significantly altered the physical structure and hydrodynamics of the Bay, whilst all developments within the area (industrial, residential, tourism etc.) have the potential to negatively impact on ecosystem health. Various techniques are available to monitor the health of the environment, including measuring of physical parameters (e.g. water temperature, oxygen levels, and circulation patterns), actual pollutants (e.g. heavy metals, hydrocarbons, microbiological indicators) and biological components of the ecosystem (e.g. birds, fish and invertebrates). Nearly all measurable parameters exhibit substantial natural variability, and it is essential that environmental monitoring is conducted over the long term (years to decades) at sufficient frequency to enable identification of human-induced changes.

Saldanha Bay and Langebaan Lagoon have long been the focus of scientific study and interest, owing to its conservation importance as well as its many unique features. The establishment of the Saldanha Bay Water Quality Trust (SBWQT) in 1996, a voluntary organization representing various organs of State, local industry and other relevant stakeholders and interest groups, gave much impetus to the monitoring and understanding of changes in the health and ecosystem functioning of this unique bay-lagoon ecosystem. Direct monitoring of a number of important ecosystem indicators was initiated by the SBWQT in 1999, including water quality (faecal coliform, temperature, oxygen and pH), sediment quality (trace metals, hydrocarbons, particulate organic carbon and nitrogen) and benthic macrofauna. The range of parameters monitored has expanded since then to include surf zone fish and rocky intertidal macrofauna (both initiated in 2005) and led to the commissioning of a “State of the Bay” technical report series in 2006. This report has been produced annually since 2008, presenting data on parameters monitored directly by the SBWQT as well as those monitored by others (government, private industry, academic establishments and NGOs).

In this 2012 State of the Bay report, available data on a variety of physical and biological parameters are presented, including activities and discharges affecting the health of the Bay (residential and industrial development, dredging, coastal erosion, shipping, and sewage and other waste waters), water quality in the Bay itself (temperature, oxygen, salinity, nutrients, and pH), sediment quality (particle size, heavy metal and hydrocarbon contaminants, particulate organic carbon and nitrogen) and ecological indicators (Chlorophyll a, aquatic macrophytes, benthic macrofauna, fish and birds). Where possible, trends and areas of concern are identified. Recommendations for future monitoring are made with a view to further improving the existing environmental monitoring program for the area.

Activities and Discharges Affecting the Bay

Human settlements surrounding Saldanha Bay and Langebaan Lagoon have expanded tremendously in recent years. This is brought home very strongly by population growth rates of over 9% per annum in Langebaan and nearly 7% in Saldanha over the period 2002 to 2004. This translates to a doubling in the population size every 8 years in the former case and every 10 years in the latter. Numbers of tourists visiting the area every year are increasing a similarly rapid rate. This rate of development translates into an equally rapid increase in the amount of waste that is produced and has to be dealt with. Major developments within the bay include the construction of the Marcus

Island causeway and the iron ore terminal, the establishment of a three small craft harbours, mariculture farms and several fish processing factories, while extensive industrial and residential development have become established around the periphery of the bay. Anthropogenic pollutants and wastes find their way into the bay from a range of activities and developments within the study area. These include dredging and port expansion, port activities, shipping, ballast water discharges and oil spills, municipal (sewage) and household discharges, discharge from fish processing factories, biological waste associated with mariculture and storm water runoff.

Coastal developments in Langebaan and Saldanha extend right to the waters edge. The lack of a development setback zone or coastal buffer places stress on the marine environment due to increased risk of erosion, trampling and habitat loss as well as allowing large volumes of storm water runoff to enter the bay and lagoon.

Several dredging events have occurred in Saldanha Bay to facilitate the development of the port, namely the construction of the Marcus Island Causeway (1973), General Maintenance Quay and Rock Quay (1974-1976), Multi-Purpose Terminal (1980) and the Small Craft Harbour (1984). The Multi-Purpose Terminal was extended in 1997/1998 which required further dredging. Maintenance dredging was performed at the Mossgas Terminal and the Multi-Purpose Terminal at the end of 2007. Additional dredging was conducted between Caisson 3 and 4 on the Saldanha side of Iron Ore Terminal in 2009/10 when 7 300 m^3 of material was removed from an area of approximately 3 000 m^2 in extent at the end of the causeway. Transnet has also proposed a Phase 2 expansion of the Iron Ore Terminal (Big Bay side) to increase its holding capacity, which would require extensive dredging and marine blasting. This proposal is currently on hold, pending improvements in the international iron ore market. Other development in and around the Bay include a reverse-osmosis desalination plant which has been constructed at the Iron Ore Terminal in Big Bay and the refurbishment and expansion of the small craft harbour at Salamander Bay in Langebaan Lagoon. Environmental Authorisation has recently been granted for a new LPG gas terminal in the bay, and the possibility of establishing an Industrial Development Zone along the north shore of the Bay and a regional desalination plant in Saldanha is also under consideration.

Human induced changes within Saldanha Bay (mostly changes in current circulation and wave activity) have also contributed to the erosion of Langebaan beach and Paradise beach. In order to mitigate this and to alter wave dynamics and reduce erosion, groynes have been constructed at the mouth of Langebaan Lagoon, which required dredging of marine sands. Dredging of the seabed has significantly altered sediment composition and had a devastating effect on the Saldanha Bay marine environment in the past, principally through the loss of benthic species. The impacts of dredging are mostly observed in the vicinity of the iron ore terminal and within Small Bay.

Storm water enters Saldanha Bay/Langebaan Lagoon via multiple storm water drains and tarred surfaces. Storm water is a major source of non-point pollutants to the bay and typically contains contaminants such as metals, bacteria, fertilizers (nutrients), hydrocarbons, plastics, pesticides and solvents. Increased volumes of storm water runoff (as a result of development) are associated with degradation of aquatic environments. Studies conducted by the CSIR indicate that the concentrations of several contaminants (nitrate, ammonia, metals and faecal coliforms) in Saldanha Bay storm water runoff are well above water quality guidelines.

Historically, two fish processing factories have discharged effluent into Small Bay, namely Southern Seas Fishing and Sea Harvest. The former ceased operations a few years ago but environmental authorisation has recently been issued that will allow the plant to reopen again. Sea Harvest discharges approximately 35 000 m^3 of effluent from their fresh fish processing effluent into Small Bay each month. This effluent contains significant quantities of organic material (suspended solids, ammonia and other nitrogenous compounds) which stimulate primary production (algal growth), consume oxygen, and can lead to deterioration in water quality in the Bay.

Saldanha Bay is the only natural sheltered embayment in South Africa and as a result it is regarded as the major area for mariculture. There are currently seven mariculture operators that farm mussels, oysters, and various other species in the bay. A total area of approximately 145 ha has been allocated to these operators. Historic studies as well as the State of the Bay surveys have shown that these culture operations can lead to organic enrichment and anoxia in sediments under the culture rafts and ropes. The source of the contamination is believed to be mainly faeces, decaying mussels and fouling species.

Ships entering the port of Saldanha take up and discharge large volumes of ballast water when offloading and loading cargo. Water from foreign ports is thus introduced to Saldanha Bay and presents risks such as the introduction of alien species and the release of water containing high concentrations of contaminants into the bay. Volumes of ballast water discharged are greatest at the iron ore terminal and have increased steadily from 1994 to 2012, aside from a slight dip in 2008. Historical measurements suggest that the mean concentrations of the trace metals (Cd, Cu, Zn, Pb and Cr) in ballast water discharged into Saldanha Bay exceed the South African water quality guidelines, indicating that ballast water discharge contributes significantly to metal contamination within the bay. Concentrations of trace metals in ballast water at present are unlikely to be as high as the historic data suggest, given the introduction of new ballast water management technique such as open ocean exchange, but this remains to be confirmed.

Water Quality

Aspects of water quality (temperature, salinity and dissolved oxygen, nutrients and chlorophyll concentrations) are often measured in an attempt to understand the origin of a body of sea water and the impacts it has on the physical and biological processes in the environment. Investigation of the available long-term data sets of temperature, salinity and dissolved oxygen suggest no evidence of long-term trends (neither increases nor decreases) in these parameters that can solely be attributed to anthropogenic factors. Natural, regional oceanographic processes appear to be the dominant processes driving the variation in water temperature, salinity, dissolved oxygen, nutrients and chlorophyll concentrations observed in Saldanha Bay. However, there is clear evidence of altered current strengths, circulation patterns and wave energy within the Bay which are ascribed to the construction of the ore terminal and causeway. The water entering Small Bay appears to remain within the confines of the Bay for longer periods than was historically the case. There is also an enhanced clockwise circulation and increased current strength flowing alongside unnatural obstacles (i.e. enhanced boundary flow, for example alongside the ore terminal). The wave exposure patterns in Small Bay and Big Bay have also been altered as a result of harbour developments in Saldanha Bay. The extent of sheltered and semi-sheltered areas has increased particularly in Small Bay, but also in Big Bay.

Regular monitoring of microbiological indicators at 20 stations in the Bay (10 in Small Bay, 5 in Big Bay and 5 in Langebaan Lagoon) was initiated by the SBWQT in 1999 and was later taken over by the Saldanha Bay Municipality. These data are compared with recommended guideline levels published by the Department of Water Affairs for recreational use and mariculture as well as more recent guidelines published by the Department of Environmental Affairs for recreational use. In the earlier parts of this record (1999-2005), coastal waters in Small Bay had faecal coliform counts well in excess of safety guidelines for both mariculture and recreational use. There have, however, been noticeable improvements in water quality in Small bay since 2006 in terms of recreational use. However, faecal coliform counts still exceed guideline levels for recreational use in some parts of Small Bay (mostly around the Bok river outfall and Hoedjiesbaai) and are well in excess of guideline limits for mariculture over a much wider area. The highest faecal coliform counts are routinely recorded at the beach sewage outlet (Bok River) and in Hoedjiesbaai and Pepper Bay. Faecal coliform and *E. coli* counts are lower in Big Bay and Langebaan Lagoon when compared to Small Bay, but several sites (Paradise Beach, Seafarm at TNPA and Mykonos Harbour) still suffer from bacterial contamination and (more concerningly) appear to be getting worse. In terms of the updated guidelines governing recreational use of coastal waters published by DEA, several sites in Small Bay (Bok River Mouth, Caravan Park and Hoedjiesbaai) were classified as "Poor" (or "Unacceptable"), one (Leentjiesklip) as "Fair" (or "Acceptable"), two (both in Pepper Bay) as "Good", and the remainder as "Excellent".

Considering the likely growth of mariculture and tourism industries in Saldanha Bay, it is imperative that further steps be taken to curb this source of pollution into the bay. Waste water from the Langebaan Waste Water Treatment Works has historically been used to water the golf course with little or none of this being discharged to sea. However, the supply of treated wastewater from Langebaan Lagoon now outstrips the irrigation requirements, and a considerable volume of the water from this plant now makes its way into the bay. This is obviously set to increase dramatically in future as development in this area continues to expand apace. Further improvements to storm water and sewerage management methods are urgently required in the whole of the Saldanha-Langebaan area. It is imperative that monitoring of bacterial contaminants in the bay and lagoon continue into the future and that serious consideration be given to further expanding and upgrade the sewage and storm water treatment facilities in these areas.

Concentrations of trace metals in marine organisms (mostly mussels) in Saldanha Bay have historically been monitored on a routine basis by the Department of Environmental Affairs (DEA) and by the mariculture farm owners. The DEA Mussel Watch Programme records concentrations of cadmium, copper, lead, zinc, iron and manganese present in the flesh of mussels at several sites along the shoreline of the Bay. Data from the DEA Mussel Watch Programme show that concentrations of lead in mussels at the monitored sites were consistently are above guideline limits for foodstuffs for as long as these data have been collected (1997-2007), while concentrations of cadmium frequently exceed these limits, and those for zinc did so occasionally. Concentrations of copper were, however, well below specified levels. No clear trends over time are evident for any of the trace metals, although recent data (post 2007) are lacking. High concentrations of trace metals along the shore is very clearly of concern and points to the need for management intervention that can address this issue as it poses a very clear risk to the health of people harvesting mussels from the shore. It is vitally important that this monitoring continue in the future and that data are made available to the public for their own safety. Sampling for the Mussel Watch programme will reportedly resume in 2013 but additional samples will also be collected and analysed as part of the State of the Bay monitoring activities in case this does not happen.

Data on trace metals concentrations in shellfish from the mariculture farms in the Bay were also obtained from DAFF (courtesy of the farm operators). These results show that trace metal concentrations away from the shore are much lower than those in nearshore water and mostly meet guidelines for foodstuffs for human consumption. The reasons for the lower concentrations of trace metals in farmed mussels compared with those on the shore may be linked with higher growth rates for the farmed mussels, and the fact that the cultured mussels are feeding on phytoplankton blooms in freshly upwelled water that has only recently been advected into the Bay from outside and is thus relatively uncontaminated.

Sediments: Shore line erosion

Shoreline erosion in Saldanha Bay, particularly around Langebaan Village, has been the subject of much controversy in recent years. Ongoing erosion for the past 30 years has been documented, with the loss of over 100 m of beach in some areas since 1960 and up to 40 m of shoreline lost in places in just the last 5 years. The cause of the erosion is the subject of much debate, some attributing this to port-associated developments and others to stabilisation of mobile dune fields and/or global change. Whatever the case, residential or holiday developments have been built in very close proximity to the shore along much of the coastline in the Bay and are now or soon will be threatened by retreating shorelines. A range of erosion protection measures have been introduced in recent years including the installation of a temporary rock revetments, groynes and gabion walls, with more to following. Recognising though that these measures are probably not the best way to deal with the problem, and that these problems of this nature are also likely to get worse in future in the face of global change (rising sea levels being particularly pertinent in this respect), legislation has been promulgated that requires development setback lines to be established along the whole South African coast. Approaches to establishing setback lines are currently being developed and tested in key sites around the country including Saldanha Bay.

Sediment quality

The distribution of mud, sand and gravel within Saldanha Bay is influenced by wave action, currents and mechanical disturbance (e.g. dredging). Under natural circumstances, the prevailing high wave energy and strong currents would tend to flush fine sediment and mud particles out the bay, leaving behind the heavier, coarser sand and gravel. Obstructions to current flow and wave energy can result in increased deposition of finer sediment (mud). Large-scale disturbances (e.g. dredging) of sediments re-suspends fine particles that were buried beneath the sand and gravel. Contaminants (trace metals and toxic pollutants) are largely associated with the mud component of the sediment and can have a negative impact on the environment. Accumulation of organic matter in benthic sediments can also give rise to problems as it depletes oxygen both in the sediments and surrounding water column as it decomposes. Historically, it was reported that the proportion of mud in the sediments of Saldanha Bay was very low, to the extent that it was considered negligible. Reduced water circulation in the bay and dredging activities has resulted in an overall increase in the mud fraction in sediments in the bay. The most significant increases in mud content in the surface sediments has been observed following dredging events, however, over several years, a significant proportion of the mud has either been flushed out or re-buried beneath sand and gravel, and the sediment composition has returned to one mostly dominated by sand and gravel. Data collected as part of the State of the Bay surveys since 1999 has shown a progressive decline in the amount of fine sediment (mud) at most sites in the Bay. This trend changed, however, with most sites exhibiting an abrupt (and somewhat concerning) increase in the amount of mud present in 2012. Areas most significant affected in this way are all located in the vicinity of (and surrounding) the ore terminal.

Particulate organic carbon (POC) and nitrogen (PON) are present at elevated levels in the sediments in certain areas of the bay, notably near the Yacht Club Basin and the Mussel Farm. It is considered most likely that the origin of the POC and PON is associated with waste discharge from the fish factories and faecal waste from the mussel rafts. Accumulation of organic waste, especially in sheltered areas where there is limited water flushing, can lead to anoxic conditions and negatively impact on the marine environment as has been seen from the species composition and abundance of the benthic communities inhabiting the sediments in the affected areas. Data collected between 1999 and 2011 mostly indicate a trend of declining levels of PON and POC, one that has unfortunately been abruptly reversed at many sites in 2012.

Contaminants (metals and toxic pollutants) are commonly associated with fine sediments and mud. In areas of the bay where fine sediments tend to accumulate, these contaminants sometimes exceed acceptable threshold levels. This is believed to be due either to naturally-occurring high levels of the contaminants in the environment (e.g. in the case of cadmium) or due to impacts of human activities (e.g. lead, copper and nickel associated with ore exports). While such trace metals are generally biologically inactive when buried in the sediment, they can become toxic to the environment when re-suspended as a result of mechanical disturbance. On average, the concentrations of all metals were highest in Small Bay, lower in Big Bay and below detection limits in Langebaan lagoon. Following the major dredging event in 1999, cadmium concentrations in certain areas in Small Bay exceeded internationally accepted safety levels, while concentrations of other trace metals (e.g. lead, copper and nickel) approached threshold levels. Subsequent to this time, there have been a number of smaller spikes in trace metal levels, mostly as a result of dredging operations. For example, trace metals in the entrance to Langebaan Lagoon were significantly elevated in 2011 following dredging operations that were conducted as part of the expansion of the Naval Boat Yard in Salamander Bay. Currently, trace metal levels are mostly well within safety thresholds but had increased slightly at a number sites in the Bay in 2012, which is consistent with the recent increase in the proportion of fine sediment (mud) at the same sites. Key areas of concern regarding heavy metal pollution within Small Bay include the Yacht Club basin and the multipurpose terminal where levels of cadmium, copper and lead are still in excess of internationally-accepted guidelines. Regular monitoring of trace metal concentrations is strongly recommended to provide an early warning of any future increases.

Hydrocarbons measured in the sediments of Saldanha Bay in 1999 were reported to be very low and not considered an environmental risk. No poly-cyclic, poly-nuclear compounds or pesticides were detected in sediments of Saldanha Bay. Sediment samples from the vicinity of the ore terminal were collected and tested for hydrocarbon contamination again in 2010, 2011 and 2012. The data from 2010 and 2011 indicated no cause for concern but the most recent (2012) data suggest that there has been a sudden increase in hydrocarbon levels to the extent that levels at all the sampling sites surrounding the ore terminal exceed precautionary threshold levels. It should be noted though that while the 2011 and 2012 samples were all analysed by the same laboratory, refinement in terms of the techniques used has led to a reduction in detection levels and this may account for the sudden change. Irrespective of what the cause is, if this is a real result then there is cause for concern and the monitoring coverage should be expanded in an effort to nail down the source of this contamination.

Aquatic macrophytes (eelgrass and saltmarshes)

Three distinct intertidal habitats exist within Langebaan Lagoon: seagrass beds, such as those of the eelgrass *Zostera capensis* (a type of seagrass)*;* saltmarsh dominated by cordgrass *Spartina maritime* and *Sarcocornia perennis*; and unvegetated sandflats dominated by the sand prawn, *Callianassa krausii* and the mudprawn *Upogebia capensis.* Eelgrass and saltmarsh beds are extremely important as they increase habitat diversity in the lagoon, provide important an food source, increase sediment stability, provide protection to juvenile fish and invertebrates from natural predators and generally support higher species richness, diversity, abundance and biomass of invertebrate fauna compared to unvegetated areas. Eelgrass and saltmarsh beds are also important for waterbirds which feed directly on the shoots and rhizomes, forage amongst the leaves or use them as roosting areas at high tide. Recent studies show that the aerial extent of seagrass beds in Langebaan Lagoon has declined by an estimated 38% since the 1960s, this being more dramatic in some areas than others (e.g. seagrass beds at Klein Oesterwal have declined by almost 99% over this period). Corresponding changes have been observed in densities of benthic macrofauna. At sites where eelgrass cover has declined, species commonly associated with eelgrass have declined in abundance, while those that burrow predominantly in unvegetated sand have increased in density. Fluctuations in the abundance of wading birds such as Terek Sandpiper, which feeds exclusively in Zostera beds have also been linked to changes in eelgrass, with population crashes in this species coinciding with periods of lowest seagrass. The loss of eelgrass beds from Langebaan Lagoon is a strong indicator that the ecosystem is undergoing a shift, most likely due to anthropogenic disturbances. It is critical that this habitat and the communities associated with it be monitored in future as further reductions are certain to have long term implications, not only for the invertebrate fauna but also for species of higher trophic levels.

In contrast, little change has been reported in the extent of saltmarshes in Langebaan Lagoon, these having declined by no more than 8% since the 1960s.

Benthic macrofauna

Soft-bottom benthic macrofauna (animals living in the sediment that are larger than 1 mm) are frequently used as a measure to detect changes in the health of the marine environment resulting from anthropogenic impacts. Measures of the numbers, abundance and biomass of species making up the benthic community from studies conducted prior to development of Saldanha Bay are compared to data from recent surveys (1999, 2005, 2008, 2009, 2010, 2011 and 2012). Prior to this period (i.e. prior to the advent of many of the major changes in the Bay) benthic macrofauna surveys of the area were conducted using slightly different methods to those of more recent studies. Nevertheless, taking these differences into consideration, it is evident that there have been significant changes in benthic communities within the Bay. The most dramatic changes are those in the overall abundance, biomass and composition of the fauna in the various section of the Bay (Small Bay, Big Bay and Langebaan Lagoon). Importantly, trends in overall abundance and biomass in the respective sections of the Bay have tracked one another very closely since 1999.

Starting off at modest levels in 1999, both abundance and biomass shot up to fairly high levels in all three sections of the Bay in 2004 before dropping down to low levels again in 2008 (regrettably no data are available to show what happened in the intervening years between 1999 and 2004 and between 2004 and 2008). Thereafter both overall abundance and biomass in all part of the Bay increased steadily year-on-year until 2011, before dropping down dramatically again in 2012 (the most recent survey).

Changes in community composition (both in terms of the contribution by different taxonomic groups and different feeding groups) have also been very similar across the three areas of the Bay with the most dramatic changes being associated with the relative contribution made by filterfeeders and Crustaceans (mudprawns, sandprawns, amphipods and isopods). Filterfeeding species are typically more sensitive to changes in water quality than detritivores or scavengers and account for much of the variation in overall abundance and biomass in the Bay. When overall abundance and biomass are low, the communities tend to be dominated by detritivores, but when they are high, they tend to be dominated by filter feeders.

The sea pen *Virgularia schultzei,* a species highly sensitive to disturbance and pollution, recorded throughout the Bay in the earliest surveys conducted in the 1970's, was not present in the earliest State of the Bay surveys (2004 and 2008) but has been recorded again in increasing numbers Big Bay since this time, suggesting an improvement in the health of the benthic community in this part of the Bay at least. Some, but not all of these changes appear to be linked to large-scale dredging events in the Bay. For example, the overall low species richness, abundance and biomass recorded in 1999, following a major dredging event in 1997/8 (extension of the Multi-Purpose Terminal), appeared to have increased by 2004 following a period of minimal disturbance, declined again to a low level in 2008 following further dredging around the MPT and Mossgass Quay, increased steadily again until crashing again spectacularly in 2012 following some fairly modest dredging activities around Caisson 3 and 4 on the Saldanha side of the Iron Ore Terminal in 2010/11.

Overall, conditions in Small Bay remain very much poorer than those in Big Bay or Langebaan Lagoon. The most severely-impacted sites within Small Bay in 2011 are the Yacht Club basin and the base of the ore terminal. These sites are prone to the accumulation of pollutants due to restricted water movement. At one point (2008) benthic fauna have been almost entirely eliminated from the Yacht Club basin in Small Bay, owing to very high levels of trace metals and other contaminants at this site (POC, Cu, Cd and Ni). Benthic macrofauna communities in this area have, however, recovered steadily year-on-year since this time and are now almost on a par with the other sites in Small Bay.

Impacts of the dredging activities in Salamander Bay for the expansions of the Naval Boatyard in this area (2010) were also clearly evident in the data from these sites for several years following this development but have now finally returned to more natural levels.

Rocky intertidal

As a component of this State of the Bay evaluation, baseline conditions relating to rocky intertidal biota present at eight sites in Saldanha Bay were first surveyed in 2005 and have been resurveyed annually since 2008. In the latest (2012) survey a total of 79 taxa were recorded from the eight study sites, most of which had also been found in the previous surveys. The faunal component was represented by 19 species/taxa of filter-feeders, 15 grazers, 6 anemones, 5 predators and scavengers, and 3 trappers. The algal component comprised 19 corticated (foliose) seaweeds, 6 ephemerals, 4 crustose (or encrusting) and 1 articulated coralline, and 1 kelp species. These species are common along much of the South African West Coast and many have been recorded by other studies conducted in the Saldanha Bay area. This includes the two alien invasive species, the Mediterranean mussel *Mytilus galloprovincialis* and the North American acorn barnacle *Balanus glandula*, both of which are present in very high numbers

The most important factor responsible for community differences among sites remains exposure to wave action and to a lesser extent shoreline topography (boulder shores being different to large rocky platforms). Within a site, the vertical emersion gradient of increasing exposure to air leads to a clear zonation of flora and fauna from low shore to high shore. Species composition and abundance has remained similar between years and any differences that were evident are considered most likely to be natural seasonal and inter-annual phenomena, rather than anthropogenically-driven changes. The only exception to this is the alien barnacle *Balanus glandula*, which was not recorded in the 2005 baseline survey, when it was most likely misidentified as the native barnacle *Chthamalus dentatus*. The alien barnacle typically dominates the mid-shores of semi-exposed sites. Its presence in South Africa has only recently been detected, but there is a suspicion that it may in fact have been present in South Africa since 1992.

A second alien barnacle species *Menesiniella regalis* was also positively identified from one of the sites in the Bay (the Dive School site in Small Bay) for the first time this year. This species originates from the Pacific coast of North America, and is most likely a new record for South Africa. Its route of introduction is not clear but likely to be the same as for most other alien species (ballast water or hull fouling). Aliens are considered to represent one of the greatest threats to rocky shore communities in Saldanha Bay, owing to their potential to become invasive thereby displacing naturally occurring indigenous species.

Fish

The current status of fish and fisheries within Saldanha Bay and Langebaan Lagoon appear to be satisfactory. Long-term monitoring by means of experimental seine-netting has revealed no statistically significant, negative trends since fish sampling began in 1986-87. If anything, abundance of key fish species at sites within or in close proximity to the Langebaan Marine Protected Area over the long term appear to be increasing which is very encouraging. Certainly, work by Kerwath *et al*. (2009) clearly demonstrated the benefits of the MPA for white stumpnose, and the protection of harders from net fishing in the MPA undoubtedly benefits this stock in the larger Bay area.

Over the shorter term, however, there are some indications that recruitment of key species such as harders, white stumpnose, gobies and silversides were lower than average in 2012. This was particularly clear in Small Bay, where the lowest harder and goby density recorded to date yet was reported. This follows the trend observed in the 2010 and 2011 reports and may be linked to high levels disturbance in this part of the Bay. This is disturbing, as Small Bay has always been disproportionately important as nursery site for the more important recreational and commercially caught fish in the Bay. The average white stumpnose density calculated from all seine net surveys to date, for example, is 0.7 fish.m^{-2} in Small Bay, compared with 0.1 fish.m^{-2} in Big Bay and 0.07 fish.m^{-2} in Langebaan lagoon. Small Bay is often viewed as the more developed or industrialised portion of the Bay and is considered by many as a 'lost cause'. These data provide a strong argument to stamp out such negative thinking and to continue lobbying strongly for enhanced protection of this portion of the Bay.

Birds

Saldanha Bay, Langebaan Lagoon and the associated islands provide important shelter, feeding and breeding habitat for at least 53 species of seabirds, 11 of which are known to breed on the islands. The islands of Malgas, Marcus, Jutten, Schaapen and Vondeling support breeding populations of African Penguin (a red data species), Cape Gannet, four species of marine cormorants, Kelp and Hartlaub's Gulls, and Swift Terns. The islands also support important populations of the rare and endemic African Black Oystercatcher. Saldanha Bay and its islands support substantial proportions of the total populations of several of these species.

There has been an overall decrease in the breeding population of African Penguin at all four islands in the Bay (Malgas, Marcus, Jutten and Vondeling). This decrease in numbers has been attributed to migration to other islands (Robben and Dassen Islands) and a reduced availability of anchovy, which is the primary food source for these birds. The population in Saldanha Bay has decreased from 2049 breeding pairs in 1987 to 518 breeding pairs in 2012, representing a 75% decrease in 25 years. This reduction in numbers is consistent with the overall downward trend evident since 2002 and strongly reinforces the argument that immediate conservation action is required to prevent further losses of these birds.

Populations of Kelp Gull have showed steady year-on-year increases in the Saldanha Bay region until 2000, most likely due to the increase in availability of food as a result of the introduction and spread of the invasive alien mussel *Mytilus galloprovincialis.* Since 2000, however, populations on the islands have been steadily decreasing, following large-scale predation by Great White Pelicans *Pelecanus onocrotalus* that was first observed in the mid-1990s. During 2005 and 2006, pelicans caused a total breeding failure of Kelp Gulls at Jutten and Schaapen Islands, the effects of which are still apparent in 2011. Regrettably no new data are available for 2012.

Hartlaub's Gull and Swift Tern populations vary erratically, with numbers fluctuating widely each year. Numbers of Hartlaubs gulls have been very low in recent years but a resurgence in the numbers of breeding pairs on Schaapen, Malgas and Meeu Islands in 2012 hopefully represents a reversal of this trend. Similarly, Swift terns bred in numbers on several of the islands in Saldanha Bay in 2012, after being completely absent for several years.

Populations of Cape Gannets and Cape Cormorants also vary each year. Cape Gannets on the West Coast have been declining since the start of an eastward shift of pelagic fish stocks in the late 1990's. This is, to some extent, compensated for by an increase in the numbers of breeding birds on the east coast (Bird Island). Recent increases in predation by Cape fur seals *Arctocephalus pusillus* and the Great White Pelican are also of concern, having been responsible for a 25% reduction in the size of the colony at Malgas Island between 2001 and 2006, with no evidence of improvement since then. No clear trends are discernable in populations of Cape Cormorants in the bay in recent years.

Bank Cormorant numbers in Saldanha Bay declined between 1990 and 2007 from more than 250 breeding pairs to fewer than 50. Numbers have since increased slightly to just under 60 breeding pairs in recent years and appear to have stabilised at this level for the moment.

Overall numbers of White-Breasted Cormorants in Saldanha Bay have been relatively constant since detailed records started in 1991, but breeding populations have shifted between islands in the bay, mostly from Meeuw to Schaapen and back to Meeuw again. Overall numbers in the bay have increased in the last two years, but it is not clear whether this trend will be sustained in the long term.

The islands in Saldanha Bay support an important number of African Black Oystercatchers. They are most numerous on Marcus, Malgas and Jutten Islands, where their populations currently stand at 126 and 168 birds, respectively. In the last 35 years (since 1980) the population has grown by 100 breeding pairs on the three main breeding islands in Saldanha Bay most likely due to the introduction and proliferation of the alien mussel *Mytilus galloprovincialis,* which is a major food item for this species. Population growth appears to have slowed in the recent years, most likely due to the fact that the new carrying capacity of the islands has now been reached.

Langebaan Lagoon and its associated warm, sheltered waters and abundance of prey, provides an important habitat for migrant waterbirds, specifically from the Palaearctic region of Eurasia. As many as 98% of the waterbirds present in the lagoon during summer months are migrant species, with an average of only 2% being resident during the remainder of the year. Langebaan Lagoon has been identified as the most important wetlands for waders on the west coast of southern Africa. Annual counts of the numbers of waders over the period 1975 to 1980 showed stable summer populations, but large variations in the number of migrants that remained over winter. Since 1980, there has been a dramatic downward trend in the numbers of Palaearctic waders at the lagoon, which is at least in part attributed to population declines as a result of disturbances to their breeding grounds. However, there has also been a dramatic decline in numbers of resident waders, which indicates that disturbances at the lagoon, such as habitat changes and human disturbance, are also significant. Regrettably it has not been possible to obtain data on waterbirds numbers in the lagoon for 2012 even though such data have reportedly been collected. It is highly recommended that the status of key species continue to be monitored in future and that these data be made available and used as an indication of environmental conditions in the area.

Introduced species

To date, an estimated 85 marine species have been recorded as introduced to South African waters, mostly though shipping activities or mariculture. At least 62 of these are thought to occur in Saldanha Bay-Langebaan Lagoon. Many of these are considered invasive, including the Mediterranean mussel, the European green crab *Carcinus maenas* and the recently-detected barnacle *Balanus glandula*. An additional twenty five species are currently regarded as cryptogenic (of unknown origin – i.e. potentially introduced) but very likely introduced. Most of the introduced species in this country have been found in sheltered areas such as harbours, and are believed to have been introduced through shipping activities, mostly ballast water. Because ballast water tends to be loaded in sheltered harbours the species that are transported originate from these habitats and have a difficult time adapting to South Africa's exposed coast. The status of some of the more common alien species in the bay are presented in the main body of the report along with trends in their distribution and abundance where these data are available (either from the State of the Bay surveys or other data sets).

Noteworthy observations that have emerged from the 2012 State of the Bay surveys is the fact that populations of the Western Pea crab *Pinnixa occidentalis,* first detected in the Bay in 2004, seem to have stabilised. The preferred range of this species in its native waters on the Pacific coast of the USA is waters deeper than 10 m. While this species made a brief incursion into Langebaan Lagoon in 2009, it is now restricted to and fully occupies the deeper waters in Big Bay and Small Bay. It is suspected though that the population may have expanded outside of the bay beyond the range of sampling that has been undertaken for this project.

Populations of the Mediterranean mussel *Mytilus galloprovincialis* and acorn barnacle Ba*lanus glandula* (which originate from European waters the Pacific coast of North America, respectively) are by far the most dominant animal species on rocky shores in the Bay. Populations of *Mytilus* appear to be growing rapidly having increased from an average of 3.0-5.4% cover in 2008/9 to around 7.8-11.1% in 2011/12, while populations of Balanus seems to be declining now, after peak in 2009. Abundance (% cover) of this species has declined from a peak of around 7.5% in 2009 to around 3.4% in 2012. Indications from studies conducted elsewhere (and indeed from the State of the Bay surveys) suggest that these two species competes directly with one another for space on the shore, and that expanding populations of *Mytilus* may be displacing those of *Balanus*.

A new alien barnacle species has also just now been identified as having been introduced to the Bay. This species, *Menesiniella regalis*, is known only by its scientific name and was first recognised as being "different" in in 2011. This species has now been formally identified and its presence is seems to be restricted to the rocky intertidal site known as Jetty in Small Bay. This species originates from the Pacific coast of North America and looks superficially very similar to the local volcano barnacle, *Tetraclita serrate*. It is considered likely that the introduction of this species occurred via shipping given the high amount of shipping traffic in Saldanha Bay much like the alien acorn barnacle, *Balanus glandula*, which also originates from the Pacific coast of North America. Changes in the population of this species in Saldanha Bay will be carefully monitored in future to see what impacts it will have on the local fauna.

Summary

In summary, developments in Saldanha Bay and Langebaan Lagoon during the past thirty years have inevitably impacted on the environment. Most parameters investigated in this study suggest some degree of negative impact occurring. Decreasing populations of birds in the bay area are of major concern. These may well be a reflection of changes in the abundance of fish, benthic macrofauna, and sediment and water quality, and also increasing levels of disturbance. Negative environmental conditions imposed on the water quality or sediments, will, in time, negatively impact on the top predators (birds and fish) of the system. A holistic approach in monitoring and assessing the overall health status of the Bay is essential, and regular (in some cases increased) monitoring of all parameters reported on here is strongly recommended.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

Alien species	An introduced species that has become naturalized.
Articulated coralline algae	Articulated corallines are branching, tree-like plants which are attached to the substratum by crustose or calcified, root-like holdfasts.
Biodiversity	The variability among living organisms from all terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems.
Biota	All the plant and animal life of a particular region.
Community structure	Taxonomic and quantitative attributes of a community of plants and animals inhabiting a particular habitat, including species richness and relative abundance structurally and functionally.
Coralline algae	Coralline algae are red algae in the Family Corallinaceae of the order Corallinales characterized by a thallus that is hard as a result of calcareous deposits contained within the cell walls.
Corticated algae	An alga that has a secondarily formed outer cellular covering over part or all of an algal thallus. Usually relatively large and long-lived.
Crustose coralline algae	Crustose corallines are typically slow growing crusts of varying thickness that can occur on rock, shells, or other algae.
Ephemeral algae	Opportunistic algae with a short life cycle that are usually the first settlers on a rocky shore.
Fauna	General term for all of the animals found in a particular location.
Flora	General term for all of the plant life found in a particular location.
Foliose algae	Leaf-like, broad and flat; having the texture or shape of a leaf.
Filter-feeders	Animals that feed by straining suspended matter and food particles from water.
Functional group	A collection of organisms of specific morphological, physiological, and/or behavioral properties.
Grazer	An herbivore that feeds on plants/algae by abrasion from the surface.
Indigenous	Native to the country not introduced.
Intertidal	The shore area between the high- and the low-tide levels.
Invertebrate	Animals that do not have a backbone. Invertebrates either have an exoskeleton (e.g. crabs) or no skeleton at all (worms).
Kelp	A member of the order Laminariales, the more massive brown algae.
Opportunistic	Capable of rapidly occupying newly available space.
Rocky shore community	A group of interdependent organisms inhabiting the same rocky shore region and interacting with each other.
Scavenger	An animals that eats already dead or decaying animals.
Shore height zone	Zone on the intertidal shore recognizable by its community.
Thallus	General form of an alga that, unlike a plant, is not differentiated into stems, roots, or leaves.
Topography	The relief features or surface configuration of an area.
Trappers	Limpets that trap kelp fronds beneath their shells.

1 INTRODUCTION

1.1 Background

Saldanha Bay is situated on the west coast of South Africa, approximately 100 km north of Cape Town and is directly linked to the shallow, tidal Langebaan Lagoon. The Bay and Lagoon are considered to be one of the biodiversity "hot spots" in the country and an area of exceptional beauty.

A number of marine protected areas have been proclaimed in and around the Bay, while Langebaan Lagoon and much of the surrounding land falls within the West Coast National Park (Figure 1.1). Langebaan Lagoon was also declared a Ramsar Site in 1988, along with a series of islands within Saldanha Bay (Schaapen, Marcus, Malgas and Jutten).

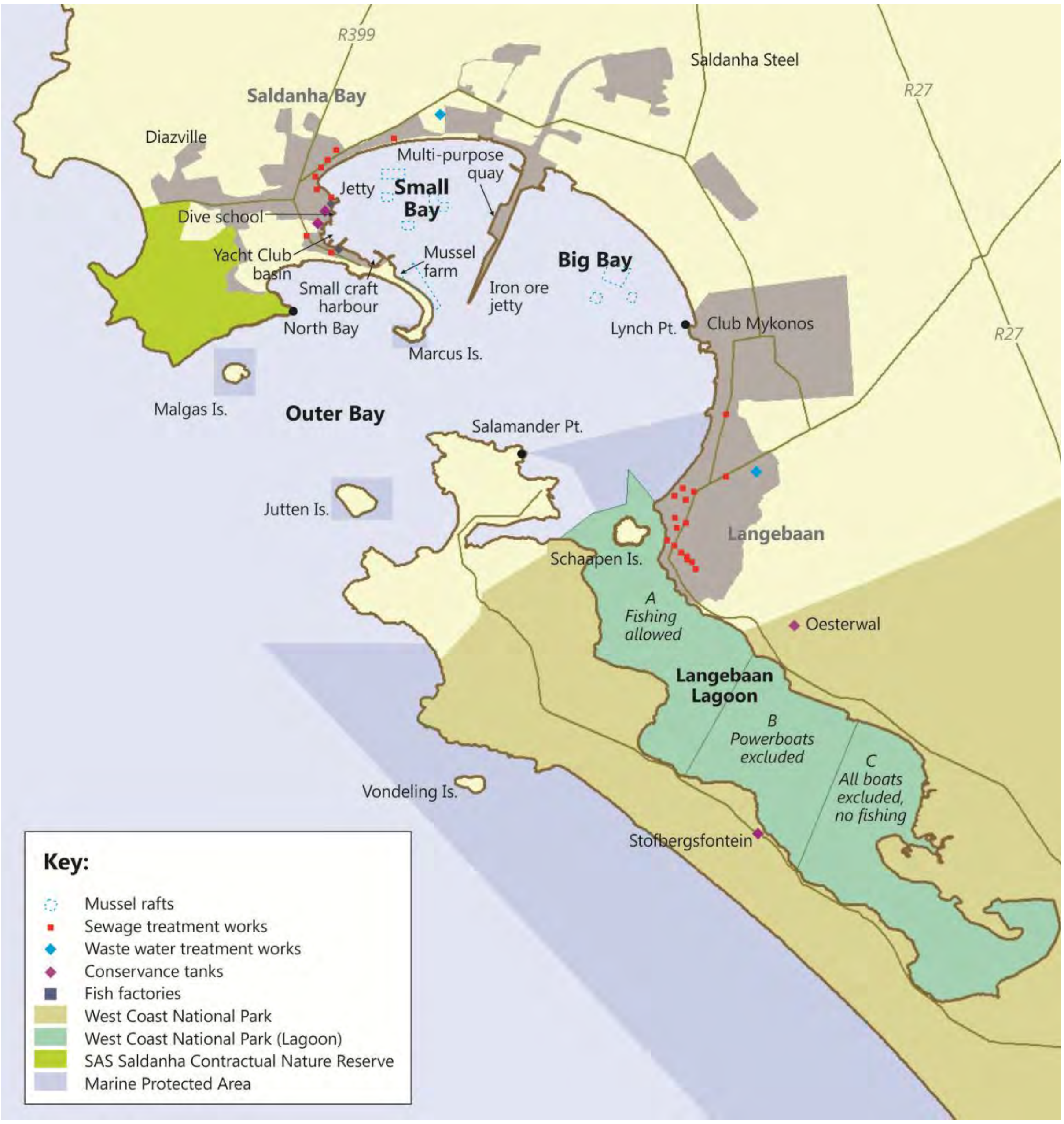


Figure 1.1. Regional map of Saldanha Bay and Langebaan Lagoon showing development (grey shading) and conservation areas.

In spite of these noteworthy successes, the history of the area has been one that is also tainted with overexploitation and abuse, the environment generally being the loser in both instances.

Saldanha Bay and Langebaan Lagoon have long been the focus of scientific study and interest largely owing to the conservation importance and its many unique features. A symposium on research in the natural sciences of Saldanha Bay and Langebaan Lagoon was hosted by the Royal Society of South Africa in 1976 in an attempt to draw together information from the various research studies that had been and were being conducted in the area. The symposium served to focus the attention of scientific researchers from a wide range of disciplines on the Bay and resulted in the development of a large body of data and information on the status of the Bay and Lagoon at a time prior to any major developments in the Bay.

More recently (in 1996), the Saldanha Bay Water Quality Forum Trust (SBWQFT), a voluntary organization representing various organs of State, local industry and other relevant stakeholders and interest groups, was inaugurated with the aim of promoting an integrated approach to the management, conservation and development of the waters of Saldanha Bay and the Langebaan Lagoon, and the land areas adjacent to, and influencing it. Since its inauguration the SBWQFT has played an important role in guiding and influencing management of the Bay and in commissioning scientific research aimed at supporting informed decision making and sustainable management of the Saldanha Bay/Langebaan Lagoon ecosystem. Monitoring of a number of important ecosystem indicators was initiated by the SBWQFT in 1999 including water quality (faecal coliform, temperature, oxygen and pH), sediment quality (trace metals, hydrocarbons, particulate organic carbon and nitrogen) and benthic macrofauna. The range of parameters monitored has since increased to include surf zone fish and rocky intertidal macrofauna (both initiated in 2005) and has culminated in the commissioning of a "State of the Bay" report series that has been produced annually since 2008.

The first State of the Bay report was produced in 2006 by Anchor Environmental and served to draw together all available information on the health status and trends in a wide range of parameters that provide insights into the health of the Saldanha Bay/Langebaan Lagoon ecosystem. The 2006 report incorporated information on trends in a full range of physico-chemical indicators including water quality (temperature, oxygen, salinity, nutrients, and pH), sediment quality (particle size, heavy metal and hydrocarbon contaminants, particulate organic carbon and nitrogen) and ecological indicators (chlorophyll a, benthic macrofauna, fish and birds). This information was drawn from work commissioned by the SBWQFT as well as a range of other scientific monitoring programmes and studies. The 2006 report was presented in two formats – one data rich form that was designed to provide detailed technical information in trends in each of the monitored parameters and the second in an easy to read form that was accessible to all stakeholders.

The success of the first State of the Bay report and the ever increasing pace of development in and around the Saldanha Bay encouraged the SBWQFT to produce the second Sate of the Bay report in 2008, and annually since this time. This (2012) report is the 56th in the series and provides an update on the health of all monitored parameters in Saldanha Bay and Langebaan Lagoon in the time since the last State of the Bay assessment (2011), and includes information on trends in all of the parameters reported on in the previous reports (2006, 2008, 2009, 2010 and 2011). It also incorporates a number of additional indicators not previously covered by the State of the Bay reports (focussing mostly on activities and discharges that affect the health of the system). Readers that are familiar with the State of the Bay report series are encouraged to consult Section 1.3 of this report which highlights new and updated information that has been included in this edition.

1.2 Structure of this report

This report draws together all available information on water quality and aquatic ecosystem health of Saldanha Bay and Langebaan Lagoon, and on activities and discharges affecting the health of the Bay. The emphasis has been on using data from as wide a range of parameters as possible that are comparable in both space and time and cover extended periods which provide a good reflection of the long term environmental health in the Bay as well as recent changes in the health status of the system. The report is composed of twelve chapters each of which addresses different aspects of the health of the system.

Chapter One introduces the State of the Bay Reporting programme and explains the origin of and rationale for the programme, and provides the report outline.

Chapter Two provides background information to anthropogenic impacts on the environment and the range of different approaches to monitoring these impacts, which captures the differences in the nature and temporal and spatial scale of these impacts.

Chapter Three provides a summary of available information on historic and ongoing activities, discharges and other anthropogenic impacts to the Bay that are likely to have had or are having some impact on environmental health.

Chapter Four summarises available information on water quality parameters that have historically been monitored in the Bay and Lagoon and reflects on what can be deduced from these parameters regarding the health of the Bay.

Chapter Five summarises available information on sediment monitoring that has been conducted in Saldanha Bay and Langebaan Lagoon with further interpretation of the implication of the changing sediment composition over time and/or related to dredging events.

Chapter Six summarises available information on long-term trends in aquatic macrophytes (seagrasses and salt marshes) in Langebaan Lagoon

Chapter Seven presents data on changes in benthic macrofauna in Saldanha Bay and Langebaan Lagoon from the 1970's to the present day

Chapter Eight addresses changes that have occurred in the rocky intertidal zones in and around Saldanha Bay over the past 20 years and presents results from a rocky intertidal monitoring survey initiated in 2005.

Chapter Nine summarises all available information on the fish community and composition in the Bay and Lagoon, as deduced from both seine and gill net surveys, and presents results from a surf zone fish monitoring survey initiated in 2005.

Chapter Ten provides detailed information on the status of key bird species utilising the offshore islands around Saldanha Bay and both resident and migrant waders utilising the feeding grounds in Langebaan Lagoon as well as providing an indication of the national importance of the area for birds.

Chapter Eleven summarise available information of marine alien species known to be present in Saldanha Bay and Langebaan Lagoon as well as trends in their distribution and abundance.

Chapter Twelve provides a tabulated summary of the key changes detected in each parameter covered in this report and assigns a health status rank to each. This chapter also provides recommendations for future environmental monitoring for the Bay and of management measures that ought to be adopted in the future.

1.3 What's new in the 2012 Edition of the State of the Bay report

Readers who are familiar with the State of the Bay report series will know that while the various chapters of this report are updated each year with new data and information that has been collected during the course of the preceding year, either through dedicated surveys commissioned by the Saldanha Bay Water Quality Trust or other dedicated individuals and agencies, much of the background or contextual information pertinent to the State of the Bay remains the same. While this background and contextual information is important, it can be a little tedious to wade through for those who have seen it all before. This section of the report thus serves to highlight what new data and information has been included in each of the chapters of this report to make it easier for those readers to home in on the material that is of greatest interest to them.

Chapter 3: Activities and Discharges Affecting the Health of the Bay

- New updated information on numbers of visitors to the West Coast National Park
- Updated information on new and existing development proposals for Saldanha (the Transnet-NPA port expansion programme, the Sunrise Energy Liquid Petroleum Gas Facility, the SANDF Salamander Bay Boat Park, the Transnet-NPA and West Coast District Municipality Desalination Plants, the new Premier Fish Processing Plant, and the proposed Southern Cross salmon farm)
- New updated information on shipping traffic and ballast water discharges, effluent volumes and quality discharged by the Saldanha and Langebaan Water Treatment Works, and effluent volume and quality discharged by the Sea Harvest fresh fish processing plant

Chapter 4: Water Quality

- New information on changes in wave energy patterns in the Bay
- New updated information on levels of microbial indicators (faecal coliforms and E. coli) in the Bay
- Information on new published guidelines for evaluating the safety of coastal waters for recreational users and how these apply to Saldanha Bay
- New updated information on levels of trace metals in farmed oysters and mussels in the Bay

Chapter 5: Sediments

- New information on long term changes in shoreline erosion in Saldanha Bay
- New management interventions to address problems of shoreline erosion in Saldanha Bay
- New methodology for defining and adopting coastal development setback lines in the West Coast District Municipality and the implications for Saldanha Bay and Langebaan
- New updated information on grain size composition and health of benthic sediment in Saldanha Bay (Particulate Organic Carbon and Nitrogen, Trace metal and hydrocarbon content)

Chapter 7: Benthic macrofauna

- New updated information on species composition, abundance, biomass and health of benthic macrofauna communities in Saldanha Bay and Langebaan Lagoon

Chapter 8: Intertidal invertebrates (Rocky Shores)

- New updated information on species composition, abundance, biomass and health of rocky intertidal invertebrate communities in Saldanha Bay and Langebaan Lagoon

Chapter 9: Fish

- New updated information on species composition, abundance, biomass and health of fish communities in Saldanha Bay and Langebaan Lagoon
- New updated information on catch and effort by commercial harder gill net permit holders in Saldanha Bay and Langebaan lagoon

Chapter 10: Birds

- New updated information on species composition, abundance and health of birds breeding on islands within Saldanha Bay

Chapter 11: Alien invasive species

- New updated information on the number, distribution and abundance of alien invasive marine species in Saldanha Bay and Langebaan Lagoon

2 BACKGROUND TO ENVIRONMENTAL MONITORING AND WATER QUALITY MANAGEMENT

2.1 Introduction

Pollution is defined by the United Nations Convention on the Law of the Sea as 'the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of the sea water and reduction of amenities'. A wide variety of pollutants are generated by man, many of which are discharged to the environment in one form or another. Pollutants or contaminants can broadly be grouped into five different types: trace metals, hydrocarbons, organochlorines, radionuclides, and nutrients. Certain metals, normally found in very low concentrations in the environment (hence referred to as trace metals) are highly toxic to aquatic organisms. These include for example Mercury, Cadmium, Arsenic, Lead, Chromium, Zinc and Copper. These metals occur naturally in the earth's crust, but mining of metals by man is increasing the rate at which these are being mobilised which is enormously over that achieved by geological weathering. Many of these metals are also used as catalysts in industrial processes and are discharged to the environment together with industrial effluent and waste water. Hydrocarbons discharged to the marine environment include mostly oil (crude oil and bunker oil) and various types of fuel (diesel and petrol). Sources of hydrocarbons include spills from tankers, other vessels, refineries, storage tanks, and various industrial and domestic sources. Hydrocarbons are lethal to most marine organisms due to their toxicity, but particularly to marine mammals and birds due to their propensity to float on the surface of the water where they come into contact with seabirds and marine mammals. Organochlorines do not occur naturally in the environment, and are manufactured entirely by man. A wide variety of these chemicals exists, the most commonly known ones being plastics (e.g. polyvinylchloride or PVC), solvents and insecticides (e.g. DDT). Most organochlorines are toxic to marine life and have a propensity to accumulate up the food chain. Nutrients are derived from a number of sources, the major one being sewage, industrial effluent, and agricultural runoff. They are of concern owing to the vast quantities discharged to the environment each year which has the propensity to cause eutrophication of coastal and inland waters. Eutrophication in turn can result in proliferation of algae, phytoplankton (red tide) blooms, and deoxygenation of the water (black tides).

It is important to monitor both the concentration of these contaminants in the environment and their effects on biota such that negative effects on the environment can be detected at an early stage before they begin to pose a major risk to environmental and/or human health.

2.2 Mechanisms for monitoring contaminants and their effects on the environment

The effects of pollutants on the environment can be detected in a variety of ways as can the concentrations of the pollutants themselves in the environment. Three principal ways exists for assessing the concentration of pollutants in aquatic ecosystems - through the analysis of pollutant concentrations in the water itself, in sediments or in living organisms. Each has their advantages and disadvantages. For example, the analysis of pollutant concentrations in water samples is often problematic owing to the fact that even at concentrations lethal to living organisms, they are difficult to detect without highly sophisticated sampling and analytical techniques. Pollutant concentrations in natural waters may vary with factors such as season, state of the tide, currents, extent of freshwater runoff, sampling depth, and the intermittent flow of industrial effluents, which complicates matters even further. In order to accurately elucidate the degree of contamination of a particular environment, a large number of water samples usually have to be collected and analysed over a long period of time. The biological availability of pollutants in water also presents a problem in itself. It must be understood that some pollutants present in a water sample may be bound chemically to other compounds that renders them unavailable or non-toxic to biota (this is common in the case of heavy metals).

Another way of examining the degree of contamination of a particular environment is through the analysis of pollutant concentrations in sediments. This has several advantages over the analysis of water samples. Most contaminants of concern found in aquatic ecosystems tend to associate preferentially with (i.e. adhere to) suspended particulate material rather than being maintained in solution. This behaviour leads to pollutants becoming concentrated in sediments over time. By analysing their concentrations in the sediments (as opposed to in the water) one can eliminate many of the problems associated with short-term variability in contaminant concentrations (as they reflect conditions prevailing over several weeks or months) and concentrations tend to be much higher which makes detection much easier. The use of sediments for ascertaining the degree of contamination of a particular system or environment is thus often preferred over the analysis of water samples. However, several problems still exist with inferring the degree of contamination of a particular environment from the analysis of sediment samples.

Some contaminants (e.g. bacteria and other pathogens) do not accumulate in sediments and can only be detected reliably through other means (e.g. through the analysis of water samples). Concentrations of contaminants in sediments can also be affected by sedimentation rates (i.e. the rate at which sediment is settling out of the water column) and the sediment grain size and organic content. As a general rule, contaminant concentrations usually increase with decreasing particle size, and increase with increasing organic content, independent of their concentration in the overlying water. Reasons for this are believed to be due to increases in overall sediment particle surface area and the greater affinity of most contaminants for organic as opposed to inorganic particles (Phillips 1980, Phillips & Rainbow 1994). The issue of contaminant bioavailability remains a problem as well, as it is not possible to determine the biologically available portion of any contaminant present in sediments using chemical methods of analysis alone.

One final way of assessing the degree of contamination of a particular environment is by analysing concentrations of contaminants in the biota themselves. There are several practical and theoretical advantages with this approach. Firstly, it eliminates any uncertainty regarding the bioavailability of the contaminant in question as it is by nature 'bio-available'. Secondly, biological organisms tend to concentrate contaminants within their tissues several hundred or even thousands of times above the concentrations in the environment and hence eliminate many of the problems associated with detecting and measuring low levels of contaminants. Biota also integrates concentrations over time and can reflect concentrations in the environment over periods of days, weeks, or months depending on the type of organism selected. Not all pollutants accumulate in the tissues of living organisms, including for example nutrients and particulate organic matter. Thus, while it is advantageous to monitor contaminant concentrations in biota, monitoring of sediment and water quality is often also necessary.

Different types of organisms tend to concentrate contaminants at different rates and to different extents. In selecting what type of organism to use for bio monitoring it is generally recommended that it should be sedentary (to ensure that it is not able to move in and out of the contaminated area), should accumulate contaminants in direct proportion with their concentration in the environment, and should be able to accumulate the contaminant in question without lethal impact (such that organisms available in the environment reflect prevailing conditions and do not simply die after a period of exposure). Giving cognisance to these criteria, the most commonly selected organisms for bio monitoring purposes include bivalves (e.g. mussels and oysters) and algae (i.e. seaweed).

Aside from monitoring concentrations of contaminant levels in water, sediments, and biota, it is also possible, and often more instructive, to examine the species composition of the biota at a particular site or in a particular environment to ascertain the level of health of the system. Some species are more tolerant of certain types of pollution than others. Indeed, some organisms are extremely sensitive to disturbance and disappear before contaminant concentrations can even be detected reliably whereas others proliferate even under the most noxious conditions. Such highly tolerant and intolerant organisms are often termed biological indicators as they indicate the existence or concentration of a particular contaminant or contaminants simply by their presence or absence in a particular site, especially if this changes over time. Changes in community composition (defined as the relative abundance or biomass of all species) at a particular site can thus indicate a change in environmental conditions. This may be reflected simply as: (a) an overall increase/decrease in biomass or abundance of all species, (b) as a change in community structure and/or overall biomass/abundance but where the suite of species present remain unchanged, or (c) as a change in species and community structure and/or a change in overall biomass/abundance (Figure 2.1). Monitoring abundance or biomass of a range of different organisms from different environments and taxonomic groups with different longevities, including for example invertebrates, fish and birds, offers the most comprehensive perspective on change in environmental health spanning months, years and decades.

The various methods for monitoring environmental health all have advantages and disadvantages. A comprehensive monitoring programme typically requires that a variety of parameters be monitored covering water, sediment, biota and community health indices.

2.3 Indicators of environmental health and status in Saldanha Bay and Langebaan Lagoon

For the requirements of the Saldanha Bay and Langebaan Lagoon State of the Bay monitoring programme a ranking system has been devised that incorporates both the drivers of changes (i.e. activities and discharges that affect environmental health) and a range of different measures of ecosystem health from contaminant concentrations in seawater to change in species composition of a range of different organisms (Figure 2.1 and Table 2.1). Collectively these parameters provide a comprehensive picture of the State of the Bay and also a baseline against which future environmental change can be measured. Each of the threats and environmental parameters incorporated within the ranking system was allocated a health category depending on the ecological status and management requirements in particular areas of Saldanha Bay and Langebaan Lagoon. An overall Desired Health category is also proposed for each environmental parameter in each area, which should serve as a target to be achieved or maintained through management intervention.

Various physical, chemical and biological factors influence the overall health of the environment. Environmental parameters or indices were selected that can be used to represent the broader health of the environment and are feasible to measure, both temporally and spatially. The following environmental parameters or indices are reported on:

Activities and discharges affecting the environment: Certain activities (e.g. shipping and small vessel traffic, the mere presence of people and their pets, trampling) can cause disturbance in the environment especially to sensitive species, that, along with discharges to the marine environment (e.g. effluent from fish factories, treated sewage, and ballast water discharged by ships) can lead to degradation of the environment through loss of species (i.e. loss of biodiversity), or increases in the abundance of pest species (e.g. red tides), or the introduction of alien species. Monitoring activity patterns and levels of discharges can provide insight into the reasons for any observed deterioration in ecosystem health and can help in formulating solutions for addressing negative trends.

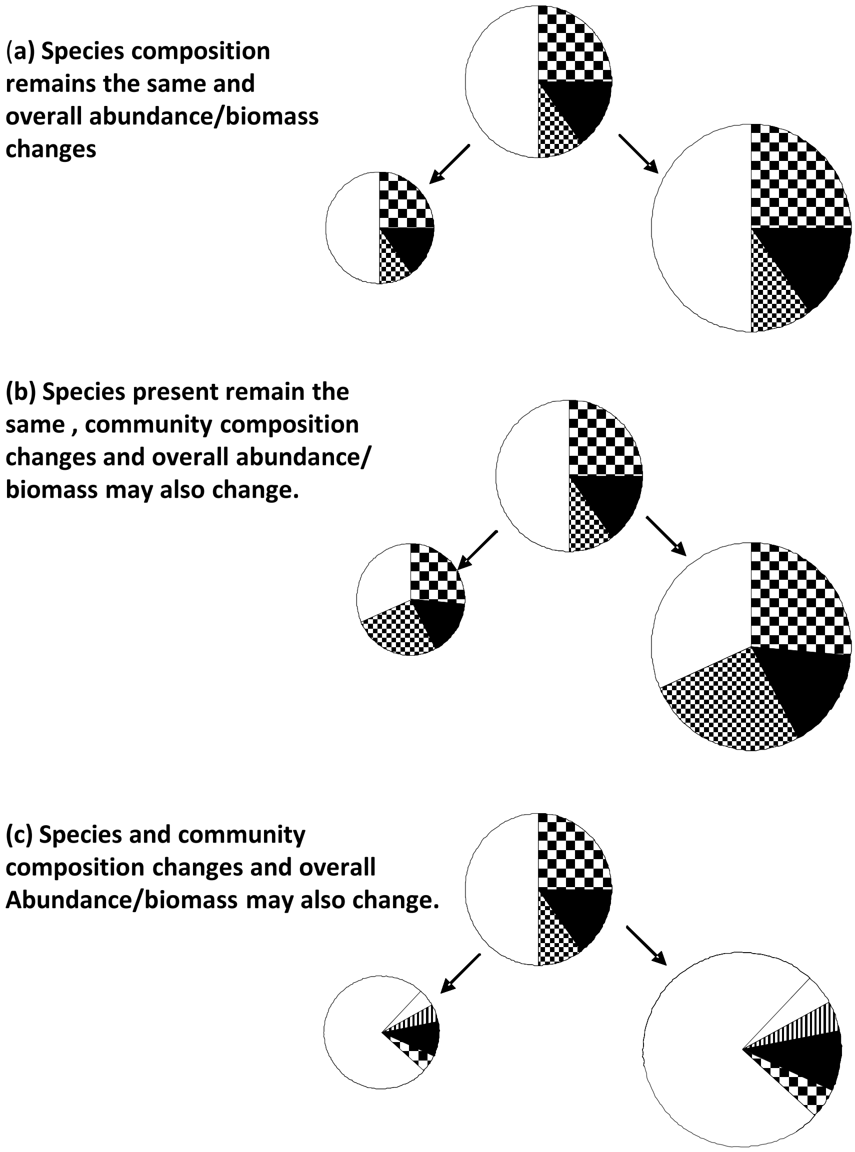


Figure 2.1. Possible alterations in abundance/biomass and community composition. Overall abundance/biomass is represented by the size of the circles and community composition by the various types of shading. After Hellawell (1986).

Water Quality: Water quality is a measure of the suitability of water for supporting aquatic life and the extent to which key parameters (temperature, salinity, dissolved oxygen, nutrients and chlorophyll a, faecal coliforms and heavy metal concentrations) have been altered from their natural state. Water quality parameters can vary widely over short time periods and are principally affected by the origin of the water, physical and biological processes and effluent discharge. Water quality parameters provide only an immediate (very short term – hours to days) perspective on changes in the environment and do not integrate changes over time.

Sediment quality: Sediment quality is a measure of the extent to which the nature of benthic sediments (particle size composition, organic content and contaminant concentrations) has been altered from its natural state. This is important as it influences the types and numbers of organisms inhabiting the sediments and is in turn, strongly affected by the extent of water movement (wave action and current speeds), mechanical disturbance (e.g. dredging) and quality of the overlying water. Sediment parameters respond quickly to changes in the environment but are able to integrate changes over short periods of time (weeks to months) and are thus good indicators or short to very short-term changes in environmental health.

Coastal development: Coastal development includes development activities such as infrastructure (harbours and launch sites, cities, towns, housing, roads and tourism), as well as dredging and the disposal of dredge spoil. Coastal developments pose a major threat to many components of marine and coastal environments, owing to their cumulative effects, which are often not taken into account by impact assessments. Associated impacts include organic pollution of runoff and sewerage, transformation of the supratidal environment, alteration of dune movement, increased access to the coast and sea, and the negative impacts on estuaries.

Shoreline erosion: Anthropogenic activities, particularly structures erected in the coastal zone (e.g. harbours, breakwaters, buildings) and dredging activities, can also profoundly influence shorelines composed of soft sediment (i.e. sandy beaches) leading to erosion of the coast in some areas and the accumulation of sediment in others. Many of the beaches in Saldanha Bay have experienced severe erosion in recent decades to the extent that valuable infrastructure is severely threatened in some areas.

Table 2.1. Ranking categories and classification thereof as applied to Saldanha Bay and Langebaan Lagoon for the purposes of this report.

Health category	Ecological perspective	Management perspective
Natural	No or negligible modification from the natural state	Relatively little human impact
Good	Some alteration to the physical environment. Small to moderate loss of biodiversity and ecosystem integrity.	Some human-related disturbance, but ecosystems essentially in a good state, however, continued regular monitoring is strongly suggested
Fair	Significant change evident in the physical environment and associated biological communities.	Moderate human-related disturbance with good ability to recover. Regular ecosystem monitoring to be initiated to ensure no further deterioration takes place.
Poor	Extensive changes evident in the physical environment and associated biological communities.	High levels of human related disturbance. Urgent management intervention is required to avoid permanent damage to the environment or human health.

Macrofauna: Benthic macrofauna are mostly short lived organisms (1-3 years) and hence are good indicators of short to medium term (months to years) changes in the health of the environment. They are particularly sensitive to changes in sediment composition (e.g. particle size, organic content and heavy metal concentrations) and water quality.

Rocky intertidal: Rocky intertidal invertebrates are also mostly short lived organisms (1-3 years) and as such are good indicators of short to medium term changes in the environment (months to years). Rocky intertidal communities are susceptible to invasion by exotic species (e.g. Mediterranean mussel), deterioration in water quality (e.g. nutrient enrichment), structural modification of the intertidal zone (e.g. causeway construction) and human disturbance resulting from trampling and harvesting (e.g. bait collecting).

Fish: Fish are mostly longer lived animals (3-10 years +) and as such are good indicators of medium to long term changes in the health of the environment. They are particularly sensitive to changes in water quality, changes in their food supply (e.g. benthic macrofauna) and fishing pressure.

Birds: Birds are mostly long lived animals (6-15 years +) and as such are good indicators of long term changes in the health of the environment. They are particularly susceptible to disturbance by human presence and infrastructural development (e.g. housing development), and changes in food supply (e.g. pelagic fish and intertidal invertebrates).

Alien species: A large number of alien marine species have been recorded as introduced to southern African waters. South Africa has at least 85 confirmed alien species, some of which are considered invasive, including the Mediterranean mussel Mytilus galloprovincialis, the European green crab Carcinus maenas, and the barnacle Balanus glandula. Most of the introduced species in South Africa have been found in sheltered areas such as harbours, and are believed to have been introduced through shipping activities, mostly ballast water. Ballast water tends to be loaded in sheltered harbours, thus the species that are transported often originate from these habitats and have a difficult time adapting to the more exposed sections of the southern African coastline, but are easily able to gain a foothold in sheltered bays such as Saldanha Bay.

3 ACTIVITIES AND DISCHARGES AFFECTING THE HEALTH OF THE BAY

3.1 Introduction

Industrial development of Saldanha Bay dates back to the early 1900's with the establishment of a commercial fishing and rock lobster industry in the Bay. By the mid-1900's Southern Seas Fishing Enterprises and Sea Harvest Corporation had been formed, with Sea Harvest becoming the largest fishing operation in Saldanha Bay to date. Human settlement and urbanization grew from village status in 1916, to an important city today with well over 28 000 people and an average population growth rate of 5.73% per year. With increasing numbers of fishing vessels operating in Saldanha Bay, and to facilitate the export of iron ore from the Northern Cape, the bay was targeted for extensive development in the early 1970's. The most significant developments introduced at this time were the causeway linking Marcus Island to the mainland, to provide shelter for ore-carriers, and the construction of the iron ore terminal. These two developments effectively separated the Bay into two separate compartments – Small Bay and Big Bay (Figure 3.1**Error! Reference source not found.**). By the end of the 1970's Saldanha Bay harbour was an international port able to accommodate large ore-carriers and deep-sea trawlers. During the 1980's a multi-purpose terminal was added to the ore terminal and a small-craft harbour was built in the western corner of Small Bay to accommodate increasing recreational and tourism activities in the bay. Development of the port continues to this day with the addition of a bulk fuel terminal, new berths for ore carriers, and soon a new LPG terminal in Big Bay. The growth in industry and urban development has meant an increase in the different types of discharges into the bay such as fish factory and mariculture discharges, storm water, and discharges relating to shipping activities such as ballast water and oil spills. Shipping channels in the Bay are also periodically dredged to ensure unrestricted access to the ore terminal by bulk carriers and oil tankers.

Sewage discharge is arguably the most important waste product in terms of continuous environmental impact that is discharged into Saldanha Bay. Sewage is harmful to biota due to its high concentrations of nutrients which stimulate primary productivity that in turn leads to changes in species composition, decreased biodiversity, increased dominance, and toxicity effects. The changes to the surrounding biota are likely to be permanent depending on distance to outlets and are also likely to continue increasing in future given the growth in industrial development and urbanisation in the area. These impacts are however manageable, can be monitored and mitigated so as to cause minimum effects.

Ballast water discharges are by far the highest in terms of volume and also continuous due to constant and increasing shipping traffic. Ballast water has, through the transport of potentially alien invasive species to new areas, the potential to impact native species and ecosystem functions, fishing and aquaculture industries, as well as public health. Ballast water discharges can, however, be effectively managed and the remit of the International Maritime Organization (IMO) is to reduce the risks posed by ballast water to a minimum through the direct treatment of the water while on board the ship, as well as by regulating the way in which ballast water is managed while the ship is at sea.

Storm water discharges are a seasonal concern and can introduce large volumes of polluted surface water such as pesticides and trace metals which can in turn be harmful to the environment and have been shown to exceed permissible concentrations in Saldanha Bay particularly after the rainy season. Storm water discharges are very difficult to manage and are bound to increase with increasing urbanization and industrial development in the areas surrounding the Bay.

Dredging in Saldanha Bay has had tremendous immediate impact on benthic micro and macrofauna, the particle suspension in the water column kills many suspension feeders like fish and zooplankton. It also blocks sunlight from penetrating the water column and causes die offs of algae and phytoplankton. The damage caused is reversible in the long term, and although the particle composition of the settled material is likely to be different, ecological functions as well as major species groups will probably return. The mitigation options for this kind of activity are limited and extremely costly.

The final important type of discharge to the Bay is oil spills. Although, extremely harmful to all biota, large oil spills are fortunately rare, and Saldanha Bay has never experienced a major spill to date. The management options in place in Saldanha are the best in South Africa with prevention being the primary focus.

Each of these aspects and their potential threat to the bay is addressed in more detail in the various subsections below.

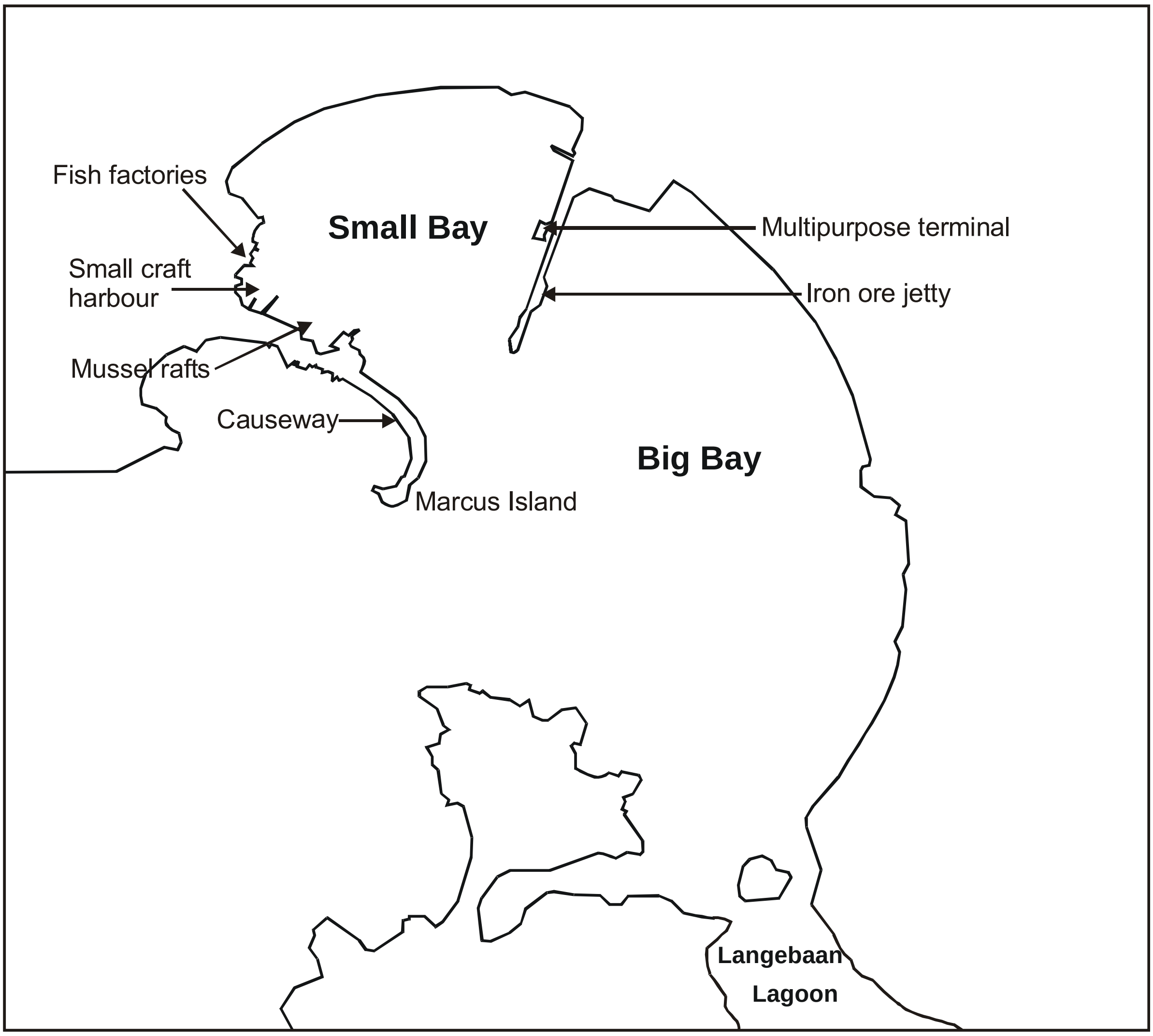


Figure 3.1. Map of Saldanha Bay indicating anthropogenic developments established since 1973 referred to in text.

3.2 Urban and industrial development

The first mention of Saldanha Bay in recorded history dates to 1601 when Joris van Spilbergen mistook the present Saldanha Bay for Table Bay. Since then the name has remained, while the original Aguada de Saldanha "watering place of Saldanha" has become known as Table Bay (Axelson 1977). In 1623, an Icelander by the name of Jon Olaffsson entered Saldanha Bay in search of whaling opportunities, only to find that French sailors had already commenced with such lucrative activities in the Bay.

Shortly after his arrival in Table Bay in 1652, Jan van Riebeeck sent a small vessel to explore the possibility of local trade opportunities in Saldanha Bay (Axelson 1977). At this stage the French had virtually hunted out the seal population, which fetched a high price for their skins. However, the abundance of sheep, fish (4 000 harders being caught in a single day) and bird's eggs rendered the Bay sufficiently valuable for the Dutch East India Company to erect markers denoting their possession of the Bay in 1657. A shortage of freshwater, however, limited development or permanent European colonization in Saldanha Bay, although four small communities eventually became established near Langebaan Lagoon.

Saldanha Bay was reported to be "rich in fish" and although the price for fish was deemed "poor", there are records of a fish trading post being established at Oostewal, Langebaan Lagoon in the early 1700's (Axelson 1977). Initially, commercial fishing interests were slow to develop in Saldanha Bay, however, by the early 1900's fishing was considered a growing industry. In 1903, a rock lobster fishery was introduced in Saldanha Bay with the North Bay Canning Company and the Saldanha Bay Canning Company being established in the early 1900's (Axelson 1977). With increasing catches of sardines in the vicinity of the Bay, canning companies soon expanded their business to incorporate sardine canning. In 1948 the North Bay Canning Company was absorbed into Southern Seas Fishing Enterprises, while in 1964 Sea Harvest Corporation was formed, subsequently becoming the largest fishing operation in Saldanha Bay, operating a fleet of deep-sea trawlers and purse seiners and providing an onshore fish packing and freezing facility.

The first whaling factory was built in 1909 at Donkergat, followed by a second in 1911 at Salamander Bay. In 1930 however, the international price for whale oil plummeted, resulting in the closure of both these factories. Whaling activities were re-established for a short period between 1960 and 1967, after which no further whaling took place in Saldanha Bay (Axelson 1977).

The establishment of fish processing factories and the substantial growth of the fishing industry in Saldanha Bay resulted in an ever increasing number of pelagic fishing vessels harbouring in the Bay and offloading their catch. During the early 1970's, the methods employed to offload the catch involved releasing substantial amounts of water, loaded with organic matter (biological waste and fish factory effluent), back into the Bay (known as "wet offloading"). Within a short period of time the marine environment within the Bay began showing severe signs of organic overloading and in 1972 a mass mortality event of marine organisms (fish and shellfish) brought the pollution situation to attention. By 1974, official waste management practices (primarily "dry offloading" of the catch) were being implemented by the fish factories to reduce the amount of organic loading in the Bay (Christie and Molden 1977).

Saldanha Bay, being the only natural harbour of significant size on the west coast of South Africa, was targeted for development of an industrial port at an early stage, and in 1971 was upgraded into an international port (Fuggle 1977). The primary purpose of the port at that stage was to facilitate the export of iron ore as part of the Sishen-Saldanha Bay Ore Export Project. The first major development in the Bay towards the realisation of these goals was the construction of the iron ore terminal and a causeway, built in 1973, that linked Marcus Island to the mainland, providing shelter for ore-carriers. During 1973 and 1974 the General Maintenance Quay and Rock Quay were added to the iron ore terminal. Between 1974 and 1976 extensive dredging was conducted to accommodate a deep-water port for use by large ore-carriers. The iron ore terminal was built with the initial intention of being used for export of ore, however, was later extended to provide for the import of oil. The construction of the iron ore terminal essentially divided Saldanha Bay into two sections: a smaller area bounded by the causeway, the northern shore and the ore terminal (called Small Bay); and a larger , more exposed area adjacent called Big Bay, leading into Langebaan lagoon (Figure 3.1**Error! Reference source not found.**). A multi-purpose terminal had been added to the ore terminal by 1980 and a small-craft harbour was built in 1984 to cater for the increase in recreational and tourism activities in the Bay. Due to the increase in heavy industries in the area in the 1990's (Namakwa Sands, Saldanha Steel), the Multi-Purpose Terminal was extended in 1998. During each phase of development undertaken in Saldanha Bay (summarized in Table 3.1), dredging and submarine blasting has been necessary. Development of the causeway and iron-ore terminal in Saldanha Bay greatly modified the natural water circulation and current patterns (Weeks *et al*. 1991) in the Bay. This led to reduced water exchange and increased nutrient loading of water within the Bay.

Figure 3.2. Composite aerial photo of Saldanha Bay and Langebaan Lagoon taken in 1960. (Source Department of Surveys and Mapping). Note the absence of the ore terminal and causeway and limited development at Saldanha and Langebaan.

In addition to the increasing fish factory effluent and the structural modifications of the Bay, the establishment of mussel mariculture ventures (of the Spanish mussel *Mytilus galloprovincialis*) in the sheltered waters of Small Bay in 1984, exacerbated the pollution and organic loading problems in the area (Stenton-Dozey *et al*. 1999).

Aerial photographs taken in 1960 (Figure 3.2), 1989 (Figure 3.3) and in 2007 (Figure 3.4) clearly show the extent of development that has taken place within Saldanha By over the last 50 years.

Table 3.1. Summary of major development in Saldanha Bay

Year	Development
1973	Causeway built linking Marcus Island and mainland
1973 – 1974	General Maintenance Quay and Rock Quay
1974 – 1976	Iron-ore terminal
1980	Multi-purpose terminal added to Iron-ore terminal
1984	Small craft harbour
1998	Multi-purpose Terminal extended

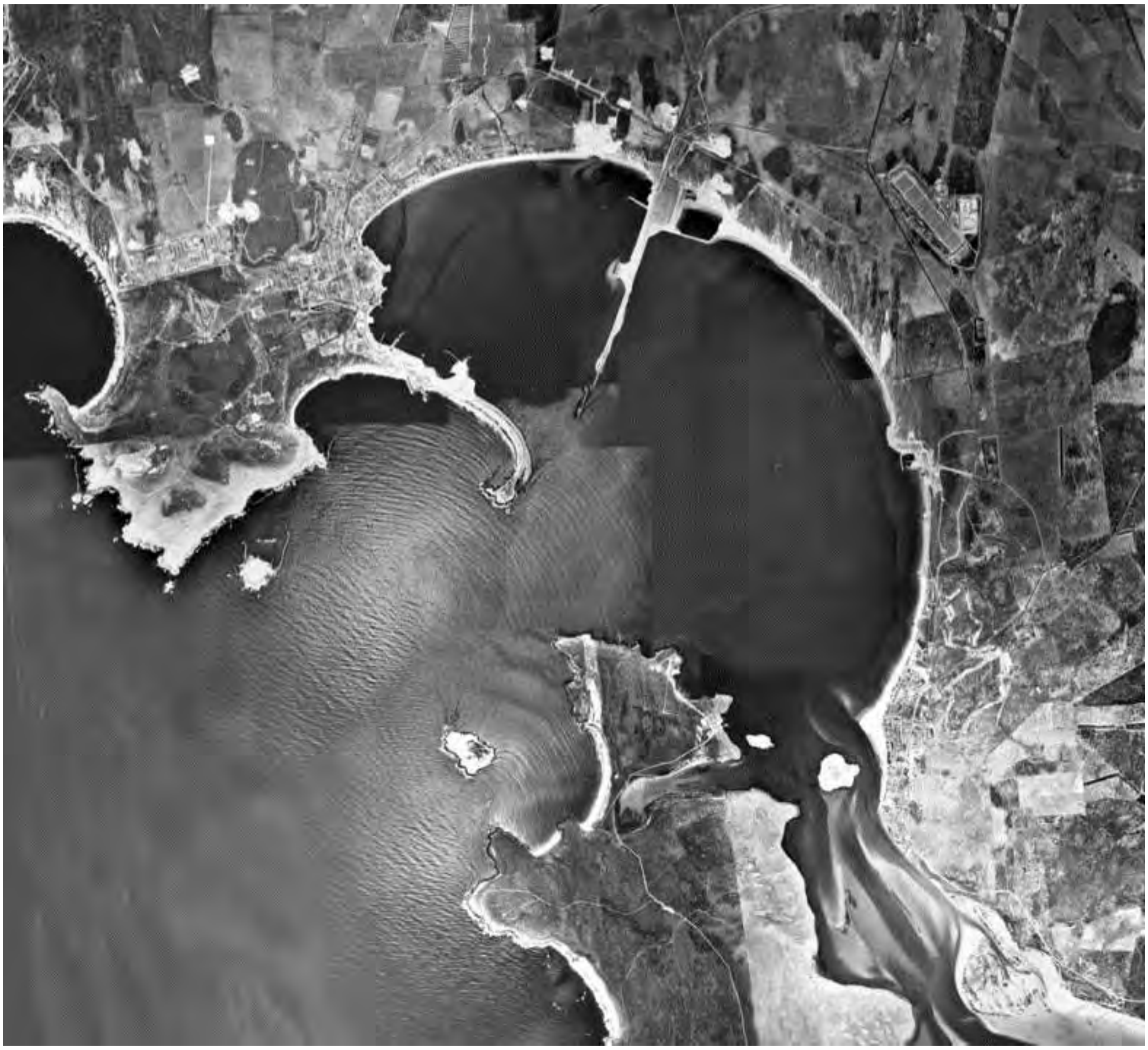


Figure 3.3. Composite aerial photo of Saldanha Bay and Langebaan Lagoon taken in 1989. (Source Department of Surveys and Mapping). Note the presence of the ore terminal, the causeway linking Marcus Island with the mainland, and expansion of settlements at Saldanha and Langebaan.

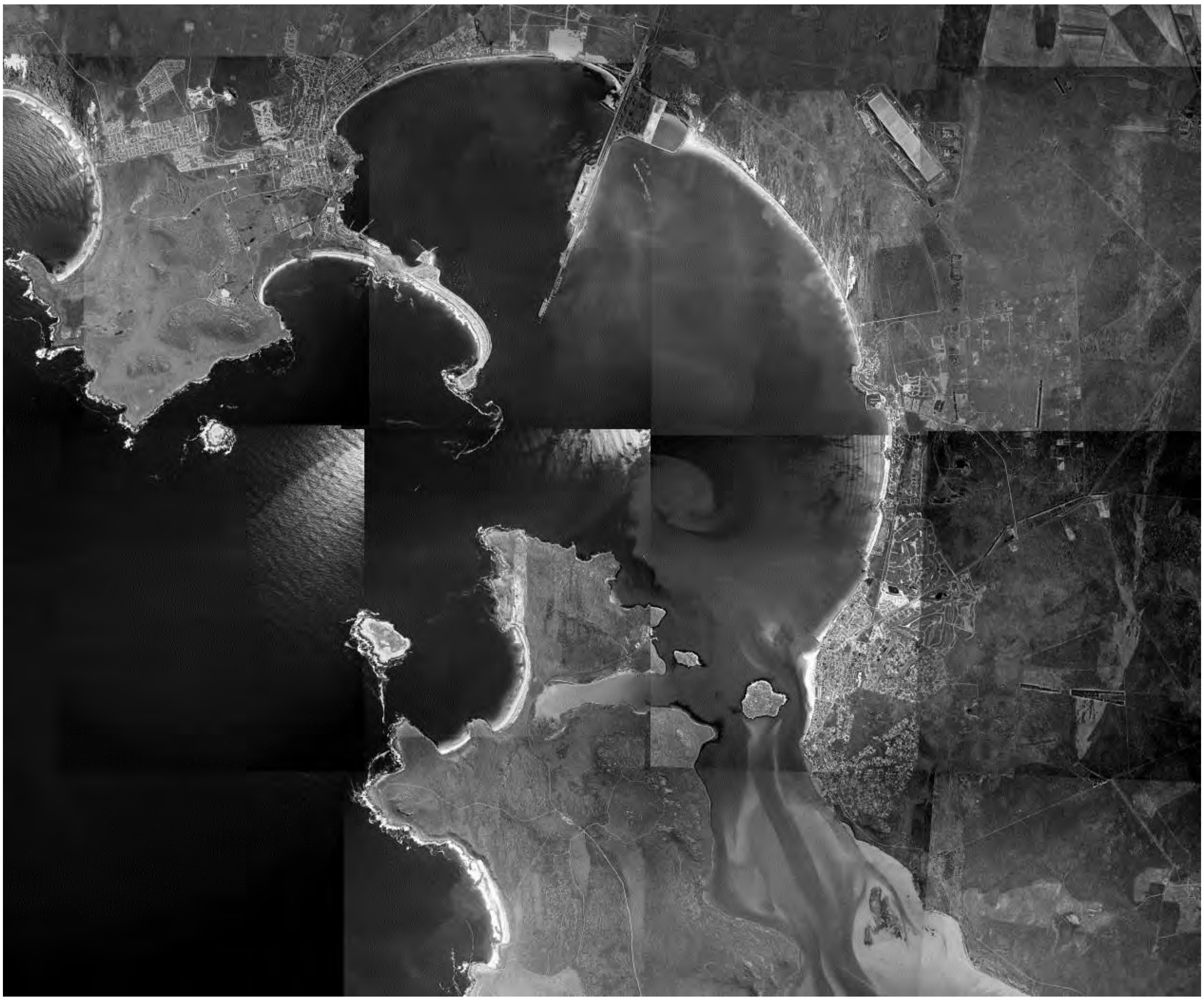


Figure 3.4. Composite aerial photo of Saldanha Bay and Langebaan Lagoon taken in 2007. (Source Department of Surveys and Mapping). Note expansion in residential settlements particularly around the town of Langebaan.

Data on population growth in the town of Saldanha and Langebaan Lagoon are available from the 1996 census and 2001 census. The 2011 census data have not yet been released. The total population of Saldanha Bay increased from 16 820 in 1996 to 21 636 in 2001, with a growth rate of 5.73%/yr. The total population in Langebaan Lagoon increased from 2 735 to 4 272 between 1996 and 2001, with a growth rate of 7.02%/yr. (Table 3.2). The human population in Saldanha Bay is thus expanding rapidly which has been attributed to the immigration of people from surrounding municipalities in search of real or perceived jobs (IDP 2006 – 2011). It was projected that by 2020 Saldanha and Langebaan would have a total human population of 77 006 and 22 312 respectively (Table 3.3.). These population increases are no doubt increasing pressure on the marine environment and the health of the Bay through increased demand for resources, trampling of the shore and coastal environments, increased municipal (sewage) and household discharges (which are ultimately disposed of in Saldanha Bay) and increased storm water runoff due to expansion of tarred and concreted areas.

Urban development around Langebaan Lagoon has encroached right up to the coastal margin, leaving little or no coastal buffer zone (Figure 3.5 and Figure 3.6). Allowing an urban core to extend to the waters' edge places the marine environment under considerable stress due to trampling and habitat loss. It also increases the risks of erosion due to removal of vegetation and interferes with certain coastal processes such as sand deposition and migration. Expansion of tarred areas will also increase the volumes of storm water entering the marine environment, which ultimately has a detrimental effect on ecosystem health via the input of various contaminants and nutrients (See section §3.3).

Table 3.2. **Total human population and population growth rates for the towns of Saldanha and Langebaan from 1996 to 2004 (Saldanha Bay Municipality, 2005).**

Location	Total Population 1996	Total Population 2001	Growth 1996-2001 (%/yr.)
Saldanha	16 820	21 626	5.73
Langebaan	2 735	4 272	7.02

Table 3.3. **Projected total human population and population growth rates for the towns of Saldanha and Langebaan (Saldanha Bay Municipality, 2005).**

Location	2005	2010	2015	2020
Saldanha	28 265	39 477	55 136	77 006
Langebaan	6 050	9 348	14 442	22 312

Figure 3.5. **Satellite image of Saldanha (Small Bay) showing little or no setback zone between the town and the Bay. Source: Google Earth.**

Figure 3.6. Composite aerial photograph of Langebaan showing absence of development setback zone between the town and the lagoon. Source: Department of Surveys & Mapping, South Africa.

An application for development was recently proposed on the Remainder of the Farm Oostewal No. 292, Langebaan (Shark Bay). The developer requested permission to divide the 82 hectare plot into 109 single residential erven, roads, public parking and ablution facilities, open spaces and conservation areas.

The application was initially rejected by the Department of Environmental Affairs and Development Planning: Directorate Land Management on the 7th of April 2011 on several grounds:

- The land contains critically endangered and endangered vegetation types. It is estimated that 85% of the site can be considered a Critical Biodiversity Area.
- The development would negatively impact on the sense of place, as the location is visually linked to the West Coast National Park.
- The development does not fit the West Coast Provincial Spatial Development Framework (despite the socio-economic benefits) as it will only reiterate unsustainable development patterns of the past.

- Social inequalities will be enforced, as the benefits will be mostly felt by society members belonging to a higher-income bracket.
- There is no need for further development, as currently 50% of existing residential properties in Langebaan are vacant.

However despite this decision, in May 2012, an appeal was lodged with the Western Cape Government – Department of Environmental Affairs and Development Planning and in October 2012, environmental authorisation was granted, with conditions attached. Development along the coastal edge of the site was rejected, with permission given for the construction of ablution facilities and public parking only. As a result, the number of residential erven permitted was reduced from 109 to 69. The boundary fence needs to be replaced with appropriate fencing approved by Cape Nature with regards to local fauna. In addition, the gate on Oostewal Road and the boom in Park Drive must be removed within 3 months of the environmental authorisation to allow public access as per Section 13 of the National Environmental Management: Integrated Coastal Management Act, 2008. Various mitigation measures must be adopted to comply with the outcomes of the faunal and botanical assessments as well as the visual impact assessment.

Industrial and urban development in and around Saldanha Bay has been matched with increasing tourism development in the area, specifically with the declaration of the West Coast National Park, Langebaan Lagoon being declared a National Wetland RAMSAR site and establishment of holiday resorts like Club Mykonos and Blue Water Bay. The increased capacity for tourism results in higher levels of impact on the environment in the form of increased pollution, traffic, fishing and disturbance. Recent data on numbers of visitors to the West Coast National Park indicate strong seasonal trends in numbers of people visiting the area (peaking in the summer months and during the flower season) (Figure 3.7). These numbers appear to have increased significantly in 2012 with almost 40,000 visitors recorded during September and December, an increase from the previous year when these peak months saw less than 30,000 tourists. Overall numbers of tourists visiting the park has increasing at a rate of around 9.2% per annum since 2005.

In terms of the Municipal Systems Act 2000 (Act 32 of 2000) every local municipality must prepare an Integrated Development Plan (IDP) to guide development, planning and management over the five year period in which a municipality is in power. A core component of an IDP is the Spatial Development Framework (SDF) which is meant to relate the development priorities and the objectives of geographic areas of the municipality and indicate how the development strategies will be co-ordinated. An SDF aims to guide decision making on an ongoing basis such that changes, needs and growth in the area can be managed to the benefit of the environment and its inhabitants. The 2006 Saldanha Municipality IDP has recently been revised and replaced with the 2011/2012 IDP. The revised SDF for the Saldanha Bay Municipality was produced in 2011 and is available on the municipality website. The revised version has adopted a holistic approach, ensuring that the municipal spatial planning of the rural and urban areas is integrated for the first time since the establishment of the municipality.

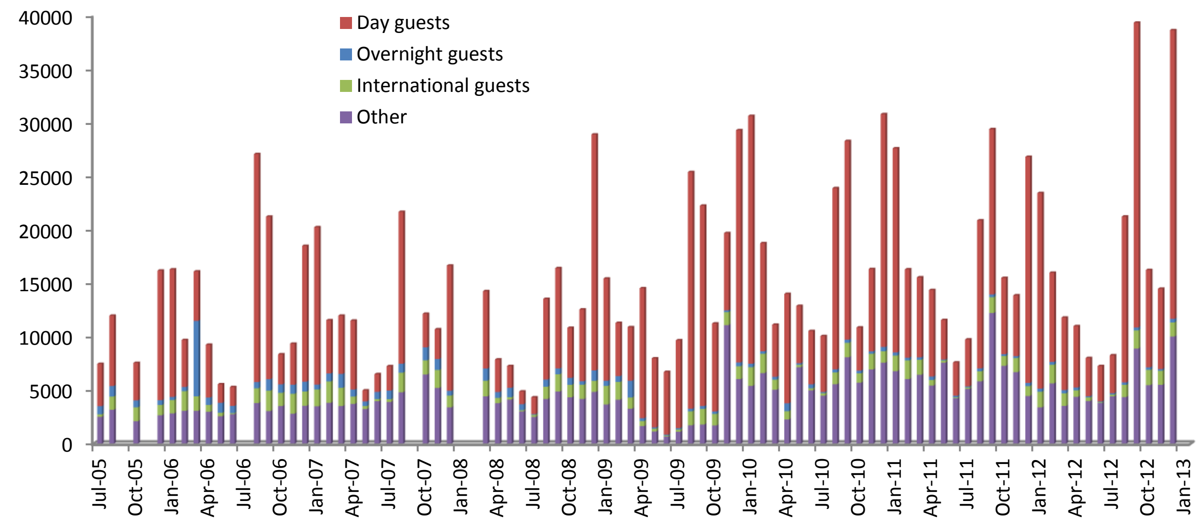


Figure 3.7. Numbers of tourists visiting the West Coast National Park since 2005 (Data from Pierre Nel, WCNP). Day guests include all South African visitors (adults and children) while Overnight guests refer those staying in SANPARK accommodation. International guests include all SADC and non-African day visitors (adults and children) while the category 'Other' includes residents, staff, military, school visits, etc. The 3-month moving average and trend over the entire period (black lines are also shown).

A study by Van der Merwe *et al.* (2005) assessing the growth potential of towns in the Western Cape (as part of the provincial SDF) identified Langebaan and Saldanha as towns with high growth potential. It was estimated that, given the projected population figures, there would be a future residential demand of 9 132 units in Saldanha and 3 781 units in Langebaan. The SDF proposes addressing these demands by increasing the residential density in specified nodes in both towns and by extending the urban edge of Saldanha in a northerly direction towards Vredenberg, and that of Langebaan inland towards the North-East.

Western Cape Department of Economic Development and Tourism (DEDT), through Wesgro (the official Investment and Trade Promotion Agency of the Western Cape), embarked on a pre-feasibility study to identify and assess the opportunities available in the industrial and business market and ascertain whether there are any binding constraints to establishing an IDZ programme at Saldanha Bay.

The National Environmental Management: Integrated Coastal Management Act 24 of 2008 (ICMA), which came into effect in December 2009, aims to ensure the integrated management of the coastline and the sustainable use of its resources. ICMA obligates municipalities to prepare and adopt Coastal Management Programmes for the coastal zone, or specific parts of the coastal zone in areas under their jurisdiction, within four years of the Act coming into effect. These statutory programmes must incorporate a vision and management objectives for the coastal zone; priorities and strategies to achieve the objectives; and performance indicators to measure management effectiveness. The Coastal Management Programme must be consistent with other municipal plans, such as the IDP. Moreover section 51 requires that an IDP be aligned with, contain the provisions of, and give effect to national and the applicable provincial coastal management programmes.

The coastal zone, as defined by ICMA, includes the following areas and any aspect of the environment on, in, under and above these areas:

- **All coastal public property** (Comprises of coastal waters; land submerged by coastal waters; islands within coastal waters; the sea shore, excluding that which was lawfully alienated before this Act came into force; State owned land declared as coastal public property; and the natural resources on or in coastal public property, the exclusive economic zone (up to 200 nautical miles offshore) and any harbour, work or other installation in coastal public property);
- **The coastal protection zone** (Comprises of the land 1km inland from the high water mark zoned for agricultural or undetermined use and the wetlands, lakes, lagoons or dams situated on this land; any land within 100 m inland of the high water mark; seashore and admiralty reserves which are not coastal public property; and land inundated by 1:50 year floods or storm events);
- **All coastal access land** (Strips of land designated by municipal by-laws to secure public access to coastal public property);
- **Coastal protected areas** (those protected areas situated wholly or partially in the coastal zone and recognised under the *Protected Areas Act.* Marine Protected Areas declared under the *Marine Living Resources Act* are recognised as protected areas);
- **The seashore** (the area between the low water mark and the high water mark);
- **Coastal waters** (territorial and internal waters of the Republic).

Future developments in and around Saldanha and Langebaan will have to be conducted in accordance with the provisions of ICMA. The following aspects of ICMA will affect future development activities in Saldanha and Langebaan:

- Section 15 of ICMA prevents any person, owner or occupier of land adjacent to the seashore from requiring any organ of state or any other person to take measures to prevent the **erosion or accretion** of the seashore, or of land adjacent to coastal public property, unless the erosion is caused by an intentional act or omission of that organ of state or other person. Moreover it prohibits the construction, maintenance or extension of any structure, or the conduct of any other measures on coastal public property to prevent or promote erosion or accretion of the seashore except as provided for in ICMA.
- Section 58 places a **duty of care** on every person who causes, has caused or may cause significant pollution or degradation of the environment, including an adverse effect to the coastal environment, to take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring, and to minimise and rectify such pollution or degradation of the coastal environment;
- Section 60 provides the Minister or MEC with the power to give notice to **repair or remove structures** in the coastal zone if the structures are likely to cause adverse effects to the coastal environment.
- **Coastal setback lines**, determined by an MEC in accordance with section 25 of the Act, will demarcate an area within which development will be prohibited or controlled in order to achieve the objectives of ICMA or coastal management objectives.

Designated coastal setback lines will help to protect biodiversity and heritage sites, ensure the safety of developments while minimizing maintenance issues. Due to the variation in conditions around the South African coast, the methodology for defining and adopting coastal setback lines is complex. WSP Africa Coastal Engineers (2010) recommend basing these setback lines on several findings: i) the long term erosion trend; ii) short term erosion trends (from storm damage); and iii) the predicted sea level rise.

The adoption of two types of setback lines has been proposed (WSP 2010). A 'coastal processes/no development' line allows for no development seaward of this line, with the exception of boardwalks to access beaches. Alternatively a 'limited or controlled development' line may be imposed that would either be equal to the 'no development' line or even further landward. These lines will be set based on a period of 100 years (to accommodate a 1:100 year storm erosion, 100 years of sea level rise and the erosion trend (where applicable) over 100 years). Currently, any development of infrastructure (temporary or permanent) which is undertaken within 100 metres of the high-water mark, requires the completion of an Environmental Impact Assessment.

3.3 Discharges and activities affecting environmental health

3.3.1 Dredging and port expansion

Dredging of the seabed is performed worldwide in order to expand and deepen existing harbours/ports or to maintain navigation channels and harbour entrances (Erftemeijer and Lewis 2006), and dredging has thus been touted as one of the most common anthropogenic disturbance of the marine environment (Bonvicini Pagliai *et al*. 1985). The potential impacts of dredging on the marine environmental can stem from both the removal of substratum from the seafloor and the disposal of dredged sediments, and include:

- Direct destruction of benthic fauna populations due to substrate removal
- Burial of organisms due to disposal of dredged sediments
- Alterations in sediment composition which changes nature and diversity of benthic communities (e.g. decline in species density, abundance and biomass)
- Enhanced sedimentation
- Changes in bathymetry which alters current velocities and wave action
- Increase in concentration of suspended matter and turbidity due to suspension of sediments. The re-suspension of sediments may give rise to:
    - Decrease in water transparency
    - Release in nutrients and hence eutrophication
    - Release of toxic metals and hydrocarbons due to changes in physical/chemical equilibria
    - Decrease in oxygen concentrations in the water column
    - Bioaccumulation of toxic pollutants
    - Transport of fine sediments to adjacent areas, and hence transport of pollutants
    - Decreased primary production due to decreased light penetration to water column

(Erftemeijer and Lewis 2006, Bonvicini Pagliai *et al*. 1985, OSPAR Commission 2004, National Ports Authority 2007).

Aside from dredging itself, dredged material may be suspended during transport to the surface, overflow from barges or leaking pipelines, during transport to dump sites and during disposal of dredged material (Jensen and Mogensen 2000 in Erftemeijer and Lewis 2006).

Saldanha Bay is South Africa's largest and deepest natural port and as a result has undergone extensive harbour development and has been subjected to several bouts of dredging and marine blasting. Saldanha is perfectly situated for the shipment of large quantities of iron ore from the Sishen mines in the Northern Cape. However, before the first shipment could be loaded the port had to be protected from strong wave activity. To remedy this, the first major development occurred in 1973 whereby Marcus Island was joined to the mainland via the construction of a causeway. Further development involved the construction of the General Maintenance Quay and the Rock Quay over the period 1974 to 1976. During this process 25 million m^3 of sediment were dredged from the Bay to facilitate the entrance of large ore carriers, and the resulting dredged material was used to construct the harbour wall (Moldan 1978). A Multi-Purpose Terminal was added to the iron ore terminal in 1980 and the Small Craft Harbour was built in 1984. These developments all required extensive dredging and submarine blasting which significantly impacted sediment composition and benthic community structure. Since this time three further dredging operations have been implemented in Saldanha Bay.

The first of these was associated with the expansion of the Multi-Purpose Terminal in 1996/7 when 2 million m^3 of material was removed from an area approximately 500 000 m^2 in extent on the Small Bay side of the ore terminal. The dredge spoil was disposed of on land in a retention pond on the eastern side of the causeway. The bottom material in Saldanha Bay consists mainly of sand interspersed with thin layers of calcrete, some silt/clay and shell fragments. Early borehole samples collected in 1995 from proposed dredging areas revealed that the substrate contained an average of 33% silt/clay of which ~73% of the silt/clay fraction had a grain size of less than 5 microns. It is thus apparent that a significant proportion of the substrate that was dredged in 1997 comprised very fine particles such as clay and calcrete (chalk is simply pulverized calcrete). When calcrete is dredged white plumes of fine particles are released into the water column (Schoonees *et al*. 1995), which occurred during the 1997 Saldanha Bay dredge event.

Maintenance dredging was required at the Mossgas quay and the Multi-Purpose Terminal in order to deepen the berth. Maintenance dredging took place at these locations from the end of 2007 to March/April 2008 with an estimated 50 000 m^3 of seabed material being removed from both terminals. The Mossgas terminal was constructed in the 80s and the depth has reduced from approximately 9 m to 6 m over the last 20 years due to sediment build-up. A similar reduction in depth has also occurred at the Multi-Purpose Terminal. The sediment that was to be dredged was mainly fine silt, fine to coarse sand, shell fragments and seaweed. At the Multipurpose berth 201 it was also expected that lead and copper would occur in elevated concentrations in the dredged sediments. The concentrations of lead (Pb) at several sites within the proposed dredge area fall in the range of special care requirements in terms of the London Convention for off-shore disposal of sediments. It has been calculated that of the 3 000 m^3 of sediments to be dredged at berth 201, approximately 300 m^3 would be Pb product that had accumulated over two decades of loading operations (National Ports Authority 2007). This material was not dumped offshore but was mixed with the rest of the dredged material to achieve appropriate dilution and disposed of on land. Environmental specifications have been published by the National Ports Authority in which the potential impacts of this maintenance dredging were outlined and recommendations were proposed for avoiding, minimizing and controlling the impacts (National Ports Authority 2007). It is expected that farther maintenance dredging at the Mossgas and Multi-Purpose terminals will not be required for a further 10 – 20 years (Mr Lyndon Metcalf, *pers. comm.*). This is due to the fact that the port is situated in a sheltered area and most loose sediments were removed during harbour construction. The depth of the port further reduces sediment transport, which might have otherwise filled in navigation channels more rapidly (Schoonees *et al*. 1995).

The third of these dredge events was undertaken in 2009/10, during which 7 300 m^3 of material was removed from an area of approximately 3 000 m^2 at the end of the cause way, between Caisson 3 and 4 on the Saldanha side of the ore terminal (Figure 3.8) (N. Jansen – Port of Saldanha pers. comm. 2011). The environmental impact assessment for the proposed dredge event was undertaken by Environmental Resources Management (ERM) in April 2008. The aim of the dredging was to increase the export capacity of the iron ore terminal though the use of a staggered ship loading arrangement, that enables both ship loaders to operate independently and simultaneously. The dredged material was used to fill the two scour holes between Caissons 5 and 6. These were revealed, during a bathymetric survey in June 2007, to have been caused by the scouring currents produced by the propellers of bulk carriers while berthing and un-berthing (ERM 2008). A final report of the outcome of the dredging operation is still to be made available by Ports of Saldanha. It was considered a successful operation (N. Jansen – National Port Authority pers. comm. 2012).

Figure 3.8. Location of the maintenance dredging site between Caissons 3 and 4 on the ore terminal.

Transnet proposed a Phase 2 Expansion of the Iron ore quay (Figure 3.9) in order to increase its export capacity from 45 million tonnes/annum to 90 million tonnes/annum. This would have required extensive dredging of soft sediments, powder calcrete, limestone, calcernite/calcretes and the removal of 90 000 m^3 granite by underwater blasting (PRDW, 2007a, b). The proposed expansion also involved the development of two new berths on the southern side (Big Bay side) of the iron ore quay and three new stockpile areas for ore.

Three alternatives were considered for the addition of the stockpile areas (PDNA and SRK Consulting 2007), namely;

1. Southward expansion requiring reclamation of approximately 50 ha of the bay
2. Northward expansion of approximately 36 ha into the undeveloped dune area
3. Eastward expansion of approximately 55 ha into the reclamation dam

An environmental impact assessment was initiated for the project in 2008 based on the final scoping report, but was cancelled prior to completion (N. Jansen – Port of Saldanha pers. comm. 2011).

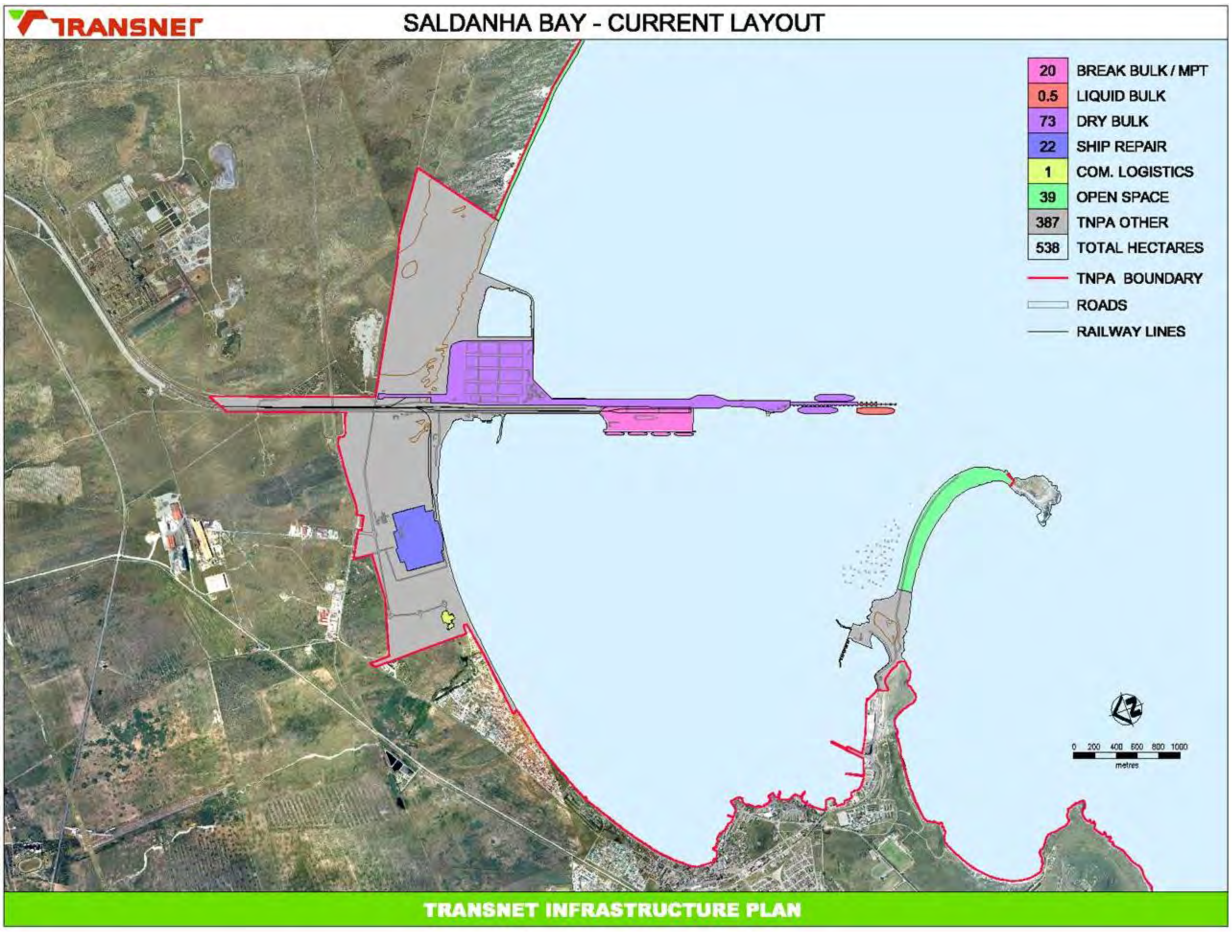


Figure 3.9. Current layout of Transnet Saldanha Bay Port (Source: Lindokuhle Mkhize, Transnet National Port Authority 2012).

In 2012, Transnet NPA proposed an upgrade of the existing General Maintenance Quay (GMQ) and the Rock Quay in Saldanha Bay. This would allow for the docking of larger vessels involved in cargo handling, thus potentially increasing the throughput capacity of the Port of Saldanha. The upgrade will entail the following:

- The extension of the existing GMQ wall by 40 m (20 m on either end) by building up the existing tapered wing walls;
- Replacement of the existing sheet pile wall at the Rock Quay;
- Maintenance dredging of approximately 15 000 m^3 in the navigation area;

- Reclamation (using dredged material) of the area between the Rock Quay and GMQ to create an additional section of quay wall.

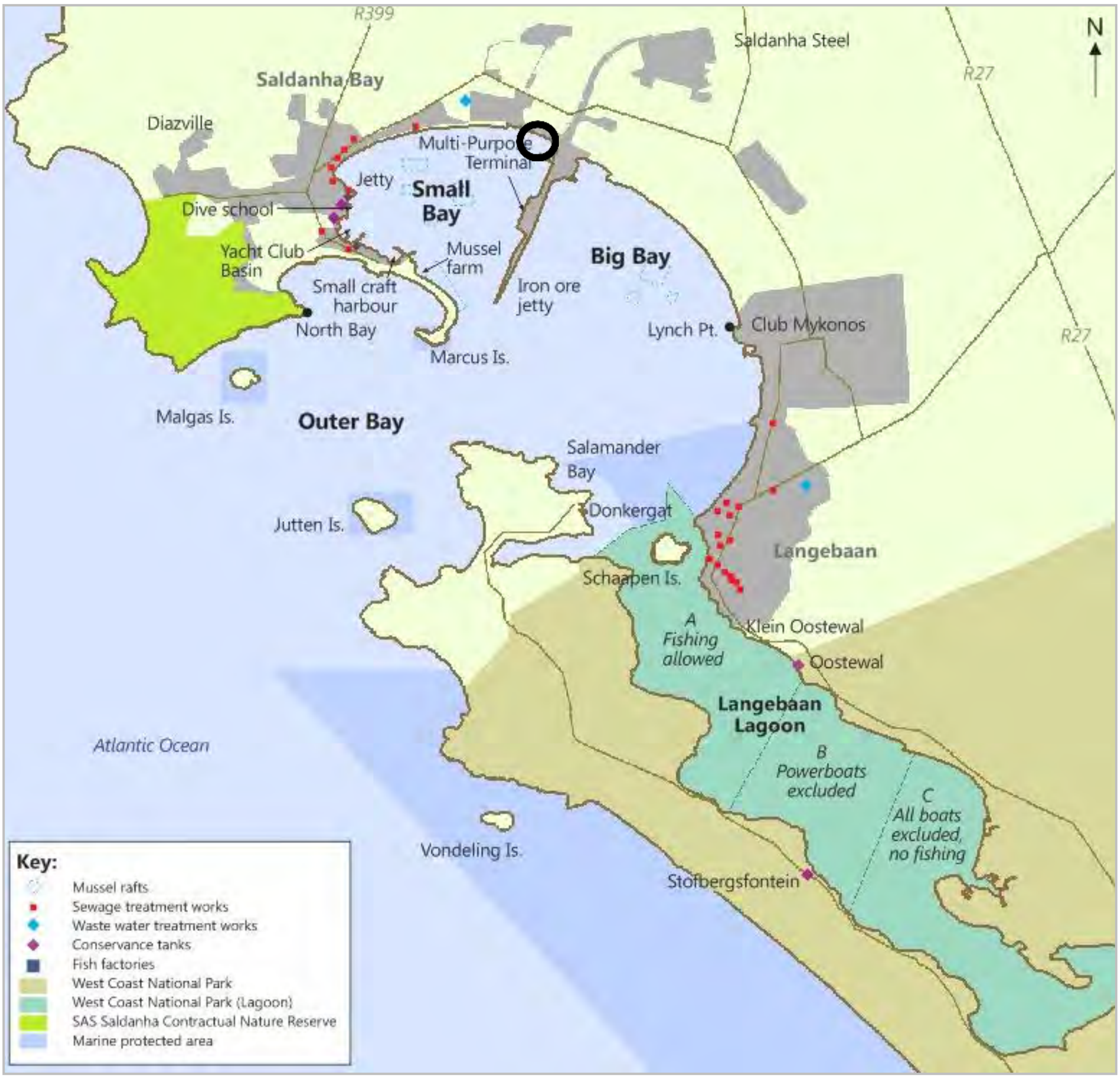


Figure 3.10. Regional map of Saldanha Bay and Langebaan Lagoon. The area of the proposed upgrade is circled in black.

An engineering report prepared by Prestige Retief Dresner Wijnberg (Pty) Ltd (PRDW) considered different dredging methodologies. One involves a pontoon-mounted long-reach excavator and the other, a DOP-pump operated from a small semi-rigid power boat. PRDW (2012) concluded that more significant dredging plumes are likely to be created by mechanical dredging, while hydraulic dredging will minimise the dredge plume.

SRK Consulting was appointed by PRDW on behalf of the TNPA to conduct the required Basic Assessment in terms of the National Environmental Management Act (107 of 1998). Anchor Environmental Consultants were subsequently appointed by SRK Consulting to undertake sediment sampling, to characterise sediment in the dredge area in terms of its granulometry and toxicity, and to provide input regarding potential impacts of the proposed project on the marine environment. As no preferred dredging method has yet been indicated, the assessment of impacts to the marine ecology was based on the worst case scenario (pontoon-mounted long-reach excavator).

It was found that the proposed dredge area is dominated by sandy sediments with a low percentage of mud (<5%) and no gravel. The area adjacent to the proposed dredge area is a deeper channel (11 m as opposed to the average (current) depth of -5m in the proposed dredge area) and has a much higher proportion of mud. The percentage Total Organic Carbon (TOC) and Nitrogen (TON) at all sites within the footprint of the proposed dredge area and at the two control sites was lower than the average recorded in Small Bay during the 2012 State of Saldanha Bay survey. The concentrations of trace metal contaminants in the sediments within the proposed dredge area are below the London Convention Action levels as well as the Effects Range Low (ERL) levels defined by the US National Oceanic and Atmospheric Administration (NOAA). The concentrations of all hydrocarbons tested fell below the detection limit of 100 ppb which is less than the ERL for most compounds and lower than the Effects Range Median (ERM) as defined by NOAA for all cases.

Habitat disturbance associated with dredging and habitat loss associated with reclamation and infrastructure development was evaluated as being of low significance given the disturbed nature of the area and the relatively small extent of the proposed activities, provided appropriate mitigation measures were adopted (these are listed in the conclusion to this study). A desktop study on dredging and sediment transport by PRDW concluded that, although sediment plumes are likely to form, the risk of these dispersing into Small Bay are relatively low due to the weak currents near the GMQ. PRDW did, however, identify a potential risk of dredging plumes dispersing into the bay under strong SE winds conditions. As such, the potential impacts of this were assessed as being of medium significance but could easily be reduced to low through the introduction of appropriate mitigation measures (avoiding dredging under strong SE winds conditions, careful selection of dredging equipment, and real-time continuous monitoring of suspended sediment levels in the water column during dredging operations to ensure that acceptable thresholds are not exceeded and using this information to inform dredging operations). Given the low fraction of fine particles (mud) and low levels of organic, trace metal and hydrocarbon contaminants in sediments in the proposed dredge area, it was considered that any turbidity plumes generated from the dredging activities and dredge spoil disposal were judged as unlikely to be of a toxic nature. Potential impacts from this source were thus assessed to be of medium significance (low with mitigation) with a medium level of confidence. The acknowledged importance of Small Bay as a mariculture area and nursery area for juveniles of commercially important fish species, and the sensitivity of both to impaired water quality, strongly supported this conclusion (medium significance impact in the absence of mitigation). This EIA is currently under consideration by the National Department of Environmental Affairs.

3.3.2 The Sishen-Saldanha oreline expansion project

Transnet in conjunction with six mining companies (Aquila Steel, Assmang, Kumba Iron Ore, PMG, Tshipi e Ntle and UMK) are now proposing an oreline expansion project. This would increase the capacity of the current Sishen-Saldanha railway and port from 60 million tonnes/annum to 90 million tonnes/annum by 2017 in order to satisfy the global demand for iron ore.

Iron ore is mined in Hotazel, Postmasburg and Sishen before being transported on a freight train 861 km to Saldanha Bay. From the train, it is loaded onto conveyor belts and then placed in stockpiles to be loaded into the holds of cargo ships. An increase in rail capacity will result in a greater volume of ore arriving in Saldanha and accordingly an increase in ship traffic will be necessary in order to transport this product globally. At present, 276 iron ore ships arrive and depart on an annual basis. In order to accommodate an increase in ship volume, further adaptations may be required of the port. These could involve further dredging of the Bay to increase the width of shipping channels, and also increased infrastructure in the port itself to improve capacity.

Environmental Resource Management (ERM) were appointed to conduct a pre-feasibility study for the project which was completed in 2012 (M. January, ERM, pers. comm.). Transnet is now conducting the feasibility stage with GIBB engineering consultants and this is due to be completed in 2015 (J. Ball, GIBB, pers. comm.).

3.3.3 Development of a Liquid Petroleum Gas Facility in Saldanha Bay

Sunrise Energy (Pty) Ltd has proposed to build an import facility for Liquid Petroleum Gas (LPG) in Saldanha Bay. LPG is a fuel mix of propane and butane which is in a gaseous form at ambient temperature, but is liquefied under increased pressure or by a temperature decrease. This plant has been proposed in order to supplement current LPG refineries in the Western Cape and ensure that industries dependant on LPG can remain in operation. The information presented below is based upon the information contained in the License Application to the Department of Environmental Affairs and Development Planning (NERSA 2010), and conveyed in a presentation to the Saldanha Bay Water Quality Forum Trust in 2010. The project includes the following components (Figure 3.11):

(i) An offshore marine component for the off-loading of LPG;
(ii) Onshore storage facility comprising six mild steel storage bullets (6 m in diameter and 60 m long) lying horizontally alongside each other in a mounded (buried) storage area (total capacity 15 000 tons);
(iii) A pipeline to the on-shore storage facility;
(iv) Two transfer bullets;
(v) Rail and road gantries and access; and
(vi) A wrapped buried pipeline to industrial customers in Saldanha Bay.

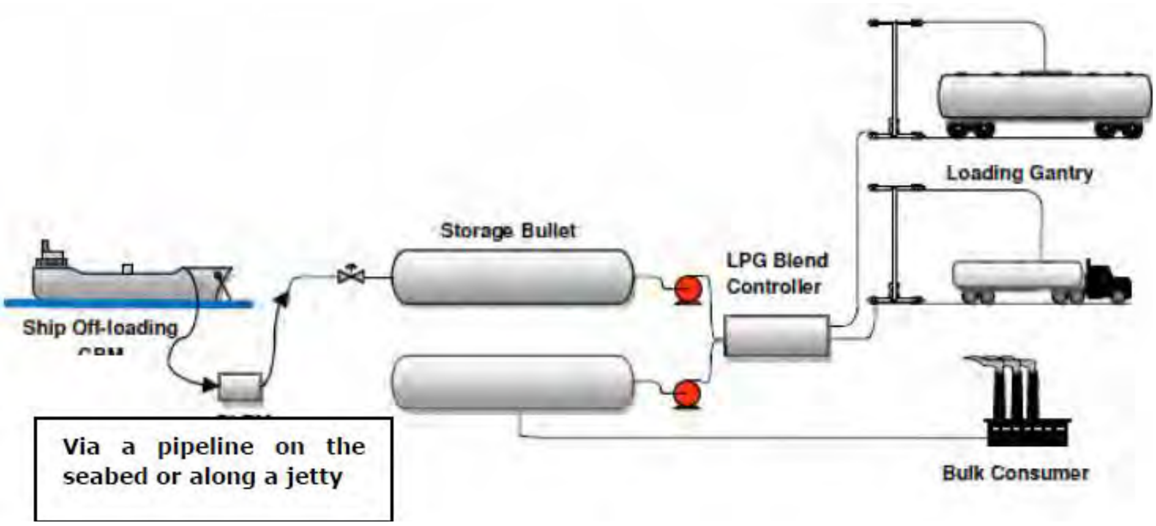


Figure 3.11. An illustration of an LPG transfer scheme (Source: ERM Final Scoping Report 2011)

An Environmental Impact Assessment (EIA) process in terms of section 24 of the National Environmental Management Act (Act No 107 of 1998) (NEMA) was initiated by ERM

Three alternative marine off-loading options were initially investigated in the EIA process, namely; jetty off-loading, single point mooring and a conventional buoy mooring (preferred option) (ERM 2010). Environmental Authorisation (EA) has recently (13 May 2013) been issued by the Department of Environmental Affairs and Development Planning (DEA&DP) for the preferred alternative. The Environmental Management Plan (EMP) for the project requires that environmental/sediment monitoring be undertaken prior to and during installation of marine infrastructure to monitor effects on the surrounding environment, and that annual monitoring of environment/sediment in the vicinity of the marine facilities to assess any potential operational impacts on water quality. It is recommended that such monitoring be undertaken as part of the Saldanha Bay Water Quality Forum Trust`s monitoring program.

3.3.4 Development of the Salamander Bay Boat yard

The Special Forces Regiment of the South African National Defence Force (SANDF) commenced the construction of a boat park in Salamander Bay at the entrance to Langebaan Lagoon in 2009, designed to house boats belonging to the regiment (Figure 3.12). The shores within Salamander Bay are dominated by sandy beaches and are considered sheltered. Soft bottom habitat dominates the subtidal benthos, which attains depths of no greater than 5 m. In order to increase the size of the boat house an area of 550 m^2 within the rocky intertidal zone was excavated and an area of 275 m^2 of subtidal soft bottom habitat was dredged to allow for the placement of two column footings and 25 wet column bases.

Figure 3.12. The Salamander Bay boat park in Saldanha (central strip of the picture).

The construction activities commenced before an Environmental Impact Assessment (EIA) had been conducted. An EIA was commissioned retrospectively in terms of section 24G of the National Environmental Management Act (Act no 107 of 1998). A marine ecology report was compiled as part of the EIA to assess the impacts which had already occurred through the development of the boat yard, and the potential impacts which may result through the long-term use of the facility. The excavation of the intertidal and subtidal areas involved the mechanical removal of large boulders and the dredging of sediments. It was indicated that the impact of this excavation was of a high consequence as it resulted in a permanent loss of habitat and organisms in both the intertidal and subtidal zones. However, the affected area was acknowledged to be small, and the habitat common to the Saldanha Bay system.

The dredging of the subtidal zone, which took place between May 2009 and May 2010, led to the release of a grey coloured sediment plume. Chemical analyses of the water and the dredged sediment indicated that there had been no contamination of cadmium or arsenic and only slightly elevated levels of lead and organic material were detected. The impact of the dredging was considered to be of a low intensity as it was local in extent and occurred intermittently, while the impacts associated with the presence of the plume were considered to be of low consequence and significance for the marine environment. The potentially very serious impacts that may result from the unearthing of iron-sulphide rich sediment were prevented by a combination of natural features and mitigation measures. Sediments were contained behind the quay wall and then removed from the construction site, while the calcites present in the surface sediments minimised the release of sulphuric acid into the environment through oxidation of the iron sulphide present.

The potential impacts, which may result from the long-term use of the new facility, were identified to include beach erosion and accretion, oil and diesel spills, disturbance of fauna and flora associated with increased boat traffic, and the unintentional release of chemicals used in boat cleaning and maintenance. Erosion and accretion of the beaches may occur as the hard flat surfaces of the quay increase flow rates in Salamander Bay. Rocks and sediment were to be reinstated against the quay wall and it was anticipated that this would mitigate any changes to water flow. The impacts of oil and diesel spills, disturbance of fauna and flora associated with increased boat traffic, and the unintentional release of chemicals used in boat cleaning and maintenance were considered to be of low significance given that oil and diesel spills are improbable and that the actual number of boats to be housed at the facility will remain relatively low. Taking into consideration all the impacts caused by the construction of the facility and all the potential impacts associated with the use thereof, it was concluded that the development of the Salamander boat yard was not expected to have significantly negative impacts on the marine environment of Salamander Bay.

Baseline data for trace metals and benthic macrofauna were collected in Salamander Bay in June 2010 (following the dredge events). Follow-up monitoring to assess long-term impacts of the project on sediments and invertebrate macrofauna in Saldanha Bay and Langebaan Lagoon were collected at the same time as the State of the Bay samples in 2011 and are presented in Section 5.3.3.2 5.3.3 of this report.

The Department of Public Works has also recently proposed constructing a breakwater at the same site (Special Forces Regiment 4 Boat Park in Salamander Bay). The upgrade will entail lengthening the existing rocky point to form a new breakwater which will extend 50 m out from the shore (Figure 3.13). Greenminded Environmental have been appointed to conduct the required basic assessment in terms of the National Environmental Management Act (107 of 1998). This study is currently underway.

Figure 3.13. Bird's eye view image of Salamander Bay showing the existing boat park, the two shipwrecks (white) and the site of the proposed breakwater (red). The breakwater may either be positioned A) on the outside of the two shipwrecks, or B) on top of sections of the shipwrecks.

3.3.5 Shipping, ballast water discharges, and oil spills

3.3.5.1 Shipping and ballast water

Shipping traffic comes with a number of associated risks, especially in a port environment, where the risks of collisions and breakdowns increase owing to the fact that shipping traffic is concentrated, vessels are required to perform difficult manoeuvres, and are required to discharge or take up ballast water in lieu of cargo that has been loaded or unloaded. Saldanha Bay is home to the Port of Saldanha, which is one of the largest ports in South Africa receiving over 400 ships per annum. The Port is comprised of an Iron export terminal for export of iron ore, an oil terminal for import of crude oil, a multi-purpose terminal dedicated mostly for export of lead, copper and zinc concentrates, and the Sea Harvest/Cold Store terminal that is dedicated to frozen fish products (Figure 3.9). There are also facilities for small vessel within the Port of Saldanha including the Government jetty used mostly by fishing vessels, the TNPA small boat harbour used mainly for the berthing and maintenance of TNPA workboats and tugs, and the Mossgas quay. Discharge of ballast by vessels visiting the iron ore terminal in particular poses a significant risk to the health of Saldanha Bay and Langebaan Lagoon.

Ships carrying ballast water has been recorded since the late nineteenth century and by the 1950s had completely phased out the older practice of carrying dry ballast. Ballast is essential for the efficient handling and stability of ships during ocean crossings and when entering a port. Ballast water is either freshwater or seawater taken up at ports of departure and discharged on arrival where new water can be pumped aboard, the volume dependant on the cargo load. The conversion to ballast water set off a new wave of marine invasions, as species with a larval or planktonic phase in their life cycle were now able to be transported long distances between ports on board ships. Furthermore, because ballast water is usually loaded in shallow and often turbid port areas, sediment is also loaded along with the water and this can support a host of infaunal species (Hewitt *et al* 2009). The global nature of the shipping industry makes it inevitable that many ships must load ballast water in one area and discharge it in another, which has an increasing potential to transport non-indigenous species to new areas. It has been estimated that major cargo vessels annually transport nearly 10 billion tonnes of ballast water worldwide, indicating the global dimension of the problem (Gollasch *et al*. 2002). It is estimated that on average, 3,000-4,000 species are transported between continents by ships each day (Carlton and Geller 1993). Once released into ports, these non-indigenous species have the potential to establish in a new environment which is potentially free of predators, parasites and diseases, and thereby outcompete and impact on native species and ecosystem functions, fishing and aquaculture industries, as well as public health (Gollasch *et al*. 2002). Invasive species include planktonic dinoflagellates and copepods, nektonic Scyphozoa, Ctenophora, Mysidacea, benthos such as annelid oligochaeta and polychaeta, crustacean brachyura and molluscan bivalves, and fish (Carlton and Geller 1993). Carlton and Geller (1993) record 45 'invasions' attributable to ballast water discharges in various coastal states around the world. In view of the recorded negative effects of alien species transfers, the International Maritime Organisation (IMO) considers the introduction of harmful aquatic organisms and pathogens to new environments via ships ballast water as one of the four greatest threats to the world's oceans (Awad *et al.* 2003).

In South Africa to date, an estimated total of 85 marine species are recorded as introduced mostly through shipping activities or mariculture and at least 62 of these are thought to occur in Saldanha Bay-Langebaan Lagoon (Mead *et al.* 2011). Three of the species recorded in Saldanha Bay are considered invasive: the Mediterranean mussel *Mytilus galloprovincialis,* the European green crab *Carcinus maenas* (Griffiths *et al.* 1992; Robinson *et al.* 2005) and the barnacle *Balanus glandula* (Laird and Griffiths 2008). Most of the introduced species are found in sheltered areas such as harbours and are believed to have been introduced through shipping activities, mostly ballast water and biofouling. Because ballast water is normally loaded in sheltered harbours, the species that are transported also originate from these habitats and thus have a difficult time adapting to South Africa's exposed coast. This might, in part, explain the low number of introduced species that have become invasive along the coast (Griffiths *et al.* 2008). Most introduced species in South Africa occur along the west and south coasts; very few having been recorded east of Port Elizabeth. This corresponds with the predominant trade routes being between South Africa and the cooler temperate regions of Europe, from where most of the marine introductions in South Africa originate (Awad *et al.* 2003). Chapter 1111 of this report deals with alien invasive species in Saldanha Bay in more detail.)

Other potentially negative effects of ballast water discharges are contaminants that may be transported with the water. Carter (1996) reports on concentrations of trace metals such as cadmium, copper, zinc and lead amongst others that have been detected in ballast water and ballast tank sediments from ships deballasting in Saldanha Bay. Of particular concern are the high concentrations of copper and zinc that in many instances exceeded the South African Water Quality Criteria (DWAF 1995a) (Table 3.4). These discharges are almost certainly contributing to trace metal loading in the water column (as indicated by their concentration in filter-feeding organisms in the Bay - see §3.3.5.1 for more on this issue).

Table 3.4. Mean trace metal concentrations in ballast water (mg/l) and ballast tank sediments from ships deballasting in Saldanha Bay (Source: Carter 1996) and SA Water Quality Guideline limits (DWAF 1995a). Those measurements in red denote non-compliance with the guidelines.

	Water	Sediment	SA WQ Guideline limit
Cd	0.005	0.040	0.004
Cu	0.005	0.057	0.005
Zn	0.130	0.800	0.025
Pb	0.015	0.003	0.012
Cr	0.025	0.056	0.008
Ni	0.010	0.160	0.025

Ballast water carried by ships visiting the Port of Saldanha is released in two stages - a first release is made upon entering Saldanha Bay (i.e. Big Bay) and the second once the ship is berthed and loading (Awad *et al*. 2003). As a result as much as 50% of the ballast water is released in the vicinity of the iron ore quay on either the Small Bay side or Big Bay side of the quay depending on which side the ship is berthed.

The total number of ships entering the Port of Saldanha has nearly doubled in the last two decades and in 2012, there were 475 ships which visited the port (Figure 3.14). The average size of vessels in use has also increased over the years, and as a result, the volume of ballast water discharged to the Bay has increased by more than double since 2004, with almost 22 million tons of ballast water being discharged during 2012 (Figure 3.15). Iron ore tankers are responsible for most of the observed increase in vessel traffic and are the ones responsible for discharging the greatest volume of ballast water into the Bay.

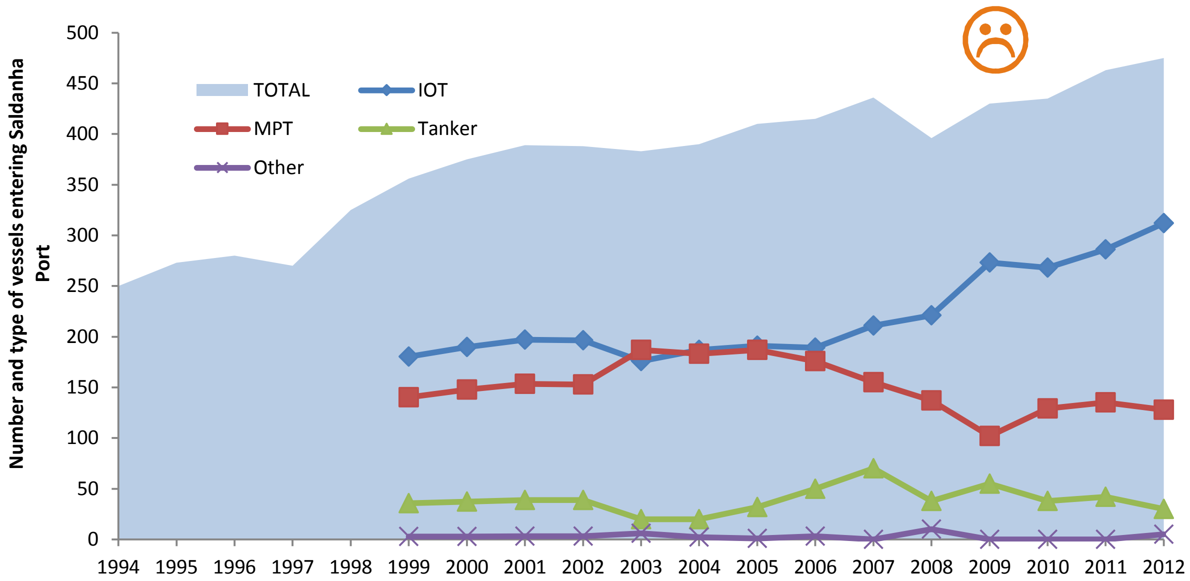


Figure 3.14. Number and types of vessels entering Saldanha Port from 1994-2012. (Sources: Marangoni 1998; Awad *et al*. 2003, Transnet-NPA unpublished data 2003-2012).

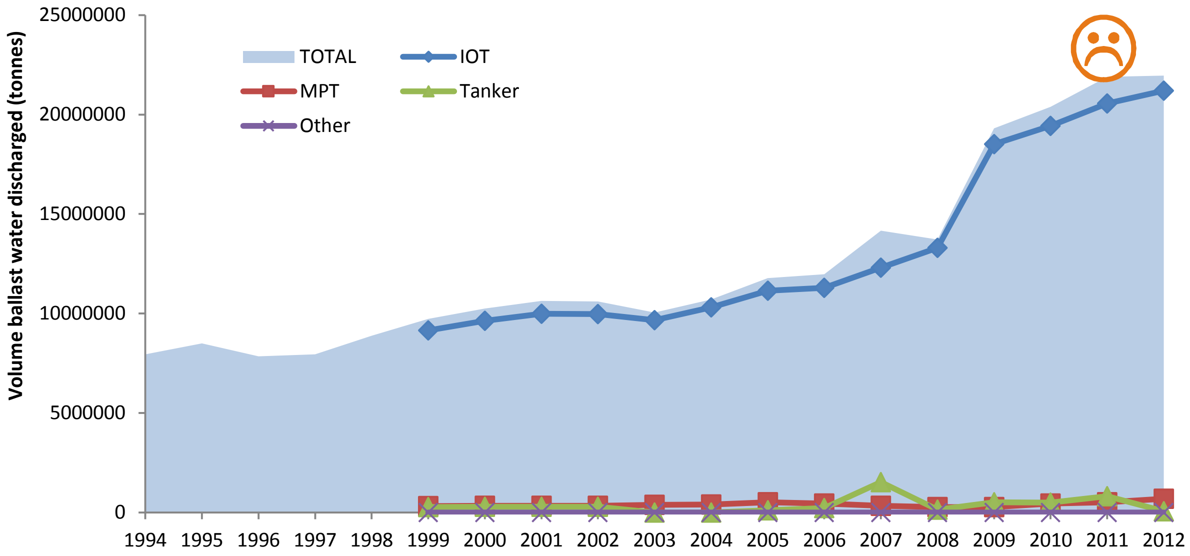


Figure 3.15. Volumes of ballast water discharge in tonnes by the different types of vessels entering Saldanha Port between 1994 and 2012. The data for 1999-2002 is an average of the total volume of discharge for those years. (Sources: Marangoni 1998; Awad *et al*. 2003, Transnet-NPA unpublished data 2003-2012).

3.3.5.2 Oil spills

Also associated with this increase in shipping traffic, is an increase in the incidence and risk of oil spills. In South Africa there have been a total of four major oil spills, two off Cape Town (1983 and 2000), one in the vicinity of Dassen Island (1994), and one in close to the St. Lucia estuary in KwaZulu-Natal (2002). In Saldanha Bay there have to date been no comparable oils spills (Martin Slabber – SAMSA, pers. comm.). Minor spills do occur however, which have the potential to severely impact the surrounding environment. In April 2002, about 10 tons of oil spilled into the sea in Saldanha Bay when a relief valve malfunctioned on a super-tanker. Booms were immediately placed around the tanker and the spill was contained. More recently in July 2007, a Sea Harvest ship spilled oil into the harbour while re-fuelling, the spill was managed but left oil on rocks and probably affected small invertebrates living on the rocks and in the surrounding sand.

In 2007 Transnet National Ports Authority and Oil Pollution Control South Africa (OPC), a subsidiary of CEF (Central Energy Fund) signed an agreement which substantially improved procedures in the event of oil spills and put in place measures to effectively help prevent spills in the Port of Saldanha. These are laid out in detail in the "Port of Saldanha oil spill contingency plan" (Transnet 2010). The plan is intended to ensure a rapid response to oil spills within the port itself and by approaching vessels. The plan interfaces with the "National oil spill contingency plan" and with the "Terminal oil spill contingency plan" and has a three tiered response to oils spills:

Tier 1: Spill of less than approximately 7 tonnes
Response where the containment, clean up and rescue of contaminated fauna can be dealt with within the boundaries of the vessel, berth or a small geographical area. The incident has no impact outside the operational area but poses a potential emergency condition.

Tier 2: Spill between 7-300 tonnes
Response where the nature of the incident puts it beyond the containment, clean up and rescue of contaminated fauna capabilities of the ship or terminal operator.

The containment of clean up requires the use of some of or the government and industry resources.

Tier 3: Spill in excess of 300 tonnes.
Response where the nature of the incident puts it beyond containment, clean up and rescue of contaminated fauna capabilities of a national or regional response. This is a large spill which has the probability of causing severe environmental and human health problems.

Upon entry to the port, all vessels undergo an inspection by the Pollution Control Officer (PCO) to minimise risks of pollution in the port through checking overboard valves and ensuring the master and crew of the vessel are familiar with the Port's environmental requirements. Every tanker is contained by booms while oil is being pumped, ensuring immediate containment of any minor spills (Martin Sabber – SAMSA, pers. comm.). The OPC has facilities and equipment to effectively secure an oil spill as well as for the handling of shore contamination including oiled sea birds and beach-cleaning equipment. However, given the environmental sensitivity of the Saldanha Bay area, particularly Langebaan Lagoon, prevention is the most important focus (CEF 2008).

3.3.6 Reverse Osmosis Desalination Plants

Desalination refers to a water treatment process whereby salts are removed from saline water to produce fresh water. Reverse Osmosis (RO) involves forcing water through a semi-permeable membrane under high pressure, leaving the dissolved salts and other solutes behind on the surface of the membrane. One desalination plant has been built in Saldanha and discharges brine into the Bay (belonging to Transet-NPA) while a second has been proposed (by the West Coast District Municipality).

3.3.6.1 Transnet-NPA Desalination Plant

Transnet-NPA (TNPA) recently commissioned a 1200 m^3/day RO desalination facility to supplement the supply of freshwater to the Iron Ore Terminal in the Port of Saldanha. Freshwater is required at the terminal for dust mitigation during the loading and offloading of iron ore (Figure 3.16). An additional 1200 m^3/day (1 RO module) of fresh water is currently required to supplement the current municipal allocation, however, in the long-term it is envisioned that the RO Plant will produce a total capacity of 3 600 m^3/day potable water (up to 3 RO modules). The project which involved the design, manufacture, supply, delivery to site, installation, testing and commissioning of one 1200 m^3/day RO train, was awarded to VWS Envig in 2008. The installation of the plant commenced in 2010 and is currently in the commissioning phase, following receipt of the Water Use License from the Department of Water Affairs in January 2012.

Figure 3.16 An iron ore vessel being loaded showing associated iron ore dust emission. Freshwater from the Transnet RO plant will be used to mitigate this impact by wetting the ore before loading.

3.3.6.1.1 Technical details and design

To achieve the planned 1200 m³/day production of potable water, the plant will require an intake of more than twice that amount of seawater (2 667 m³/day); with approximately 45% being converted to potable water, and 55% being returned to the sea as brine (1 467 m³/day) and backwash waste. The seawater will be passed through a pre-treatment process to remove suspended solids, biological matter and other particles that may clog the RO membranes. Pre-treatment will also entail the addition of a non-oxidising biocide to control biological activity, and a coagulant to assist with the removal of suspended solids and organics and reduce the turbidity. Water will be passed through a dual media filter (DMF) to remove suspended solids and organics. This filter will need be backwashed periodically. The pre-treated sea water will then be dosed with anti-scalant and forced through a semi-permeable membrane (within the RO modules) by a high pressure pump. This process results in a high salinity solution (brine) and a very low salinity solution (fresh water). The brine and DMF backwash water will be discharged into the sea and the potable water will be diverted to the storage reservoir(s), with a capacity of 5 000 m³, for use in dust mitigation.

The flocculant and non-oxidising biocide used during the pre-treatment process as well as the anti-scalant will be blended and discharged with the brine into the sea. Cleaning In Place (CIP) chemicals will be used for the cleaning of the RO membranes, and the wash water containing these chemicals will be disposed of either via the municipal sewer system (with approval from the municipality) or at a suitable disposal site, and will not be contained in the brine discharged back into the ocean.

The RO plant is located on the southern section of the quay of the iron ore handling facility, on a gravel area adjacent to the Multi-Purpose Terminal. The environment at this site was entirely transformed and there was no indigenous vegetation found on the site prior to the construction. The intake system was designed as 6 boreholes located on the beach, alongside the Multi-Purpose Terminal. However, during the pilot operational phase, it was discovered that these beach wells contained oil deposits. As a result, the intake pipelines are now located in the Bay. The discharge pipeline is located at Caisson 3 and consists of a single port diffuser at 16 to 18 m water depth.

3.3.6.1.2 Potential Impacts

A Basic Assessment commenced in 2007 and was conducted by PD Naidoo & Associates (Pty) Ltd and SRK Consulting Scientists and Engineers Joint Venture (PDNA/SRK Joint Venture). A total of four specialist studies were commissioned to assess the potential impacts. These studies included a botanical study, a marine study, a groundwater resources study and a heritage resources assessment. Three alternative sites for the location of the RO Plant and various site specific alternatives with regards to intake and discharge location and infrastructure were considered in each of the studies. The site and specifications authorised for the construction of the RO plant (described above) are hereafter referred to as the "authorized site". The botanical study, groundwater resources study and heritage study indicated that the construction and operation of the RO plant would have no significant impacts on the indigenous flora or vegetation, the groundwater or any heritage resources, at the authorized site respectively.

The key impacts to the marine environment that were identified in the marine study fell into two main categories; those associated with the construction phase and those associated with the operational phase (Van Ballegooyen *et al*. 2007). The issues associated with the **construction phase** included:

- Onshore construction issues: human activity, air, noise and vibration pollution, dust, blasting and piling driving, disturbance of coastal flora and fauna);
- Construction and installation of a water discharge and intake pipeline issues: construction site, pipe lay-down areas, trenching of pipeline(s) in the marine environment and consequent disturbance of subtidal biota); and
- Construction and installation of intake boreholes.

The issues associated with the **operational phase** included:

- altered flows at the discharge resulting in ecological impacts (*e.g*. flow distortion/changes at the discharge, and effects on natural sediment dynamics);
- the effect of elevated salinities in the brine water discharged to the bay;
- biocidal action of non-oxidising biocides such as dibromonitrilopropionamide (DBNPA) in the effluent;
- the effects of co-discharged waste water constituents, including possible tainting effects affecting both mariculture activities and fish factory processing in the bay;
- the effect of the discharged effluent having a higher temperature than the receiving environment;
- direct changes in dissolved oxygen content due to the difference between the ambient dissolved oxygen concentrations and those in the discharged effluent; and
- indirect changes in dissolved oxygen content of the water column and sediments due to changes in phytoplankton production as a result of altered nutrient dynamics (both in terms of changes in nutrient inflows and vertical mixing of nutrients) and altered remineralisation rates (with related changes in nutrient concentrations in near bottom waters) associated with near bottom changes in seawater temperature due to the brine discharge plume.

The marine specialist report assessed the impacts of RO plants with several different designs at three sites. It was expected that the impacts of construction at the authorized site would be very low as these construction activities would have utilized existing infrastructure as their basis and construction activities would not have been extensive. Operational impacts associated with the intake of water through boreholes were expected to be insignificant to low. All potential impacts associated with the discharge of brine through a pipeline at Caisson 3 (the authorized site) were expected to be of a low to very low level, with the exception of the use of oxygen scavengers with no mitigation measures, which was expected to have a medium level impact. A monitoring programme was included in the marine specialist report. Aspects of the environment which require monitoring include the benthic macrofauna communities, dissolved oxygen levels in the near bottom waters in the immediate vicinity, trace metals and tainting substances in the RO plant effluent, toxicity of the effluent, and temperature, salinity and suspended solids in the near-field. Monitoring activities commenced during the second half of 2010 in order to establish a baseline prior to the RO plant coming into operation. Follow-up monitoring will be undertaken when the plant is finally brought online.

3.3.6.2 West Coast District Municipality Desalination Plant

The West Coast District Municipality (WCDM) has proposed the construction of an additional RO plant in the Saldanha Bay area. The West Coast has limited water resources (due to its semi-arid nature) but yet is required to supply 22 towns and 876 farms across the region with potable water. Currently water is supplied by the Voëlvlei and Misverstand dams on the Berg River, and the Langebaan road aquifer, however, the volume allocated from these sources for this is close to the maximum possible. During a feasibility study in 2007 to assess the most viable solution to the water scarcity issue in the WCDM, several sources of additional water were considered. These included:

- The Twenty-four Rivers Scheme
- Lowlift pumps at the Misverstand Dam
- The Michel's pass Diversion
- Groundwater potential
- Water Quality Management
- Alien vegetation clearing

The most cost-effective solution was a 25 500 m^3/day sea water desalination plant. This would be a climate-independent solution, offering 100% water security. It would facilitate sustainable economic development in towns such as Malmesbury and Langebaan, both of which have been identified as high growth potential areas.

3.3.6.2.1 Technical details and design

The proposed plant will be located in Saldanha Bay and have an intake capacity of approximately 60 000 m^3/day with a production of 25 500 m^3/day permeate water when operating at full capacity. An estimated 34 500 m^3 of brine will be discharged daily into the sea. However, the intake capacity could be increased to 58 million m^3/annum to assist with brine dispersion and allow for recirculation which will minimise biofouling of the pipes.

The plant will have a lifespan of 25 years (with a possibility of extension) and will be built in three phases (of 8 500 m^3/day production) to be completed and running at full capacity by 2026.

The plant (excluding pipelines) will cover an area of approximately ± 50 000 m^2 and be composed of the following elements:

- Feedwater intake and brine discharge structures and associated terrestrial and marine pipelines
- Feedwater pump station
- Feedwater transfer pipelines from the pump station to the SWRO plant

- Pre-treatment facility to pre-filter the water before it enters the RO membranes
- Buildings housing RO membranes to produce the permeate for potable water
- Extension/upgrading of existing roads and infrastructure
- Development of internal access roads
- Chemical infrastructure for conditioning of the pre- and post-filtered water
- Pump stations for permeate and brine
- Electrical power lines and transformer yards
- Holding reservoir (size TBC)
- Sludge handling and disposal facilities
- Formation of dunes with excess material
- Operational site of ± 50 000 m^2 including all infrastructures and surrounded by a security fence
- Distribution terrestrial pipelines for permeate from the holding reservoir to the Municipal Bestaansklip Reservoir along existing servitudes, road reserves or cadastral boundaries.

3.3.6.2.2 Potential Impacts

A Scoping and Environmental Impact Assessment Process is required in order to ensure compliance with the National Environmental Management Act (Act no 107 of 1998) as amended and the EIA Regulations (2010).

The CSIR was commissioned by Worley Parsons South Africa (Pty) Ltd) to prepare an environmental screening study which identified potential impacts with ten alternative locations and the associated infrastructure routes for power and pipelines. Taking into account technical, financial and environmental concerns, two sites were identified as the most feasible with minimal impacts. These sites were investigated in further detail during the Environmental Impact Assessment (EIA) phase and are included in the Final EIA report (CSIR 2013).

One of these sites is located on the property of the ArcelorMittal Smelter in Saldanha Bay. The marine feed water intake would operate in Big Bay, while the brine discharge site is currently under investigation for either Big Bay or Danger Bay. Constructing the plant at the former site would require long-term access to the Transnet iron ore jetty, which has not been authorised. In addition the quality of the intake water may be of concern in future. For example the presence of sediment, organic nutrients, bacteria, heavy metals and calcrete fines could affect the maintenance of the plant, as well as increase costs associated with pre-treatment processes and membrane preservation. In addition, impacts from mariculture, shipping activities and dredging could affect the plant (CSIR 2013).

The other (preferred) location for the RO plant, towards the northern head of Danger Bay on a portion of municipal owned land. In this scenario, both the intake and discharge lines will be located in Danger Bay (Figure 3.17). This site is situated within a South African National Biodiversity Institute (SANBI) designated Conservation Biodiversity Area (CBA) with a highly sensitive area which contains one vulnerable plant species and a medium sensitive area with one threatened plant species. The Danger Bay site has, however, previously been mined for sand resulting in fragmented vegetation patches and vehicle tracks. If the sensitive areas are avoided and mitigation measures applied, the terrestrial ecological impact have been rated as being of medium significance (CSIR 2013).

Several major impacts (of medium significance) associated with the construction of the RO plant were identified in the EIA. These are the following:

- Disturbance and destruction of intertidal beach macrofauna during pipeline;

- Accidental spillage or leakage of fuel, chemicals, or lubricants;
- Disturbance and destruction of subtidal sandy and rocky reef biota and;
- Effects of blasting on macrophytes, invertebrates and marine communities (including fish and marine mammals).

Figure 3.17 Map showing preferred location of intake and discharge points for the WCDM desalination plant. Source: CSIR 2013.

However the majority of issues are related to the operational phase including:

- Altered flows at the intake and discharge resulting in ecological impacts;
- Elevated salinities due to the brine water discharge;
- Biocidal action of residual chlorine and/or other non-oxidising;
- Effects of co-discharged waste water constituents;
- Elevated temperatures of the effluent relative to the receiving environment;
- Changes (direct and indirect) in dissolved oxygen;
- Changes in phytoplankton production as a result of changes in nutrient dynamics and;
- Changes in remineralisation rates.

However, given the "no-go" alternative with predicted severely limited water supplies for the West Coast District Municipality, the mitigation of these impacts is seen to be the most logical way forwards.

3.3.7 Sewage and associated waste waters

Sewage is by far the most dominant (by volume) waste product discharged into rivers, estuaries and coastal waters worldwide. However, sewage is not the only organic constituent of waste water, received by sewage treatment plants, other degradable organic wastes, which can result in nutrient loading, include:

- Agricultural waste
- Food processing wastes (e.g. from fish factories and slaughter houses)
- Brewing and distillery wastes
- Paper pulp mill wastes
- Chemical industry wastes
- Oil spillages

Our present knowledge of the impacts of waste waters on water systems has, until recently, largely been based on lake-river eutrophication studies. However, recent focus on how anthropogenic nutrient enrichment is affecting near-shore coastal ecosystems is emerging (for a review see Cloern 2001; Howarth *et al* 2011). In general, the primarily organic discharge in waste water effluents contains high concentrations of nutrients such as nitrates and phosphates (essentially the ingredients in fertilizers). Existing records provide compelling evidence of a rapid increase in the availability of Nitrogen and Phosphorus to coastal ecosystems since the mid-1950's (Cloern 2001). These nutrients stimulate the growth and primary production of fast-growing algae such as phytoplankton and ephemeral macroalgae, at the expense of slower-growing vascular plants and perennial macroalgae (seagrasses) which are better adapted to low-nutrient environments. This process requires oxygen, and with high nutrient inputs, oxygen concentrations in the water can become reduced which can lead to deoxygenation or hypoxia in the receiving water (Cloern 2001). When phytoplankton die and settle to the bottom, aerobic and anaerobic bacteria continue the process of degradation. However, if the supply rate of organic material continues for an extended period, sediments can become depleted of oxygen leaving only anaerobic bacteria to process the organic matter. This then generates chemical by-products such as hydrogen sulphide and methane, which are toxic to most marine organisms (Clark, 1986). The sediments and the benthic communities they support are thus amongst the most sensitive components of coastal ecosystems to hypoxia and eutrophication (Cloern 2001). The ecological responses associated with decreasing oxygen saturation in shallow coastal systems include the initial escape of sensitive demersal fish, followed by mortality of bivalves and crustaceans, and finally mortality of other molluscs, with extreme loss of benthic diversity (Vaquer-Sunyer and Duarte 2008; Howarth *et al* 2011). Vaquer-Sunyer and Duarte (2008) propose a precautionary limit for oxygen concentrations at 4.6 mg O_2/litre equivalent to the 90th percentile of mean lethal concentrations, to avoid catastrophic mortality events, except for the most sensitive crab species, and effectively conserve marine biodiversity.

Some of the indirect consequences of an increase in phytoplankton biomass and high levels of nutrient loading are a decrease in water transparency and an increase in epiphyte grown, both of which have been shown to limit the habitat of benthic plants such as seagrasses (Orth and Moore 1983). Furthermore, there are several studies documenting the effects that shifts in natural marine concentrations, and ratios of nitrates, phosphates and elements such ammonia and silica, have on marine organisms (Herman *et al* 1996; van Katwijk *et al* 1997; Hodgkiss and Ho 1997; Howarth *et al* 2011). For instance, the depletion of dissolved Silica in coastal systems, as a result of nutrient enrichment, water management and the building of dams, is believed to be linked to worldwide increases in flagellate/dinoflagellate species which are associated with harmful algal blooms, and are toxic to other biota (Hodgkiss and Ho 1997; Howarth *et al* 2011). The toxic effect that elevated concentrations of ammonia have on plants has been documented for *Zostera marina*, and shows that plants held for two weeks in concentrations as low as 125 µmol start to become necrotic and die (van Katwijk *et al* 1997).

The effects of organic enrichment, on benthic macrofauna in Saldanha Bay, have been well documented (Jackson and McGibbon 1991, Kruger 2002, Kruger *et al*. 2005, Stenton-Dozey 2001). Tourism and mariculture are both important growth industries in and around Saldanha Bay, and both are dependent on good water quality (Jackson and Gibbon 1991). The growth of attached algae such as *Ulva sp.* and *Enteromorpha sp.* on beaches is a common sign of sewage pollution (Clark 1986). Nitrogen loading in Langebaan Lagoon associated with leakage of conservancy/septic tanks and storm water runoff has resulted in localised blooms of *Ulva sp*. in the past. In the summer 1993-94, a bloom of *Ulva lactuca* in Saldanha Bay was linked to discharge of nitrogen from pelagic fish processing plants (Monteiro *et al.* 1997). Dense patches of *Ulva sp.* are also occasionally found in the shallow embayment of Oudepos (CSIR 2002). Organic loading is a particular problem in Small Bay due to reduced wave action and water movement in this part of the Bay caused by harbour structures such as the Ore Terminal and the Causeway, as well as the multitude of organic pollution sources within this area (e.g. fish factories, mariculture farms, sewage outfalls, sewage overflow from pump stations, and storm water runoff). Langebaan Lagoon is also sheltered from wave action but strong tidal action and the shallow nature of the lagoon make it less susceptible to the long term deposition of pollutants and organic matter (Monteiro 1999 in CSIR 2002).

There is one waste water treatment works (WWTW) in Saldanha and one in Langebaan. The WWTW in Saldanha disposes of treated effluent into the Bok River where it drains into Small Bay adjacent to the Blouwaterbaai Resort. In addition to sewage waste, the WWTW in Saldanha also receives and treats industrial waste water from a range of industries in Saldanha:

- Sea Harvest
- Hoedtjiesbaai Hotel
- Protea Hotel
- Southern Seas Fishing (no longer in operation)
- Bongolethu Fishing Enterprises
- SA Lobster
- Cape Reef Products
- TNPA
- Arcelor Mittal
- Namaqua Sands
- Abattoir
- Duferco

These discharges reportedly often place the plant under considerable stress and result in the discharge of substandard effluent (CSIR 2002).

Until recently the Langebaan WWTW did not discharge any effluent into the sea as all of it was used it to irrigate the local golf course. However, increasing volumes of effluent received by this plant is yielding more water than is required for irrigation and some of this is now discharged into the Bay. There are nine sewage pump stations in Saldanha Bay and two conservancy tanks, all of which are situated on the western border of Small Bay. The conservancy tanks are positioned adjacent to the Yacht Club. There are eighteen sewage pump stations in Langebaan situated throughout the town, many of which are near the edge of the lagoon, and three conservancy tanks spread around the edge of the lagoon at Oostewal, Stofbergsfontein and Oudepos (Figure 3.18).

Sewage effluent can enter the Saldanha/Langebaan marine environment via three routes, namely:

- Discharge of treated sewage effluent in the Bok River which drains into Small Bay;

- Overflow of sewage pump stations as a result of pump malfunction of power failures;
- Seepage or overflow from septic or conservancy tanks.

Historically a number of these pump stations used to overflow from time to time directly into the Bay when the pumps malfunctioned. This is now a rare event, however, as much of the associated infrastructure has been upgraded recently and is now regularly maintained.

The Saldanha WWTW operates under an exemption issued by the Department of Water Affairs (DWAF) in terms of the Water Act of 1956 which authorises the release of a total volume of 958 000 m^3 per year. The volume of waste water that is permitted to be released from the Langebaan WWTW is 588 000 m^3 per year. Up until recently at least, most of the waste water from this plant was used to irrigate the golf course. Table 3.5 shows the general standards as specified under the Water Act 54 (1956), and the revised general limits specified under the National Water Act 36 of 1998 for various other parameters and substances contained in the released waters of the WWTW of Saldanha and Langebaan.

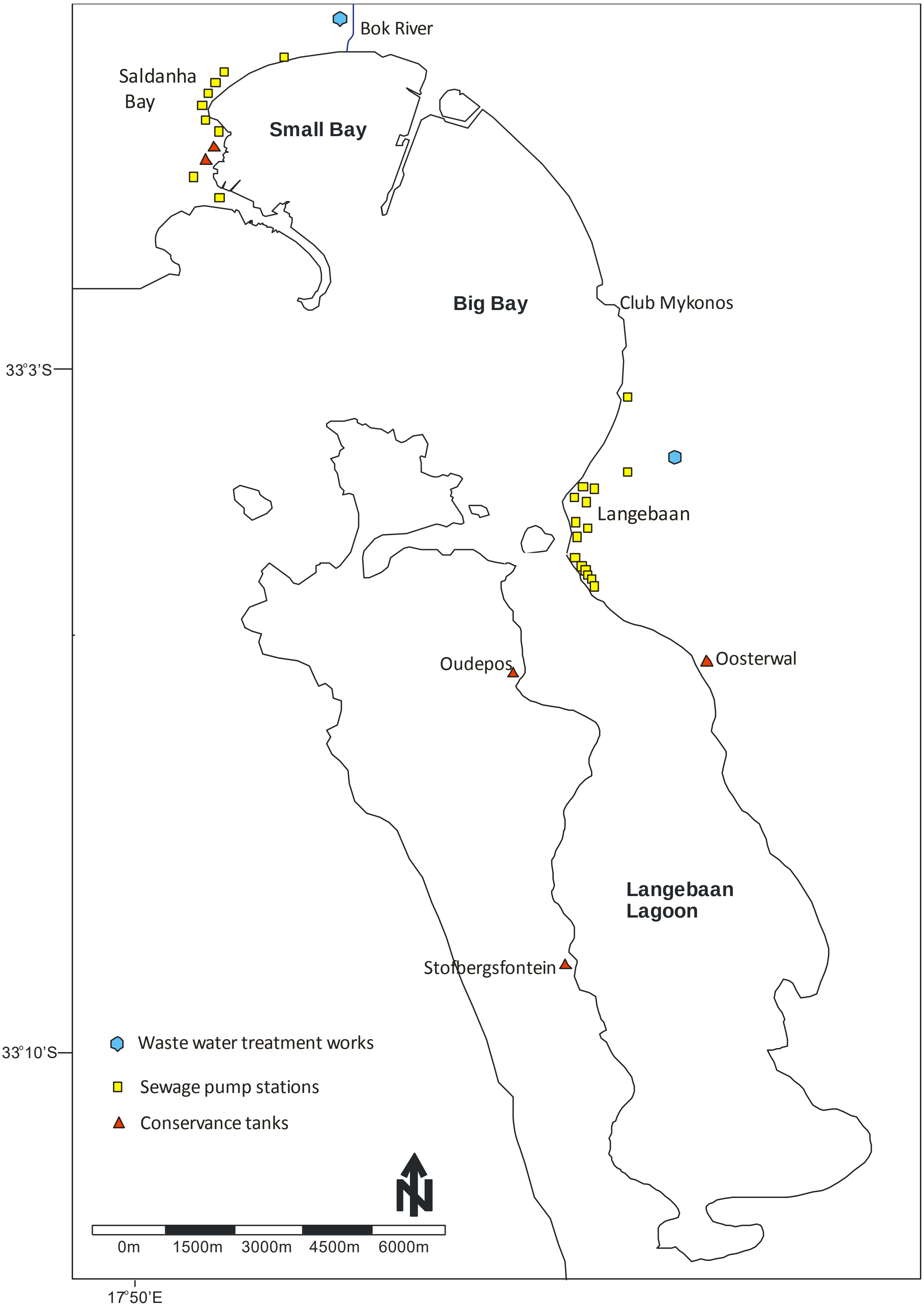


Figure 3.18. Location of waste water treatment works, sewage pump stations and conservancy tanks in Saldanha and Langebaan area (2011).

Table 3.5. General standards as specified under the Water Act 54 (1956) and revised general limits specified under the National Water Act 36 of 1998.

SUBSTANCE/PARAMETER	GENERAL STANDARDS UNDER THE WATER ACT (1956)	GENERAL LIMIT FOR GENERAL AUTHORISATION UNDER THE NATIONAL WATER ACT (1998)
Temperature	35°C	-
Electrical Conductivity measured in milliSiemens per meter (mS/m)	75	70 above intake to a maximum of 150
pH	5.5-9.5	5.5-9.5
Chemical Oxygen Demand (mg/l)	75	75 (after removal of algae)
Suspended Solids (mg/l)	25	25
Soap, oil or grease (mg/l)	2.5	2.5
Ortho-Phosphate as P (mg/l)	-	10
Nitrate/Nitrite as Nitrogen (mg/l)	-	15
Ammonia (ionised and un-ionised) as N (mg/l)	10	3
Fluoride (mg/l)	1	1
Chlorine as Free Chlorine (mg/l)	0.1	0.25
Dissolved Cyanide (mg/l)	0.5	0.02
Dissolved Arsenic (mg/l)	0.5	0.02
Dissolved Cadmium(mg/l)	0.05	0.005
Dissolved Chromium (VI) (mg/l)	0.05	0.05
Dissolved Copper (mg/l)	1	0.01
Dissolved Iron (mg/l)	-	0.3
Dissolved Lead (mg/l)	0.1	0.01
Dissolved Manganese (mg/l)	0.4	0.1
Mercury and its compounds (mg/l)	0.02	0.005
Dissolved Selenium (mg/l)	0.05	0.02
Dissolved Zinc (mg/l)	5.0	0.1
Boron (mg/l)	1	1
Phenolic compounds as phenol (mg/l)	0.1	-
Faecal Coliforms (per 100 ml)	100	1000

3.3.7.1 Water quality parameters associated with the Saldanha WWTW

Before 2005, the average daily volume discharged rarely exceeded 2000 m^3, but volumes of effluent released have subsequently been increasing steadily over time. During the winter months in 2009, 2010 and 2011, there were three occasions of non-compliance where average volumes discharged exceeded the maximum annual limit (which equates to an average daily maximum of 2625 m^3) allowed in terms of the exemption issued by DWAF (Figure 3.19).

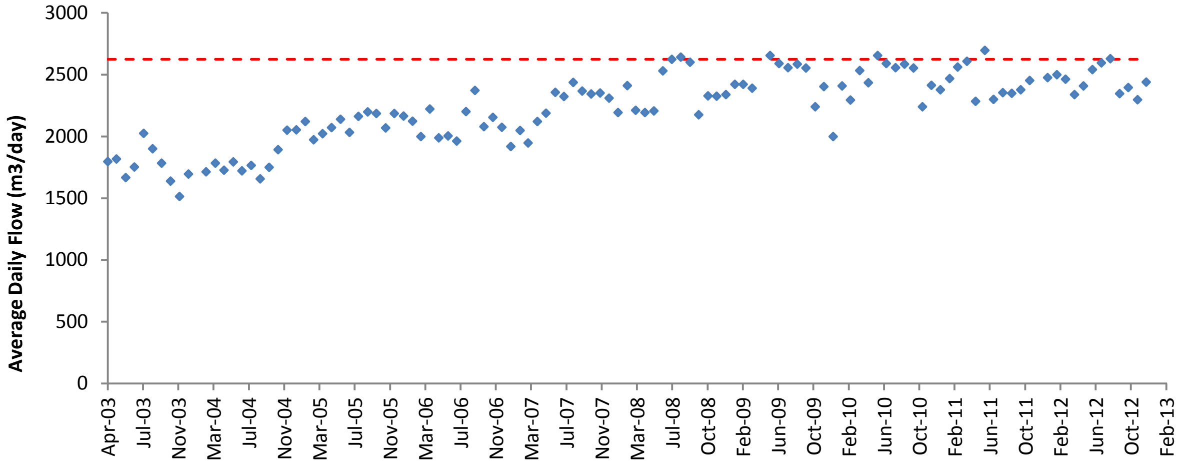


Figure 3.19. Monthly trends in the volume of effluent released from the Saldanha WWTW, Apr 2003-December 2012, and authorised total volume per year expressed as a daily limit (red line). Allowable discharge limits as specified in terms of the exemption issued by DWAF under the National Water Act 1998 are represented by the dashed red line.

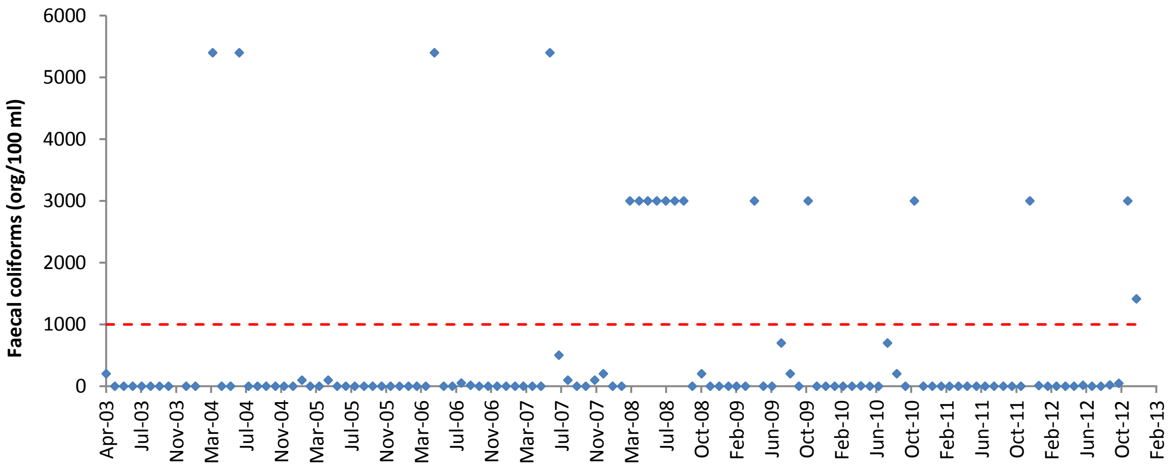


Figure 3.20. Monthly trends in the numbers of Faecal Coliforms in effluent released from the Saldanha WWTW, April 2003 - December 2012. Allowable limits as specified in terms of a General Authorisation under the National Water Act 1998 are represented by the dashed red line.

Concentrations of faecal coliforms in the effluent from the WWTW exceeded allowable limits specified on 17 occasions since 2003 (15% of the time) (Figure 3.20). Allowable limits for Total Suspended Solids were exceeded on 10% of the occasions on which measurements were made (Figure 3.21), and measurements for Chemical Oxygen Demand (COD) exceeded allowable limits 23% of the time (Figure 3.22). Chemical Oxygen Demand is commonly used to indirectly measure the amount of organic compounds in water.

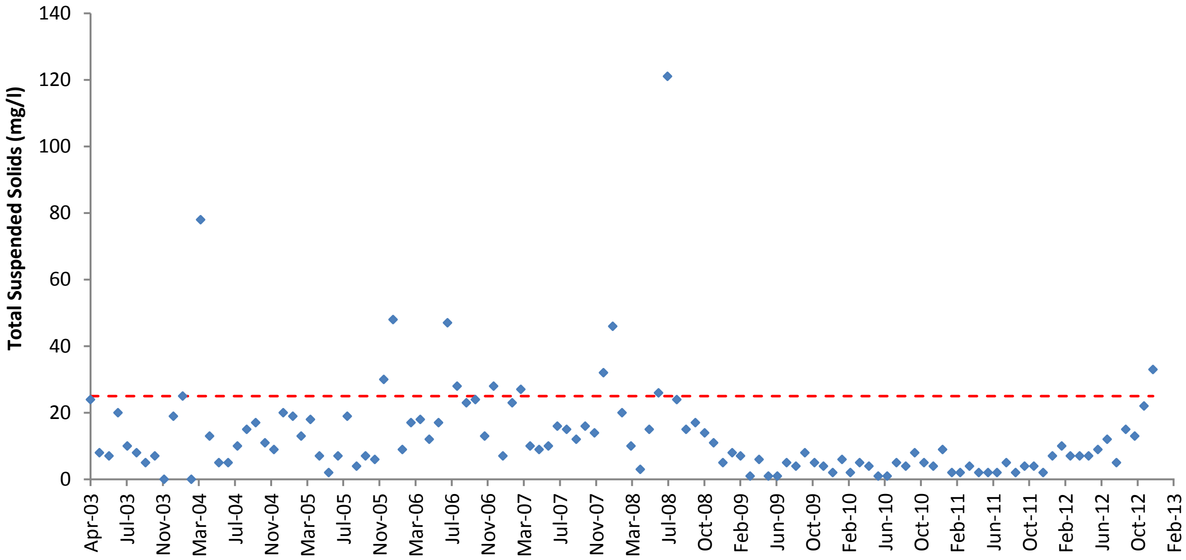


Figure 3.21. Monthly trends in the numbers of Total Suspended Solids in effluent released from the Saldanha WWTW, April 2003 - December 2012. Allowable limits as specified in terms of a General Authorisation under the National Water Act 1998 are represented by the dashed red line.

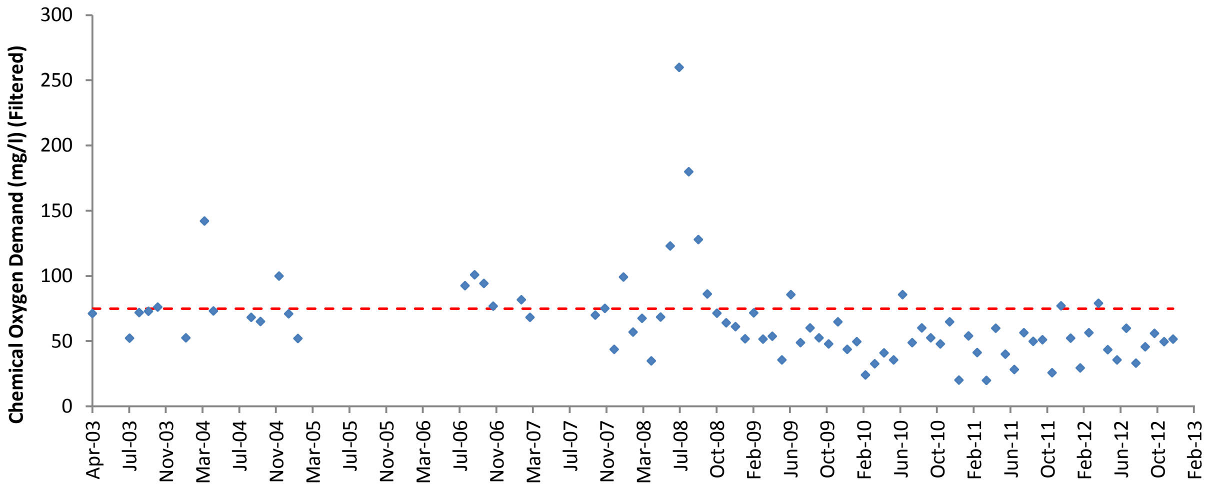


Figure 3.22. Monthly trends in the numbers of Chemical Oxygen Demand in effluent released from the Saldanha WWTW, April 2003 - December 2012. Allowable limits as specified in terms of a General Authorisation under the National Water Act 1998 are represented by the red line.

A worrying sign is the levels of Ammonia Nitrogen discharged which are consistently above the allowable margin of 3 mg/l; allowable limits being exceeded 95% of the time (Figure 3.23). Nitrate Nitrogen limits were exceeded on 16% of the occasions (Figure 3.24).

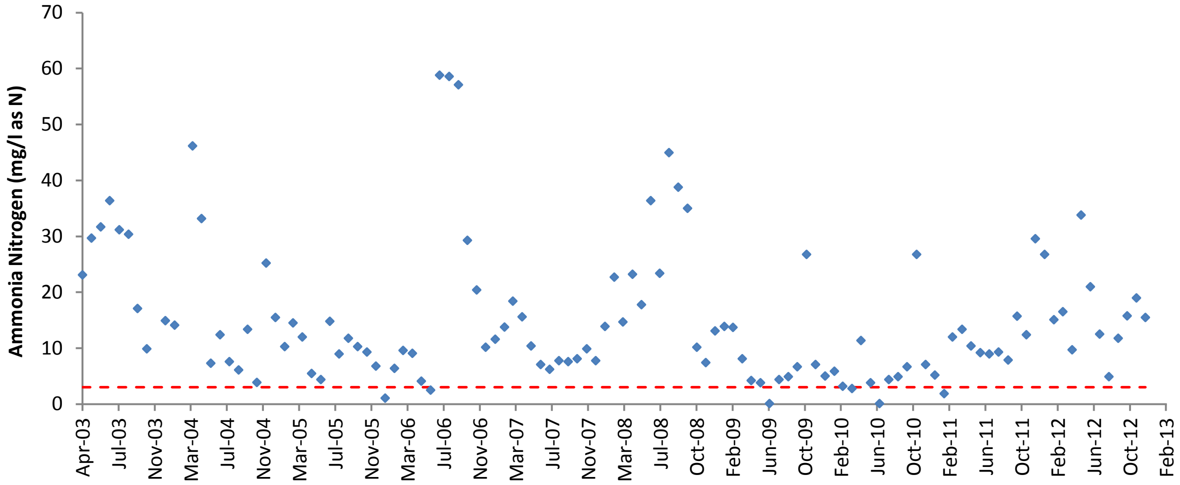


Figure 3.23. Monthly trends in Ammonia Nitrogen for effluent released from the Saldanha WWTW Apr 2003-December 2012. Allowable limits as specified in terms of a General Authorisation under the National Water Act 1998 are represented by the red line.

The concentration of phosphorus in the effluent has only been measured since October 2007 showing a distinct seasonal pattern, with the highest values occurring during the summer months and lowest values in winter. This is consistent with the higher influx of visitors during summer. In recent years values have remained mostly below the allowable limit of 10 mg/l, however limits were exceeded on several occasions in 2012 (Figure 3.25).

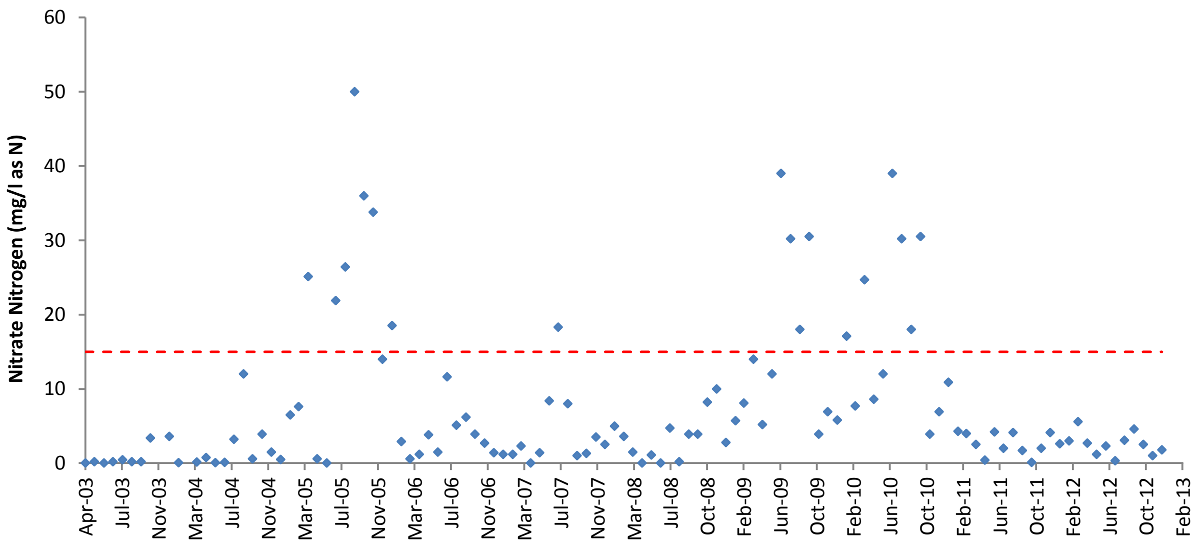


Figure 3.24. Monthly trends in Nitrate Nitrogen for effluent released from the Saldanha WWTW Apr 2003 - December 2012. Allowable limits as specified in terms of a General Authorisation under the National Water Act 1998 are represented by the red line.

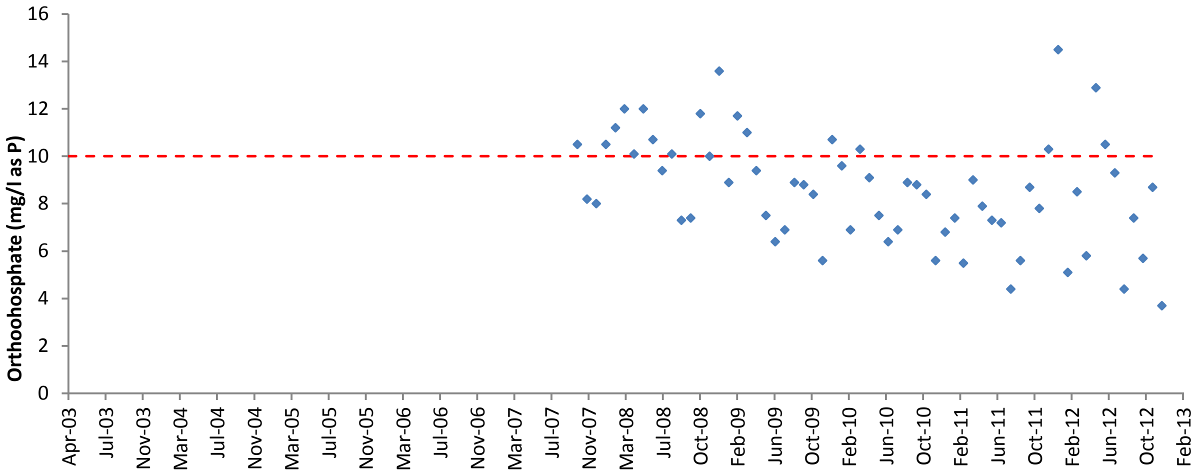


Figure 3.25. Monthly trends in water quality parameters Orthophosphate for effluent released from the Saldanha WWTW Apr 2003-December 2012. Allowable limits as specified in terms of a General Authorisation under the National Water Act 1998 are represented by the red line.

Chlorine gas, generated through a process of electrolysis, is toxic to most organisms and is used to sterilise the final effluent (i.e. kill bacteria and other pathogens present in the effluent) before it is released into settling ponds or the environment. Chlorine breaks down naturally through reaction with organic matter and in the presence of sunlight, but should not exceed a concentration 0.25 mg/l in terms of the general authorisation under which the Saldanha WWTW operates. The frequency of exceedence for this parameters since 2003 is 47% (Figure 3.26).

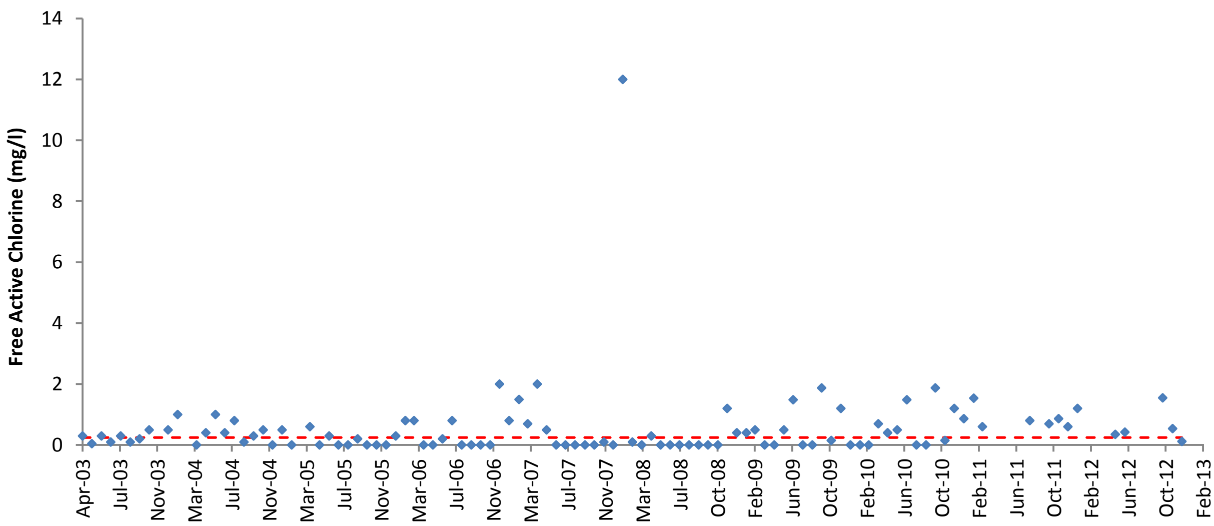


Figure 3.26. Monthly trends in Free Active Chlorine for effluent released from the Saldanha WWTW Apr 2003-December 2012. Allowable limits as specified in terms of a General Authorisation under the National Water Act 1998 are represented by the red line.

3.3.7.2 Water quality parameters associated with the Langebaan WWTW

Water quality parameters associated with effluent from the Langebaan WWTW have only been measured since June 2009. The water use license permits an average daily flow of 1611 m^3 but this is frequently exceeded (Figure 3.27). Faecal coliforms counts have exceeded the allowable limits specified on 6 occasions since 2009, which correspond to 14% of time (Figure 3.28).

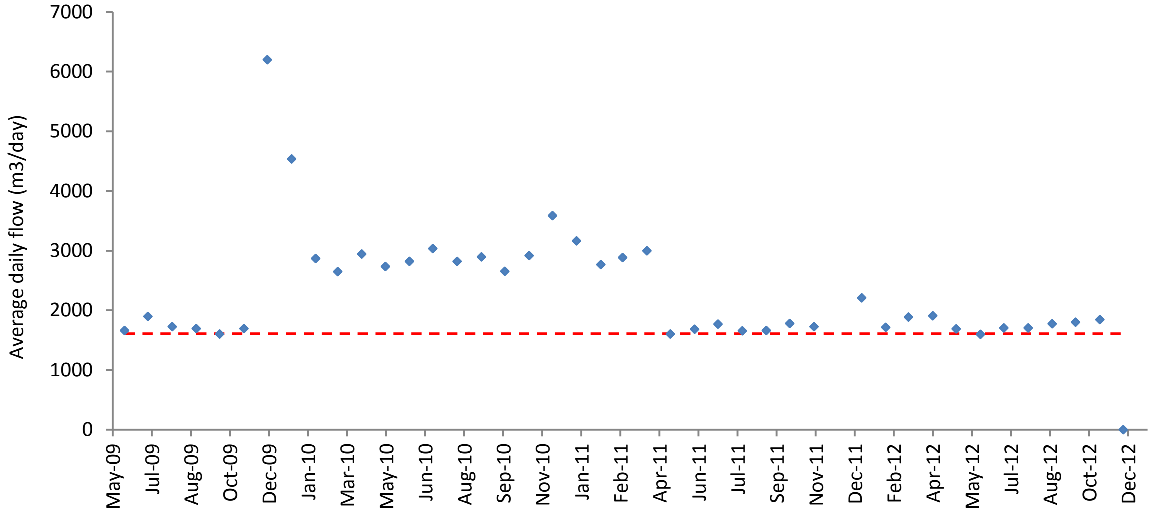


Figure 3.27. Trends in the volume of effluent discharged from the Langebaan WWTW in the period June 2009-December 2012.

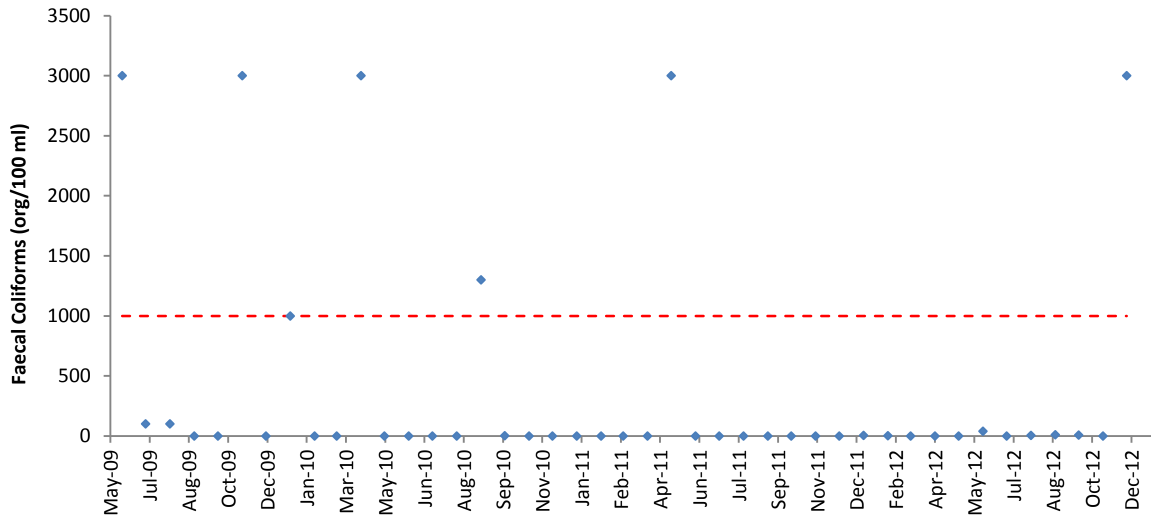


Figure 3.28. Monthly trends in the numbers of Faecal Coliforms in effluent released from the Langebaan WWTW, June 2009 - December 2012. Allowable limits as specified in terms of a General Authorisation under the National Water Act 1998 are represented by the red line.

Total Suspended Solids have only once exceeded the allowable limits (Figure 3.29), while measurements for Chemical Oxygen Demand exceeded allowable limits on 23% of sampling occasions but no non-compliance in 2012 (Figure 3.30).

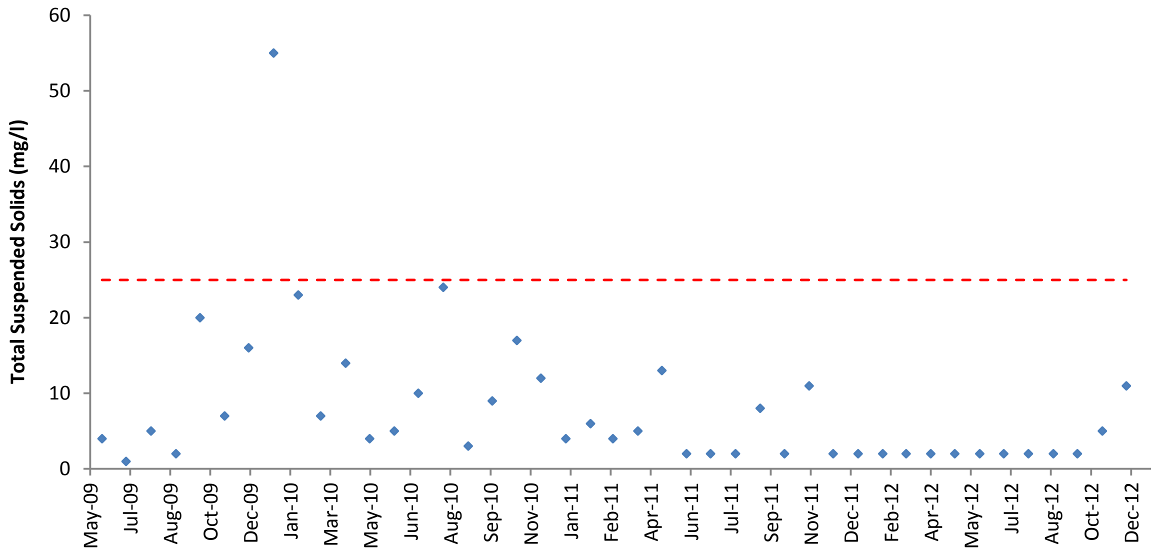


Figure 3.29. Monthly trends in Total Suspended Solids in effluent released from the Langebaan WWTW, June 2009 - December 2012. Allowable limits as specified in terms of a General Authorisation under the National Water Act 1998 are represented by the red line.

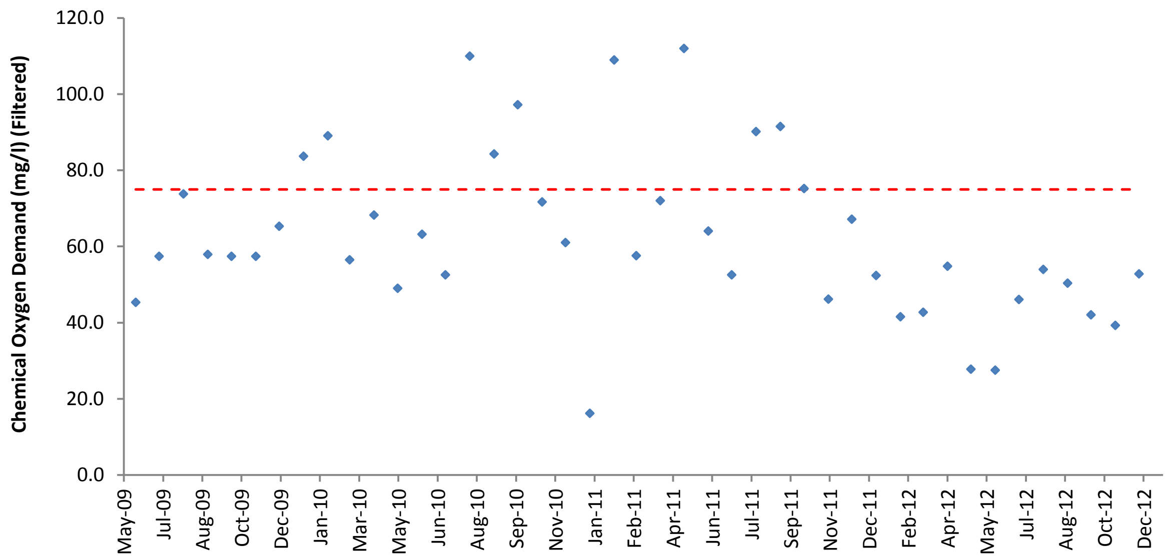


Figure 3.30. Monthly trends in Chemical Oxygen Demand (filtered) in effluent released from the Langebaan WWTW, June 2009-December 2012. Allowable limits as specified in terms of a General Authorisation under the National Water Act 1998 are represented by the red line.

The levels of Ammonia Nitrogen discharged from the Langebaan WWTW have frequently (86% of the time) exceeded the allowable limit of 3 mg/l since measurements began in June 2009, however, concentrations have decreased overall (Figure 3.31). In 2012, 8 out of 12 sampling occasions showed non-compliance, however only three of these recorded concentrations greater than 10 mg/l. The levels of Nitrate Nitrogen have not exceeded allowable limits since measurements began in 2009 (Figure 3.32). Orthophosphate concentrations fluctuate in a seasonal pattern similar to that seen at the Saldanha WWTW and have in the last two years remained below the allowable limit (Figure 3.33). Levels of free active chlorine have exceeded allowable limits 68% of the time since monitoring commenced (Figure 3.34), with a maximum of 6.6 mg/l recorded in November 2012.

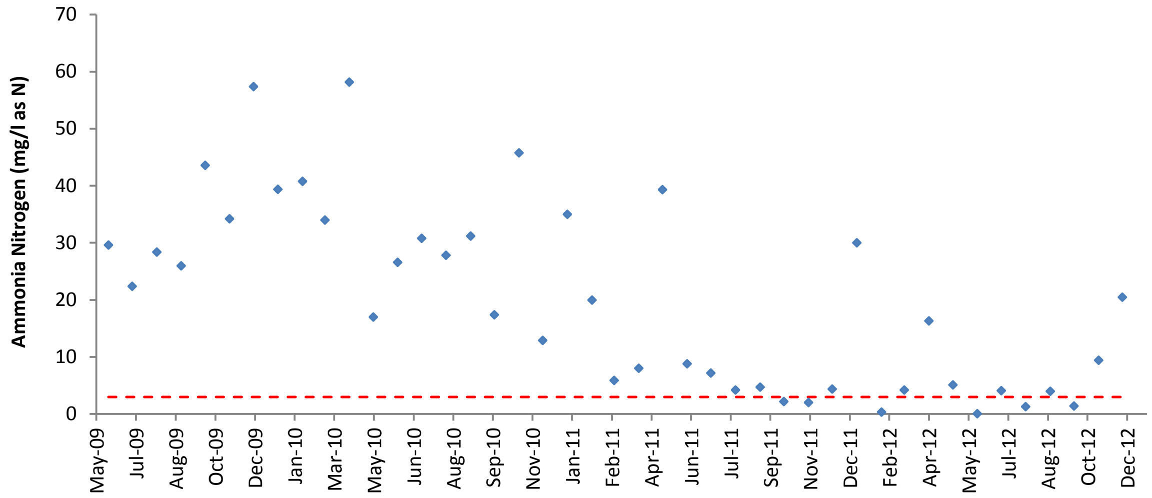


Figure 3.31. Monthly trends in the concentration of Ammonia Nitrate in effluent from Langebaan WWTW, June 2009 - December 2012. Allowable limits as specified in terms of a General Authorisation under the National Water Act 1998 are represented by the red line.

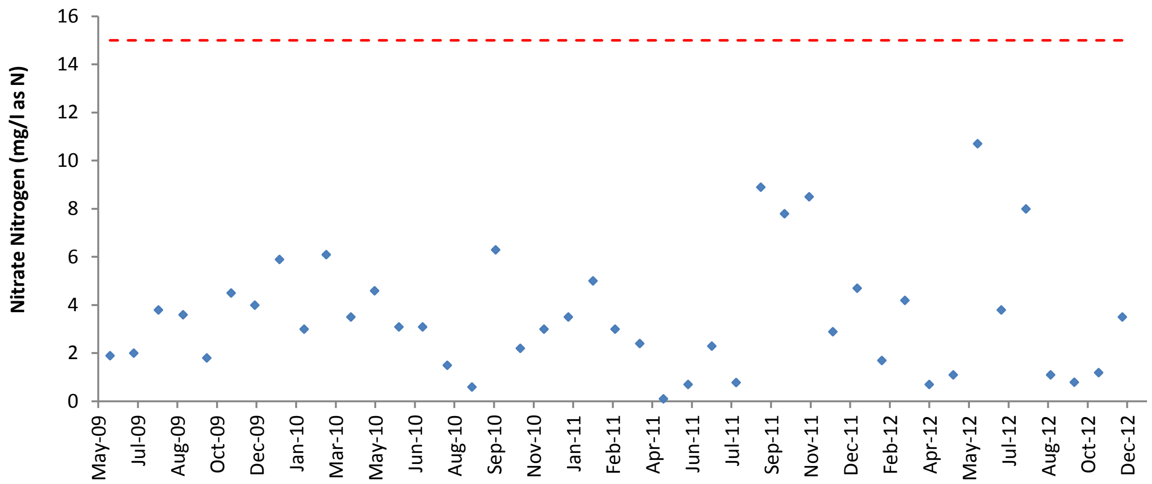


Figure 3.32. Monthly trends in the concentration of Nitrate Nitrogen in effluent from Langebaan WWTW, June 2009 - December 2012. Allowable limits as specified in terms of a General Authorisation under the National Water Act 1998 are represented by the red line.

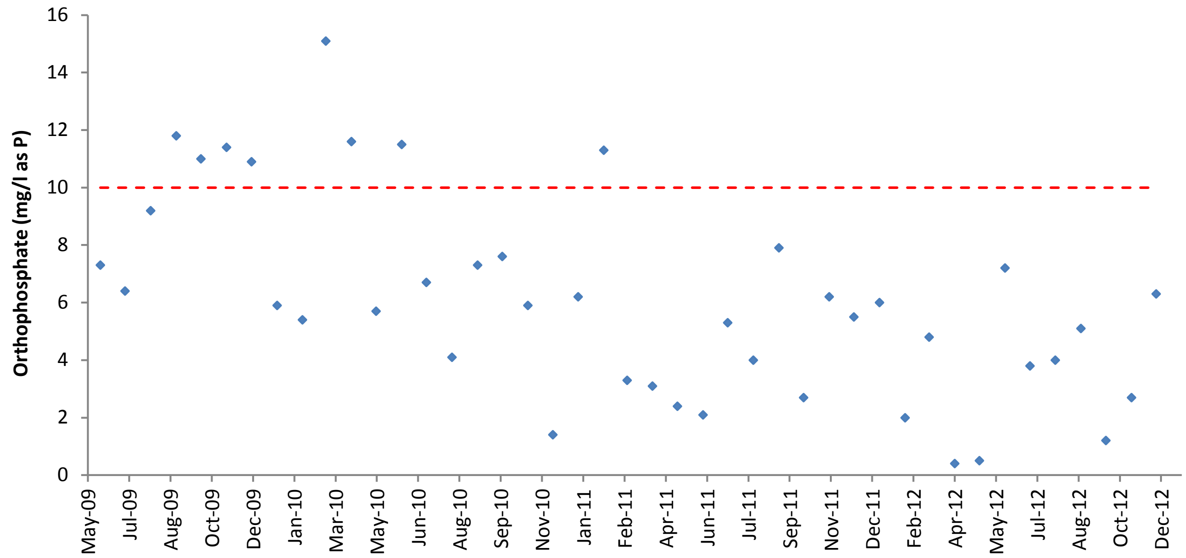


Figure 3.33. Monthly trends in the concentration of Orthophosphate in effluent from Langebaan WWTW, June 2009 - December 2012. Allowable limits as specified in terms of a General Authorisation under the National Water Act 1998 are represented by the red line.

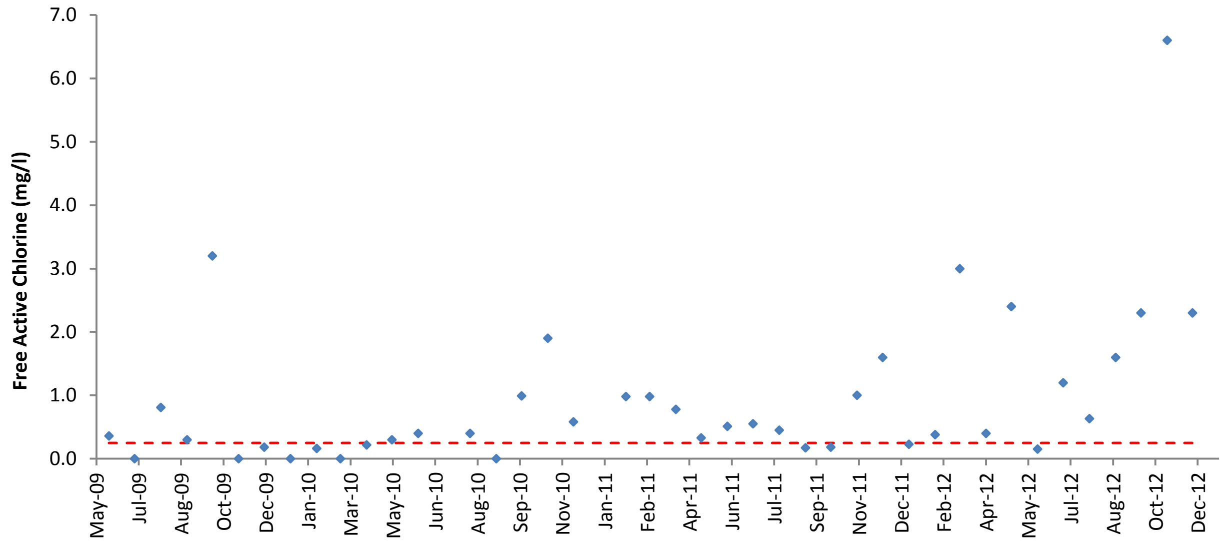


Figure 3.34. Monthly trends in the concentration of Free Active Chlorine in effluent from Langebaan WWTW, June 2009 - December 2012. Allowable limits as specified in terms of a General Authorisation under the National Water Act 1998 are represented by the red line.

3.3.7.3 Summary

In general the waste water treatment plans at Saldanha and Langebaan are having difficulties in keeping effluent levels and water quality parameters under the general limits specified under the National Water Act 36 of 1998. Of particular concern are the consistently high concentrations of Nitrates, in the form of Ammonia, being discharged at Saldanha. Ammonia has been shown to be toxic to plants and seagrasses at very low concentrations. Chlorine levels in the effluent from both WWTWs are high, exceeding the limits of a general authorisation almost half of the time.

3.3.8 Storm water

Storm water runoff, which occurs when rain flows over impervious surfaces into waterways, is one of the major non-point sources of pollution in Saldanha Bay (CSIR 2002). Sealed surfaces such as driveways, streets and pavements prevent rainwater from soaking into the ground and the runoff typically flows directly into rivers, estuaries or coastal waters. Storm water running over these surfaces accumulates debris and chemical contaminants, which then enters water bodies untreated and may eventually lead to environmental degradation. Contaminants that are commonly introduced into coastal areas via storm water runoff include metals (Lead and Zinc in particular), fertilizers, hydrocarbons (oil and petrol from motor vehicles), debris (especially plastics), bacteria and pathogens and hazardous household wastes such as insecticides, pesticides and solvents (EPA, 2003).

It is very difficult to characterise and treat storm water runoff prior to discharge, and this is due to the varying composition of the discharge as well as the large number of discharge points. The best way of dealing with contaminants in storm water runoff is to target the source of the problem by finding ways that prevent contaminants from entering storm water systems. This involves public education as well as effort from town planning and municipalities to implement storm water management programmes.

The volume of storm water runoff entering waterways is directly related to the catchment characteristics and rainfall. The larger the urban footprint and the higher rainfall, the greater the runoff will be. At the beginning of a storm a "first flush effect" is observed, in which accumulated contaminants are washed from surfaces resulting in a peak in the concentrations of contaminants in the waterways (CSIR 2002). Several studies have shown degradation in aquatic environments in response to an increase in the volume of storm water runoff (Booth and Jackson 1997, Bay *et al.* 2003).

Storm water runoff that could potentially impact the marine environment in Saldanha and Langebaan originates from industrial areas (490 ha), the Saldanha Bay residential area (475 ha), industrial sites surrounding the Port of Saldanha (281 ha), and Langebaan to Club Mykonos (827 ha) (Figure 3.35). All residential and industrial storm water outlets drain into the sea. There are approximately 15 outlets in the Saldanha Bay residential area. Historically, storm water from the Port of Saldanha and ore terminal was allowed to overflow into the Bay but most of this is now diverted to storm water evaporation ponds and any material settling in these ponds is trucked to a landfill site. The number of storm water outlets in Saldanha Bay industrial zone (along the western margin of Small Bay) and the number of drains between Langebaan and Club Mykonos is unknown (CSIR 2002).

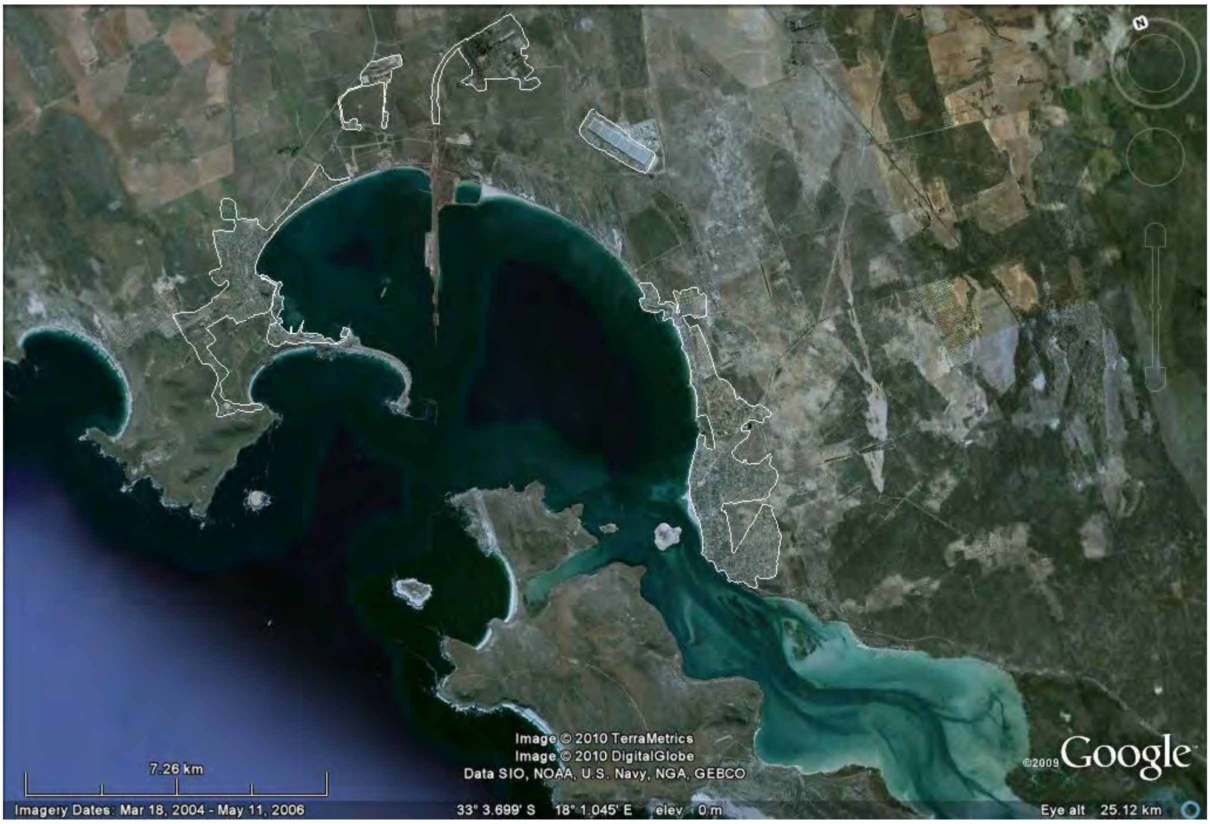


Figure 3.35. Spatial extent of residential and industrial areas surrounding Saldanha Bay and Langebaan Lagoon from which storm water runoff is likely to enter the sea (areas outlined in white). Note that runoff from the Port of Saldanha and ore terminal have been excluded as this is now reportedly all diverted to storm water evaporation ponds.

The CSIR (2002) estimated the monthly flow of storm water entering Saldanha Bay and Langebaan Lagoon using rainfall data and runoff coefficients for residential and industrial areas. In this report, these estimates have been updated by obtaining more recent area estimates of industrial and residential developments surrounding Saldanha Bay and Langebaan Lagoon using Google Earth and by acquiring longer term rainfall data (Figure 3.35 and Table 3.6). Runoff coefficients used to calculate storm water runoff from rainfall data were 0.3 for residential areas and 0.45 for industrial areas (CSIR 2002). Note that runoff from the Port of Saldanha and ore terminal have been excluded from these calculations.

Table 3.6. Monthly rainfall data (mm) for Saldanha Bay over the period 1895-1999 (source Visser *et al*. 2007). MAP = mean annual precipitation.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
MAP	6	8	11	25	47	61	64	46	25	18	13	8	332
Ave. rain days	1.4	1.4	2.2	3.8	6.2	7.1	7.5	6.4	4.8	3.0	1.9	1.8	47.5
Ave./day	4.1	5.5	5.1	6.6	7.6	8.5	8.5	7.3	5.2	6.0	6.6	4.6	7.0

Typical concentrations of various storm water constituents (metals, nutrients, bacteriological) for industrial and residential storm water from South Africa and elsewhere were extracted from the literature by the CSIR in 2002 (Table 3.7). These values are obviously rough estimates as site specific activities will have a strong influence on storm water composition and ideally more accurate data should be acquired by monitoring of contaminants in the storm water systems of Saldanha and Langebaan. Storm water contaminant concentrations entering the sea from the Port of Saldanha were available from average monthly concentrations measured from residential and industrial sites in Saldanha over a four year period (1999-2002, Table 3.7). It is clear that the estimated concentrations of many of the potentially toxic compounds are above the South African 1998 water quality guidelines for coastal and marine waters (values indicated in red). It is likely that introduction of contaminants via storm water runoff negatively impact the health of the marine environment, especially during the "first flush" period as winter rains arrive.

Table 3.7. Typical concentrations of water quality constituents in storm water runoff (residential and Industrial) (from CSIR 2002) and South Africa 1998 Water Quality Guidelines for the Natural Environment (*) and Recreational Use (**). Values that exceed guideline limits are indicated in red.

Parameter	Residential	Industrial	Water Quality Guidelines
Total Suspended Solids (mg/l)	500	600	-
Chemical Oxygen Demand (mg/l)	60	170	-
Nitrate-N (mg/l)	1.2	1.4	0.015*
Total Ammonia-N (mg/l)	0.3	0.4	0.6*
Orthophosphate-P (mg/l)	0.07	0.1	-
Cadmium (mg/l)	0.006	0.005	0.004*
Copper (mg/l)	0.05	0.05	0.005*
Lead (mg/l)	0.3	0.1	0.012*
Zinc (mg/l)	0.4	1.1	0.025*
Faecal coliform counts (counts/100 ml)	48 000	48 000	100**

Storm water runoff is highly seasonal and peaks in the wet months of May to August. Due to the rapid pace of holiday and retail development in the area, Langebaan residential area produces the greatest volumes of storm water runoff, followed by the industrial areas, with lower volumes arising from the Saldanha residential area (CSIR 2002). The actual load of pollutants entering the Bay and Lagoon via this storm water can only be accurately estimated when measurements of storm water contaminants in the storm water systems of these areas are made.

3.3.9 Fish processing plants

Three fishing companies currently discharge wastewater into Saldanha Bay: Sea Harvest, SA Lobster Exporters (Marine Products), Live Fish Tanks (West Coast) – Lusitania (CSIR 2002). The locations of the fish factory intake and discharge points are shown in Figure 3.36.

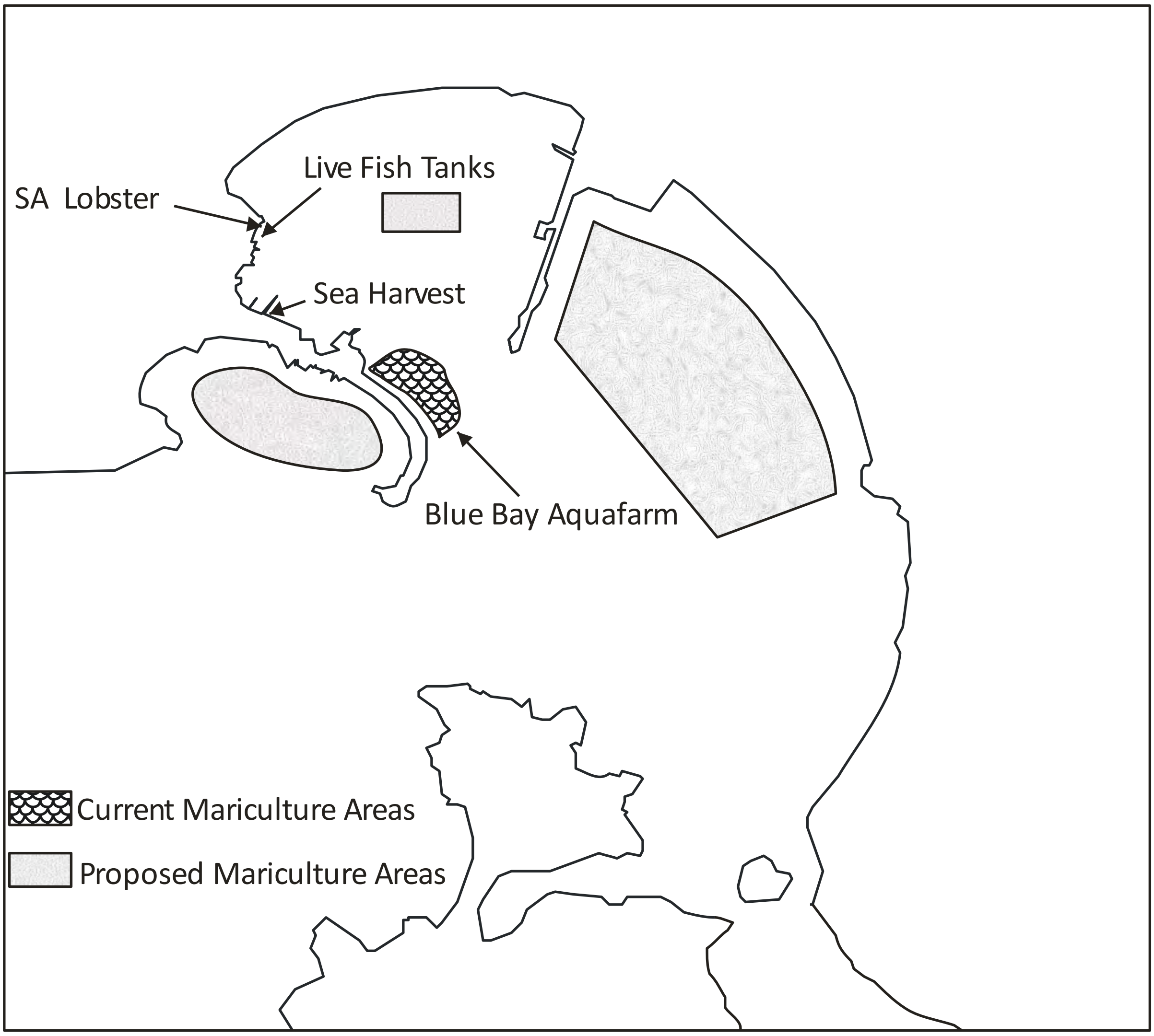


Figure 3.36. Location of seawater intakes and discharges for seafood processing in Saldanha Bay together with location of current and proposed mariculture operations

Southern Seas Fishing (now trading as Premier Fishing) previously discharged wastewater into the Bay but closed its factories approximately 5 years ago. Premier Fishing now intends on re-commissioning and upgrading the existing fishmeal and fish oil processing plant. The plant was operational for 50 years prior to operations being suspended in 2008 for commercial reasons.

For the upgrade and re-commissioning of the Premier Fishing plant, a Scoping and Environmental Impact Assessment process is required in terms of the National Environmental Management Act 107 of 1998, the Environmental Impact Assessment Regulations 2010 and the National Environmental Management: Air Quality Act 39 of 2004. SRK Consulting (South Africa) (Pty) Ltd was appointed by Premier fishing as the independent Environmental Assessment Practitioner to undertake the S&EIA process. Anchor Environmental Consultants in turn were appointed to provide a specialist assessment of the likely impacts of effluent discharges from the processing plant on the water quality and marine ecology in Saldanha Bay and recommend mitigation measures.

Potential risks associated with the upgrade and re-commissioning of the fishmeal plant on the marine environment in Saldanha Bay were identified as falling into three main categories:

- Disturbance to and/or mortality of marine life and coastal birds due to upgrading of existing facilities, including the removal of old equipment and infrastructure, the upgrading of equipment and reconstruction of portions of the plant (Construction impacts)
- Disturbance to and/or mortality of marine life due to the intake and discharge of sea water, used for cooling purposes, in the near shore environment (Seawater cooling operational impacts)
- Disturbance to and/or mortality of marine life due to discharge of wastes into the marine environment from the fishmeal plant (Fish factory operational impacts)

It is anticipated that approximately *500 m³* of cooling water will be discharged from the plant per hour at 30°C. This is in the order of 15-16°C above ambient in winter and 16-19°C above ambient in summer. While this may sound alarming, thermal plume modelling studies have shown that provided appropriate mitigation measures are employed in the design of the outfall structures, the temperature of the effluent will have dropped to within 1°C of ambient temperatures within 15 m of the discharge point and thus poses little risk to the ecology of the bay or the mariculture operations therein.

The potential impacts of discharge of organic matter from the plant were also assessed in this study, and were also shown to be of limited concern provided appropriate mitigation measures are adopted. These include a complete ban on the discharge of "blood water", "process water" and "wash water" to the Bay. Bloodwater (water pumped on board the fishing vessel together with the fish and that remains with the fish until discharge at the factory) is to be returned to the vessels and discharged at sea at least 5 nautical miles of the coast; process water (residual waste water derived from the fish processing operations) will be evaporated off (to enable collection of all solid material), condensed, and the condensate discharged with the cooling water; and wash water (water derived from washing the factory floor and other surfaces) will be diverted to the local waste water treatment works. The condensed liquids that will be discharged with the cooling water are likely to have elevated nutrient, particularly ammonia and ammonium. However, levels of these two compounds (0.01 mg/l for ammonia and 0.19 mg/l for ammonium) are well below internationally accepted environmental safety limits, and are hence not of significant concern.

The following additional mitigation measures were proposed:

- Ensure no hydrocarbon leaks from vehicles used on the plant;
- Ensure no leaks or spillages of matter from the plant during the removal of equipment and cleaning of infrastructure;
- Inform & empower all staff about sensitive marine species & suitable disposal of construction waste;
- Filter effluent on start-up of plant to remove plastic particles;
- Velocity of the intake flow not to exceed 0.15m/s;
- The intake pipes to draw seawater in horizontally;
- The intake pipes to be positioned at least 2 m off the seabed;
- The intake pipes to be positioned at least 0.5m below the Mean Low Water Spring;
- The outfall to incorporate the following design feature: discharge point on the seabed, angled at 45° to the horizontal, or discharge horizontally at 3 m below MLWS;
- The outfall pipe diameter not to exceed 300 mm diameter;
- No bloodwater to be discharged within 5 NM of the coast.
- Total volume of effluent o be discharged to the marine environment (cooling water and condensed liquids only) must not exceed 30 m^3/h and concentrations of ammonia and suspended solids in the effluent not to exceed levels as follows: Ammonia: 20 mg/l, suspended solids: 500 mg/l;

- Samples of effluent discharged to the marine environment should be collected on a weekly basis whilst the plant is in full production and must be submitted to an independent analytical laboratory for characterisation. Results of the analyses should be submitted to the Branch Oceans and Coasts of the Department of Environmental Affairs to ensure compliance with permit conditions.
- No spillages on the Terminal or within the processing plant to come into contact with the marine environment;
- A contingency plan to be formulated to address instances of equipment failure or malfunction to divert any fish material or liquids away from the marine environment;
- An environmental control officer to be appointed and be present during the offloading of fish to ensure that protocols are followed and, if a contravention is made, ensure that the stipulated enforcement actions are taken;
- Runoff from hardened surfaces should rather be diverted to evaporation ponds and residual material from these ponds should be disposed of at an approved landfill site
- Runoff from such surfaces to be diverted to evaporation ponds and residual material from these ponds should be disposed of at an approved landfill site

Discharges from the fish factories are subject to National Water Act (1998) under the jurisdiction of the Department of Water Affairs. These activities are classified as a water use and require a license (DWAF, 2000a). The National Environmental Management: Integrated Coastal Management Act (Act No. 24, 2008) states that no person is allowed to discharge effluent from a source on land into coastal waters without a permit.

The composition of the effluent from Sea Harvest was last surveyed in 2001 and again in 2012 (Entech 1996 In CSIR 2002, F. Hickley, Sea Harvest) (Table 3.8). Monthly discharge for the Sea Harvest factory was in the region of 70 000 m^3/month in 2001.

Table 3.8. Characterisation of effluent from Sea Harvest Fish Processing Plant (Data from CSIR 2002 and F. Hickley, Environmental Officer for Sea Harvest). SA WQ guidelines are based on those published in 1998, as the 2009 revised guidelines do not offer recommended physico-chemical targets except for temperature and pH.

	Sea Harvest (2001)	Sea Harvest (2012)	SA WQ Guidelines
Effluent volume (m^3/month)	69 595	-	-
Suspended solids(mg/l)	164	158	*
Combustable solids (mg/l)	144	-	*
Fat, Oil and grease(mg/l)	212	-	*
Ammonia-N (mg/l)	164	147	0.020 mg/l
Kjeldahl Nitrogen-N (mg/l)	83	99	-
Phosphate-P (mg/l)	34	-	-
Faecal coliform (CFU/100 ml)	751	1347	-
E. coli (CFU/100ml)	5	789	†

* Water should not contain floating particulate matter, debris, oil, grease, wax, scum, foam or any similar floating materials and residues from land-based sources in concentrations that may cause nuisance.
Water should not contain materials from non-natural land-based sources which will settle to form putrescence.

† Max 100 CFU in 80 % of the samples and max 2 000 in 95 % of the samples

Sea Harvest discharge fresh fish processing (FFP) effluent into the sea daily. This includes seawater that has been used as wash-water as well as freshwater effluent originating from the fish processing. Monthly volumes of effluent discharged in the sea from 2004 to 2007 by Sea Harvest are shown in Table 3.8. The volume of effluent disposed by Sea Harvest increased radically from August 2006 to November 2007, and then decreased drastically again. It is not clear why this increase occurred, as data reporting and environmental monitoring at Sea Harvest have suffered irregularities due to high staff turnover (F. Hickley, pers. comm.). The volumes of effluent discharge released from May 2004 to May 2006 resemble those reported by the CSIR for 2001 and 2002, which ranged between 50 000 to 90 000 m^3/month. Regular monitoring of effluent quality produced was re-initiated in 2010. It is estimated that approximately 1 152 m^3 of effluent is released on a daily basis (35 000 m^3/month, Paul Cloete, Environmental Officer, Sea Harvest Corporation (Pty) Ltd, pers. comm.). Variations in the characteristics of this effluent are shown in Figure 3.37.

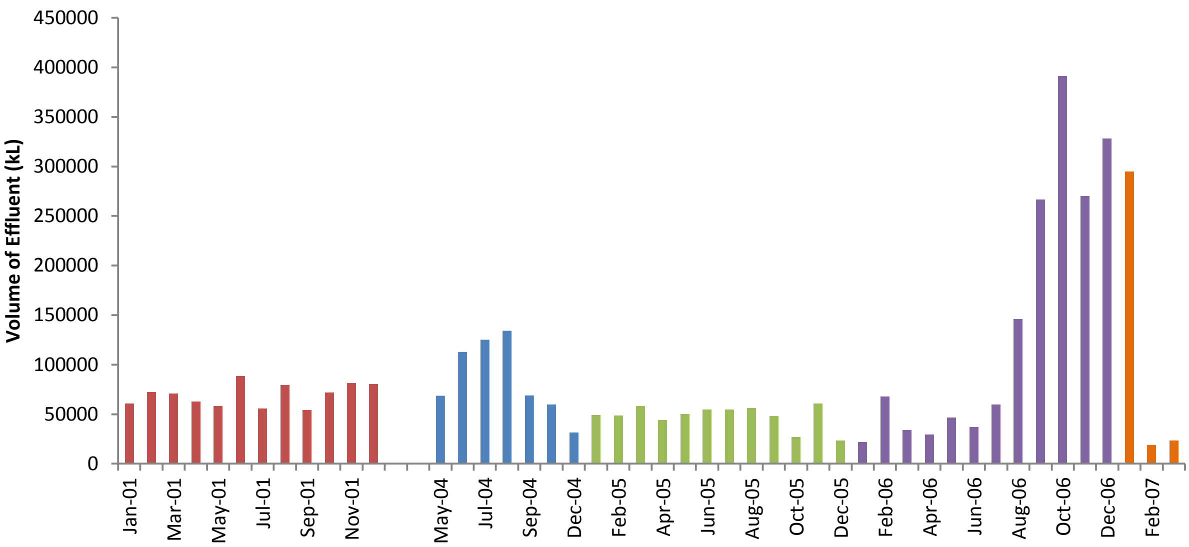


Figure 3.37. Total monthly discharge of fresh fish processing effluent (FFP) disposed to sea by Sea Harvest from January 2001 to March 2007.

Measured levels of faecal coliforms in the effluent are relatively high, in the range of 0 to 3 300 CFU/100 ml, averaging 1347cfu/100 ml during 2012 (an increase from the 2011 average of 965 cfu/100 ml) (Figure 3.38). The source of this contamination is not clear, as faecal coliforms are derived from the guts of warm blooded animals such as human and livestock rather than cold blooded animals such as fish.

Levels of suspended solids, ammonia and nitrate/nitrite are similar to those reported for the earlier period (2001/2, Figure 3.38). It is not clear what permit conditions are attached to the discharge of effluent from the Sea Harvest factory but these levels are certainly well in excess of those permissible in terms of a General Authorisation under the National Water Act (1998).

SA Lobster Exporters discharges seawater from their operations into Pepper Bay. The average monthly effluent volumes range from 40 000 m^3 to approximately 60 000 m^3, and this water cycles through tanks where live lobsters are kept prior to packing (CSIR 2002). Live Fish Tanks (West Coast)-Lusitania take up and release wash water from Pepper Bay. Neither discharge volume or water quality is being monitored on a routine basis (CSIR 2002, but it is reported to be not markedly different from ambient seawater, as it basically cycles through tanks where live lobsters are kept prior to packaging (CSIR 2002).

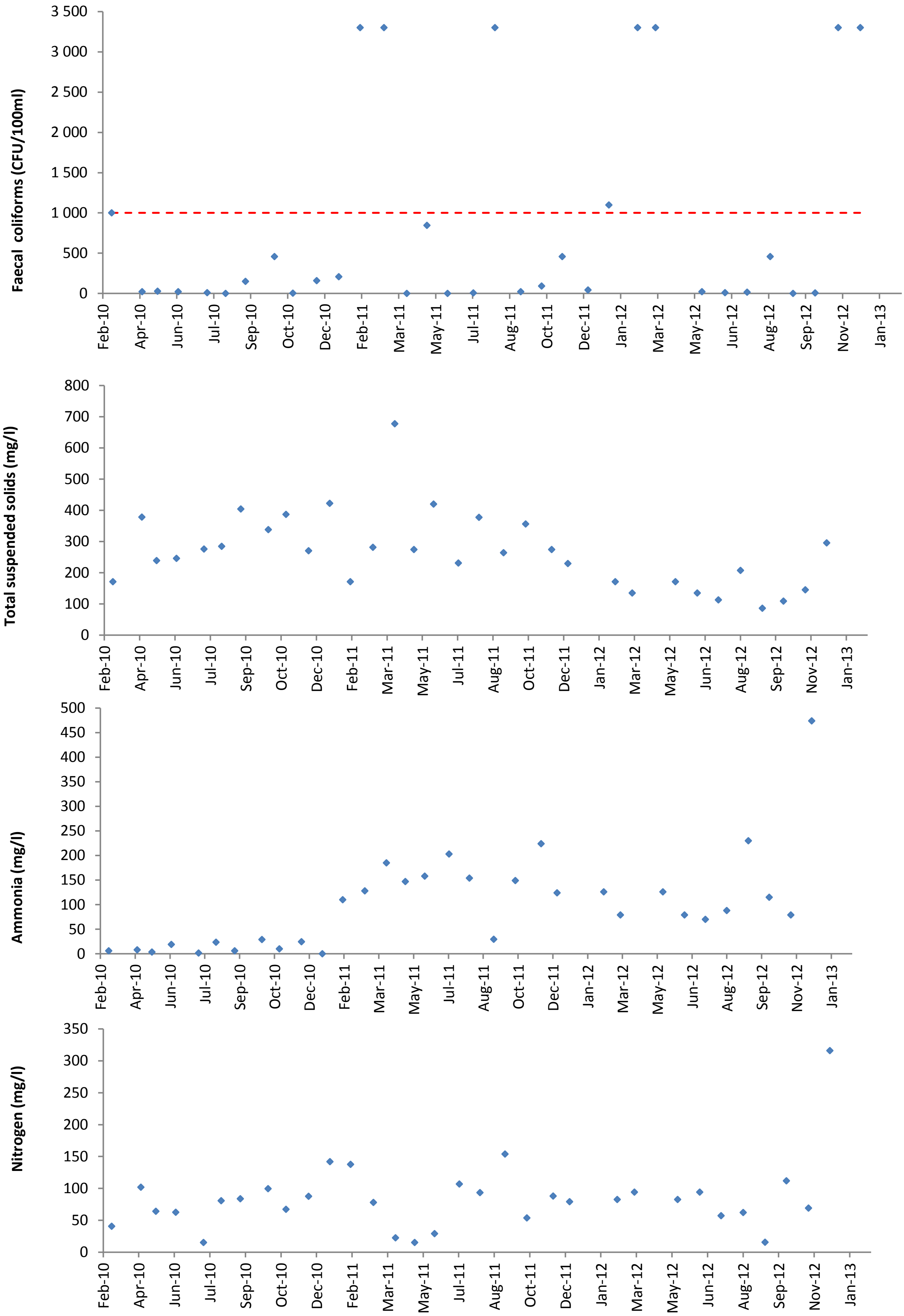


Figure 3.38. Monthly trends in the numbers of faecal coliforms, total suspended solids, ammonia and nitrogen concentration in effluent from the Sea Harvest fresh fish processing (FFP) plant discharged into Small Bay in the period Feb 2011 to Dec 2012.

3.3.10 Mariculture

Saldanha Bay is the only natural sheltered embayment in South Africa and as a result it is regarded as the major area for mariculture (Stenton-Dozey *et al*. 2001). The Bay was zoned to cater for mariculture operations in 1997 and approximately 1 000 ha were demarcated for mariculture (Stenton-Dozey *et al*. 2001). A total area of approximately 145 ha has been allocated to seven mariculture operators within Saldanha Bay (Table 3.9). All operators have the rights to farm mussels (although only three of them currently exercise this) and six of the operators also farm oysters. Abalone, scallops, red bait and seaweed are each cultured on one of the farms. Blue Bay Aquafarm, the largest and oldest of the current farms, have had rights to approximately 50 hectares of water at the entrance of Small Bay since 2002. The other six operators have had rights to smaller areas in both Small Bay and Big Bay since 2010. All rights have a maximum duration of 14 years.

A recent study by Olivier *et al*. (2013) investigated the ecological carrying capacity of Saldanha Bay with regards to bivalve (in particular mussels and oysters) farming. The findings indicate that the sector could increase 10 to 28 fold, potentially creating an additional 940 to 2500 jobs for the region without compromising the environment.

Table 3.9. Details of marine aquaculture rights issued in Saldanha Bay (source: DAFF *pers. comm.* 2013). Black crosses indicate current products of the farms, while red crosses indicate the products for which rights exist but are not currently farmed.

	Products							
Company	**Mussels**	**Oysters**	**Abalone**	**Scallops**	**Red Bait**	**Seaweed**	**Area (Location*)**	**Duration of right**
Blue Bay Aquafarm (Pty) Ltd	x	x					**50.9 ha (SB)**	**2002-2016**
Blue Sapphire Pearls CC	x	x	x			x	**5 ha (SB)**	**2010-2024**
Imbaza Mussels (Pty) Ltd (previously trading as Masiza Mussel Farm (Pty) Ltd)	x						**30 ha (SB)**	**2010-2024**
Saldanha Bay Oyster Company (previously trading as Striker Fishing CC)	x	x		x			**25 (BB)**	**2010-2024**
West Coast Aquaculture (Pty) Ltd	x	x			x		**15 ha (SB)**	**2010-2024**
West Coast Oyster Growers CC	x	x					**5 ha (SB) 5 ha (BB)**	**2010-2024**
West Coast Seaweeds (Pty) Ltd	x	x					**5 ha (SB) 5 ha (BB)**	**2010-2024**

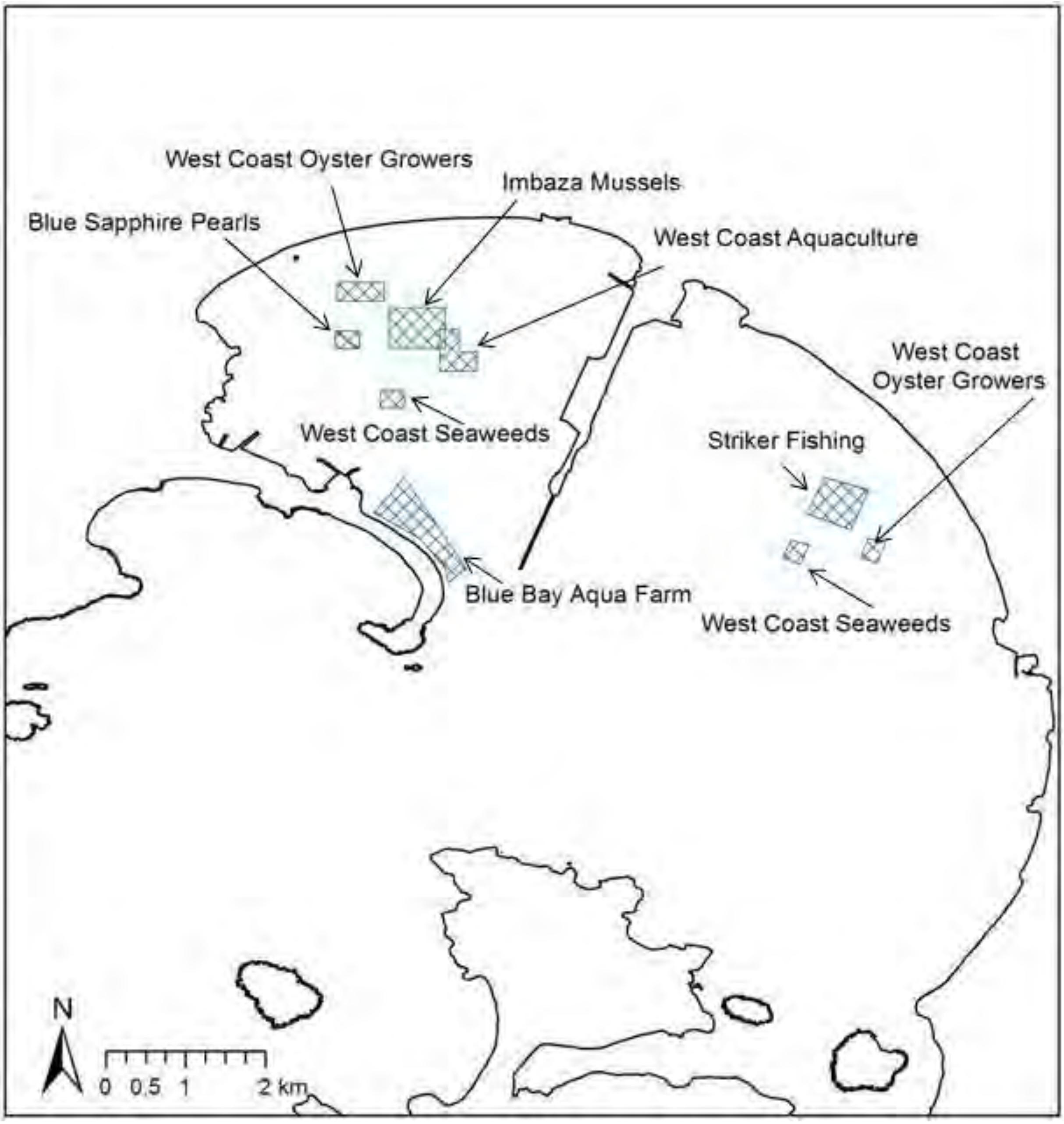


Figure 3.39. Allocated mariculture concession areas in Saldanha Bay 2012.

Raft culture of mussels has taken place in Saldanha Bay since 1985 (Stenton-Dozey *et al*. 2001). Larvae of the mussels *Mytilus galloprovincialis* and *Choromytilus meridionalis* attach themselves to ropes hanging from rafts and are harvested when mature. Mussels are graded, washed and harvested on board a boat. Overall mussel productivity peaked at approximately 740 tons in 2008 following a lull in productivity between 2005 and 2007 (Figure 3.40). There was a decrease in productivity in 2009 which was followed by an increase in 2010 (with the peak productivity at 700 tons). In 2009 and 2010 the mussel sub-sector (based in Saldanha Bay) was the second highest contributor to the overall mariculture productivity for the country (DAFF 2010, DAFF 2011).

A study conducted between 1997 and 1998 found that the culture of mussels in Saldanha Bay created organic enrichment and anoxia in sediments under mussel rafts (Stenton-Dozey *et al.*

2001). The ratios of carbon to nitrogen indicated that the source of the contamination was mainly faeces, decaying mussels and fouling species. In addition, it was found that the biomass of macrofauna was reduced under the rafts and the community structure and composition had been altered (Stenton-Dozey *et al*. 2001).

Ongoing environmental impact monitoring surveys undertaken in Saldanha Bay by the Department of Agriculture, Forestry and Fisheries will provide an indication of the environmental impact of oyster culture (DAFF, unpublished data). However, visual observations of the benthos underneath oyster rafts and preliminary data show minimal impact in this area when compared to other sites within the Bay.

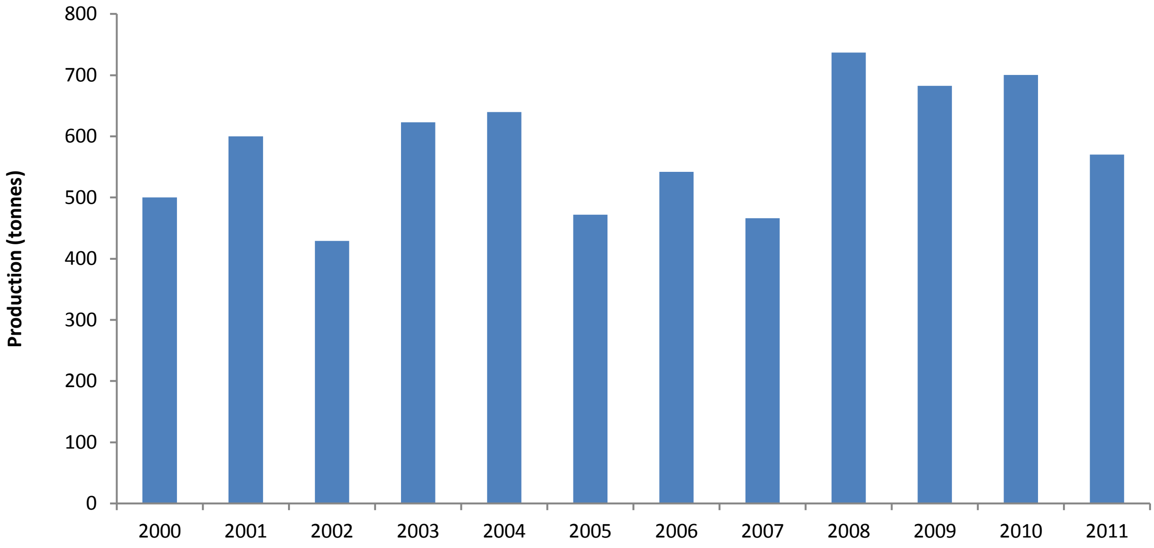


Figure 3.40. Overall annual mussel productivity (tonnes) in Saldanha Bay between 2000 and 2011 (source: DAFF, 2012)

3.3.10.1 Southern Cross Salmonid Farm

In addition to the mariculture farms currently established in Saldanha Bay, a project involving the cage culture of salmon or trout has been proposed. Southern Cross Salmon Farm (Pty) Ltd has appointed AquaEco to prepare a final scoping report for the proposed offshore salmon and trout farm. This report was submitted to the National Department of Environmental Affairs (DEA) and the Western Cape Department of Environmental Affairs & Development Planning (DEA&DP) in June 2012, as part of the Environmental Impact Assessment (EIA) process.

There are two sites under consideration for this project (of approximately ten and twenty hectares), both of which will be utilised if environmental authorisation is awarded (AquaEco 2012). The approximate central coordinates for the sites which have been leased from Transnet National Port Authority are:

- 33°02’05.88’’S and 17°57’00.92’’E (North Bay site ± 20 Ha)
- 33°04’39.04’’S and 17°57’54.58’’E (Off Jutten Island ± 10 Ha)

The initial phase of the project will involve 4 large cages (25 meters in diameter and an operational depth of 15 metres) and two smaller cages (15 metre diameter and operational depth).

The water depth will be between 20 and 28The smaller cages will be utilised for the development of younger fish and the transfer of fingerlings or market ready fish. Each large cage is expected to have an output of 100 tonnes marketable fish per year. An additional four large cages will be added each year, with an annual output of 1200 tonnes anticipated for the third year of production (AquaEco 2012).

The cages utilised are of an internationally tested design. A floating circular collar constructed of high density polyethylene will be attached to a circular polyethylene net pen which will contain the fish (Figure 3.41). Each individual cage will be anchored to the seafloor via an anchor grid, designed for adverse sea conditions while preventing the entanglement or injury of marine fauna. Cages will be highly visible with lights, markers and radar reflectors in use to minimise vessel or animal collision. However, the project will be insured for equipment salvage in case of damage to the infrastructure (AquaEco 2012).

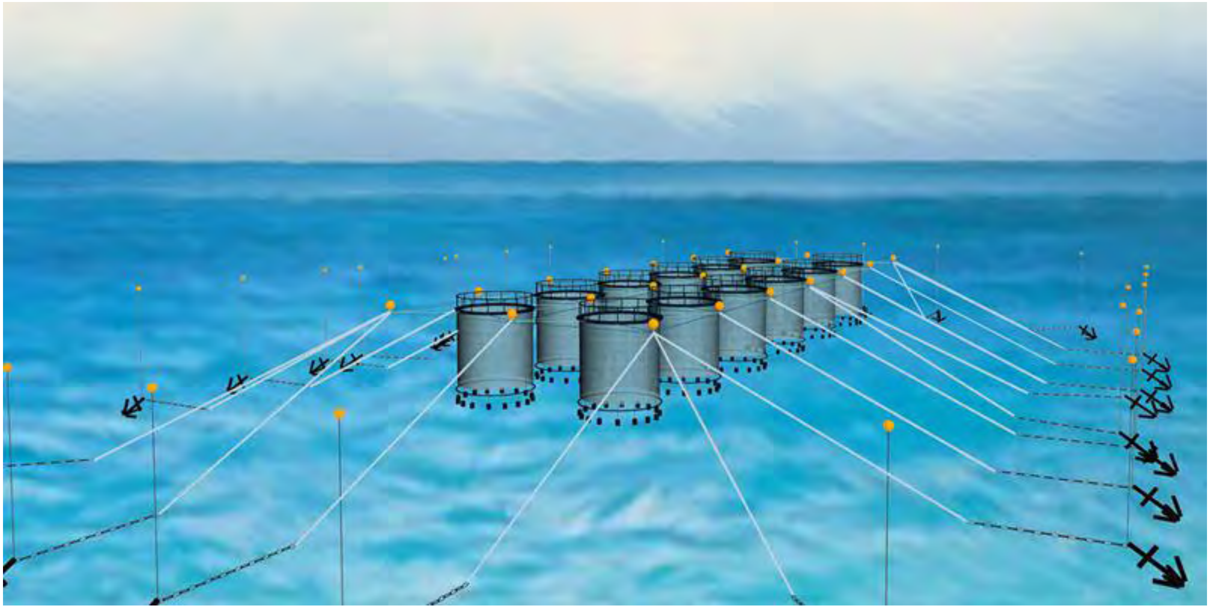


Figure 3.41. Proposed setup of the Southern Cross offshore salmonid farm.

The species in question are *Salmo salar*, the Atlantic salmon, and *Onchorhynchus mykiss*, the rainbow trout. Both species are non-native to South Africa, however *O. mykiss* is farmed in many parts of the country in freshwater systems. Marine cage culture of *S. salar* was piloted in Gansbaai a several years ago, however, this reportedly failed when the cages (which were heavily fouled) sank in strong seas. The biofouling accumulated on the cage mesh due to a lack of suitable cleaning equipment (specifically a suitable size work boat equipped with a crane) (Hutchings *et al.* 2011). It is not clear from the scoping report how this issue will be dealt with, although it does mention the regular removal of nets so it can be assumed that the maintenance craft will be suitable for this task.

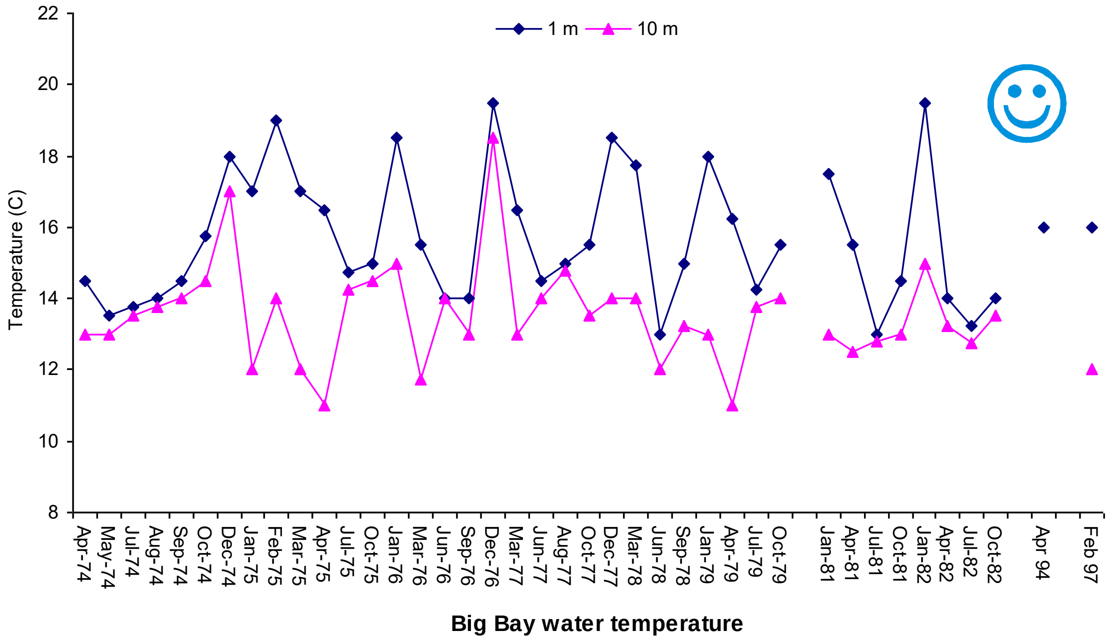
4 WATER QUALITY

The temperature, salinity (salt content) and dissolved oxygen concentration occurring in marine waters are the variables most frequently measured by oceanographers in order to understand the origins, physical and biological processes impacting on, or occurring within a body of sea water. Long-term data series of these three variables exist for Saldanha Bay and these are discussed in some detail below. Other measurable physical and chemical variables such as nutrient levels (specifically dissolved nitrate – a limiting nutrient for phytoplankton growth), chlorophyll concentration (a measure of primary production), current strengths and circulation patterns have been reported on in various studies and the key findings or trends are also summarised in this chapter.

4.1 Water temperature

Water temperature records for Saldanha Bay and Langebaan Lagoon were first collected during 1974-75 as part of a detailed survey by the then Sea Fisheries Branch, Department of Industries (now Marine and Coastal Management, Department of Environmental Affairs and Tourism). The survey was initiated to collect baseline data of the physical and chemical water characteristics prior to the development of the Bay as an industrial port. The findings of this survey were published in a paper by Shannon and Stander (1977). Surface water temperatures prior to the construction of the iron ore/oil Terminal and Marcus Island causeway varied from 16-18.5˚C during summer (January 1975) and 14.5-16˚C during winter (July 1975). During both periods, higher temperatures were measured in what is now the northern part of Small Bay and within Langebaan Lagoon, whilst cooler temperatures were measured at sampling stations in Outer Bay and Big Bay. The water column was found to be fairly uniform in temperature during winter and spring (i.e. temperature did not change dramatically with depth) and the absence of a thermocline (a clear boundary layer separating warm and cool water) was interpreted as evidence of wind driven vertical mixing of the shallow waters in the Bay. A clear shallow thermocline was observed at about 5 m depth, during the summer and autumn months at some deeper stations and was thought to be the result of warm lagoon water flowing over cooler sea water. The absence of a thermocline at other shallow sampling stations was once again considered evidence of strong wind driven vertical mixing. Shannon and Stander (1977) suggested that there was little interchange between the relatively sun-warmed Saldanha Bay water and the cooler coastal water through the mouth of the Bay, but rather a "slopping backwards and forwards tidal motion".

The Sea Fisheries Research Institute continued regular monitoring (quarterly) of water temperature (and other variables) in Saldanha Bay until October 1982. These data were presented and discussed in papers by Monteiro *et al*. (1990) and Monteiro and Brundrit (1990). The temperature time series for Small Bay and Big Bay is shown in Figure 4.1. This expanded data series allowed for a better understanding of the oceanography of Saldanha Bay. The temperature of the surface waters was observed to fluctuate seasonally with surface sun warming in summer and cooling in winter, whilst the temperature of deeper (10 m depth) water shows a smaller magnitude, non-seasonal variation, with summer and winter temperatures being similar (Figure 4.1). In most years, a strong thermocline separating the sun warmed surface layer from the cooler deeper water was present during the summer months at between 5-10 m depth. During the winter months, the thermocline breaks down due to surface cooling and increased turbulent mixing, and the water column becomes nearly isothermal (surface and deeper water similar in temperature) (Figure 4.1). Unusually warm, deeper water was observed during December 1974 and December 1976 and was attributed to the unusual influx of warm oceanic water during these months (Figure 4.1).



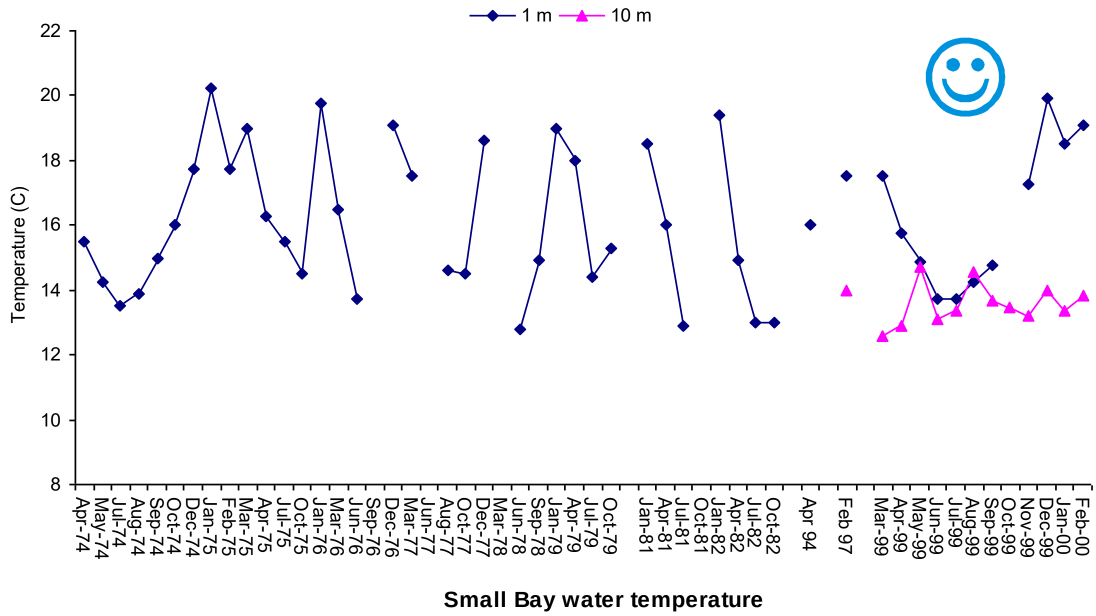


Figure 4.1. Water temperature time series at the surface and at 10m depth for Big Bay and Small Bay, Saldanha Bay

Warm oceanic water is typically more saline and nutrient-deficient than the cool upwelled water that usually occurs below the thermocline in Saldanha Bay. This was reflected in the high salinity (Figure 4.2), and low nitrate and chlorophyll concentration (a measure of phytoplankton production) measurements taken at the same time (Monteiro and Brundrit 1990). Monteiro *et al.* (1990) suggested that the construction of the Marcus Island causeway and the iron ore/oil Terminal in 1975 had physically impeded water movement into and out of Small Bay, thus increasing the residence time and leading to systematically increasing surface water temperatures when compared with Big Bay. There appears to be little support for this in the long-term temperature time series (Figure 4.1) and although the pre-construction data record is limited to only one year, Shannon and

Stander (1977) show Small Bay surface water being 2°C warmer than that in Big Bay during summer, prior to any harbour development. It is likely that the predominant southerly winds during summer concentrate sun warmed surface water in Small Bay, whilst much of the warm surface layer is driven out of Big Bay into the outer Bay by these same winds.

More detailed continuous monitoring of temperature throughout the water column at various sites in Outer Bay, Small Bay and Big Bay during a two week period in February-March 1997, also allowed better understanding of the mechanisms causing the observed differences in the temperature layering of the water column. The summer thermocline is not a long-term feature, but has a 6-8 day cycle. Cold water, being denser than warmer water, will flow into Saldanha Bay from the adjacent coast when wind driven upwelling brings this cold water near to the surface. The inflow of cold, upwelled water into the Bay results in a thermocline, which is then broken down when the cooler bottom water flows out the Bay again. This density driven exchange flow between Saldanha Bay and coastal waters is estimated to be capable of flushing the bay within 6-8 days, substantially less than the approximately 20 day flushing time calculated based on tidal exchange alone by Shannon and Stander (1977). The influx of nutrient rich upwelled water into Saldanha Bay is critical in sustaining primary productivity within the Bay, with implications for human activities such as fishing and mariculture. The fact that the thermocline is seldom shallower than 5 m depth means that the shallower parts of Saldanha Bay, particularly Langebaan Lagoon, are not exposed to the nutrient (mainly nitrate) import from the Benguela upwelling system. As a result these shallow water areas do not support large plankton blooms and are usually clear.

The most recent monitoring of water temperature in Saldanha Bay was conducted by the CSIR (Monteiro *et al.* 2000) over the period March 1999-February 2000. This was the most intensive long-term temperature record to date, with continuous measurements (every 30 minutes) taken at 1 m depth intervals over the 11 m depth range of the water column where the monitoring station was situated in Small Bay. The average monthly temperature at the surface (1m) and bottom (10 m) for this period is shown in Figure 4.1. These data confirmed the pattern evident in earlier data, showing a stratified (layered) water column for spring-summer caused by wind driven upwelling, with the water column being more or less isothermal (of equal temperatures) during the winter (Figure 4.1). The continuous monitoring of temperature also identified a 3 week break in the usual upwelling cycle during December 1999, with a consequent gradual warming of the bottom water. Once again, this "warm water" event (although the water column remained stratified indicating that the magnitude of this event was not as great as those observed during December 1974 and 1976 events) was associated with a decrease in phytoplankton production (due to reduced import of nitrate) which, in turn, impacted negatively on local mussel mariculture yields (Monteiro *et al.* 2000).

4.2 Salinity

The salinity data time series covers much of the same period as that for water temperature and salinity data was extracted from the studies of Shannon and Stander (1977), Monteiro and Brundrit 1990, Monteiro *et al.* (1990) and Monteiro *et al.* (2000) (Figure 4.2). There was little variation in the salinity with depth in the water column and the values recorded at 10 m depth are presented in Figure 4.2. Under summer conditions when the water column is stratified, surface salinities may be slightly elevated due to evaporation and therefore salinity measurements from the deeper water more accurately reflect those of the source water. Salinities of the inshore waters along the west coast typically vary between 34.6-34.9 parts-per-thousand (ppt), or grams of salt per kilogram of sea water) (Shannon 1966), and the salinity values recorded for Saldanha Bay usually fall within this range. During summer months when wind driven coastal upwelling within the Benguela region brings cooler South Atlantic Central Water to the surface, salinities are usually lower than during the winter months when the upwelling front breaks down and South Atlantic surface waters move against the coast (warm surface waters are more saline due to evaporation).

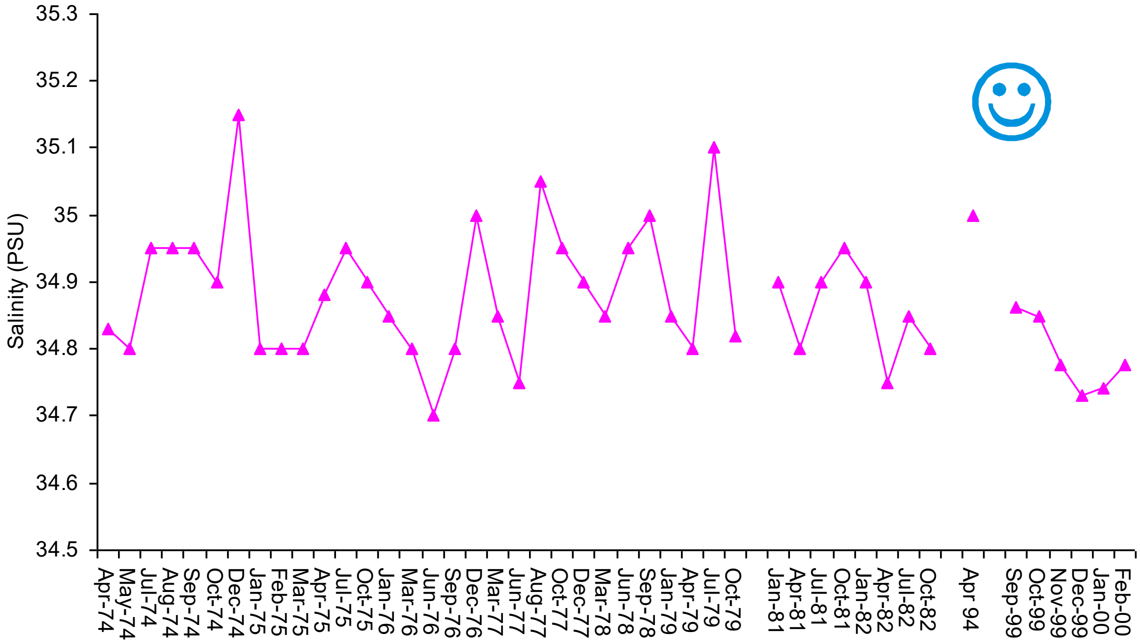


Figure 4.2. Time series of salinity records for Saldanha Bay

The salinity time series shows salinity peaks in December 1974 and 1976 which reflects the warm water inflows that occurred at this time (Figure 4.2). Higher than normal salinity values were also recorded in August 1977 and July 1979 and although this was not reflected in the temperature time series (probably due to rapid heat loss and mixing during winter), the salinity peaks do indicate periodic inflows of surface oceanic water into Saldanha Bay.

Oceanic surface waters tend to be low in nutrients and therefore limit primary production (phytoplankton growth). These oceanic water intrusions into Saldanha Bay, that were identified from the temperature and salinity measurements, corresponded to low levels of nitrate and chlorophyll concentrations measured at the same time as salinity and temperature peaks (Monteiro and Brundrit 1990) (Figure 4.3). This highlights the impacts of the changes in physical oceanography (water temperature and salinity) in the immediate area on the biological processes (nitrate and chlorophyll) occurring within Saldanha Bay (Monteiro and Brundrit 1990). Data concerning these parameters cover a short period only (1974-1979) and as such are little use in examining effects of human development on the Bay.

4.3 Dissolved oxygen

Sufficient dissolved oxygen in sea water is essential for the survival of nearly all marine organisms. Low oxygen (or anoxic conditions) can be caused by excessive discharge of organic effluents (for example, from fish factory waste or municipal sewage) and microbial breakdown of this excessive organic matter depletes the oxygen in the water. The well-known “black tides” and associated mass mortality of numerous marine species, which occasionally occur along the west coast, result from the decay of large plankton blooms under calm conditions. Once all the oxygen in the water is depleted, anaerobic bacteria (not requiring oxygen) continue the decay process, causing the characteristic sulphurous smell. Apparent oxygen utilization (AOU - a measure of the potential available oxygen in the water that has been used by biological processes) values for Small and Big Bay over the period April 1974 - October 1982 and July 1988 are given in Monteiro *et al*. (1990). AOU is defined as the difference between the saturated oxygen concentration (the highest oxygen concentration that could occur at a given water temperature e.g. 5 ml/l) and the measured value (e.g. 1 ml/l) – hence positive AOU (5 ml/l – 1 ml/l = 4 ml/l) values indicate an oxygen deficit (indicated in red in Figure 4.4). More recent data on oxygen concentration in Small Bay (covering the period September 1999-February 2000) were provided by Monteiro *et al.* (2000). During this study, oxygen concentration at 10 m depth was recorded hourly by an instrument moored in Small Bay, these values were converted to AOU and the monthly average plotted in Figure 4.3.

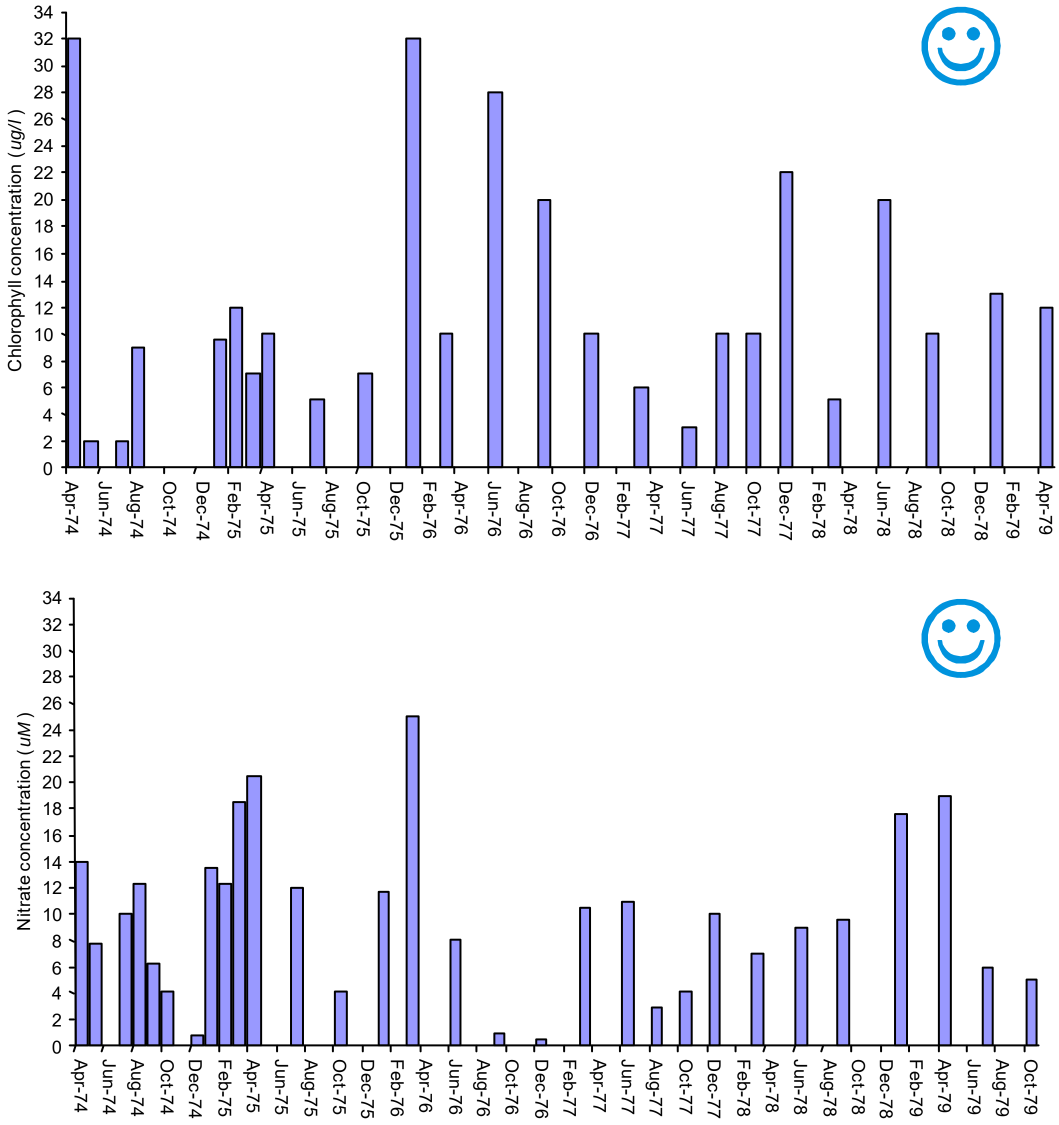


Figure 4.3. Time series of chlorophyll and nitrate concentration measurements for Saldanha Bay.

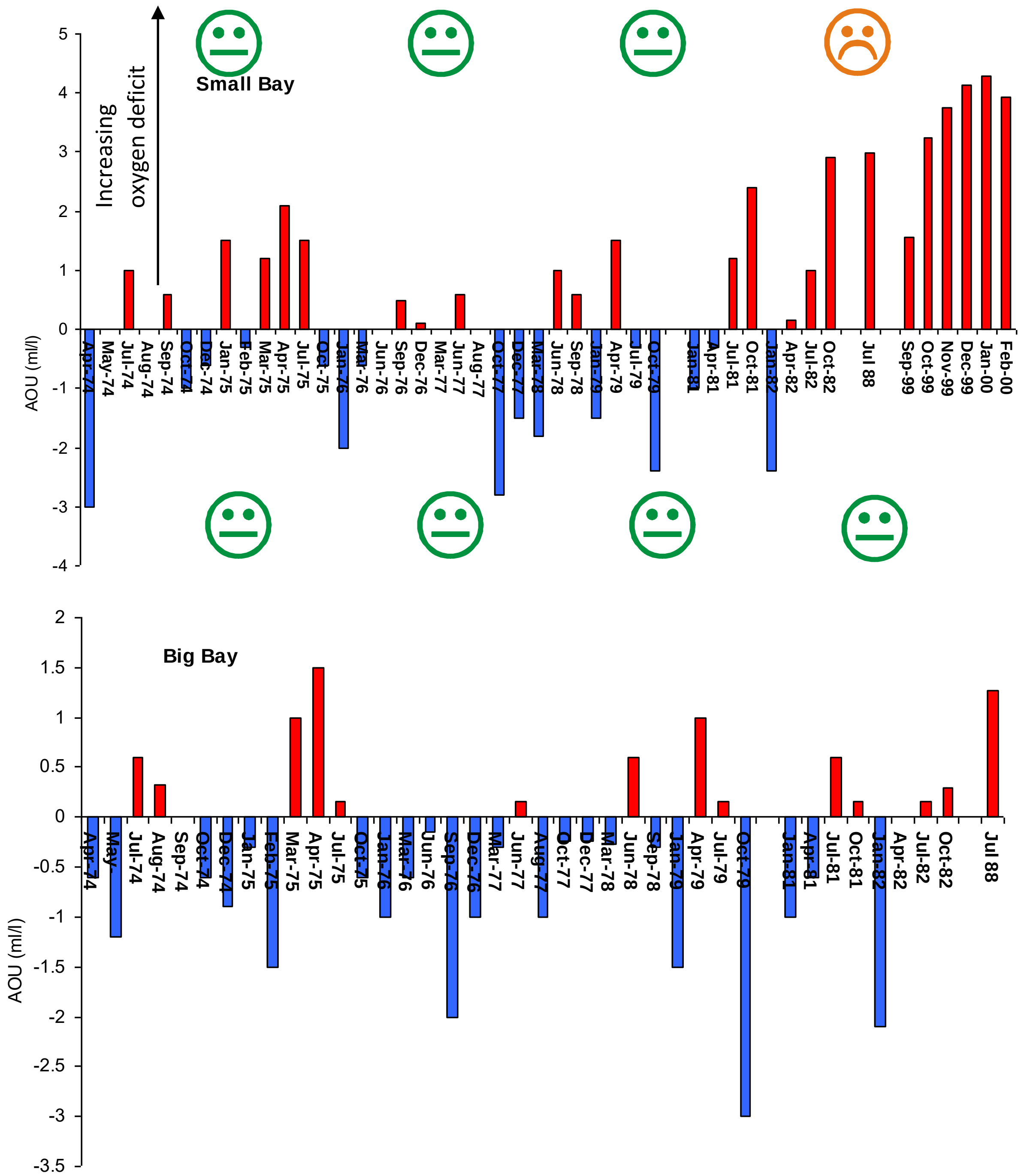


Figure 4.4. Apparent oxygen utilization (AOU) time series Small Bay and Big Bay, Saldanha Bay. (Note: Positive values in red indicate an oxygen deficit).

There is no clear trend evident in the AOU time series, low oxygen concentrations (high AOU values) occur during both winter and summer months (Figure 4.4). Small Bay does experience a fairly regular oxygen deficit during the winter months, whilst Big Bay experiences less frequent and lower magnitude oxygen deficits. Monteiro *et al.* (1990) attributed the oxygen deficit in Small Bay largely to anthropogenic causes, namely reduced flushing rates (due to the causeway and ore terminal construction) and discharges of organic rich effluents. The most recent data (September 1999-February 2000) indicate a persistent and increasing oxygen deficit as summer progresses (Figure 4.4). It is clear that oxygen levels within Small Bay are very low during the late summer months, likely as a result of naturally occurring conditions, however, the ecological functioning of the system could be further compromised by organic pollutants entering the Bay. There is evidence of anoxia in localised areas of Small Bay (e.g. under the mussel rafts, within the yacht basin) that is caused by excessive organic inputs. Monteiro *et al.* (1997) identified the effluent from a pelagic fish processing factory as the source of nitrogen that resulted in an *Ulva* seaweed bloom in Small Bay.

4.4 Circulation and current patterns

Circulation patterns and current strengths prior to the development (1974-75) in Saldanha Bay were investigated using several techniques (drogues, dye-tracing, drift cards and sea-bed drifters). Surface currents (within the upper five meters) are complex and appeared to be dependent on wind strength and direction as well as the tidal state. Within Small Bay, currents were weak (5-15 cm.s^{-1}) and tended to be clockwise (towards the NE) irrespective of the tidal state or the wind (Figure 4.5A). Greater current strengths were observed within Big Bay (10-20 cm.s^{-1}) and current direction within the main channels was dependent on the tidal state (Figure 4.5A). The strongest tidal currents were recorded at the mouth of Langebaan Lagoon (50-100 cm.s^{-1}), these being either enhanced or retarded by the prevailing wind direction (Figure 4.5A). Currents within the main channels in Langebaan Lagoon were also relatively strong (20-25 cm.s^{-1}). Outside of the main tidal channels, surface currents tended to flow in the approximate direction of the prevailing wind with velocities of 2-3 % of the wind speed (Shannon and Stander 1977). Current strength and direction at 5 m depth was similar to that at the surface, but was less dependent on wind direction and velocity and appeared to be more influenced by the tidal state. Currents at 10 m depth at the mouth of the Bay were found to be tidal (up to 10 cm. s^{-1}, either eastwards or westwards) and in the remainder of the Bay, a slow (5 cm.s^{-1}) southward or eastward movement, irrespective of the tidal state, was recorded.

The currents and circulation of Saldanha Bay subsequent to the construction of the Marcus Island causeway and the iron ore/oil Terminal were described by Weeks *et al*. (1991a). Historical data of drogue tracking collected by the Sea Fisheries Research Institute during 1976-1979 were analysed in this paper. This study confirmed that wind is the primary determinant of surface currents in both Small Bay and Big Bay; although tidal flows do influence currents below the thermocline and are the dominant forcing factor in the proximity of Langebaan Lagoon. Weeks *et al.* (1991a) noted that because much of the drogue tracking was conducted under conditions of weak or moderate wind speeds, the surface current velocities measured (5-20cm.s^{-1}), were probably underestimated. The authors concluded that the harbour construction had constrained water circulation within Small Bay, enhancing the general clockwise pattern and increasing current speeds along the boundaries, particularly the south-westward current flow along the iron ore/oil Terminal (Figure 4.5B). More recent data collected during strong NNE wind conditions in August 1990 revealed that greater wind velocities do indeed influence current strength and direction throughout the water column (Weeks *et al*. 1991b). These strong NNE winds were observed to enhance the surface flowing SSW currents along the ore terminal in Small Bay (out of the Bay), but resulted in a northward replacement flow (into the Bay) along the bottom, under both ebb and flood tides. The importance of wind as the dominant forcing factor of bottom, as well as surface, waters was further confirmed by Monteiro and Largier (1999) who described the density driven inflow-outflow of cold bottom water into Saldanha Bay during summer conditions when prevailing SSW winds cause regional scale upwelling.

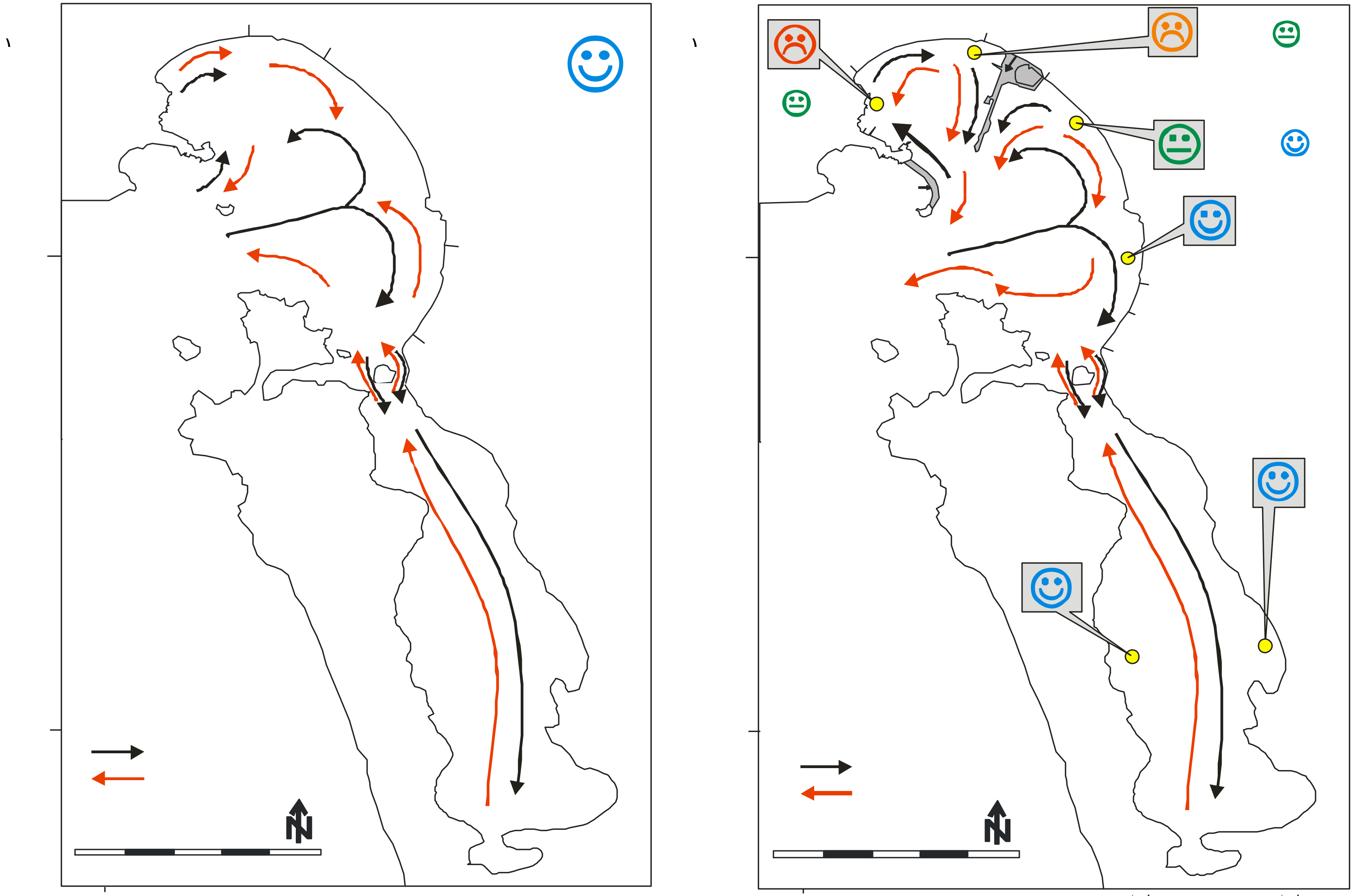


Figure 4.5. **Schematic representation of the surface currents and circulation of Saldanha Bay (A) prior to the harbour development (Pre-1973) and (B) after construction of the causeway and iron-ore terminal (Present). (Adapted from Shannon and Stander 1977 and Weeks *et al*. 1991a)**

4.5 Wave action

Construction of the iron ore terminal and the Marcus Island causeway has also had a major impact on the distribution of wave energy in Saldanha Bay, particularly in the area of Small Bay. Prior to port development in Saldanha Bay, Flemming (1977) distinguished four wave-energy zones in the Bay, defined as being a centrally exposed zone in the area directly opposite the entrance to the Bay, two adjacent semi-exposed zones on either side and a sheltered zone in the far northern corner of the Bay (Figure 4.6). The iron ore terminal essentially divided the Bay into two parts, eliminated much, if not all, the semi-exposed area in Small Bay, greatly increased the extent and degree of shelter in the north-western part of Small Bay, and also subtly altered wave exposure patterns in Big Bay (see predicted wave field data from WSP Africa 2010, Figure 4.7).

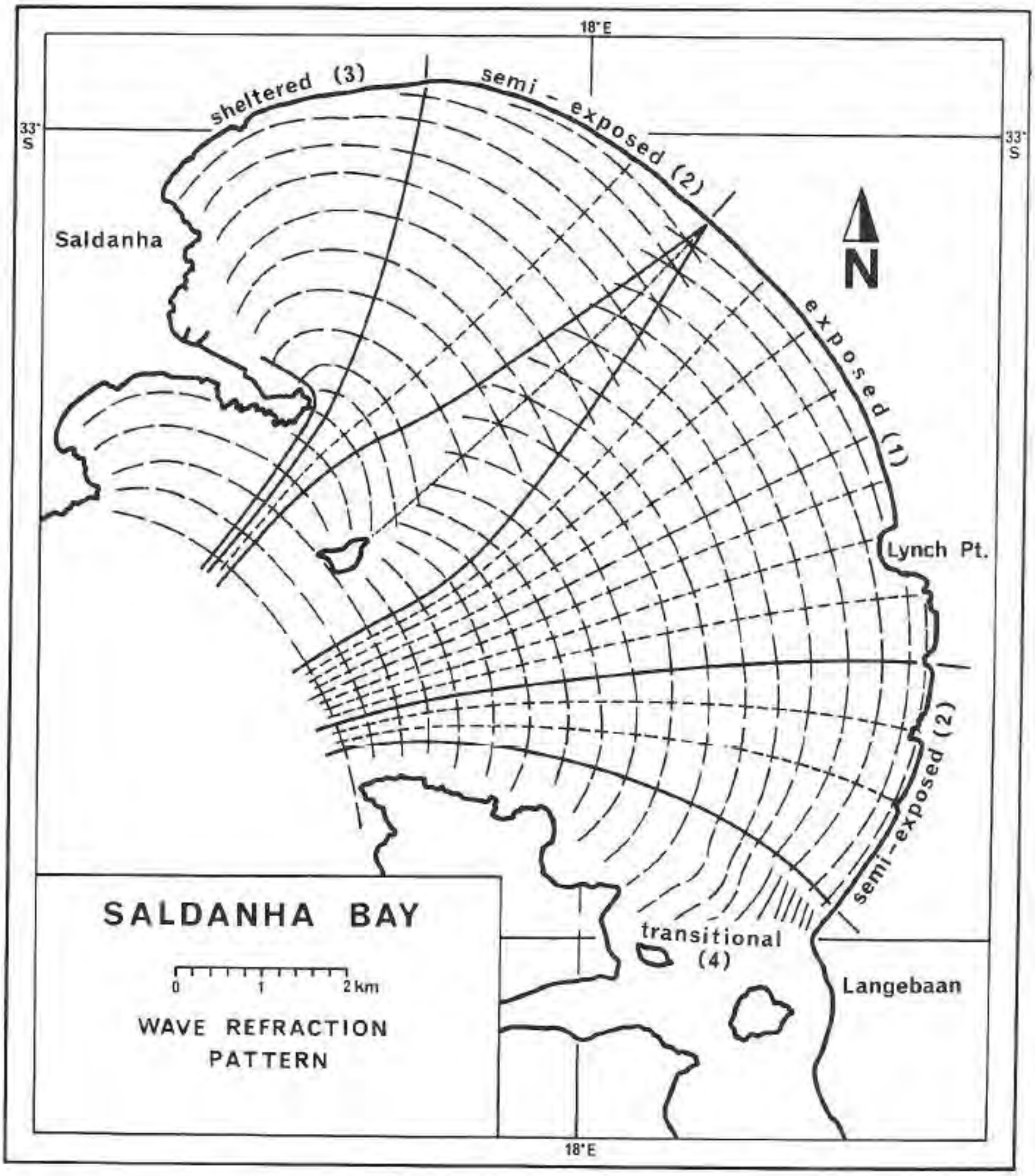


Figure 4.6. Predicted wave field at Saldanha showing wave height and direction. Source: Flemming (1977).

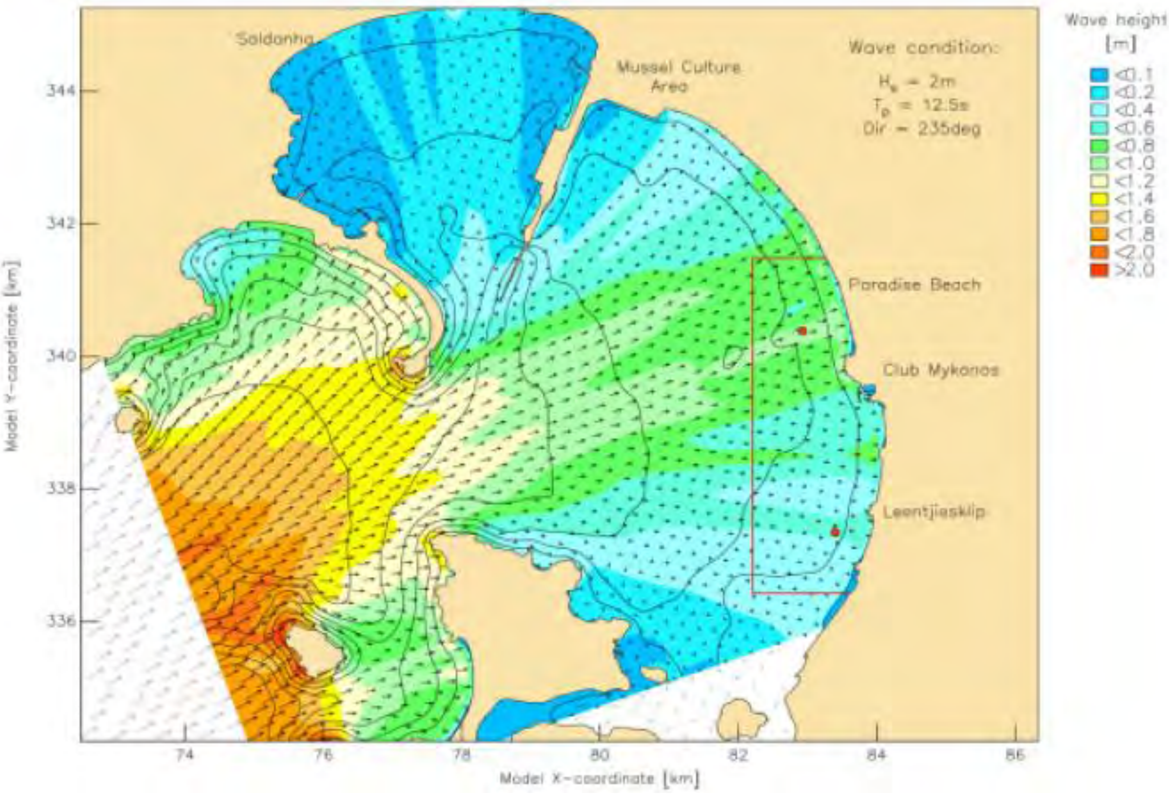


Figure 4.7. Predicted wave field at Saldanha showing wave height and direction. Source: WSP Africa Coastal Engineers (2010).

4.6 Microbiological monitoring

Faecal pollution contained in, for example, untreated sewage or storm water runoff, may introduce disease-causing micro-organisms into coastal waters. These pathogenic micro-organisms constitute a threat to recreational water users and consumers of seafood. Bacterial indicators are used to detect the presence of faecal pollution. These bacterial indicators, however, only provide indirect evidence of the possible presence of water borne pathogens and may not accurately represent the risk to water users (Monteiro *et al.* 2000). Historically, the DWAF (1995) and (1996b) guidelines for inland and coastal waters respectively, have been used to assess compliance in respect of human health criteria. However as of 2011, these have been replaced with the South African Water Quality Guidelines for Coastal Marine Waters Volume 2: Interim Guidelines for Recreational Use (Department of Environmental Affairs, 2011). Sampling in Saldanha Bay and Langebaan lagoon is still undertaken in accordance with the 1995/1996 DWAF protocol but these data are evaluated in accordance with these and the 2011 DEA protocols.

4.6.1 DWAF 1995 and 1996 guidelines

The DWAF (1995) and (1996b) guidelines for inland and coastal waters respectively, identified three recreational user groups; full-contact, intermediate-contact and non-contact recreation. Full contact recreation included swimming and diving among other activities. Partial-contact recreation covered activities such as water skiing, canoeing and angling as well as paddling and wading. Non-contact recreation activities included picnicking and hiking alongside water bodies.

Target limits were based on counts of faecal coliforms in a sample of water and were linked to the estimated amount of water that needed to be ingested to become ill from pathogenic organisms, Table 4.1. In addition to recreational users, water was analysed to assess compliance with mariculture guidelines as these filter feeding organism can accumulate pathogenic organisms in their bodies and thereby infect people that consume them.

In 1998 the council for Scientific and Industrial research (CSIR) were contracted by the Saldanha Bay Water Quality Forum Trust (SBWQFT) to undertake fortnightly sampling of microbiological indicators at 15 stations within Saldanha Bay. The initial report by the CSIR, covering the period February 1999 to March 2000, revealed that within Small Bay, faecal coliform counts frequently exceeded the guidelines for both mariculture and contact recreation (100 faecal coliforms occurring in 80% of samples analysed) at 9 of 10 sampling stations. These results indicated that there was indeed a health risk associated with the collection and consumption of filter feeding shellfish (mussels) and with contact recreation water (i.e. swimming, diving etc.) in Small Bay. Much lower faecal coliform counts were recorded at stations within Big Bay, with the exception of the 80th percentile guideline for mariculture being exceeded at one station (Paradise beach); all other stations ranged within the guidelines for mariculture and recreational use (Monteiro *et al*. 2000).

Table 4.1. Maximum acceptable count of faecal coliforms (per 100 ml sample) for mariculture and recreational use

Purpose/Use	Guideline value
Recreational (full water contact)	100 faecal coliforms in 80% of samples 2000 faecal coliforms in 95% of samples
Mariculture	20 faecal coliforms in 80% of samples 60 faecal coliforms in 95% of samples

Regular monitoring of microbiological indicators within Saldanha Bay has continued to the present day, now undertaken by the Saldanha Bay Municipality, and the available data now covers the period February 1999 to December 2012 for 20 stations (10 in Small Bay, 5 in Big Bay and 5 in Langebaan Lagoon). Data during this period has, for the most part, been collected on a monthly or bimonthly basis since 1999 at 14 stations within Small and Big Bay in Saldanha, with the exception of Station 11 (Seafarm - TNPA) where no data was collected during 2003, 2004, 2008 and 2010. Regular data collection was initiated at some of the Langebaan sites in 2004. Samples were collected at sites 19 and 20 (Kraalbaai North and South respectively) for the first time in 2012. Only faecal coliform limits were included in this analysis.

These data indicate that nearshore coastal waters in Saldanha Bay have improved since 1999 until recently at least. Four sites in the Bay (specifically Site 7 – the beach at the Hoedjiesbaai Bay Hotel, Site 8 - the beach at caravan park, Site 9 - the beach at the Bok River mouth and Site 14 - Langebaan North - Leentjiesklip) did not meet the 80th percentile guideline limits for recreational use in 2012 (Table 4.2). Two of these sites (Site 8 and 9) did not meet the 95th percentile limits either (Table 4.3). Overall levels of compliance in 2012 for the 80th and 95th percentile show a decrease in environmental health compared to recent years.

As far as the guideline limits for mariculture are concerned, which are much stricter than the recreational limits, levels of compliance were predictably much lower. At least 7 sites (out of a total of 20) were not compliant in respect of the 80th percentile limits for faecal coliforms for mariculture in 2012 (Table 4.4), while 8 were not compliant in respect of the 95th percentile limits (Table 4.5). Many of the non-compliant sites exceeded the limit by quite a large margin (especially sites 7, 8 and

9 in the case of the 80th percentile and sites 5, 7, 8, 9 and 14 in the case of the 95th percentile). The worst site was at the beach at the Bok river mouth (Site 9). Overall levels of compliance had deterioration in relation to 2011. Levels of faecal coliforms at one of the new sites sampled, Site 19 – Kraalbaai North, also exceeded the 95th percentile limits for mariculture.

Time series plots and linear regression analysis of the faecal coliform and *E. coli* counts were carried out for selected sites within Small Bay, Big Bay and Langebaan. Many of the sampling stations within Small Bay show a statistically significant decrease in faecal coliform and *E. coli* concentrations over the long term (last ten years), although still remain relatively high. However, faecal coliform and E. coli concentrations appear to be increasing at Stations 2 (Small Craft Harbour), 8 (Beach at Caravan Park) and 10 (General Cargo Quay – TNPA) (Figure 4.8), which is very concerning. Station 4 (Saldanha Bay yacht club) showed a significant improvement in bacterial counts, while Stations 7 (Hoedjiesbaai Bay), 8 (Beach at Caravan park) and 9 (Beach at Bok river mouth) showed no significant change, but had consistently high concentrations of faecal coliform and *E. coli* (Figure 4.9 and Figure 4.10).

Time series plots for the four most frequently sampled sites in Big Bay are shown in Figure 4.11. Although the levels of faecal coliforms and *E. coli* at these stations are mostly lower than at stations in Small Bay, the trend over time is that of deterioration in four of the sites, Seafarm at TNPA, Mykonos (Paradise Beach), General Cargo Quay TNPA and Langebaan North - Leentjiesklip.

The Langebaan sites have fairly high microbiological levels (Figure 4.13), with a noticeable deterioration at Tooth Rock. There was insufficient data for the Kraalbaai sites to detect any trends over time at this site.

Table 4.2. **Sampling site compliance (based on faecal coliform counts) for 10 sites in Small Bay, 5 sites in Big Bay and 5 sites in Langebaan Lagoon. Average faecal coliform concentration of samples calculated within the 80th percentile limit specified in South African Water Quality Guidelines for recreational use (100 organisms/100 ml) for 18 sites. Numbers in black indicate compliance with regulations, while red numbers indicate non-compliance. "-" indicates that no samples were collected in that year. (Source: Saldanha Bay Water Quality Forum Trust).**

	Site	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Small Bay	1. Beach at Mussel Rafts	157	2	0	4	0	0	0	0	2	0	3	0	0	2
	2. Small Craft Harbour	111	14	8	6	14	7	4	0	0	0	11	0	0	4
	3. Small Quay - Sea Harvest	476	89	37	93	93	93	15	7	13	5	23	4	16	5
	4. Saldanha Yacht Club	996	514	972	240	240	460	240	9	20	7	7	5	6	4
	5. Pepper Bay - Big Quay	834	172	2400	186	460	240	93	93	23	23	15	23	23	43
	6. Pepper Bay - Small Quay	758	182	240	43	83	93	23	15	15	4	7	240	6	11
	7. Hoedjiesbaai Bay Hotel - Beach	442	105	1052	240	222	181	150	27	128	43	240	240	186	328
	8. Beach at Caravan Park	94	38	201	62	83	43	75	9	41	93	93	168	51	328
	9. Beach - Bok River Mouth	938	190	692	1100	460	240	240	35	93	412	460	53	63	716
	10. General Cargo Quay - TNPA	8	2	4	0	0	0	0	0	0	0	0	0	0	0
Big Bay	11. Seafarm - TNPA	7	6	0	0	-	-	0	0	0	-	0	-	4	6
	12. Mykonos - Paradise Beach	3	6	0	0	0	0	9	0	0	0	7	0	0	2
	13. Mykonos - Harbour	18	21	3	7	9	0	0	4	9	9	23	4	22	5
	14. Langebaan North - Leentjiesklip	5	5	6	9	9	2	0	2	4	5	4	0	13	116
	16. Leentijiesklip	-	-	240	93	36	15	10	9	15	4	9	9	18	15
Langebaan	15. Langebaan Main Beach	-	-	79	0	0	0	4	0	0	0	43	4	3	23
	17. Langebaan Yacht Club	-	-	-	-	-	17	4	2	12	1	23	4	6	9
	18. Tooth Rock	-	-	-	-	-	5	7	2	4	12	9	5	0	22
	19. Kraalbaai North	-	-	-	-	-	-	-	-	-	-	-	-	-	4
	20. Kraalbaai South	-	-	-	-	-	-	-	-	-	-	-	-	-	4

Table 4.3. Sampling site compliance (based on faecal coliform counts) for 10 sites in Small Bay, 5 sites in Big Bay and 5 sites in Langebaan Lagoon. Average faecal coliform concentration of samples calculated within the 95th percentile limit specified in South African Water Quality Guidelines for recreational use (2000 organisms/100 ml) for 18 sites. Numbers in black indicate compliance with regulations, while red numbers indicate non-compliance. "-" indicates that no samples were collected in that year. (Source: Saldanha Bay Water Quality Forum Trust).

	Site	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Small Bay	1. Beach at Mussel Rafts	720	3	1	7	15	4	15	0	4	9	4	19	0	13
	2. Small Craft Harbour	330	16	110	23	28	41	240	9	4	15	81	9	4	52
	3. Small Quay - Sea Harvest	2374	279	240	230	240	237	43	41	23	11	240	9	86	25
	4. Saldanha Yacht Club	12831	1508	2400	1100	1100	1100	1100	40	23	46	67	9	22	4
	5. Pepper Bay - Big Quay	3312	324	4600	383	460	438	460	2360	88	155	43	93	86	262
	6. Pepper Bay - Small Quay	3565	642	612	189	449	231	93	43	85	34	76	460	21	130
	7. Hoedjiesbaai Bay Hotel - Beach	1154	119	2400	799	460	438	240	429	460	155	1100	460	2500	1240
	8. Beach at Caravan Park	692	45	588	1945	233	225	150	85	220	1100	240	1820	427	2580
	9. Beach - Bok River Mouth	2794	216	2840	2400	2335	1036	1100	93	423	1100	1100	416	227	2580
	10. General Cargo Quay - TNPA	18	2	20	4	4	4	4	14	9	7	4	0	4	4
Big Bay	11. Seafarm - TNPA	13	20	21	3	-	-	23	4	4	-	8	-	4	48
	12. Mykonos - Paradise Beach	4	7	9	0	4	7	23	10	4	4	20	8	3	12
	13. Mykonos - Harbour	786	29	6	130	439	15	9	88	139	24	203	20	86	25
	14. Langebaan North - Leentjiesklip	35	9	212	93	23	86	4	9	9	15	349	6	34	1100
	16. Leentijiesklip	-	-	284	876	93	88	28	22	23	16	76	37	43	149
Langebaan	15. Langebaan Main Beach	-	-	518	0	0	0	4	0	0	4	405	20	67	48
	17. Langebaan Yacht Club	-	-	-	-	-	723	23	40	41	23	405	173	210	36
	18. Tooth Rock	-	-	-	-	-	18	23	4	20	91	37	20	20	26
	19. Kraalbaai North	-	-	-	-	-	-	-	-	-	-	-	-	-	70
	20. Kraalbaai South	-	-	-	-	-	-	-	-	-	-	-	-	-	18

Table 4.4. **Sampling site compliance (based on faecal coliform counts) for 10 sites in Small Bay, 5 sites in Big Bay and 5 sites in Langebaan Lagoon. Average faecal coliform concentration of samples calculated within the 80th percentile limit specified in South African Water Quality Guidelines for mariculture use (20 organisms/100 ml) for 18 sites. Numbers in black indicate compliance with regulations, while red numbers indicate non-compliance. "-" indicates that no samples were collected in that year. (Source: Saldanha Bay Water Quality Forum Trust).**

	Site	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Small Bay	1. Beach at Mussel Rafts	157	2	0	4	0	0	0	0	2	0	3	0	0	2
	2. Small Craft Harbour	111	14	8	6	14	7	4	0	0	0	11	0	0	4
	3. Small Quay - Sea Harvest	476	89	37	93	93	93	15	7	13	5	23	4	16	5
	4. Saldanha Yacht Club	996	514	972	240	240	460	240	9	20	7	7	5	6	4
	5. Pepper Bay - Big Quay	834	172	2400	186	460	240	93	93	23	23	15	23	23	43
	6. Pepper Bay - Small Quay	758	182	240	43	83	93	23	15	15	4	7	240	6	11
	7. Hoedjies Bay Hotel - Beach	442	105	1052	240	222	181	150	27	127	43	240	240	186	328
	8. Beach at Caravan Park	94	38	201	62	83	43	75	9	41	93	93	168	51	328
	9. Beach - Bok River Mouth	938	190	692	1100	460	240	240	35	93	412	460	53	63	716
	10. General Cargo Quay - TNPA	8	2	4	0	0	0	0	0	0	0	0	0	0	0
Big Bay	11. Seafarm - TNPA	7	6	0	0	-	-	0	0	0	-	0	-	4	6
	12. Mykonos - Paradise Beach	3	6	0	0	0	0	9	0	0	0	7	0	0	2
	13. Mykonos - Harbour	18	21	3	7	9	0	0	4	9	9	23	4	22	5
	14. Langebaan North - Leentjiesklip	5	5	6	9	9	2	0	2	4	5	4	0	13	116
	16. Lentijiesklip	-	-	240	93	36	15	10	9	15	4	9	9	18	15
Langebaan	15. Langebaan Main Beach	-	-	79	0	0	0	4	0	0	0	43	4	3	23
	17. Langebaan Yacht Club	-	-	-	-	-	17	4	2	12	1	23	5	6	9
	18. Tooth Rock	-	-	-	-	-	5	7	2	4	12	9	5	0	22
	19. Kraalbaai North	-	-	-	-	-	-	-	-	-	-	-	-	-	4
	20. Kraalbaai South	-	-	-	-	-	-	-	-	-	-	-	-	-	4

Table 4.5. **Sampling site compliance (based on faecal coliform counts) for 10 sites in Small Bay, 5 sites in Big Bay and 5 sites in Langebaan Lagoon. Average faecal coliform concentration of samples calculated within the 95th percentile limit specified in South African Water Quality Guidelines for mariculture use (60 organisms/100 ml) for 18 sites. Numbers in black indicate compliance with regulations, while red numbers indicate non-compliance. "-" indicates that no samples were collected in that year. (Source: Saldanha Bay Water Quality Forum Trust).**

	Site	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Small Bay	1. Beach at Mussel Rafts	720	3	1	7	15	4	15	0	4	9	4	19	0	13
	2. Small Craft Harbour	330	16	110	23	28	41	240	9	4	15	81	9	4	52
	3. Small Quay - Sea Harvest	2374	279	240	230	240	237	43	41	23	11	240	9	86	25
	4. Saldanha Yacht Club	12831	1508	2400	1100	1100	1100	1100	40	23	46	67	9	22	4
	5. Pepper Bay - Big Quay	3312	324	4600	383	460	438	460	2360	88	155	43	93	86	262
	6. Pepper Bay - Small Quay	3565	642	612	189	449	231	93	43	85	34	76	460	21	130
	7. Hoedjies Bay Hotel - Beach	1154	119	2400	799	460	438	240	429	460	155	1100	460	2500	1240
	8. Beach at Caravan Park	692	45	588	1945	233	225	150	85	220	1100	240	1820	427	2580
	9. Beach - Bok River Mouth	2794	216	2840	2400	2335	1036	1100	93	423	1100	1100	416	227	2580
	10. General Cargo Quay - TNPA	18	2	20	4	4	4	4	14	9	7	4	0	4	4
Big Bay	11. Seafarm - TNPA	13	20	21	3	-	-	23	4	4	-	8	-	4	48
	12. Mykonos - Paradise Beach	4	7	9	0	4	7	23	10	4	4	20	8	3	12
	13. Mykonos - Harbour	786	29	6	130	439	15	9	88	139	24	203	20	86	25
	14. Langebaan North - Leentjiesklip	35	9	212	93	23	86	4	9	9	15	349	6	34	1100
	16. Lentijiesklip	-	-	284	876	93	88	28	22	23	16	76	37	43	149
Langebaan	15. Langebaan Main Beach	-	-	518	0	0	0	4	0	0	4	405	20	67	48
	17. Langebaan Yacht Club	-	-	-	-	-	723	23	40	41	23	405	173	210	36
	18. Tooth Rock	-	-	-	-	-	18	23	4	20	91	37	20	20	26
	19. Kraalbaai North	-	-	-	-	-	-	-	-	-	-	-	-	-	70
	20. Kraalbaai South	-	-	-	-	-	-	-	-	-	-	-	-	-	18

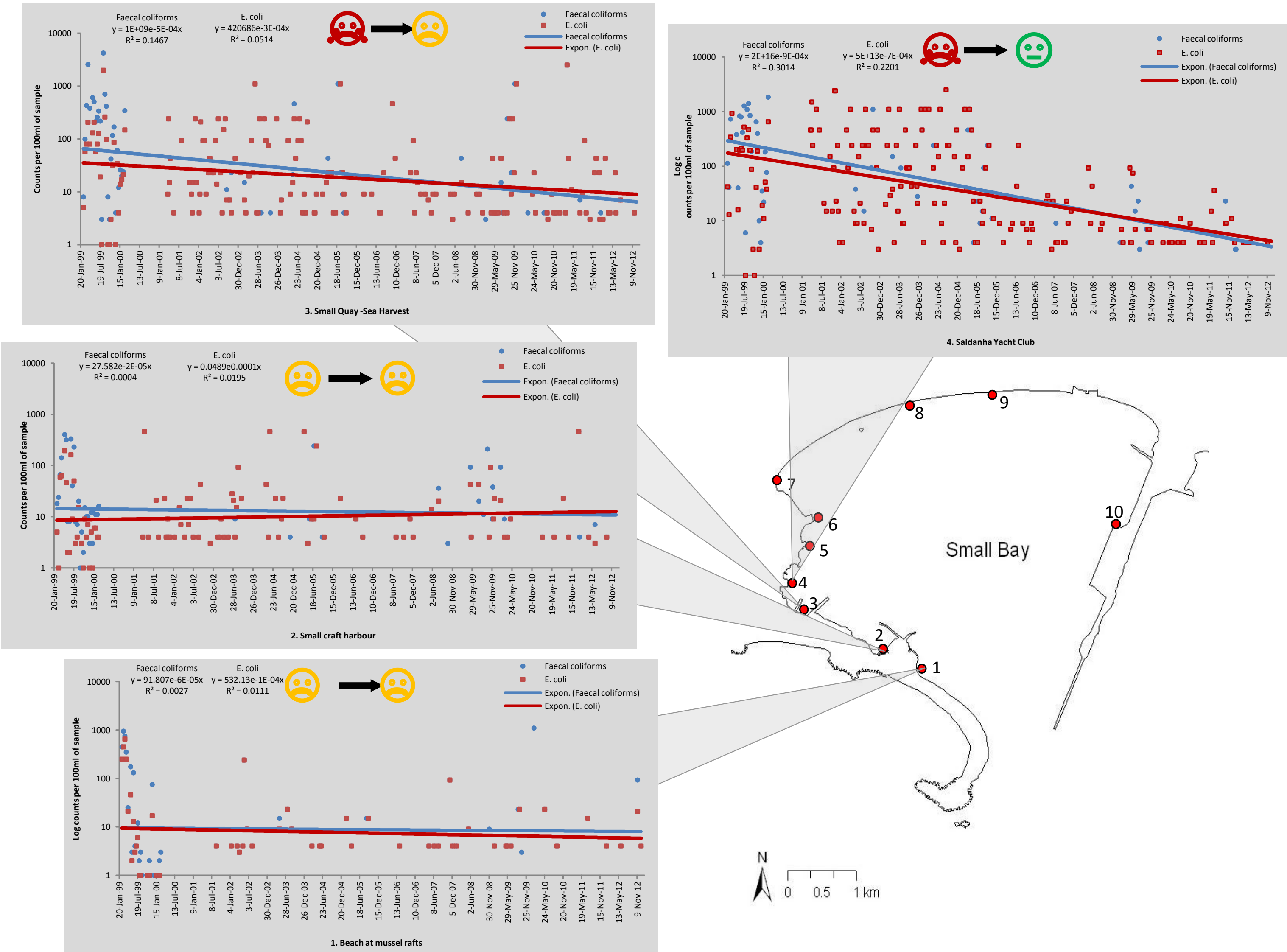


Figure 4.8. **Faecal coliform and *E. coli* counts at 4 of the 10 sampling stations within Small Bay (Feb 1999 - Dec 2012). A downward slope of the regression (solid red and blue lines) is indicative of improving water quality, while an upward slope in these lines in indicative of decreasing water quality.**

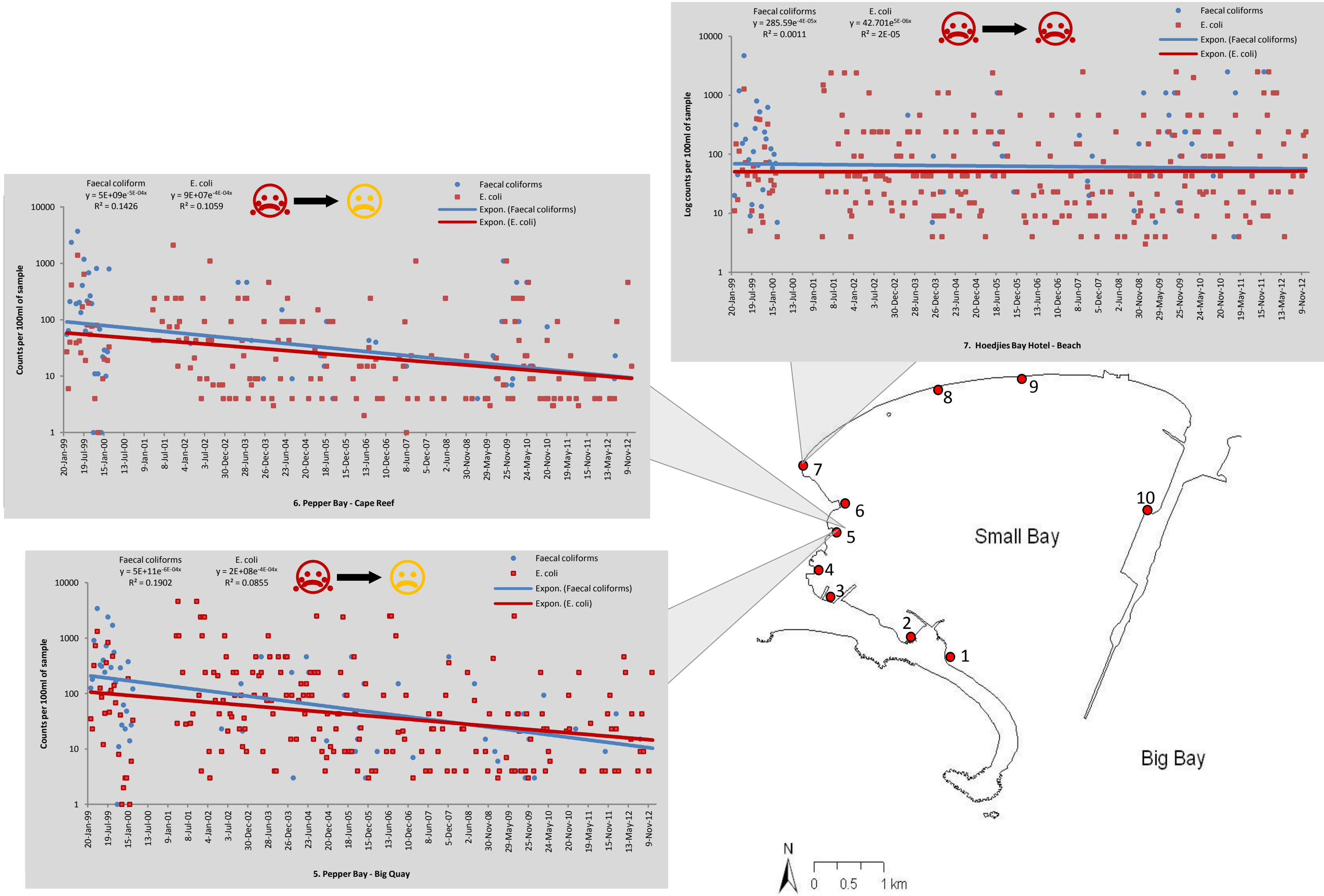


Figure 4.9. **Faecal coliform and *E. coli* logarithmic counts at 3 of the 10 sampling stations within Small Bay (Feb 1999 - Dec 2012). A downward slope of the regression (solid red and blue lines) is indicative of improving water quality, while an upward slope in these lines in indicative of decreasing water quality.**

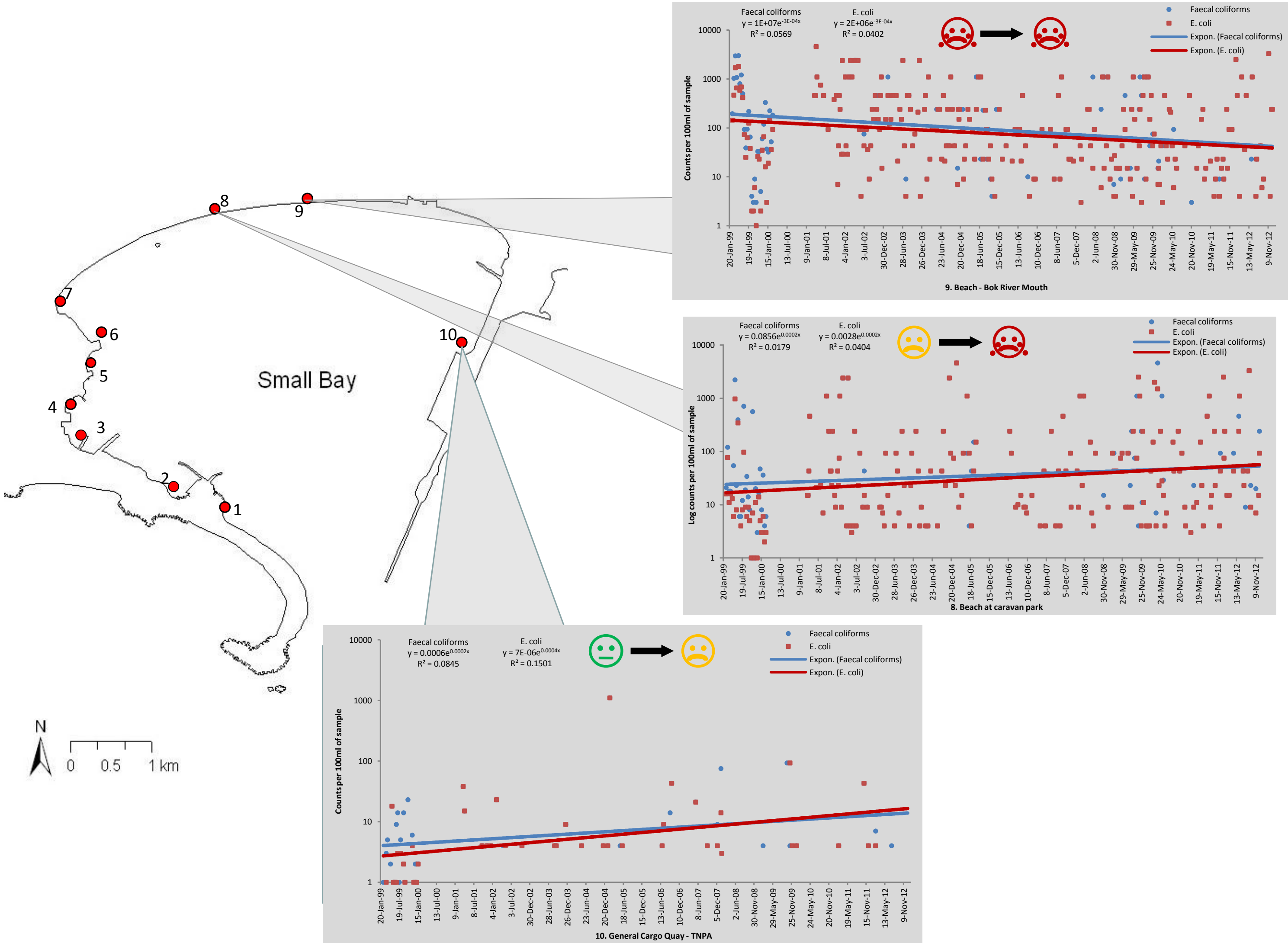


Figure 4.10. Faecal coliform and *E. coli* logarithmic counts at 4 of the 10 sampling stations within Big Bay (Feb 1999 - Dec 2012). A downward slope of the regression (solid red and blue lines) is indicative of improving water quality, while an upward slope in these lines in indicative of decreasing water quality.

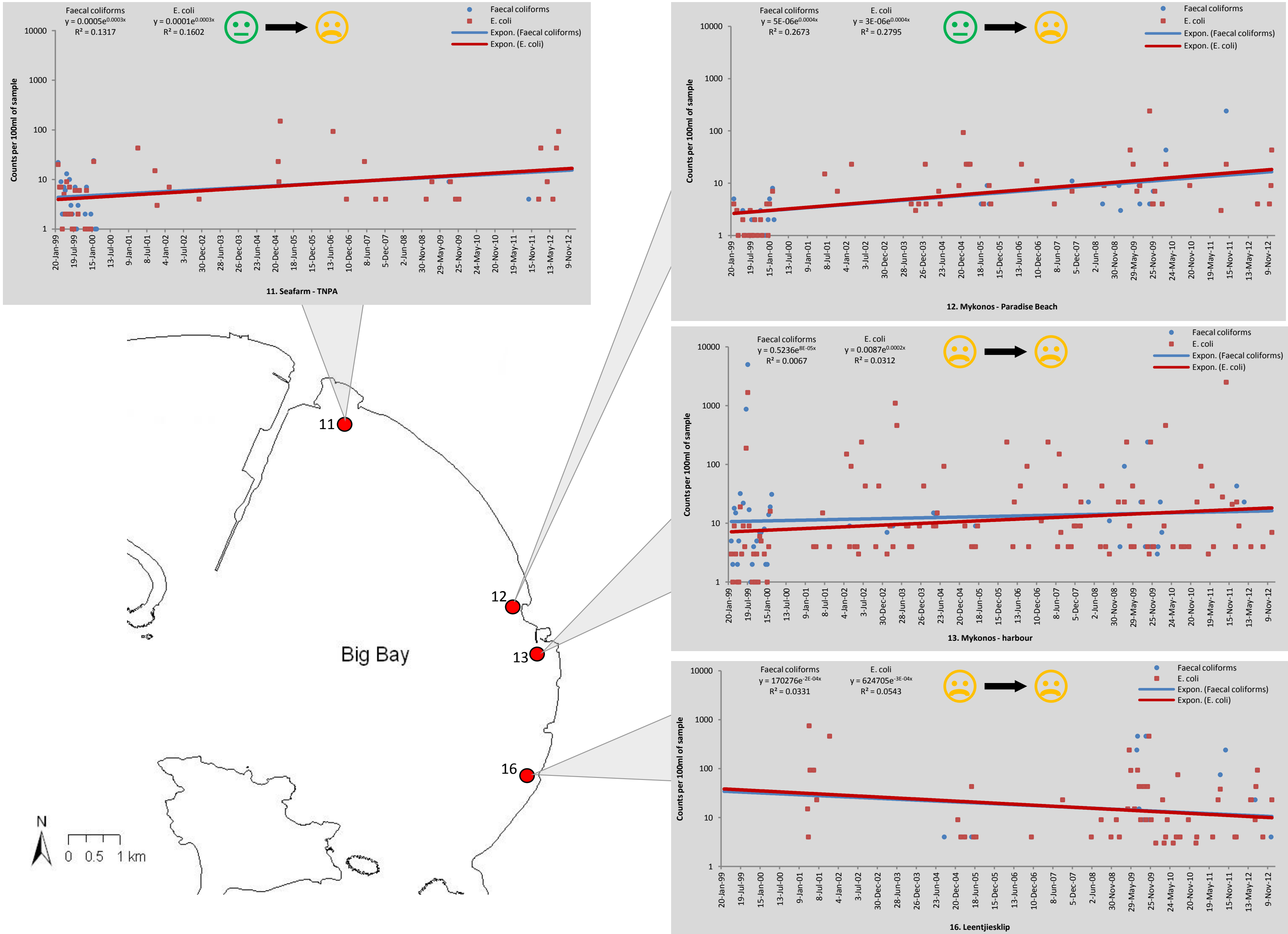


Figure 4.11. Faecal coliform and *E. coli* logarithmic counts at 4 sampling stations within Big Bay (Feb 1999 - Dec 2012). A Downward slope of the regression (solid red and blue lines) is indicative of improving water quality, while an upward slope in these lines in indicative of decreasing water quality.

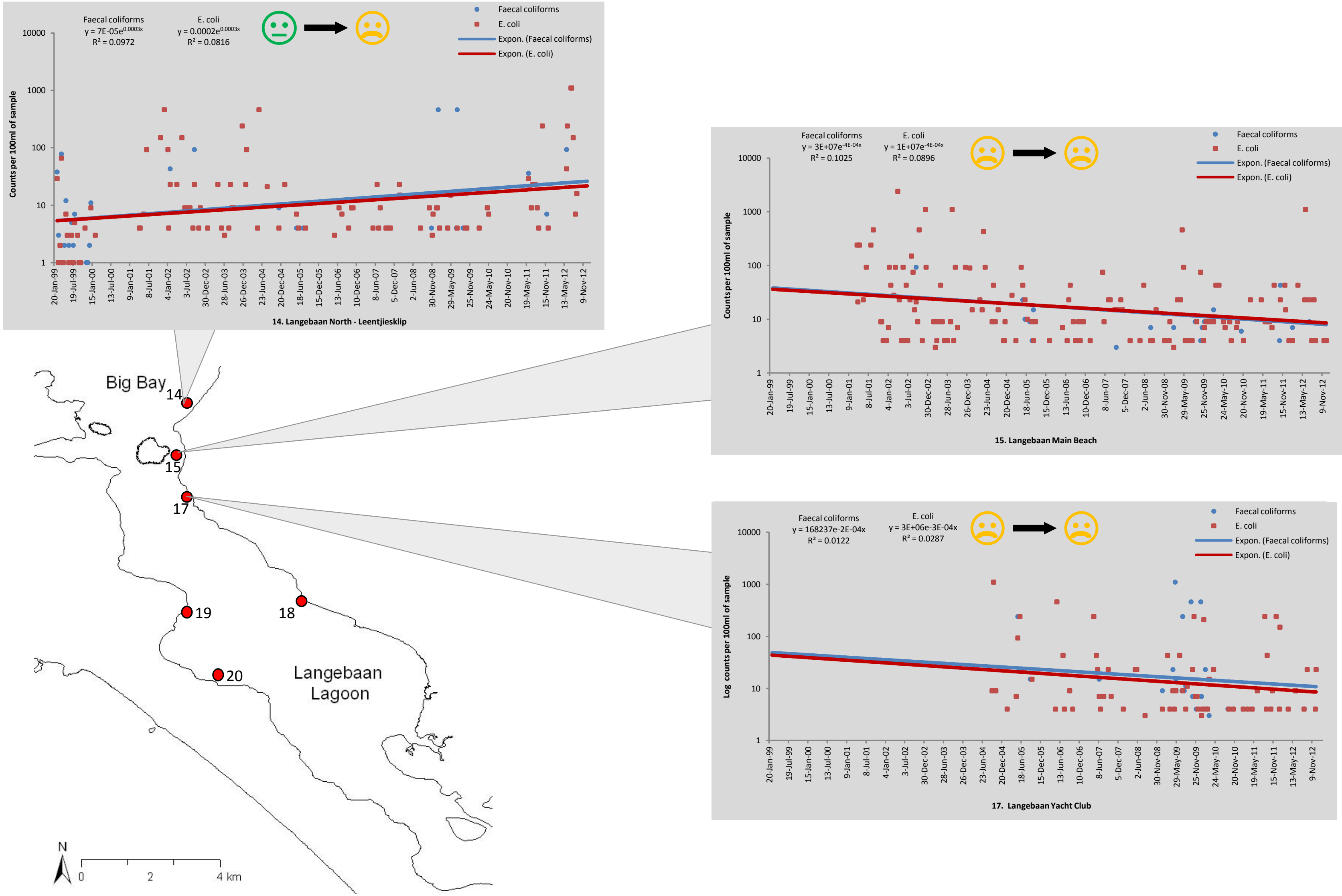


Figure 4.12. **Faecal coliform and *E. coli* logarithmic counts at 3 sampling stations within Langebaan Lagoon (Feb 1999 - Dec 2012). A Downward slope of the regression (solid red and blue lines) is indicative of improving water quality, while an upward slope in these lines in indicative of decreasing water quality.**

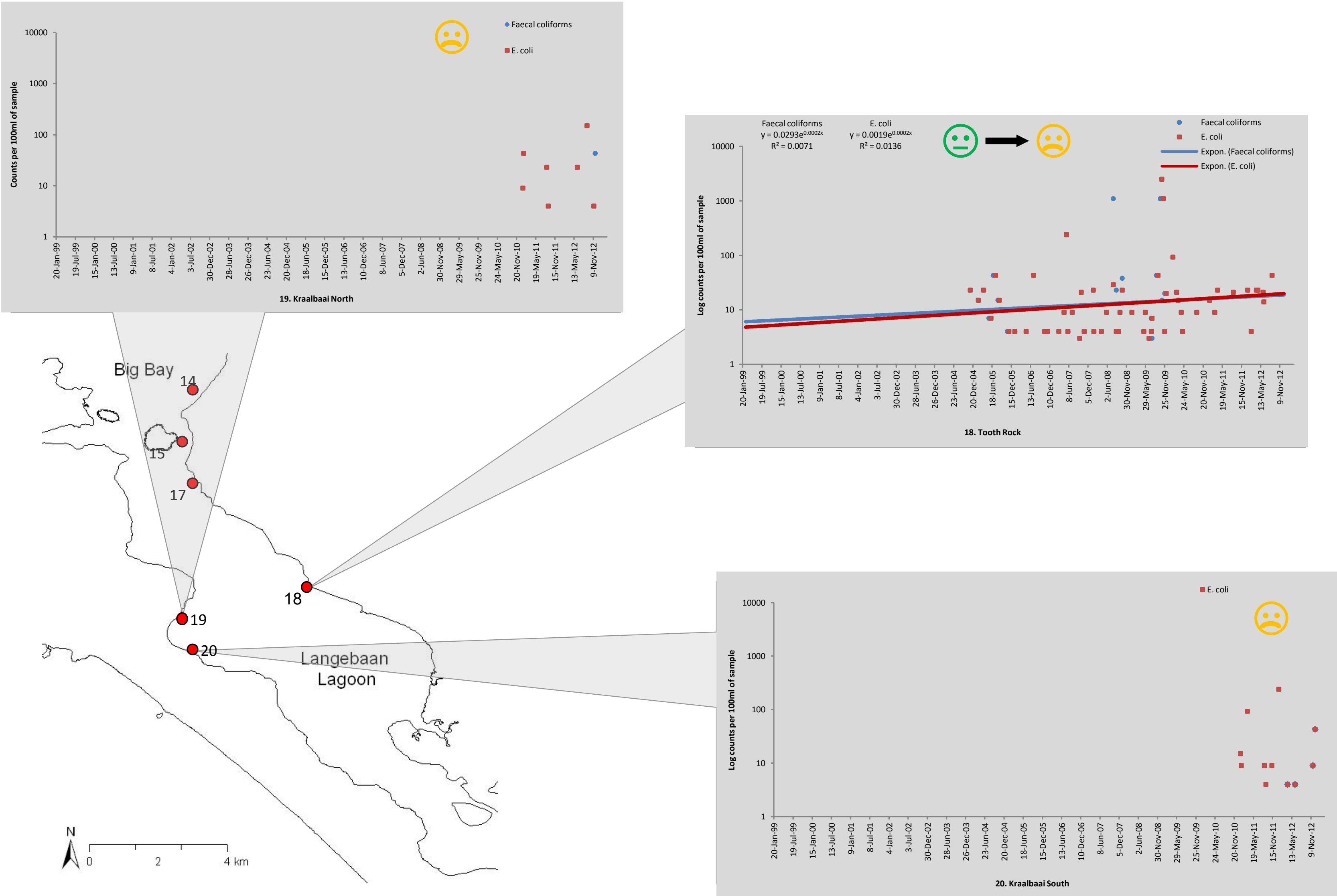


Figure 4.13. Faecal coliform and *E. coli* logarithmic counts at 3 sampling stations within Langebaan Lagoon (Feb 1999 - Dec 2012). A Downward slope of the regression (solid red and blue lines) is indicative of improving water quality, while an upward slope in these lines in indicative of decreasing water quality.

4.6.2 Revised final guidelines for recreational waters of South Africa's coastal marine environment

The DWAF guidelines were re-written following an international review of guidelines for coastal waters, which highlighted several shortcomings in those developed by South Africa. The revised guidelines (RSADEA 2011) do not distinguish between different levels of contact recreation. Instead, aesthetics (which includes bad odours, discolouration of water and presence of objectionable matter), human health and safety (gastrointestinal problems, skin, eye, ear and respiratory irritations, physical injuries and hypo-/hyperthermia), and mechanical interference are considered. Indicators used are the presence of objectionable matter, water temperature and pH and the levels of intestinal *Enterococci* (and *E. coli* where necessary).

Rather than a using a measure of actual condition, a compliance index has been developed to determine deviation from a fixed limit. This method is increasingly used across Europe to determine the compliance in meeting stringent water quality targets within specified time frames (e.g. Carr and Rickwood 2008). Compliance data are usually grouped into broad categories, indicating the relative acceptability of different levels of compliance. For example, a low count of bacteria would be "Excellent" while a "Poor" rating would indicate high levels of bacteria. These methods are to be trialled in South Africa over a few years to assess applicability and feasibility while determining target limits.

The Hazen statistical method is recommended for dealing with non-parametric data (assumes data does not belong to a particular distribution). The data is ranked into ascending order and then percentile values are calculated using a formula. Target limits, based on counts of intestinal Enterococci and *E. coli*, for recreational water use are indicated below (Table 4.6). In order to calculate 95th percentiles, a minimum of 10 data points are required, while the 90th percentile estimates require only 5 data points.

Table 4.6. Target limits for *Enterococci* and *E. coli* based on revised final guidelines for recreational waters of South Africa's coastal marine environment (RSADEA 2011)

Category	Estimated risk per exposure	Enterococci (count/100 ml)	E. coli (count/100ml)
Excellent	2.9% (GI) illness risk	≤ 100 (95 percentile)	≤ 250 (95 percentile)
Good	5% GI illness risk	≤ 200 (95 percentile)	≤ 500 (95 percentile)
Sufficient/Fair (minimum requirement)	8.5% GI illness risk	≤ 185 (90 percentile)	≤ 500 (90 percentile)
Poor (unacceptable)	>8.5 % GI illness risk	>185 (90 percentile)	>500 (90 percentile)

Data from January 1999 to December 2012 has been re-analysed using these methods to assess overall health rankings (Table 4.7). Due to the absence of data on intestinal *Enterococci* over the sampling period, *E. coli* has been used as an indicator species to evaluate the microbiological health of the Bay. The data for each year was assessed for compliance by evaluating both the 90th and 95th percentiles. Ten samples were required from each site per year to assess compliance. Many of the sites did not meet this minimum limit and are thus listed as having 'Insufficient Data'. Several sites appeared to have no data collected in some years. Sampling at the Langebaan Yacht Club, Tooth Rock and Kraalbaai North and South was only initiated once the sampling programme had begun, so the 'No data' status is understandable for these sites. However, sampling at Seafarm – TNPA has been insufficient, with irregular data collection in recent years. In order to prevent this pattern being repeated in future, data should be collected at all twenty sites on a bi-monthly basis throughout the year.

The revised ranks of 20 sites around the Saldanha Bay area are presented in Table 4.7. Three sites in Small Bay (Site 7. Hoedjies Bay Hotel – Beach, Site 8. Beach at Caravan Park, and Site 9. Beach - Bok River Mouth) were ranked as 'Poor'. In the case of Site 9 this represented a significant drop from Excellent in 2011 to Poor in 2012, for Site 8 a drop from Fair to Poor and no change for Site 9. Site 14 Langebaan North – Leentjiesklip was rated as Fair in 2012 (down from Excellent in 2011) and the two sites in Pepper Bay (Site 5. Big quay and Site 6. Small quay) were rated as Good (both down from Excellent in 2011). The remaining sites were all rated as Excellent in 2012. This represented an improvement in health status for Site 3 Small Quay - Sea Harvest and Site 13 Mykonos – Harbour, which were both rated as Fair in 2011.

Guidelines state that samples should be collected 15-30 cm below the surface. In order to minimise contamination and reduce sediment content, samples should be collected on the seaward side of a recently broken wave. Samples to be tested for *E. coli* counts should be analysed within 6-8 hours of collection, and those to be tested for intestinal *Enterococci*, within 24 hours. Analyses should be completed by an accredited laboratory, preferably one with ISO 17025 accreditation.

It is recommended that samples are analysed for intestinal *Enterococci* preferably over *E. coli*. Several studies have shown that thermotolerant coliforms and *E. coli* to be relatively poor indicators of health risks in marine waters. These organisms are also less resilient than *Enterococci* (and other pathogenic bacteria) so if analysis is focused on coliforms, the risk could be underestimated due to mortality occurring in the time taken between collection and analysis.

Table 4.7. Sampling site compliance (based on E. coli counts) for 10 sites in Small Bay, 5 sites in Big Bay and 5 sites in Langebaan Lagoon. Ratings are calculated using Hazen percentiles, (with the 90th and 95th percentile results being grouped together to give an overall rating per annum. "ID" indicates that samples were collected that year, but there were insufficient data to allow calculation of Hazen percentiles. "ND" indicates that no data were collected in that year.

	Site	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Small Bay	1. Beach at Mussel Rafts	Fair	ID	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
	2. Small Craft Harbour	Excellent	ID	Good	Excellent	Excellent	Excellent	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
	3. Small Quay - Sea Harvest	Fair	ID	Excellent	Excellent	Fair	Excellent	Fair	Excellent	Excellent	Excellent	Good	Excellent	Fair	Excellent
	4. Saldanha Yacht Club	Poor	ID	Poor	Fair	Poor	Poor	Poor	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
	5. Pepper Bay - Big Quay	Poor	ID	Poor	Fair	Fair	Fair	Fair	Poor	Excellent	Excellent	Fair	Excellent	Excellent	Good
	6. Pepper Bay - Small Quay	Poor	ID	Fair	Good	Excellent	Good	Excellent	Excellent	Good	Excellent	Good	Good	Excellent	Good
	7. Hoedjies Bay Hotel - Beach	Fair	ID	Poor	Fair	Good	Poor	Poor	Good	Fair	Excellent	Fair	Fair	Poor	Poor
	8. Beach at Caravan Park	Fair	ID	Fair	Poor	Excellent	Fair	Poor	Excellent	Good	Poor	Fair	Good	Fair	Poor
	9. Beach - Bok River Mouth	Poor	ID	Poor	Poor	Poor	Poor	Poor	Excellent	Fair	Poor	Poor	Fair	Excellent	Poor
	10. General Cargo Quay - TNPA	Excellent	ID	Excellent	Excellent	Excellent	Excellent	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Big Bay	11. Seafarm - TNPA	Excellent	ID	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	ID	Excellent	Good	ID	Excellent
	12. Mykonos - Paradise Beach	Excellent	ID	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
	13. Mykonos - Harbour	Fair	ID	Excellent	Excellent	Fair	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Fair	Excellent
	14. Langebaan North - Leentjiesklip	Excellent	ID	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Fair
	16. Lentijiesklip	ND	ND	Good	Fair	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Langebaan	15. Langebaan Main Beach	ND	ND	Fair	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Good	Excellent	Excellent	Excellent
	17. Langebaan Yacht Club	ND	ND	ND	ND	ND	ID	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
	18. Tooth Rock	ND	ND	ND	ND	ND	ID	Excellent	Excellent	Excellent	Excellent	Fair	Excellent	Excellent	Excellent
	19. Kraalbaai North	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	Excellent
	20. Kraalbaai South	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	Excellent

In addition to this, an operational management process was recommended for South Africa, following Enterococci counts (Figure 4.14). A mode is assigned based on the levels of Enterococci in a single count (Green or Amber) or on consecutive counts (Red). Each mode outlines a plan of action to be undertaken to deal with the problem.

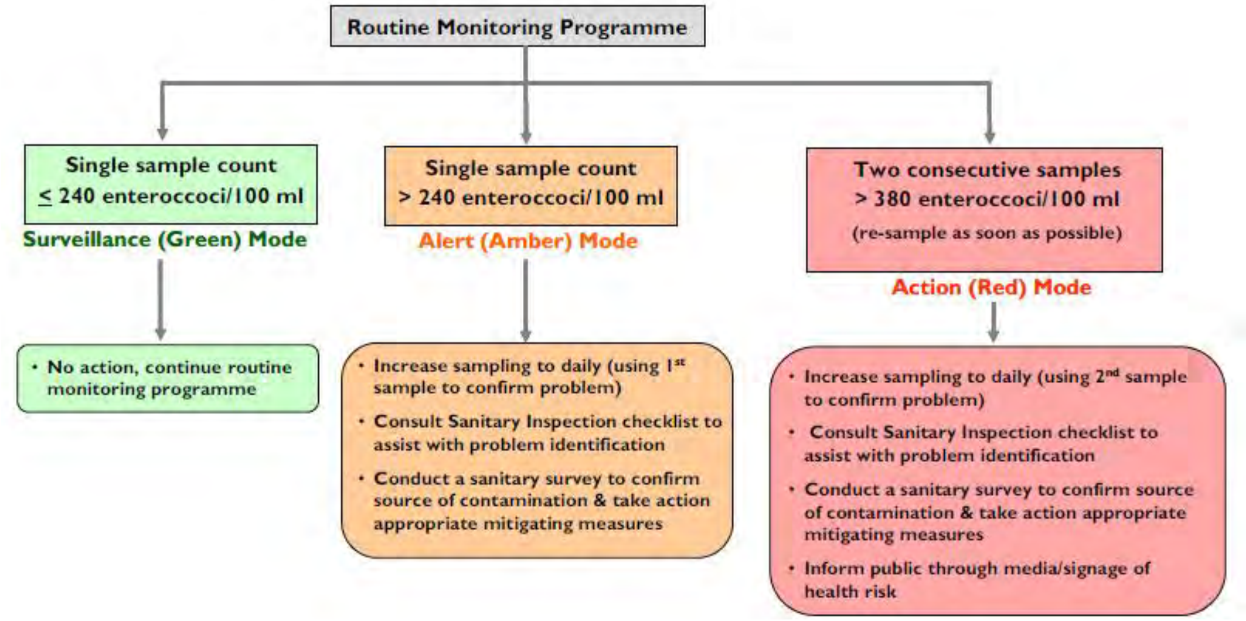


Figure 4.14. An illustration of the proposed routine monitoring programme to be trialled in South Africa. Source: South African Water Quality Guidelines for Coastal Marine Waters (RSADEA 2011).

4.7 Trace metal contaminants in the water column

There is an increasing global trend emerging in countries like Canada, Australia, New Zealand and South Africa to monitor the long-term effects of water quality by assessing the impacts thereof on specific marine species or species assemblages. Mussels and oysters, i.e. filter feeding organisms, are considered to be good indicator species for the purpose of monitoring water quality as they tend to accumulate trace metals, hydrocarbons and pesticides in their flesh. Mussels are sessile organisms (anchored in one place for their entire life) and will be affected by both short-term and long-term trends in water quality. Monitoring the contaminant levels in mussels can therefore provide early warnings for poor water quality and dramatic changes in contaminant levels in the water column.

Trace/heavy metals are often regarded as pollutants of aquatic ecosystems. However, they are naturally occurring elements, some of which (e.g. copper & zinc) are actually required by organisms in considerable quantities (Phillips 1980). Aquatic organisms accumulate essential trace metals that occur naturally in water as a result of, for example, geological weathering. All of these metals, however, have the potential to be toxic to living organisms at elevated concentrations (Rainbow 1995). Human activities greatly increase the rates of mobilization of trace metals from the earth's crusts and this can lead to increases in their bioavailability in coastal waters via natural runoff and pipeline discharges (Phillips 1995). Dissolved metal concentrations in water are typically low (and therefore present analytical problems), have high temporal and spatial variability (e.g. with tides, rainfall events etc.) and most importantly reflect the total metal concentration rather than the portion that is available for uptake by aquatic organisms (Rainbow 1995). Measuring metal concentrations in sediments resolves some of the analytical and temporal variability problems (as metals accumulate in sediments over time & typically occur at higher concentrations than dissolved levels), but still does not reflect their bioavailability. Measuring metal concentrations in the tissues of aquatic organisms appears to be the most suitable method for assessing ecotoxicity as the metals are frequently accumulated to high (easily measurable) concentrations and reflect a time-integrated measure of bioavailable metal levels (Rainbow 1995).

Filter feeding organisms such as mussels of the genus Mytilus have been successfully used as bio-indicator organisms in environmental monitoring programs throughout the world (Kljakovic-Gaspic *et al.* 2010). These mussels are abundant, have a wide spatial distribution, are sessile, are able to tolerate changes in salinity, are resistant to stress, and have the ability to accumulate a wide range of contaminants (Phillips & Rainbow 1993, Desideri *et al.* 2009, Kljakovic-Gaspic *et al*. 2010).

Elevated levels of cadmium, for example, reduce the ability of bivalves to efficiently filter water and extract nutrients, thereby impeding successful metabolism of food. Cadmium can also lead to injury of the gills of bivalves further reducing the effectiveness of nutrient extraction. Similarly, elevated levels of lead result in damage to mussel gills and increased growth deficiencies and mortality. Elevated levels of zinc are known to suppress growth of bivalves and at levels between 470 to 860 mg/l and can result in mortality of the mussels (South African Water Quality Guidelines for Coastal Marine Waters, Mariculture).

In 1985 the Directorate: Marine and Coastal Management (MCM) of the Department of Environmental Affairs and Tourism initiated a "Mussel Watch" Programme whereby mussels (either brown mussels *Perna perna* or Mediterranean mussels *Mytilus galloprovincialis*) were collected every six months (Apr/May and October) from 26 coastal sites. Mussels have been collected from five stations in Saldanha Bay since 1997. Data from the Saldanha Bay Mussel Watch programme are currently, however, only available between 1997-2001 and 2005-2007 due to a backlog in processing of samples. No new data were received for the 2012 period, however, the programme is due to resume in 2013. Additional samples will also be collected and analysed as part of the 2013 State of the Bay surveys to ensure that this data is available to the public.

As part of this programme, mussel samples are analysed for the metals cadmium (Cd), copper (Cu), lead (Pb), zinc (Zn), iron (Fe) and manganese (Mn), hydrocarbons and pesticides. A new automated method for sample preparation, including microwave digestion, has recently been adopted (Watling 1981; G. Kiviets *pers. comm*.). Data from the mussel watch programme are represented in Figure 4.15 where the maximum legal limits prescribed for each contaminant in shellfish for human consumption in South Africa, as stipulated by the Regulation R.500 (2004) published under the Foodstuffs, Cosmetics and Disinfectants Act, 1972 (Act 54 of 1972), are indicated in red text. Where guidelines have not been specified in national legislation those adopted by other countries have been used (Table 4.8).

Data supplied by the Mussel Watch Programme (Figure 4.15) show that concentrations of Lead in mussels at the monitored sites are consistently above guideline limits for foodstuffs over the period 1997–2007, while concentrations of Cadmium frequently exceed these limits, and those for Zinc do so occasionally. Concentrations of Copper are, however, well below specified levels (Table 4.8). No clear trends over time are evident for any of the trace metals, although recent data (post 2007) are lacking.

Concentrations of lead in mussels from Saldanha Bay tend to be consistently high at the TNPA site (at the base of the iron ore terminal on the Small Bay side, values generally greater than 60 ppm), occasionally spiking to very high level at this site (715 ppm in Oct 2001), but tend to be lower at the other sites (mostly below 10 ppm), although they occasionally spike to high levels at these sites as well (e.g. 250 ppm at the mussel rafts site at the base of the Marcus Island causeway). Compared with the guideline limit of 0.5 ppm these levels are extremely high and are very concerning. These high levels of Lead in are almost certainly linked to the export of Lead ore from the multipurpose quay, which is situated in close proximity to the TNPA site. Levels of Cadmium in mussels from Saldanha Bay are less variable than Lead and appear to be of a similar magnitude at all sites (mostly between 1-10 ppm) but occasionally exceed this level. Relative to guideline levels this is very high and is also cause for concern for anyone who may be consuming these mussels. Levels of Zinc are mostly within the range of 50-200 ppm but occasionally have been observed to spike to levels as high as 400 ppm or more which is way in excess of the guideline limit of 150 ppm listed by the Canadian authorities (Table 4.8).

Table 4.8. Regulations relating to maximum levels for metals in molluscs in different countries

Country	Cu (ppm)	Pb (ppm)	Zn (ppm)	As (ppm)	Cd (ppm)	Hg (ppm)
South Africa[1]		0.5		3.0	3.0	0.5
Canada[2]	70.0	2.5	150.0	1.0	2.0	
Australia & NZ[3]		2.0			2.0	0.5
European Union[4]		1.5			1.0	0.5
Japan[5]		10.0			2.0	0.2
Switzerland[2]		1.0			0.6	0.5
Russia[6]		10.0			2.0	
South Korea[2]		0.3				
USA[7, 8]		1.7			4.0	
China[9]					2.0	
Brazil[10]						0.5
Israel[10]						1.0

1. Regulation R.500 (2004) published under the Foodstuffs, Cosmetics and Disinfectants Act, 1972 (Act 54 of 1972)
2. Fish Products Standard Method Manual, Fisheries & Oceans, Canada (1995).
3. Food Standard Australia and New Zealand (website)

4. Commission Regulation (EC) No. 221/2002
5. Specifications and Standards for Foods. Food Additives, etc. Under the Food Sanitation Law JETRO (Dec 1999)
6. Food Journal of Thailand. National Food Institute (2002)
7. FDA Guidance Documents
8. Compliance Policy Guide 540.600
9. Food and Agricultural Import Regulations and Standards.
10. Fish Products Inspection Manual, Fisheries and Oceans, Canada, Chapter 10, Amend. No. 5 BR-1, 1995.

Rights holders engaged in bivalve culture (mussels and oysters) in South Africa are also required to report on concentrations in harvested organisms on an annual basis. Data were obtained for three trace metal indicators (Cadmium, Lead and Mercury) for three farms (Blue Bay Aquafarm, West Coast Aquaculture, West Coast Oyster Growers and Striker Fishing) in Saldanha Bay covering the period 1993-2012 (Figure 4.16). In addition, Arsenic levels were assessed for the first time in 2012. Data from these farms suggest that the situation in the deeper parts of the Bay where the farms are located is less of a problem than in the case with the nearshore coastal water where the Mussel Watch programme samples are collected.

Concentrations of Lead were consistently above guideline levels in the period prior to 2000, albeit nowhere near as high as for the nearshore mussel samples (never more than 3 ppm), but since this time have been mostly within guideline limits (i.e. less than 0.5 ppm). None of the farms were above the guidelines in 2012 for Lead concentrations, with lab analyses reporting 0 ppm in all samples (Figure 4.16).

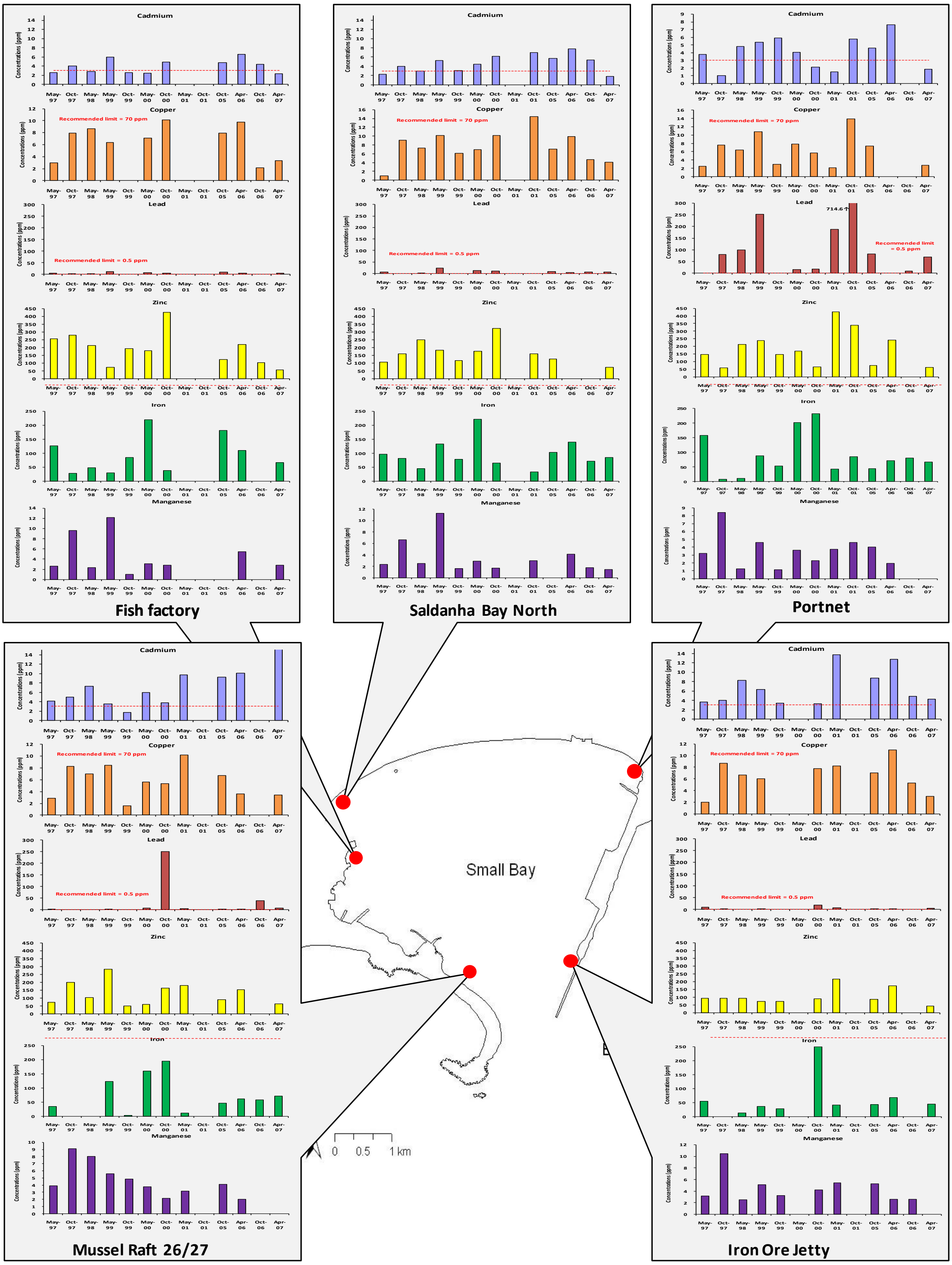


Figure 4.15. Trace metal concentrations in mussels collected from five sites in Saldanha Bay as part of the Mussel Watch Programme. (Source of data: G. Kiviets, Marine and Coastal Management, Department of Environmental Affairs and Tourism). Recommended maximum limits for trace metals in seafood as stipulated in South African legislation are shown as a dotted red line.

Concentrations of Mercury in the mussel flesh from the farms has also mostly been within guideline limits (i.e. less than 0.5 ppm), apart from one or two spikes above this level (maximum concentration recorded = 1.7 ppm in 1994). Similar to the lead results, all farm samples collected during the 2012 period contained 0 ppm Mercury (Figure 4.16).

Concentrations of Cadmium have always been within guideline limits (<3 ppm) for farmed mussels but have approached this level on occasion (maximum level recorded = 2.9 ppm). All of the samples collected in 2012 were below the guidelines with the highest concentration recorded in oysters from the West Coast Aquaculture farm, with 2.29 ppm Cadmium (Figure 4.16).

Samples were analysed for Arsenic for the first time in 2012, and all farms were within the guidelines except the Saldanha Bay Oyster Company (Figure 4.16). Oyster samples analysed from this farm recorded a concentration of 3.15 ppm.

The reasons for the lower concentrations of trace metals in farmed mussels compared with those on the shore may be linked to higher growth rates for the farmed mussels, and the fact that the cultured mussels are feeding on phytoplankton blooms in freshly upwelled water has recently been flushed into the Bay from outside. These are compared with mussels on the shore which have been filtering water trapped in the Bay for a longer period and as a result may contain a greater quality of suspended sediment and associated contaminants.

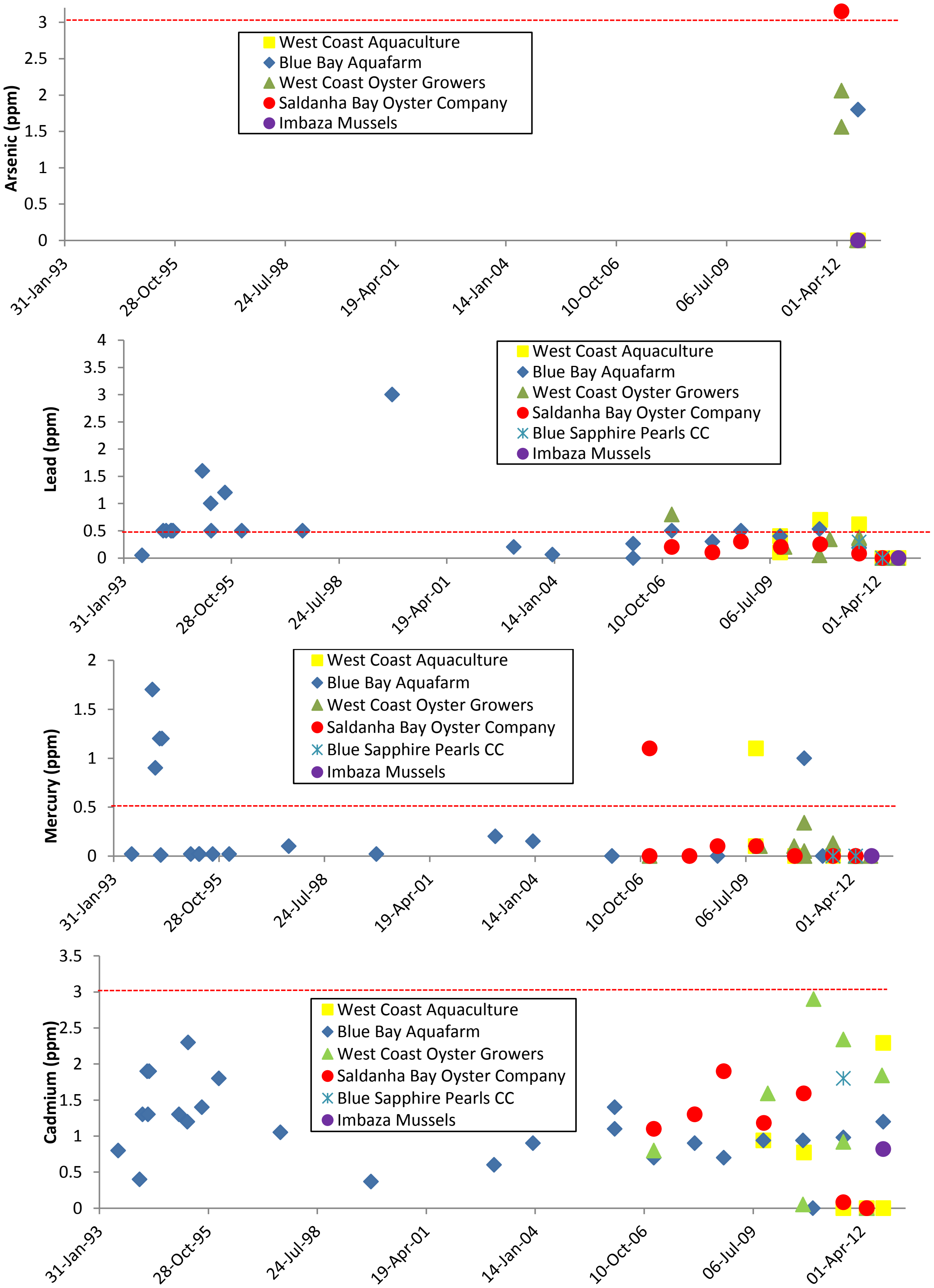


Figure 4.16. Concentrations of Lead, Mercury Cadmium and Arsenic in mussels and oysters from six bivalve culture operations in Saldanha Bay from 1993 to 2012. Recommended maximum limits for trace metals in seafood as stipulated in South African legislation are shown as a dotted red line.

4.8 Summary of Water Quality in Saldanha Bay and Langebaan Lagoon

There are no long term trends evident in the water temperature, salinity and dissolved oxygen data series that solely indicate anthropogenic causes. In the absence of actual discharge of industrially heated sea water into the Bay, water temperature is unlikely to show any change that is discernible from that imposed by natural variability. Admittedly there is limited pre-development data (pre 1975), so although it is conceivable that construction of the causeway and ore/oil Terminal has impeded water flow thus increasing residence time and increasing water temperatures, salinity and likely decreasing oxygen concentration, particularly in Small Bay, there is little data to support this. Given that cold, nutrient rich water influx during summer is density driven; dredging shipping channels could have facilitated this process which would be evident as a decrease in water temperature and salinity and an increase in nitrate and chlorophyll concentrations. Once again there is little evidence of this in the available data series. Natural, regional oceanographic processes (wind driven upwelling or downwelling and extensive coast–Bay exchange) rather than internal, anthropogenic causes, appear to remain the major factors affecting physical and chemical water characteristics in Saldanha Bay. The construction of physical barriers (the iron ore/oil Terminal and the Marcus Island causeway) does appear to have changed current strengths and circulation within Small Bay, resulting in increased residence time (decreased flushing rate), enhanced clockwise circulation and enhanced boundary flows. There has also been an increase in sheltered and semi-sheltered wave exposure zones in both Small and Big Bay subsequent to harbour development.

The microbiological monitoring program provides evidence that while many of the monitoring sites in Small Bay still have faecal coliform counts in excess of the safety guidelines for both mariculture and recreational use, there is a trend of improving compliance at many sites for which the relevant authorities should be commended. However, the situation in Small Bay remains a concern, with many sites exceeding levels for safe recreational activities. Given the current importance and likely future growth of both the mariculture and tourism industries within Saldanha Bay, it is imperative that whatever efforts have been taken in recent years (e.g. upgrading of sewage and storm water facilities to keep pace with development and population growth) to combat pollution by faecal coliforms in Small Bay should be increased and applied more widely. Continued monitoring of bacterial indicators (intestinal *Enterococci* in particular), to assess the effectiveness of adopted measures, is also required and should be undertaken at all sites on a bimonthly basis.

Ever increasing volumes of ballast water are discharged into Saldanha Bay on an annual basis. This poses an enormous risk in respect of the introduction of alien species as well as contaminants in the ballast water (trace metals, *E. coli*, etc.). Compliance with ballast water treatment requirements (e.g. open ocean exchange, on-board treatment systems) designed to minimize the risks of alien introductions should be rigorously enforced and voluntary compliance with any additional measures strongly encouraged.

Data supplied by the Mussel Watch Programme (DEA) and mariculture operators in Saldanha Bay suggest that concentrations of trace metals are high along the shore (particularly for Lead near the multipurpose quay) and frequently or even consistently (in the case of Lead) result in mussels on the shore registering concentrations that are in excess of guideline levels for foodstuff. Fortunately, levels of trace metals in cultured oysters and mussel are much lower (mostly within guideline limits), and presumably reflect lower levels of trace metals in the offshore waters. High concentrations of trace metals along the shore is very clearly of concern and points to the need for management intervention that can address this issue as it poses a very clear risk to the health of people harvesting mussels from the shore. Regrettably no new data have been available from this programme since 2007, however the monitoring is due to commence in 2013. Additional samples will also be collected and analysed as part of the 2013 State of the Bay surveys to ensure that this data is available to the public.

5 SEDIMENTS

5.1 Introduction

This Chapter addresses sedimentary processes and marine sediment quality in Saldanha Bay. Issues pertaining to sedimentary processes in Saldanha Bay relate mostly to erosion of the soft (sandy) shorelines in the Bay, while issues pertaining to sediment quality relate mostly to changes in grain size composition and accumulation of trace metals and other contaminants in marine sediments in the Bay.

5.2 Shoreline erosion in Saldanha Bay and Langebaan lagoon

5.2.1 Background

The majority of sandy beaches worldwide are affected by erosion - a problem which has been greatly exacerbated by development of human settlements in the coastal zone (Bird 1985). Globally, 70% of beaches are classed as receding; 20–30% are stable, while 10% are accreting (Schlacher *et al*. 2008). Under natural conditions, sea level rise would cause the entire coastal system, including beach and dune systems, to retreat inland. In instances where coastal systems are bound by barriers, walls, or heavily vegetated dunes, these features are likely to restrict inland migration and would result in beach loss rather than migration (Feagin *et al.* 2005). Salt marshes are under immediate threat if the rate of sea level rise exceeds that of vertical accretion.

Beach erosion in Saldanha Bay, particularly at Langebaan Beach, has been the subject of much controversy in recent years. Ongoing erosion for the past 30 years has been documented, with the loss of over 100 m of beach in some areas since 1960 and up to 40 m of shoreline lost in places in just the last 5 years (McClarty et al. 2006, Gericke 2008).

Windblown sand is likely to have been a major part of the Langebaan/Saldanha system. Many of the beaches, particularly Spreeuwalle, have dune fields associated with them. The largest dune field in the area is the Geelbek dunefield. This dune field lies directly to the southeast of the Langebaan Lagoon. The south-easterly wind that predominates in summer would tend to transport sand from 17 mile beach (Yzerfontein) to the Geelbek dunes and in turn from the Geelbek Dunes into Langebaan (Gericke 2008).

Inside Saldanha Bay, where wave action is of greater significance than inside the protected Langebaan Lagoon, littoral drift is a major factor in sediment transport. While waves on the west coast typically originate in the South or South West, they tend to refract around the headlands at the mouth of the Bay and approach the shore from the West or North West, particularly along the section of coast between Spreeuwalle and the North Langebaan beach. The predominant littoral drift is therefore in a southerly direction, rather than a northerly direction as observed on the rest of the West Coast (Compton, 2004).

It is not clear whether storms in the Saldanha/Langebaan region will increase in frequency or intensity but it is a possible scenario of global climate change, which coupled with long term changes in sea level and average wave height, could result in greater shifts in shoreline over less time. This may necessitate greater setback lines for development that those currently in place (Gericke 2008).

5.2.2 Human impacts on the system

Over the years, several major changes have taken place in Saldanha Bay which are likely to have affected the sedimentary system. These include construction of the Marcus Island causeway and the Transnet Ore Terminal in the early 1970s, the ongoing construction of residential and commercial properties on the beachfront, dredging in the bay, the slow, steady encroachment of vegetation on the Geelbek dune system, and ongoing dredging that takes place around the Ore Terminal.

5.2.2.1 Construction of the Marcus Island Causeway and the Transnet Ore Terminal

The Marcus Island causeway and the Transnet Ore Terminal are similar structures from a sedimentary point of view. They both extend far beyond the littoral zone where waves have limited ability to influence sediment movement. They are therefore barriers separating areas where littoral drift could occur. In the case of the Ore Terminal, this structure separates the beach to the north west of the terminal from Spreeuwalle to the south east. As a result, Spreeuwalle has lost access to one of its sediment sources.

The ore terminal may also have changed the wave dynamics in the area by refracting or reflecting some of the incoming swells. This could cause the angle of wave incidence at beaches near the pier (such as Spreeuwalle) to have changed sufficiently for the littoral drift to reverse, or decrease significantly.

Before the construction of the Marcus Island Causeway, waves could travel on both sides of the island. These waves would have been refracted inward around the island cause both constructive and destructive interference. At a point opposite the island, the shoreline would have been subject to much larger and more powerful waves. This generally causes beach slopes to form at less steep gradients, but also tends to remove smaller sediment particles.

5.2.2.2 Stabilisation of the Geelbek dune system

The Geelbek dunes have been subjected to continuous encroachment by vegetation over the last 70 years (Gericke 2008). When dune encroachment occurs, sediment is held in place by the roots of plants and the wind speed at ground level is considerably reduced. This means that the dune system become less effective as a sediment source. However it does still function as a sediment sink. This means that sand which is taken by the north-westerly wind from Langebaan's beaches to the Geelbek dune systems will not return as quickly when the south-easterly wind returns. This is likely to have resulted in a net loss of sediment from the beaches to the dunes.

5.2.2.3 Shoreline development

When sea level, wind or wave conditions change, shorelines react by changing their nature, their shape, or their position. Many of Langebaan's residential or holiday developments have been built in very close proximity to the sandy shorelines. These communities are all vulnerable to beach erosion. In some places the width of the beach has been reduced by as much as 150 m, leaving the house built on the first set of dunes unprotected against storm damage (Gericke 2008, Figure 5.1).

5.2.3 Changes in beach and dune morphology

Gericke (2008) studied changes in the sedimentary features of the Langebaan Lagoon and Saldanha Bay area between 1960 and 2000. It was found that the beaches in particular had changed significantly over this period, with a large section of the North Langebaan beach having completely disappeared between 1988 and 2000.

Gericke's (2008) study was updated last year and includes new data from 2000 to 2012 (Gericke 2012). Five rocky outcrops were selected across the study site and a change in width for each site and for each image measured. The mean for each image taken between 1960 and 2012 was used as a proxy for tidal amplitude at the time that each photo was taken. This was simply multiplied by beach length to find the expected tidal variation for each beach area. All data were corrected for tidal variation.

Figure 5.1. A) Under natural circumstances, dune vegetation can "move" with the beach as it erodes and accrete under the influence of natural processes. B) Protection of infrastructure erected too close to the high water mark, on the other hand, necessitates construction of artificial barriers and leads to the loss of the beach ecosystem and associated amenities.

The relative change in beach area at Langebaan Beach and Spreeuwalle over the period 1960 to 2012 is shown in Figure 5.2. The marked dip in the sediment area in 1977 (Figure 5.2) is unexplained and could relate to the tide variation the day the picture was taken (which was not recorded) or transitory storm influence. The significant increase in sediment accumulation from 1977 to 1988 at Spreeuwalle can be attributed to the construction of the harbour wall between 1973 and 1976, and subsequent support of the wall using approximately 250,000 m^2 of beach sand. After the construction, however, sediment became trapped at Spreeuwalle as a result of the harbour decreasing the longshore drift south towards Langebaan beach and (McClarty 2008). The sediment area at Langebaan beach also increased between 1977 and 1988, and is attributed to the additional beach sand added to Spreeuwalle beach and an increase in the littoral drift of the sediment to Langebaan beach. After 1988, there was a significant drop in sediment area of about 270,000 m^2, which may be partially related to sediment transport being prevented by the harbour wall. It can be expected that should the beaches at Leentjiesklip 1, 2 and 3 become depleted, Langebaan beach would lose sediment at a more rapid rate.

Both Spreeuwalle and Langebaan beach are showing increasing variability in beach area since 2000 (Figure 5.2). The variation also appears to be synchronised for the two beaches, implying a common cause for both. It is not clear exactly what the cause is, but variability in local or regional wind or wave characteristics may play a role. Dredging may also have contributed.

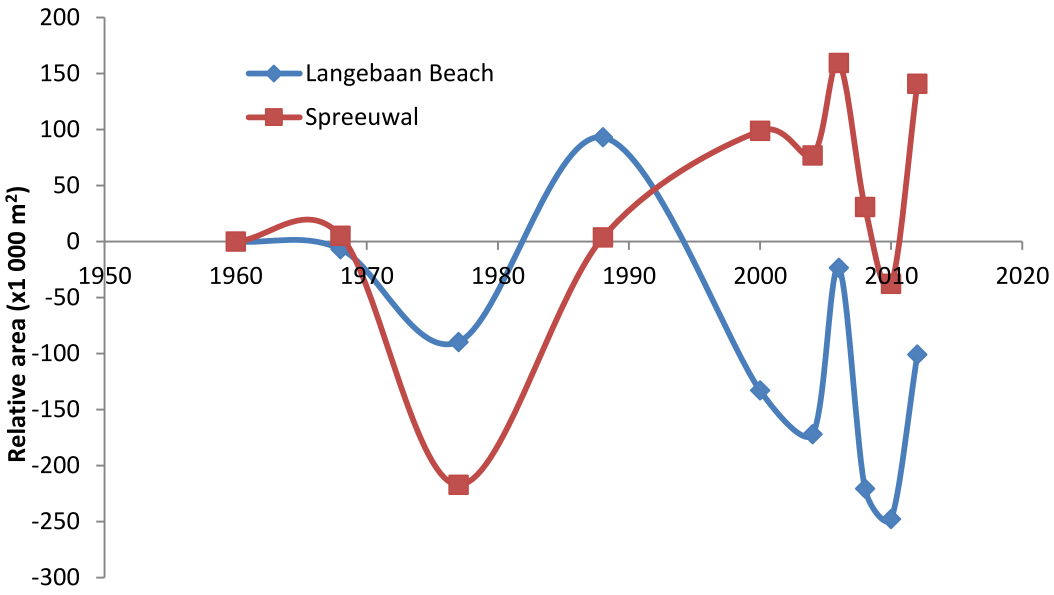


Figure 5.2. Graph showing the relative change in beach area over time for Spreeuwalle and Langebaan Beach (1960-2012).

Gericke (2008) did not distinguish between small-scale (within beach) and large scale (between beach) variation. There is also no recognition of the redistribution of sediment along a beach. For example, a small section in the middle of Spreeuwalle has been severely eroded over time, much more so than other sections of this beach. This can be much more effectively illustrated by defining a transect line at the most eroded section of this beach (Figure 5.3) and measuring variation in the width of the beach at this point over time, correcting for tidal variation.

From this, it is clear that the width of this section of beach has decreased from 27 m to 7m between 2000 and 2012. It is not known what is causing the erosion but it is recommended that a study be conducted focussing on the possible reversal of littoral drift by diffraction of waves passing the Marcus Island Causeway and Transnet Iron Ore Terminal (Gericke 2012).

This trend is concerning as it implies that the beach will disappear altogether in less than a decade. A much more likely scenario, however, is that the absolute rate of change will decrease in future, but that the size of the affected area will increase, engulfing larger sections of Spreeuwalle Beach.

Figure 5.3. Spreeuwalle beach showing the position of the transect line in the middle of the beach.

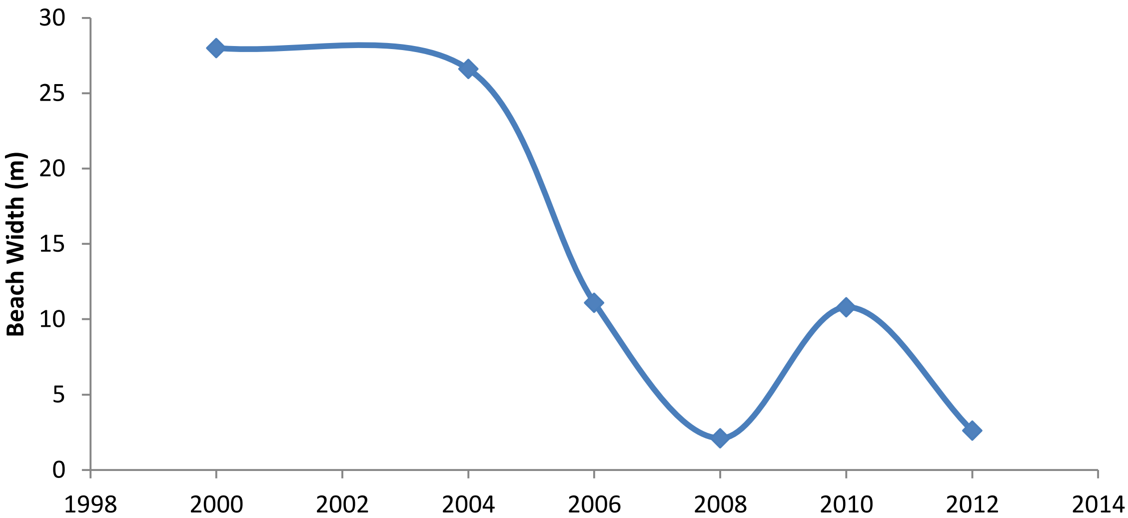


Figure 5.4 Variation in beach width across a transect on the central section of Spreeuwalle.

Gericke (2008) also analysed the Geelbek dune system and the loss of bare sands in this area over the period 1960 to 2000. He recorded a massive 70% reduction of bare sands from close to 13 million m^2 present in 1960 to less than 4 million m^2 in 2000.

Gericke (2008) concluded that the construction of the ore terminal had led to a reduction in sediment transport from Spreeuwalle beach which is currently being trapped in the northern corner of the beach, reducing the supply of sands to the beaches further south. Changes on the two beaches are often out-of-sync with one another, with major accretion and erosion events on Langebaan beach lagging behind Spreeuwalle by a period of up to five years. The reasons advocated for this include the possibility that beaches in between these two sites are acting as intermediate reservoirs for sediment. If this is indeed correct, then changes on these beaches, notably the recent erosion observed on the southern end of Spreeuwalle beach (possibly linked to a severe storm event in 2008) does not bode well for what will happen to Langebaan beach in the future.

Alien vegetation encroachment by Port Jackson (*Acacia saligna*) and Rooikraans (*Acacia cyclops*) is thought to be a contributing factor in the loss of sand from the Geelbek dune system. The consequences of this encroachment at Langebaan have not yet been studied. However, it is known that heavily vegetated dunes restrict the natural movement of dune systems and possible inland migration of the coastal system (Feagin 2005). The salt marshes on Langebaan Lagoon have not suffered any significant changes in area over the same time period (Gericke 2008).

An analysis of long-term trends in the shoreline at Paradise Beach and Leentjiesklip, some 1.5 and 5.0 km to the south of the shoreline transect depicted in Figure 5.3, respectively, was undertaken by WSP Africa Coastal Engineers (2010b) whilst testing methods proposed for establishment of development setback lines for the Western Cape (see §5.2.5.1 for more details on this). Shoreline variation was analysed at 5 cross-sections (lines) at each site by measuring the distance, roughly perpendicular, from a fixed landward reference line to the high-water mark in a series of aerial photograph spanning the period 1960-2007. The locations of the cross-sections analysed and the respective high-water mark are shown in Figure 5.5. From these analyses it was clear that there was a long-term trend of erosion of the shore at Paradise Beach but little change at Leentjiesklip. Paradise beach is contiguous with Spreeuwalle where Gerrike (2008) measure a similar amount of erosion, while Leentjiesklip is a much shorter beach bound by rocky headlands on either side (Figure 5.20) is presumably well protected from erosion.

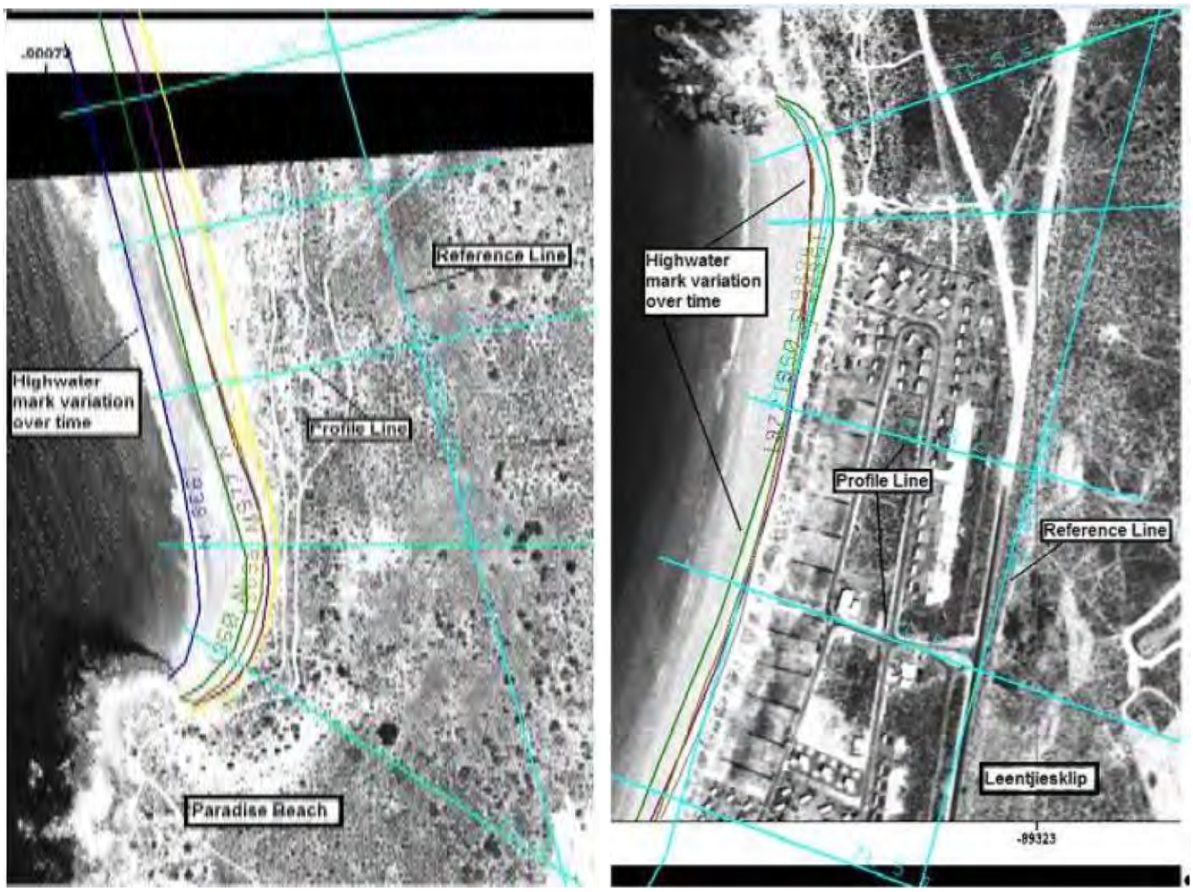
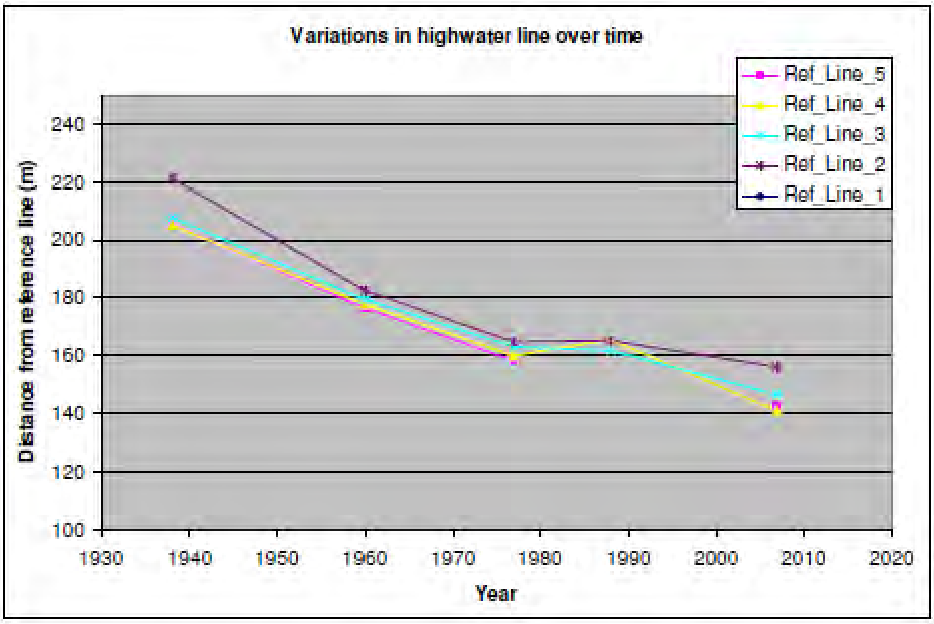


Figure 5.5. **Transect (profile) lines (in light blue) used by WSP Africa Coastal Engineers (2010b) to assess long-term changes in the shoreline at Paradise Beach (left) and Leentjiesklip (right) in Saldanha. The high water mark determined from each historical photograph is also shown in dark blue (1938), dark green (1960), purple (1977), light blue (1988), light green (1989) and yellow (2007). Source: WSP Africa Coastal Engineers (2010b).**



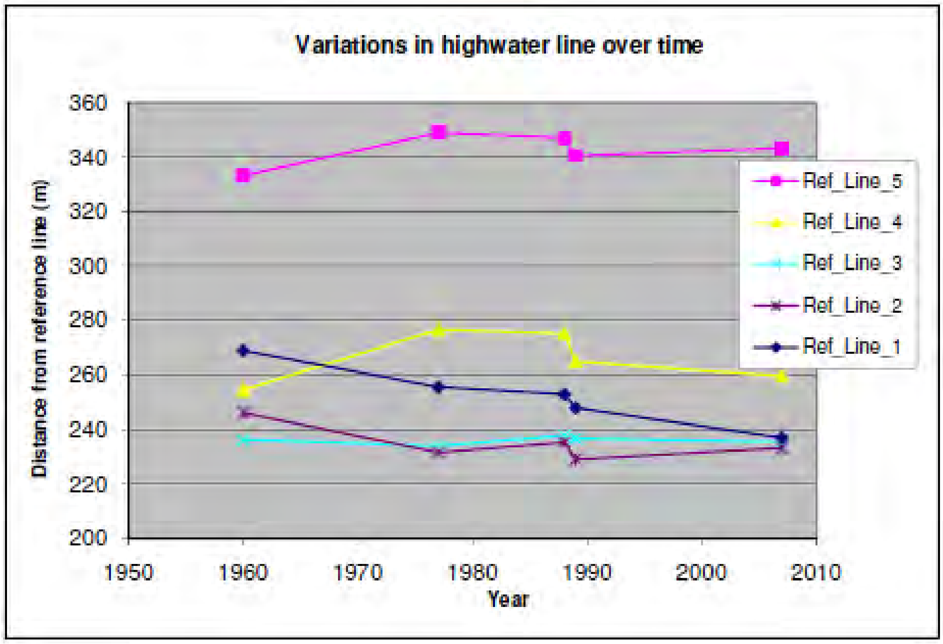


Figure 5.6. Variation in distance from a fixed point to the high water mark along a series of transect (reference) lines at Paradise Beach (top) and Leentjiesklip (bottom) over the period 1960-2007.

5.2.4 Management interventions to address shoreline erosion in Saldanha Bay

As outlined above, coastal erosion has been a persistent problem in Saldanha Bay and Langebaan since the late 1960s. This came to head in the late 1990s when a number of beachfront houses were lost as a result of shoreline erosion in Langebaan village. Since then a number of erosion protection measures have been implemented including the installation of a temporary rock revetment spanning over 1.5 km of shoreline, construction of two groynes at the entrance to the Lagoon, and a gabion wall at Paradise Beach in front of the Club Mykonos Resort. Authorisation was required from the Western Cape Department of Environmental Affairs and Development Planning (DEA&DP) in terms of the National Environmental Management Act (107) of 1998 (as amended) for these developments. A description of the process followed in each case is provided in the subsection below.

In addition to these shoreline protection measures, a process has been initiated by the Western Cape Government Department of Environmental Affairs & Development Planning to delineate coastal set-back lines for the whole of the Western Cape. As a first step, WSP Africa Coastal Engineers (Pty) Ltd were appointed to develop methodology for defining and adopting coastal development setback lines. Subsequently Royal Haskoning DHV (previously SRK Consulting) were appointed to undertake pilot projects on the development of coastal development setback lines in the Overberg and West Coast District Municipalities. A summary on approach taken and progress to date on the development of setback lines in the West Coast District Municipality is also presented in Section 0.

5.2.4.1 Langebaan beach erosion management measures

In 1997, after severe storms resulted in the loss of residential properties, the need to protect and restore northern Langebaan beach became apparent. A temporary solution was sought through the construction of three sections of rock revetment along the beach (Figure 5.7), mostly in an effort to prevent any further loss of property. Erosion continued along the sections of coastline adjacent to the revetment, however. This prompted the then Department of Environmental Affairs and Tourism (now the Branch: Oceans and Coasts, of the Department of Environmental Affairs) to contract Southern Oceaneering CC in 2003, to carry out an urgent beach reclamation programme following intensive investigations into various solutions by coastal engineers, PRDW, and the necessary EIA approvals granted by DECAS in 2001. This involved the construction of two groynes using Geotextile Sand Containers (GSCs) and the deposition of large quantities of sand dredged from Saldanha Bay to extend the beach area (Figure 5.8).

Figure 5.7. Rock revetments constructed along the beach at Langebaan in an effort to protect coastal infrastructure.

Different sized GSCs (i.e. 2.5 m³, 12 m³ and 20 m³) were filled with sand collected from two adjacent areas where sand was mixed continually with pumped sea water creating a "slurry" which was then emptied into the bags and stitched closed. The GSC units were then positioned by crane in the water, assisted by a team of divers. The first 250 m groyne (reduced from the planned 448 m due to strong currents at the face) was completed in 2005 and the second 360 m groyne in 2007. Critical to the project was the beach replenishment programme which involved dredging large amounts of sand from areas in the vicinity of groyne 1, and depositing sand north of the 2nd groyne up to the southern extent of Leentjiesklip No.1 (Figure 5.8). Approximately 380 000 m³ of material was dredged until the end of the programme in November 2008.

Monitoring in the form of bi-annual beach profile surveys are conducted by the Saldanha Bay Municipality (in collaboration with Prestige Retief Dresner Wijnberg (PRDW) since completion of the groynes and reclamation in October 2009. The beach profile survey record extends back to before 1997 and provides a good basis for long-term monitoring of impacts to the coastline resulting from the Langebaan Beach Restoration Project.

The beach profile surveys indicate that there is little unseasonal erosion and accretion in the area. The rock revetments which were supposed to be a temporary solution cannot be removed as they still serve a critical role in erosion prevention. The revetments to the South have been covered partially with sand but to the North the main revetment is still exposed. It is not know at this stage whether further reclamation of the beach to the North will eventually enable the revetment to be removed. It is more likely that the revetment will remain and will eventually be covered with sand through artificial deposition and some natural accretion. The beaches south of Groyne 1, adjacent to the channel, appear dynamically stable (Mclarty, PRDW, *pers. comm.* 2012). However, there is still considerable structural damage on the northern Groyne (the second one constructed), with some of the bags suffering from wave damage during storms between 2007 and present (Anton Vonk, PRDW 2010 pers. comm.). There are currently sub-optimal volumes of sand at the North end of the beach (Common Ground 2012). Regardless of the cause, it is apparent that while the groynes installed at Langebaan may have trapped some sand and prevented extensive beach loss in their immediate vicinity, they have not succeeded in stabilising the greater Langebaan Beach (Gericke 2012).

Much needed maintenance is required to prevent further degradation of these groynes and other erosion protection infrastructure in the Bay. While such interventions would normally require environmental authorisation (i.e. Basic Assessment of Scoping and EIR), agreement was recently reached between the Saldanha Bay Municipality and DEADP that such works could be undertaken in terms of an Environmental Management Plan. The DEA&DP Guideline for Environmental Management Plans describes situations that may trigger the need for an Environmental Management Plan (EMP). In the case of the site-specific Langebaan erosion control measures, where a scoping or an Environmental Impact Assessment (EIA) process has not been undertaken, agreement has been reached with the DEA&DP that an EMP should be prepared and submitted to the DEA&DP as the basis for an overarching implementation plan:

"For certain applications, the authorities may not require scoping or impact assessment following the submission of the initial application. For example, this may occur for small-scale projects; projects in non-sensitive environments; projects where the negative impacts have already been assessed in analogous EIAs and found to be minimal; and/or projects fully aligned with the land use zoning. Nonetheless, an EMP may be required for authority approval (e.g. application to erect and operate a cellular telephone communications mast within a residential area)."

In accordance with this, it was agreed that an Environmental Management and Maintenance Plan (EMMP) would suffice for the repairs, maintenance and future management of the two existing two groynes and revetment at Langebaan North Beach. Common Ground Consulting was appointed to prepare the EMMP and has recently released this for public comment (Common Ground 2013a). The EMMP includes recommendations for the following:

- Repositioning of the Geotextile Sand Containers (GSCs) making up the two groynes that have been displaced;
- Supply and installation of new GSCs;
- Repairing damaged GSCs where possible;
- Removing damaged GSCs that are, in the opinion of the coastal engineering consultant, no longer adding to the required function of the structure
- Repair or divert the existing stormwater outlet adjacent to Noord Street that is scouring the sleeping the revetment in this area
- Repair damaged areas of the quarried armour rock revetment by placing additional rock (approximately 100 m^3) in the damaged areas

Works required for this purpose will be conducted with a crane that will be positioned on the groynes and will rebuild the groyne from the land towards the sea (highest to lowest points). Sand will be sourced from the adjacent seabed and a cradle will be used to assist with the filling and placing of the bags. Ongoing maintenance will be conducted between February and April of each year when weather conditions are most favourable. No maintenance is planned to be conducted on the groynes seaward of the low water mark at this stage but should this be required in future this will be undertaken using a marine craft (barge, floating crane, etc.). An Environmental Management Plan (EMP) will be drafted to provide the necessary management and reporting procedures for the contractor appointed to undertake the works, and an Environmental Monitoring Committee (EMC) will be established to assist with monitoring of the contractor's activities.

The following additional monitoring is also recommended:

- Annual level survey of the crest of the two groynes with spot heights at 2 m centres (November each year).
- Annual level survey of the crest of the rock revetments running from Leentjiesklip 1 in the north to the root of Groyne 1 in the south with spot heights at 5 m centres (November each year)
- "Baywide" bathymetric survey of the seafloor across the project area (November every two years)
- Aerial photographic survey of the project area at consistent tidal levels (November every two years).

The beach profile data, bay-wide bathymetric survey data and aerial photos will be used to assess the state of the beaches, sand spit and seafloor and to establish any medium-term trend, while the crest level surveys will be used to compare the levels with as-built levels for these structures to determine and scope annual maintenance requirements for the groynes and revetment.

Figure 5.8 Groynes and rock revetment at Langebaan North beach. Source: Google Earth.

Coastal erosion is also a problem at a number of other sites opposite the town of Langebaan. This includes the area in from of the Leentjiesklip Caravan Park (Figure 5.9), the Alabama Street slipway (Figure 5.10) and the terraced concrete walkway at the end of Uitsig Street (Figure 5.11). A separate EMMP has been prepared by Common Ground Consulting (Common Ground 2013b) to covers repairs and maintenance at these sites. For the Leentjiesklip Caravan Park site a number of potential options have been identified in the EMMP:

1. Short term interventions not requiring an engineering solution (e.g. redirecting stormwater away from the dunes to minimise scour and erosion of the dune and beach, banning users from dumping braai coals on the dunes, erecting a low rope-and-pole fence to prevent users from walking directly through the dunes rather than using the existing boardwalks, and improving user education and awareness);
2. Reshaping the foredune including removal of access road and construction of a submerged barrier (Figure 5.12);
3. Reshaping the foredune including removal of access road and partial demolition of southernmost dwelling, and construction of a submerged barrier; or
4. Managed retreat.

Figure 5.9. Shoreline erosion at the Leentjiesklip Caravan Park. Source: Common Ground Consulting (2013).

Figure 5.10. Erosion protection measures at the Alabama Street Slipway. Source: Common Ground Consulting (2013).

Figure 5.11. Terraced concrete walkway at the end of Uitsig Street. Source: Common Ground Consulting (2013).

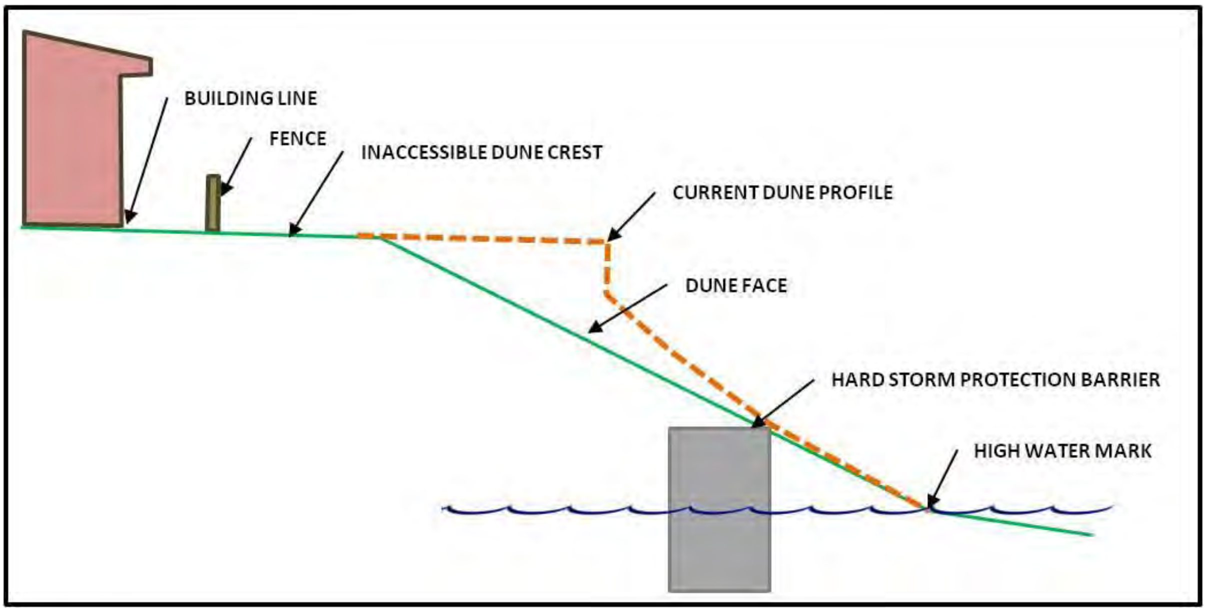


Figure 5.12 Submerged storm protection barrier proposed for Leentjiesklip Caravan Park (Common Ground Consulting 2013b).

Potential positive and negative impacts associated with all of these options have been assessed and are documented in the EMMP. It was concluded that the short-term interventions as described above should be implemented immediately but that further erosion control measures (one or more of the remaining options) are necessary and must be implemented as soon as possible, as funding becomes available. A preferred alternative must be selected and a detailed EMP drawn up for the necessary works. Serious safety concerns exist at this site as the status quo is dangerous and could result in harm to the public.

In the case of the Alabama street slipway the following actions are proposed:

- GSCs damaged by vandalism should be replaced.
- These should also be protected from further damage by a "paddock" type barrier between the access road behind and the GSCs to discourage people walking across them or they should be covered with sand and vegetated with natural vegetation. Pedestrian access to the beach during high tide should be provided by a walkway constructed over the geocontainers.
- Improvements to the existing stormwater drainage should also be made to prevent scouring from the landward side.
- Removal of the access road behind the GSC 'wall' should be investigated as this would allow improved management of the upper beach area and extension of the GSC wall if and when necessary.

As is the case with the Leentjiesklip Caravan Park, the potential positive and negative impacts of these measures have been assessed and it is recommended that they be implemented as soon as possible, as funding becomes available. However, maintenance at this site is not as urgent and it does not pose a risk to the public at present.

In the case of the Melck Street Walkway it is recommend that the existing structure be demolished and rebuilt to ensure the repair of all hidden cavities. It is further recommended that the new structure be built on the same footprint and of a similar shape as the old structure and that it should be designed such that it can:

- Prevent fines from washing out from underneath or behind the structure;
- Allow seepage water to escape through the structure;
- Provide access to the public along the coastline during high tides;
- Penetrate deep enough into the sand to either reach bedrock or to prevent undermining by long term erosion; and
- Requires little or no maintenance.

Three design alternatives have been proposed:

1. Geosynthetic Sand Container (GSC) wall (Figure 5.13);
2. Replacement concrete steps (Figure 5.14); and
3. Rock revetment (Figure 5.15).

The potential positive and negative impacts of these measures have been assessed and it is recommended that they be implemented as soon as possible, as funding becomes available. Once a decision has been made on which option to select, a detailed EMP for the construction works will need to be drawn up before this can commence.

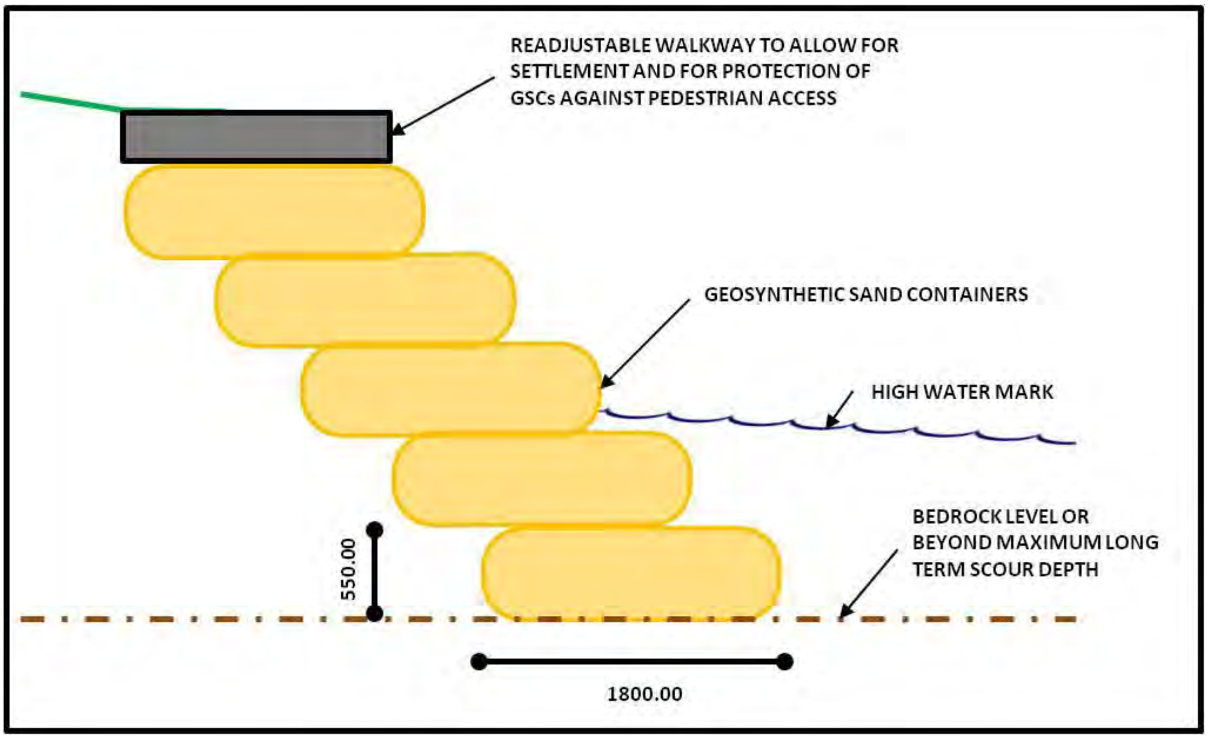


Figure 5.13. Design proposal 1 for the proposed Melck Street walkway: Geosynthetic Sand Container wall. Source: Common Ground Consulting (2013b).

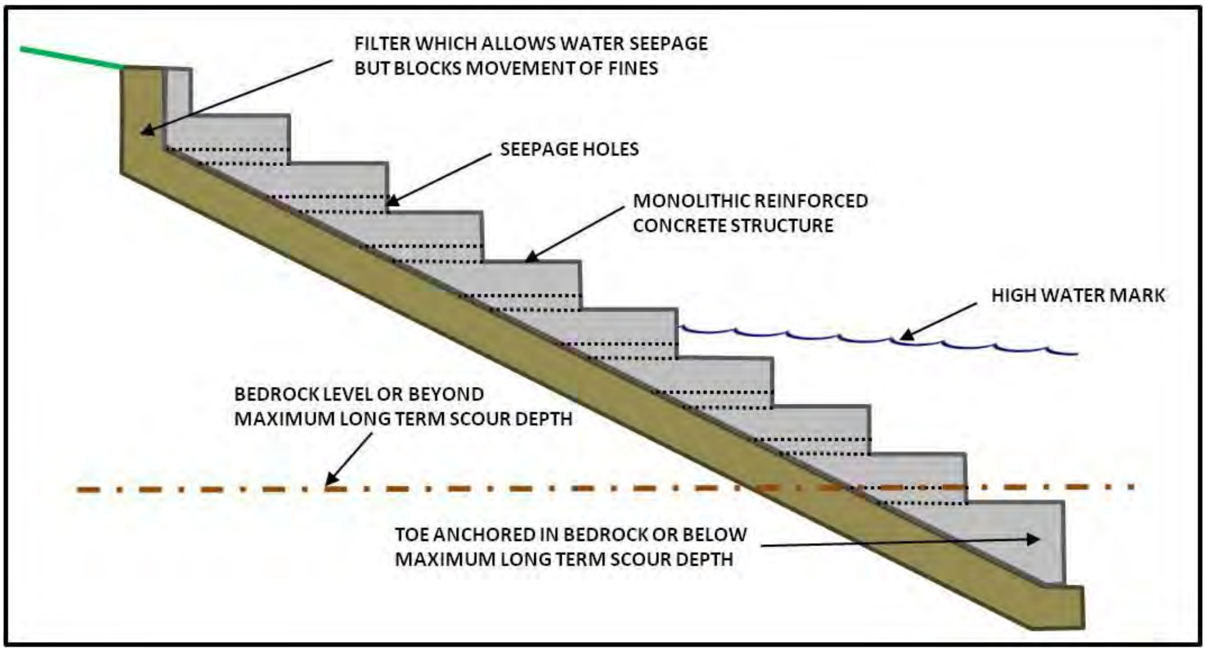


Figure 5.14. Design proposal 2 for the proposed Melck Street walkway: Concrete steps. Source: Common Ground Consulting (2013b).

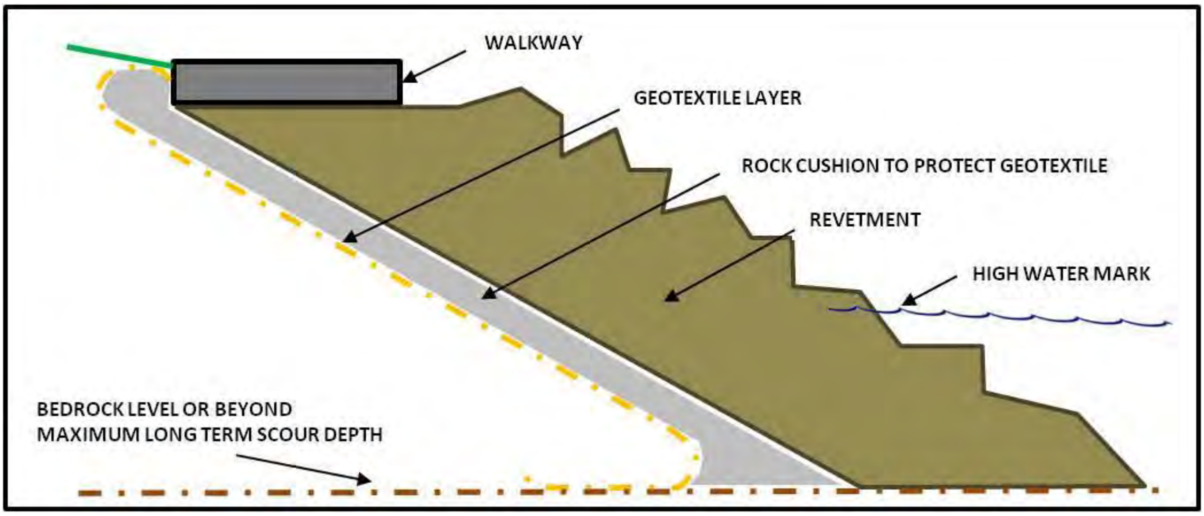


Figure 5.15. Design proposal 3 for the proposed Melck Street walkway: Rock revetment. Source: Common Ground Consulting (2013b).

5.2.4.2 Paradise beach erosion management

Paradise Beach is located close to the town of Langebaan next to the Club Mykonos Holiday Resort and is within the jurisdiction of the Saldanha Local Municipality. Erosion along Paradise Beach has been ongoing at least since 2005 (Karen Opitz, Common Ground pers. comm. 2007) and is currently threatening the houses built along the beach front (Figure 5.16). Unmitigated erosion also threatens to destroy sewage collection tanks, which at the moment lie buried 3-4m from the dune-edge, and this would result in pollution of the marine environment via leaking sewage.

An environmental impact assessment was commissioned by the Paradise Beach Homeowners Association (PBHA) in 2007 and undertaken by Common Ground Consulting (Coetzee 2007), with input from coastal engineer Anton Vonk and a botanist. They listed various possible reasons for the erosion at Paradise beach including the construction of the Marcus island causeway, iron ore jetty and other large-scale developments in the Bay that might have influenced current patterns or wave action in this area, as well as the destruction of dune vegetation which would otherwise have helped stabilize the dunes and prevent erosion, and inappropriate discharge of storm water within the frontal dune area in the past.

To prevent further erosion and protect the houses, the construction of a gabion wall (rock-filled wire mesh cages) was proposed as a short-term solution to prevent further erosion while an appropriate long-term solution was investigated. The gabion wall, some 190-230 m long with 1:1 slope, would run at the foot of the existing frontal dune. The proposed long -term solution included the construction of an offshore structure, such as a groyne, to change the wave and current dynamics suspected to be underlying cause of the erosion. A positive Record of Decision (ROD) for the construction of the gabion wall was issued by the Department of Environmental Affairs and Development Planning, Western Cape (DEADP), and construction was initiated during 2010 (J. Kotze – Langebaan Ratepayers Association, pers. comm. 2011). These works have been completed but it should be noted that work undertaken by WSP Africa Coastal Engineers (2010b) to investigate methodology for use in determining setback lines within the coastal zone, demonstrated that the recommended erosion setback line for Paradise Beach should be situated well behind the first line of properties on the beachfront and that any efforts to mitigate erosion at this site may well be in vain. More details are provided on this in §5.2.5.3 below.

Figure 5.16 Coastal erosion at Paradise Beach near Club Mykonos.

5.2.5 Coastal setback lines

5.2.5.1 Methodology for Defining and Adopting Coastal Development Setback Lines

Historically, development in the coastal zone has been regulated through the Environmental Impact Assessment (EIA) regulations (Government Notice R543 published in terms of the National Environmental Management 1998) (NEMA) which require that an EIA be conducted for the development of any infrastructure within 100 m of the high-water mark. Recognising, however, that as well as being sensitive, vulnerable, and often stressed ecosystems, coastal areas are also highly dynamic in both space and time, and cannot be boxed within fixed boundaries, the approach to controlling development in coastal areas is set to change. This is particularly pertinent in the light of climate change where rising sea-levels and the potential increase in the frequency and intensity of storm events are upping the stakes even further. These proposed changes are being implemented through the National Environmental Management: Integrated Coastal Management Act of 2009 (ICMA) which call for coastal development setback lines to be determined for all coastal areas. Specifically, section 25 of the ICMA indicates the priority for setback lines to be established (or changed from existing locations), as follows:

1. An MEC must in regulations published in the Gazette—
- *(a) establish or change coastal set-back lines—*
  - *(i) to protect coastal public property, private property and public safety;*
  - *(ii) to protect the coastal protection zone;*
  - *(iii) to preserve the aesthetic values of the coastal zone; or*
  - *(iv) for any other reason consistent with the objectives of this Act; and*
- *(b) prohibit or restrict the building, erection, alteration or extension of structures that are wholly or partially seaward of that coastal set-back line.*

The establishment of setback lines is to follow a participatory approach:

2. Before making or amending the regulations referred to in subsection (1), the MEC must—
- *(a) consult with any local municipality within whose area of jurisdiction the coastal set-back line is, or will be, situated: and*
- *(b) give interested and affected parties an opportunity to make representations in accordance with Part 5 of Chapter 6.*

Setback line is to be plotted on maps as part of zoning and made available to public, as indicated in the ICMA:

3. A local municipality within whose area of jurisdiction a coastal set-back line has been established must delineate the coastal set-back line on a map or maps that form part of its zoning scheme in order to enable the public to determine the position of the set-back line in relation to existing cadastral boundaries.

In response to the above motivation and legal requirements, the Department of Environmental Affairs & Development Planning (DEA&DP) commissioned WSP Africa Coastal Engineers (Pty) Ltd to develop a methodology for defining and adopting coastal development setback lines in the Western Cape and to test the methodology in the Cape Town Metropolitan area and in the Saldanha Bay Municipal area in consultation with the municipal authorities. WSP Africa Coastal Engineers issued a final report entitled Development of a Methodology for Defining and Adopting Coastal Development Setback Lines in May 2010 (WSP Africa Coastal Engineers 2010a).

In this report they included recommendations for two types of setback line, one that demarcates "non-negotiable" areas for development and the other which is negotiable for limited or controlled development. These are as follows:

1. **A coastal processes (or no-development') setback line** which demarcates the setback required for coastal erosion, wave penetration during storms (i.e. the limit of the wave hazard zone), and wind-blown sand transport. Development seawards of this line is non-negotiable as infrastructure in this area is likely to be at risk and/or can induce erosion on neighbouring shorelines. The only exception to be considered here are measures to protect the shoreline such as wooden walkways across sensitive dunes.
2. **A limited or controlled development setback line** demarcating the setback required for issues such as aesthetics, buffer zones, and for protection biodiversity and heritage resources (e.g. shipwrecks and shell middens). Limitations on development within (seawards) of this line should be defined by the requirements of aesthetic or biodiversity protection. Different lines may be defined for different reasons (e.g. biodiversity, heritage or aesthetics).

The report also recommended that each setback line have a time period associated with it, the recommended period being 100 years as this would take account of 1: 100 year storm erosion, sea level rise, and flood events. It was also recommended that the lines, once set, should only be revised in the face of (i) significant changes in global conditions, (ii) unforeseen changes in local or regional circumstances (e.g. significant change in river sand transport budget), (iii) after significant time has passed (e.g. 50 years for a 1:100 years setback line), and (iv) changes in policy regarding an established setback line. Furthermore, it was recommended that the setback lines be scientifically determined regardless of existing development, that they apply equally to mining operations and development

The process for determining setback lines included requirements for significant enabling studies including aerial topographic studies, wave modelling studies, water-level and storm surge analyses, and storm erosion modelling studies, as well as collection of significant additional data including: aerial photographs and/or maps, hydrographic charts, zoning scheme data, sediment graons size distributions, wind data, wave data, water-levels, beach topography data, biodiversity maps, heritage maps and socio-cultural information.

Once this information has been accumulated it is then possible to determine the Coastal Processes (or no-development') Setback Line, being the maximum of the following:

1. The total erosion setback distance which includes the sum of the following components: setback distance for sea level rise + long-term erosion (100 years) distance + setback to allow for estuary mouth meander (where applicable) + allowance for dune/cliff collapse (if applicable);
2. The wind-blown sand setback distance based on the wind transport rose, demarcate wind-blown sand corridors and dunes (some of which may have been vegetated) and estimate setback taking account of guidelines from Tinley (1985);
3. The setback required for wave run-up based on wave time series data (at least 10 years), water level data from storm surge analyses, maximum wave run-up, and the 1:100 year wave run-up;

4. The setback required to mitigate flood risk due to wave overtopping by determining if waves significantly overtop the coastal barrier, estimating wave overtopping during storm and elevated water-level conditions and an assessment of whether drainage systems are able to deal with the volume of water coming in.

Box 5.1. Specific guidelines relating to the establishment of setbacks for wind-blown sand and dunes (Tinley 1985).

- Where bush-covered coastal dunes form a distinct series of ridges and troughs parallel to the beach, the setback lines should be well seawards of the third trough and ridge;
- Where multiple small dune barrier ridges occur on shorelines which are growing seawards (accreting) the setback line should be established where the oldest landward ridges are already covered in bush (younger ridges are colonised by pioneer plant species and are still in an unstable state);
- The setback line should be situated landward of bare mobile dune areas, unless approved and accepted stabilisation is conducted;
- Where relatively small vegetated dunes occur as a single or double ridge only, the setback should be confined to the landward base of the dunes; and
- In steep and board dune cordons (e.g. as in the Wilderness area) the setback line should be confined to the landward base of the dunes.

The process for determining limited development setback line for biodiversity protection is as follows (WSP Africa Coastal Engineers 2010a):

1. Consult the CapeNature/SANBI biodiversity maps on Critical Biodiversity Areas (CBA's).
2. Refer to the biodiversity map data indicating:
   a) The reasons for the biodiversity status indicated on the map;
   b) The proposed management actions in the area concerned.
3. Conduct a site visit with a biodiversity specialist to validate the biodiversity map content (the maps have scale limitations and may be slightly outdated).
4. From the above actions, assign appropriate setback/buffer area where development is to be limited/controlled.
5. Ensure the biodiversity specialist reviews and concurs with the result.
6. Applying the judgement of the biodiversity specialist, it is proposed that the setback line not be situated landward of the line of permanent vegetation along the shore.
7. The setback line for biodiversity must be recorded

The process for determining limited development setback line for biodiversity protection is as follows (WSP Africa Coastal Engineers 2010a):

1. Ensure that the following are considered in the establishment of setback for limited/controlled development:
   a) Public access
   b) Aesthetic features

c) Shading by structures
d) Significant landscapes

2. Setback lines determined for any of the above must be recorded as this will be useful in later assessments or in response to queries relating to the limited/controlled development setback line.

5.2.5.2 Development setback lines for the West Coast District Municipality

Royal Haskoning DHV (previously SRK Consulting) were appointed by the Western Cape Department of Environmental Affairs & Development Planning to delineate coastal set-back lines for the West Coast District Municipality (WCD). The project is still ongoing and to date only a "physical process line" has been generated. The method adopted for doing this was loosely based on that proposed by WSP Africa Coastal Engineers (2010a, see §5.2.5.1). It is a five-step process, and relies on wave run-up modelling for the current, short- (20 year), medium- (50 year) and long- (100 year) term, and is applied as follows (Royal HaskoningDHV 2013):

Step 1:	Offshore wave height	Direction and height
Step 2:	Wave run-up	Current wave run up (HWM), and short, medium & long term wave run up
Step 3:	Storm beach retreat	A fixed distance
Step 4:	Sea level rise (Bruun's Rule)	The amount of shoreline retreat for short, medium & long term sea level rise
Step 5:	Long terms beach retreat	Aerial photo analysis

Offshore wave height and period (including the 1:10 and 1:100 year storm wave height and period) was determined using available wave statistics, wave run-up heights for 1:10, 1:20, 1:50 and 1:100 year events were determined using the models of Mather *et al.* (Mather *et al.* 2010) for sandy shorelines and the Eurotop manual for rocky shorelines (Pullen 2008), and short term storm erosion risk along the coastline was assessed as being 20 m on average for sandy shorelines. Movement of the shoreline inland is a function of increased inundation (due to sea level rise) as well as increased sediment losses from increased wave energy (also an effect of climate change). This was assessed for three different scenarios termed low risk (sea level rise of 200 mm combined with a 1:20 year storm event), medium risk (sea level rise of 500 mm combined with a 1:50 year storm event) and high risk (1000 mm sea level rise combined with a 1:100 year storm event). On sandy shores, the amount of long term retreat was estimated in accordance with the Bruun's Rule (Bruun 1962), while in the case of rocky shorelines, where shoreline retreat is anticipated, the additional sea level rise was simply added to the wave run up positions. The authors correctly point out that the method used is not strictly correct as a 1:100 year storm event can occur at any time in the future (i.e. will not necessarily only be combined with a sea level rise of 1000 mm) but does simplify the outputs. The final physical process line is then generated by joining the highest of the "stacked" wave run-up lines derived from separate modelling studies undertaken for rocky and sandy sections of the shoreline. An example of this is shown below (Figure 5.17), while the final physical process lines for the various scenarios (low, medium and high risk for the area around Saldanha Bay are shown in (Figure 5.18). Note that these physical process lines have only been generated for the open ocean coastal areas to date as further wave modelling for the enclose bays is still under way.

Figure 5.17. Wave run up (thin coloured lines) and risk lines (incorporating shoreline retreat) (thicker lines) for an area due south of the Small craft harbour prepared by Royal HaskoningDHV (2013) for DEADP. The yellow lines are for the low risk scenario (sea level rise of 200 mm combined with a 1:20 year storm event), orange lines the medium risk scenario (sea level rise of 500 mm combined with a 1:50 year storm event) and red lines the high risk scenario (1000 mm sea level rise combined with a 1:100 year storm event). Purple lines depict all three scenarios on the rocky shoreline areas. (Note that no shoreline retreat is anticipated in these areas.)

Figure 5.18. Physical process lines (wave run-up + and shoreline retreat) prepared by Royal HaskoningDHV (2013) for the area around Saldanha Bay. Yellow lines correspond with the low risk scenario (sea level rise of 200 mm combined with a 1:20 year storm event), orange lines with the medium risk scenario (sea level rise of 500 mm combined with a 1:50 year storm event), and red lines the high risk scenario (1000 mm sea level rise combined with a 1:100 year storm event). Purple lines depict all three scenarios on the rocky shoreline areas. (Note that no shoreline retreat is anticipated in these areas.).

Figure 5.19. Physical process lines (wave run-up + and shoreline retreat) prepared by Royal HaskoningDHV (2013) for the area around Saldanha Bay. Yellow lines correspond with the low risk scenario (sea level rise of 200 mm combined with a 1:20 year storm event), orange lines with the medium risk scenario (sea level rise of 500 mm combined with a 1:50 year storm event), and red lines the high risk scenario (1000 mm sea level rise combined with a 1:100 year storm event). Purple lines depict all three scenarios on the rocky shoreline areas. (Note that no shoreline retreat is anticipated in these areas.).

5.2.5.3 Development Setback lines – Langabaan case study

As part of developing a methodology to determine development setback lines in the Western Cape (WSP Africa Coastal Engineers 2010a, summarised in §5.2.5.1 above) the proposed methodology was tested by means of a number of case studies, one of which focussed on two areas of shoreline in Saldanha Bay - Leentjiesklip and Paradise Beach (Figure 5.20). Both the coastal process/no development setback and the limited/controlled development lines were determined using this methodology for each site. Results of this exercise are summarised below.

The following data were employed in this assessment, coupled with observations from a site inspection:

- Offshore waves and wind data
- Geo-referencing historical aerial
- Bio-diversity maps from Cape Nature
- Sediment grain size distribution data
- SDF Saldanha Bay Municipality
- Heritage maps Heritage Western Cape
- Survey data from City of Cape Town
- South African Navy (SAN) Hydrographical Charts

These data were used in deriving the following conclusions:

- shoreline will retreat due to sea level rise will amount to 20 m and 23 m at Paradise Beach and Leentjiesklip, respectively according to the Bruun formula (Bruun 1962) and 6.0 m and 12.0 m respectively when assessed in accordance with a sea level rise of 1m over 100 years at selected cross sections at each site.
- Horizontal setback distances required for the long term erosion trend at Paradise Beach and Leentjiesklip were estimated based on analysis of historical aerial photographs and determined to be 0 for Leentjiesklip and in the range of 56-262 m for Paradise Beach.
- Horizontal setback distances required for short term erosion induced by storms, tides, etc., were estimated at 92-120 m at Paradise Beach and 15-56 m at Leentjiesklip, also based on an assessment of aerial photographs.
- Horizontal setback distances required for storm erosion was assessed using numerical modelling and reported as 0 m at Leentjiesklip and 14.2m at Paradise Beach.
- No setback distance was allowed for windblown sand as it was found that windblown sand does not pose a major problem at either site.
- No setback distance was allowed for wave run-up and flooding as this (wave run-up) was found to be lower than that of the dune crest level in both cases.

Based on this, it was concluded that the total setback should be determined by the setback for coastal erosion, and is indicated in Figure 5.21 below. The development setback line at Paradise Beach is set much further inland than at Leentjiesklip owing to the erosion that has taken place to date at this site.

Figure 5.20. Location of the test sites used by WSP Africa Coastal Engineers (2010b) in Saldanha Bay and extent of the study areas (in red) for each site. Source: WSP Africa Coastal Engineers (2010b).

Figure 5.21. Configuration of development setback lines for Paradise Beach (left) and Leentjiesklip (right) as proposed by WSP Africa Coastal Engineers (2010b).

In considering the need for limited/controlled development setback lines, Critical Biodiversity maps were used to assess the biodiversity status of the area, documents pertaining to archaeological and paleontological surveys conducted in the area were investigated to determine if any sites of heritage importance exist which should be considered, It was found that the Paradise Beach site and the Leentjiesklip site falls within a zone deemed as 'No Natural Remaining Area' (i.e. the areas in question are considered irreversibly transformed and no rehabilitation is feasible). Similarly, available literature suggests that any heritage sites of interest are located seaward of the no-development setback line. Thus it was deemed unnecessary to include additional limited/controlled development setback lines in either of these areas.

5.3 Sediment quality

5.3.1 Changes in sediment particle size composition in the Bay

The particle size composition of the sediments occurring Saldanha Bay and Langebaan Lagoon are strongly influenced by the wave energy and current circulation patterns in the system. Courser or heavier sand and gravel particles are found in areas with high wave energy and strong currents as the movement of water in these areas suspends fine particles (mud and silt) and flushes these out of the area. Disturbances to the wave action and current patterns, which reduce the movement of water, can result in the deposition of mud in some areas. Since 1975, industrial developments in Saldanha Bay (Marcus Island causeway, iron ore terminal, multi-purpose Terminal and establishment of a yacht harbour) have resulted in some level of obstruction to the natural patterns of wave action and current circulation prevailing in the Bay. The extent to which changes in wave exposure and current patterns has impacted on sediment deposition and consequently on benthic macrofauna (animals living in the sediments), has been an issue of concern for many years. The quantity and distribution of different sediment grain particle sizes (gravel, sand and mud) through Saldanha Bay prescribes the status of biological communities and the extent of possible organic loading that may occur in Saldanha Bay.

Contaminants, such as metals and organic toxic pollutants, are predominantly associated with fine sediment particles (mud or cohesive sediments). This is due to the fact that fine grained particles have a relatively larger surface area for the adsorption and binding of pollutants. Higher proportions of mud, relative to sand or gravel, can thus lead to high organic loading and trace metal contamination. It follows then that with a disturbance to natural wave action and current patterns, an increase in the proportion of mud in the sediments of Saldanha Bay, could result in higher organic loading and dangerous levels of metals occurring (assuming that these pollutants continue to be introduced to the system). Furthermore disturbance to the sediment (e.g. dredging) can lead to re-suspension of the mud component from underlying sediments, along with the associated organic pollutants and metals. It may take several months or years following a dredging event before the mud component that has settled on surface layers is scoured out of the Bay by prevailing wave and tidal action. Changes in sediment particle size in Saldanha Bay are of particular interest here and are summarised in this section.

5.3.1.1 Historical data

The earliest studies reporting on the sediments of Saldanha Bay and Langebaan Lagoon were conducted by Flemming (1977) prior to large scale development of the area. Flemming (1977), however, did not report specifically on the distribution of the mud component of the sediments in Saldanha Bay and Langebaan Lagoon as, at that time, they were considered to have an "overall low content". The mud component in Saldanha Bay prior to development (1977) was thus considered to be negligible and the sediments comprised predominantly sand particles (size range from 2 mm to 63 µm).

Due to concern in the deteriorating water quality in Saldanha Bay, however, sediment samples were collected again in 1989 and 1990, these data are presented in this report (Jackson and McGibbon 1991). At the time of the Jackson and McGibbon study, the iron ore terminal had been established dividing the Bay into Small Bay and Big Bay, the multi-purpose quay had been added to the ore terminal, various holiday complexes had been established on the periphery of the Bay and the mariculture industry had begun farming mussels in the sheltered waters of Small Bay. The 1989 and 1990 studies revealed that sediments occurring in both Small Bay and Big Bay were still primarily comprised of sand particles but that mud now made up a noticeable, albeit small, component at most sites in the Bay (Figure 5.26). The Jackson and McGibbon (1991) study concluded that an increase in organic loading in the Bay had indeed occurred although this was not strongly reflected in the sediment analysis conducted at the time.

The next study on sediment particle size in Saldanha Bay occurred nearly a decade later, in 1999. However, immediately preceding this (in 1997/98) an extensive area adjacent to the ore terminal was dredged (indicated by arrows in Figure 5.26), resulting in a massive disturbance to the sediments of the Bay. The 1999 study clearly shows a substantial increase in the percentage of mud particles making up the sediment composition, specifically at the Multi-purpose Quay, Channel end of the ore terminal, the Yacht Club Basin and the Mussel Farm area (Figure 5.26). Two sites least affected by the dredging event were the North Channel site in Small Bay and the site adjacent to the Ore Jetty in Big Bay. The North Channel site is located in shallow water where the influence of strong wave action and current velocities are expected to have facilitated in flushing out the fine sediment particles (mud) that are likely to have arisen from dredging activities. Big Bay remained largely unaffected by the dredging event that occurred in Small Bay and is presumably mediated to some extent by the scouring action of oceanic waves prevalent at this site.

Subsequent studies conducted in 2000 and 2001 indicated that the mud content of the sediment remained high but that there was an unexplained influx of coarse sediment (gravel) in 2000 followed by what appears to be some recovery over the 1999 situation. The 2000 results are somewhat anomalous and may be related to an unidentified processing error that arose when the samples were analysed. Sampling conducted in 2004 shows almost complete recovery of sediments over the 1999 situation to a majority percentage of sand in five of the six sites examined for this report (Figure 5.26). The only site where a substantial mud component remained was at the Multi-purpose Quay. The shipping channel adjacent to the Quay is the deepest section of Small Bay (artificially maintained to allow passage of vessels) and is expected to concentrate the denser (heavier) mud component of sediment occurring in the Bay.

The survey conducted in 2008 revealed that there had been an increase in the percentage of mud at all sites, most notably in the Yacht Club Basin and at the Multi-purpose Quay. This was probably due the maintenance dredging that took place at the Mossgas and Multi-purpose quays at the end of 2007/beginning of 2008 (see §3.3.1). The Yacht Club basin and the Small Bay side of the Multi-purpose quay are sheltered sites with reduced wave energy and are subject to long term deposition of fine grained particles. The benthic macrofauna surveys conducted between 2008 and 2011 revealed that benthic health at both the Yacht Club basin and adjacent to the Multi-purpose Quay was severely compromised, with benthic organisms being virtually absent from the former (see Chapter 7).

Smaller dredging programmes were also undertaken in the Bay 2009/10, when 7 300 m3 of material was removed from an area of approximately 3 000 m^2 between Caisson 3 and 4 near the base of the Iron ore terminal on the Saldanha side, and a 275 m^2 area in Salamander Bay was dredged to accommodate an expanded the SANDF Boat park. The former programme seems to have had a minimal impact of the Bay while the latter was potential more significant and is discussed in detail in §5.3.1.2 and 5.3.3.

The percentage mud in the Bay sediments has decline at most sites in Small Bay over the period 2008 to 2011. This bay-wide progressive reduction in mud content suggests a shift in the balance between the rate at which fine sediments are suspended and deposited and the rate at which currents and wave activities flush fine sediments from the Bay.

Unfortunately no early historical data is available for grain size distribution in Langebaan Lagoon, and only the recent results from the 2004, 2008, 2009, 2010 and 2011 surveys could be included in this report. During these surveys, the sediments in Langebaan Lagoon were principally composed of medium to fine grained sands with a very small percentage of mud. This is most likely due to the strong tidal currents experienced in the Lagoon.

In summary, the natural, pre-development state of sediment in Saldanha Bay comprised predominantly sand particles; however, developments and activities in the bay (causeway, ore terminal, Yacht Club Harbour and mussel rafts) reduced the overall wave energy and altered the current circulation patterns. This compromised the capacity of the system to flush the bay of fine particles and led to the progressive accumulation of mud (cohesive sediment) in surface sediments in the Bay, followed in more recent times by a reduction in the mud fraction. Dredge events, which re-suspended large amounts of mud from the deeper lying sediments, seem to be a dominant contributor to the elevated mud content in the Bay and results of surveys have shown a general pattern of an increase in mud content following dredge events followed by a recovery in subsequent years. Any future dredging or other such large-scale disturbance to the sediment in Saldanha Bay are likely to result in similar increases in the mud proportion as was evident in 1999, with accompanying increase in metal content (refer to § 5.3.3 for more details on this).

5.3.1.2 Sediment Particle size results for 2012

Sediment samples were collected from a total of 32 sites in April 2012 to be tested for particle size composition, particulate organic carbon and nitrogen and trace metals. Twelve of the sites were in Small Bay, seven in Big Bay, two in Donkergat, two in Salamander Bay and nine in Langebaan Lagoon (

Figure 5.23).

All sites throughout the system comprised predominantly sand (particle size ranging between 63 µm and 2000 µm). The sites in Small Bay had on average the highest proportion of mud (7.4%), followed by Big Bay (4.6%), Salamander Bay (2.5%), Donkergat (1.9%) and finally Langebaan Lagoon with the lowest average proportion of mud (0.8%). A very low proportion of gravel (particles exceeding 2000 µm) was found at all sites, with all but 6 sites comprising less than 1% gravel. The areas with the highest gravel content included Site LL38 at the entrance to Langebaan Lagoon (5.7%), Site BB22 adjacent to the Ore Jetty (4.7%), Donkergat (average 1.5%) and Salamander Bay (average 1.6%).

Mud is the most important particle size component to monitor given that fine grained particles provide a larger surface area to which contaminants bind. In 2012 the highest proportion of mud recorded in the sediments was found in the vicinity of the Ore Jetty in Small Bay and Big Bay, and the mussel farms in Small Bay (Figure 5.25). The sites beneath the mussel farm and in the shipping channel adjacent to the Ore Jetty are the deepest within Small Bay and are expected to yield sediments with a higher mud fraction than elsewhere in the Bay. Similarly, sites adjacent to the Ore Jetty on the Big Bay side are relatively deep and are thus also expected to have a high mud content. There were, however, two deep sites within Big Bay; one at the southern end of Big Bay (BB29) and at the entrance to the Bay (BB20) which, despite being relatively deep, had moderate and low mud content respectively. The low mud content at these sites is likely to be a result of the exposed nature of these sites and the relatively strong currents that they are subjected to. The remainder of sites in Big Bay had a relatively moderate to low mud content and Langebaan Lagoon had very low mud content (Figure 5.25).

The percentage mud found in the sediments of the middle reaches of Small Bay (in the vicinity of the mussel farms and Ore Jetty) and the northern reaches of Big Bay (in the vicinity of the Ore Jetty) increased between 2011 and 2012 (Figure 5.24 and Figure 5.25). Mud content recorded in 2012 at the Mussel Farm and Multi-purpose Quay in Small Bay increased to a level comparable to that seen in 2010 and remains lower than that recorded in 2008 (Figure 5.26). The mud content at the site adjacent to the Ore Jetty in Big Bay increased substantially and is comparable to the levels recorded in 1999 following dredging (Figure 5.26). It is unclear whether the reason for the increased mud content is due to increased input of fine particles (natural and anthropogenic) or a reduction in the water movements in the area.

No significant change in the mud content was seen in the northern reaches of Small Bay, the southern end of the Ore Jetty and at the Yacht Club Basin between 2011 and 2012 (Figure 5.26). There was a very minor increase in the percentage mud found in Langebaan Lagoon between 2011 and 2012 and no changes were seen in Donkergat, Salamander Bay and the southern reaches of Big Bay (Figure 5.24 and Figure 5.25).

Table 5.1. Particle size composition and percentage organic carbon and nitrogen in surface sediments collected from Small Bay (SB), Big Bay (BB), Langebaan Lagoon (LL), Salamander Bay (S) and Donkergat (D) in 2012. (Particle size analysed by Scientific Services, and TOC and TON analysed by CSIR).

	Sample	*Gravel (%)*	*Sand (%)*	*Mud (%)*	*TOC (%)*	*TON (%)*	*C:N*
Small Bay (SB)	SB1	0.00	89.34	10.66	7.41	0.25	34.45
	SB2	0.29	98.38	1.33	0.43	0.02	29.24
	SB3	0.32	96.02	3.67	2.11	0.12	21.23
	SB8	0.00	96.40	3.60	4.79	0.07	85.94
	SB9	1.14	87.50	11.36	2.11	0.19	13.06
	SB10	0.63	98.41	0.96	0.54	0.03	22.33
	SB14	0.20	86.73	13.08	4.48	0.26	20.49
	SB15	0.92	88.78	10.30	1.49	0.11	15.63
	SB16	0.00	95.10	4.90	2.62	0.15	20.12
	SB42	0.11	97.41	2.47	1.55	0.09	19.66
	SB43	0.05	77.09	22.87	8.75	0.54	18.83
	SB44	0.15	96.13	3.72	0.30	0.04	8.78
Big Bay (BB)	BB20	0.64	95.97	3.39	5.47	0.35	18.34
	BB21	0.00	93.76	6.24	1.47	0.08	21.72
	BB22	4.71	83.77	11.52	8.26	0.16	58.75
	BB25	0.11	98.88	1.01	1.16	0.06	21.05
	BB26	0.13	92.41	7.46	0.82	0.03	38.03
	BB29	0.51	96.89	2.60	2.06	0.19	12.44

	Sample	Gravel (%)	Sand (%)	Mud (%)	TOC (%)	TON (%)	C:N
	BB30	0.00	100.00	0.00	1.33	0.06	26.26
Donkergat	D1	0.00	98.03	1.97	4.12	0.58	8.33
	D2	3.20	94.59	2.21	0.79	0.14	6.78
Salamander Bay	S1	1.69	95.74	2.57	0.69	0.10	7.77
	S2	1.55	95.01	3.45	4.14	0.17	28.57
Langebaan Lagoon (LL)	LL31	0.00	99.54	0.46	1.19	0.06	21.73
	LL32	0.00	99.68	0.32	0.14	0.05	3.43
	LL33	0.00	99.14	0.86	0.15	0.02	9.46
	LL34	0.46	98.76	0.77	0.21	0.03	7.58
	LL37	0.00	99.09	0.91	0.12	0.02	7.43
	LL38	5.67	91.11	3.21	0.42	0.07	7.33
	LL39	0.00	100.00	0.00	1.72	0.03	59.16
	LL40	0.00	99.50	0.50	0.13	0.02	9.88
	LL41	0.00	99.62	0.38	0.12	0.02	5.83

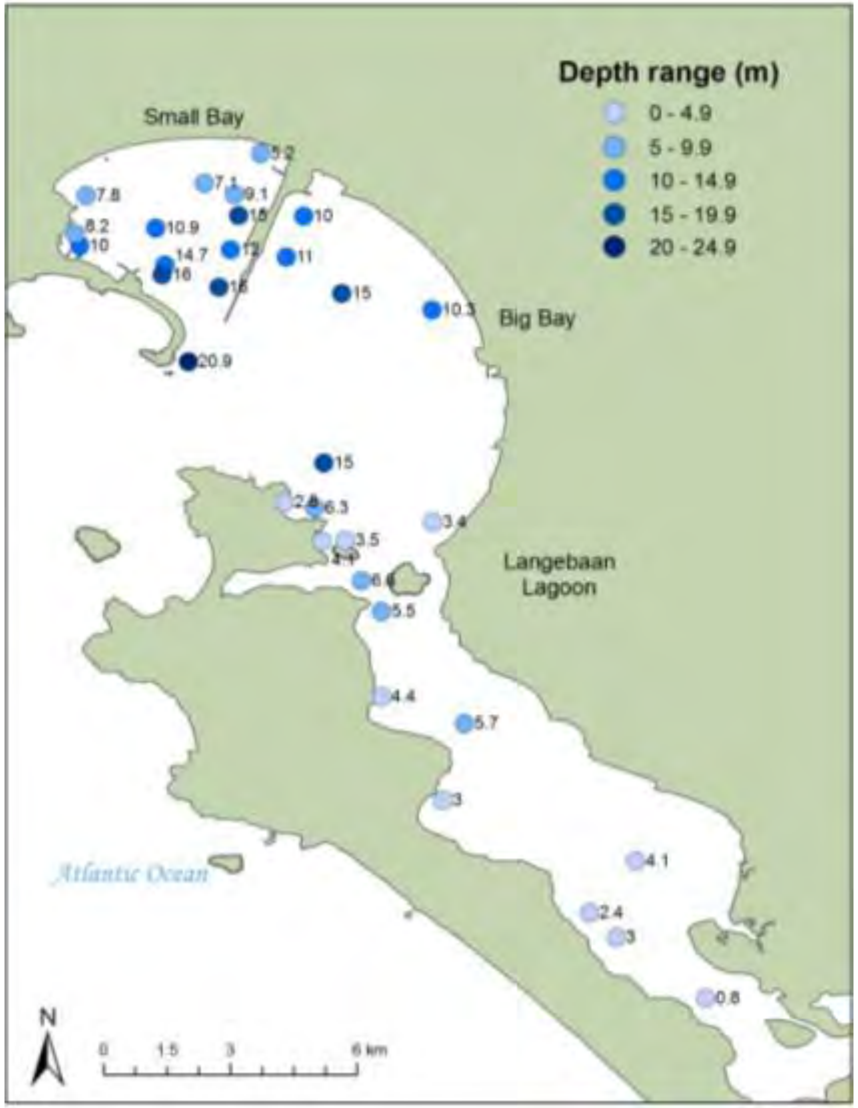


Figure 5.22. Depth of sites sampled in Saldanha Bay and Langebaan Lagoon in 2012.

Figure 5.23. Sediment sampling sites in Saldanha Bay and Langebaan Lagoon for 2012. Sites sampled from pre-1980 to 2010 are marked and labelled in red.

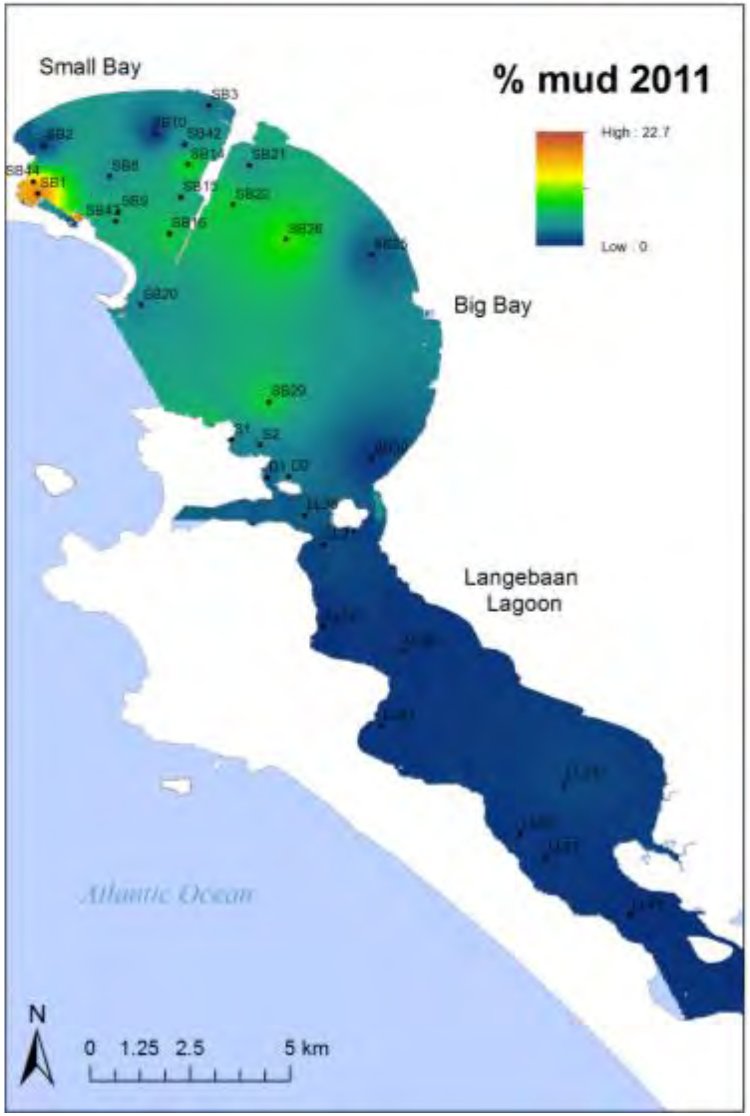


Figure 5.24. Variation in the percentage mud in sediments in Saldanha Bay and Langebaan Lagoon as indicated by the 2011 survey results.

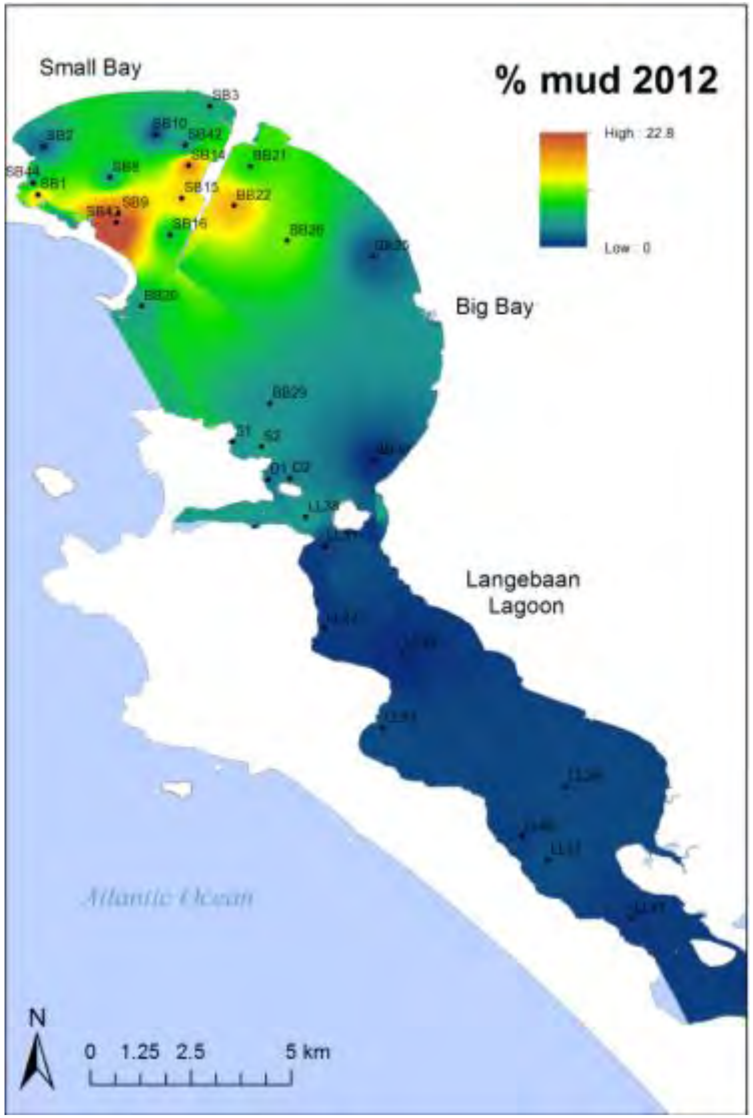


Figure 5.25. Variation in the percentage mud in sediments in Saldanha Bay and Langebaan Lagoon as indicated by the 2012 survey results.

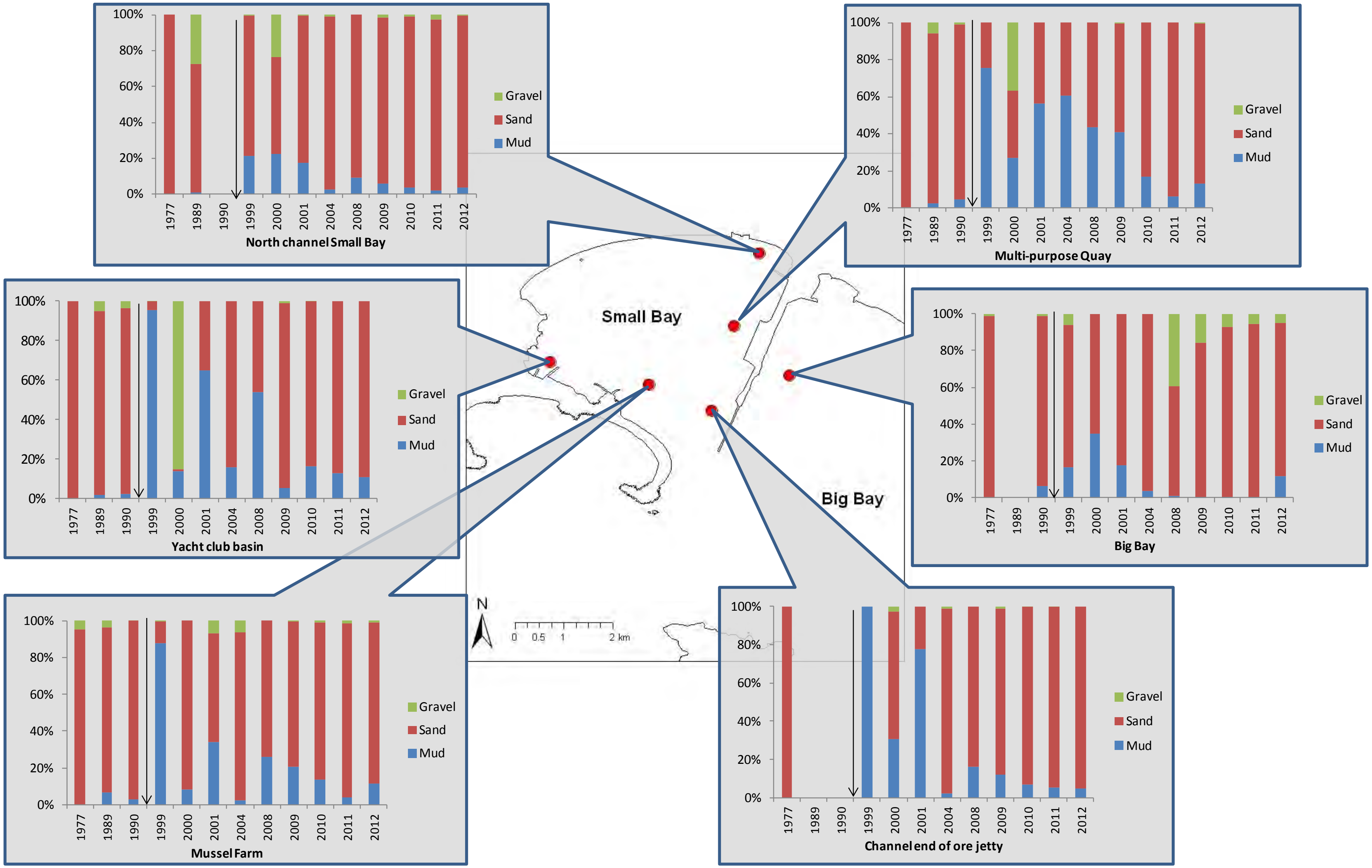


Figure 5.26. Particle size composition (percentage gravel, sand and mud) of sediments at six localities in the small bay area of Saldanha Bay between 1977 and 2012.

5.3.2 Particulate Organic Carbon (POC) and Nitrogen (PON) in sediment in the Bay

Particulate organic carbon (POC) and particulate organic nitrogen (PON) accumulates in the same areas as mud (cohesive sediment) as most organic particulate matter is of a similar particle size range and density to that of mud particles (size <60 µm) and settles out of the water column together with the mud. Hence POC and PON are most likely to accumulate in sheltered areas with low current strengths, where there is limited wave action and hence limited dispersal of organic matter. While the accumulation of organic matter in the sediments doesn't necessarily directly impact the environment, bacterial breakdown of the organic matter can (and often does) lead to hypoxic (low oxygen) or even anoxic (no oxygen) conditions. Under such conditions, anaerobic decomposition prevails, which results in the formation of sulphides such as hydrogen sulphide (H_2S). Sediments high in H_2S concentrations are characteristically black, foul smelling and toxic for most living organisms.

The most likely sources of organic matter in Saldanha Bay are from phytoplankton production at sea and the associated detritus that forms from the decay thereof, fish factory waste discharged into the Bay, faecal waste concentrated beneath the mussel and oyster rafts in the Bay, treated sewage effluent discharged into the Bay from the waste water treatment works (Saldanha & Langebaan), and the leaking of sewage from septic tanks and conservancy tanks. The molar ratios of carbon to nitrogen (C:N ratio) can also be useful in determining the sources of organic contamination. Organic matter originating from marine algae typically has a C:N ratio ranging between 6 and 8, whereas matter originating from terrestrial plant sources exceeds this. Fish factory waste is nitrogen-rich and thus extremely low C:N ratios would be expected in the vicinity of a fish waste effluent outfall. However; nitrogen is the limiting nutrient for primary productivity in most upwelling systems including the Benguela, and the discharge of nitrogen-rich waste from fish factories has been linked to algal blooms using stable isotope studies (Monteiro *et al*. 1997). The excess nitrogen in the system is taken up by algae thereby allowing for bloom development. By consuming the nitrogen the bloom effectively increases the C:N ratio. In addition phytoplankton production and decomposition will then add to the levels of organic matter within the system.

POC levels in Saldanha Bay were mostly very low (between 0.2 and 0.5%) throughout the Bay prior to any major development (pre-1974). The next available POC data was collected in 1989 after the construction of the iron ore terminal and the establishment of the mussel farms in Small Bay. At this stage all sites monitored had considerably elevated levels of POC with the greatest increase occurring in the vicinity of the Mussel Farm. POC levels peaked at 16.9% at this site in 1990. The reason for this extremely high POC percentage is uncertain. Through all subsequent years of POC monitoring (1990, 1999, 2000, 2001, 2004, 2008, 2009 and 2010), levels have remained higher than those reported prior to development.

5.3.2.1 Spatial trends in POC and PON

Spatial variation in the amount of POC and PON recorded in the sediments in Saldanha Bay and Langebaan Lagoon in 2012 is presented in Figure 5.27 and Figure 5.28. The concentration of POC is generally highest in the deeper parts of the Bay, around the Ore Jetty, multi-purpose terminal and at the mussel farms in Small Bay, and where there is a high concentration of mud. The notable exceptions include the deepest site, site BB20, at the entrance to the Bay, which had a relatively low mud content and high POC, and sites in Donkergat and Salamander Bay, which were shallow with low mud content and high POC. The concentration of PON was highest in the vicinity of the mussel farms in Small Bay, across the entrance to Big Bay and in Salamander Bay and Donkergat. The concentration of PON did not correspond well with that of mud content or depth.

One would expect the spatial distribution of fine sediments to match that of particulate organic matter given that both settle out of the water column at similar rates. The observed differences between the spatial distribution of muddy sediments and that of particulate organic matter suggest that other events (anthropogenic or natural) are contributing organic matter in different regions of the system at different rates. The elevated POC at Donkergat and Salamander Bay are likely to be a result of the dredging activities that took place in this area between 2009 and 2010. The low mud content in this area suggests that it is not an area subject to a high deposition or retention rate. It therefore follows that the POC in the area is of local origin from a fairly recent event.

5.3.2.2 Spatial trends in the C:N ratio

The C:N ratio at all sites in Small Bay and Big Bay exceeded that which is expected for matter originating from marine productivity (Figure 5.29). The only exception to this was the site adjacent to the outfall pipe at a fish factory in the Yacht Club basin which had a C:N ratio of 9. There are two possible reasons for these elevated C:N ratios; the first being that the organic matter found in these areas originated from terrestrial sources (e.g. sewage). The alternate explanation is that natural decomposition processes reduced the amount of nitrogen present thereby elevating the C:N ratio. This process is known as denitrification and it occurs in environments where oxygen levels have been depleted (anoxic or hypoxic) and nitrates are present. Under these conditions, denitrifying bacteria are likely to dominate as they are able to substitute oxygen, normally required for organic matter degradation, through nitrate reduction (Knowles 1982, Tyrrell and Lucas 2002). In areas where photosynthetic rates are very high, such as in upwelling systems, or where there is a high degree of organic input, a high biological oxygen demand deeper in the water column and sediments can lead to complete oxygen utilisation.

Denitrification may be responsible for the elevated C:N ratios in the deep areas where a high POC content was recorded and stratification is possible. It is however highly unlikely that this process is responsible for the elevated C:N ratios at all reported sites given that many of the sites with high C:N ratios are in highly exposed, shallow areas with low organic content. It thus seems likely the organic matter in many areas of the system originates from a terrestrial source.

Most of the sites in Langebaan Lagoon and those in Salamander Bay and Donkergat had a C:N ratio within that which is expected to have originated from marine production.

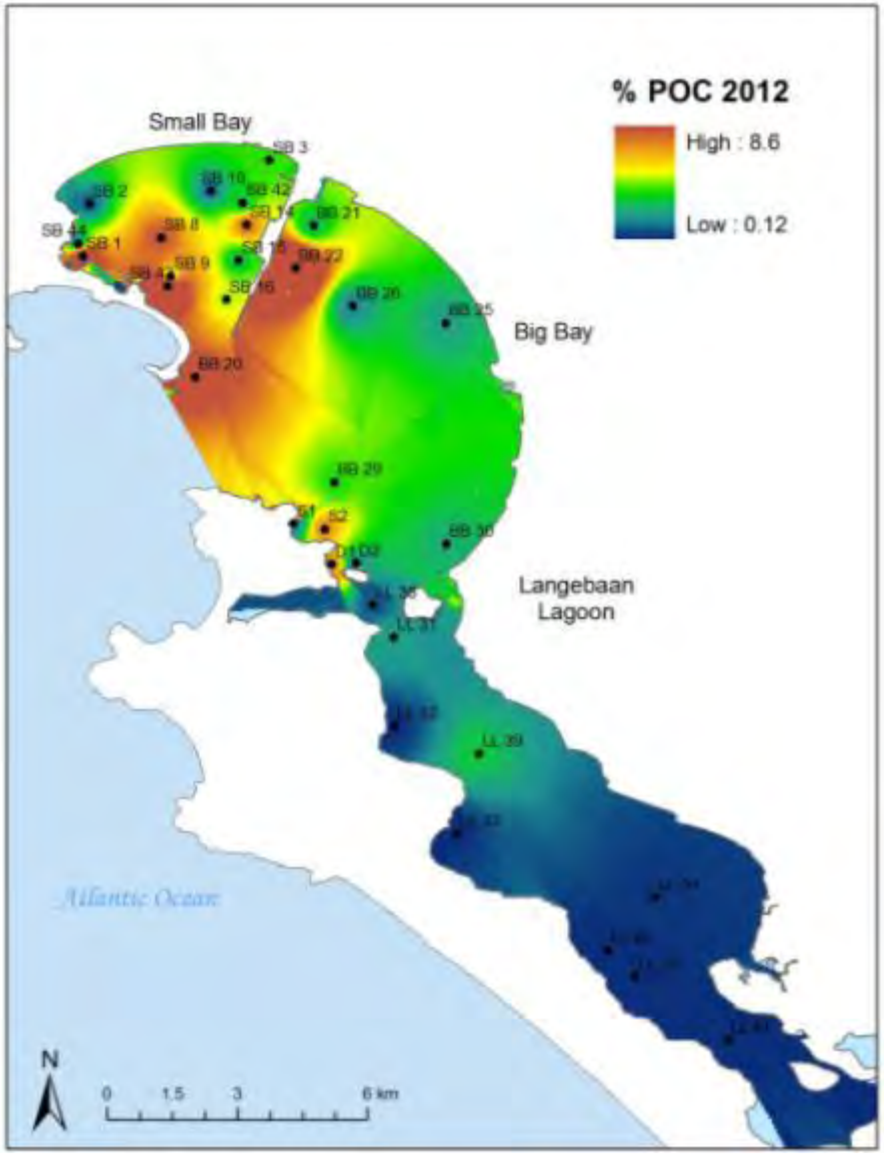


Figure 5.27. Variation in the percentage Particulate Organic Carbon in Saldanha Bay and Langebaan Lagoon as indicated by the 2012 survey results.

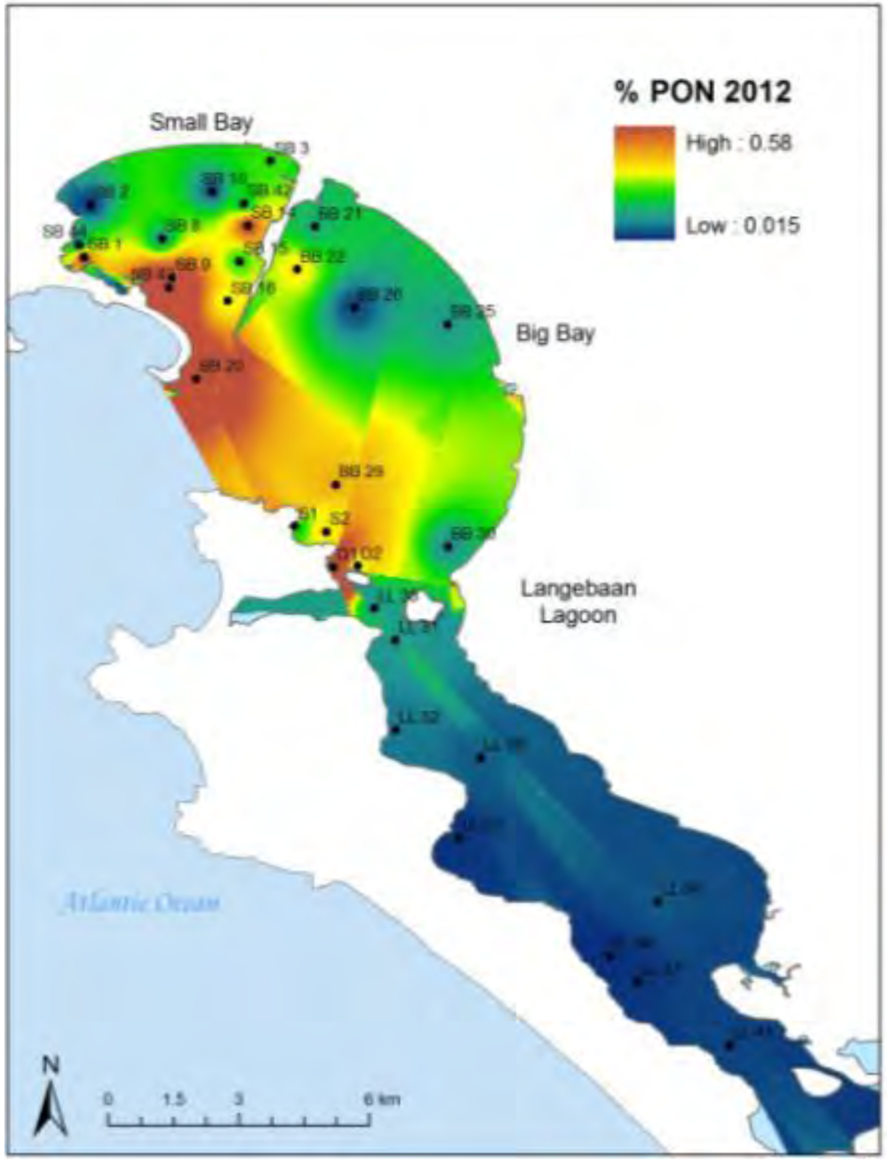


Figure 5.28. Variation in the percentage Particulate Organic Nitrogen in Saldanha Bay and Langebaan Lagoon as indicated by the 2012 survey results.

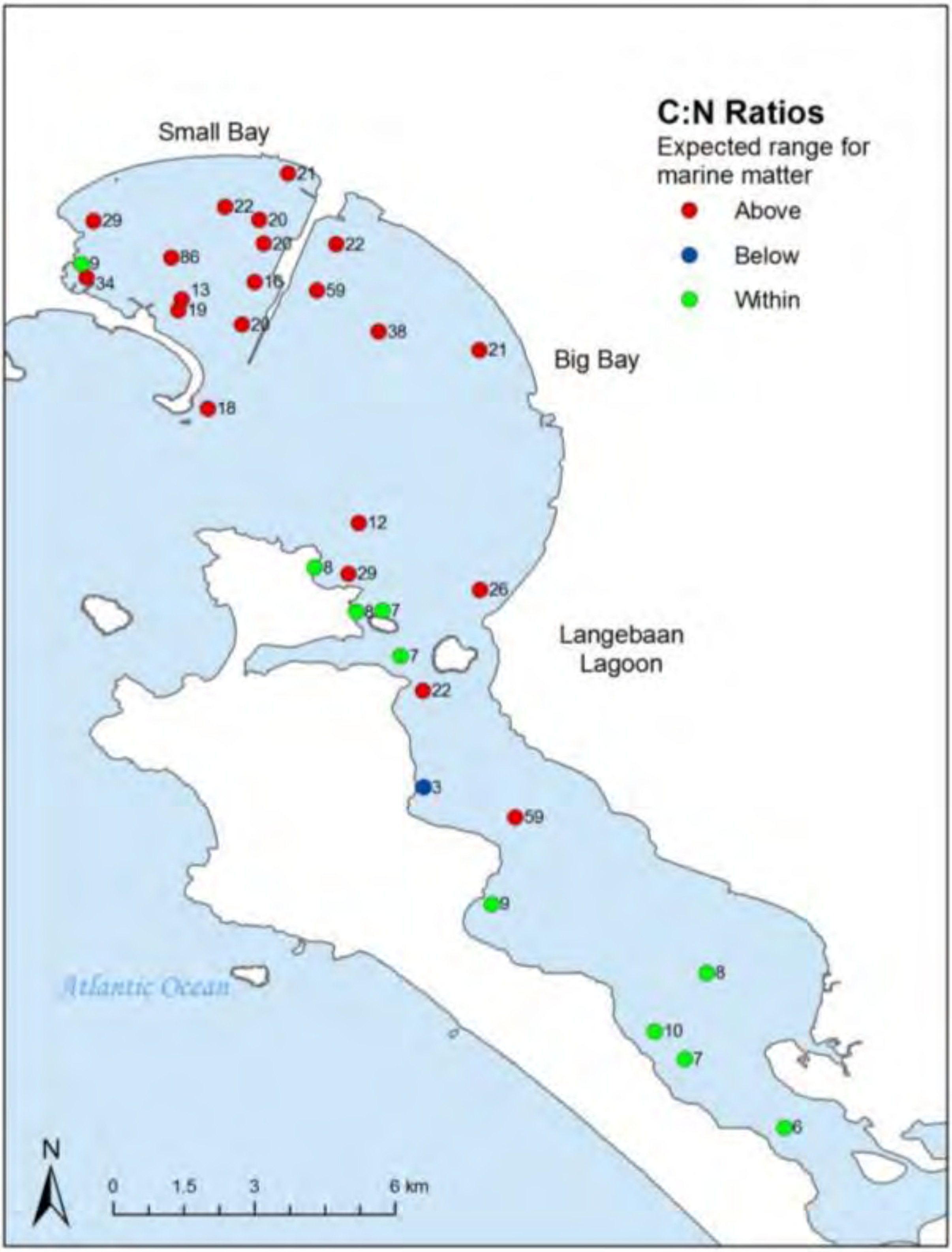


Figure 5.29. Map showing C:N ration at different at sites surveyed in Saldanha Bay and Langebaan Lagoon in 2012 (red = exceeds range expected for marine production, green= within range expected for marine production and blue = below range expected for marine production)

5.3.2.3 Temporal trends

5.3.2.3.1 Particulate organic carbon

A total of six sites have been sampled and POC compared at various stages between 1974 and 2012. The sediments from the Yacht Club Basin (SB1) and Multi-purpose Quay (SB14) consistently had the highest POC content of the six sites sampled since 1989. POC at the Mussel Farm (SB9) historically had elevated POC but since 2008 levels have been mostly low. The POC at all six sites has increased since 2010, most alarmingly in Big Bay and in the Yacht Club basin. The reasons for the substantial increase at these sites is not clear (see §5.3.2.1 above).

Historically, elevated organic carbon levels in sediments at the Yacht Club Basin has been attributed to a combination of organic matter input from dredge events and the fish factories and high retention rates due to the sheltered nature of the area. Elevated levels of organic carbon at the mussel farm site was attributed to the deposition of faecal pellets and biogenic waste. Elevated organic carbon levels at the Multi-purpose Quay is also most likely attributable to the historical dredging that took place at the site and a relatively higher retention rate of organic matter and fine sediments, given the depth and the sheltered nature of the site.

The historical data has shown that that levels of organic matter typically increases immediately following a dredging event and declines in subsequent years. This suggests the re-suspension of organic matter from deeper sediments and the subsequent settling of this matter is a primary contributor to organic matter in surface sediments in the Bay. The only exception to this trend was that of the mussel farm site. This suggests that the mussel farm activities had a stronger local influence at that particular site than that of the dredging activities.

The increase in POC in Small Bay and Bay since 2010, however, does not appear to be related to dredging operations.

5.3.2.3.2 Particulate organic nitrogen

Sources of organic nitrogen in Small Bay include fish factory wastes, biogenic waste from mussel and oyster culture, sewage effluent from the waste water treatment works and leaking of sewage from septic tanks. PON had not been measured in early (historic) studies of the Bay, and data are only available from 1999 onwards. Historically the PON concentrations have been greatest at the Yacht Club Basin, Multi-purpose Quay and near the Mussel rafts (Figure 5.31). This was considered to be linked to the discharge of waste from the fish processing plants in this area, faecal waste accumulating beneath the mussel rafts and dredging operations at the Multi-purpose Terminal. The 2012 data indicate a reduction in the PON at the Yacht Club Basin and, Multi-purpose Quay and an increase at the Mussel rafts. Increases in PON were seen at the North end of the Ore Jetty and in Big Bay. All sites had high C:N ratios which suggest that the area had been subject to an overall increase in organic material and that the material was either of a high carbon content (terrestrial origins) or that it had been subject to denitrification.

High organic loading of the sediments generally results in hypoxic conditions, which are unsuitable for most life forms. The high organic loading at the Yacht Club Basin has had a notable detrimental impact on marine benthic fauna as is evident from the macrofauna survey results (see Chapter7 for more details on this).

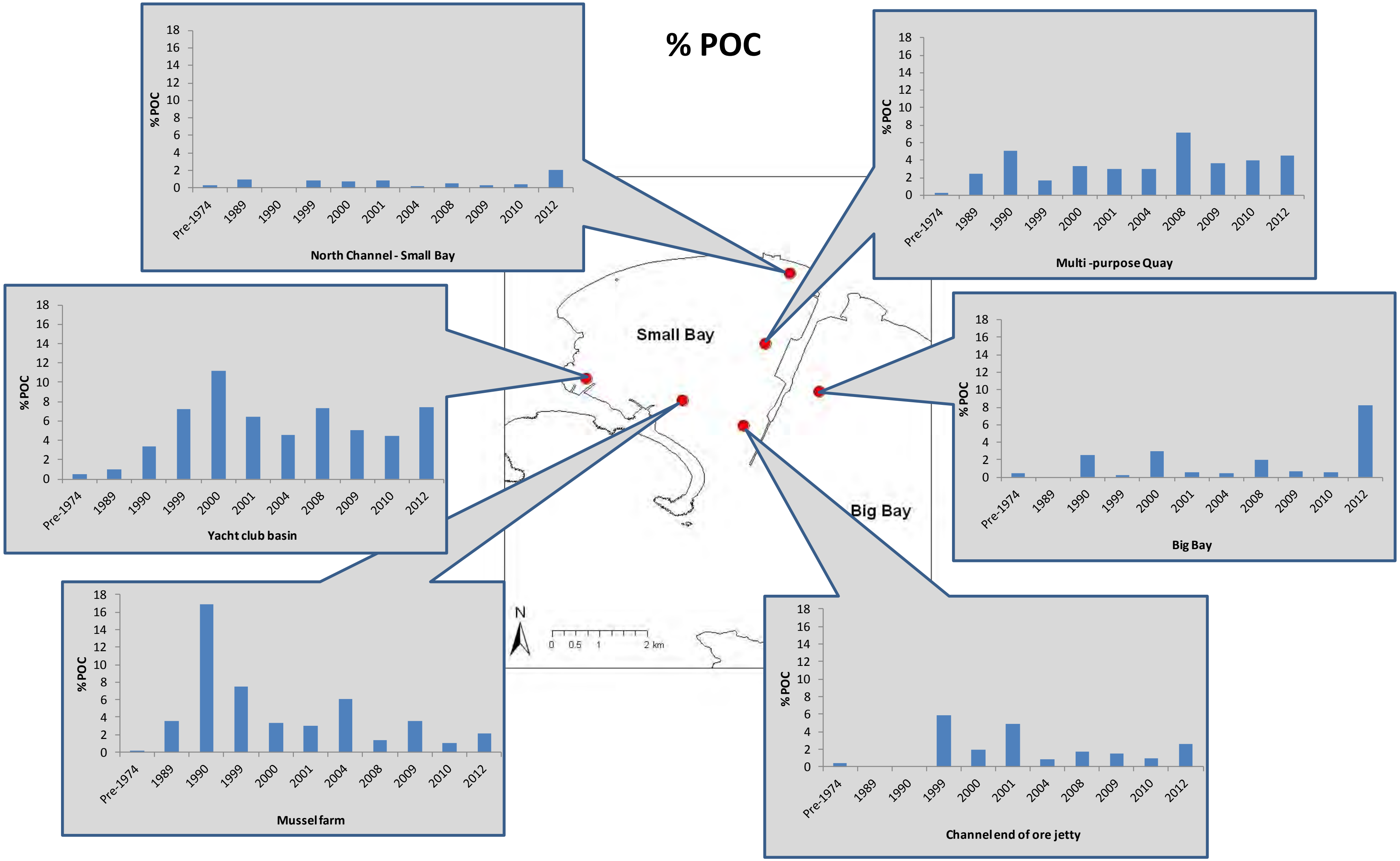


Figure 5.30. Particulate Organic Carbon (POC) percentage occurring in sediments of Saldanha Bay at six locations between 1999 and 2012

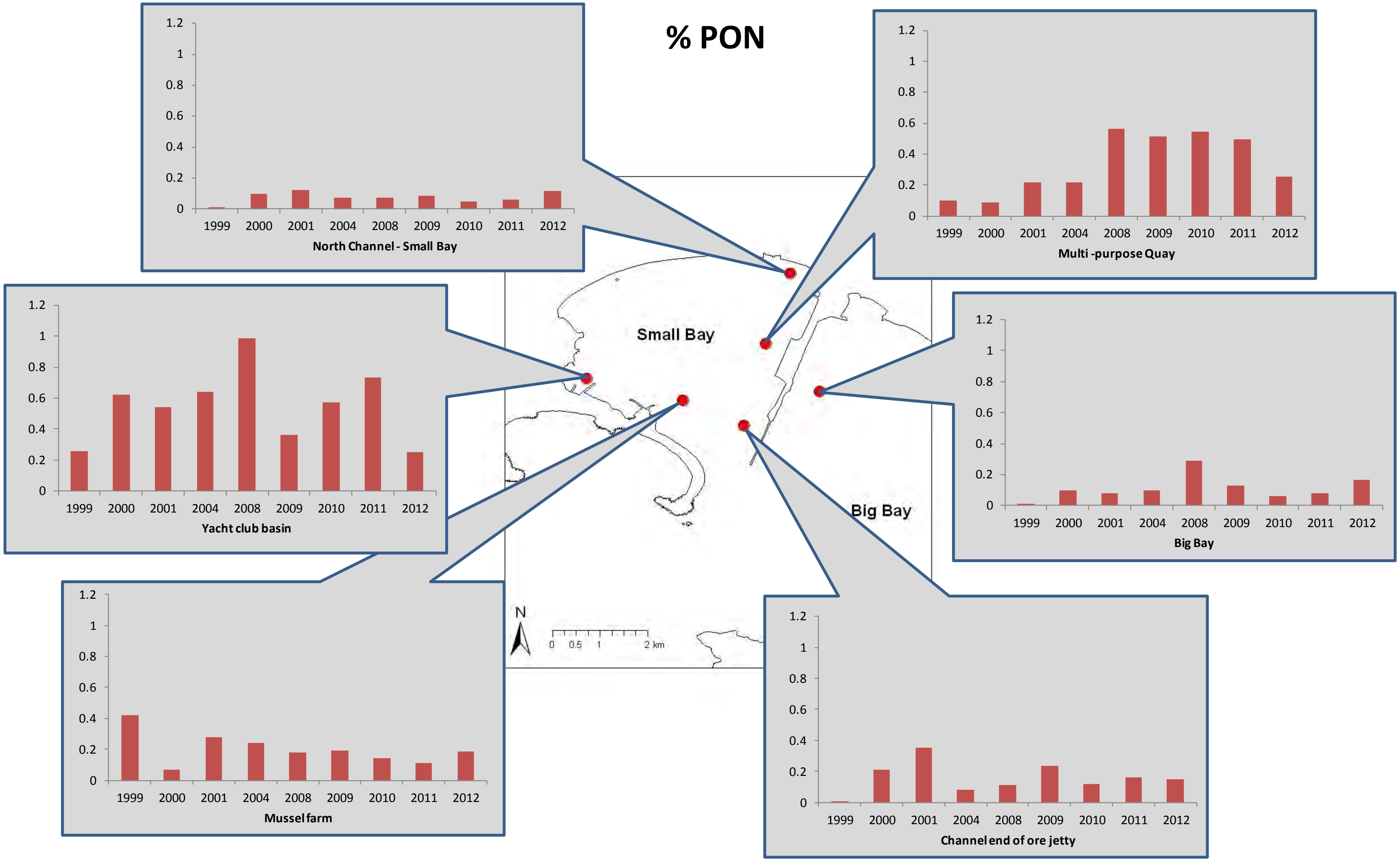


Figure 5.31. Particulate Organic Nitrogen (PON) percentage occurring in sediments of Saldanha Bay at six locations between 1999 and 2012

5.3.2.3.3 C:N Ratios

Figure 5.32 indicates that the C:N ratio reported in Small Bay and Big Bay was exceptionally high for most sites in both 2008 and 2012. This may be due to terrestrial inputs of organic matter or denitrification as discussed above. The 2009 and 2010 results indicated that organic content originated mostly from marine productivity.

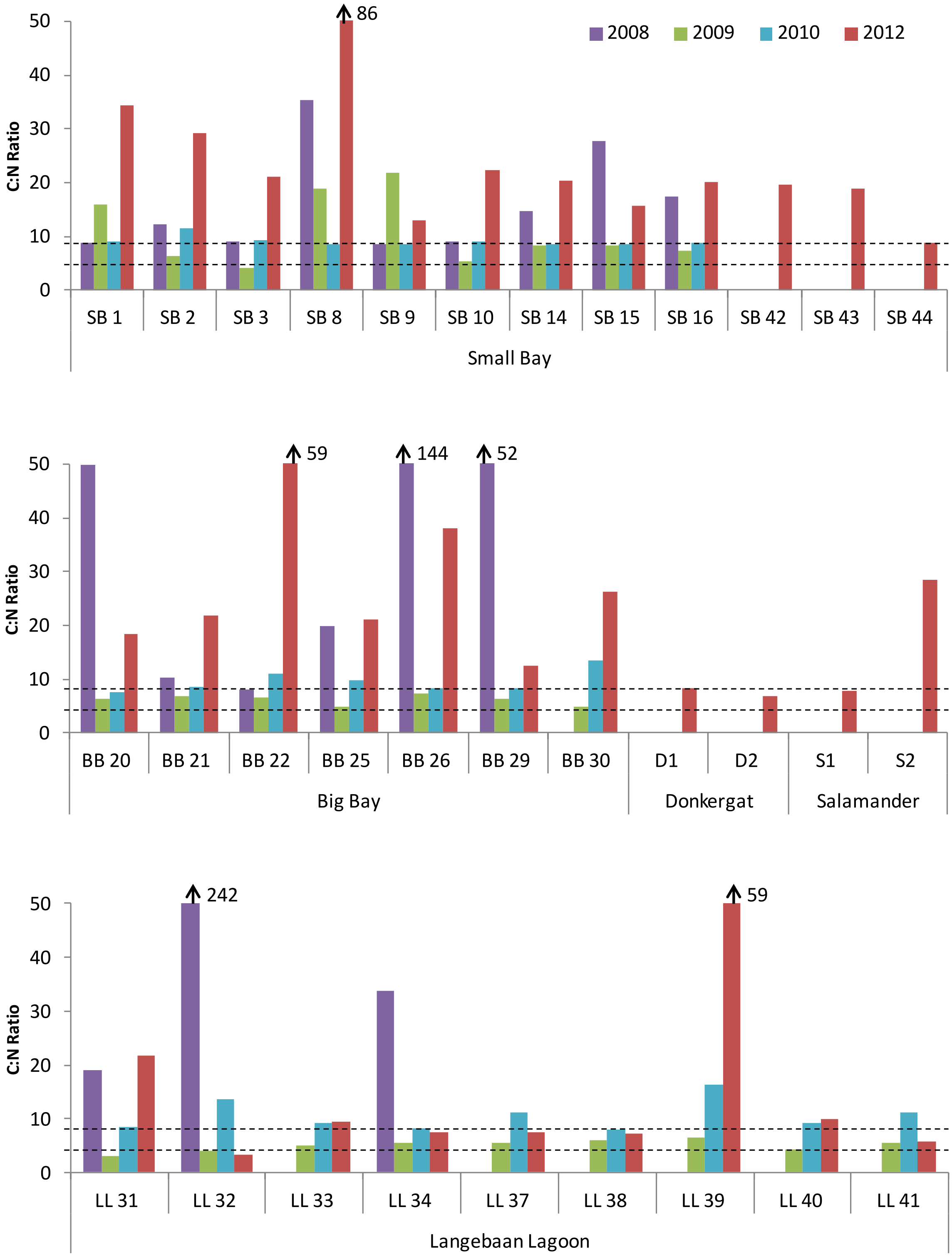


Figure 5.32. Carbon to Nitrogen ratios in Saldanha Bay and Langebaan Lagoon between 2008 and 2012.

5.3.3 Trace Metals

Trace metals occur naturally in the marine environment, and some are important in fulfilling key physiological roles. Disturbance to the natural environment by either anthropogenic or natural factors can lead to an increase in metal concentrations occurring in the environment particularly sediments. An increase in metal concentrations above natural levels or at least above established safety thresholds can result in negative impacts on marine organisms, especially filter feeders like mussels that tend to accumulate metals in their flesh. High concentrations of metals can also render these species unsuitable for human consumption. Metals are strongly associated with the cohesive fraction of sediment (i.e. the mud component) and with particulate organic carbon (POC). Metals occurring in sediments are generally inert (non-threatening) when buried in the sediment but can become toxic to the environment when they are converted to the more soluble form of metal sulphides. Metal sulphides are known to form as a result of natural re-suspension of the sediment (strong wave action resulting from storms) and from anthropogenic induced disturbance events like dredging activities.

The Benguela Current Large Marine Ecosystem (BCLME) Programme reviewed international sediment quality guidelines in order to develop a common set of sediment quality guidelines for the coastal zone of the BCLME (Angola, Namibia and west coast of South Africa) (Table 5.2). The BCLME guidelines cover a broad concentration range and still need to be refined to meet the specific requirements of each country within the BCLME region (BCLME 2006). There are thus no official sediment quality guidelines that have been published for the South African marine environment as yet, and it is necessary to adopt international guidelines when screening sediment metal concentrations. The National Oceanic and Atmospheric Administration (NOAA) has published a series of sediment screening values, which cover a broad spectrum of concentrations from toxic to non-toxic levels as shown in Table 5.2.

The Effects Range Low (ERL) represents the concentration at which toxicity may begin to be observed in sensitive species. The ERL is calculated as lower 10^{th} percentile of sediment concentrations reported in literature that co-occur with any biological effect. The Effects Range Median (ERM) is the median concentration of available toxicity data. It is calculated as lower 50^{th} percentile of sediment concentrations reported in literature that co-occur with a biological effect (Buchman 1999). The ERL values represent the most conservative screening concentrations for sediment toxicity proposed by the NOAA, and ERL values have been used to screen the Saldanha Bay sediments.

Table 5.2. Summary of BCLME and NOAA metal concentrations in sediment quality guidelines

Metal (mg/kg dry wt.)	BCLME region (South Africa. Namibia, Angola)			NOAA[2]	
	Special care	Prohibited		ERL	ERM
Cd	1.5 – 10	> 10		1.2	9.6
Cu	50 – 500	>500		34	270
Pb	100 – 500	> 500		46.7	218
Ni	50 – 500	> 500		20.9	51.6
Zn	150 – 750	> 750		150	410
[1](BCLME 2006), [2] (Long *et al*. 1995, Buchman 1999)					

5.3.3.1 Historic data

Dramatic increases in trace metal concentrations, especially those of cadmium and lead after the start of the iron ore export from Saldanha Bay, raised concern for the safety and health of marine organisms, specifically those being farmed for human consumption (mussels and oysters). Of particular concern were the concentrations of cadmium which exceeded the lower toxic effect level published by the NOAA. Both lead and copper concentrates are exported from Saldanha Bay and it was hypothesised that the overall increase of metal concentrations was directly associated with the export of these metals. The concentrations of twelve different metals have been evaluated on various occasions in Saldanha Bay; however, the overall fluctuations in concentrations are similarly reflected by several key metals throughout the time period. For the purposes of this report, four metals that have the greatest potential impact on the environment were selected from the group. These are cadmium (Cd), lead (Pb), copper (Cu) and nickel (Ni).

The earliest data on metal concentrations in Saldanha Bay were collected in 1980, prior to the time at which iron ore concentrate was first exported from the ore terminal. The sites sampled were 2 km north of the Multi-purpose Quay (Small Bay) and 3 km south of the Multi-purpose Quay (Big Bay) and metals reported on included lead (Pb), cadmium (Cd) and copper (Cu). Concentrations of these metals in 1980 were very low, well below the sediment toxicity thresholds. Subsequent sampling of metals in Saldanha Bay (for which data is available) only took place nearly 20 years later in 1999. During the period between these sampling events, a considerable volume of ore had been exported from the Bay, extensive dredging had been undertaken in the Bay (1997/98), and the Mussel Farm and the small craft harbour (Yacht Club Basin) had been established (1984). As a result of these activities, the concentrations of metals in 1999 were very much higher (up to 60 fold higher) at all stations monitored. This reflects the accumulation of metals in the intervening 20 years, much of which had recently been re-suspended during the dredging event and had settled in the surficial (surface) sediments in the Bay. Concentrations of most metals in Saldanha Bay were considerably lower in the period 2000-2010, although nowhere near levels measured in 1980. This closely mirrors changes in the proportion of mud in the sediments, and most likely reflects the removal of fine sediments together with the trace metal contaminants from the Bay, by wave and tidal action. Monitoring surveys between 2001 and 2011 indicates that with a few exceptions, metal concentrations had continued to decrease in Saldanha Bay and were much reduced from the exceptionally high concentrations recorded in 1999 and 2000.

5.3.3.2 Analysis and results for 2012

Sediments were analysed for concentrations of aluminium (Al), iron (Fe), copper (Cu), cadmium (Cd), nickel (Ni), lead (Pb) and zinc (Zn). For the purpose of this report only the data for Cd, Cu, Pb, Ni and Fe are presented as these are the metals deemed to pose the greatest threat to the health of the marine environment. Metals in the sediments were analysed by Scientific Services using a Nitric Acid (HNO_3) / Perchloric Acid ($HClO_3$)/ Hydrogen Peroxide (H_2O_2)/ Microwave digestion and JY Ultima Inductively Coupled Plasma Optical Emission Spectrometer. The concentrations of metals in the sediments of Saldanha Bay and Langebaan Lagoon in 2012 are shown in Table 5.3.

Table 5.3. Concentrations (MG/KG) of metals in sediments collected from Saldanha Bay in 2012.

	Sample	Al	Fe	Cd	Cu	Ni	Pb
***ERL Guideline (mg/kg)**		-	-	**1.2**	**34**	**20.9**	**46.7**
Small Bay (SB)	SB1	16555	11462	**2.4**	**40.8**	12.6	20.5
	SB2	2025	2761	0.0	1.1	2.2	5.6
	SB3	2551	3276	0.0	4.1	2.4	18.1
	SB8	2698	3118	0.0	0.8	2.1	4.8
	SB9	3925	5923	0.1	2.0	3.5	5.7
	SB10	1692	2393	0.0	1.1	1.4	5.6
	SB14	8140	8711	0.7	13.5	7.4	**46.3**
	SB15	24256	18792	**3.2**	14.6	19.0	7.0
	SB16	3097	3995	0.2	2.6	2.8	3.5
	SB42	2122	2899	0.0	1.2	1.5	7.2
	SB43	7446	7738	0.7	6.0	7.5	7.5
	SB44	3664	3383	0.4	5.6	3.0	5.9
Big Bay (BB)	BB20	3159	3151	0.4	2.6	3.4	1.7
	BB21	3108	3666	0.0	1.0	2.6	2.7
	BB22	3547	4133	**1.3**	2.9	4.9	4.8
	BB25	1352	1555	0.0	0.0	1.2	1.4
	BB26	2802	3128	0.1	0.4	2.0	2.0
	BB29	3797	4040	0.1	1.9	2.7	5.8
	BB30	902	1076	0.0	0.0	0.2	0.1
Donkergat	D1	4363	4340	0.4	1.6	3.6	6.8
	D2	4238	4830	0.0	0.7	3.5	3.9
Salamander Bay	S1	3209	3973	0.1	3.4	1.9	12.3
	S2	4163	3902	0.1	1.6	3.7	2.4
Langebaan Lagoon (LL)	LL31	2439	3020	0.0	0.0	2.2	1.8
	LL32	1965	3716	0.0	0.0	1.8	2.3
	LL33	1504	2267	0.0	0.3	2.2	0.9
	LL34	2103	2547	0.0	0.3	2.7	0.5
	LL37	1969	1939	0.0	0.0	1.5	0.3
	LL38	3983	4590	0.1	0.8	6.3	3.9
	LL39	1220	1749	0.0	0.0	0.9	0.8
	LL40	1476	1548	0.0	0.0	1.2	0.5
	LL41	2253	2029	0.0	0.0	1.7	0.5

***Effects Range Low guideline stipulated by NOAA at which toxic effects are likely to be observed in sensitive marine species.**
DL = Detection Limit

The ERL guideline for Cd was exceeded at the Yacht Club Basin and at two sites on either side of the ore jetty. The ERL guideline for Cu was exceeded at the Yacht Club Basin, while the ERL guideline for lead was exceeded adjacent to the multi-purpose terminal. The concentrations of Cd, Cu, Ni and Pb were below the ERL guideline at all other sites within the Bay and Lagoon. Comparing these results to the ERL guidelines provides a useful indication of areas in the Bay that may be toxic to living organisms. However this comparison does not provide an indication of whether the build-up of a trace metal is due directly to anthropogenic contamination of the environment with that particular metal or whether it is an indirect result of other environmental perturbations, for example a high concentration of mud.

The concentrations of metals in sediments are affected by grain size, total organic content and mineralogy. Since these factors vary in the environment, one cannot simply use high absolute concentrations of metals as an indicator for anthropogenic metal contamination. Metal concentrations are therefore commonly normalized to a grain-size parameter or a suitable substitute for grain size, and only then can the correct interpretation of sediment metal concentrations be made (Summers *et al*. 1996). A variety of sediment parameters can be used to ***normalize metal concentrations***, and these include Al, Fe and total organic carbon. Aluminium or iron are commonly used as normalisers for trace metal content as they ubiquitously coat all sediments and occur in proportion to the surface area of the sediment (Gibbs 1994); they are abundant in the earth's crust and are not likely to have a significant anthropogenic source (Gibbs 1994, Summers *et al.* 1996); and ratios of metal concentrations to Al or Fe concentrations are relatively constant in the earth's crust (Summers *et al.* 1996). Normalized metal/aluminium ratios can be used to estimate the extent of metal contamination within the marine environment, and to assess whether there has been enrichment of metals from anthropogenic activities. In this study, metal concentrations were normalized against (divided by) aluminium and not iron due to the known anthropogenic input of iron from the iron ore quay and industrial activity in Saldanha Bay. The normalized concentrations of trace metals at the sites sampled in 2012 were used to interpolate the normalized metal concentrations over the full extent of the Bay and Lagoon using GIS software. These interpolations provide an indication of the spatial variation in the extent of contamination of the various trace metals in the Bay and the Lagoon.

Several studies have been conducted to determine the relative abundance of metals in crustal materials (Taylor, 1964; Taylor and McLennan, 1981; Martin and Whitfield, 1983 and Turekin and Wedepohl, 1961). The results of these studies (summarized in Table 1.5.4) are useful for the assessment of the extent of metal contamination resulting from anthropogenic activity.

Table 1.5.4. Relative abundance of metals in crustal materials (Metal:Aluminum ratio x 10^{-4}) (Adapted from Windom 1988).

	Average crust	Upper crust
Cd:Al	0.24	-
Cu:Al	6.7	3
Ni:Al	9.1	2.4
Pb:Al	1.5	1.8

Another means of evaluating the extent of contamination of sediments by metals is to calculate the extent to which the sediments have been enriched by such metals since development started. ***Metal enrichment factors*** were calculated for Cd, Pb and Cu relative to the 1980 sediments (Table 5.5). Unfortunately historic enrichment factors could not be calculated for Ni as no data was available for this element in 1980. Enrichment factors equal to (or less than) 1 indicate no elevation relative to pre-development sediments, while enrichment factors greater than 1 indicate a degree of metal enrichment within the sediments over time. Enrichment factors were not calculated for Langebaan Lagoon since all concentrations were below the detection limits.

The extent of contamination for Cd, Cu, Ni and Pb is assessed and discussed below using both the normalized metal concentrations and the metal enrichment factors.

5.3.3.2.1 Cadmium

The normalized Cd values measured in 2012 exceeded that which is expected for average crustal materials at sites in the vicinity of the yacht club basin, mussel farm, ore jetty, multipurpose terminal and at the entrance to Big Bay. The normalized Cd value at sites in the northern extent of Small Bay along the shore of Big Bay and within the Lagoon neared that expected for crustal material. This suggests that there may be a source of cadmium pollution affecting areas within Small Bay and Big Bay. Cd is a trace metal used in electroplating, in pigment for paints, in dyes and in photographical process. The likely sources of Cd to the marine environment are in emissions from industrial combustion process, from metallurgical industries, from road transport and waste streams (OSPAR 2010). A likely point source for Cd contamination in the marine environment is that of stormwater drains. Cd is toxic and liable to bioaccumulation, and is thus a concern for both the marine environment and human consumption (OSPAR 2010). It is unlikely that the contamination of Cd in the Bay is a result of storm water drainage given the area in which elevated Cd: Al ratios are experienced, and, given the spatial pattern, it is more likely that the Cd contamination is resulting from shipping and boating. The areas where this is particularly concerning include site SB1 (yacht club basin), site SB15 (adjacent to ore jetty on Small Bay side) and BB22 (adjacent to ore jetty on Big Bay side) as the level of contamination at these sites exceeds the ERL limits. Furthermore the enrichment values for these three sites since 1980 is very high indicating significant contamination of these areas with Cd since 1980.

5.3.3.2.2 Copper

The normalized Cu values measured in 2012 exceeded that which is expected for average crustal materials at all sites in Small Bay and the sites on the northern and western side of Big Bay. Normalized Cu values along the shore of Big Bay and within the Lagoon neared that expected for crustal material. This suggests that there may be a source of copper pollution affecting Small Bay and most of Big Bay. Copper (Cu) is used as a biocide in antifouling products as it very effective for killing marine organisms that attach themselves to the surfaces of boats and ships. Anti-fouling paints release Cu into the sea and can make a significant contribution to Cu concentrations in the marine environment (Clark 1986). The areas with elevated normalized Cu values also correspond with those with high levels of boat traffic. It is thus likely that anti-fouling paints used on boats may have been contributing Cu to the system. It must be noted that no sites are situated in close proximity to Mykonos and the yacht club in Langebaan Lagoon. It is possible that both these areas have also been contaminated by Cu. The Cu concentration at the Yacht Club Basin in Saldanha Bay is of concern given that it exceeds the ERL guideline, the normalised value indicates the pollution source is anthropogenic and the enrichment factor is alarmingly high.

5.3.3.2.3 Nickel

The normalized Ni values measured in 2012 exceeded that which is expected for average crustal materials in patches within the Lagoon and Saldanha Bay. Nickel is introduced to the environment by both natural and anthropogenic means. Natural means of contamination include wind-blown dust derived from the weathering of rocks and soils, fires and vegetation (Cempel & Nickel 2006). Common anthropogenic sources include the combustion of fossil fuels and the incineration of waste and sewerage (Cempel & Nickel 2006). Contamination of the Bay by Nickel is not of great concern though, as Nickel concentrations are well below the ERL guideline limits.

5.3.3.2.4 Lead

The normalized Pb values measured in 2012 exceeded that which is expected for average crustal materials at all sites in Saldanha Bay (with the exception of one southern Big Bay site) and extending much of the way south into the Lagoon. This suggests that there anthropogenically derived Pb is being added to the system. This is a worldwide problem and is generally associated with mining, smelting and the industrial use of Pb (OSPAR 2010). Pb is a persistent compound which is toxic aquatic organism and mammals, and thus the contamination is of concern for the marine environment and human consumption (OSPAR 2010). The area adjacent to the multi-purpose terminal had the highest normalized Pb values indicating that this area is subject to high levels of lead pollution. Indeed the enrichment factor for the site nearest to the multi-purpose terminal was very high (57.9) and the concentration of lead at this site exceeded the ERL.

Table 5.5. Enrichment factors for Cadmium, Copper and Lead in sediments collected from Saldanha Bay in 2012 relative to sediments from 1980

	Sample	Cd	Cu	Pb
	1980 average	**0.08**	**0.41**	**0.80**
Small Bay	SB1	**32.29**	**99.46**	**25.64**
	SB2	-0.40	2.61	6.70
	SB3	0.55	**10.09**	**22.64**
	SB8	-0.05	2.066	6.04
	SB9	0.81	4.86	7.11
	SB10	0.00	2.58	7.04
	SB14	9.51	33.00	**57.91**
	SB15	**42.23**	**35.63**	8.72
	SB16	2.73	6.30	4.41
Big Bay	BB20	5.09	6.29	2.12
	BB21	-0.33	2.52	3.34
	BB22	**16.76**	7.00	5.95
	BB25	-0.25	0.00	1.71
	BB26	1.72	0.86	2.48
	BB29	1.75	4.63	7.25
	BB30	0.00	0.00	0.18

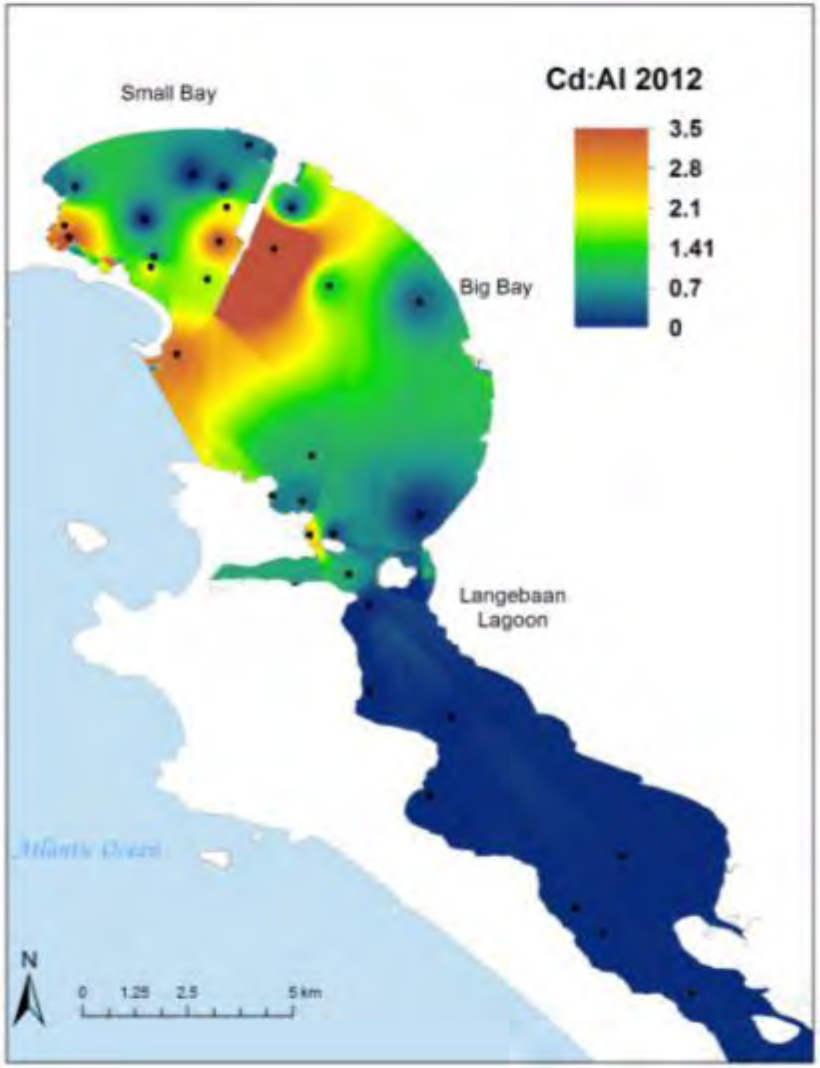


Figure 5.33. Spatial interpolation of normalized cadmium values based on values measured in Saldanha Bay and Langebaan Lagoon in 2012 (normalised using Al) (the average crust value = 0.24).

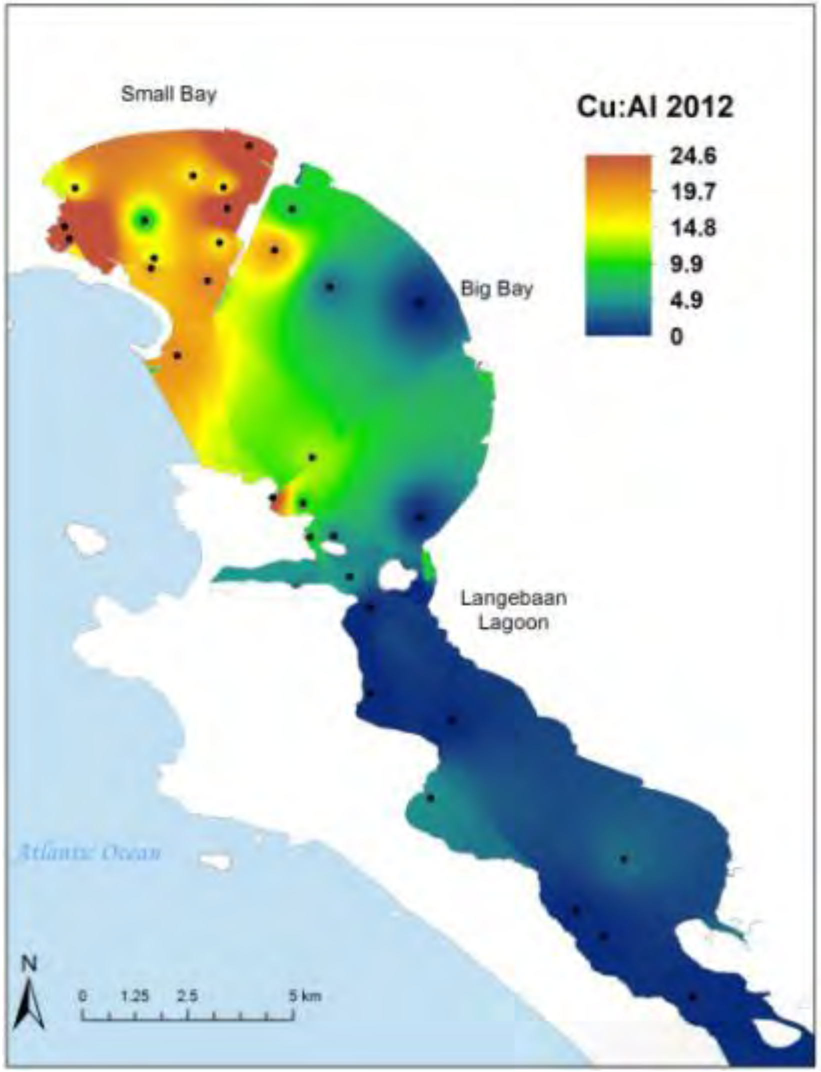


Figure 5.34. Spatial interpolation of normalized copper values based on values measured in Saldanha Bay and Langebaan Lagoon in 2012 (normalized using Al). (The average crust value = 6.7).

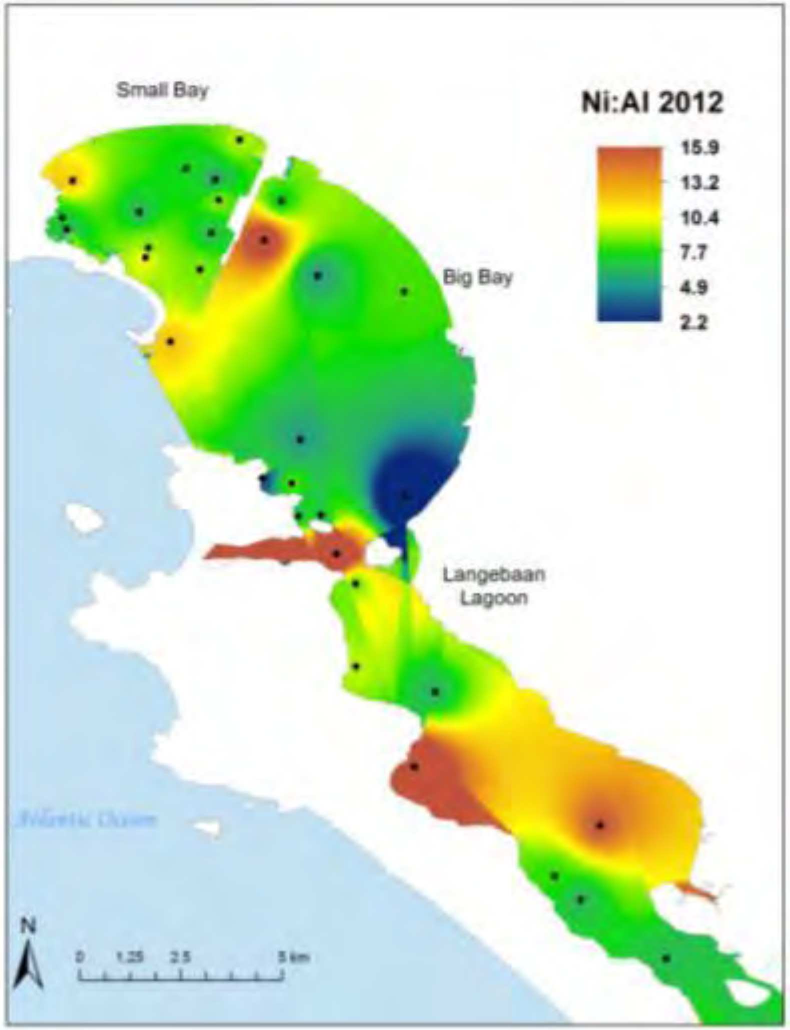


Figure 5.35. Spatial interpolation of normalized nickel values based on values measured in Saldanha Bay and Langebaan Lagoon in 2012 (normalised using Al). (the average crust value = 9.1).

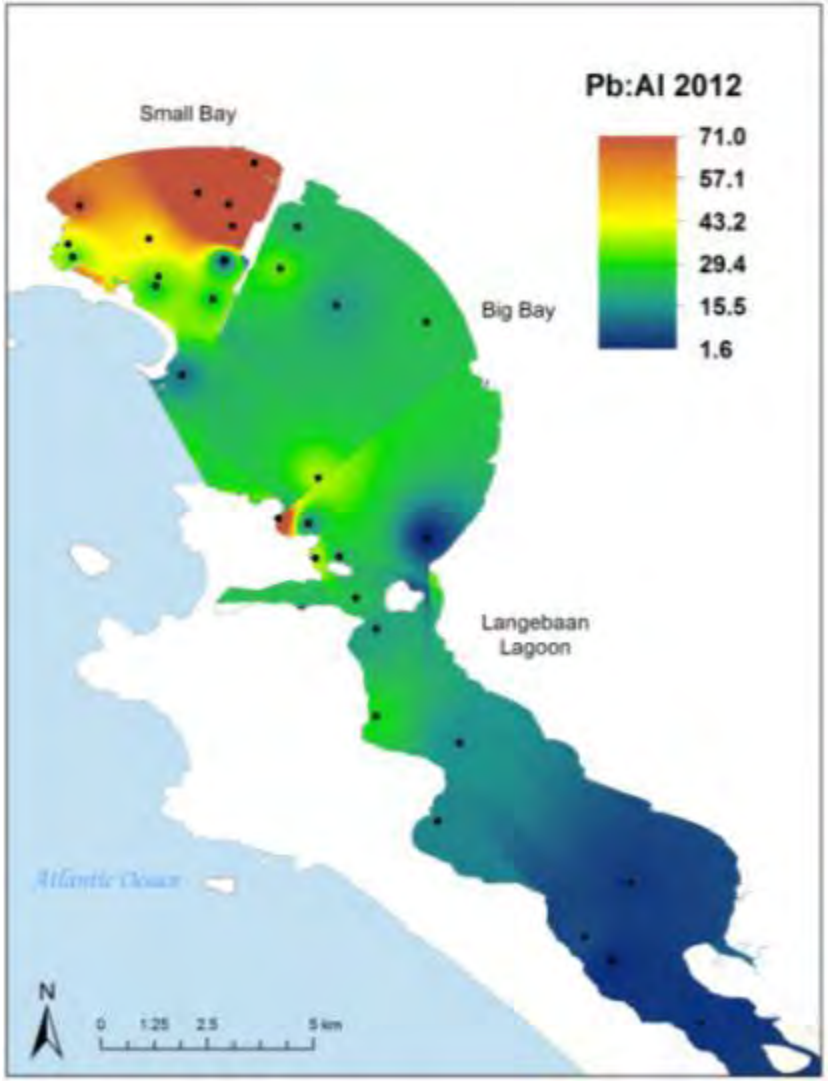


Figure 5.36. Spatial interpolation of normalized lead values based on values measured in Saldanha Bay and Langebaan Lagoon in 2012 (normalised using Al). (the average crust value = 1.5).

5.3.3.3 Temporal variation

The temporal variation in the concentration of trace metals in the most heavily contaminated areas (Small Bay and along the ore jetty in Big Bay) relative to the ERL guideline is discussed below.

5.3.3.3.1 Cadmium

There was a considerable increase in the concentrations of Cadmium detected in the sediments of Saldana Bay between 1980 and 1999. In 1999, the levels of cadmium recorded at the Mussel Farm, the Yacht Club Basin and the Channel End of the Ore Terminal exceeded the ERL toxicity threshold of 1.2 mg/kg established by NOAA (Figure 5.37). Cadmium concentrations have shown a progressive and dramatic decrease in the period 1999-2010, however, the results of 2011 and 2012 indicated that cadmium concentrations were once again increasing in the Yacht Club Basin and on the Big Bay side of the ore jetty. Of particular concern is the yacht club basin were cadmium concentrations have exceeded the ERL threshold in 2011 and 2012.

5.3.3.3.2 Copper

The total concentration of copper in the sediments of the sites assessed temporally has remained below the ERL threshold consistently since 1980, with the exception of the yacht club basin which exceeded the ERL in 1999, 2008 and between 2010 and 2012. All sites showed an increase in the copper concentration between 1980 and 1999. No clear pattern has emerged since though, with some fluctuations between years. The concentration of copper appeared to be relatively stable between 2001 and 2012 at all six sites.

5.3.3.3.3 Nickel

The concentration of nickel was the highest at the yacht club basin and the mussel farm sites in 1999 where it exceeded the ERL threshold. Since 1999, nickel concentrations have decline markedly at both sites, never again exceeding the ERL threshold. Peak nickel concentration at the remaining four sites was observed in 2000, though concentrations did not exceed the ERL threshold. Since 2000, levels of Nickel have declined at all four of these sites. The 2012 results indicated a slight increase in the concentration of nickel at all six sites, though it remains well below the ERL threshold value.

5.3.3.3.4 Lead

The concentration of lead peaked and exceeded the ERL threshold at the yacht club basin and mussel farm site in 1999. The concentration of lead at these sites has not exceeded the ERL level since this time. The concentrations of lead at either end of the ore jetty and at the site in Big Bay have fluctuated over the last 12 years with no apparent pattern and have remained relatively low and well below the ERL threshold. The concentration of lead site adjacent to the multi-purpose terminal has frequently exceeded the ERL threshold over the last 12 years. Fluctuations in the concentration of lead at this site do not follow any clear pattern though. This result suggests that industrial and shipping activities taking place at the multi-purpose terminal are contaminating the adjacent marine environment with lead.

5.3.3.3.5 Iron

The temporal variations in the concentration of iron in sediments around the ore terminal in Saldanha Bay is shown in Figure 5.41. The concentration of iron increased between 1999 and 2004 at sites 14 and 15 which are in closest proximity to and on the downwind side (of the predominant southerly winds) of the multi-purpose quay. This may have been due to increases in volumes of ore handled or increases in losses into the sea over this period, or simply reflects accumulation of iron in the sediments over time. There was a reduction in the concentration of iron in the sediments at most sites on the Small Bay side of the ore terminal between 2004 and 2010. Dredging took place at the multi-purpose quay in 2007 and the removal of iron rich sediment at Site 15 is probably the reason for the dramatic decrease in iron concentration recorded at this station between 2008 and 2009 sampling. Sediment iron concentration at this site did increase to the highest levels yet recorded in 2009, but decreased again in 2010 samples. The 2011 survey revealed that iron concentrations had increased at most sites around the ore terminal despite reductions in the mud contents at all sites. This suggests that fluctuations in iron content are a result of iron inputs rather than the flushing experienced at the sites.

Transnet has implemented a number of new dust suppression measures in recent years (SRK 2009, Viljoen *et al.* 2010). Dust suppression mitigation measures implemented since mid-2007 include conveyer covers, a moisture management system, chemical dust suppression, surfacing of roads and improved housekeeping (road sweeper, conveyer belt cleaning, vacuum system, dust dispersal modelling and monitoring) amongst others. The volume of ore handled at the bulk quay has increased from around 4.5 million tons per month during 2007-2008 to around 6.5 million tons during 2009-2010 (~50% increase), yet the concentration of iron in the sediments at sites adjacent to the ore terminal remained fairly stable or decreased between 2009 and 2010. Relatively small fluctuations in the concentration of iron were seen at 5 of the 6 site between 2010 and 2012. This does suggest that the improved dust control methods implemented since 2007 have been successful in reducing the input to the marine environment. However the concentration of iron at one site increased very dramatically in 2012. The reasons for the increase at this site but not at any of the other sites is not unclear. Ongoing monitoring of sediment iron concentration may reveal whether the reduction seen at all other sites can be sustained at the anticipated higher volumes of ore handling in the near future.

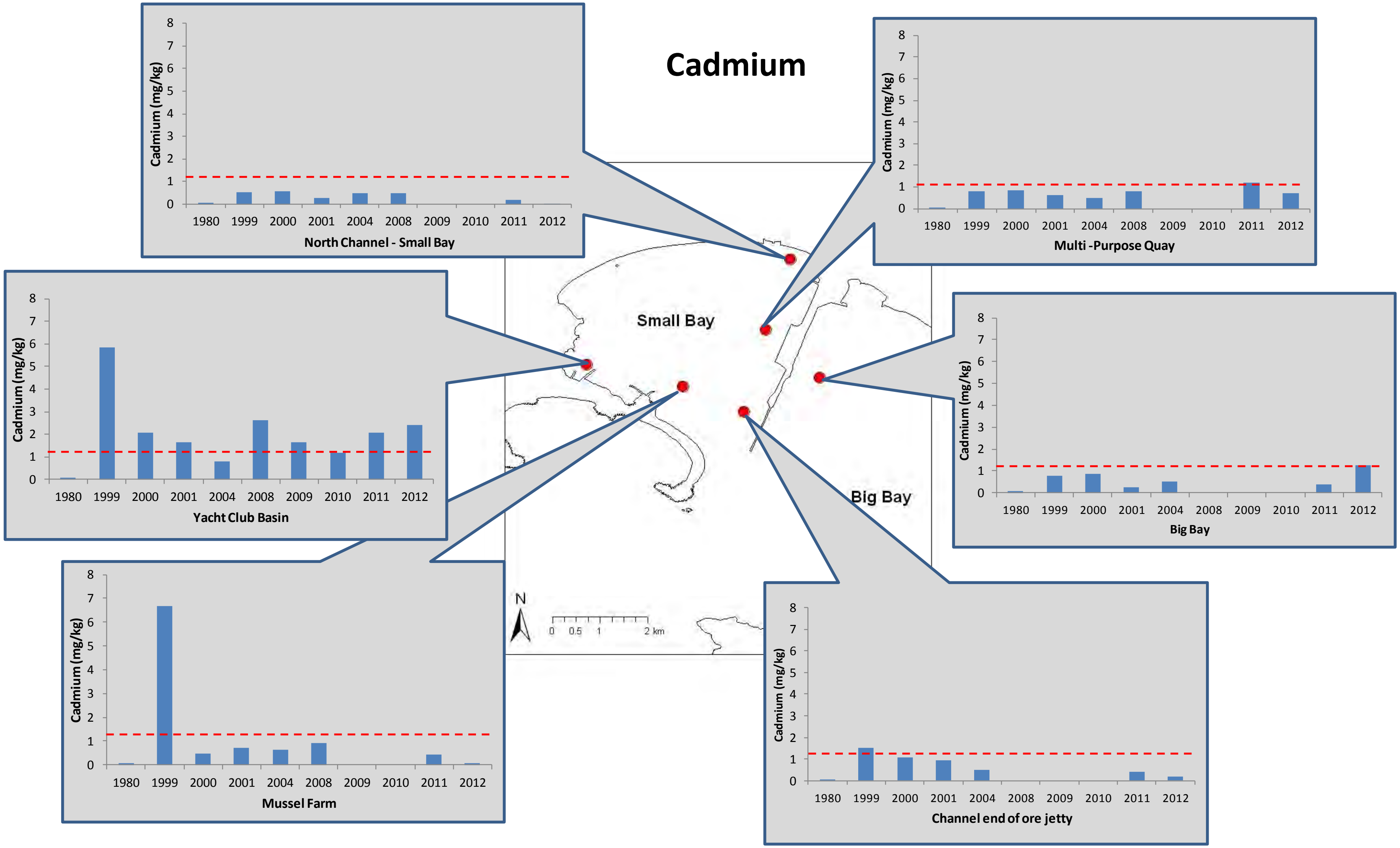


Figure 5.37. Concentrations of Cadmium (Cd) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2012. Dotted lines indicate Effects Range Low values for sediments

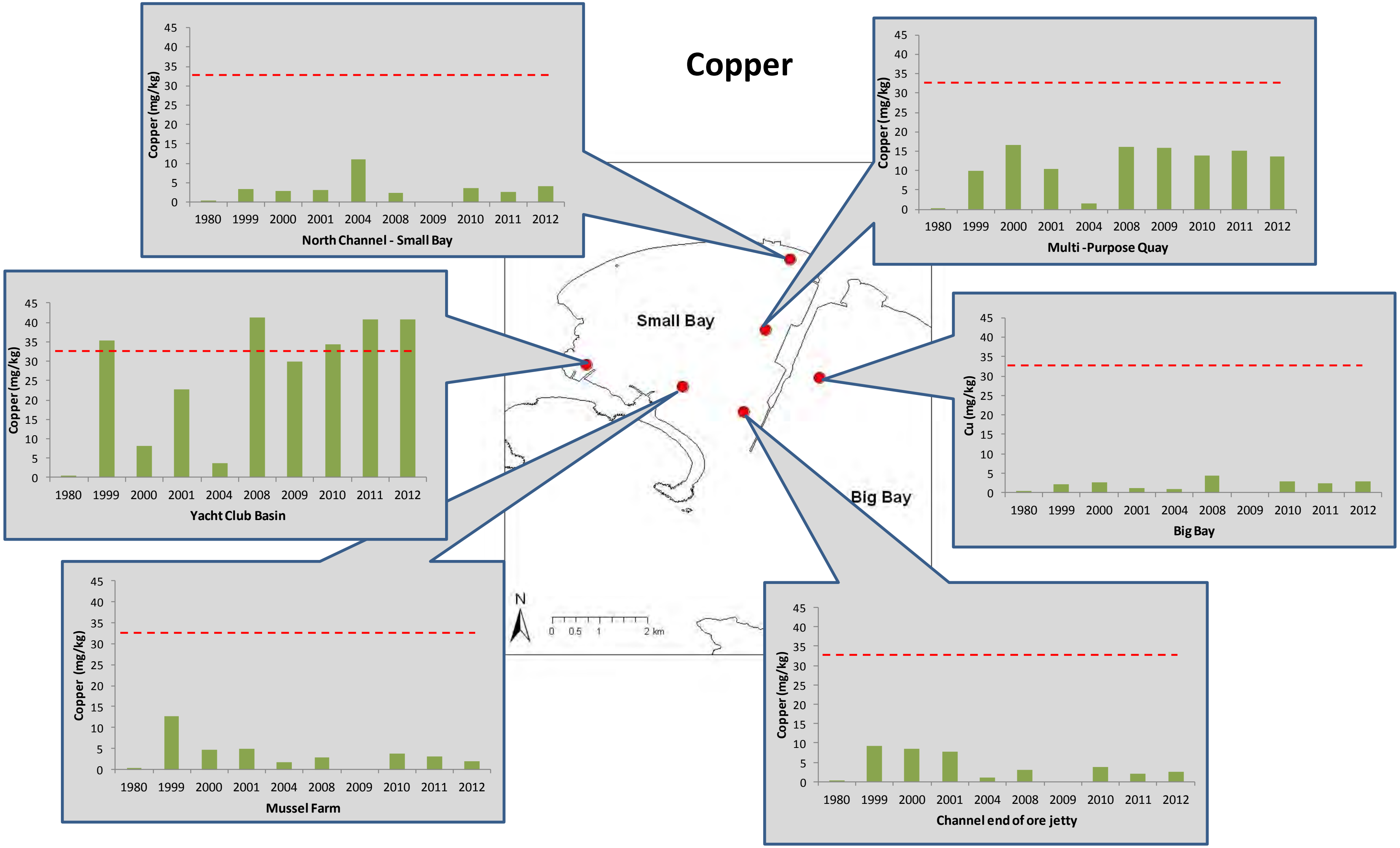


Figure 5.38. Concentrations of Copper (Cu) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2012. Dotted lines indicate Effects Range Low values for sediments

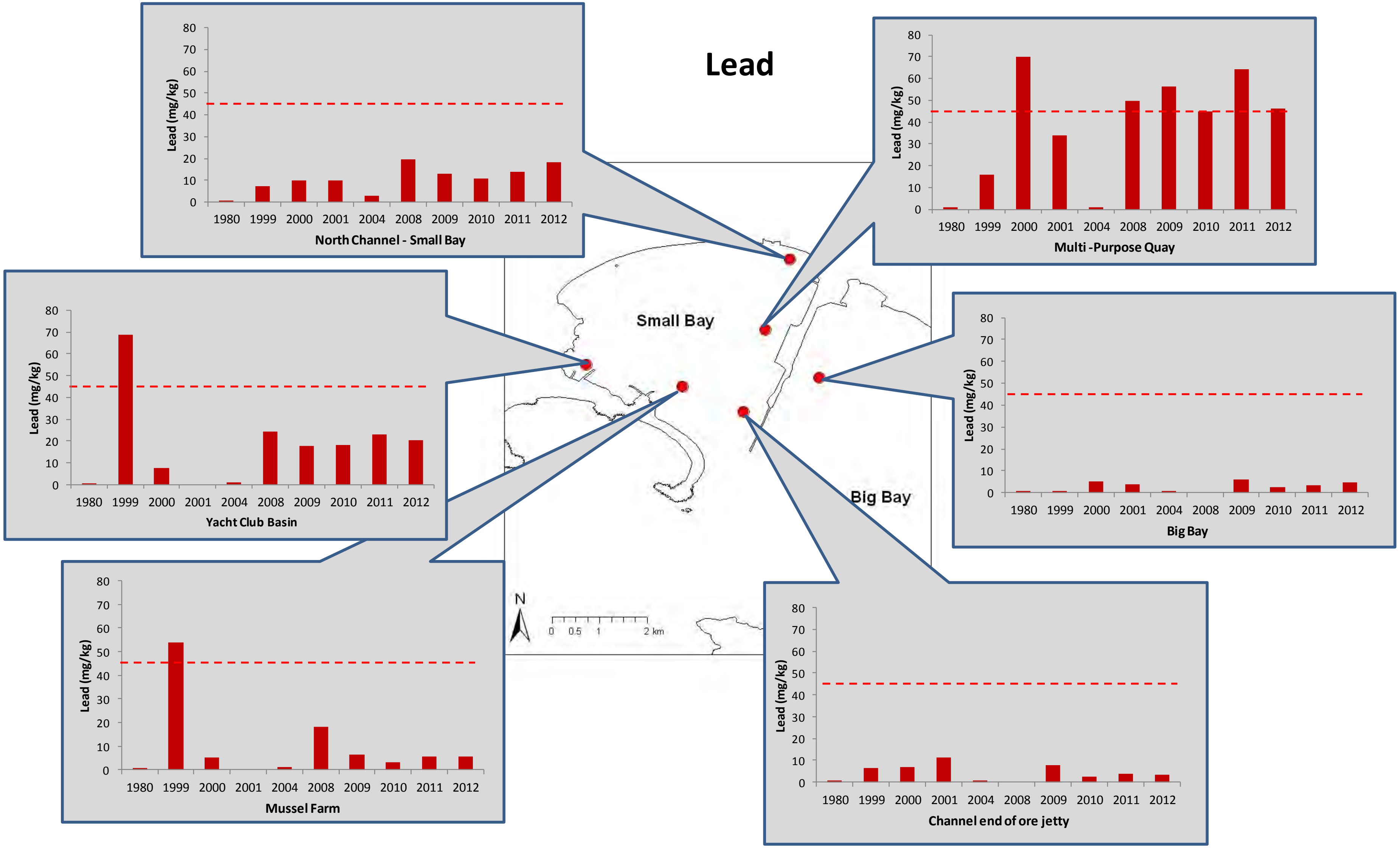


Figure 5.39 Concentrations of Lead (Pb) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2012. Dotted lines indicate Effects Range Low values for sediments

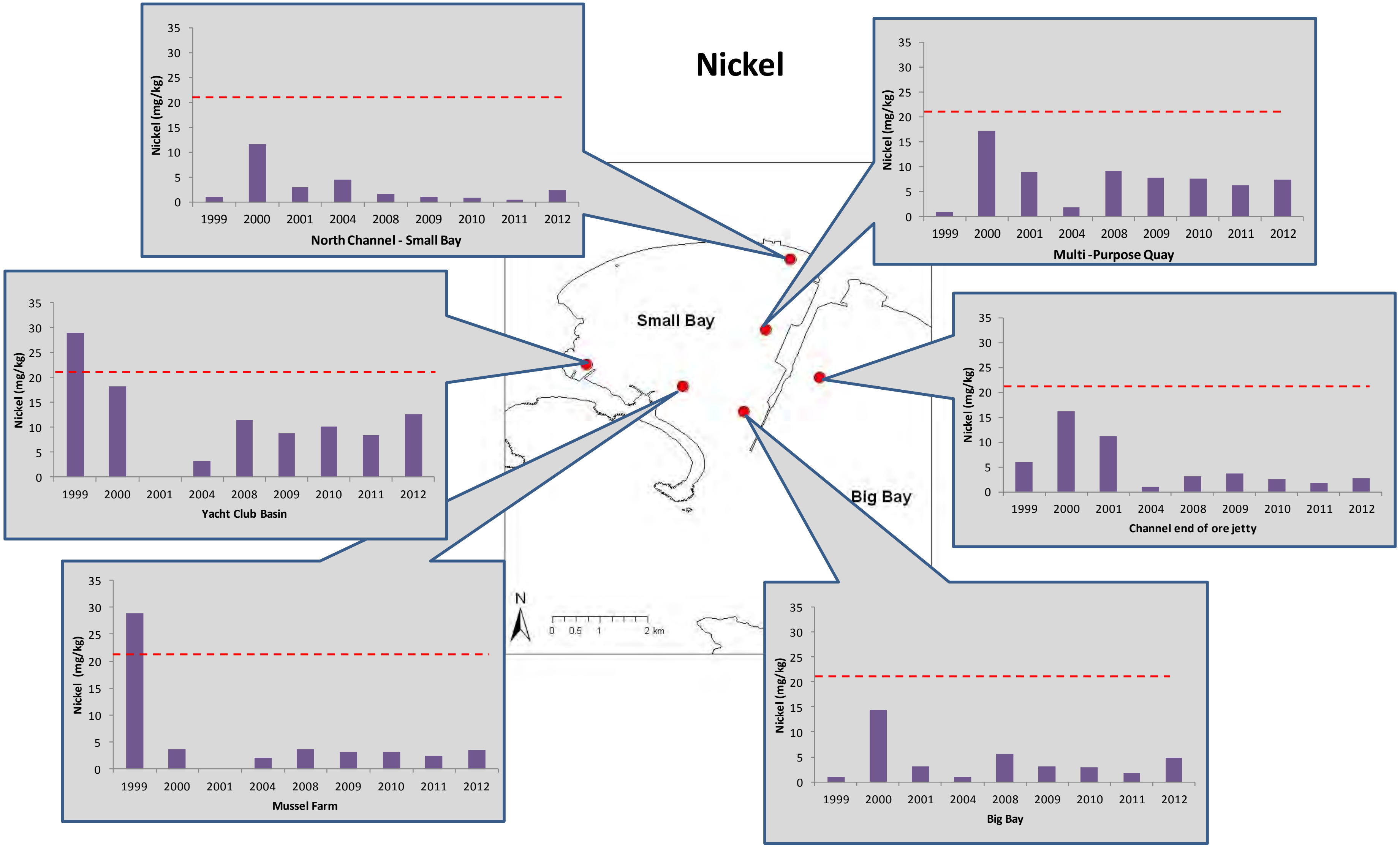


Figure 5.40. Concentrations of Nickel (Ni) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2012. Dotted lines indicate Effects Range Low values for sediments

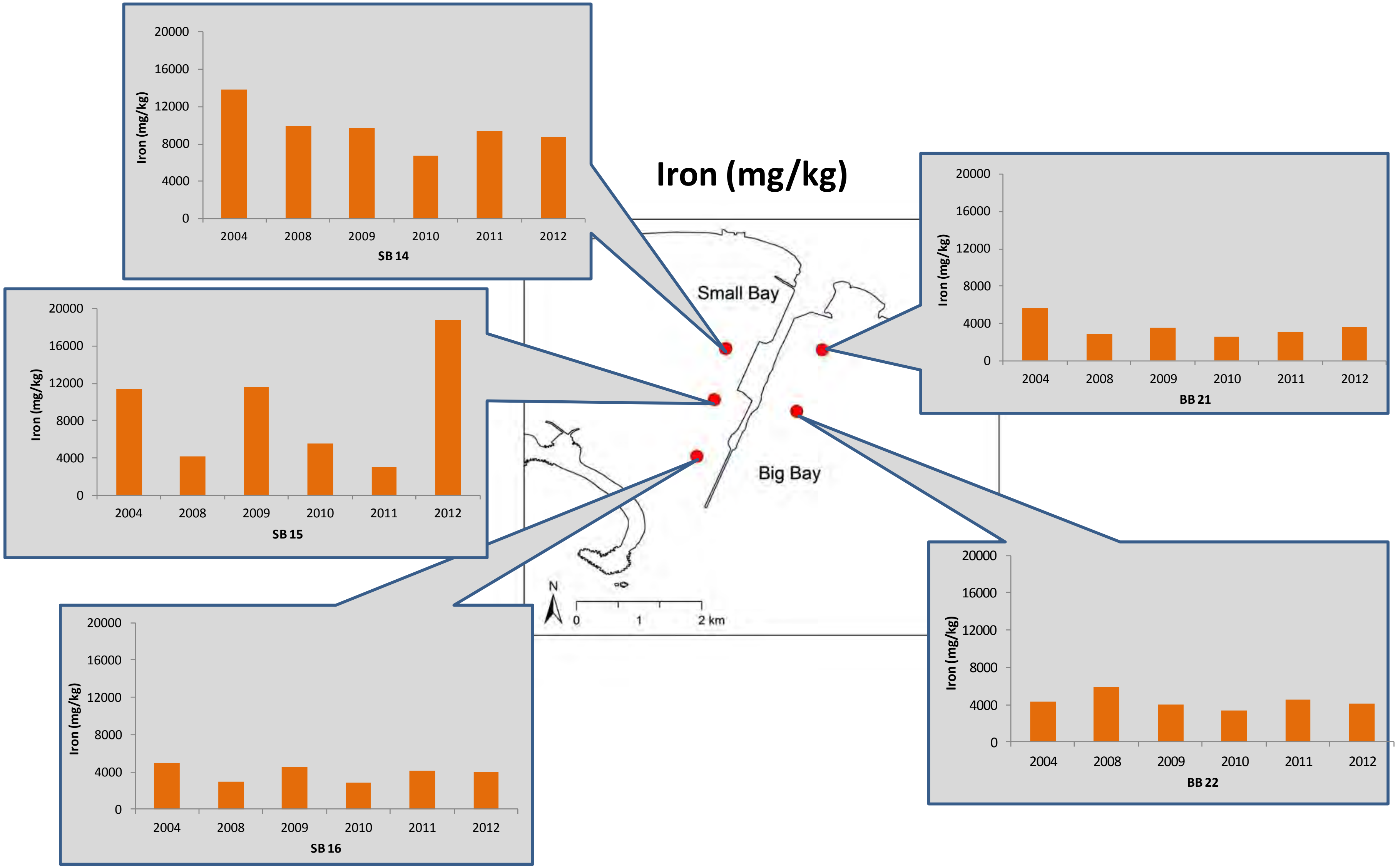


Figure 5.41. Concentrations of Iron (Fe) in mg/kg recorded at five sites in Saldanha Bay between 2004 and 2012.

5.3.4 Hydrocarbons

Poly-aromatic hydrocarbons (PAH) (also known as polynuclear- or polycyclic-aromatic hydrocarbons) are present in significant amounts in fossil fuels (natural crude oil and coal deposits), tar and various edible oils. They are also formed through the incomplete combustion of carbon-containing fuels such as wood, fat and fossil fuels. PAHs are one of the most wide-spread organic pollutants and they are of particular concern as some of the compounds have been identified as carcinogenic for humans (Nikolaou *et al*. 2009). PAHs are introduced to the marine environment by anthropogenic means (combustion of fuels) and by natural means (oil welling up or products of biosynthesis) (Nikolaou *et al.* 2009). PAHs in the environment are found primarily in soil, sediment and oily substances, as opposed to in water or air, as they are lipophilic (mix more easily with oil than water) and the larger particles are less prone to evaporation. The highest values of PAHs recorded in the marine environment have been in estuaries and coastal areas, and in areas with intense vessel traffic and oil treatment (Nikolaou *et al*. 2009).

Samples collected in Saldanha Bay in 1999 were analysed for the presence of hydrocarbons. No PAHs were detected in the samples, but low levels of contamination by aliphatic (straight chain) molecules, which pose the lowest ecological risk, were detected. This suggested that the main source of contamination is the spilling and combustion of lighter fuels from fishing boats and recreational craft (Monteiro et al. 1999).

Sediment samples were collected at five sites in the vicinity of the ore quay and in April 2010 and tested for hydrocarbon contamination. The total petroleum hydrocarbon contamination for all sites, with the exception of SB14, fell below the ERL value stipulated by the NOAA. The total petroleum hydrocarbon concentration at site SB14 was equal to the ERL value. Sediment samples from the same five sites were analysed by the CSIR for hydrocarbon content in 2011. No hydrocarbons were detected at a detection limit of 20 mg/kg in 2011. The results from the 2012 survey indicate that there has been a substantial increase in TPH levels such that the ERL threshold was exceeded at all 5 sites surveyed (Table 5.3). It is not clear if this is a real result or reflects a change in methods used to analyse the samples. (Note that samples were analysed by CSIR Analytical Laboratories in 2011 and 2012 but reported detection levels have been reduced.)

Table 5.6. Total Petroleum Hydrocarbons (mg/kg) in sediment samples from five stations in Saldanha.

	Total Petroleum Hydrocarbons (mg/kg)
ERL*	***4***
ERM**	***44.7***
SB14	34
SB15	35
SB16	24
BB21	20
BB22	17

***Effects Range Low guideline stipulated by NOAA at which toxic effects are likely to be observed in sensitive marine species.**

6 AQUATIC MACROPHYTES IN LANGEBAAN LAGOON

Three distinct intertidal habitats exist within Langebaan Lagoon: seagrass beds, such as those of the eelgrass *Zostera capensis;* salt marsh dominated by cordgrass *Spartina maritime* and Sarcocornia perennis; and unvegetated sandflats dominated by the sand prawn, *Callianassa krausii* and the mudprawn *Upogebia capensis* (Siebert and Branch 2005a,b). Sand and mud pawns are considered ecosystem engineers as their feeding and burrowing activities modify the local environmental conditions, which in turn modify the composition of the faunal communities (Rhoads and Young 1970, Woodin 1976, Wynberg and Branch 1991). Seagrass beds and salt marshes perform an opposite and antagonistic engineering role to that of the sand and mud prawns as the root-rhizome networks of the seagrass and saltmarsh plants stabilize the sediments (Siebert and Branch 2005a). In addition, the three dimensional leaf canopies of the seagrass and saltmarsh plants reduce the local current velocities thereby trapping nutrients and increasing sediment accretion (Kikuchi and Peres 1977; Whitfield 1989, Hemmingra and Duarte 2000). The importance of seagrass and saltmarsh beds as ecosystem engineers has been widely recognized. The increased food abundance, sediment stability, protection from predation and habitat complexity offered by seagrass and saltmarsh beds provide nursery areas for many species of fish and invertebrates and support, in many cases a, higher species richness, diversity, abundance and biomass of invertebrate fauna compared to unvegetated areas (Kikuchi & Peres 1977, Whitfield 1989, Hemmingra and Duarte 2000, Heck *et al*. 2003, Orth *et al*. 2006, Siebert and Branch 2007). Seagrass and saltmarsh beds are also important for waterbirds some of which feed directly on the shoots and rhizomes, forage amongst the leaves or use them as roosting areas at high tide (Baldwin & Lovvorn 1994, Ganter 2000, Orth *et al*. 2006).

Figure 6.1. Seagrass (black) and saltmarsh (green) near Bottelary in Langebaan Lagoon. Source: Google Earth.

6.1 Long term changes in seagrass in Langebaan Lagoon

Seagrass beds are particularly sensitive to disturbance and are declining around the world at rates comparable to the loss of tropical rainforests, placing them amongst the most threatened ecosystems on the planet (Waycott *et al*. 2009). The loss of seagrass beds is attributed primarily to anthropogenic impacts such as coastal eutrophication, alterations to food webs caused by the overexploitation of predatory fish, and modified sediment dynamics associated with coastal and harbour development (Waycott *et al*. 2009). The loss of seagrass meadows has been shown to have profound implications for the biodiversity associated with them, including loss of invertebrate diversity, fish populations, that use the sheltered habitat as nurseries, and waterbirds, that use the seagrass meadows as foraging grounds during their non-breeding period (Hughes *et al*. 2002).

Long-term changes in seagrass beds in Langebaan Lagoon have been investigated by Angel *et al*. 2006 and Pillay *et al*. (2010). Angel *et al*. (2006) focused on long term trends at Klein Oesterwal and Bottelary, and was able to show that the width of the *Z. capensis* bed changed substantially between 1972 and 2004, with three major declines evident in this period (Figure 6.2). The first occurred in the late 1970s, and was followed by a slow recovery in the early 1980's, the second occurred between 1988 and 1993 and the third between 2002 and 2004 (Angel *et al*. 2006). Mirroring this decline were the striking fluctuations of the small endemic limpet *Siphonaria compressa*, which lives on the leaves of *Z. capensis* and is completely dependent on the seagrass for its survival. The densities of *S. compressa* collapsed twice in this period to the point of local extinction, corresponding with periods of reduced seagrass abundance (Figure 6.2). At Bottelary, the width of the seagrass bed and densities of *S. compressa* followed the same pattern as at Klein Oesterwal, with a dramatic collapse of the population between 2002 and 2004, followed by a rapid recovery in 2005 (Angel *et al*. 2006). The first decline in seagrass cover coincided with blasting and dredging operations in the adjacent Saldanha Bay, but there is no obvious explanation for the second decline (Angel *et al*. 2006).

Pillay *et al*. (2010) documents changes in seagrass *Zostera capensis* abundance at four sites in the Lagoon – Klein Oesterwal, Oesterwal, Bottelary and the Centre banks using a series of aerial photographs covering the period 1960 to 2007. During this time the total loss of *Z. capensis* amounted to 38% or a total of 0.22 km^2 across all sites. The declines were most dramatic at Klein Oesterwal where close to 99% of the seagrass beds were lost during this period, but were equally concerning at Oesterwal (82% loss), Bottelary (45% loss) and Centre Bank (18% loss) (Pillay *et al*. 2010). Corresponding changes were also observed in densities of benthic macrofauna at these sites, with species that were commonly associated with Zostera beds such as the starfish *Parvulastra exigua* and the limpets *Siphoneria compressa* and *Fisurella mutabilis* and general surface dwellers such as the gastropods *Assiminea globules*, *Littorina saxatilis*, and *Hydrobia* sp. declining in abundance, while those species that burrowed predominantly in unvegetated sand, such as amphipods *Urothoe grimaldi* and the polychaetes *Scoloplos johnstonei* and *Orbinia angrapequensis* increased in density. Pillay *et al*. (2010) was also able to show that the abundance of at least one species of wading bird Terek sandpiper which feeds exclusively in Zostera beds was linked to changes in the size of these beds, with population crashes in this species coinciding with periods of lowest seagrass abundance at Klein Oesterwal. By contrast, they were able to show that populations of wader species that do not feed in seagrass beds were more stable over time.

While the precise reasons for the loss of *Z. capensis* beds remain speculative, the impact of human disturbance cannot be discounted, particularly at Klein Oesterwal where bait collection is common (Pillay *et al*. 2006). By 2007 the intertidal habitat at Klein Oesterwal had been transformed from a seagrass bed community to an unvegetated sand flat which was colonized by the burrowing sandprawn *Callinassa kraussi* and other sandflat species that cannot live in the stabilized sediments promoted by the seagrass (Pillay *et al*. 2010). The burrowing sandprawn turns over massive quantities of sediment and once established effectively prevents the re-colonization of seagrass and the species associated with it (Siebert and Branch 2005, Angel *et al*. 2006). The long-term effects of the loss of seagrass at Klein Oesterwal, and to lesser degree at Bottelary and the Central banks, are not yet fully understood. However, studies suggest that the reduced seagrass bed coverage and the associated changes to macro-invertebrates may have cascading effects on higher trophic levels (Whitfield *et al*. 1989, Orth *et al*. 2006). Alterations to fish species diversity and abundance, and changes in the numbers of water birds that forage or are closely linked to seagrass beds may be seen in Langebaan Lagoon as a result of the loss of seagrass beds (Whitfield *et al*. 1989, Orth *et al*. 2006).

The loss of seagrass beds from Langebaan Lagoon is a strong indicator that the ecosystem is undergoing a shift, most likely due to anthropogenic disturbances. It is critical that this habitat and the communities associated with it be monitored in future as further reductions are certain to have long term implications, not only for the invertebrate fauna but also for species of higher trophic levels.

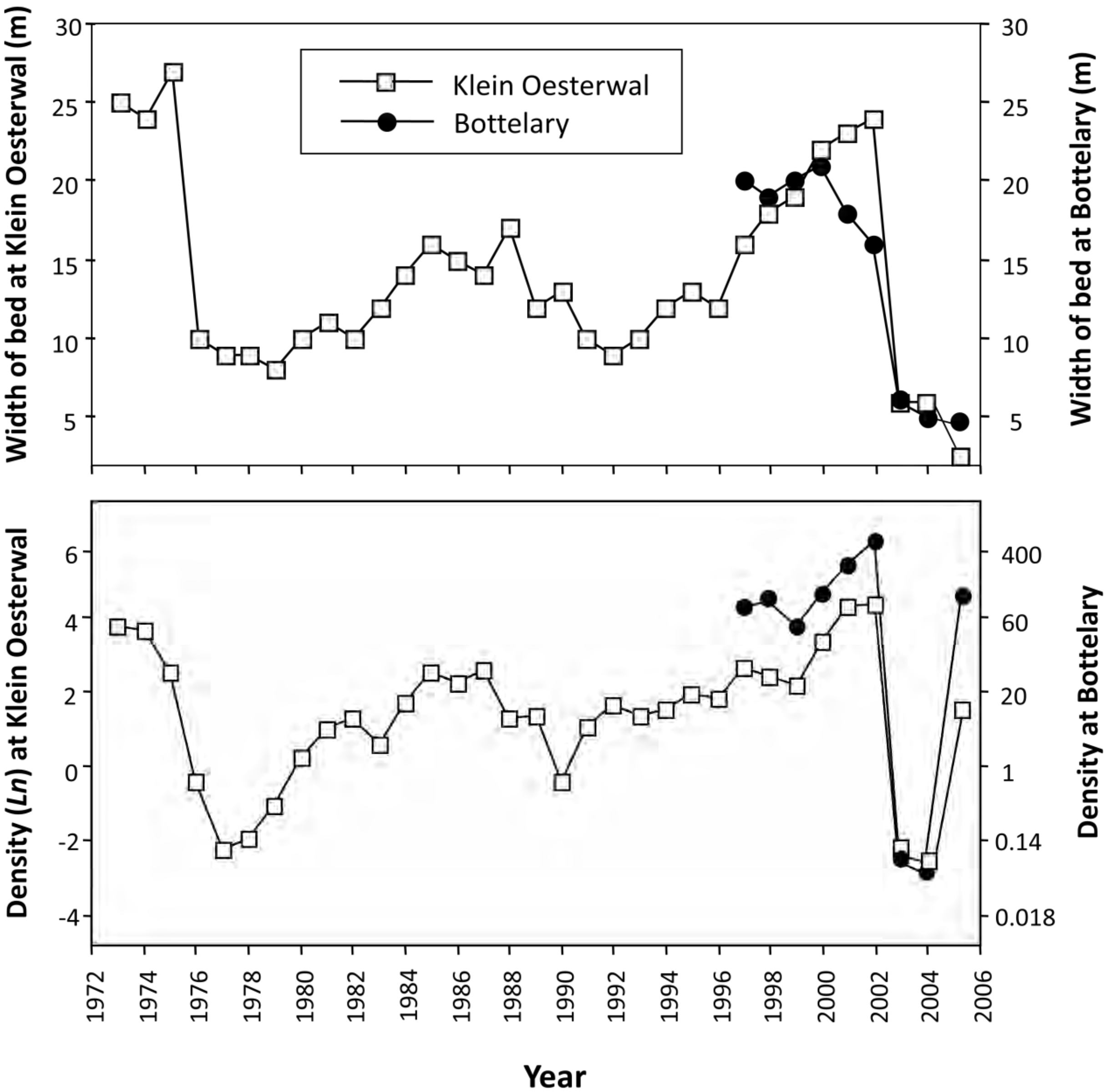


Figure 6.2. Width of the Zostera beds and density of *Siphonia* at Klein Oesterwal and Bottelary in Langebaan Lagoon, 1972-2006.

6.2 Long term changes in Saltmarshes in Langebaan Lagoon

Saltmarshes in Langebaan are reportedly an important habitat and breeding ground for a range of fish, bird and invertebrate species (Christie 1981, Day 1981, Gerrike 2008). Langebaan Lagoon incorporates the second largest salt marsh area in South Africa, accounting for approximately 30% of this habitat type in the country, being second only to that in the Knysna estuary (Allanson *et al*. 1999).

Long term changes in salt marshes in Langebaan Lagoon were investigated by Gerrike (2008) using aerial photographs taken in 1960, 1968, 1977, 1988 and 2000. He found that overall saltmarsh area had shrunk by only a small amount between 1960 and 2000, losing on average 8 000 m^2 per annum. Total loss during this period was estimated at 325 000 m^2, or 8% of the total (Figure 6.3,). Most of this loss has been from the smaller patches of salt marsh that existed on the seaward edge of the main marsh. This is clearly evident from the change in the number of saltmarsh patches in the lagoon over time, which has declined from between 20 and 30 in the 1960s and 70s to less than 10 at present. Gerrike (2008) attributed the observed change over time to increases in sea level that would have drown the seaward edges of the marshes or possibly reduced sediment inputs from the terrestrial edge (i.e. reduced input of windblown sand due to stabilization by alien vegetation and development).

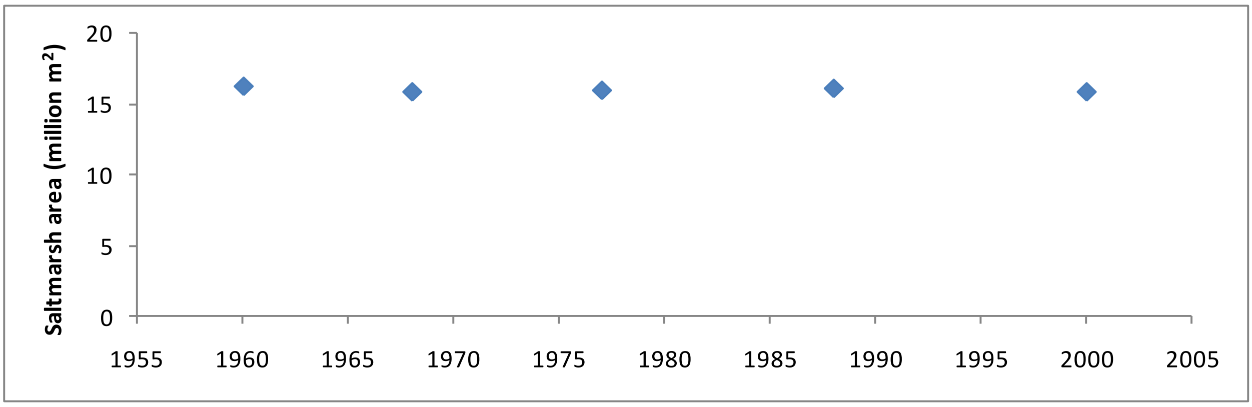


Figure 6.3. Change in saltmarsh area over time in Langebaan Lagoon. (Data from Gerricke 2008)

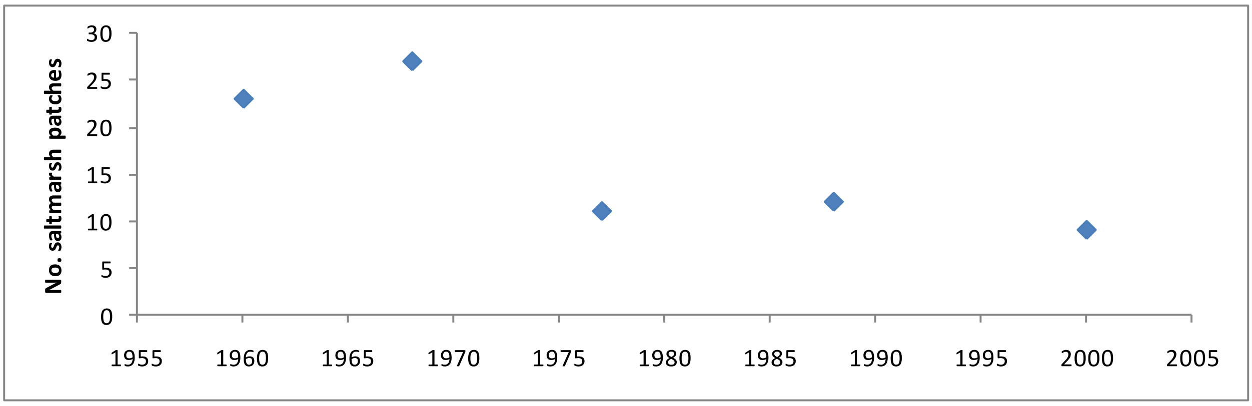


Figure 6.4. Change in the number of discrete saltmarsh patches over time in Langebaan Lagoon. (Data from Gerricke 2008)

7 BENTHIC MACROFAUNA

7.1 Background

It is important to monitor biological criteria in addition to physico-chemical and ecotoxicological variables as biological indicators provide a direct measure on the state of the ecosystem. Benthic macrofauna are the biotic component most frequently monitored to detect changes in the health of the marine environment. This is largely because these species are short lived and, as a consequence, their community composition responds rapidly to environmental changes (Warwick 1993). Given that they are also relatively non-mobile (as compared with fish and birds) they tend to be directly affected by pollution and they are easy to sample quantitatively (Warwick 1993). Furthermore they are scientifically well-studied, compared with other sediment-dwelling components (e.g. meiofauna and microfauna) and taxonomic keys are available for most groups. In addition community response to a number of anthropogenic influences has been well documented.

Organic matter is one of the most universal pollutants affecting marine life and it can lead to significant community disturbance, particularly in semi-enclosed or closed bays where water circulation is restricted, such as Saldanha Bay. High organic loading typically leads to eutrophication, which may bring about a number of community responses amongst the benthic macrofauna. These include increased growth rates, disappearance of organisms due to anoxia, changes in community composition and reduction in the number of species following repeat hypoxia and even complete disappearance of benthic organisms in severely eutrophic and anoxic sediments (Warwick 1993). The community composition of benthic macrofauna is also likely to be impacted by increased levels of other contaminants such as trace metals and hydrocarbons found in the sediments. Furthermore, areas that are frequently disturbed by mechanical means (e.g. through dredging) are likely to be inhabited by a greater proportion of opportunistic pioneer species.

The main aim of monitoring the health of an area is to detect the effects of stress, as well as to monitor recovery after an environmental perturbation. There are numerous indices, based on benthic invertebrate fauna information, which can be used to reveal conditions and trends in the state of ecosystems. These indices include those based on community composition, diversity and species abundance and biomass. Given the complexity inherent in environmental assessment it is recommended that several indices be used (Salas *et al*. 2006). The community composition, diversity, and species abundance and biomass of soft bottom benthic macrofauna samples, collected in Saldanha Bay and Langebaan Lagoon in 2012, are considered in this report.

7.2 Historic data on benthic macrofauna communities in Saldanha Bay

The oldest records of benthic macrofauna species occurring in Saldanha Bay date back to the 1940's, prior to the construction of the iron-ore terminal and Marcus Island causeway. Due to differences in sampling methodology, data from these past studies are not directly comparable with subsequent studies and as such cannot be used for establishing conditions in the environment prior to any of the major developments that occurred in the Bay. Moldan (1978) conducted a study in 1975 where the effects of dredging in Saldanha Bay on the benthic macrofauna were evaluated. Unfortunately, this study only provided benthic macrofauna data after the majority of Saldanha Bay (Small Bay and Big Bay) had been dredged. A similar study conducted by Christie and Moldan (1977) in 1975 examined the benthic macrofauna in Langebaan Lagoon, using a diver-operated suction hose, and the results thereof provide a useful description of baseline conditions present in the Lagoon from this time.

Studies, conducted in the period 1975-1990, examined the benthic macrofauna communities of Saldanha Bay and/or Langebaan Lagoon, but are also, regrettably not comparable with any of the earlier or even the more recent studies. Recent studies conducted by the CSIR in 1999 (Bickerton 1999) and Anchor Environmental Consultants in 2004 and 2008-2011 do, however, provide benthic macrofauna data from Saldanha Bay and Langebaan Lagoon that are comparable with those collected in 2012. In the intervening years between 1975 and 1999, significant development took place in Saldanha Bay (previously described in this report) including ore export and dredging of Small Bay in 1997/98. The 1999 study was conducted approximately 12 months after dredging and is representative of a recovering benthic community. Direct comparisons to earlier studies are further complicated due to different equipment being used in 1975 than in 1999 to present. The study conducted in 1975 in Saldanha Bay (Moldan 1978) made use of a modified van Veen grab weighted to 20 kg which sampled an area of 0.2 m^2 from the surface fraction of sediment. Subsequent surveys, from 1999 to present, made use of a diver-operated suction sampler with a sampling area of 0.24 m^2 to a depth of 30 cm. The former sampling technique (van Veen grab) would be expected to sample a smaller proportion of benthic macrofauna due to its limited ability to penetrate the sediment beyond the surface layers. The suction sampler is effective in penetrating to a depth of 30 cm, which is the range in which larger species, like prawns and crabs, are expected to occur. The study conducted in 1975 in Langebaan Lagoon (Christie and Moldan 1977) and those conducted by Anchor Environmental Consultants both made use of a diver-operated suction sampler which sampled an area of 0.24m^2. However, in 1975 a depth of 60 cm was sampled while in surveys since 2004 a depth of only 30 cm was sampled. Thus, considering the differences in sampling techniques employed, it is likely that the changes reflected by the data between the 1975 and 1999-2008 in Saldanha Bay and Langebaan Lagoon are a function both of real changes that occurred in the Bay and an artefact of differences in sampling methodology. The location of sites sampled during 1975 and 1999-2012 studies also differed (Figure 7.1), however, the broad distribution of sites throughout the sampling area ensures that the data collected are representative of Small Bay, Big Bay and Langebaan Lagoon and as such, can be compared with one another.

7.3 Approach and methods used in monitoring benthic macrofauna in 2012

7.3.1 Sampling

A total of 32 sites were sampled for benthic macrofauna in 2012, 12 of which were in Small Bay, seven in Big Bay, nine in Langebaan Lagoon, two in Salamander Bay and two in Donkergat (Figure 7.1). The water depth ranged from 0.8 m to 21 m, with the shallowest sites being those in Langebaan Lagoon (Table 1.7.1). Samples were collected using a diver-operated suction sampler, which sampled an area of 0.08 m^2 to a depth of 30 cm and retained benthic macrofauna (>1 mm in size) in a 1 mm mesh sieve bag. Three samples were taken at each site and pooled, resulting in a total sampling surface area of 0.24 m^2 per site. Three hand-core samples were taken at sites less than 2 m deep (LL41), totalling a sampling surface area of 0.08 m^2. All macrofauna abundance and biomass data were ultimately standardised per unit area (m^2). These methods correspond exactly with those employed in 1999, 2004 and 2008-2011 and thus facilitate comparisons between these sets of data. Samples were stored in plastic bottles and preserved with 5% formalin.

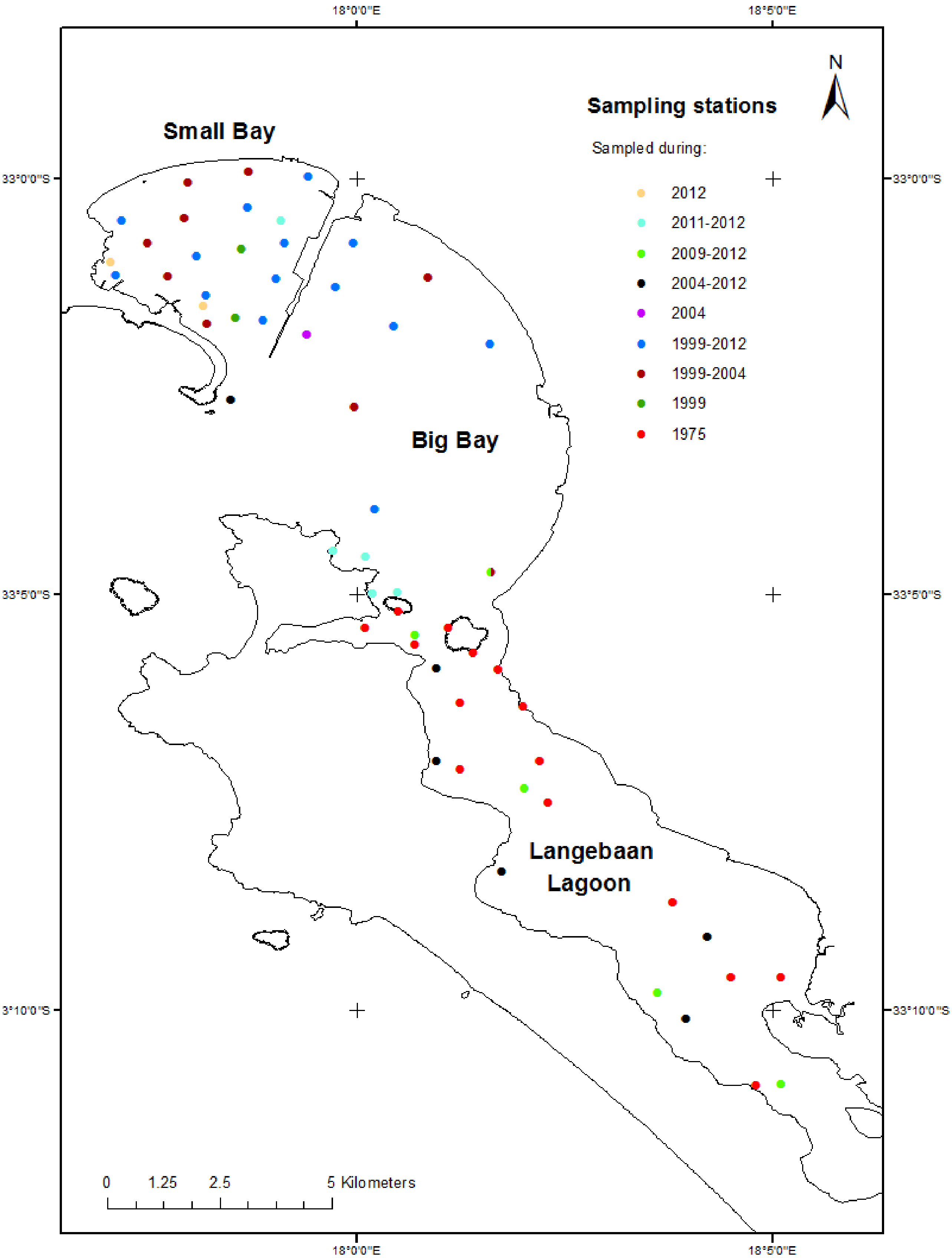


Figure 7.1. **Sites sampled for benthic macrofauna between 1975 and 2012 in Saldanha Bay and Langebaan Lagoon.**

Table 1.7.1. Depth at each of the sites sampled in 2012.

Small Bay	Depth (m)	Big Bay	Depth (m)	Langebaan Lagoon	Depth (m)	Salamander/ Donkergat	Depth (m)
SB1	10	BB20	20.9	LL31	5.5	D1	4.1
SB2	7.8	BB21	10	LL32	4.4	D2	3.5
SB3	5.2	BB22	11	LL33	3	S1	2.8
SB8	10.9	BB25	10.3	LL34	4.1	S2	6.3
SB9	14.7	BB26	15	LL37	3		
SB10	7.1	BB29	15.8	LL38	6.6		
SB14	15	BB30	3.4	LL39	5.7		
SB15	12.2			LL40	2.4		
SB16	16			LL41	0.8		
SB42	9.1						
SB43	16						
SB44	8.2						

In the laboratory, samples were rinsed of formalin and stained with Rose Bengal to aid sorting of biological from non-biological matter. All fauna were removed and preserved in 1% phenoxetol (Ethyleneglycolmonophenylether) solution. The macrofauna were then identified to species level where possible, but at least to family level in all instances. The validity of each species was then checked on The World Register of Marine Species (WoRMS, www.marinespecies.org). The biomass (blotted wet mass to four decimal places) and abundance of each species was recorded for each sample.

7.3.2 Statistical Analysis

The data collected from this survey were used for two purposes 1) to assess spatial variability in the benthic macrofauna community structure and composition between sites in 2012 and 2) to assess changes in benthic community structure over time (i.e. in relation to past surveys). Both the spatial and temporal assessments are necessary to provide a good indication of the current state of health of the system.

7.3.2.1 Community structure and composition

Changes in **benthic species composition** can be the first <u>indicator of disturbance</u>, as certain species are more sensitive (i.e. likely to decrease in abundance in response to stress) while others are more tolerant of adverse conditions (and may increase in abundance in response to stress, taking up space or resources vacated by the more sensitive species). Monitoring the temporal variation in community composition also provides an <u>indication of the rate of recovery</u> of the ecosystem following disturbances in different areas of the system. This allows one to more accurately predict the impacts of proposed activities. "Recovery" following environmental disturbance is generally defined as the establishment of a successional community of species which progresses towards a community that is similar in species composition, density and biomass to that previously present (C-CORE 1996 and Newell 1998). The rate of recovery is dependent on environmental conditions and the communities supported by such conditions. Given the spatial variation in environmental conditions (largely influenced by depth and exposure) and anthropogenic disturbance throughout Saldanha Bay and Langebaan Lagoon, it is expected that recovery will vary throughout system.

It has been shown that species with a high fecundity, rapid growth rate and short life-cycle are able to rapidly invade and colonise disturbed areas (Newell 1998). These species are known as "r-strategists", pioneer or opportunistic species and their presence generally indicates unpredictable short-term variations in environmental conditions as a result of either natural factors or anthropogenic activities. In stable environments the community composition is controlled predominantly by biological interactions rather than by fluctuations in environmental conditions. Species found in these conditions are known as "K-strategists" and are selected for their competitive ability. K-strategists are characterised by long-life spans, larger body sizes, delayed reproduction and low mortality rates. Intermediate communities with different relative proportions of opportunistic species and K-strategists are likely to exist between the extremes of stable and unstable environments.

The statistical program PRIMER 6 (Clarke and Warwick 1993) was used to analyse the benthic macrofauna data. Data were root-root (fourth root) transformed and converted to a similarity matrix using the Bray-Curtis similarity coefficient. A cluster analysis was performed in order to find 'natural groupings' between samples (sites). The results of the cluster analysis are displayed on a dendrogram which graphs similarity of significant clusters of sites (revealed using a SIMPROF analysis). These results were plotted geographically using ArcGIS to reveal any spatial trends in the sites grouped according community composition similarity. SIMPER analysis was used to identify species principally responsible for the clustering of sites. These results were used to characterise different regions of the system based on the communities present at the sites. It is important to remember that the community composition is a reflection of not only the physico-chemical health of the environment but also the ability of communities to recover from disturbance.

7.3.2.2 Diversity Indices

Diversity indices provide a measure of diversity, i.e. the way in which the total number of individuals is divided up among different species. Understanding changes in benthic diversity is important because increasing levels of environmental stress generally *decreases* diversity. Two different aspects of community structure contribute to community diversity, namely *species richness* and *equability* (*evenness*). Species richness refers to the total number of species present while equability or evenness expresses how evenly the individuals are distributed among different species. A sample with greater evenness is considered to be more diverse. It is important to note when interpreting diversity values that predation, competition and disturbance all play a role in shaping a community. For this reason it is important to consider physical parameters as well as other biotic indices when drawing a conclusion from a diversity index.

The following measures of diversity were calculated for each sampling location using PRIMER V 6:

The *Shannon-Weiner diversity index* (H'): $H' = -\Sigma_i p_i(\log p_i)$ (1)

Where p_i is the proportion of the total count arising from the *i*th species. This is the most commonly used diversity measure and it incorporates both species richness and equability.

The *Pielou's evenness index* (J'): $J' = H'_{observed} / H'_{max}$ (2)

Where H'_{max} is the maximum possible diversity which would be achieved if all species were equally abundant (= *log* S). This is the most common expression of equability.

The *Margalef's index* (d) of species richness: $D = (S-1)/ \log N$ (3)

Where S is the total number of species and N is the total number of individuals.

Species richness is often simply referred to as the total number of species (S), but this is very dependent on sample size. The *Margalef's index* thus incorporates the total number of individuals (N) and is a measure of the total number of species present for a given number of individuals.

The diversity (H') value for each site was plotted geographically and this was used to interpolate vales for the entire system using ArcGIS in order to reveal any spatial patterns. The average diversity value was also then calculated for four pre-designated locations for past surveys from 1999 to present: Small Bay, Big Bay, Langebaan Lagoon and the Naval Base (consisting of Salamander and Donkergat sites surveyed from 2011 to present). In order to test if the observed changes in diversity were statistically significant ($p<0.5$) between years, the diversity value (H') for Small Bay, Big Bay and Langebaan Lagoon were analysed for variances using a one-way ANOVA and the post hoc Fisher LSD test.

7.3.2.3 Integration of Indices with Environmental Variables

The aim of these analyses was to determine how environmental variables (metal concentrations, organic content of sediment, grain size) relate to the observed biological patterns in macrobenthic community structure. This was achieved by superimposing the concentrations of individual environmental variables onto biotic multi-dimensional scaling (MDS) plots. An MDS plot is a spatial representation of the Bray Curtis similarity analysis. MDS plots are constructed using PRIMER V6 from the similarity matrix in order to view similarities between sample sites. Like the dendrogram, samples with similar species composition and abundance cluster together, while those that are less similar are placed further apart. The values of various environmental variables are superimposed on MDS plots as circles of varying diameter (the larger the circle, the higher the concentration). These are known as 'bubble plots' and they allow one to easily identify the sites at which certain contaminants are elevated, as well as to determine if contamination patterns have any correlation to biotic structure.

7.4 Benthic macrofauna survey results: 2012

7.4.1 Community Structure and Composition

7.4.1.1 Spatial analyses

The cluster and SIMPROF analysis, based on abundance of benthic macrofauna, revealed 6 statistically similar groups of sites indicated by the red lines on the dendrogram (Figure 7.2). Significant clusters were displayed geographically using GIS, which revealed a clear spatial pattern (Figure 7.5).

Cluster E has an average similarity of 28% and consists of sites located near the Iron Ore Jetty and mariculture operations in both Small Bay and Big Bay (

Figure 7.5). These sites are located in deeper water ranging from 10.3 to 16.0 m depth (Table 1.7.1, Figure 7.13). Historically they have shown a high level of disturbance due to a combination of dredging events, mariculture activities and reduced circulation. A SIMPER analysis revealed that high abundance of the polychaete *Nephtys hombergii* contributed 39% alone towards the significant clustering of these sites, followed by the invasive alien pea crab, *Pinnixa occidentalis* (20%) and the amphipod, *Ampelisca anomola* (20%). *Ampelisca sp*. are detritivores and are known to be abundant in dredged areas and on fine sand. It is thus not surprising that they had become dominant at sites in close proximity to the Ore Terminal in Small Bay and Big Bay given that this area has undergone periodic dredging.

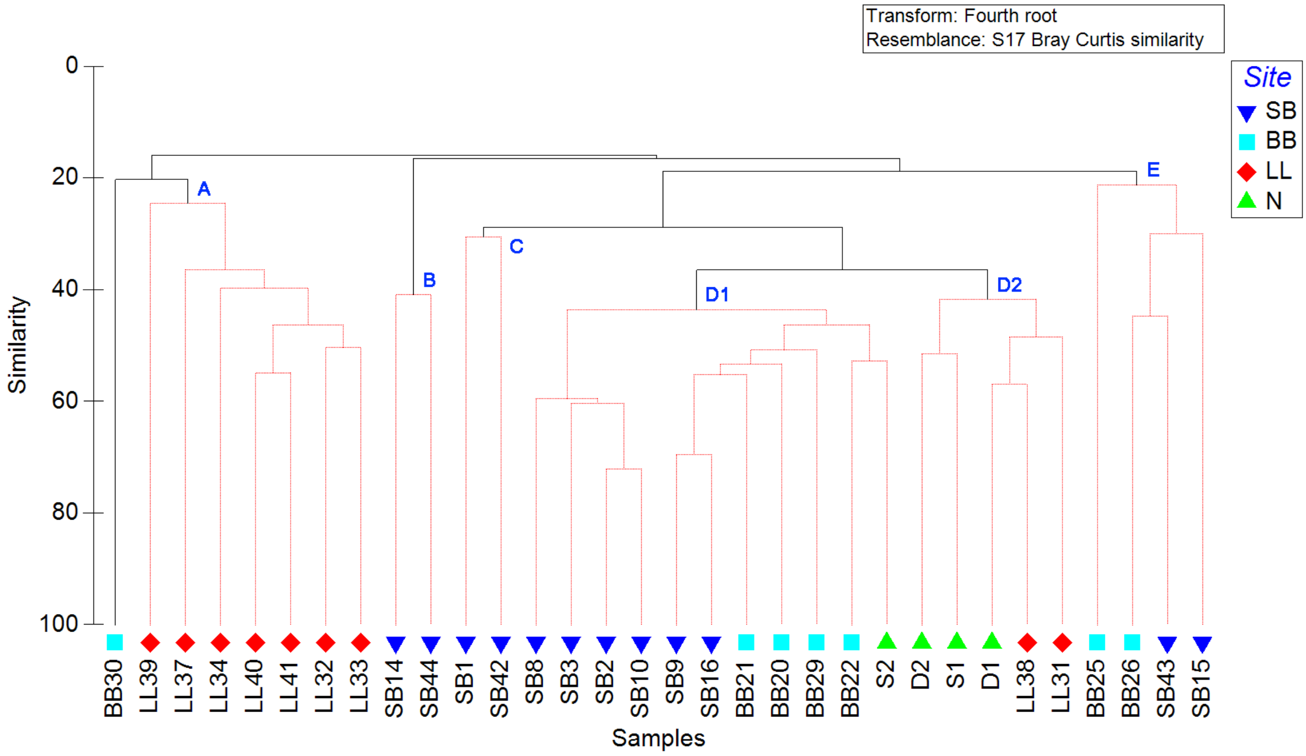


Figure 7.2. Dendrogram representing the similarity of sites (Bray Curtis Similarity) based on the abundance of benthic macrofauna sampled in 2012 at Small Bay (SB), Big Bay (BB), Langebaan Lagoon (LL), Salamander Bay (S) and Donkergat (D) – collectively designated N in the key. Clusters of sites significantly similar are represented by the red dotted lines (SIMPROF).

The Langebaan Lagoon samples are split between clusters A and D2, both of which are independent of Saldanha Bay samples. This suggests that Langebaan Lagoon supports a different benthic community to Saldanha Bay, which is consistent with results obtained in previous surveys (2004 to present). Cluster A (37% average similarity) consists entirely of samples from the southern part of Langebaan Lagoon (Figure 7.5). *Callichirus kraussi*, *Orbinia angrapequensis*, *Natatolana hirtipes* and *Marphysa depressa* were the most abundant species recorded in the lagoon and contribute a cumulative 55% to the overall similarity of cluster A. Water depth at these sites ranged from 0.8 to 5.7 m (Table 1.7.1, Figure 7.13) with very low levels of percentage mud (Figure 7.4) and heavy metal contamination (See Chapter 5 for more details on this).

The remaining northern Langebaan sites (LL31 and LL38) were clustered with the Donkergat and Salamander sites (except for S2) in cluster D2. SIMPER results indicate that presence of *Upogebia capensis*, *Notomastus latericeus* and *Natatolana hirtipes* contribute a cumulative 52% to the overall similarity of this cluster.

The cluster analysis also allowed us to identify sampling sites that are 'outliers'. These are sites that have a very different species composition to other samples taken from the same area and thus do not fit into any clusters. Species composition may differ at these sites due to anthropogenic impacts (such as pollution discharge) or certain environmental variables (e.g. different depth zone or sediment grain size composition). For the first time since 2008 site SB1 is not an outlier and, together with site SB42, forms Cluster C (30.5% average similarity). As was evident in previous surveys, SB1 is characterized by very high levels of organic pollution and high trace metal concentrations. This has resulted in records of low species abundance and diversity with two species recorded in 2008, four species in 2009 and 2010, and five species in 2011. For this reason it has always been an outlier until the current 2012 survey which, despite relatively high levels of persistent pollution, has seen an improvement in diversity with nine species recorded at SB1. However, this is still below the average species diversity of 10.8 for sites within Small Bay. *Terebella pterochaeta*, *Lysianassa certain* and *Nephtys hombergii* contribute a cumulative 70% to the overall similarity of Cluster C. Site BB30 is the only outlier observed in the dendrogram. This is largely attributable to the different physical conditions present at this site – higher wave exposure and coarser sediment – attracting a different benthic invertebrate community in comparison to other sites in the system.

Cluster B consists of sites SB14 and SB44, which share an average similarity of 41%. Despite both sites occurring in areas of known high anthropogenic disturbance (Iron Ore terminal and yacht basin), it is unclear as to what is driving the observed similarities in species composition between these two sites as the percentage mud, POC and PON are all lower at SB44 in comparison with SB14. Taxa responsible for the clustering of these two sites include: *Tellina gilchristi*, *Nephtys hombergii*, *Nassarius speciosus* and *Pectinaria capensis* collectively contributing to 100% of the similarity.

Sites within cluster D1 are located throughout Small Bay, on both sides of the Iron Ore Terminal and in the vicinity of Salamander Bay. Within this cluster, separation of the Small Bay sites from the remaining Big Bay sites can be observed, with Small Bay sites and Big Bay sites being grouped independently of each other in the dendrogram (Figure 7.2). Water depth at the sites in Cluster A2 ranged from 5.3-20.9 m, with a mean of 11.4 m, and includes sites with relatively high and low percentage mud (Table 1.7.1, Figure 7.4). This suggests that neither particle size, nor depth is the principle driver of benthic invertebrate community composition. Taxa contributing to 67% of the overall similarity within this cluster include *Upogebia capensis* (35%), *Ochetostoma capensis* (19%) and *Glycera tridactyla* (11.6%).

The five sites making up Cluster D2 are located within close proximity of each other (Figure 7.5), occurring in Salamander Bay, Donkergat and northern Langebaan Lagoon. As with Cluster A2, the mud prawn *Upogebia capensis* was the dominant species contributing 32% to overall similarity within the cluster. *Upogebia capensis*, an opportunistic species, is typically found in sheltered bays where it creates burrows in fine muddy substrata. The mud prawn, which is common at most sites in Small Bay, has been dominant within Small Bay since the early nineties. Their initial increase in Small Bay was attributed to a reduction in water movement resulting from the construction of the iron ore terminal and the Marcus Island causeway (Jackson and McGibbon 1991). The dominance of these species in these areas suggests that these sites are in the early phases of recovery or that the sites are subject to ongoing unpredictable environmental variations.

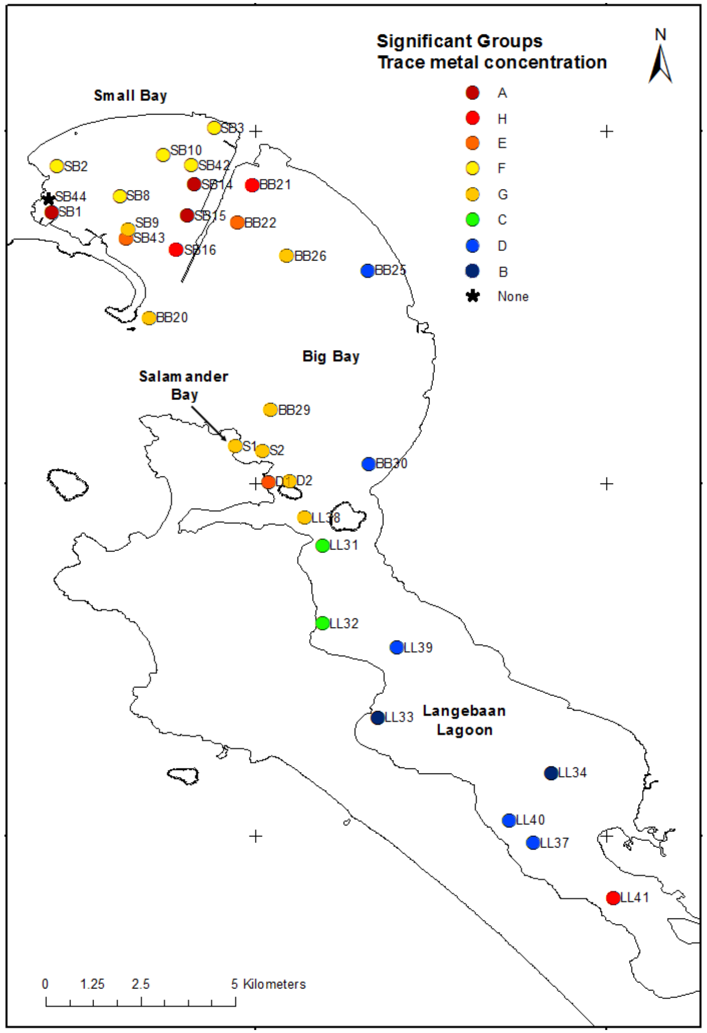


Figure 7.3: Geographic representation of the results of a PRIMER analysis showing significant clustering of sites based on the similarity of trace metal concentrations (Euclidean Distance). Group A generally had the highest concentrations for all metals and group E the lowest (SIMPER analysis)

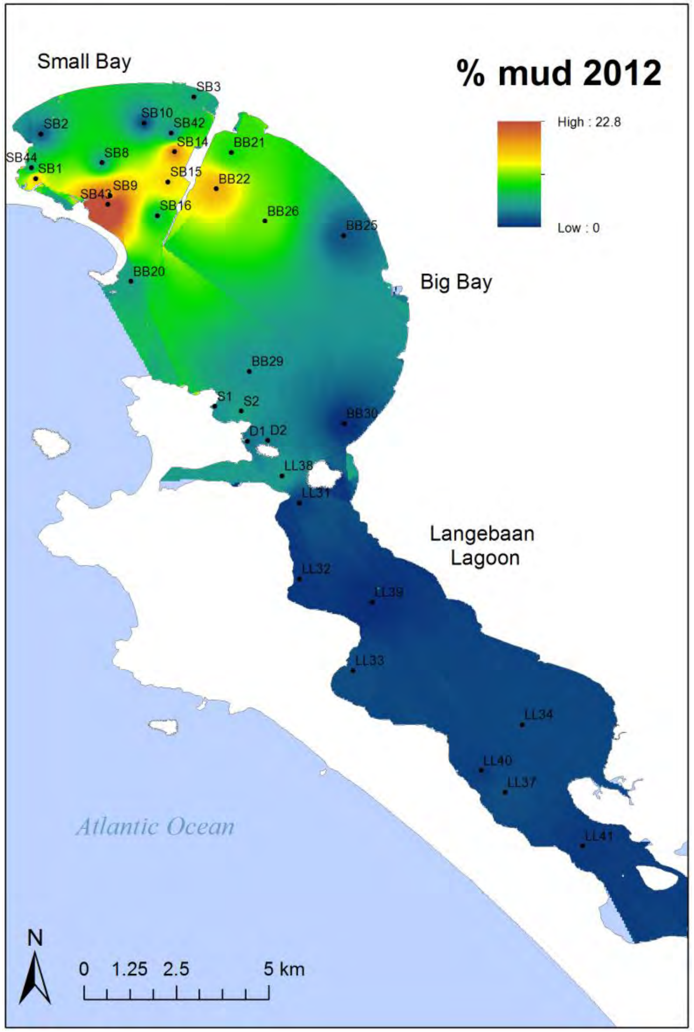


Figure 7.4: Variation in the percentage mud in sediments in Saldanha Bay and Langebaan Lagoon as indicated by the 2012 survey results.

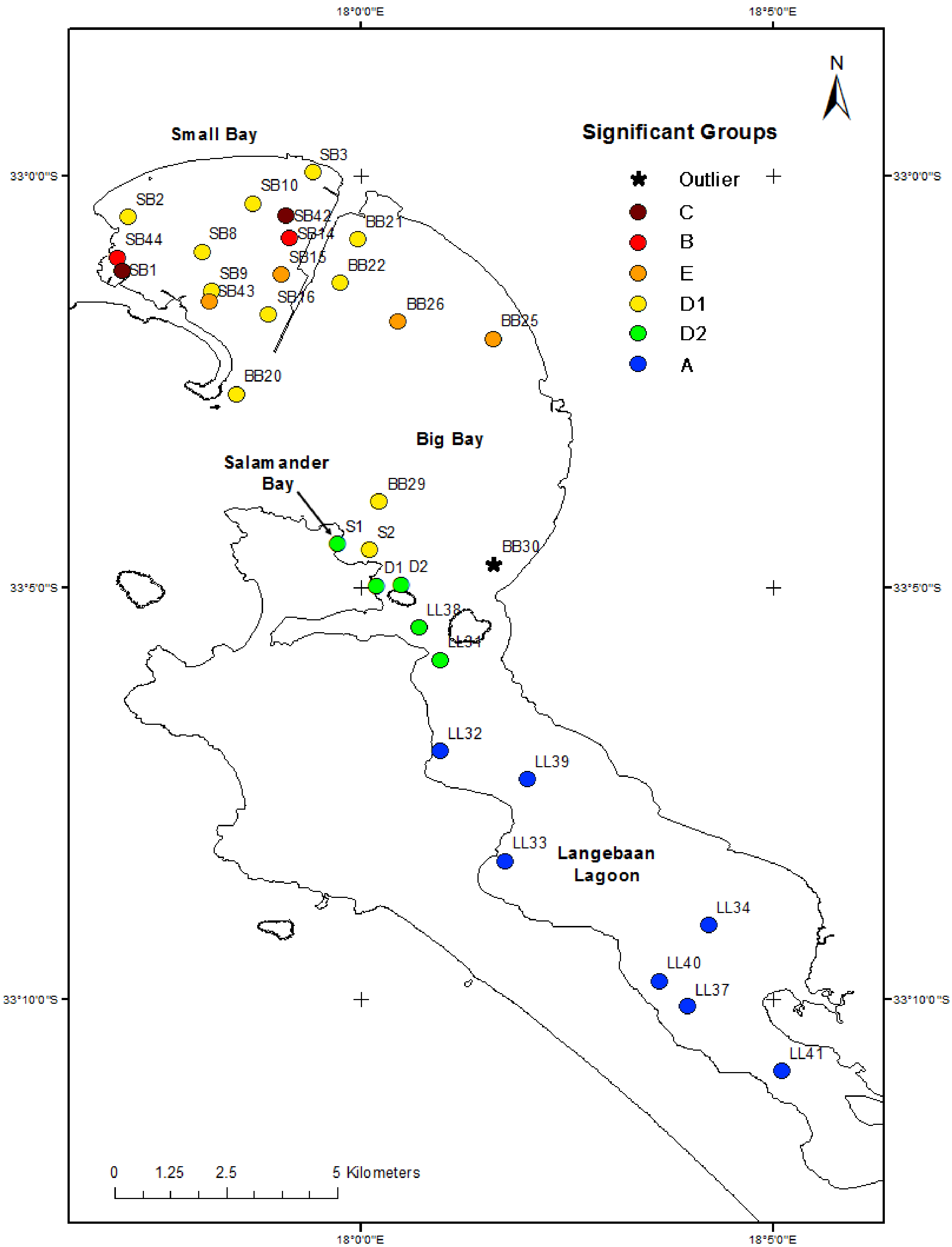


Figure 7.5. **Geographic representation of the results of a PRIMER similarity analysis showing significant clustering of sites based on the abundance of benthic macrofauna (Bray-Curtis coefficient).**

Table 1.7.2. Taxa responsible for the significant clustering of sites (Figure 1.2), listed in order of percentage contribution to group similarity (highest to lowest). Taxa contributing 90% to the similarity of groups A, B and C are shown.

	A (37%)		B (41%)		C (30.5%)	
	Species	**Common name/group**	**Species**	**Common name/group**	**Species**	**Common name/group**
Taxa contributing 90% to similarity of group	*Callichirus kraussi*	Sand prawn	*Tellina gilchristi*	Gilchrist's tellin	*Terebella pterochaeta*	Tangleworm
	Orbinia angrapequensis	Wooly polychaete	*Nephtys hombergii*	Sand worm	*Lysianassa ceratina*	Compact amphipod
	Natatolana hirtipes	Hairy legged isopod	*Nassarius speciosus*	Purple-lipped dog whelk	*Nephtys hombergii*	Sand worm
	Marphysa depressa	Estuarine wonder worm	*Pectinaria capensis*	Cone-tube worm	*Upogebia capensis*	Mud prawn
	Glycera tridactyla	Polychaete			*Spiroplax spiralis*	Three-legged crab
	Spiroplax spiralis	Three-legged crab				
	Upogebia africana	Estuarine mud prawn				
	Hymenosoma orbiculare	Crown crab				
	Ampelisca palmata	Four-eyed amphipod				
	Betaeus jucundus	Shrimp				
	Nephtys hombergii	Sand worm				
	Eunoe nodulosa	Polychaete				
	Capitella capitata	Club worm				

Table 1.7.3. Taxa responsible for the significant clustering of sites (Figure 1.2), listed in order of percentage contribution to group similarity (highest to lowest) - taken from a SIMPER analysis. Only taxa contributing 90% to the similarity of groups D1, D2 and E are shown.

	D1 (48.2%)		D2 (45.5%)		E (28%)	
	Species	**Common name/group**	**Species**	**Common name/group**	**Species**	**Common name/group**
Taxa contributing 90% to similarity of group	*Upogebia capensis*	Mud prawn	*Upogebia capensis*	Mud prawn	*Nephtys hombergii*	Sand worm
	Ochetostoma capense	Tongue worm	*Notomastus latericeus*	Club worm	*Pinnixa occidentalis*	Pea crab
	Glycera tridactyla	Polychaete	*Natatolana hirtipes*	Hairy legged isopod	*Ampelisca anomala*	Four-eyed amphipod
	Spiroplax spiralis	Three-legged crab	*Maldanidae sp. A*	Polychaete	*Lumbrineris heteropoda difficilis*	False earthworm
	Nassarius speciosus	Purple-lipped dog whelk	*Nephtys hombergii*	Sand worm	*Ochetostoma capense*	Tongue worm
	Eunoe nodulosa	Polychaete	*Pisces A*	Goby		
	Nephtys hombergii	Sand worm	*Hymenosoma orbiculare*	Crown crab		
			Hippomedon normalis	Amphipod		
			Ochetostoma capense	Tongue worm		
			Lysianassa ceratina	Compact amphipod		
			Diopatra monroi	Case worm		
			Phtisica marina	Caprellid amphipod		
			Orbinia angrapequensis	Wooly polychaete		

7.4.1.2 Temporal Analysis

Small Bay

Changes in the abundance of benthic macrofauna in the Bay have been examined both in terms of the relative importance of different feeding groups (i.e. trophic functioning which reflects changes in food availability) and taxonomic groups (i.e. different species which differ in size, growth rates and other characteristics).

From a trophic functioning perspective, filter feeding species have been the dominant functional group amongst the benthic macrofauna in Small Bay since detailed surveys were started in 1999, apart from a brief "upset" in 2008 (Figure 7.6). The "upset" in 2008 saw a massive reduction in the abundance of species in this group in the Bay (and indeed in benthic macrofauna abundance in the Bay as a whole) to the extent that the next most important trophic group, the detritivores came to dominate at this time. Filterfeeders in the Bay consist mostly of the opportunistic mud prawn (*Upogebia capensis*) and smaller amphipod species belonging to the genus *Ampelisca* (Figure 7.6). Another important filterfeeding macrofaunal species in the Bay are the sea pens *Virgularia schultzei*. This species was once very abundant, particularly in the period prior to major development, and was present throughout Big Bay and Small Bay. It is now completely absent from Small Bay but still present in Big Bay albeit in small numbers. It is likely that major changes in the state of the environment in the Saldanha Bay caused by human development, most notably the development of the iron-ore terminal and the causeway linking Marcus Island to the mainland, were responsible for the loss of this species. Detritivores, the second most important group of benthic macrofauna in Small Bay, comprise mostly of tongue worms (*Ochaetostoma capense*) and polychaetes belonging to the genera *Polydora* and *Euclymene*. These species are less sensitive to water quality and changes in wave movement patterns and hence tend to increase in abundance of even dominate when conditions deteriorate.

From a taxonomic perspective, Crustaceans have dominated the benthic macrofauna in terms of biomass and abundance in all surveys conducted since 1999. The 2008 survey revealed that there had been a drastic reduction in the overall biomass and abundance of benthic macrofauna in Small Bay. This was most likely a result of the dredging activities conducted at the Mossgas quay and the Multi-Purpose Quay in 2007/08. Much of the reduction in biomass in 2008 could be accounted for by the reduced biomass of crustaceans, however the abundance of crustaceans did not decrease in the same manner. This indicates that many small crustaceans (most likely r-selective) dominated the benthic community following dredging.

Since 2008 the average biomass in Small Bay has been increasing. This increase in biomass can be principally accounted for by the increased biomass of crustaceans and tongue worms (Echiuroidea) between 2008 and 2011. Interestingly, the abundance of crustaceans declined between 2008 and 2009, while the biomass increased. This suggests that the community had shifted from one composed primarily of small, opportunistic crustaceans to one composed of fewer, larger, (most likely K-selective) crustaceans in 2009. Small (low biomass)[1] polychaetes increased substantially in abundance between 2008 and 2009, then declined again in 2010. This suggests that the polychaetes were able to compete with small opportunistic crustaceans and colonise the recently disturbed benthic habitat between 2008 and 2009. It is likely that the polychaetes were then outcompeted between 2009 and 2010 by the growing populations of larger crustacean species. This is a possible indication of the succession in benthic macrofauna communities following the

[1] This is evident given that the overall biomass of polychaetes did not increase substantially while the abundance did. These are most likely small, fast growing r-selected species.

2007/08 dredging. Other signs of the recovery of the system, evident from the 2010 and 2011 surveys, include the increase in the average biomass and abundance of gastropods and bivalves between 2008 and 2011. However, the 2011 survey revealed a substantial increase in the abundance of polychaetes. This increase was not reflected by the biomass results, indicating that once again the Small Bay sites had been colonised by small polychaete species. The reasons for this increase are not clear given that, based on the increases in other taxonomic groups, the ecosystem did not appear to have been negatively disturbed by anthropogenic or natural perturbations. The increase in small polychaete species (predominantly detritivores) is likely to be a result of biological interactions.

In contrast, the current 2012 survey shows an overall decrease in abundance and biomass of benthic macrofauna to an all-time low (Figure 7.6). However, the decrease in biomass is not as severe as the observed decrease in abundance which would suggest a shift in community succession from many small individuals (r-selective) to fewer large individuals (k-selective) – an indication of recovery. It appears that the slight decrease in proportion of filter feeders and increase in proportion of detritivores may be a result of higher percentage mud present throughout most of Small Bay (Figure 7.4).

Big Bay

From a taxonomic perspective, crustaceans and polychaetes have dominated the benthic macrofauna community in Big Bay in terms of abundance in all surveys conducted since 1999, while crustaceans and tongue worms (Echiuroidea) have dominated in terms of biomass. The overall biomass and abundance of benthic macrofauna in Big Bay increased between 1999 and 2004. This is an indication that the benthic environment in Big Bay had been recovering since the dredging events of 1997/8. A dramatic decrease in both the abundance and biomass of benthic macrofauna in Big Bay was seen between 2004 and 2008. It is likely that this was a response to the dredging events in Small Bay (maintenance dredging of the Multi-Purpose Terminal) in 2007/8 and off north beach at the northern end of Langebaan Lagoon. Much of the reduction in biomass and abundance could be attributed to the loss of crustaceans. There was also a dramatic reduction in the density of polychaetes between 2004 and 2008.

There was a substantial increase in the abundance and biomass of benthic macrofauna in Big Bay between 2008 and 2009. Much of the increase in abundance was attributed to the increase in polychaetes. This was, however, not reflected in the biomass, indicating that the community had become dominated in terms of abundance by small polychaetes. The increase in the overall biomass of the benthic community between 2008 and 2009 was principally attributed to an increase in crustacean biomass. The results of the 2010 survey revealed that the abundance of benthic macrofauna had decreased while the biomass had increased. This indicates that fewer, larger organisms were dominating, and possibly leading to a reduction in the number of smaller organisms through predatory or competitive community interactions. This is a typical sign of the succession of a system following a disturbance. Interestingly, the abundance of polychaetes and crustaceans increased dramatically between 2010 and 2011. This result was not reflected in the biomass results indicating that small crustaceans and polychaetes had colonised the Big Bay area by 2011. The reason for the dramatic increase in the abundance of small polychaetes and crustaceans in Big Bay is not clear. A similar increase in the abundance of small polychaetes was also seen in Small Bay. It is likely that a natural Bay-wide fluctuation, possibly based on nutrient availability and productivity, may have occurred between 2010 and 2011, which supported an increase in the abundance of small polychaetes. The stability of other taxonomic groups and of the proportions of functional groups suggests that the system has not been subject to a negative disturbance and remains in a state of recovery following dredge events.

The biomass of the benthic community in Big Bay has been dominated by filter feeders in all years except 2008 when scavengers became dominant. The increased proportion of scavengers was not reflected in terms of abundance suggesting that few, large scavenging species and many, small opportunistic detritivores colonised the benthic habitat following dredging. Since 2008, the benthic community has shifted back to one dominated by filter feeders both in terms of abundance and biomass, indicating that larger filter feeding species had re-established. A dramatic ten-fold decrease in mean abundance from 5216 ind./m^2 in 2011 to 562 ind./m^2 in 2012 was observed (Figure 7.7). Again, the decrease in mean biomass from 879 g/m^2 in 2011 to 647 g/m^2 in 2012 was not as severe as the decrease in abundance, which supports the notion of a shift towards a recovery in the benthic macrofauna community of Big Bay (r-selective to k-selective species). No change was observed in the proportion of total biomass for each functional group between 2011 and 2012.

Langebaan Lagoon

Langebaan Lagoon generally supports a much lower abundance and biomass of benthic macrofauna than Saldanha Bay. This may be due to the fast water movements and high levels of tidal variation experienced in the Lagoon. The Lagoon is dominated in terms of abundance by polychaetes and crustaceans and in terms of biomass, by crustaceans.

The overall biomass in Langebaan Lagoon declined sharply between 1975 and 2004. The reduction in biomass was linked to a reduction in the abundance of many of the taxa present in 1975 (bivalves, polychaete worms, gastropods, echinoderms, and sea-pens). The overall abundance and biomass of macrofauna in Langebaan Lagoon declined sharply again between 2004 and 2008. The 2008 survey also indicated that the proportion of filter feeders had declined considerably.

The biomass then almost doubled between 2008 and 2009, principally owing to a marked increase in crustaceans. The abundance of macrofauna did not increase proportionately suggesting that larger-bodied crustaceans colonised the lagoon between 2008 and 2009. There were further increases in the abundance and biomass of benthic macrofauna between 2009 and 2010. The increase in the overall biomass in Langebaan Lagoon in 2010 was mainly due to increases in the biomass of polychaetes and echinoderms while the increased abundance of macrofauna was principally attributed to a marked increase in detritivorous crustaceans. The 2011 survey revealed that the abundance of small (low biomass) polychaetes had increased in the Lagoon, while the overall biomass of crustaceans had increased. In addition bivalve communities had increased in both abundance and biomass. The overall biomass measured in 2010 and 2011 exceeded that measured in 1975, however the diversity of taxa has been reduced and crustaceans overwhelmingly dominate the benthic macrofauna biomass. This suggests that the Lagoon may have undergone an ecosystem shift. The 2011 survey results suggest that the Lagoon is in a relatively healthy state given the increases in biomass and abundance and relative stability of functional groups. However, similar to that seen in Saldanha Bay, there had been an increase in the abundance of small polychaetes. The results of the sediment survey in 2011 also revealed system-wide reduction in the mud content and increases in the concentrations of some trace metals. The sediment results coupled with the system wide trends seen in the benthic macrofaunal communities certainly suggest a system wide perturbation, the source or cause of which is unclear.

As with Small Bay and Big Bay, a decrease in mean abundance from 2906 ind./m^2 in 2011 to 660 ind./m^2 in 2012 was observed in Langebaan Lagoon (Figure 7.8). Again, this was not reflected as severely in the mean biomass which saw a reduction from 378 g/m^2 in 2011 to 313 g/m^2 in 2012. Apart from a slight decrease in the mean abundance and biomass of predators, no major changes in the proportion of total abundance and biomass for each functional group were observed between 2011 and 2012. The best possible explanation for these observations, as seen with Small Bay and Big Bay, is a shift in community succession from many small individuals (r-selective) to fewer large individuals (k-selective), indicating a system-wide trend towards recovery in the benthic macrofauna community.

Naval base – Salamander and Donkergat

Both the biomass and the abundance of benthic macrofauna increased dramatically at all sites sampled in Salamander Bay and Donkergat between 2010 and 2011 (Figure 7.9 and Figure 7.10) apart from D1 which saw a decrease in biomass despite an increase in abundance. The polychaete, *Polydora* sp. (an opportunistic detritivore) accounted for the massive increase in abundance at Salamander Site 1, while the larger, filter feeding mud prawn, *Upogebia capensis*, accounted for the dramatic increase in both biomass and abundance at Salamander Site 2.

The 2012 results revealed a substantial decrease in the abundance of benthic macrofauna in Salamander Bay and at site D1 in Donkergat. Much of this reduction can be accounted for by the loss of the small polychaetes such as *Polydora* sp. There was also a reduction in the numbers of the large mud prawn, *Upogebia capensis*, at site S1, which would account for some of the reduction in abundance and the reduction in biomass between 2011 and 2012. The overall increase in biomass seen at site S2 can be accounted for by the increase in *Upogebia capensis* abundance. The trend in the composition, biomass and abundance of benthic macrofauna seen at sites S1, S2 and D1, and the significant loss of the small, opportunistic polychaetes (*Polydora* sp.) suggests that the benthic communities at these sites are in a state of recovery and potentially progressing past a pioneering phase.

Interestingly site D2 showed a different trend to that seen at the other three sites, with an increase in abundance and a decrease in biomass. This suggests that small, opportunistic species had colonised the area since 2011. This may be an indication of disturbance or may represent a natural fluctuation in the community. The benthic macrofaunal community in Salamander Bay and Donkergat in 2012 is dominated both in terms of biomass and abundance by filter feeders. One filter feeder, the opportunistic mud prawn *U. capensis,* accounts for most of the macrofauna biomass at this site.

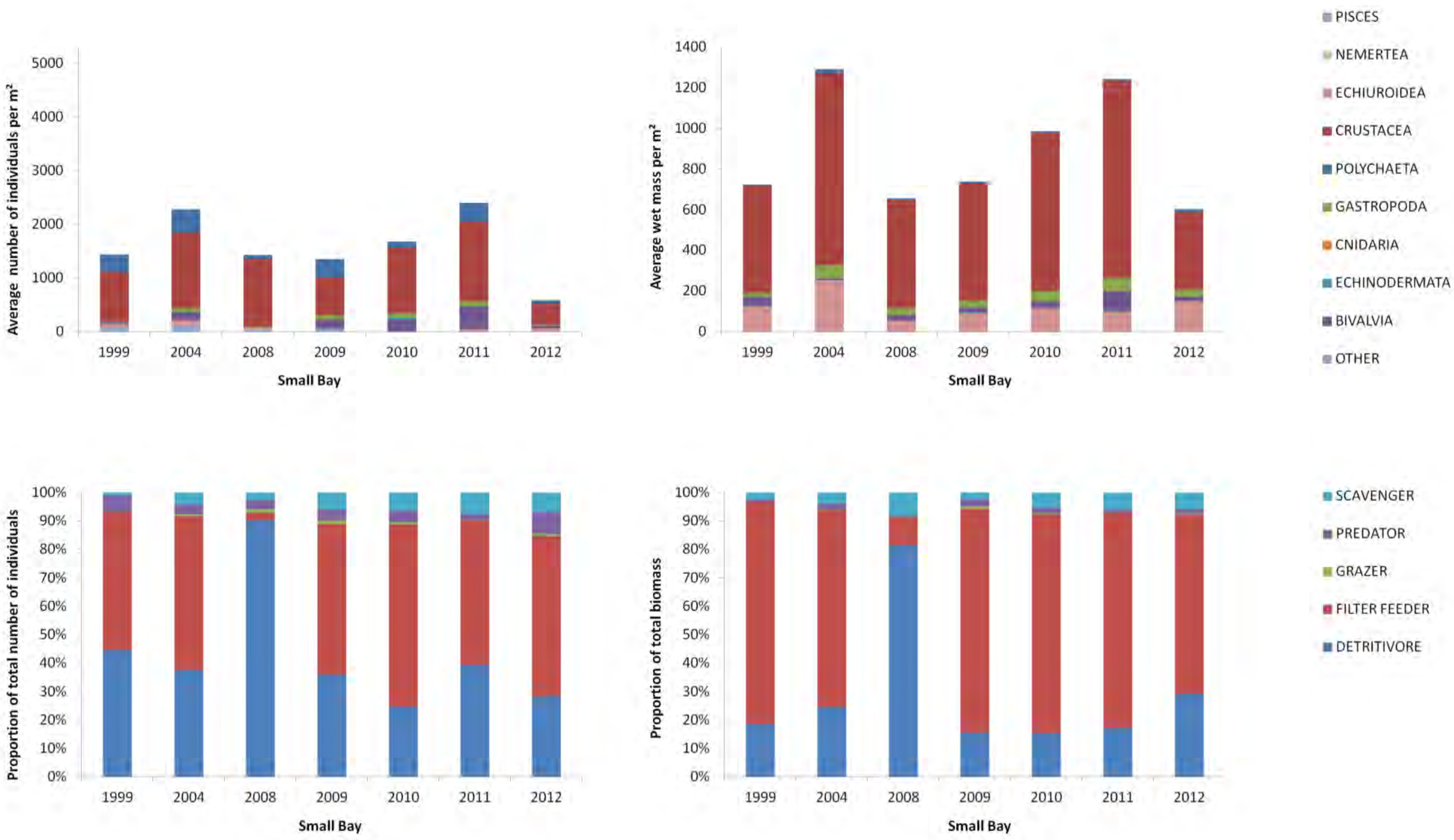


Figure 7.6. **Overall trends in the abundance and biomass (g/m²) of benthic macrofauna in Small Bay as shown by taxonomic and functional groups.**

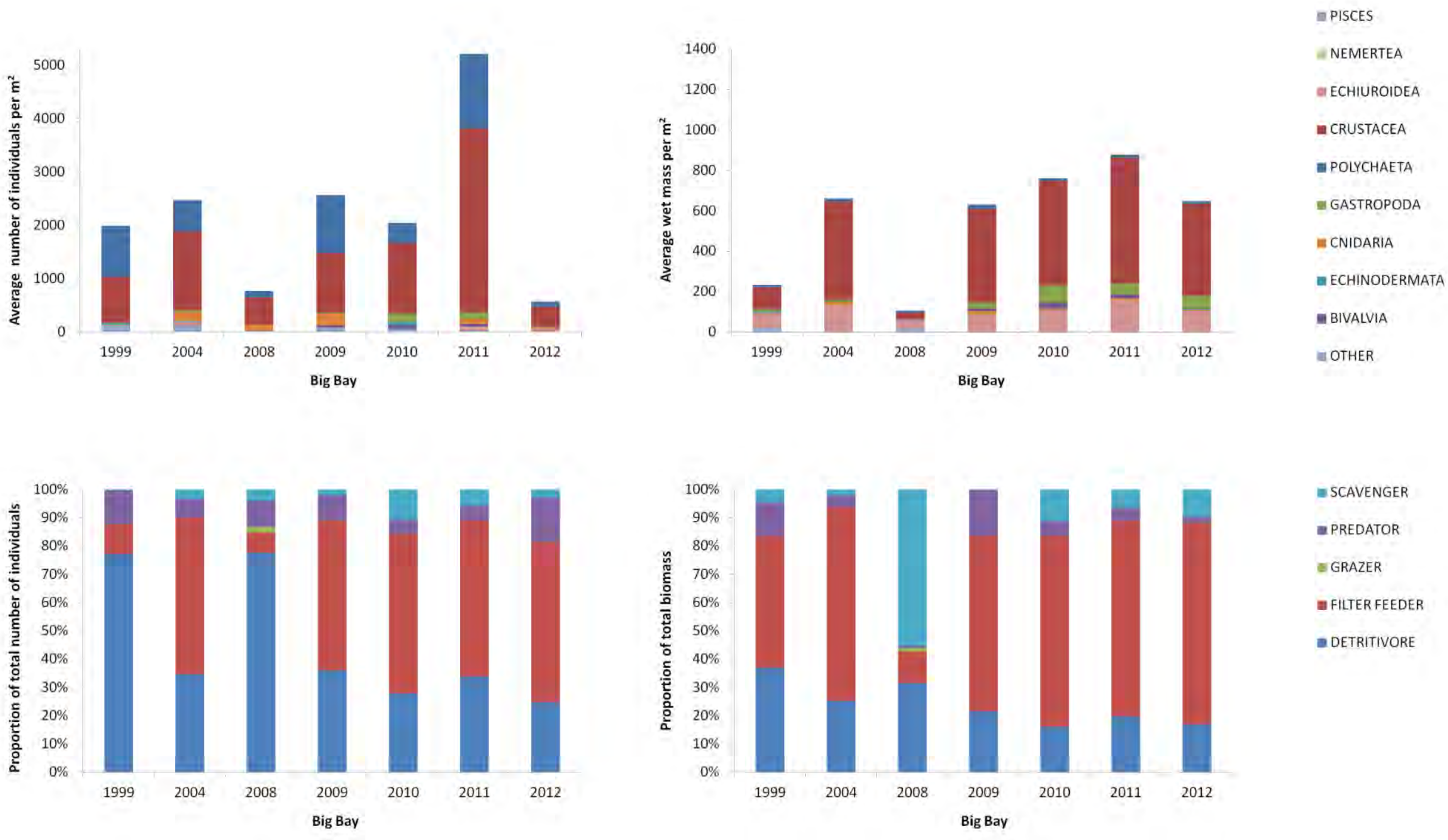


Figure 7.7. Overall trends in the biomass and abundance (g/m^2) of benthic macrofauna in Big Bay as shown by taxonomic and functional groups.

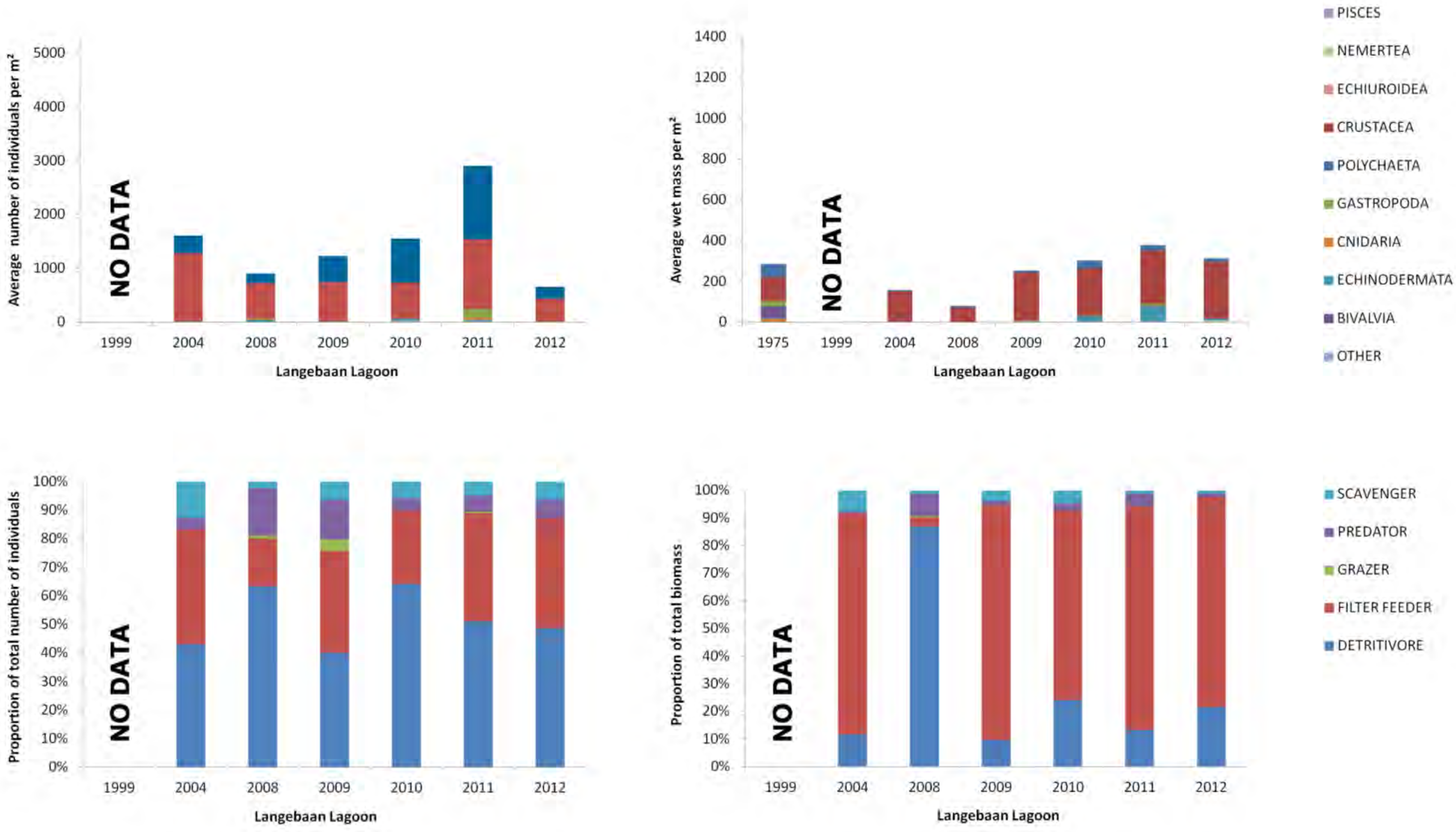


Figure 7.8. **Overall trends in the biomass (g/m^2) and abundance of benthic macrofauna in Langebaan Lagoon as shown by taxonomic and functional groups.**

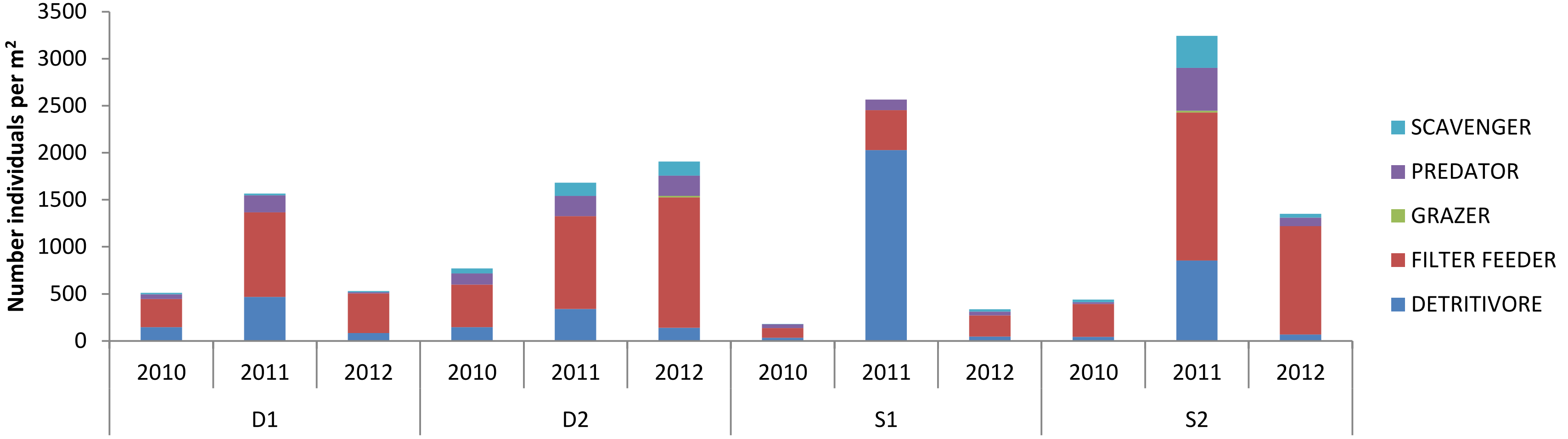


Figure 7.9. Abundance of benthic macrofauna by functional group in Salamander Bay and Donkergat in 2010, 2011 and 2012.

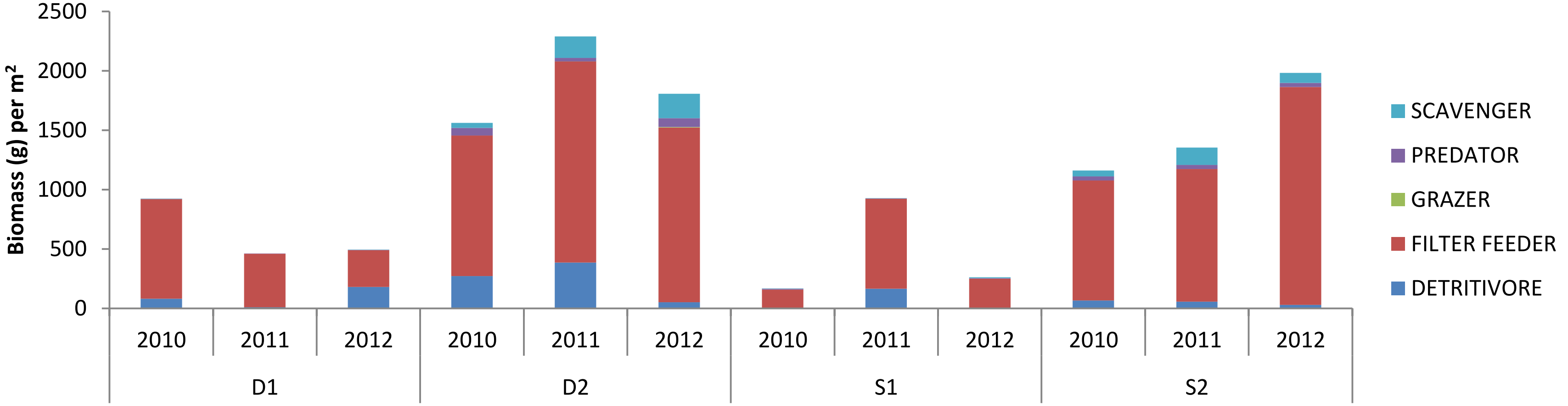


Figure 7.10: Biomass of benthic macrofauna by functional group in Salamander Bay and Donkergat in 2010, 2011 and 2012.

7.4.2 Species Diversity Indices

7.4.2.1 Spatial Analysis

Trends in species diversity (represented by the Shannon Weiner Index, H') for Saldanha Bay and Langebaan Lagoon in 2012 are presented in Figure 7.11. No statistically, significant differences in mean H' diversity were observed between Small Bay, Big Bay and Langebaan Lagoon ($p>0.05$) in these data.

The lowest H' diversity index in Small Bay was recorded at the Multi-purpose Quay (SB14). This is mostly likely due to chronic disturbance at the site that allows a small number opportunistic species to colonize the area and prevent longer living K-strategist species from becoming established. The diversity at the remainder of sites in Small Bay was low to moderate. The area has been subject to permanent modifications to current patterns following the development of the causeway and ore terminal. This coupled with the range of ongoing activities and discharges in and around Small Bay, is likely to have changed the nature of the environment such that communities are unable to revert to their original pre-development state. However, the analysis of the community composition suggests that "recovery" to a healthy, albeit modified community state, is possible. The patchy diversity values as well as the spatial variations in community composition are indicative of community recovery rates which vary over spatial scales and are dependent on both the nature of the environment (depth and exposure) and the frequency and type of anthropogenic disturbance.

The diversity of benthic macrofauna in Big Bay was fairly low throughout, with the exception of BB25 which had a comparatively moderate diversity. The analysis of the sediment characteristics suggested that the central and southern areas of Big Bay were in a relatively healthy state compared to the rest of the system. It is likely that the communities at these sites are stable with low levels of environmental disturbance. The intermediate disturbance hypothesis suggests that at very low frequencies of disturbance most of the community will reach and remain at a climax state with competitive exclusion reducing the diversity to moderate levels. The sediment analysis results form 2012 suggest that the northern areas of Big Bay along the Ore Terminal have similar levels of contamination to that seen in Small Bay. The relatively low species diversity at these sites suggests that this area of Big Bay has been more recently or frequently disturbed than the central part of the Bay. Site BB30, which also showed a relatively low diversity, is a very shallow and exposed site. The communities at this site are thus subject to ongoing natural disturbance and are not likely to progress much beyond a pioneer phase with relatively low diversity values. Indeed, site BB30 was dominated by a high abundance of fairly small predatory polychaetes belong to the group Glyceridae.

Spatial patterns of diversity were patchy throughout the Lagoon with maximum H' diversity recorded towards the southern half at LL34 (2.44) and LL37 (2.32), consistent with previous surveys. The Lagoon comprises a system of shallow sand bars and deeper channels which are subject to strong currents and tidal activities. This ongoing natural disturbance varies spatially and temporally depending on sediment dynamics within the lagoon. It is likely that high diversity levels recorded at many of the sites may be a result of intermediate levels of disturbance. This would allow for succession beyond the pioneer phase, thereby increasing diversity of the communities but without attaining stability. The areas with low diversity may be a result of high levels of disturbance selecting for a few opportunistic species.

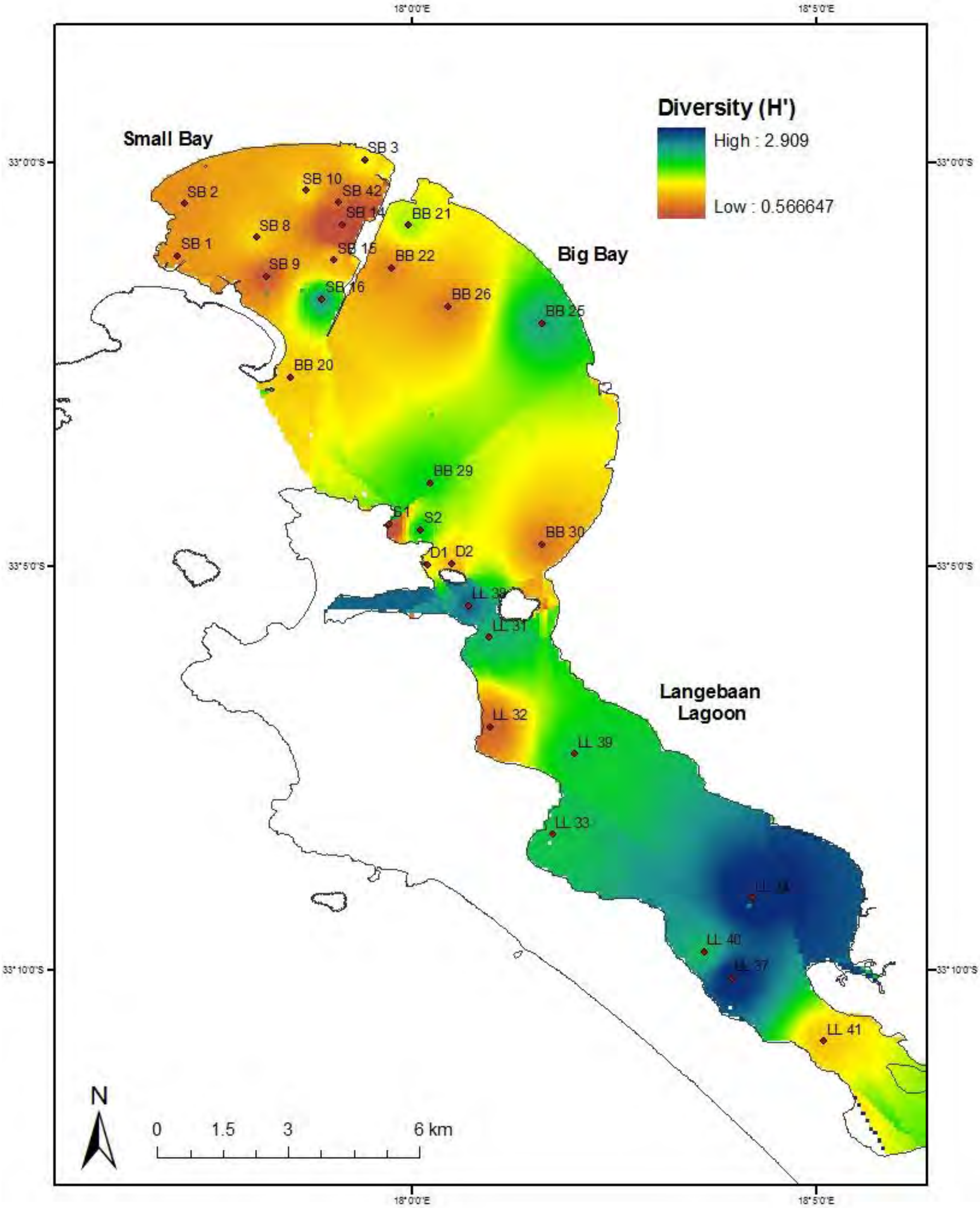


Figure 7.11. Variation in the diversity of the benthic macrofauna in Saldanha Bay and Langebaan Lagoon as indicated by the 2012 survey results. (H' = 1.5 indicates low diversity, H' = 3.5 indicates high diversity).

7.4.2.2 Temporal Analysis

Species Diversity (H') within Small Bay (Figure 7.12), decreased significantly between 1999 and 2008 ($p<0.05$). Results indicate that average diversity for Small Bay increased from 2009 to 2010, however, this is not statistically significant. No change was observed between 2010 and 2011 but a decrease was again observed between 2011 and 2012, but was again not statistically significant. In general the average H' values calculated for Small Bay across time are low and relatively stable suggesting that recovery of the community may not have progressed much beyond a pioneering phase.

Fluctuations in average species diversity (H') observed in Big Bay, across time, are relatively stable and are not statistically significant. The mean diversity of Big Bay is slightly greater than that recorded in Small Bay which may suggest that recovery of the area is beyond a pioneering phase.

Again, fluctuations of average species diversity (H') observed in Langebaan Lagoon and the Naval Base over time, are relatively stable and are not statistically significant. The area is subject to natural disturbance (strong currents and tidal variation) and under such conditions the diversity of benthic communities is expected to fluctuate slightly, hence the observed patchiness and moderate to high average diversity indices.

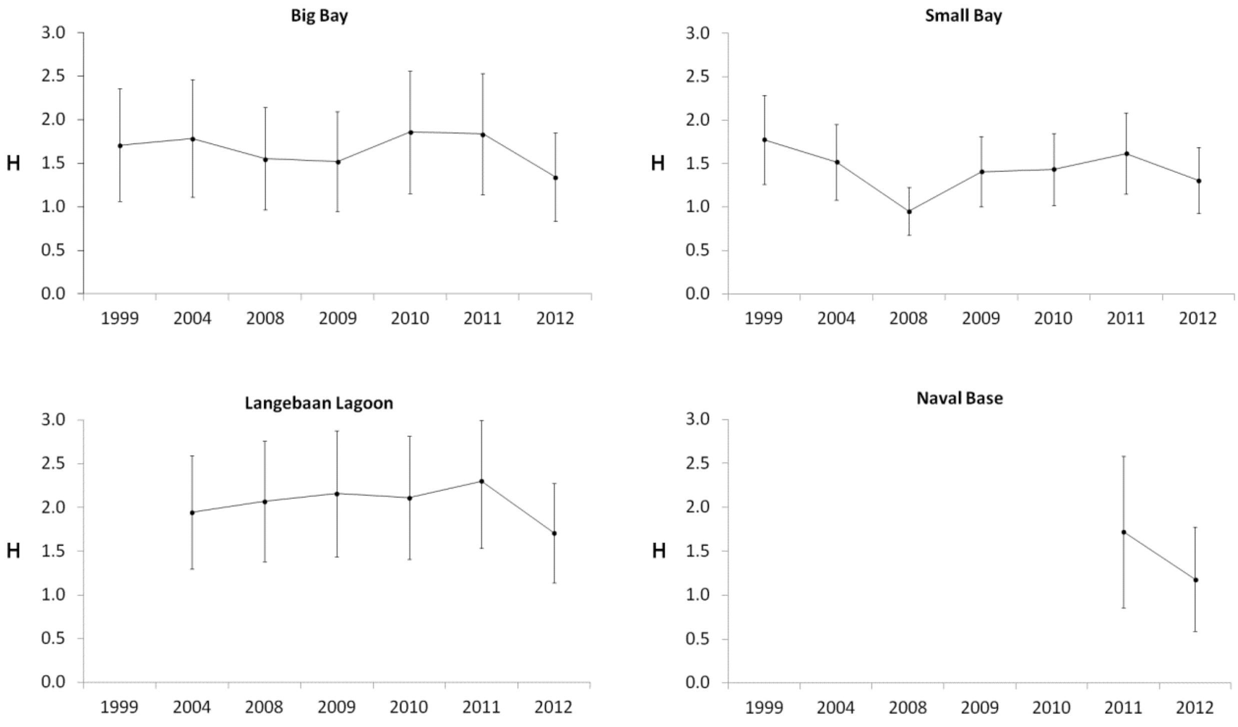


Figure 7.12. Average Shannon Weiner diversity indices across time (H') (± 1 Standard Error) for Big Bay, Small Bay, Langebaan Lagoon and the Naval base.

7.4.3 Linking Ecological Indices to Environmental Variables

MDS plots were generated from macrobenthic abundance data to identify if there were any similarities in community structure between samples drawn from different areas of the Bay and Lagoon (Figure 7.13). Environmental data was then superimposed on top of the MDS plots in the form of bubbles that are scaled in accordance with the magnitude/concentration of the parameter in question (i.e. larger bubbles represent higher concentrations of metals for example). The aim of superimposing bubble plots onto the macrobenthic MDS was to assess whether the spatial variability in the benthic community composition was linked to any specific contamination gradients or environmental variable(s).

Depth and percentage mud appear to be the principle abiotic factors that correlate with, and most likely lead to distinctions in the benthic macrofauna community composition between Langebaan Lagoon and Saldanha Bay. Saldanha Bay is deeper and the sediments contain a higher percentage of mud compared to Langebaan Lagoon. This higher proportion of fine grained particles also correlated with trace metal content. This can clearly be seen at site SB1, SB14 and SB15 which had some of the highest percentage mud content and high trace metal content. Site SB1 represents an impoverished community with a very low abundance and diversity of benthic macrofauna (only 9 species recorded). This site was also identified as impoverished in previous surveys, most likely owing to the high concentrations of organic matter and anoxic conditions within the sediments. Indeed, this site has elevated levels of copper, nickel and lead relative to other sites sampled. In addition it has relatively high concentrations of organic carbon (TOC) and mud. Site SB14 had a higher number of species (14) but was completely dominated by one species, the deposit feeding bivalve *Tellina gilchristi*. Site SB15 had a lower species count (6) and was dominated by an opportunistic amphipod species *Ampelisca palmata*.

The concentrations of trace metals did correlate with the distinction in community composition seen between sites in Small Bay and adjacent to the Ore Terminal in Big Bay, and sites in the central and southern reaches of Big Bay. Any further distinction between the other sites sampled in Small Bay according to benthic macrofauna community composition does not clearly correlate with any of the other environmental variables measured. It is likely that natural community interactions and possibly other environmental variables not measured in this report are having an influence on the community composition in Small Bay.

Figure 7.13 indicates that Langebaan Lagoon is characterised by shallow water depths, and sediments with low percentage mud, particulate organic carbon and very low to negligible concentrations of trace metals (with the exception of Ni). This suite of abiotic factors clearly correlates with the cluster of Langebaan sites that have been grouped according to benthic macrofauna community structure. This indicates that this particular suite of abiotic factors strongly influences the benthic macrofauna communities. More fine scale differences between the benthic communities within the lagoon are clearly not shaped by the abiotic variables considered here and it is likely that other factors such as water circulation patterns and community interactions influence the species composition within the lagoon.

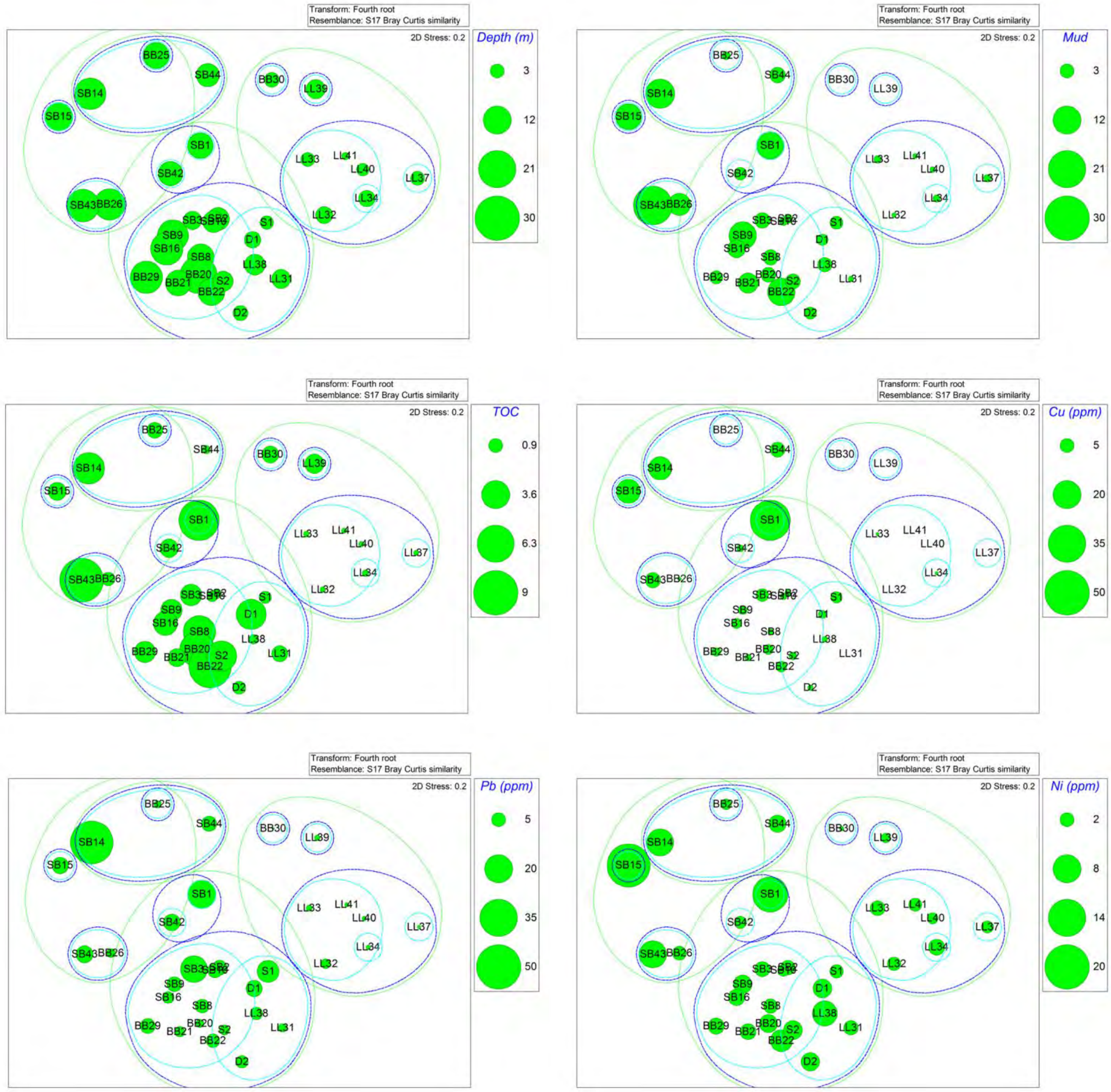


Figure 7.13. **MDS of Saldanha Bay benthic macrofauna abundance (2012) with superimposed circles representing concentrations of select metals: Cu, Pb and Ni. Circle size is proportional to magnitude of concentration (increasing circle size = larger concentration)**

7.5 Discussion

Macrobenthic community structure within Saldanha Bay has been the subject of several studies, most of which focus on anthropogenic impacts to benthic health. Kruger *et al*. (2005) studied the changes in epibenthos within Saldanha Bay as reflected in dredge samples collected in the 1960s and 2001, and found that there was a substantial change in benthic communities before and after harbour development. Severe declines in a number of species were reported, along with a change in the relative dominance of different trophic (feeding) groups, with a reduction in the number of suspension feeders and an increase in the numbers of opportunistic scavengers and predators (Kruger *et al*. 2005). Organisms that preferred sheltered habitats also became more common. These changes were attributed to the restricted flow, altered wave energy, deposition of fine sediments and increased organic matter, which resulted from harbour construction and fish factory and mussel farm effluents (Kruger *et al*. 2005).

Previous studies also indicate that the most significant changes in benthic faunal structure occurred directly after dredging and deepening of the harbour from 1974 to 1976. Up to 25 million cubic meters of sediment were dredged from the Bay, and the dredge spill was used to construct the new harbour wall (Moldan 1978). Dredging directly impacts benthic community structure for a variety of reasons: many organisms are either directly removed or buried, there is an increase in turbidity and suspended solids, organic matter and toxic pollutants are released and anoxia occurs from the decomposition of organic matter (Moldan 1978). Within Saldanha Bay, many species disappeared completely after dredging (most notably the sea-pen, *Virgularia schultzei*) and were replaced by opportunistic species such as crabs and polychaetes (Moldan 1978). Harbours are known to be some of the most highly altered coastal areas that characteristically suffer poor water circulation, low oxygen concentrations and high concentrations of pollutants in the sediment (Guerra-Garcia and Garcia-Gomez 2004). Beckley (1981) found that the marine benthos near the iron-ore loading terminal in Saldanha Bay was dominated by pollution-tolerant, hardy polychaetes. This is not surprising since sediments below the ore terminal were found to be anoxic and high in hydrogen sulphide (characteristically foul smelling black sludge).

Small Bay

An assessment of the temporal variation in the composition, abundance, biomass and diversity of benthic macrofauna communities in Small Bay revealed two principle drivers influencing the benthic ecology in the area. The first and most obvious being the construction of the Ore Terminal and the Marcus Island causeway. These developments altered and reduced currents and wave energy in Small Bay. This permanent and ongoing impact has modified and reduced the capacity of the benthic environment to recover from large scale perturbations like dredging. In addition, this has changed the nature of the environment and by doing so has changed the community structure and composition of species which can be supported by that environment. It is thus unlikely that benthic communities will ever recover to the pre-development state in Small Bay. However, this does not suggest the ecosystems in Small Bay cannot reach a "healthy" state. Indeed, increases in the abundance, biomass and diversity of benthic macrofaunal communities since 2008 do indicate the ongoing recovery of the area. Assessments of the community composition within Small Bay in 2012 reveal spatial variations with sites in the northern reaches (further from dredged areas and Ore Terminal) having larger species and slightly higher diversity values. This suggests that impact intensity and recovery rates vary over spatial scales within Small Bay.

The second principle driver of change with fairly wide-scale impacts in Small Bay is dredging. Dredge events have generally lead to an increase in mud content and trace mental contamination levels, coupled with a reduction in macrofauna biomass, abundance and diversity. In the years immediately after dredge events the benthic communities were dominated by fast growing opportunistic species such as the amphipods, *Ampelisca spinimana* and *A. anomala*. The most recent dredging event in Small Bay was the maintenance dredging at the Mossgas quay and the Multi-Purpose Terminal. Dredging took place at these locations from the end of 2007 to March/April 2008 with an estimated 50 000 m^3 of seabed material being removed from both terminals in order to deepen the berth. The 2008 survey of sediments revealed that there had been increases in the percentage mud, particulate organic carbon, cadmium, lead, copper and nickel at most of the Small Bay sites and as a result, significant changes in the benthic macrofauna community structure were observed. The average abundance and biomass of benthic macrofauna decreased and the diversity index (H') decreased indicating that the proportion of fast growing opportunistic species in the community had increased. Indeed, the opportunistic amphipods, *Ampelisca spinimana* and *A. anomala*, had become dominant species in the Small Bay macrofauna community. *Ampelisca sp*. are detritivores and are abundant in dredging and on fine sand, and thus it is not surprising that they had become dominant at several sites in Small Bay.

Data on physical parameters from 2009 and 2010 (percentage mud, particulate organic carbon and trace metal concentrations) indicated an improvement in the health of the Bay. Signs of the succession of the benthic macrofaunal community were evident when assessing temporal variation in community composition between 2008 and 2010. The 2008 results indicated that the abundance of the dominant mud prawn, *Upogebia capensis* was greatly reduced following dredging. With the reduction of *U. capensis,* smaller pioneer species, more tolerant of disturbed conditions (viz. increased fines, organic carbon and trace metals), increased in abundance and came to dominate the community in this area. In this case the opportunistic, tolerant species were the amphipods, *Ampelisca spinimana* and *A. anomala.* A year later (2009), following improvements to the physical environment, it was clear that with the still slightly suppressed levels of *U. capensis*, detritivorous and filter feeding polychaetes were able to colonise Small Bay and become dominant species while *Ampelisca spp*. populations had reduced. It is likely that the amphipods were being outcompeted by the polychaetes and *U. capensis*. Another year later (2010) and following further improvements to physical parameters in the bay, the abundance and biomass of polychaetes had declined, while there had been further increases in the abundance and biomass of *U. capensis*. In addition there had been increases in the abundance of the detritivorous, bivalve *Tellina gilchristi* and the carnivorous, gastropod *Nassarius speciosus.* It is possible that *U. capensis* has become a climax species for the present day Small Bay system which has been drastically altered from its historical state by the development of the causeway and iron ore terminal. The 2011 survey results revealed two clear clusters of sites based on community composition, one cluster around the Ore Terminal and one in the northern reaches of Small Bay. Those around the Ore Terminal were distinguished from the northern sites by high abundances of the opportunistic species such *Ampelisca spp*. The sites around the Ore Terminal also had a slightly lower diversity than those to the north. This indicates that the intensity or frequency of impact at these sites was greater and that the community is at an earlier stage of succession than the sites in northern Small Bay.

A variety of ongoing activities within Small Bay are also likely to compromise ecosystem health including the discharge of effluents from fish factories, mariculture operations, shipping traffic, port and boating activity, discharge of sewerage effluent (via the Bok River, which drains into Small Bay), seepage or overflow from sewerage pump stations and septic tanks, and residential and industrial storm-water runoff (CSIR 2002). Environmental perturbations caused by these activities are most likely exacerbated by the poor water circulation and reduced wave energy within Small Bay, which effectively reduces the flushing capacity of the Bay and results in the build-up of contaminants.

Pollution tolerant species have previously been found in high abundance at sites adjacent to fish factory outfalls (Christie and Moldan 1977). Effluent discharged from the fish factories contains high levels of organic matter (mainly bloodwater, fish flesh and offal), that settles out at varying distances from the outlet. Once it settles on the bottom, the organic matter in the effluent is broken down by detritivores, which ultimately leads to hypoxia or even anoxia. Anaerobic conditions thus often prevail close to fish factory outlets and this adversely effects macrobenthic diversity and abundance (Christie and Moldan 1977). While it was not possible to isolate the effects of the fish factory effluent in this study, earlier studies have found that benthic macrofaunal communities within Small Bay in the immediate vicinity of the outfalls from these factories were impoverished, and that diversity increased with distance from the fish factory (Christie and Moldan 1977; Jackson and McGibbon 1991). It is quite likely therefore that the effects of this continued discharge of waste to Small Bay contributed to the decline in overall health of the system between 1999 and 2008.

Mussel and oyster farms the major mariculture activities which take place in Saldanha Bay. A study conducted in 1993 revealed that raft-culture of mussels in Small Bay was adversely affecting benthic ecology, with disturbed communities occurring beneath 78% of the mussel rafts (Stenton-Dozey *et al*. 1999). This was attributed to the high organic loading beneath the raft, resulting from faeces produced by mussels and other fouling organisms such as the sea squirt *Ciona intestinalis* settling and decomposing on the bottom below the rafts. Benthic communities below the mussel rafts were characterised by deposit feeders and carnivores with a rapid turnover time, and hence labelled as unstable (Stenton-Dozey *et al*. 1999). Again, mussel rafts are likely to have contributed to the declines in benthic diversity and health observed in Small Bay between 1999 and 2008, but it has not been possible to isolate these effects in this study.

Results from the current 2012 survey show that the Small Bay sites are divided among four different clusters, two of which consist of heavily impacted sites. The macrofauna community at site SB1 is starting to show signs of recovery, given the observed increase in number of species and abundance. For the first time it is no longer an outlier and is clustered with site SB42, a site located along the Iron Ore jetty also heavily impacted, however to a lesser degree than SB1 has been impacted in the past. The other two heavily impacted sites, SB44 and SB14 are in close proximity to SB1 and SB42 and are also clustered together. The remaining sites in the northern part of Small Bay and at the end of the Iron Ore Terminal are clustered together with some Big Bay sites along the Iron Ore terminal and to the southern end of Big Bay near the Naval Base development. The northern sites in Small Bay were previously the least impacted of those in Small Bay. The fact that they now share increased similarity with other sites near the Iron Ore Jetty and near the Naval Base would suggest either decrease in the health of the macrofaunal communities at the Northern Small Bay sites or an improvement in the health of the other sites near the Iron Ore terminal and Naval Base. The latter is more likely given the observed reduction in abundance and biomass – i.e. communities consisting of fewer larger animals (K-strategists) as opposed to many small animals (R-strategists), which is indicative of a shift towards recovery in the benthic macrofauna community of Small Bay.

Big Bay

The sites within Big Bay showed no grouping of their own and clustered with one of two significant groups from Small Bay (Figure 7.2, Figure 7.5). Site BB26, located near the oyster rafts, and SB43, near the mussel rafts, are clustered together in their own subgroup and share 45% similarity. It is likely that the disturbance associated with the adjacent mariculture activity has a strong influence on the benthic community structure and is driving the observed similarity at these sites. Sites BB25 and SB15 are situated further away from the mariculture rafts. As a result, they are not as heavily impacted and therefore share lower similarity to the subgroup of BB26 and SB43.

The second cluster of sites from Big Bay and Small Bay also cover a wide range of depths and vary a lot in terms of the mud content, hence it is unclear as to what may be driving similarity in benthic community structure between sites within this cluster. What can be deduced is that communities at these sites are dominated by *Upogebia capensis* (35%), *Ochetostoma capense* (19%) and *Glycera tridactyla* (11.6%). These species are commonly found in sheltered habitats and have since become established in Saldanha Bay following the construction of the Marcus Island causeway and Iron Ore terminal in the early 1970's. As is the case with Small Bay, it is possible that these species have become a climax species for the present day Big Bay system which too has been altered from its historical state by the development of the causeway and iron ore terminal.

The analysis of the sediment characteristics suggested that the central and southern areas of Big Bay were in a relatively healthy state compared to the rest of the system. It is likely that the communities at these sites are stable with low levels of environmental disturbance. The intermediate disturbance hypothesis suggests that at very low frequencies of disturbance most of the community will reach and remain at a climax state with competitive exclusion reducing the diversity to moderate levels. Site BB30, which showed a relatively low diversity is a very shallow and exposed site. The communities at this site are thus subject to ongoing disturbance and are not likely progress much beyond a pioneering phase with relatively low diversity values. Indeed site BB30 was dominated by a high abundance of small deposit feeding polychaetes belong to the Spionidae family. The suspension feeding sea pen, *Virgularia schultzei,* was also found in high abundance at sites at the southern and central reaches of Big Bay. These organisms are typical K-strategists and thus support the notion that the area is in a relatively stable state.

Generally crustaceans and polychaetes have dominated the benthic macrofauna community in Big Bay in terms of abundance in all surveys conducted since 1999, while crustaceans and tongue worms (Echiuroidea) have dominated in terms of biomass. An overall increase in biomass, abundance and diversity of benthic macrofauna in Big Bay 1999 and 2004 suggested that the communities had been recovering since the dredging events of 1997/8. The dramatic decrease in abundance, biomass and diversity of benthic macrofauna in Big Bay between 2004 and 2008 was likely to be a response to the dredging events in Small Bay (maintenance dredging of the Multi-Purpose Terminal) in 2007/8 and off north beach at the northern end of Langebaan Lagoon. Much of the reduction in biomass and abundance could be attributed to the loss of crustaceans and polychaetes.

A significant decrease in mean biomass of benthic macrofauna from 2011 to 2012 was not as severe as the observed decrease in abundance. Furthermore, the community composition in terms of both taxonomic and functional groups did not change which, like Small Bay, is indicative of succession in the benthic macrofauna community towards recovery in the wake of a disturbance event (r-selective to k-selective species).

Salamander Bay and Donkergat

The depth of the sites sampled in Salamander Bay and Donkergat ranged between 2.8 m and 6.3 m, which is a similar depth range to sites sampled in the Lagoon, at the southern end of Big Bay and in the northern reaches of Small Bay. The results of the 2011 sediment analysis revealed that the sediments in the Donkergat and Salamander Bay areas had a relatively low mud content similar to that of the northern reaches of Small Bay, but greater than the Lagoon or southern reaches of Big Bay. This, in addition to the position of the sites within embayments and on the opposite site of Big Bay to the dominant swell direction, suggests that the Donkergat and Salamander areas are slightly more sheltered than the Lagoon and the eastern side of Big Bay. The percentage organic matter in the sediments was at a relatively moderate level also comparable to that of the northern parts of Small Bay.

Interestingly, the 2011 trace metal concentrations greatly exceeded that found in the Lagoon, Big Bay or the northern reaches of Small Bay, and instead resembled that found in the most contaminated sites in Small Bay; namely the Yacht Club Basin and the Multi-purpose quay. Contaminants, such as metals, are predominantly associated with fine sediment particles (mud or cohesive sediments). This is due to the fact that fine grained particles have a larger surface area for the adsorption and binding of pollutants. Higher proportions of mud, relative to sand or gravel, can thus lead to high trace metal contamination. Based on the particle size composition, under pristine conditions in Donkergat and Salamander Bay trace metal concentrations would be expected to be less than or equal to, but certainly not exceeding the concentrations seen at sites in the northern reaches of Small Bay. The fact that concentrations of trace metals in Donkergat and Salamander Bay exceeded that seen in Big Bay and the northern reaches of Small Bay suggests that the area had been subjected to disturbance. The dredging events that took place in 2009 and 2010 as part of the boat yard construction process re-suspended sediments and the associated trace metals. This activity was most likely the principle contributor to the contamination seen in Donkergat and Salamander Bay. Another contributor might include the unintentional releases of chemicals from boat cleaning processes and anti-foulants, although the extent to which this may have occurred is not known.

Analysis of sediment data from 2012 suggests that no impacts of the dredging to the particle size composition in Donkergat and Salamander Bay can be detected in 2012. Similarly, data on trace metal content suggests that contamination levels in Donkergat and Salamander have decreased to their former natural levels apart from site D1 which displayed similar trace metal contamination to site SB43 in Big Bay. This suggests that contaminants that were resuspended during dredging have not yet been completely dispersed or assimilated. However, the assessment of trends in contaminant levels suggests that factors external to Donkergat and Salamander Bay specifically are also likely to be contributing to trace metal contamination.

The 2012 macrofauna species composition, biomass and abundance for three of the four sites (S1, D1 and D2) do certainly suggest some level of recovery since 2011 having clustered with two northern Langebaan Lagoon sites; LL38 and LL34. The reduced diversity values and overwhelming dominance of the opportunistic and relatively large mud prawn, *Upogebia capensis,* does suggest that the communities are still in a pioneering phase and relatively poor state. Given the relatively greater diversity and reduced biomass (i.e. more K-selected taxa), site S2 was clustered together with a combination of sites from Big Bay and Small Bay (group D1) thus showing signs of accelerated recovery in comparison to the other Donkergat and Salamander Bay sites. The fact that the 2010, 2011 and 2012 benthic macrofauna communities in Donkergat and Salamander Bay, were statistically distinct from one another each year, indicates a dynamic community undergoing succession following a disturbance (dredging).

Langebaan Lagoon

The benthic macrofauna communities sampled in Langebaan Lagoon have been significantly different to those in Saldanha Bay in all surveys since 2004. This is most likely due to differences in the physical and biogeochemical processes predominating in the marine environment of Langebaan Lagoon compared with those in the Bay (CSIR 2002). The macrofauna in Langebaan Lagoon has been dominated by several small opportunistic species such as amphipods and polychaetes which suggests the system is relatively unstable and the benthic communities prone to high natural disturbance levels. Furthermore, the Lagoon generally supports a much lower abundance and biomass of benthic macrofauna than Saldanha Bay. The low stability of the environment in the Lagoon is most likely a result of the fast water movements and high levels of tidal variation rather than an anthropogenic disturbance. However, historically there is some evidence suggesting that anthropogenic activities had a negative impact on the benthic ecology.

The overall biomass and species diversity in Langebaan Lagoon declined after 1975 following dredging. The reduction in biomass was linked to a loss in the abundance of many of the taxa present in 1975 (bivalves, polychaete worms, gastropods, echinoderms, and sea-pens).

Changes in macrobenthos in Langebaan Lagoon may also be related to the recent invasion by the European mussel *Mytilus galloprovincialis*. During the mid-1990s an introduced alien invasive mussel *M. galloprovincialis* began establishing dense intertidal beds on two intertidal sand flats close to the mouth of Langebaan Lagoon (Hanekom and Nel 2002). The mussel beds reached an estimated biomass of close to eight tons in 1999 raising concerns that the invasion could spread to the rest of the lagoon and other sandy substrata (Hanekom and Nel 2002). A comparative study between invaded and non-invaded areas showed a replacement of sandbank species communities by those typically found in rocky shores where the mussel provided the hard substratum suitable for their settlement (Robinson and Griffiths 2002). In early 2001, however, the mussels had started to die off and by mid-2001 only dead shells and anoxic sands remained. The precise causes of the die off have not been established but siltation and lowered food availability are suggested as possible reasons behind the declines (Hanekom and Nel 2002). In an effort to prevent the re-settlement of the mussel South African National Parks began to remove dead mussel shells in late 2001 (Robinson *et al*. 2007b). A study looking at the ecological impacts of the invasion and subsequent clearing of the dead shells was done comparing pristine non-invaded areas, invaded areas that had living mussel beds, un-cleared areas with no living mussels but a thick remnant mussel shell layer, and areas cleared of dead mussels (Robinson *et al*. 2007). The study found that community composition differed significantly between non-invaded and invaded areas where mussel created a multilayered complex habitat promoting the colonization of rocky-shore species. This significantly increased biomass but not species diversity, reflecting a replacement of the natural sandy ecosystem for a typical rocky-shore system (Robinson *et al*. 2007). After the die-off and subsequent clearing of the dead shell remains, some recovery was already evident between non-invaded and cleared areas after only 5 months. Although no significant differences were found between non-invaded and cleared areas, the absence of more than 50% of the species from the cleared areas shows that total recovery had still not been attained. The mussel invasion thus dramatically altered natural community composition which remained different from non-invaded areas even 5 months after the clearing, when the study ended. Fortunately this invasion was short-lived.

The overall abundance and biomass of macrofauna in Langebaan Lagoon declined sharply again between 2004 and 2008. The 2008 survey also indicated that the proportion of filter feeders had been drastically reduced. These results were possibly linked to the dredging that took place at the northern end of lagoon as part of the beach erosion mitigation. The biomass then almost doubled between 2008 and 2009, principally owing to a marked increase in crustaceans. The abundance of macrofauna did not increase proportionately suggesting that larger-bodied crustaceans colonised the lagoon between 2008 and 2009. There were further increases in the abundance and biomass of benthic macrofauna between 2009 and 2010. The 2011 survey revealed that the abundance of small (low biomass) polychaetes had increased in the Lagoon, while the overall biomass of crustaceans had increased. In addition bivalve communities had increased both in terms of abundance and biomass. The overall biomass measured in 2010 and 2011 exceeded that measured in 1975, however, the diversity of taxa has been reduced and crustaceans overwhelmingly dominated the benthic macrofauna biomass. This suggests that the Lagoon may have undergone an ecosystem shift. The 2011 survey results suggested that the Lagoon is in a relatively healthy state given the increases in biomass and abundance and relative stability of functional groups. However, similar to that seen in Saldanha Bay, there had been an increase in the abundance of small polychaetes. No significant changes were observed in the 2012 survey results with similar levels of abundance, biomass and species composition recorded. The results of the sediment survey in 2011 and 2012 also revealed system-wide reduction in the mud content and increases in the concentrations of some trace metals. The sediment results coupled with the system wide trends seen in the benthic macrofaunal communities certainly suggest a system wide perturbation, the source or cause of which is unclear.

The average diversity of macrofauna in Langebaan Lagoon was relatively low in 2004, but increased between 2004 and 2008 and 2008 and 2009 such that the lagoon supported a moderate level of diversity. This suggests that benthic macrofauna communities have been in a state of recovery following a major perturbation in the past. This recovery seems to vary spatially as diversity values are very patchy around the Lagoon. The 2010 survey revealed that there had been a very slight decrease in the diversity of macrofauna. By 2011 the average diversity of benthic macrofaunal communities in the Lagoon had increased to a fairly high level of diversity. The area is subject to natural disturbance (strong currents and tidal variation) and under such conditions the diversity of benthic communities is expected to fluctuate slightly, be relatively patchy and remain moderate to high. This is likely to be the reason for the observed decrease in diversity, mean abundance and biomass of benthic macrofauna in Langebaan Lagoon for 2012. The Lagoon comprises a system of shallow sand bars and deeper channels which are subject to strong currents and tidal activities. This ongoing natural disturbance varies spatially and temporarily depending on sediment dynamics within the lagoon. The high diversity levels recorded at many of the sites may be a result of intermediate levels of disturbance which would allow for communities to pass the pioneering phase and increase in diversity but without reaching a stable state. The areas with low diversity may be a result of high levels of disturbance selecting for a few opportunistic species.

7.6 Summary of benthic macrofauna findings

Soft-bottom benthic macrofauna (animals living in the sediment that are larger than 1 mm) are frequently used as a measure to detect changes in the health of the marine environment resulting from anthropogenic impacts. Measures of the numbers, abundance and biomass of species making up the benthic community from studies conducted prior to development of Saldanha Bay are compared to data from recent surveys (1999, 2005, 2008, 2009, 2010 and 2011). Prior to this period (i.e. prior to the advent of many of the major changes in the Bay) benthic macrofauna surveys of the area were conducted using slightly different methods to those of more recent studies. Nevertheless, taking these differences into consideration, it is evident that there have been significant changes in benthic communities within the Bay. The most dramatic changes are those in the overall abundance, biomass and composition of the fauna in the various section of the Bay (Small Bay, Big Bay and Langebaan Lagoon). Importantly, trends in overall abundance and biomass in the respective sections of the Bay have tracked one another very closely since 1999.

Starting off at modest levels in 1999, both abundance and biomass shot up to fairly high levels in all three sections of the Bay in 2004 before dropping down to low levels again in 2008 (regrettably no data are available to show what happened in the intervening years between 1999 and 2004 and between 2004 and 2008). Thereafter both overall abundance and biomass in all three parts of the Bay increased steadily year-on-year until 2011, before dropping down dramatically again in 2012 (the most recent survey).

Changes in community composition (both in terms of the contribution by different taxonomic groups and different feeding groups) have also very similar across the three areas of the Bay with the most dramatic changes being associated with the relative contribution made by filterfeeders and Crustaceans (mudprawns, sandprawns, amphipods and isopods). Filterfeeding species are typically more sensitive to changes in water quality than detritivores or scavengers and account for much of the variation in overall abundance and biomass in the Bay. When overall abundance and biomass are low, the communities tend to be dominated by detritivores, but when they are high, they tend to be dominated by filter feeders.

The sea pen *Virgularia schultzei,* a species highly sensitive to disturbance and pollution, recorded throughout the Bay in the earliest surveys conducted in the 1970’s, was not present in the earliest State of the Bay surveys (2004 and 2008) but has been recorded again in increasing numbers Big Bay since this time, suggesting an improvement in the health of the benthic community in this part of the Bay at least. Some, but not all of these changes appear to be linked to large-scale dredging events in the Bay. For example, the overall low species richness, abundance and biomass recorded in 1999, following a major dredging event in 1997/8 (extension of the Multi-Purpose Terminal), appeared to have increased by 2004 following a period of minimal disturbance, declined again to a low level in 2008 following further dredging around the MPT and Mossgass Quay, increased steadily again until crashing again spectacularly in 2012 following some fairly modest dredging activities around Caisson 3 and 4 on the Saldanha side of the Iron Ore Terminal in 2010/11.

Overall, conditions in Small Bay remain very much poorer than those in Big Bay or Langebaan Lagoon. The most severely-impacted sites within Small Bay in 2011 are the Yacht Club basin and the base of the ore terminal. These sites are prone to the accumulation of pollutants due to restricted water movement. At one point (2008) benthic fauna have been almost entirely eliminated from the Yacht Club basin in Small Bay, owing to very high levels of trace metals and other contaminants at this site (POC, Cu, Cd and Ni). Benthic macrofauna communities in this area have, however, recovered steadily year-on-year since this time and are now almost on a par with the other sites in Small Bay.

Impacts of the dredging activities in Salamander Bay for the expansions of the Naval Boatyard in this area (2010) were also clearly evident in the data from these sites for several years following this development but have now finally returned to more natural levels.

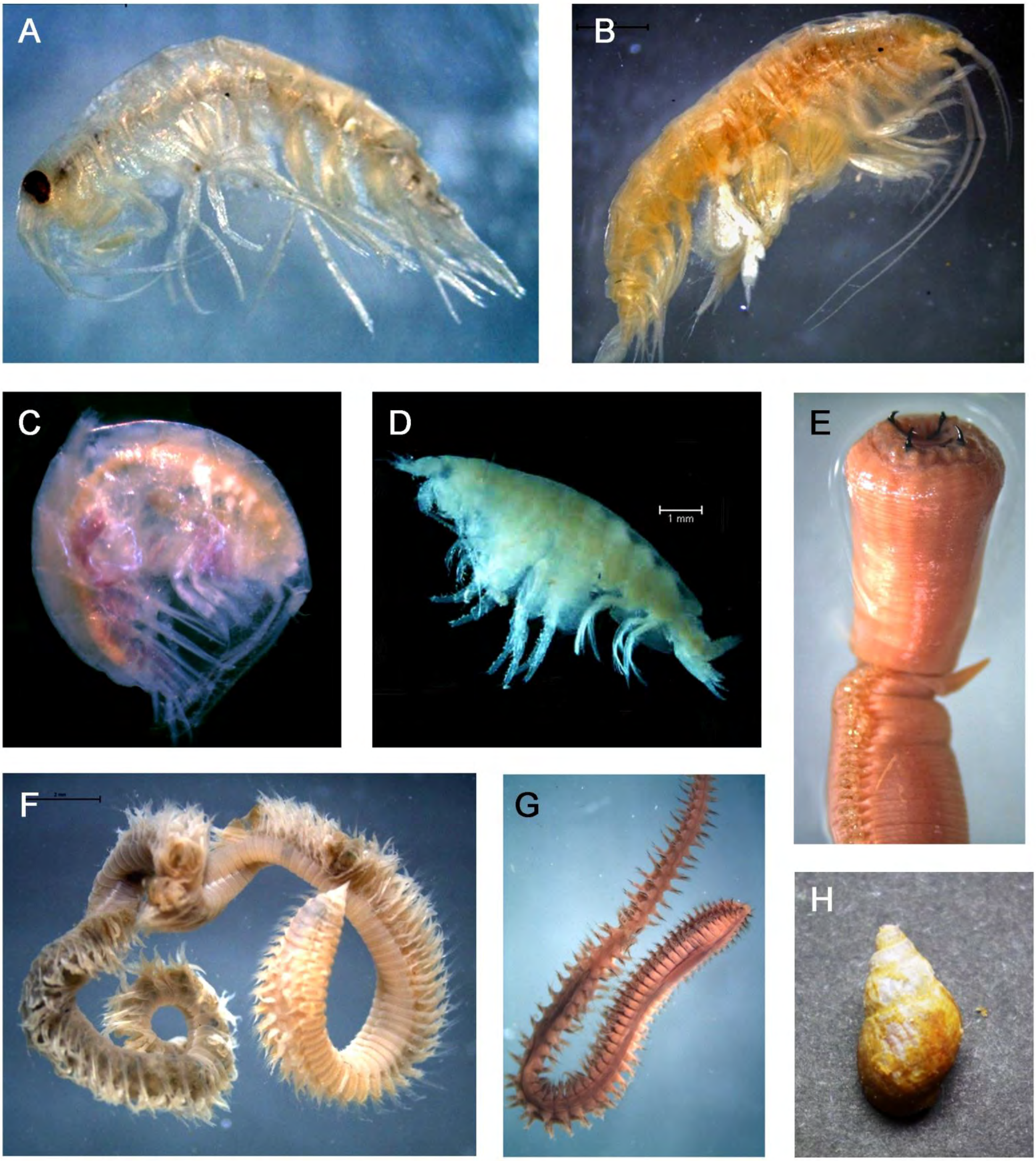


Figure 7.14. Benthic macrofauna species frequently found to occur in Saldanha Bay and Langebaan Lagoon, photographs by: Nina Steffani and Aiden Biccard. A – *Paramoera capensis*, B – *Ampelisca brevicornis*, C – *Ampelisca palmata*, D – *Hippomedon normalis*, E – *Glycera tridactyla*, F – *Orbina angrapequensis*, G – *Nephtys hombergii,* H – *Nassarius vinctus*.

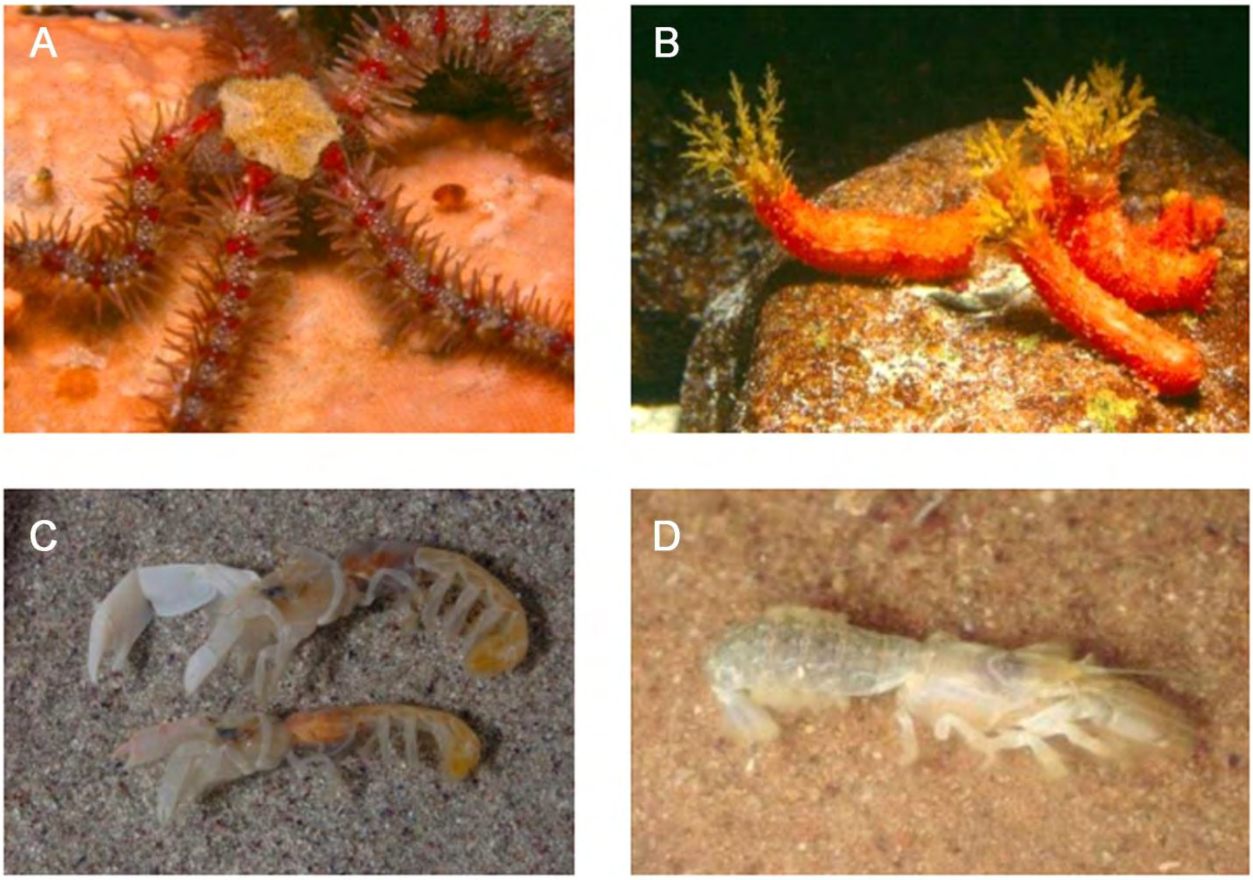


Figure 7.15. Benthic macrofauna species frequently found to occur in Saldanha Bay and Langebaan Lagoon, photographs by: Charles Griffiths. A – Ophiuroidea, B - *Pseudonella insolens*, C - *Callichirus kraussi,* D – *Upogebia capensis*.

8 INTERTIDAL INVERTEBRATES (ROCKY SHORES)

8.1 Background

Despite the known changes that have taken place within the Saldanha Bay system over the last fifty years, almost no historical data exists on the state of rocky-shores in the area. Species presence/absence data was collected by undergraduate students of the University of Cape Town at Lynch Point Schaapen Island between 1965 and 1974 (Griffith *pers. comm.*). The accuracy and reliability of this data is, however, questionable and it is thus of limited value for monitoring changes in the health of the Bay ecosystems. Only a single historical study by Robinson *et al*. (2007) has examined the species composition of rocky intertidal communities Saldanha Bay in any level of detail. This study examined changes in community composition on the rocky-shores of Marcus Island between 1980 and 2001, focusing on the impact of the alien invasive Mediterranean mussel, *Mytilus galloprovincialis*

Monitoring of rocky intertidal communities in the Bay was initiated as part of the State of the Bay monitoring programme in an effort to fill the gap in knowledge relating to rocky intertidal communities in the Bay. The first rocky shore survey for this programme was conducted in 2005, the results of which are presented in the first 'State of the Bay' report (Anchor Environmental Consultants 2006). Eight rocky shores spanning across a wave exposure gradient from very sheltered to exposed, were sampled in Small Bay, Big Bay and Outer Bay as part of this baseline. These surveys were repeated in 2008, 2009 and 2010 (Anchor Environmental Consultants 2009, 2010, 2011). In agreement with results from the baseline survey, it was concluded that wave force is primarily responsible for shaping the intertidal rocky shore communities. More sheltered shores are dominated by seaweeds, while sites more exposed to higher wave energy are characterised by filter-feeders. It was suggested that the construction of the Marcus Island causeway and the Iron Ore Terminal had reduced the wave energy reaching rocky shores in Small Bay, having thus led to a change in community structure. As no historical data exist from these shores for confirmation, this remains speculative though. The results further indicated that the topography of the shore also influences community structure as sites consisting of rocky boulders had different biotic cover to shores with a flatter profile. Geographic location is also of importance, for example sampling stations on the bird breeding island Schaapen Island are situated in a transitional zone between the Saldanha Bay and the Langebaan Lagoon system. These same sites are also affected by high nutrient input through seabird guano that favours algal growth. Generally, the Saldanha Bay communities were healthy apart from the presence of two alien invasive species, the Mediterranean mussel *Mytilus galloprovincialis* and the North American barnacle *Balanus glandula*.

This chapter present results from the third annual monitoring survey conducted in May 2011.

8.2 Approach and Methodology

8.2.1 Study Sites

Spread along the shoreline of Saldanha Bay, eight rocky shore sampling sites were first visited during the baseline survey in 2005, and annually since 2008. The 2011 survey was conducted over the period 15-18 April 2011. Figure 8.1 depicts the location of the study sites. The sites Dive School and Terminal are situated along the northern shore in Small Bay. Marcus Island, Iron Ore Terminal and Lynch Point are in Big Bay, as are the sites Schaapen Island East and West, located on Schaapen Island in the entrance to Langebaan Lagoon. The site North Bay is situated in Outer Bay at the outlet of Saldanha Bay.

Figure 8.1, Location of the eight rocky shore study sites in Saldanha Bay.

The sampling sites have specifically been chosen to take into account the effects of differing degrees of wave exposure and topographical heterogeneity (type of rock surface and slope). Dive School (DS) and Jetty (J) are very sheltered sites with gentle slopes, consisting of boulders and rubble interspersed with sandy gravel (Figure 8.2). Schaapen Island East is situated in a little baylet and is relatively sheltered and mostly flattish with some rougher rock sections (Figure 8.2). Schaapen Island West is slightly more exposed and flat with some parts of ragged topography (Figure 8.2).

Dive School

Very Sheltered

Boulders and Rubble

Jetty

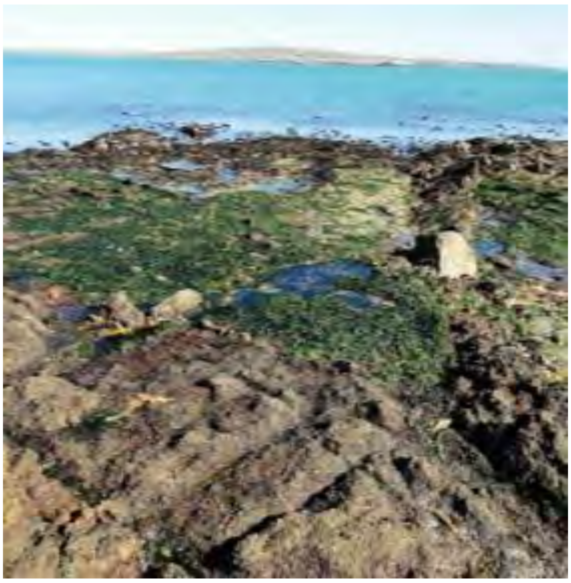
Very Sheltered

Boulders and Rubble

Schaapen Island East

Sheltered to Semi-exposed

Flattish with some ragged sections



Schaapen Island West

Sheltered to Semi-exposed

Semi-steep with some ragged sections

Figure 8.2. Rocky shore study sites in Saldanha Bay (top right to left bottom): Dive School, Jetty, Schaapen Island East, and Schaapen Island West.

Iron Ore Jetty

Semi-exposed

Very steep with large boulders

Lynch Point

Semi-exposed

Flat with crevices

North Bay

Semi-exposed to exposed

Flat mid and high shore with

large boulders in the low shore

Marcus Island

Exposed

Flat shore

Figure 8.3. Rocky shore study sites in 2010 (top right to bottom left): Iron Ore Terminal, Lynch Point, North Bay, and Marcus Island.

The site at the Iron Ore Terminal (IO) is sheltered to semi-exposed with a very steep slope resulting in a very narrow total shore width (distance from low water to high water mark). The rocky surface of this site comprises of medium-sized broken boulders that are piled up to support a side arm of the iron ore terminal (Figure 8.3), which encircles a small area that was previously used for aquaculture purposes. The semi-exposed site Lynch Point (L) has a relatively smooth surface with occasionally deep crevices running across (Figure 8.3). North Bay (NB) is semi-exposed to exposed with a relatively flat high and mid shore (Figure 8.3). The low shore consists of large unmovable square boulders separated by channels. The rocky intertidal site on Marcus Island (M) is very flat and openly exposed to the swell (Figure 8.3).

8.2.2 Methods

The unique physical environment of the rocky intertidal alternately exposes it to air and submerges it under water, creating a steep vertical environmental gradient for the biota that inhabits these shores. Rocky shores can thus be partitioned into different zones according to shore height level whereby each zone is distinguishable by their different biological communities (Menge & Branch 2001). At each study site, the rocky intertidal was divided into three shore height zones: the high, mid and low shore. In each of these zones, six 100°x°50-cm quadrats were randomly placed on the shore and the percentage cover of all visible species recorded as primary (occurring on the rock) and secondary (occurring on other benthic fauna or flora) cover, and individual mobile organisms counted to calculate densities within the quadrat area ($0.5m^2$). The quadrat was subdivided into smaller squares, to aid in the estimation of the percentage cover. Finally, the primary and secondary cover data for both mobile and sessile organisms were combined and down-scaled to 100%. This survey protocol is consistent with the previous survey protocols.

A species list is provided in the Appendix. Sampling is non-destructive, *i.e.* the biota is not removed from the shore, and smaller infaunal species (*e.g.* polychaetes, amphipods, isopods) that live in the complex matrix of mussel beds or dense stands of algae are thus not recorded in this survey protocol. Additionally, some algae and invertebrates cannot be easily identified to generic or species level in the field and are thus recorded under a general heading only (*e.g.* crustose and articulate corallines, red turfs, sponge, colonial ascidian). For further analysis, intertidal species were categorized into ten functional groups: a) *grazers*, mostly limpet species, b) *trappers*, limpet species that specifically trap kelp fronds beneath their shells, c) *filter-feeders*, particularly sessile suspension feeders such as mussels and barnacles, d) *mobile predators* and *scavengers*, such as carnivorous whelks, e) *anemones*, f) *crustose*[2] and g) *articulated coralline*[3] *algae*, h) *corticated* [4] and i) *ephemeral foliose*[5] *seaweeds* and j) *kelps*.

[2] *Crustose (or encrusting) corallines* - Crustose corallines are typically slow growing crusts of varying thickness that can occur on rock, shells, or other algae.
[3] *Articulated corallines* - Articulated corallines are branching, small tree-like plants, which are attached to the substratum by crustose or calcified, root-like holdfasts.
[4] *Corticated algae - Algae that have secondarily formed outer cellular covering over part or all of an algal thallus. Usually relatively large and long-lived.*
[5] *Ephemeral algae* - Opportunistic algae with a short life cycle that are usually the first settlers on a rocky shore.

8.2.3 Data Analysis

The similarities or dissimilarities among the quadrats from the eight different study sites are analysed with multivariate analyses techniques employing the software package PRIMER 6. These methods are useful for a graphical presentation of the results obtained from the typically large data sets collected during ecological sampling. The principle aim of these techniques is to discern the most conspicuous patterns in the community data. Comparisons between intertidal communities are based on the extent to which they share particular species at similar levels of occurrence. Patterns in the data are represented graphically through hierarchical clustering (dendrogram) and multi-dimensional scaling (MDS) ordination techniques. The former produces a dendrogram in which samples with the greatest similarity are fused into groups, and these are successively grouped into clusters as the similarity criteria defining the groups are gradually reduced. MDS techniques compliment hierarchical clustering methods by more accurately 'mapping' the sample groupings two-dimensionally in such a way that the distances between samples represent their relative similarities or dissimilarities.

Whether (a priori defined) groups of samples (e.g. sites, treatments, years) are statistically different is analysed by means of PERMANOVA. PERMANOVA is a routine for testing the simultaneous response of one or more variables to one or more factors in an analysis of variance (ANOVA) experimental design on the basis of any resemblance measure, using permutation methods (Anderson *et al.* 2008). In essence, the routine performs a partitioning of the total sum of squares according to the specified experimental design, including appropriate treatment of factors that are fixed or random, crossed or nested, and all interaction terms. A distance-based pseudo-*F* statistic is calculated in a fashion that is analogue to the construction of the *F* statistic for multi-factorial ANOVA models. P-values are subsequently obtained using an appropriate permutation procedure for each term. Following the main overall test, pair-wise comparisons are conducted. Significance level for the PERMANOVA routine is $p < 0.05$.

The contributions of each species to the average dissimilarity between two sites, and to the average similarity within a site, are assessed using a SIMPER (Similarity Percentages) analysis. The taxa are identified, which appear to be principally responsible for differences detected in community structure between sites or groups.

A variety of diversity indices were determined that are used as measures of some attribute of community structure. Diversity indices include:

- *Species number* - total number of species present.
- *Percentage cover* - the part of the intertidal rocky surface that is covered by biota (fauna and flora).
- *Evenness* - expresses how evenly the individuals are distributed among the different species, in other words whether a shore is dominated by individuals of one or few species (low evenness) or whether all species contribute evenly to the abundance on the shore (high evenness). The index is constrained between 0 and 1 where the index increases towards 1 with less variation in communities.
- *Shannon-Wiener diversity index* - a measurement of biodiversity taking into account the number of species and the evenness of the species. The index is increased either by having additional unique species, or by having a greater species evenness.

8.3 Results and Discussion

8.3.1 Species Diversity and Zonation

The survey of the eight rocky shores yielded a total of 84 species/taxa, of which 50 taxa were invertebrates (59.5%) and 34 (40.5%) algae. The faunal component was represented by 16 species of grazers, 3 trappers, 7 predators and scavengers, 6 anemones, and 18 filter-feeders. The algal component comprised 22 corticated (foliose) seaweeds, 6 ephemerals, 1 kelp, 4 crustose (or encrusting) corallines and 1 articulated coralline (it has to be pointed out that this is a gross underestimation of coralline taxa as most species are not identifiable in the field and are thus lumped into larger groups).

The overall taxa count has remained relatively constant over the years with most taxa having also been recorded during one or more of the previous monitoring years (Anchor Environmental Consultants 2006, 2009, 2010, and 2011). Furthermore many of the species are also listed by other studies conducted in the Saldanha Bay area (e.g. Simons 1977, Schils *et al.* 2001, Robinson *et al.* 2007). The species are generally common to the South African West Coast (e.g. Day 1974, Branch *et al.* 2010a), including the two alien invasive species, the Mediterranean mussel *Mytilus galloprovincialis* and the acorn barnacle, *Balanus glandula*. The former was introduced from Europe sometime in the 1970's, but is now the dominant west coast mussel, forming a dense mid- to low shore band in wave-exposed areas (Hockey & van Erkom Schurink 1992). The presence of *B. glandula*, originating from the Pacific coast of North America, has only been recognized more recently (Simon-Blecher *et al.* 2008), but it seems that the species has been in South Africa since at least the early 1990s and it is now the most abundant intertidal barnacle along the southern west coast (Laird & Griffiths 2008). The alien's presence was overlooked for many years as it was mistaken for the indigenous species *Chthamalus dentatus*. Apparently as a result of the invasion by *B. glandula*, the formerly abundant *C. dentatus* is now very rare on South African west coast shores (Laird & Griffiths 2008). At the Saldanha Bay monitoring study sites, the alien barnacle was first confidently identified in 2008. It is, however, assumed that it had been present during the baseline survey in 2005 but was confused with the indigenous barnacle. Consequently, in all analyses involving the 2005 dataset, *C. dentatus* abundances are converted to *B. glandula*.

The composition and distribution of the rocky intertidal biota is strongly influenced by the prevailing wave exposure at a shore as well as substratum topography. Within a site, however, shore height is the critical factor as the interface between air and water along with the action of tides and waves result in a vertical emersion gradient of increasing exposure to air from low shore to high shore. Clear, well studied, patterns of zonation of flora and fauna thus exist on rocky shores (Stephenson & Stephenson 1972). The effects of wave action are generally attenuated up-shore and superseded by the uniformly severe desiccation stress experienced high on the shore. Consequently the high shores were relatively similar among the sites being mostly barren with few species. At the very sheltered boulder shores Dive School and Jetty, considerable amounts of sand and gravel had also accumulated amongst the boulders. Typical high shore species, particularly at the sheltered sites, included the winkle *Oxystele variegata* and towards the more exposed sites the small periwinkle *Afrolittorina knysnaensis* with average densities often exceeding 100 individuals per 0.5 m^2 (Figure 8.4). The alien *B. glandula* occurred at almost all high shores but with very low cover (on average <1%). Barren rock accounted for >95% at most high shores. The exceptions were Schaapen East, which had occasional patches of blue-green algae, and Marcus Island were a dense low carpet of the ephemeral algae *Ulva* spp. with occasional tufts of another ephemeral, *Porphyra capensis*, covered >70% of the high shore (Figure 8.4). Ephemerals are opportunistic algae that have short life cycles and are usually the first settlers on a rocky shore after a disturbance event. Their dominant presence is normally short-lived (Maneveldt *et al.* 2009).

Figure 8.4. **From top left clockwise: High shore at Dive School showing *Oxystele variegata* and sand/gravel accumulation among the boulders; high shore at North Bay showing the *Afrolittorina knysnaensis* on rock and accumulating in crevices; blue-green algae patch at Schaapen East high shore; and low growing *Ulva* carpet with *Porphyra capensis* tufts at the high shore at Marcus Island. See text for more information.**

O. variegata extended into the mid shore at the very sheltered sites Dive School and Jetty, but also occurred in low numbers at the other mid shores. The occasional limpet *Cymbula granatina* was also recorded. Algal cover was limited to the encrusting red algae *Ralfsia verrucosa* and some stands of *Ulva* spp. and *Gigartina polycarpa*.

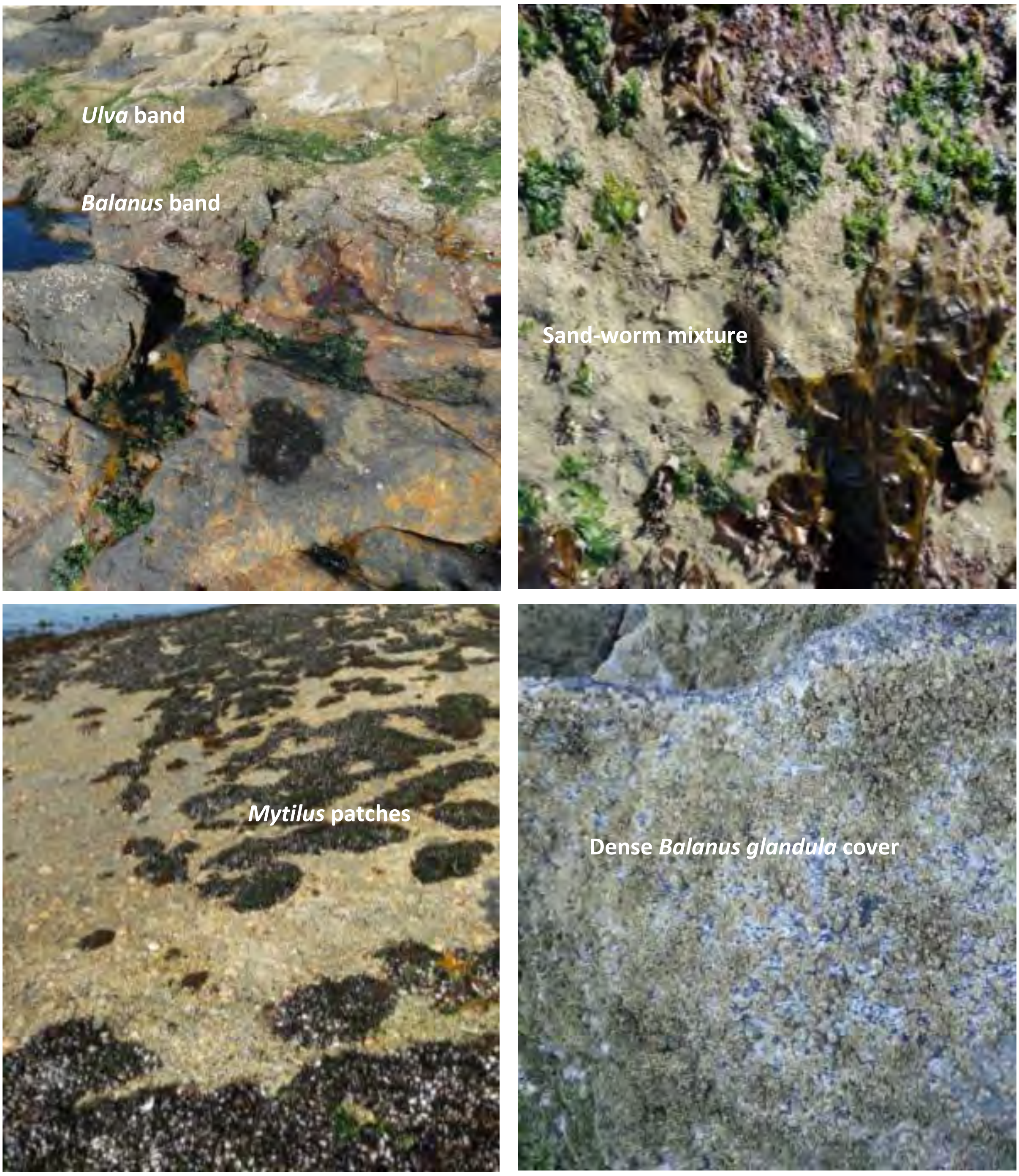


Figure 8.5. **From top left clockwise: *Ulva-Balanus* band at the mid shore at Schaapen Island East; the sand-tubeworm compact mixture at Schaapen Island West with Ulva; dense *Balanus glandula* cover at Iron Ore Terminal; and *Mytilus* patches interspersed with *Balanus* and *Scutellastra granularis* patches at Marcus Island. See text for more information.**

At the Schaapen Island sites, the Dwarf cushion-star *Parvulastra exigua* was locally common in moist cracks and rock-depressions, as were the false limpets *Siphonaria serrata* and *S. capensis*. At Schaapen Island East, the upper mid-shore was characterized by distinct bands of *Ulva* and *B. glandula* (Figure 8.12). In contrast, alive barnacles were largely absent from the mid shore at Schaapen Island West although some empty shells still attached to the rock were encountered. Instead, at this site a tube-building polychaete was common. This tubeworm was deeply embedded in a compact matrix of sand, maybe cemented so compact by some secretion of the worm (Figure 8.12). This sand-worm mixture covered the mid shore in large patches, making up to 12% of the biotic cover there.

With increasing wave force, the mid shore was dominated by filter feeders, specifically *M. galloprovincialis* and *B. glandula* (Figure 8.12). The latter was particularly abundant at the semi-exposed site Iron Ore Terminal with 75% cover. Algal presence was generally low with some cover by the ephemerals *Ulva* spp. and *Porphyra capensis*, as well as the seaweeds *Caulacanthus ustulatus* and *Nothogenia erinacea*. Mobile animals included the limpets *Scutellastra granularis*, *Siphonaria serrata*, and the tiny periwinkle *Afrolittorina knysnaensis* nestling in amongst the barnacles. The scavenging whelk *Burnupena* spp. was encountered in low numbers at most sites.

Differences in community structure were most pronounced at the low shore where the energy of waves is most effective. Generally, biotic cover within a shore increased towards the low shore, but cover also increased among the shores with intensifying wave force (from 28% at the low shore at Jetty to 84% at Marcus Island). At the very sheltered sites, faunal cover was very low with some mussel and mixed barnacle cover (*B. glandula*, *Amphibalanus amphitrite* and *Notomegabalanus algicola*). At Dive School, the two indigenous mytilids, *Aulacomya ater* and *Choromytilus meridionalis*, as well as the alien *M. galloprovincialis* co-occurred, albeit at very low densities. Algal cover was only slightly higher, consisting primarily of encrusting *Ralfsia verrucosa*, the foliose seaweeds *Gigartina polycarpa*, *Nothogenia erinacea* and the green ephemeral alga *Ulva* spp. Mobile animals included the limpet *Cymbula granatina*, the winkle *Oxystele tigrina*, *Parvulastra exigua*, and the sea urchin *Parechinus angulosus*, often found in groups in pools or crevices hidden under pieces of shell or gravel (Figure 8.6). Few large specimens of the false plum anemone *Pseudoactinia flagellifera* were also encountered there.

At the sheltered Schaapen Island sites, the ground cover was dominated by a diverse array of up to 20 different algae species. Most common were 'pink' encrusting corallines (a variety of species), followed by foliose seaweeds such as *Gigartina polycarpa*, *Aeodes orbitosa*, *Mazzaella capensis*, *Gymnogongrus glomeratus*, *Ulva* sp., and a low growing turf-forming mixture of fine red algae (Figure 8.6). Particularly at Schaapen Island West, the mid-shore sand-worm mixture extended down into the low intertidal, often surrounding and intertwined with, algal stands. Occasionally, the sand had washed away and the thin stiff tubes of the polychaetes emerged (Figure 8.6).

Burrowing in this sandy substrate were dense colonies of the red-chested sea cucumber *Pseudocnella insolens*, often numbering >350 individuals per 0.5m^2 (Figure 8.6). Sessile invertebrates were rare but mobile animals included the limpets *Fissurella mutabilis* and *Cymbula granatina*, the cushion star *Parvulastra exigua*, the winkle *Oxystele tigrina* and the scavenging whelk *Burnupena* spp.

The semi-exposed site Iron Ore Terminal was still characterized by algae, in particular encrusting species, as well as *Sarcothalia stiriata*, *Mazzaella capensis*, *Hypnea spicifera*, *Nothogenia erinacea*, *Plocamium* spp., *Ulva* spp. and near the infratidal zone the kelp *Laminaria pallida* (Figure 8.6). Mussels and barnacles were present but with low cover, the latter primarily represented by the giant barnacle *Austromegabalanus cylindricus* (Figure 8.6). Very common was the pear-shaped limpet *Scutellastra cochlear*, followed by *S. barbara* and *Cymbula granatina*.

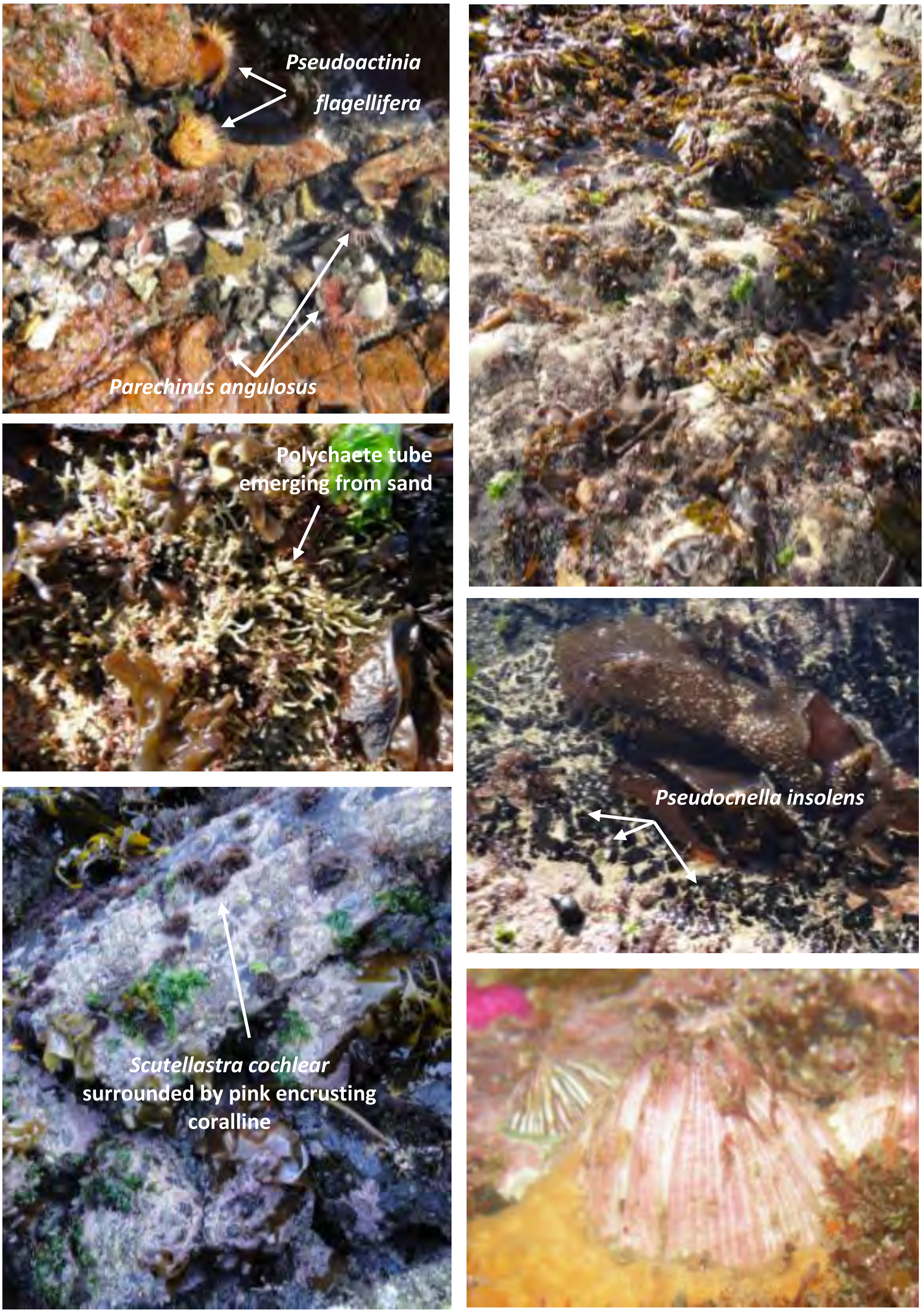


Figure 8.6. From top to bottom right: *Parechinus angulosus* and *Pseudoactinia flagellifera* in the low shore pool at Dive School; overview of low shore at Schaapen Island East; close-up of tube-building polychaete emerging from sand; the sea cucumber *Pseudocnella insolens* embedded in sand; overview of low shore at Iron Ore Terminal; and close up of the giant barnacle *Austromegabalanus cylindricus*. See text for more information.

Figure 8.7. From top left clockwise: *Scutellastra cochlear* patch in association with 'pink' encrusting coralline algae on a low shore boulder at Lynch Point; overview of the low shore at North Bay showing kelp growing in the infratidal; *Aulacomya ater* patch at the low shore at Marcus Island; overview of the low shore at Marcus Island.

With a further increase in wave action, the low intertidal became progressively dominated by sessile filter-feeders, particularly *M. galloprovincialis* with up to 40% cover at North Bay (Figure 8.7). At Marcus Island, the indigenous ribbed mussel *Aulacomya ater* occurred in patches and could locally be more dominant than *M. galloprovincialis* (Figure 8.7). This is in stark contrast to the mid shore, which is clearly dominated by the alien mussel and also to earlier years, where the alien mussel was the characterizing mussel species at this site (Robinson *et al.* 2007). Barnacle presence was largely restricted to secondary growth of *Notomegabalanus algicola* on mussel shells. Mobile fauna was characterized by dense patches of *Scutellastra cochlear* as well as *S. barbara*, *S. granularis* and the kelp-trapping *S. argenvillei*, *Cymbula granatina*, *C. miniata* and *Fissurella mutabilis*. The predatory whelks *Burnupena* spp. and *Nucella cingulata* were found hidden in the mussel matrix, feeding on mussels. Encrusting and, to a lesser degree, articulated corallines were the main algae species. Foliose seaweeds were represented by *Champia lumbricalis* and *Plocamium* spp., which are typical for wave swept shores, and minor cover of *Sarcothalia stiriata*, *Ulva* spp., red turf, and *Laminaria pallida* at the infratidal fringe (Figure 8.7). In *S. cochlear* patches, narrow gardens of fast-growing, fine red algae (e.g. *Gelidium micropterum*, *G. pristiodes*, *Herposiphonia heringii*) fringed larger individuals; the gardens serve as food source and are territorially defended and fertilized by the limpets (Figure 8.7).

8.3.2 Spatial Variation in Community Composition

Figure 8.10 illustrates biotic cover, species number, evenness, and Shannon-Wiener diversity indices at the eight rocky shore sites (indices are calculated for the whole shore across all zones). Foremost it is apparent that the amount of rock surface covered by animals and seaweeds steadily increased with increasing wave exposure, with the exception of North Bay, where great parts of the very smooth rock surface was devoid of intertidal life. The two very sheltered boulder beaches in Small Bay were generally impoverished with little biotic cover and lowest species numbers, whereby Dive School had on average twice as many species as Jetty. There is a certain trend of increasing species richness with greater wave exposure with the highest species count at Marcus Island. In contrast, Dive School and Jetty had highest evenness. This indicates that the communities were not dominated by one or few species but rather all species were more or less equally abundant. Evenness reduced towards semi-exposed sites but increased again at greater exposure levels. A similar picture is evident for the Shannon-Wiener diversity index. Lowest evenness and diversity were found at Iron Ore Terminal. A low evenness means that the biota is dominated by one or few species, which at Iron Ore Terminal is clearly the invasive barnacle *B. glandula*.

The abundances (as opposed to the space they occupy on the rock surface specified as percentage cover) of the most common mobile species per site are illustrated in Figure 8.9. Only few mobile species occurred at the high shore, the most prominent being the typical high shore species *Oxystele variegata* at the very sheltered sites and the periwinkle *Afrolittorina knysnaensis*. The mid shore had a greater array of common mobile species: *O. variegata* was still relatively common at very sheltered mid shores, as was *O. tigrina*. Whereas *Siphonaria serrata* and *C. granatina* were present at nearly all mid shores, *Scutellastra granularis* and *A. knysnaensis* were more abundant at semi-exposed to exposed sites.

A. knysnaensis is normally abundant primarily in the upper intertidal where it congregates in crevices to escape the heat of the day, while emerging at night or on moist days to feed (Branch *et al.* 2010a). Particularly at Iron Ore Terminal, however, this snail was also abundant at the mid shore where it lives amongst the barnacle *B. glandula* (Figure 8.10). For a rocky shore in Table Bay, it has been shown that the abundance of *A. knysnaensis* is strongly positively correlated with that of *B. glandula* (M. Van Zyl, University of Cape Town, unpublished data 2009 cited in Griffiths *et al.* 2011). Laird & Griffiths (2008) also found a very noticeable difference between barnacle invaded and non-invaded areas reporting that *A. knysnaensis* were more abundant, and extended farther down the shore, in invaded areas where they nestled between dense colonies of *B. glandula*. The study demonstrated positive correlations for all shore heights. It is suggested that the barnacle cover increases habitat complexity and provides shelter for the periwinkles from strong wave action.

For the eight study sites in Saldanha Bay, such positive relationship is, however, not that conclusive when the data across all shore heights are included. Although the correlation is statistically significant, there are many situations in the high shore were *B. glandula* were absent but periwinkles plentiful (Figure 8.11). However, confining the analysis to the mid-shore, were the alien barnacle thrives particularly well and is densest, the positive relationship is evident (Figure 8.11). In the high shore where wave stress is minimal, the periwinkle is naturally abundant; in the mid-shore, however, wave stress increases and without shelter, the periwinkle normally declines in abundance. This would suggest that *A. knysnaensis* abundance is independent of the barnacle's presence in the highest intertidal but lower down the shore, the barnacle matrix offers refuge and/or greater substrate complexity for the periwinkle to extend its range lower down the shore.

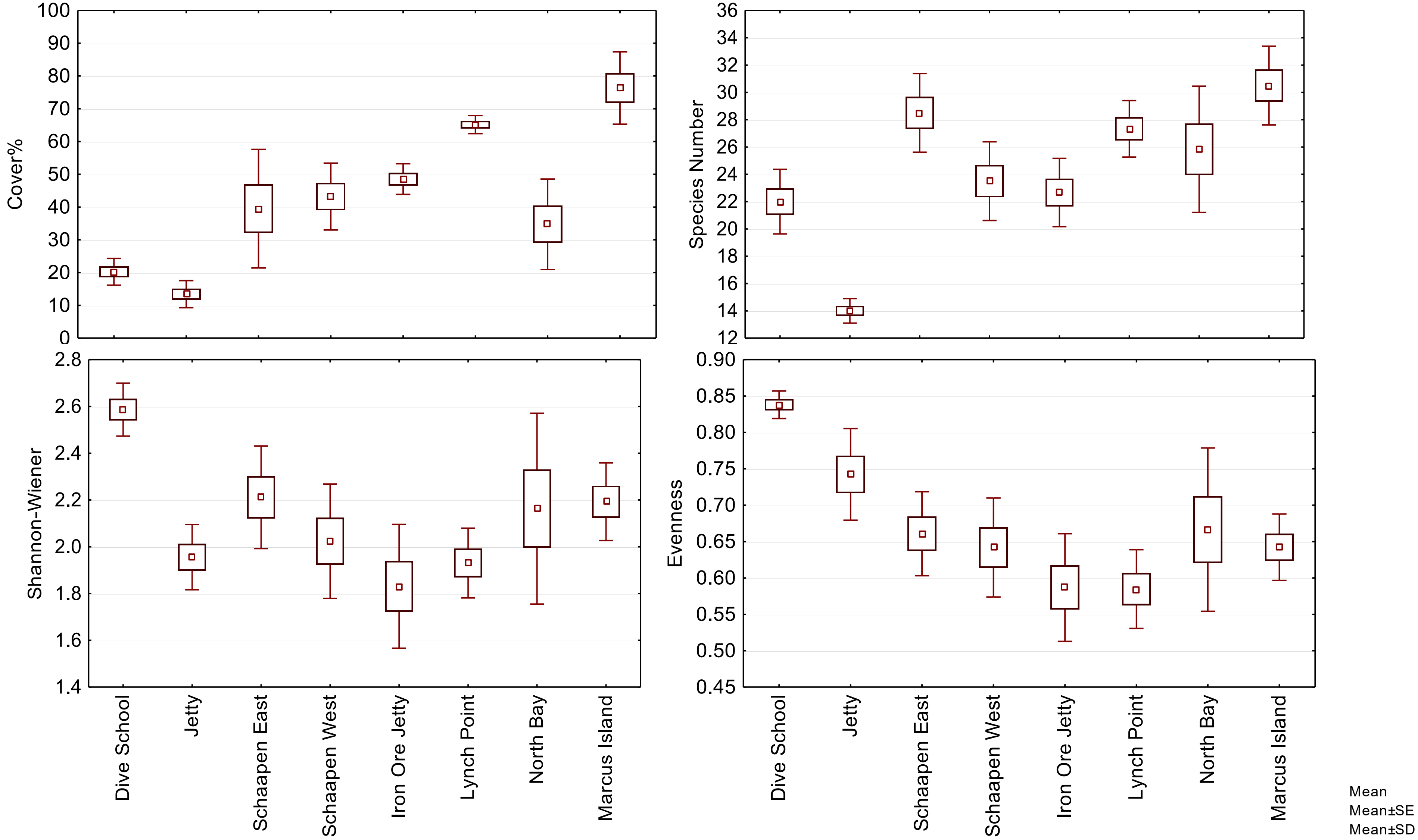


Figure 8.8. Box & whisker plots of per cent cover, species number, evenness and Shannon-Wiener diversity at the eight rocky shore sites. Sites are sorted from left to right according to increasing wave exposure.

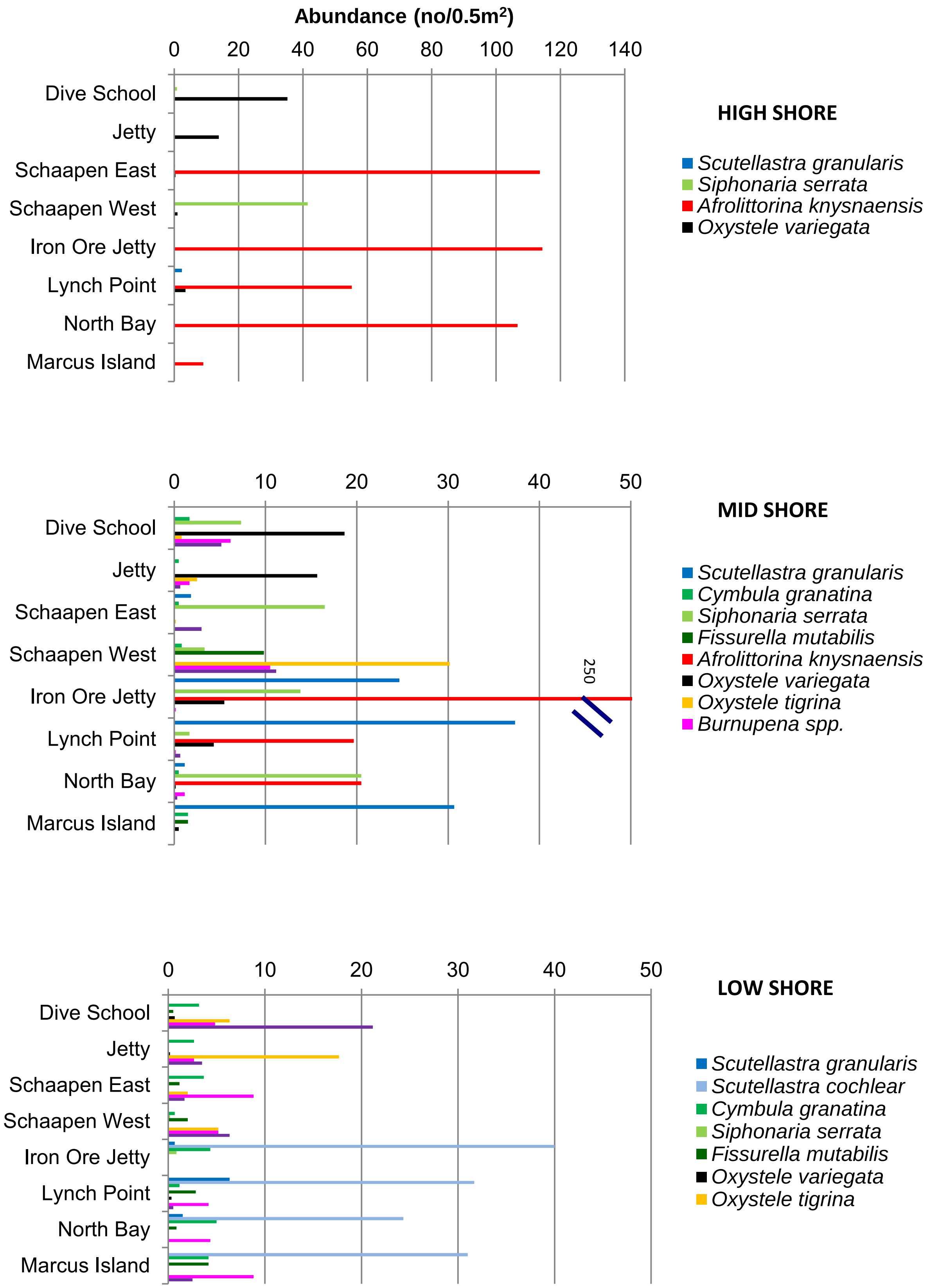


Figure 8.9. **Mean abundance (number/0.5 m²) of the most common mobile species at the eight rocky shores in 2011. Sites are sorted from top to bottom according to increasing wave exposure.**

Figure 8.10. **The periwinkle *Afrolittorina knysnaensis* nestling in amongst the alien barnacle *Balanus glandula* at the mid shore at Iron Ore Terminal.**

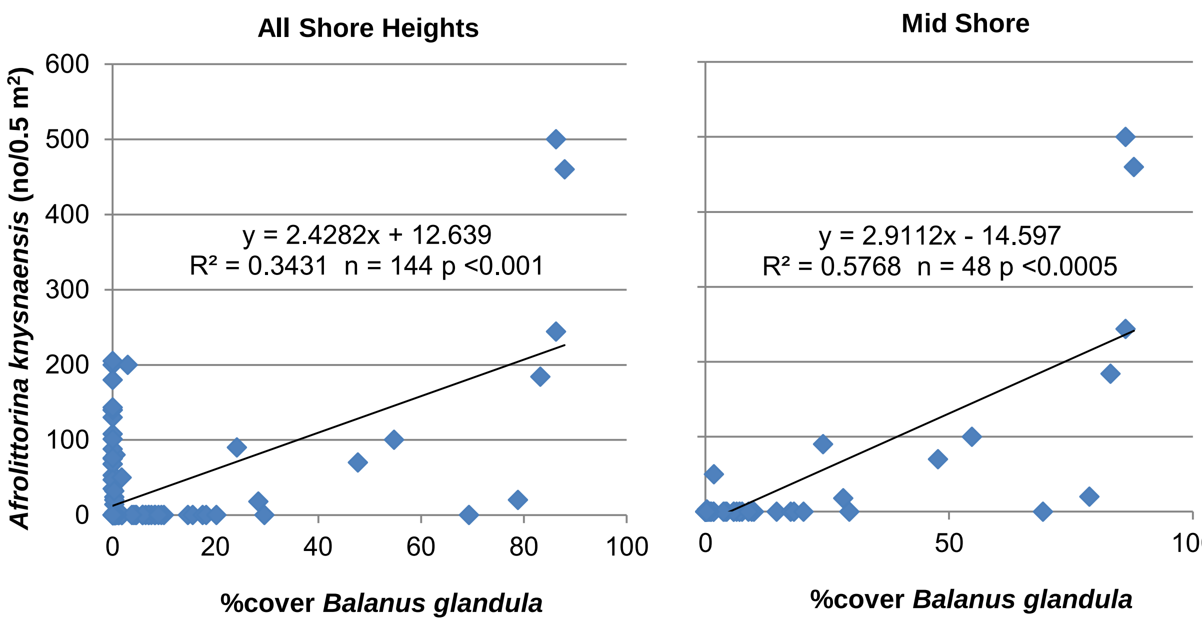


Figure 8.11. **Relationship between Afrolittorina knysnaensis and *Balanus glandula* for all zones combined (left) and for the mid shore only (right). Equations and statistical significances are provided for each graph.**

Mobile animals in the low shore included *O. tigrina*, which was common at sheltered to semi-exposed sites and *Parvulastra exigua*, frequently encountered in rock depressions and pools. *C. granatina* and *Burnupena* spp. occurred at all low shores at relatively equal densities, whereas *S. cochlear* was restricted to wave swept shores where it lives in patches of dense aggregations.

It is understandable that the vertical gradient of emersion up the shore creates a stress gradient that has important ecological effects, creating the clear zonation patterns observed on rocky intertidal shores. Among shores, however, the structure of biotic communities is also affected by a horizontal gradient of exposure to wave action, from sheltered bays to exposed headlands. Viewing the distribution of the various functional groups shows obvious differences among the shores with regard to exposure (Figure 8.12). Very sheltered shores had generally low biotic cover consisting primarily of grazers and trappers (i.e. the limpet *Cymbula granatina*), with minor cover of sessile filter feeders and encrusting algae. The sheltered Schaapen Islands sites were dominated by algae (encrusting and foliose algae) but with further increase in wave force, filter feeders were clearly the most important group. At Marcus Island, ephemeral algae were also abundant.

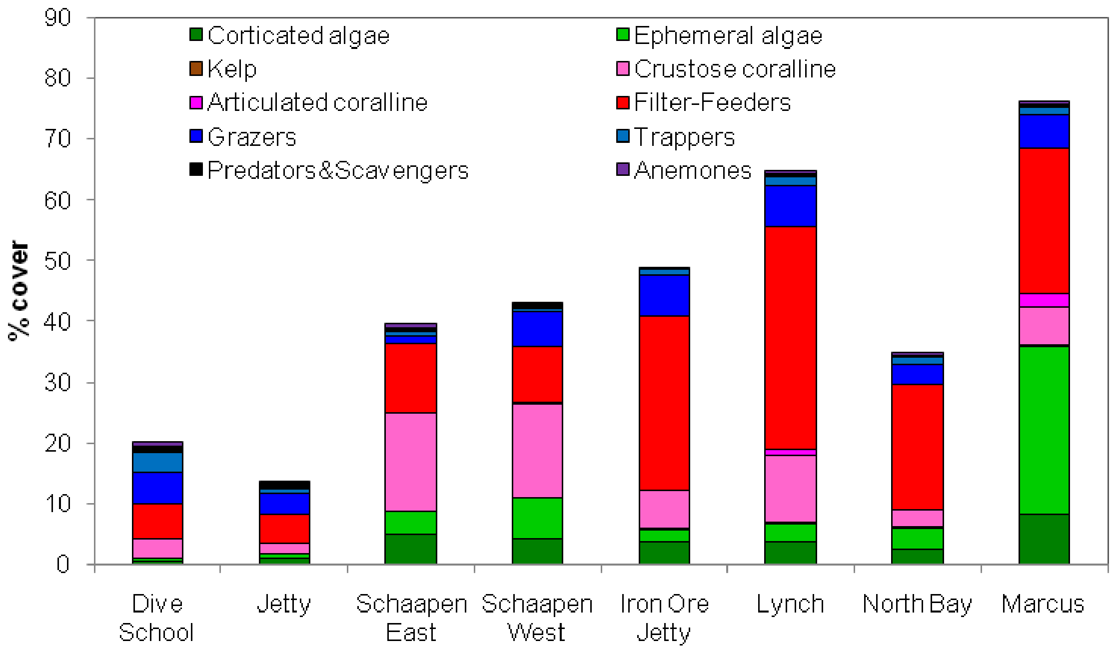


Figure 8.12. Contribution of the functional groups to the biotic cover (%) across the whole rocky shore at the eight study sites (sorted from left to right according to increasing wave exposure).

Multivariate analysis (i.e. cluster analysis and multi-dimensional scaling) finally confirms the clear separation of the rocky shores with regard to wave exposure (Figure 8.13). At a 50% similarity level the sites group into three major groups: Group 1 contains the very sheltered shores Dive School and Jetty, Group 2 consists of the two sheltered Schaapen Island sites, whereas all other more exposed sites fall into Group 3. At a higher similarity level of 60%, most of the sites within the groups separate from each other, displaying a great within-site similarity. Only the three exposed sites Lynch Point, North Bay and Marcus Island still cluster together (Group 3A), signifying that the communities at these shores are relatively similar, while the steep Iron Ore Terminal shores splits off.

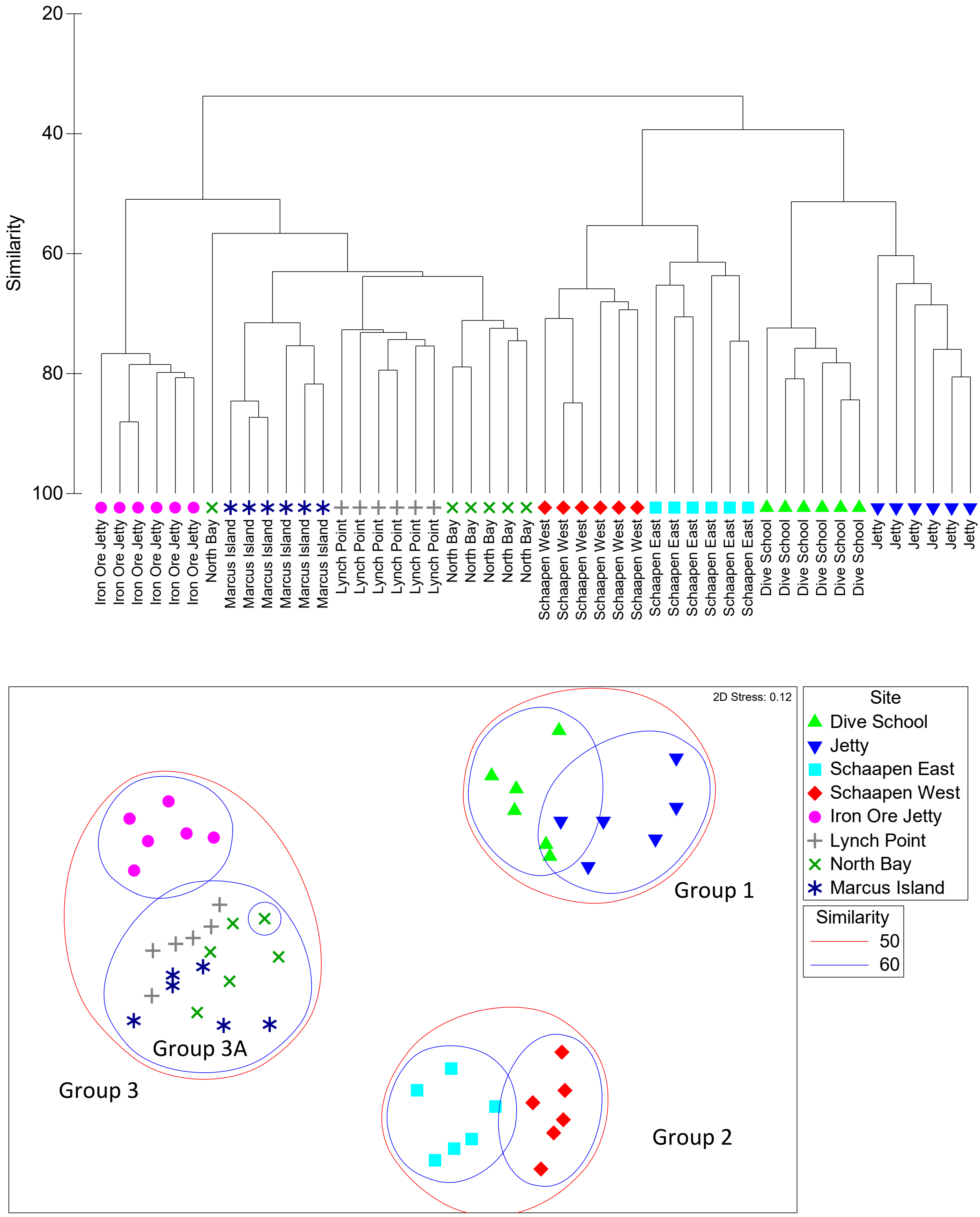


Figure 8.13. Dendrogram (top) and multi-dimensional scaling (MDS) plot (bottom) of the rocky shore communities at the eight study sites in 2011. The circles in the MDS plot indicate a 50% (red) and 60% (blue) similarity level. See text for further explanation.

That exposure to wave action affects the distribution of organisms on a rocky shore is a well described phenomenon (e.g. Lewis 1964, McQuaid & Branch 1984, Raffaelli & Hawkins 1996, Bustamante *et al.* 1997, Menge & Branch 2001, Denny & Gaines 2007). Increasing exposure reduces siltation and increases the supply of dissolved oxygen and particulate food, favouring certain sessile, filter-feeding species, leading to an elevation of overall biomass (McQuaid & Branch 1985, Bustamante & Branch 1996, Bustamante *et al.* 1995, Steffani & Branch 2003a). A recent study has also shown that at the southern African west coast wave exposure has a positive effect on the recruitment of mussels and (to a lesser extent) barnacles (Pfaff *et al.* 2011). At the same time, increasing exposure carries an increased risk of dislodgement and physical damage, limiting the range of susceptible and physically fragile species. In contrast, sheltered shores are typically dominated by algae (McQuaid & Branch 1985) as species richness of most floral phyla and groups decrease with increasing exposure. However, it appears that the effect of wave exposure on plants varies with phyla and functional form group, as some forms can better withstand hydrodynamic forces than others (Denny & Gaylord 2002, Nishihara & Terada 2010).

In contrast to the unidirectional nature of the vertical emersion gradient, the horizontal gradient is less well defined: some species do well on wave-exposed shores, some do best in shelter and others under intermediate conditions. Many species of intertidal animals and plants have evolved morphologies and behaviours specifically adapted to cope with wave-imposed forces. Despite these adaptations, hydrodynamic and impact forces can at times cause massive damage to rocky shore communities that fundamentally alters the structure and function of exposed rocky habitats, creating changes that can persist for many years. The magnitude of physical disturbance is less on protected shores, and as a result, the structure of protected communities is different from that of exposed assemblages.

While wave force is clearly the main factor for differences among the shores, shore topography is also of importance. In the dendrogram and MDS plot, the very flat Schaapen Island sites drastically diverge from the two boulder shores Dive School and Jetty, and the steep semi-exposed boulder shore Iron Ore Terminal separates from the more flattish smoother semi-exposed to exposed shores Lynch Point, North Bay and Marcus Island (Figure 8.13). The roughness of the substratum or generally termed habitat structure can be a crucial factor driving species richness, abundance and even body size (Kostylev *et al.* 2005). Habitat structure is generally thought to have two independent components: complexity, the physical architecture of a habitat; and heterogeneity, the relative abundance of different structural features such as boulders or crevices within a habitat (McCoy & Bell 1991). Effects of habitat structure on organism body size and abundance can be interrelated because the availability of microhabitat space within a habitat depends both on abundance and body size (Guarnieri *et al.* 2009). Smaller organisms can be more numerous than larger organisms in complex structure, because they have more useable space and require fewer resources per individual. Hence, habitat structure may shape the overall relationship between abundance and body size of an assemblage. For example, studies have shown that many mobile animals exhibit preferential movement from topographically simple locations (e.g. smooth surface) into those with more structural complexity (e.g. crevices, rugged surface) where they a more protected from hydrodynamic forces (McGuinness & Underwood 1986, Kostylev *et al.* 2005, O'Donnell & Denny 2008). This may not just apply to physical complexity but also microhabitats offered by biota. For example, it seems that *A. knysnaensis* uses the complex structure provided by barnacles to extend its range further down the shore (see text above). Mobile invertebrates can also respond to environmental extremes by moving between microhabitats to ameliorate thermal and desiccation stress (Meager *et al.* 2011), and again *A. knysnaensis* displays such behaviour. Distribution of sessile species, however, is driven by the longer-term processes of settlement, growth and mortality (Guarnieri *et al.* 2009). Substratum availability, microtopography and surface smoothness, can be limiting factors at local scale, and invertebrate larvae have developed complex behaviours and finely tuned discriminatory abilities to ensure successful settlement in the face of variations in substratum properties (Guarnieri *et al.* 2009). Topographic complexity influence the settlement and persistence of benthic organisms, as planktonic larvae are more likely to be retained on rough surfaces while water movement may wash them off smooth surfaces (Eckman 1990, Guarnieri *et al.* 2009). This might explain the low sessile cover found on the very smooth rocks at North Bay (see Figure 8.12).

Boulder shores also contain greater microhabitat diversity (e.g. upper and lower side of the boulders) than rocky platforms. Where boulders are large, the tops of these boulders stay immersed for a significantly longer period than smaller boulders (or flat platforms), with each single boulder essentially having its own shore height zonation. During low tide, the top layer of boulders provides the lower layers with shade, thus maintaining lower temperatures and higher moisture content (Takada 1999). Layers of boulders increase the surface area for attachment of organisms, but may reduce water movement thus accumulating detritus, which can lead to low oxygen conditions. Large boulders have been shown to considerably reduce the water flow velocity with invertebrate biomass decreasing significantly downstream of boulders (Guichard & Bourget 1998). Smaller boulders, on the other hand, may be unstable as they can turn over in heavy weather, and have often been found to have a more impoverished community than larger rocks (McGuinness 1987, Londoño-Cruz & Tokeshi 2007, McClintock *et al.* 2007). Boulder fields are thus are typically found to differ in their species assemblages to flatter shores (e.g. Sousa 1979, McGuinness 1984, McQuaid *et al.* 1985, McGuiness & Underwood 1986, Takada 1999, Cruz-Motta *et al.* 2003, Davidson *et al.* 2004, Hir & Hily 2005).

While shore topography is a likely factor controlling the difference in community structure between Dive School and Jetty, and the rocky shores on Schaapen Island, it may also be related to the fact that Schaapen Island lies in the transition zone between Saldanha Bay and Langebaan Lagoon. The water in the Lagoon is generally warmer with also slightly higher salinities compared to the Bay. This in turn translates into differences in their biological communities (Day 1959, Robinson *et al.* 2007). For example, there is a distinct separation in algal composition between communities from the Bay and the Lagoon, as the latter harbours a considerable number of South Coast seaweeds due to its warmer waters (Schils *et al.* 2001). Perlemoenpunt, located less than 1 km from Schaapen Island on the western site of the entrance to Langebaan Lagoon is described as the transition area between the Bay and the Lagoon, but with a marked Lagoon affinity (i.e. high similarity with the Lagoon sites) in its overall algal composition. Differences in community composition between the Bay and the Lagoon are also described for zooplankton, and rocky and sandy substrate assemblages (Day 1959, Grindley 1977, Anchor Environmental Consultants 2006, 2009, 2010, 2011).

8.3.3 Temporal Analysis

Temporal variation in biotic cover, species number, evenness, and species diversity at the eight rocky shores from 2005 to 2011 are depicted in Figure 8.14 and Figure 8.15. Cover and population indices at the very sheltered site Dive School varied only slightly, while at the second sheltered boulder beach Jetty there was a general increase in all population measures until 2010, decreasing again in 2011. Schaapen East displayed little variation in biotic cover but species number, evenness and diversity increased peaking in 2009, although reducing thereafter. Schaapen West, in contrast, experienced a drastic increase in percentage cover until 2010 due to abundant growth of ephemeral and blue-green algae, but these had almost vanished in 2011. This temporal dominance of ephemerals has probably led to the considerable decline in evenness and diversity observed from 2005 to 2008, which are since then on the increase again. Biotic cover at Iron Ore Terminal, on the other, hand changed little with time, but species number and more pronounced evenness and diversity had a noticeable peak in 2010. Intertidal communities at Lynch Point and North Bay displayed minor temporal fluctuations in cover and species number, whereas evenness and diversity at Lynch Point peaked in 2009 and show a decreasing trend at North Bay. The most prominent changes were recorded at Marcus Island where both percentage cover and species number steadily increased since 2005. Evenness and diversity, however, show no consistent trend.

Temporal trends in rocky shore community patterns at the eight study sites are illustrated in Figure 8.16. Consistent for all years is the clustering according to wave exposure, with the three same main groups of Dive School and Jetty in Group 1, the Schaapen Island sites in Group 2, and the semi-exposed to exposed sites in Group 3. A certain inter-annual variability within each site is also evident, but this is more pronounced at some of the sites than at others. At Iron Ore Terminal, for example, the replicates from 2005 and 2010 separate from those from 2008 and 2011, while 2009 samples are in between. Similar is apparent for Schaapen West and Marcus Island. The greatest within-site variability (or patchiness) occurs at the boulder beach Jetty where the replicates per year often disperse widely.

PERMANOVA tests, conducted for each site over the years, confirm significant differences with regard to year ($p = 0.001$ for all tests). Further pair-wise testing reveals that for every site-by-year combination tested, interannual changes in community composition are significant (note that for the sake of brevity only combinations involving subsequent years are shown) (Table 8.1). However, the similarities among the rocky shore communities between the tested years are very high, especially for the last two years (from 54 to up to 70%). This suggests that for each site temporal changes in community structure, although statistically significant, are minor.

The SIMPER test reveals which species are responsible for the observed differences in community structure among the years. Only species contributing >5% to the dissimilarity at any specific site are listed in Table 8.2. For brevity, only comparisons between 2010 and the current dataset are presented here. At most of the sites, only one or two species contributed significantly (>5%) to the differences in community structure between 2010 and 2011, and at Lynch Point and North Bay, no single species contributed >5%. Most contributing taxa were algae, mainly ephemeral blue-green algae (Cyanobacteria) that had decreased in abundance at all sites where they previously were common. This is particularly evident at Schaapen West where the disappearance of blue-green algae at the high shore contributed ~10% to the temporal dissimilarity. It is well described that blue-green algae can cover great areas of open high shore rocks early on in the successional process temporarily, developing a thin 'biofilm' together with other microscopic algae (e.g. diatoms and spores of macroalgae) (Robles 1982, Cubit 1984, Maneveldt *et al.* 2009). Ephemeral blue-green algae may also be indicative of organic pollution (Pinedo *et al.* 2007). Both Schaapen Island and Marcus Island are closed to the general public and anthropogenic nutrient input into the high shore is unlikely, but the islands are important bird resting and breeding sites with a vast abundance of fertilizing guano. The arrival of blue-green algae at the high shores of Schaapen East, Schaapen West and Marcus Island were in the analysis of the 2010 survey data identified as the only noteworthy change in community structure since 2009 (Anchor Environmental Consultants 2011), and it was suggested that the plentiful nutrient supply from bird guano may have triggered the blue-green algae growth if washed into the intertidal after heavy rains (Bosman & Hockey 1986, 1988).

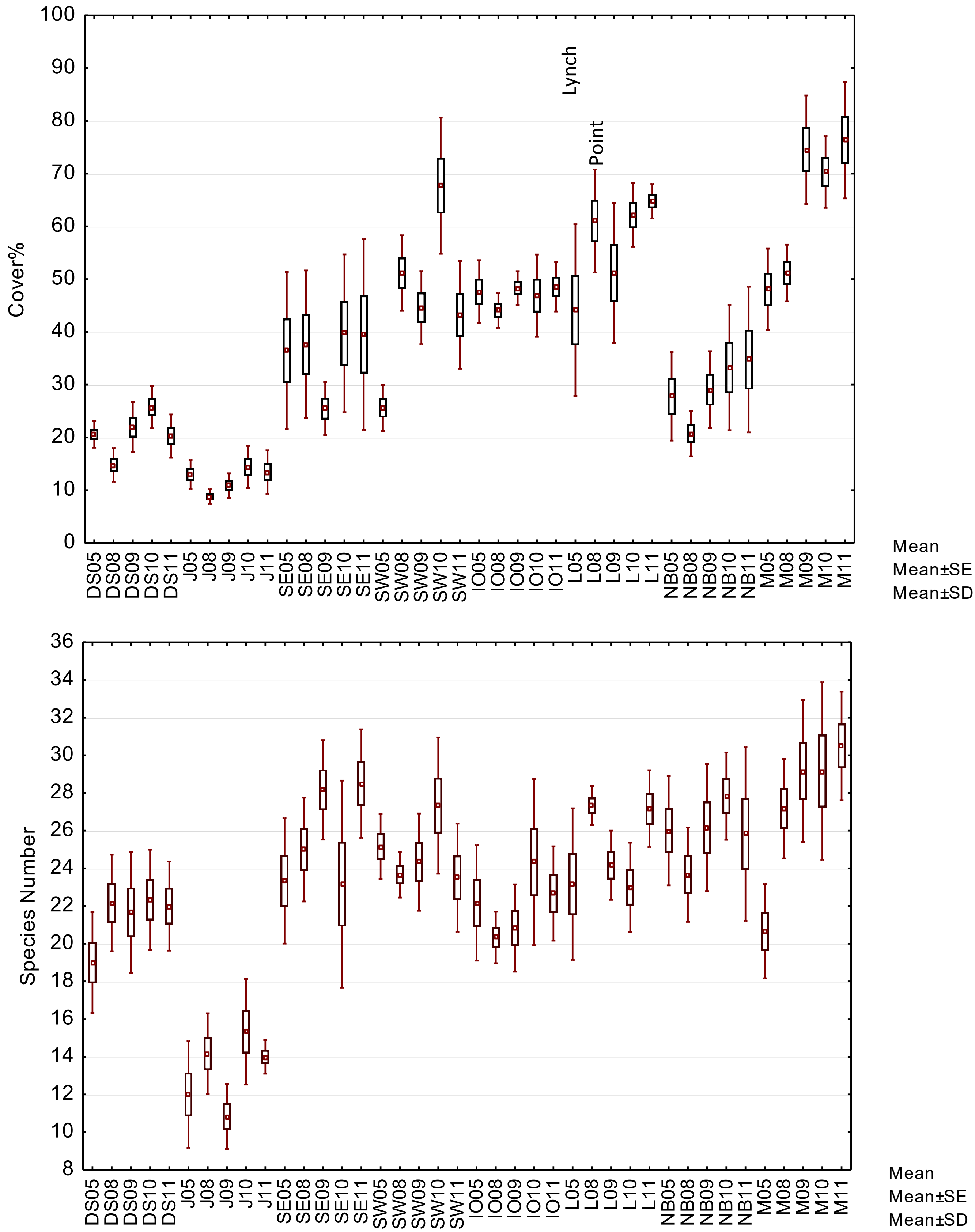
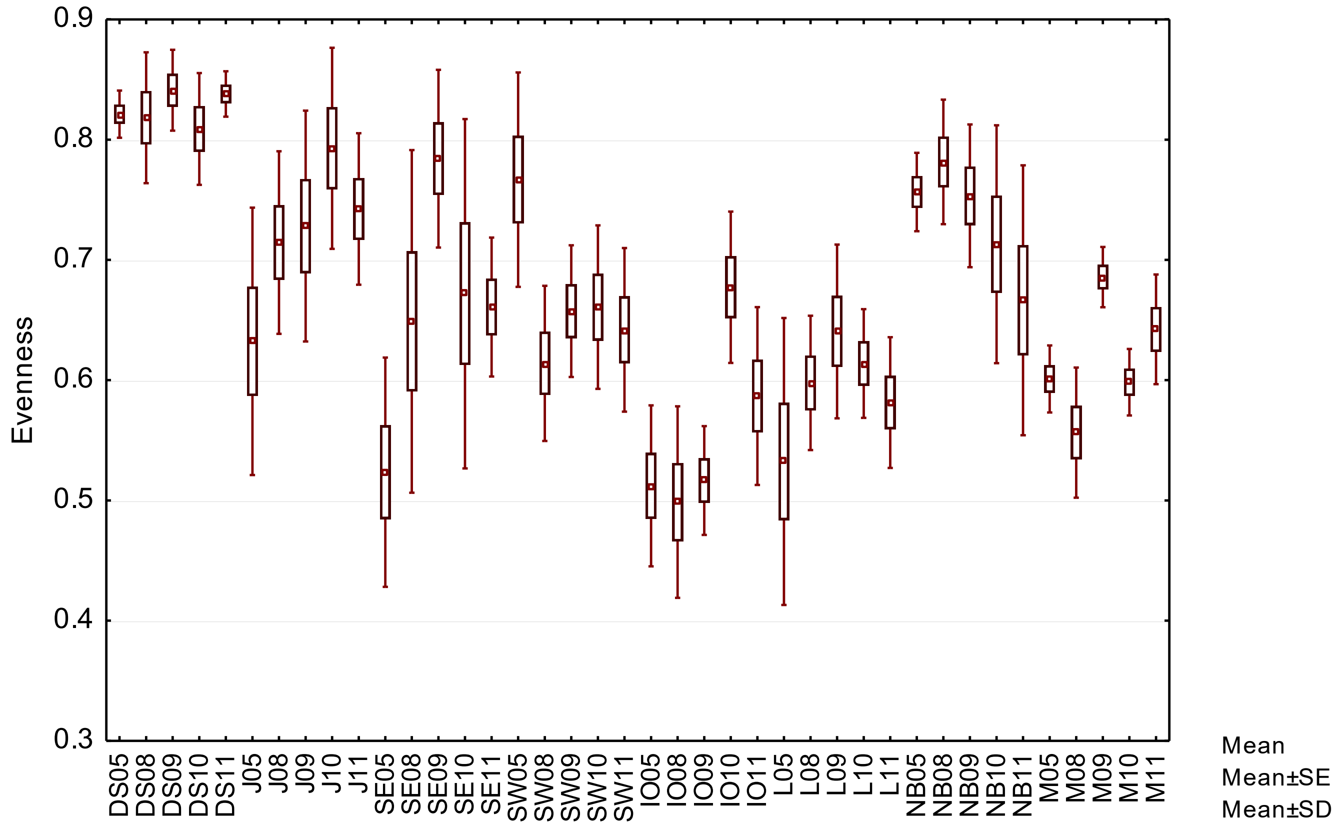


Figure 8.14. Temporal changes of % cover and species number (mean ± SE) from 2005 to 2011 at the eight rocky shore sites (DS = Dive School, J = Jetty, SE = Schaapen East, SW = Schaapen West, IO = Iron Ore Terminal, L = Lynch Point, NB = North Bay, M = Marcus Island).


Evenness
0.9
0.8
0.7
0.6
0.5
0.4
0.3
DS05 DS08 DS09 DS10 DS11 J05 J08 J09 J10 J11 SE05 SE08 SE09 SE10 SE11 SW05 SW08 SW09 SW10 SW11 IO05 IO08 IO09 IO10 IO11 L05 L08 L09 L10 L11 NB05 NB08 NB09 NB10 NB11 M05 M08 M09 M10 M11
Mean
Mean±SE
Mean±SD

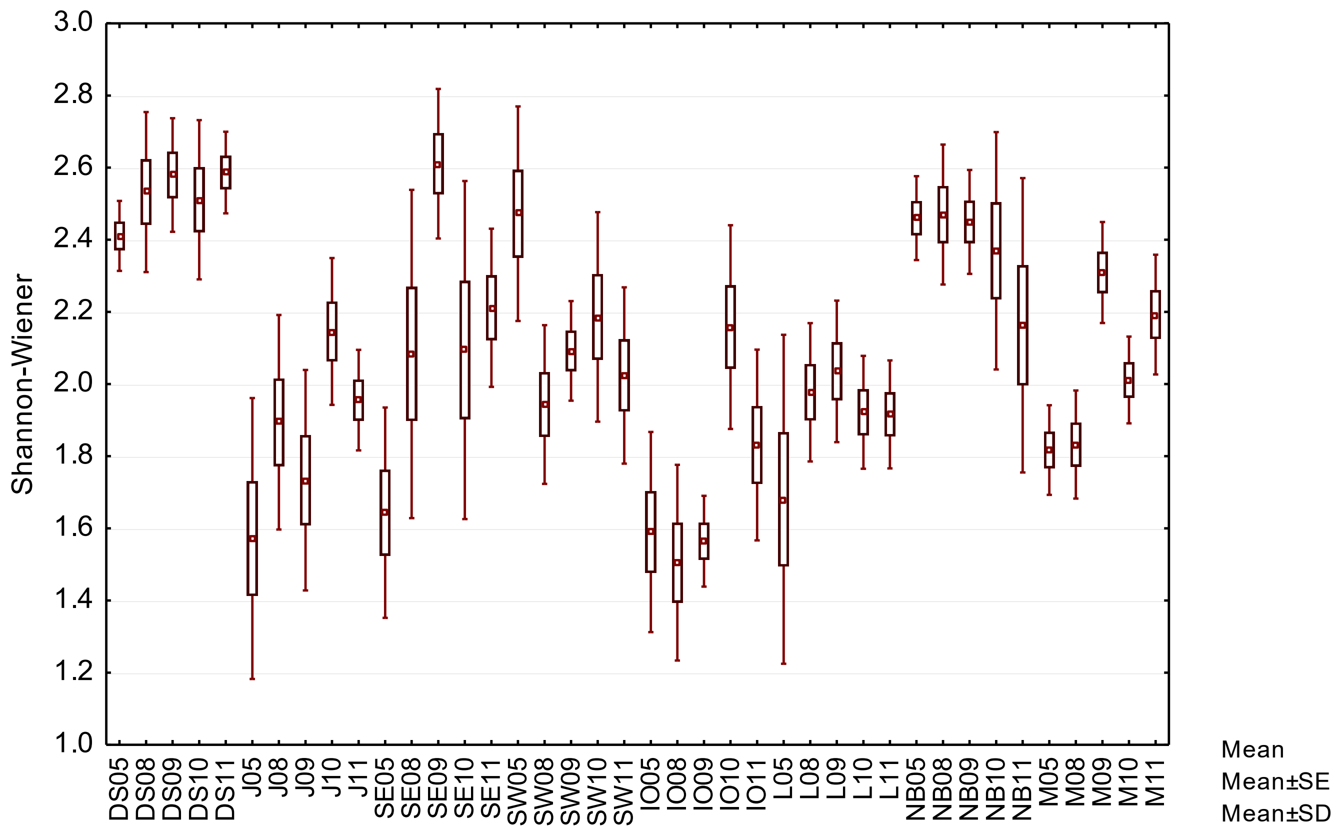

Shannon-Wiener
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
DS05 DS08 DS09 DS10 DS11 J05 J08 J09 J10 J11 SE05 SE08 SE09 SE10 SE11 SW05 SW08 SW09 SW10 SW11 IO05 IO08 IO09 IO10 IO11 L05 L08 L09 L10 L11 NB05 NB08 NB09 NB10 NB11 M05 M08 M09 M10 M11
Mean
Mean±SE
Mean±SD

Figure 8.15. Temporal changes of evenness and Shannon-Wiener diversity indices (mean ± SE) from 2005 to 2011 at the eight rocky shore sites. (DS = Dive School, J = Jetty, SE = Schaapen East, SW = Schaapen West, IO = Iron Ore Terminal, L = Lynch Point, NB = North Bay, M = Marcus Island).

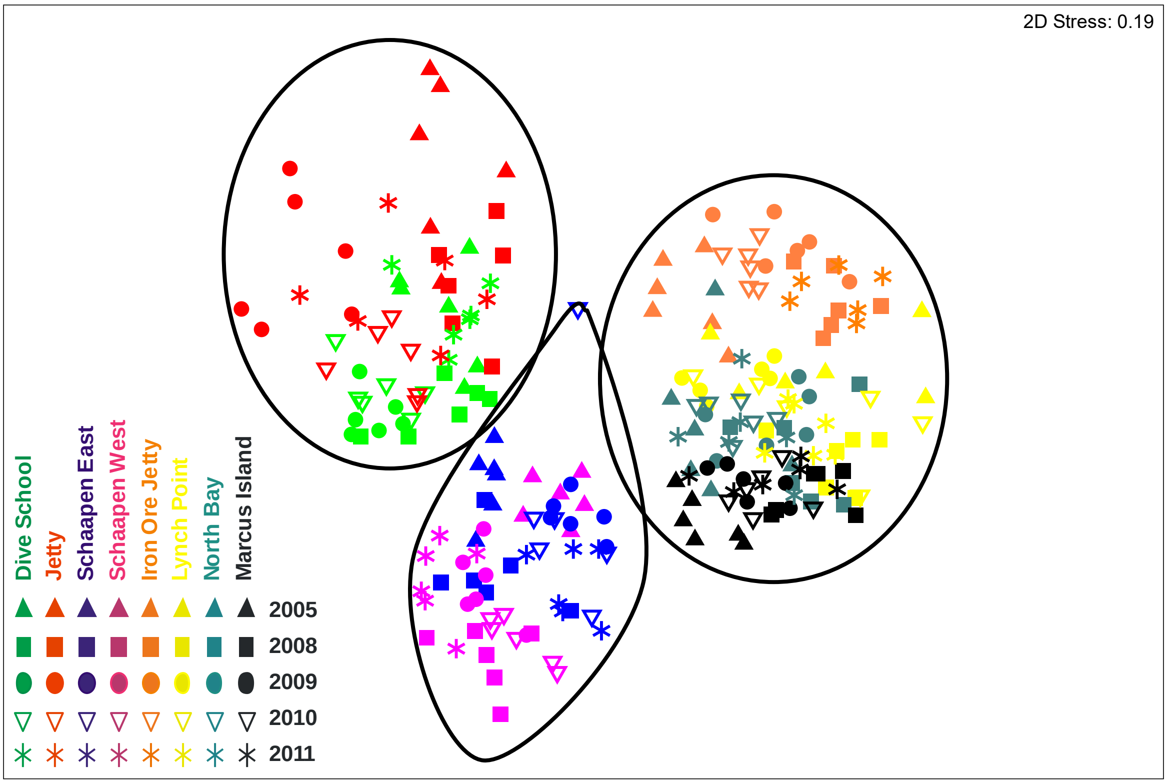


Figure 8.16. Multi-dimensional scaling (MDS) plot of the rocky shore communities at the eight study sites from 2005 to 2011. The circles delineate a 40% similarity level.

Another seaweed that had declined in abundance was *Gigartina polycarpa* at Dive School and Iron Ore Terminal, whereas *Sarcothalia stiriata* increased at the latter site. Changes in barnacle cover had also contributed to dissimilarities, specifically at the two very sheltered boulder beaches Dive School and Jetty, where *B. glandula* was absent in 2010 but present in 2011, while the striped barnacle *Amphibalanus amphitrite* occurred in 2010 at Jetty and Iron Ore Terminal but not in 2011. In general though, average dissimilarities between the years per site were low, indicating that temporal differences in rocky shore communities were small (Table 8.2).

Temporal variations in abundance of functional groups at the eight study sites are illustrated in Figure 8.17. At the two sheltered boulder beaches Dive School and Jetty, filter feeders and ephemerals had slightly decreased while corticated algae and grazers had increased with time. In 2011, however, algae other than encrusting were sparse. At Schaapen East, filter feeders depicted an increasing and ephemerals a decreasing trend, while encrusting corallines fluctuated strongly. At Schaapen West, biotic cover had steadily increased until 2010, especially encrusting corallines and ephemerals. The latter group had drastically declined by 2011, reducing the overall cover. Iron Ore Terminal and Lynch Point remained relatively constant over time, with only minor variations in encrusting coralline and ephemeral cover at Lynch Point. At North Bay, there was a drastic increase in filter feeders until 2010, remaining at the same level in 2011. Corallines and ephemerals again showed slight temporal fluctuations. At Marcus Island, ephemeral algae had greatly increased from 2005 to 2009 while at the same time corticated algae and filter feeders declined. The substantial ephemeral cover resulted in an overall greater biotic cover in 2009. In 2010, ephemerals had somewhat reduced but returned again 2011.

Table 8.1. PERMANOVA pairwise-testing results following significant main-tests. Only the relevant pairwise comparisons for the years 2005 vs. 2008, 2008 vs. 2009, 2009 vs. 2010, and 2010 vs. 2011 per site are shown. Significant (p < 0.05) differences are highlighted in italic. Number of permutations are 462 for all pairwise comparisons. Percent similarity among the years tested are also provided.

Figure 1: Groups	Figure 2: Pseudo-F	Figure 3: Significance Level	Figure 4: % Similarity
Dive School 2005 vs. 2008	2.5041	*0.003*	62.1
Dive School 2008 vs. 2009	2.9203	*0.003*	59.3
Dive School 2009 vs. 2010	1.5954	*0.002*	70.2
Dive School 2010 vs. 2011	2.1833	*0.004*	66.8
Jetty 2005 vs. 2008	2.8132	*0.002*	65.6
Jetty 2008 vs. 2009	3.4427	*0.002*	47.7
Jetty 2009 vs. 2010	2.2527	*0.007*	59.5
Jetty 2010 vs. 2011	2.8509	*0.001*	53.5
Schaapen East 2005 vs. 2008	3.4945	*0.007*	52.9
Schaapen East 2008 vs. 2009	2.3635	*0.004*	64.4
Schaapen East 2009 vs. 2010	2.4761	*0.005*	58.4
Schaapen East 2010 vs. 2011	2.0324	*0.002*	56.2
Schaapen West 2005 vs. 2008	3.465	*0.003*	48.0
Schaapen West 2008 vs. 2009	2.8932	*0.003*	55.8
Schaapen West 2009 vs. 2010	2.4896	*0.002*	66.9
Schaapen West 2010 vs. 2011	2.9673	*0.002*	58.7
Iron Ore Terminal 2005 vs. 2008	3.2623	*0.002*	50.2
Iron Ore Terminal 2008 vs. 2009	2.7982	*0.003*	60.6
Iron Ore Terminal 2009 vs. 2010	3.1414	*0.002*	61.8
Iron Ore Terminal 2010 vs. 2011	3.321	*0.002*	67.8
Lynch Point 2005 vs. 2008	2.4023	*0.003*	56.3
Lynch Point 2008 vs. 2009	2.6826	*0.003*	58.2
Lynch Point 2009 vs. 2010	2.6087	*0.003*	57.5
Lynch Point 2010 vs. 2011	1.9785	*0.001*	65.9
North Bay 2005 vs. 2008	1.9355	*0.001*	59.5
North Bay 2008 vs. 2009	1.8012	*0.002*	63.4
North Bay 2009 vs. 2010	1.7216	*0.005*	67.1
North Bay 2010 vs. 2011	1.9676	*0.002*	65.0
Marcus Island 2005 vs. 2008	3.559	*0.002*	56.8
Marcus Island 2008 vs. 2009	2.5676	*0.002*	63.7
Marcus Island 2009 vs. 2010	2.8566	*0.003*	67.2
Marcus Island 2010 vs. 2011	2.3449	*0.003*	68.7

Table 8.2. SIMPER results listing the species that contribute >5% to the dissimilarity between 2010 and 2011 at each site. The % cover data are averages across the six replicates per site, and are on the fourth-root transformed scale.

Site	Species	2010 %cover	2011 %cover	Contribution %	Average dissimilarity
Dive School	*Balanus glandula*	0.0	1.13	8.64	33.2
	Gigartina polycarpa	1.17	0.38	6.35	
Jetty	*Balanus glandula*	0.0	1.39	11.78	46.5
	Amphibalanus amphitrite	1.26	0	10.70	
	Ralfsia verrucosa	1.27	0.74	5.49	
	Ulva spp.	1.03	0.51	5.42	
Schaapen East	Blue green algae	1.76	0.86	6.30	43.8
Schaapen West	Blue green algae	1.85	0.0	9.45	41.3
Iron Ore Terminal	*Amphibalanus amphitrite*	1.24	0.0	8.62	32.2
	Gigartina polycarpa	0.92	0.0	6.42	
	Sarcothalia stiriata	0	0.85	5.92	
	Austromegabalanus cylindricus	0.11	0.86	5.30	
Lynch Point	Red turf	0	0.75	4.61*	34.1
North Bay	*Laminaria pallida*	0	0.77	4.75*	35.0
Marcus Island	Blue green algae	1.05	0.0	5.97	31.3

* Note that at these sites none of the species contributed >5% to the dissimilarity. The species with the highest contribution is thus listed.

From the temporal pattern displayed by the rocky shore communities, it is evident that at none of the sites there is a directional change in community composition that would indicate a persistent change, such as for example the arrival or loss of a species. Rather the communities show temporal fluctuations, reflecting for example dominance of ephemerals over one or more years (e.g. Schaapen West and Marcus Island). Ephemeral algae typically show strong temporal variation in their abundances (Griffin *et al.* 1999, Maneveldt *et al.* 2009). They generally have short life-cycles and dense populations are therefore only temporarily. Recruitment and survival success is also strongly related to environmental conditions that will vary from year to year. Ephemeral assemblages also vary in their species distribution and density according to the successional stage of the shore or patch on the shore. For example, limpet exclusion experiments on the south-western Cape resulted in an immediate recruitment of blue-green algae and *Porphyra*, which were after a couple of months replaced by *Ulva* spp. This green alga in turn, was then replaced by encrusting and corticated algae with time (1-2 years, Maneveldt *et al.* 2009). Changes in ephemeral algae cover over the years are thus likely to be a natural seasonal and interannual phenomenon, and there is no reason to assume anthropogenic influences.

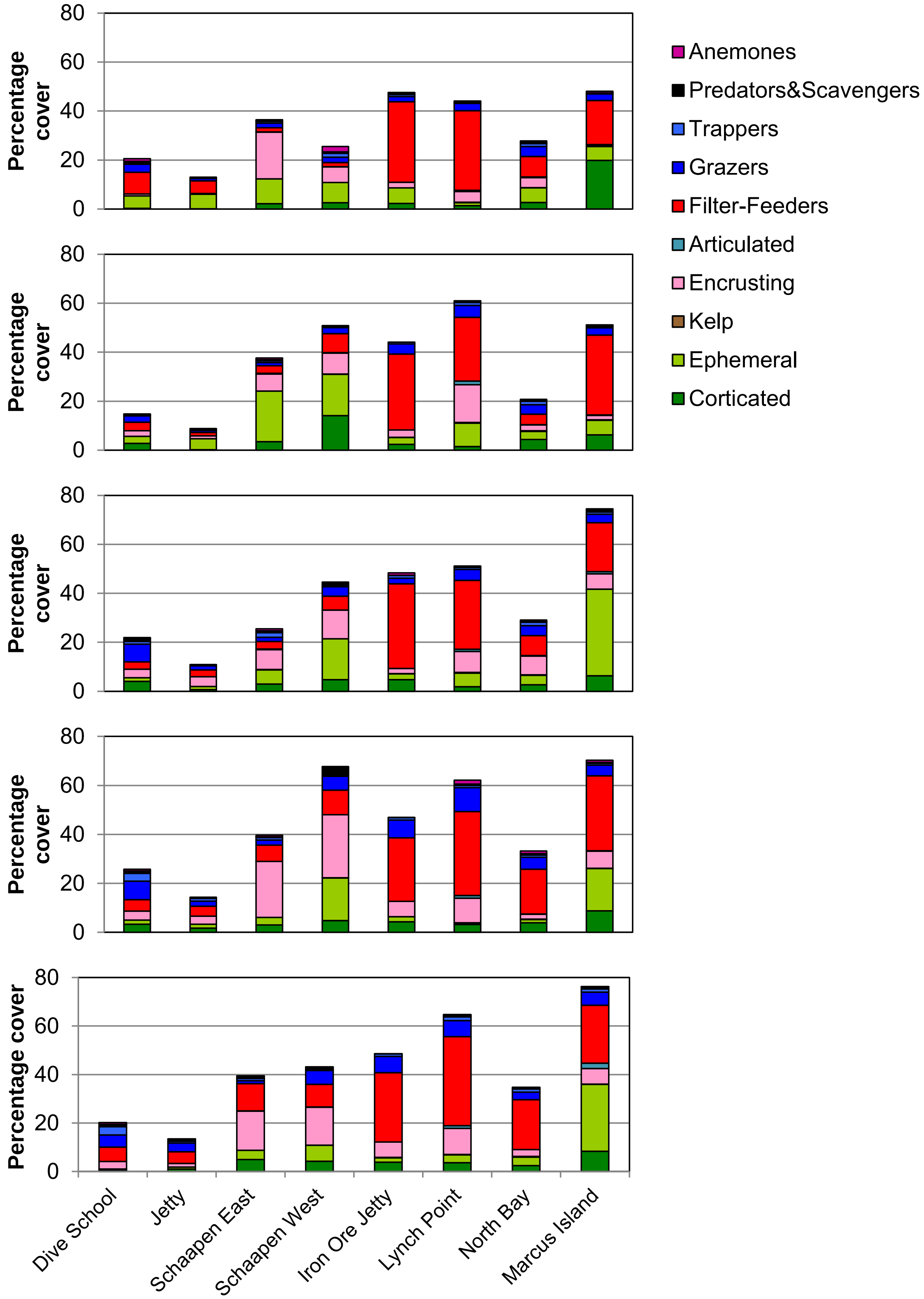


Figure 8.17. The mean percentage cover of the various functional groups at the study sites in 2005, 2008, 2009, 2010, and 2011 (from top to bottom).

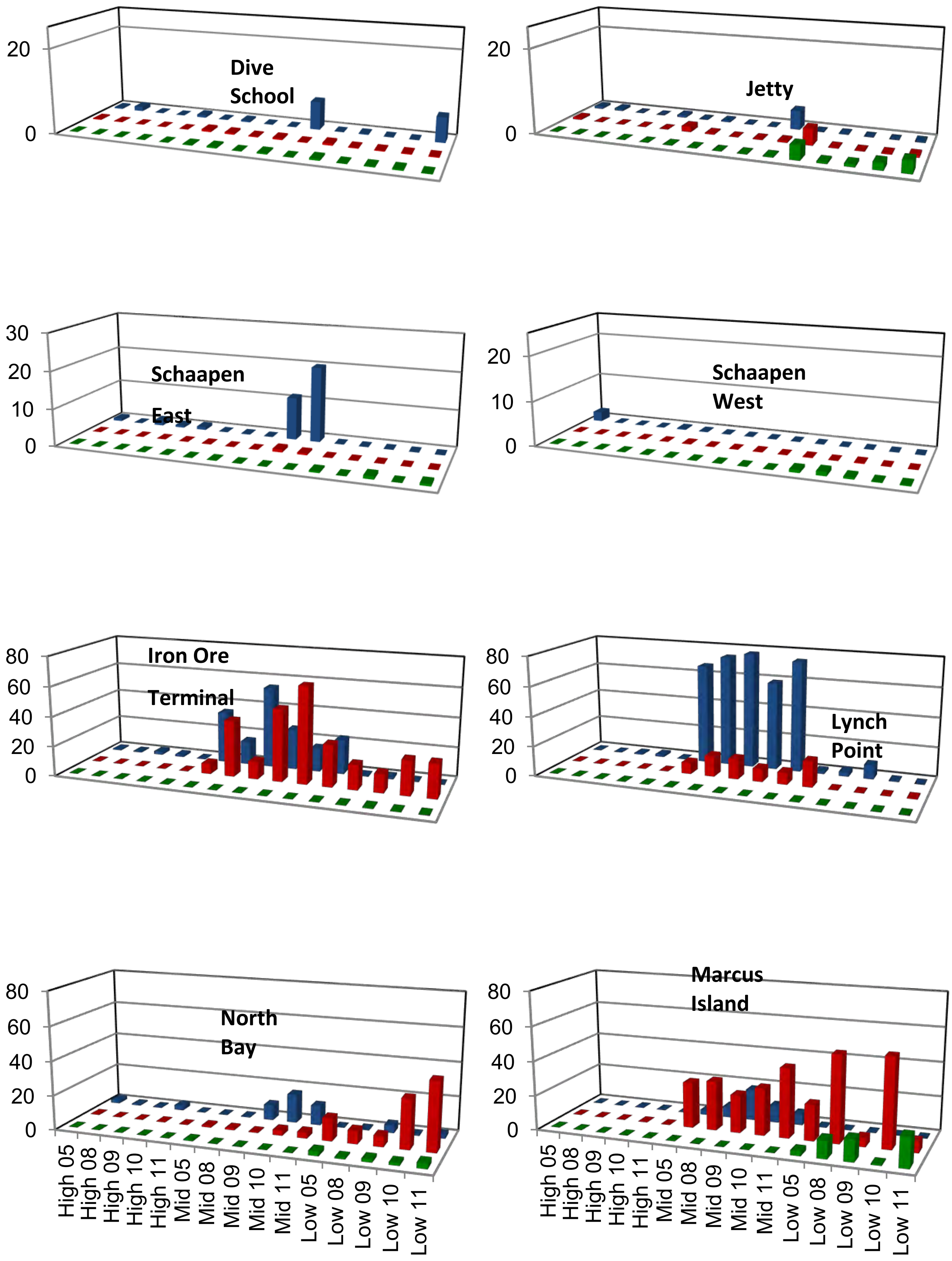


Figure 8.18. Mean percentage cover of the indigenous Aulacomya ater (green) and the aliens Mytilus galloprovincialis (red) and Balanus glandula (blue) at the eight study sites over the years. Note the difference in scale between the top four and bottom four graphs.

Some of the sites experienced also temporal fluctuations in filter feeder abundance. Unquestionably, the two most prominent filter feeders along the southern west coast are the alien invasive *B. glandula* and *M. galloprovincialis*. A worldwide well known coastal invader, *M. galloprovincialis* has been described as the ecologically most important and numerically dominant marine alien species along the southern African coast (Robinson *et al.* 2005). It was first recorded in 1979 in Saldanha Bay, and has now a distribution bridging three marine biogeographic provinces, covering over 2000 km of coastline (Robinson *et al.* 2005). The rate of increase and abundance of *M. galloprovincialis* is generally promoted by exposure to strong wave action (Branch *et al.* 2008). Along the west coast of South Africa, *M. galloprovincialis* dominates the rocky intertidal at the expense of various competitively inferior indigenous mussel and limpet species (Griffiths *et al.* 1992, Steffani & Branch 2003a, b, Branch & Steffani, 2004, Robinson *et al.* 2007, Branch *et al.* 2008, 2010b). In general, its competitive strength and impact on other elements of the fauna increases with wave exposure (Branch *et al.* 2008, 2010b). In comparison with the indigenous mussels *Choromytilus meridionalis* and *Aulacomya ater*, *M. galloprovincialis* has a faster growth rate, greater fecundity, and superior tolerance to desiccation (van Erkom Schurink & Griffiths 1991, 1993, Hockey & van Erkom Schurink 1992). This led to an upshore broadening of the width of intertidal mussel beds where this species has invaded (Hockey & van Erkom Schurink 1992).

The time of arrival of the alien barnacle *B. glandula* is unknown, but it can be traced back to at least 1992 (Laird & Griffiths 2008). Similar to *Mytilus*, it is assumed that is has been introduced to South Africa in the ballast waters of ships (or attached to their hulls) that arrived in the port of Saldanha Bay (Griffiths *et al.* 2011). In 2008, its range extended from Cape Point 400 km northwards along the West Coast, but it is, at present at least, absent from the South Coast (Laird & Griffiths 2008). It is now the most common barnacle along the cool-temperate west coast (Griffiths *et al.* 2011). The high densities of intertidal B. glandula suggest that it has significant ecological impacts on the local biota; for example it is thought that it allows the indigenous periwinkle *A. knysnaensis* to extend its range further down the shore by providing increased habitat complexity and shelter from waves (Griffiths *et al.* 2011).

Relative changes in percentage cover of the two alien invasives as well as the indigenous ribbed mussel *Aulacomya ater*, depict clear spatial and temporal patterns (Figure 8.18). As expected, both *B. glandula* and mussel cover is generally sparse at wave-protected shores. At Schaapen East, however, the barnacle invaded the mid shore in 2010 and had by April 2011 doubled its spread to cover 20% of the rock (see Figure 8.5). At semi-exposed sites, B. glandula is strongly represented in the mid shore where it is often the most dominant species, covering for example nearly 80% of the shore at Iron Ore Terminal. In contrast, the high and low shores of this site are almost barnacle free. Mussels are also restricted to the mid shore. At Lynch Point both *B. glandula* and *Mytilus* are common in the mid shore, whereby the relative dominance of one species over the other fluctuated over the years. In the low shore, however, *B. glandula* is typically rare and *Mytilus* the dominant filter feeder. With further increases in wave exposure, *B. glandula* cover in the mid shore reduces and *Mytilus* is the general dominant filter feeder (e.g. Marcus Island).

The general picture thus emerges that *B. glandula* is most common at mid shores of semi-exposed sites, but rarer at exposed sites and low shores; a similar shore-distribution pattern as described by Laird & Griffiths (2008). *M. galloprovincialis*, on the other hand, fares best at wave-exposed sites and lower down the shore (see also Branch *et al.* 2008, 2010b). The distribution patterns of the two species suggest thus differences in their preferential habitats but it seems that there are areas of overlap. For example, at the mid shore of the semi-exposed to exposed site Lynch Point, mussel and barnacle cover fluctuated strongly, clearly showing that an increase of one taxa resulted in the decrease of the other. In other words, it could be that at this site, where the degree of wave action is suitable for both, the barnacle and mussel compete. Many studies of competition on intertidal rocky shores have shown that the resource most often competed for by sessile organisms is space and that upper and/or lower vertical distribution boundaries on the shores are partly due to the relative ability of the species to compete for space (see review by Menge & Branch 2001). The varying interannual success in competing for space might in turn be related to varying success in larval development, settlement and/or recruitment. For most benthic marine organisms, fluctuations in the arrival of broadly dispersing pelagic larvae are among the most important factors driving population dynamics (Roughgarden *et al.* 1988, Menge *et al.* 1997, Menge & Branch 2001). Because dispersal and supply of larvae to suitable settlement habitats are highly dependent upon coastal water movements during larval development, large variability in recruitment can occur over various spatial and temporal scales and may be greatly influenced by the effects of topography and season on oceanographic processes. A recent study on settlement and recruitment dynamics of mussels and barnacles (mostly *M. galloprovincialis* and *B. glandula* by virtue of their dominance) in the southern Benguela upwelling region (Pfaff *et al.* 2011), found that recruitment of both mussels and barnacles was strongly seasonal, with peaks in austral summer (November to January) and spring (August to October), respectively. There was further a strong spatial variation, which was on a regional scale related to differences in upwelling strength (upwelling centre at headlands versus downstream bays), and on a local scale due to differences of wave exposure, whereby recruitment rates were consistently higher in wave-exposed than in protected habitats. Inter-annual variability in recruitment intensity at a particular site was for both taxa, however, only moderate but still observable, and may thus result in temporal variability of adult populations. Without more research and particularly experimental work, however, it cannot be ascertained whether there is indeed competitive interaction between *Mytilus* and *Balanus*, and whether the barnacle's zonation pattern is determined by the mussel.

The only indigenous filter feeder of any importance at the study sites was the ribbed mussel *Aulacomya ater*. Present only with very low cover at the low shores of most shores, *A. ater* had at the low shore of Marcus Island increased in abundance from 2005 to 2009, almost disappeared in 2010 only to return again in 2011 with an average of 17% cover. An earlier study by Robinson and co-workers (2007) investigated the impacts and implications of the invasion of the intertidal zone at Marcus Island by *Mytilus*. A single data set taken in 1980 prior to the invasion was compared to a survey conducted in 2001, using the same technique as the original sampling. Before the invasion, dense stands of mussels, primarily *Aulacomya ater*, were restricted to the low shore, whereas scarce cover of *Choromytilus meridionalis* was recorded in the mid and low shore. In 2001, *Mytilus* had heavily invaded all zones except the very high shore, and replaced the indigenous mussels in the low shore. The mid shore, previously a patchy environment, comprising mainly bare rock interspersed with patches of algae and large limpets, was transformed to a less patchy but structurally more complex mussel matrix with increased invertebrate densities and species richness. The authors concluded that the invasion had its greatest impact in the mid-to-low shore, and is clearly displacing *A. ater* from the rock surface. Experimental manipulations conducted on the West Coast of South Africa confirm a negative impact of *Mytilus* presence on *A. ater* abundance (Branch *et al.* 2010b). Although a direct comparison between the 2001 survey at Marcus Island and the current surveys is not possible (Robinson *et al.* 2007 reported density not percentage cover) it seems likely that up until 2008, *Mytilus* cover had even further increased and *A. ater* reduced. The strong decline of *Mytilus* cover in 2009 may has temporarily released the local mussel from the competitive pressure, but with the return of the alien mussels, it all but disappeared again. In 2011, however, *Mytilus* cover had again drastically declined while *A. ater* gained in cover. Such short cycles in relative dominance especially for the relatively slower growing indigenous mussel (van Erkom Schurink & Griffiths 1993) is somewhat surprising. When undistributed, the *Mytilus* matrix at Marcus Island's low shore is very dense and multilayered (Robinson *et al.* 2007, pers. obs.). Surveying of the shore is done by non-destructive methods (see Method section) and any biota hidden in the deepest layer of the tight matrix cannot be seen without removing the top layer. A. ater can often been found burrowed in the *Mytilus* matrix (Griffiths *et al.* 1992, Steffani & Branch 2003b), and it is thus possible that deep in the lowest depth of the mussel bed, *A. ater* is always present, but is only exposed when the top *Mytilus* layer is removed by, for example, storm waves that often impact the exposed shore of Marcus Island.

This would explain why firstly *Mytilus* cover reduced, i.e. removed by wave action, and secondly *A. ater* cover is recorded, i.e. only now visible and recordable with non-destructive methods.

Invasive alien species have been identified as one of the major threats to the maintenance of biodiversity in the marine environment (Carlton & Geller 1993, Carlton 1999, Ruiz *et al.* 1999, IUCN 2009), particularly in the context of global climate change (Occhipinti-Ambrogi 2007, Occhipinti-Ambrogi & Galil 2010). To date, 22 confirmed extant marine aliens, plus 18 cryptogenic species, have been recorded from South African waters, with one additional species found in on-land mariculture facilities (Griffiths *et al.* 2009). The true number of introduced species may well exceed these estimates by several times. The major means of introduction is international shipping, i.e. via ballast water and as attachment to the hulls of ships, followed by aquaculture (Galil *et al.* 2008). Saldanha Bay is a deepwater harbour receiving vessels from all over the world and it thus likely that one of the greatest perils to the intertidal (and in fact all other) communities in Saldanha Bay is the introduction of alien species, and their potential to become invasive.

8.4 Summary of Findings

A total of 84 taxa were recorded from the eight study sites, most of which had also been found in the previous survey years. The faunal component was represented by 16 species of grazers, 3 trappers, 7 predators and scavengers, 6 anemones, and 18 filter-feeders. The algal component comprised 22 corticated (foliose) seaweeds, 6 ephemerals, 1 kelp, 4 crustose (or encrusting) corallines and 1 articulated coralline. The species are generally common to the South African West Coast and many are listed by other studies conducted in the Saldanha Bay area including the two alien invasive species, the Mediterranean mussel *Mytilus galloprovincialis* and the North American acorn barnacle *Balanus glandula*.

Within a site, the vertical emersion gradient of increasing exposure to air leads to a clear zonation of flora and fauna from low shore to high shore. Differences among the rocky shores, however, are strongly influenced by the prevailing wave exposure at a shore as well as substratum topography. Very sheltered shores had generally low biotic cover consisting primarily of grazers and trappers, with minor cover of sessile filter feeders and encrusting algae. With increasing wave force, filter feeders were clearly the most important group. The two very sheltered boulder beaches in Small Bay separate from the flat Schaapen Island sites, which may also be related to geographic location as Schaapen Island lies in a transitional zone between the Bay and the Lagoon, and to the nutrient input through seabird guano that favours algal growth on Schaapen Island. Similarly, the steep boulder beach Iron Ore Terminal separates from the other more flattish semi-exposed to exposed sites.

From the temporal pattern displayed by the rocky shore communities, it is evident that at none of the sites there is a directional change in community composition that would indicate a persistent change, such as for example the arrival or loss of a species. Rather the communities show temporal fluctuations, reflecting the temporary dominance of short-lived ephemeral species and/or interannual variation in larval supply or recruitment success. In general, rocky shore communities were relatively stable with only minor changes over the years.

The two most important filter feeders, being also the characteristic species at most shores and zones, are the aliens *M. galloprovincialis* and *B. glandula*. The latter is most abundant at mid shores of semi-exposed sites, but rarer at exposed sites and low shores. *M. galloprovincialis*, on the other hand, fares best at wave-exposed sites and lower down the shore. It is likely that one of the greatest threats to rocky shore communities in Saldanha Bay is the introduction of alien species via shipping, and their potential to become invasive.

9 FISH COMMUNITY COMPOSITION AND ABUNDANCE

9.1 Introduction

The waters of Saldanha Bay and Langebaan Lagoon support an abundant and diverse fish fauna. Commercial exploitation of the fish within the Bay and lagoon began in the 1600's by which time the Dutch colonists had established beach-seine fishing operations in the region (Poggenpoel 1996). These fishers' targeted harders *Liza richardsonii* and other shoaling species such as white steenbras *Lithognathus lithognathus* and white stumpnose *Rhabdosargus globiceps*, with much of the catch dried and salted for supply to the Dutch East India Company boats, troops and slaves at the Castle in Cape Town (Griffiths *et al*. 2004). Commercial netfishing continues in the area today, and although beach-seines are no longer used, gill-net permits holders targeting harders landed an estimated 590 tons valued at approximately R1.8 million during 1998-1999 (Hutchings and Lamberth 2002a). Species such as white stumpnose, white steenbras, silver kob *Argyrosomus inodorus*, elf *Pomatomus saltatrix*, steentjie *Spodyliosoma emarginatum*, yellowtail *Seriola lalandi* and smoothhound shark *Mustelus mustelus* support large shore angling, recreational and commercial boat line-fisheries which contribute significantly to the tourism appeal and regional economy of Saldanha Bay and Langebaan. In addition to the importance of the area for commercial and recreational fisheries, the sheltered, nutrient rich and sun warmed waters of the Bay provide a refuge from the cold, rough seas of the adjacent coast and constitute an important nursery area for the juveniles of many fish species that are integral to ecosystem functioning.

The importance and long history of fisheries in the Bay and Lagoon, has led to an increasing number of scientific data on the fish resources and fisheries in the area. Early studies, mostly by students and staff of the University of Cape Town investigated fish remains in archaeological middens surrounding Langebaan Lagoon (Poggenpoel 1996), whilst many UCT Zoology Department field camps sampled fish within the lagoon (unpublished data). Gill net sampling with the aim of quantifying bycatch in the commercial and illegal gill net fishery was undertaken during 1998-99 (Hutchings & Lamberth 2002b). A once of survey for small cryptic species utilizing rotenone, a fish specific, biodegradable toxin that prevents the uptake oxygen by small fish, was conducted by Anchor Environmental Consultants (AEC) during April 2001 (Awad *et al.* 2003). The data from the earlier gill netting and rotenone sampling survey was presented in the "State of the Bay 2006" report (Anchor Environmental Consultants 2006). Seine-net sampling of near-shore, sandy beach fish assemblages was conducted over short periods during 1986-1987 (UCT Zoology Department, unpublished data), in 1994 (Clark 1997), and 2007 (Anchor Environmental Consultants, UCT Zoology Department). Monthly seine-net hauls at a number of sites throughout Saldanha Bay-Langebaan over the period November 2007-November 2008 were also conducted by UCT M.Sc. student Clement Arendse who was investigating white stumpnose recruitment. These data were reported on in the "State of the Bay 2008" report (Anchor Environmental Consultants 2009).

Other recent research on the fish fauna of the area includes acoustic tracking and research on the biology of white stumpnose within Langebaan lagoon and Saldanha Bay, monitoring of recreational shore and boat angler catches and research on the taxonomy and life history of steentjies and sand sharks and (Kerwath *et al*. 2009, Næsje *et al.* 2008, Tunley *et al.* 2009, Attwood *et al.* 2010). Key findings of these studies include evidence that the Langebaan lagoon MPA effectively protects white stumpnose during the summer months that coincides with both peak spawning and peak recreational fishing effort (Kerwath *et al.* 2009). White stumpnose within the Saldanha-Langebaan system grow more rapidly and mature earlier than populations elsewhere on the South African coast (Attwood *et al.* 2010). Male white stumpnose in Saldanha Bay reach maturity in their second year at around 19 cm fork length (FL) and females in their third year at around 22 cm FL (Attwood *et al.* 2010). Similar differences in growth rate and the onset of maturity for steentjies between Saldanha Bay and south coast populations were reported by Tunley *et al.* (2009). These life history strategies (relatively rapid growth and early maturity) are probably part of the reason that stocks of these species in Saldanha and Langebaan have to date, been resilient to rapidly increasing recreational fishing pressure. Results from angler surveys indicate that approximately 92 tons of white stumpnose is landed by anglers each year (Næsje *et al.* 2008). Further details of the results of these studies were reported on in the State of the Bay 2008 report (Anchor Environmental Consultants 2009). The research on sand sharks suggests that the common sand shark species in Bay and Lagoon is actually *Rhinobatos blockii*, not *R. annulatus* as previously thought (Dunn & Schultz UCT Zoology Department personal communication). New information on the life history of this species has been collected and will be published in the near future.

The Saldanha Bay Water Quality Forum Trust (SBWQFT) commissioned Anchor Environmental to undertake experimental seine-net sampling of near shore fish assemblages at a number of sites throughout the Saldanha-Langebaan system during 2005, 2008, 2009, 2010, 2011 and 2012 as part of the monitoring of ecosystem health "State of the Bay" programme. In the 2006 report it was noted that the existing seine-net survey data was the most suitable for comparative analyses over time and it was recommended that future seine-net surveys were conducted during late summer - early autumn, as this was the timing of peak recruitment of juveniles to the near-shore environment, as well as the timing of most of the earlier surveys. Since 2008, seine-net surveys have therefore been conducted during March-April of each year. These studies have made a valuable contribution to the understanding of the fish and fisheries of the region.

This report presents and summarizes the data for the 2012 seine-net survey and investigates trends in the fish communities by comparing this with data from previous seine-net surveys (1986/87, 1994, 2005, 2007-2012) in the Saldanha- Langebaan system. Recent data on the commercial catch and effort of harders (the principal target of the net fisheries in the Bay) are also presented and compared to the results of the experimental seine net surveys. A similar comparison of commercial and recreational white stumpnose catches to fishery independent, experimental seine net survey data was presented in the 2011 State of the Bay report.

9.2 Methods

9.2.1.1 Field sampling

Experimental seine netting for all surveys covered in this report was conducted using a beach-seine net, 30 m long, 2 m deep, with a stretched mesh size of 12 mm. Replicate hauls (3-5) were conducted approximately 50 m apart at each site during daylight hours. The net was usually deployed from a small rowing dinghy 30-50 m from the shore. Areas swept by the net were calculated as the distance offshore multiplied by the mean width of the haul. Sampling during 1986-87 was only conducted within the lagoon where 30 hauls were made, whilst 39 and 33 replicate hauls were made at 8 and 11 different sites during 1994 and 2005 surveys respectively in the Bay and Lagoon. During 2007, 21 hauls were made at seven sites in the Bay and Lagoon and for the last four years, 2-3 hauls have been made at each of 15 standard sites every April (2008-2012) (Figure 9.1). Large hauls were sub-sampled on site, the size of the sub-sample estimated visually and the remainder of the catch released alive. Unfortunately a computer failure during data capture in the field led to the loss of the 2012 data for three lagoon sites (Churchaven, Kraalbaai and Schaapen Island) and one Big Bay site (Leentjiesklip). This does not impact the analysis and interpretation of the Big Bay data (only 1 out of 6 sites), but does significantly affect interpretation of data summarised for the Lagoon, and as a result statistical analysis of temporal trends in the lagoon ichthyofauna community is not undertaken this year.

9.2.1.2 Data analysis

Numbers and mass of fish caught were corrected for any sub-sampling prior to data analysis. All fish captured were identified to species level where possible and abundance calculated as the number of fish per square meter sampled. During the seven most recent seine-net surveys (2005 onwards) the total of each species caught was weighed to the nearest gram. The weight of any fish released alive was calculated from published length-weight relationships (Mann 2000). For the purposes of this report, abundance data were used for analysis of spatial and temporal patterns.

The number of species caught, average abundance and associated variance of fish (all species combined) during each survey were calculated and graphed. The average abundance of the most common fish species caught in the three main areas of the system, namely Small Bay, Big Bay and Langebaan lagoon during each survey, were similarly calculated and presented graphically. The average abundance of the four-five most ubiquitous species in the system over all survey years was calculated and plotted for each sampling site.

In order to investigate changes in the entire fish community composition between years, multivariate statistical analysis were conducted using the PRIMER software. Fish density data were fourth-root transformed and the Bay-Curtis similarity index was used to create similarity matrices. Relationships between years were represented using multidimensional scaling and these were statistically tested using two way mixed model PERMANOVA tests with years as a fixed effect and sites as a random effect (this takes into account the variability between sampled sites when comparing samples between years). The principal species contributing to dissimilarities between years were identified using the SIMPER routine.

The status of the commercial net fishery in the Saldanha Bay system (that targets harders *Liza richardsonii*), i.e. the health of the adult stock as opposed to the juvenile recruitment that is assessed by the experimental seine net fishery, was investigating using data from commercial catch returns from net-fish permit holders active throughout the Saldanha Bay – Langebaan area over the period January 2006 – December 2012. These data were obtained from the Department of Agriculture, Forestry and Fisheries (DAFF).

These data include information on the number of fishers, the date, and the catch of each species. Commercial rights holders are required by law to complete daily catch returns, but these are not frequently validated (i.e. are reliant on the honesty of the permit holder). These data are fisheries dependent – i.e. not an independent scientific survey (such as the experimental seine net survey) and therefore reflect the behaviour of the fishery (targeting, gear and catch restrictions etc.) as well as the relative abundance (or availability to the fishery) of the adult stock. Catch-per-unit-effort (CPUE) was used as an estimate of relative abundance of harders in the Saldanha-Langebaan system in each year. The rational is that the more abundant the species is in the fished area, the more will be caught per unit fishing time. This was calculated as the number of harders caught per boat-day fished. The average annual catch rate was then graphically compared to the average annual catch of juvenile harders in the fishery independent seine net surveys.

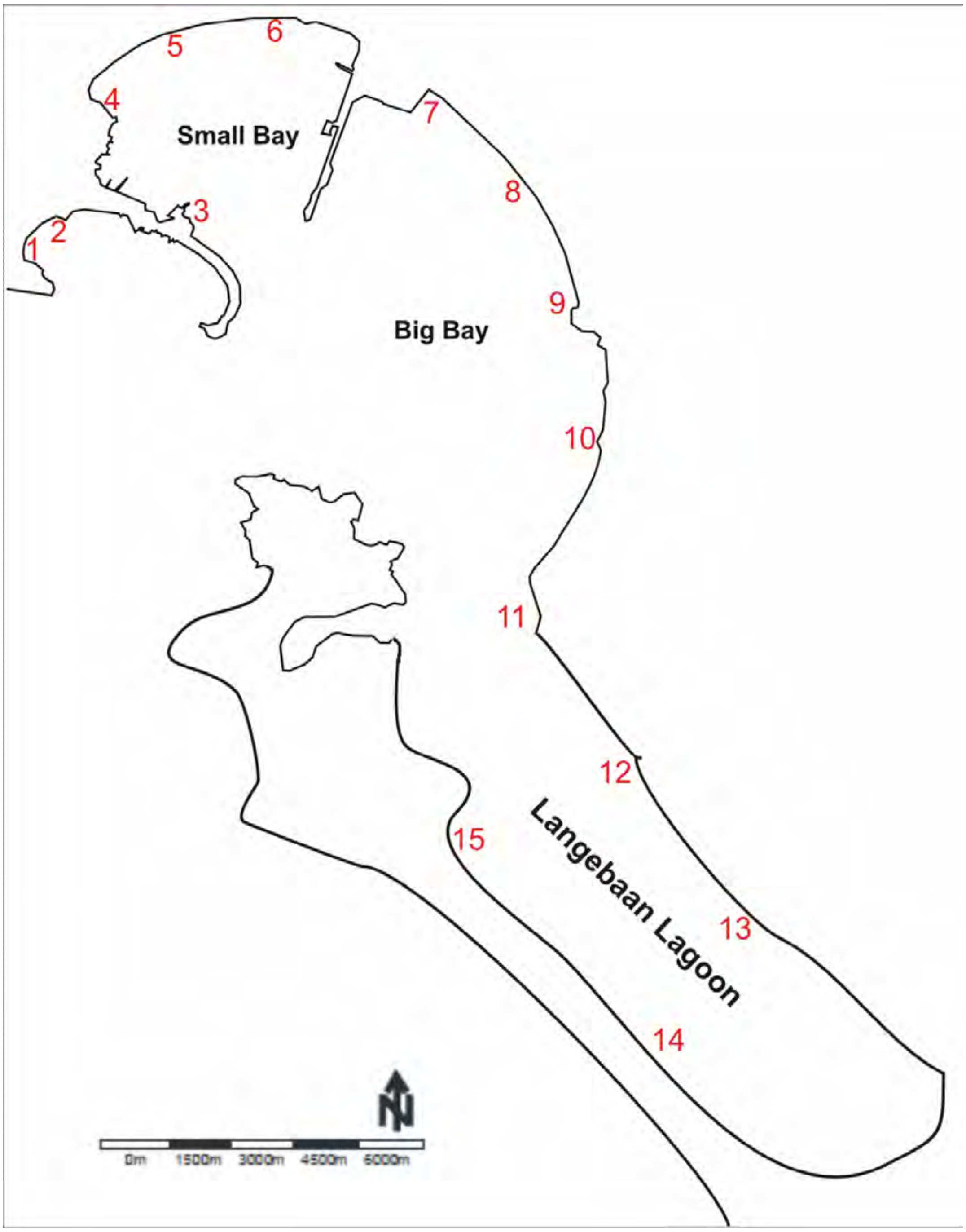


Figure 9.1. **Sampling sites within Saldanha Bay and Langebaan lagoon where seine net hauls were conducted during the 2005 and 2007-2012 annual sampling events. 1: North Bay west, 2: North Bay east, 3:Small craft harbour, 4: Hoedjiesbaai, 5: Caravan site, 6: Blue water Bay, 7: Sea farm dam, 8: Spreeuwalle, 9: Lynch point, 10: Strandloper, 11: Schaapen Island, 12: Klein Oesterwal, 13: Bottelary, 14: Churchaven, 15: Kraalbaai.**

9.3 Results

9.3.1 Description of inter annual trends in fish species diversity

During the 2012 annual survey, no less than six fish species were recorded for the first time. All of these new records were from Big Bay samples and include juveniles of species typically found in deeper offshore waters e.g. angel fish *Brama brama* and John dory *Zeus faber*, as well as species typically found east of Cape Point such as carpenter *Argyrozona argyrozona*, bluefin gurnard *Chelidonichthys kumu* and streepie *Sarpa salpa*. The occurrence of these species for the first time in samples is most likely the result of natural variation in regional and local oceanographic conditions rather than any anthropogenic influences. The other two species not previously recorded in experimental seine net samples, sardine *Sardinops* sagax and barbel *Galeichthyes feliceps* are common on the west coast. The total species count in all surveys to date now stands at 44 species taking into account the three different species of goby of the genus *Caffrogobius*, namely: *C. nudiceps, C. gilchristi* and *C. caffer* that have been identified in samples from the Bay. Due to the uncertainty surrounding identification of these species in earlier surveys, they have been grouped at the generic level for data presented reports since 2008. The species list and abundance of each species caught in Small Bay, Big Bay and the Lagoon during each of the different surveys are shown in Table 9.1, Table 9.2 & Table 9.3 respectively. Considering data from all surveys conducted to date, a greater diversity of species have been captured in Big Bay (33) , with slightly fewer in Small Bay (26) in the Lagoon (21) (Table 9.1, Table 9.2 & Table 9.3). Species richness is typically highest in Small Bay and varied little over time, although in 2009 & 2010 there was a slight reduction in the number of species caught in Small Bay, this increased again in 2011-12 (Figure 9.2). Slightly more variation in the number of species caught over the period of sampling is apparent for Langebaan lagoon and Big Bay with the most diverse samples collected from Big Bay during 2012 (Figure 9.2). The very low species count for Lagoon during the 2012 survey is undoubtedly a result of the data loss for three of the five sampled sites and should not be regarded as a true indication of the fish diversity in this area.

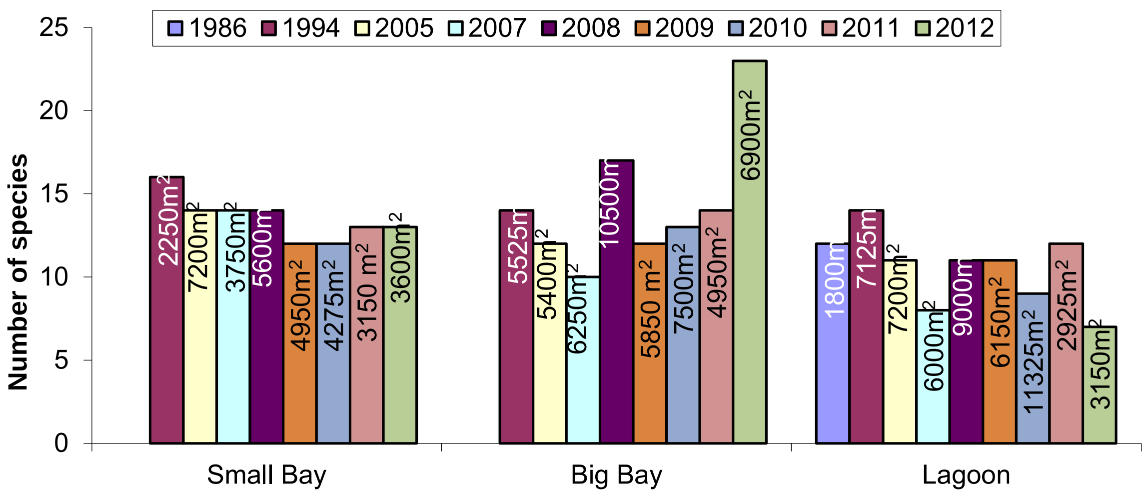


Figure 9.2. Fish species richness during nine seine-net surveys in Saldanha Bay and Langebaan lagoon conducted over the period 1986-2012. The total area netted in each area and survey is shown. Note: The low species richness for Langebaan lagoon during 2012 is an artefact due to data loss.

The actual species composition in the different areas between the surveys does change substantially between years, but the same ubiquitous species occur in nearly all surveys in the three areas (Table 9.1, Table 9.2 & Table 9.3). Within Small Bay, eight species have occurred in all surveys to date, with pipefish only absent in the 2005 sample, and gurnard not captured for the first time in 2011 and again in 2012. Five of the 33 species recorded in Big Bay occurred in all surveys with three more, silversides, False Bay klipvis and elf only absent in one survey each (2007, 1994 and 2009 respectively). Similarly, six of the 19 species found in the lagoon occurred in all surveys with the exception of the 2012 survey where the Knysna sand goby was not recorded (but this is almost certainly due to the loss of data from three lagoon sites). It appears that Small Bay has the highest proportion of “resident” species that occur there consistently, whilst a larger proportion of the Big Bay and Langebaan Lagoon ichthyofauna occur seasonally or sporadically in these areas. Short term fluctuations in diversity and abundance of near shore sandy beach fish communities with changes in oceanographic conditions are the norm rather than the exception (see for e.g. Clark 1994). In the earlier surveys (1994-2008), average species richness and abundance (all species combined) was generally highest in Small Bay and lowest in Big Bay (Figure 9.2, Figure 9.3). Since then, (with the exception of the 2011 survey) average estimated abundance in Small Bay and the Langebaan lagoon has been similar or greater in the Lagoon and in the case of species diversity; more species have been captured in Big Bay during the past three annual sampling events. This may simply be an indication of the high variability in surf zone fish densities that will be recorded when shoaling species are part of the fish assemblage, rather than an indication in fundamental changes in the fish communities.

9.3.2 Description of inter-annual trends in fish abundance and current status of fish communities in Small Bay, Big Bay and Langebaan lagoon

Within the Saldanha-Langebaan system, harders, silversides and gobies numerically dominated the catches for all surveys (Figure 9.3). Overall the catches made during the 2012 survey were the lowest on record for all three areas. Within Small Bay, estimated fish density was substantially lower than recorded for any earlier survey. Although estimated density was the lowest yet recorded for Big Bay, and substantially lower than the 2011 catch, it was within the historical range and similar to that recorded in 2005, 2009 and 2010. The 2012 overall abundance estimate for Langebaan lagoon sites cannot be taken as an accurate reflection due to the data loss (Figure 9.3).

Estimated white stumpnose, nude goby and blacktail abundance, that was above average in Small Bay during the 2007 and 2008 surveys has remained below these maxima in this region since 2009 (Figure 9.4). It now appears that the peak densities attained by these species during 2007-2008 were the exception, and the lower densities recorded before and after this period represent the more typical situation. The estimated density of harders and silversides during 2012 however, do appear to be in decline and well below the long-term average. Within Big Bay too, lower than average fish density was observed during the 2012 sampling, although white stumpnose density was not the lowest on record (Figure 9.4). During the 2009 survey, the densities of all the more common fish species in Small and Big Bay were lower than the preceding two years and in some cases the lowest recorded during sampling thus far. The 2012 survey saw a similar situation and it appears that the unfavourable environmental conditions that reduced the spawning success of adults and/or caused high mortality rates of eggs, larval and juveniles of several species during the 2008-2009 periods, returned during 2011-2012 summer.

Table 9.1. Average abundance of fish species (number.m^{-2}) recorded during annual beach seine-net surveys in Small Bay, Saldanha.

Year		Apr-94		Oct-05		Apr-07		Apr-08		Apr-09		Apr-10		Apr-11		Apr-12	
Species	**Common name**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**
Argyrozona argyrozona	*silverfish*															0.0002	0.0002
Atherina breviceps	silverside	1.3084	0.4004	0.0410	0.0136	0.9690	0.1802	1.6505	0.6931	0.109	0.052	0.3397	0.1121	0.6420	0.2777	0.1539	0.0607
Caffrogobius sp.	goby	0.0160	0.0035	0.1294	0.0983	1.0888	0.5198	0.0162	0.0122	0.019	0.009	0.0039	0.0024	0.0307	0.0272	0.0007	0.0005
Cancelloxus longior	snake eel															0.0002	0.0002
Cheilidonichthys capensis	gurnard	0.0022	0.0010	0.0082	0.0023	0.0003	0.0003	0.0004	0.0004	0.0006	0.0003	0.0007	0.0007				
Clinus latipennis	False Bay Klipvis									0.0004	0.0004	0.0006	0.0006				
Clinus sp. larvae	Klipvis larvae							0.0004	0.0004								
Clinus superciliosus	super klipvis	0.0080	0.0018	0.0028	0.0016	0.0090	0.0044	0.0142	0.0049	0.0030	0.0022	0.0017	0.0007	0.0250	0.0104	0.0588	0.0391
Diplodus sargus capensis	black tail	0.0022	0.0017	0.0178	0.0086	0.0532	0.0202	0.4437	0.2204	0.062	0.043	0.0011	0.0011	0.0007	0.0007	0.0390	0.0217
Etrumeus terres	red eye sardine	0.0009	0.0009														
Gilchristella aestuaria	estuarine round herring			0.0026	0.0020												
Gonorhynchus gonorhynchus	beaked sand eel			0.0001	0.0001			0.0004	0.0004								
Haploblepherus pictus	dark shy Shark									0.0002	0.0002			0.0019	0.0019	0.0011	0.0007
Heteromycteris capensis	Cape sole	0.0049	0.0018	0.0017	0.0011	0.0162	0.0074	0.0022	0.0013	0.026	0.009	0.0108	0.0037	0.0185	0.0097	0.0042	0.0017
Lithognathus sp	steenbras sp.			0.0079	0.0037												
Liza richardsonii	harder	0.6951	0.4400	0.5847	0.3283	2.1429	0.8870	0.8742	0.4165	0.4181	0.1867	1.1895	0.2816	38.4739	25.3006	0.1075	0.0464
Mustelus mustelus	smoothhound shark	0.0027	0.0022			0.0009	0.0007										
Myliobatis aquila	eagle ray	0.0013	0.0005	0.0004	0.0003	0.0079	0.0074							0.0004	0.0004		
Pomatomus saltatrix	elf	0.0009	0.0009			0.0013	0.0013	0.0003	0.0003					0.0007	0.0007		
Poroderma africana	striped catshark	0.0009	0.0005														
Psammogobius knysnaensis	Knysna sand gobi											0.0028	0.0026			0.0037	0.0014
Raja clavata	thornback skate					0.0011	0.0007										
Rhabdosargus globiceps	white stumpnose	0.0618	0.0259	0.0079	0.0031	5.0564	1.1656	0.4191	0.1487	0.0562	0.0179	0.0822	0.0328	0.0244	0.0122	0.0640	0.0301
Rhinobatos blockii	bluntnose guitar fish	0.0009	0.0005	0.0013	0.0005	0.0153	0.0092	0.0007	0.0004	0.0010	0.0006	0.0008	0.0008	0.0006	0.0006	0.0012	0.0006
Spondyliosoma emarginatum	steentjie	0.0013	0.0009	0.0092	0.0072			0.0003	0.0003					0.0237	0.0237		
Syngnathus temminckii	pipe fish	0.0022	0.0012			0.0037	0.0019	0.0257	0.0125	0.0004	0.0002	0.0035	0.0021	0.0033	0.0018	0.0148	0.0140
Trachurus trachurus	horse mackerel							0.0094	0.0094								
Total		**2.11**	**0.51**	**0.81**	**0.32**	**9.37**	**2.30**	**3.46**	**1.17**	**0.70**	**0.21**	**1.64**	**0.26**	**39.25**	**25.21**	**0.31**	**0.11**
Number of species	**26**	**16**		**14**		**14**		**15**		**12**		**12**		**13**		**13**	
Number of hauls	**59**	**5**		**12**		**6**		**12**		**12**		**12**		**12**		**9**	
Total area sampled (m^2)	**28 025**	**2250**		**7200**		**3750**		**5600**		**4950**		**4275**		**3150**		**3600**	

Table 9.2: Average abundance of fish species (number.m^{-2}) recorded during annual beach seine-net surveys in Big Bay, Saldanha. Ave = average, SE = standard error.

Year		Apr-94		Oct-05		Apr-07		Apr-08		Apr-09		Apr-10		Apr-11		Apr-12	
Species	**Common name**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**
Atherina breviceps	silverside	0.0003	0.0002	0.0025	0.0012			0.1257	0.0624	0.094599	0.06874	0.02889	0.013	0.1679	0.0769	0.0059	0.0037
Blennophis sp	blenny sp.			0.0001	0.0001			0.0001	0.0001								
Brama brama	angelfish															0.0001	0.0001
Caffrogobius sp.	goby							0.0002	0.0002	0.003086	0.00196			0.0005	0.0005	0.0001	0.0001
Callorhinchus capensis	St Joseph	0.0017	0.001													0.0002	0.0002
Cancelloxus longior	snake eel			0.0001	0.0001							0.0003	0.0003	0.0004	0.0003	0.0008	0.0006
Cheilidonichthys capensis	gurnard	0.0021	0.0012	0.0079	0.0043	0.0005	0.0003	0.0054	0.0023	0.00216	0.00101	0.0001	0.0001	0.0063	0.0039	0.0001	0.0001
Cheilidonichthys kumu	bluefin gurnard															0.0002	0.0002
Chorisochismus sp?	suckerfish sp.							0.0001	0.0001								
Clinus latipennis	False Bay klipvis			0.0017	0.0006	0.0003	0.0002	0.0007	0.0003	0.000679	0.00041	0.0002	0.0002	0.0002	0.0002	0.0009	0.0005
Clinus sp. larvae	Klipvis larvae							0.0027	0.0019								
Clinus superciliosus	super klipvis	0.0037	0.001					0.0017	0.0008	0.000556	0.00056	0.0002	0.0001			0.0011	0.0005
Dasyatis chrysonota	blue stingray									0.00037	0.00037	7.4E-05	7E-05				
Diplodus sargus capensis	black tail					0.0004	0.0004	0.0009	0.0004								
Engraulis japonicus	anchovy											0.0002	0.0002				
Galeichthyes feliceps	barbel															0.0001	0.0001
Gonorhynchus gonorhynchus	beaked sand eel	0.0005	0.0003														
Haploblepherus pictus	dark Shy Shark									0.000185	0.00019						
Heteromycteris capensis	Cape sole	0.0725	0.0347	0.0014	0.0006	0.0897	0.0437	0.0433	0.0232	0.014074	0.0083	0.01067	0.005	0.0086	0.0036	0.0058	0.0018
Liza richardsonii	harder	0.3877	0.1218	0.2098	0.0595	1.4077	0.7576	0.1805	0.0450	0.120123	0.03651	0.2153	0.0777	0.9968	0.4905	0.0951	0.0490
Mustelus mustelus	smoothhound shark	0.0013	0.0006	0.0001	0.0001											0.0004	0.0003
Myliobatis aquila	eagle ray	0.0049	0.0027			0.0003	0.0003										
Parablennius cornutus	blenny													0.0002	0.0002		
Pomatomus saltatrix	elf	0.0005	0.0003	0.0001	0.0001	0.0159	0.0157	0.0430	0.0265			0.0068	0.0031	0.0217	0.0096	0.0101	0.0041
Psammogobius knysnaensis	Knysna sand gobi					0.0006	0.0004							0.0006	0.0004		
Rhabdosargus globiceps	white stumpnose	0.003	0.0012	0.0207	0.0177	0.3358	0.1098	0.2012	0.0523	0.050062	0.02662	0.05096	0.023	0.1341	0.1204	0.0722	0.0214
Rhabdosargus holubi	Cape stumpnose													0.0007	0.0007	0.0046	0.0046
Rhinobatos blockii	bluntnose guitar fish	0.0066	0.0022	0.0022	0.0017	0.0029	0.0017	0.0019	0.0013	0.000123	0.00012	0.0009	0.0008	0.0009	0.0008	0.0013	0.0011
Sardinops sagax	sardine															0.0007	0.0007
Sarpa salpa	streepie															0.0002	0.0002
Spondyliosoma emarginatum	steentjie	0.0004		0.0004	0.0002			0.0003	0.0002							0.0002	0.0002

Year		Apr-94		Oct-05		Apr-07		Apr-08		Apr-09		Apr-10		Apr-11		Apr-12	
Species	**Common name**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**
Syngnathus temminckii	pipe fish	0.0002	0.0002					0.0004	0.0003	0.000185	0.00019	0.0002	0.0002	0.0002	0.0002	0.0007	0.0003
Trachurus trachurus	horse mackerel							0.0001	0.0001							0.0002	0.0002
Zeus faber	John dory															**0.0002**	**0.0002**
Total		**0.48**	**0.12**	**0.25**	**0.06**	**1.85**	**0.77**	**0.61**	**0.14**	**0.29**	**0.09**	**0.31**	**0.08**	**1.34**	**0.61**	**0.17**	**0.06**
Number of species	**33**	**14**		**12**		**10**		**17**		**12**		**13**		**14**		**23**	
Number of hauls	**120**	**14**		**12**		**6**		**18**		**18**		**18**		**18**		**16**	
Total area sampled (m2)	**52 875**	**5525**		**5400**		**6250**		**10500**		**5850**		**7500**		**4950**		**6900**	

Table 9.3. Average abundance of fish species (number.m^{-2}) recorded during annual beach seine-net surveys in Langebaan Lagoon. Ave = average, SE = standard error.

Year		1986-87		Apr-94		Oct-05		Apr-07		Apr-08		Apr-09		Apr-10		Apr-11		Apr-12	
Species		**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**	**Ave**	**SE**
Atherina breviceps	silverside	1.1916	0.2595	1.1865	0.307	0.0524	0.0246	0.0786	0.0335	0.1416	0.0492	0.0654	0.0267	0.1206	0.0377	0.2857	0.1054	0.2280	0.0816
Blennophis sp.	blenny sp.					0.0001	0.0001												
Caffrogobius sp.	goby	0.0888	0.0530	0.0608	0.018	0.1776	0.1267	0.3072	0.1262	0.0626	0.0150	0.0748	0.0335	0.0973	0.0318	0.3764	0.1419	0.0003	0.0003
Cheilidonichthys capensis	gurnard			0.002	0.0010	0.0038	0.0019			0.0001	0.0001								
Clinus latipennis	False Bay klipvis					0.0163	0.0085			0.0001	0.0001	0.0002	0.0002						
Clinus superciliosus	super klipvis	0.0698	0.0369	0.0063	0.0038	0.0006	0.0005					0.0031	0.0029						
Diplodus sargus capensis	blue stingray	0.0120	0.0111									0.0003	0.0002						
Heteromycteris capensis	Cape sole			0.0009	0.0004	0.0014	0.0007	0.0027	0.0033	0.0331	0.0139	0.0145	0.0083	0.0148	0.008	*0.0032*	0.001	0.0003	0.0003
Lichia amia	leervis			0.0002	0.0002														
Liza richardsonii	harder	0.2452	0.0971	0.7182	0.1941	0.3452	0.1453	3.8468	3.3679	0.1548	0.1066	0.3750	0.0980	9.5032	7.4567	*1.572*	0.5388	0.2239	0.0771
Parablennius cornutus	blenny											0.0002	0.0002						
Pomatomus saltatrix	elf			0.0001	0.0001									0.0002	0.0002	0.0013	0.001		
Poroderma africana	Striped catshark															0.001	0.001		
Psammogobius knysnaensis	Knysna sand gobi	0.0958	0.0455	0.4916	0.1487	0.1411	0.0457	0.6768	0.2501	0.2237	0.0700	0.2736	0.0661	0.1691	0.0336	0.1176	0.0765	0.1722	0.0244
Rhabdosargus globiceps	white stumpnose	0.0009	0.0008	0.0055	0.0025	0.0001	0.0001	0.2016	0.2170	0.0354	0.0293	0.0263	0.0167	0.2445	0.1582	0.0959	0.0447	0.0146	0.0053
Rhabdosargus holubi	Cape stumpnose															0.0114	0.0114		
Rhinobatos blockii	bluntnose guitar fish			0.0176	0.0100			0.0011	0.0006	0.0008	0.0004	0.0065	0.0032			0.0005	0.0005	0.0003	0.0003
Solea bleekeri	blackhand sole			0.0006	0.0003			0.0004	0.0003	0.0003	0.0002			0.0001	0.0001	0.0003	0.0003		
Spondyliosoma emarginatum	streepie	0.0001	0.0001							0.0009	0.0009			0.0001	0.0001	0.0006	0.0006		
Syngnathus temminckii	pipefish	0.0063	0.0025	0.0007	0.0004														
Trachurus trachurus	maasbanker			0.0001	0.0001														
Total		**1.71**	**0.30**	**2.49**	**0.431**	**0.69**	**0.18**	**5.12**	**3.20**	**0.65**	**0.16**	**0.84**	**0.13**	**10.15**	**7.44**	**2.4658**	**0.5227**	**0.2740**	**0.146**
Number of species	**21**	**9**		**14**		**11**		**8**		**11**		**11**		**9**		**12**		**7**	
Number of hauls	**134**	**30**		**20**		**12**		**9**		**15**		**13**		**15**		**14**		**6**	
Total area sampled (m²)	**70875**	**18000**		**7125**		**7200**		**6000**		**9000**		**6150**		**11325**		**2925**		**3150**	

Naturally high variability in recruitment strength is frequently observed for marine fish species and it is likely that natural environmental fluctuations rather than anthropogenic factors that caused the poor recruitment in 2009 and 2011/12, as abundance was low throughout the system. The lower than average recruitment (with the exception of white stump in Big Bay) into the surf zones of Small Bay and Big Bay suggests that it was a "poor" year for egg, larval and juvenile survival within the Bay as a whole. Either the environmental conditions were not suitable for the survival of eggs and larvae, or it was not good for the survival of young juveniles. The decline in abundance for most species at Small Bay sites does, however, appear more severe and sustained (was low since 2009) than that at Big Bay (where recovery in abundance was observed during 2010-2011) and remains a cause for concern.

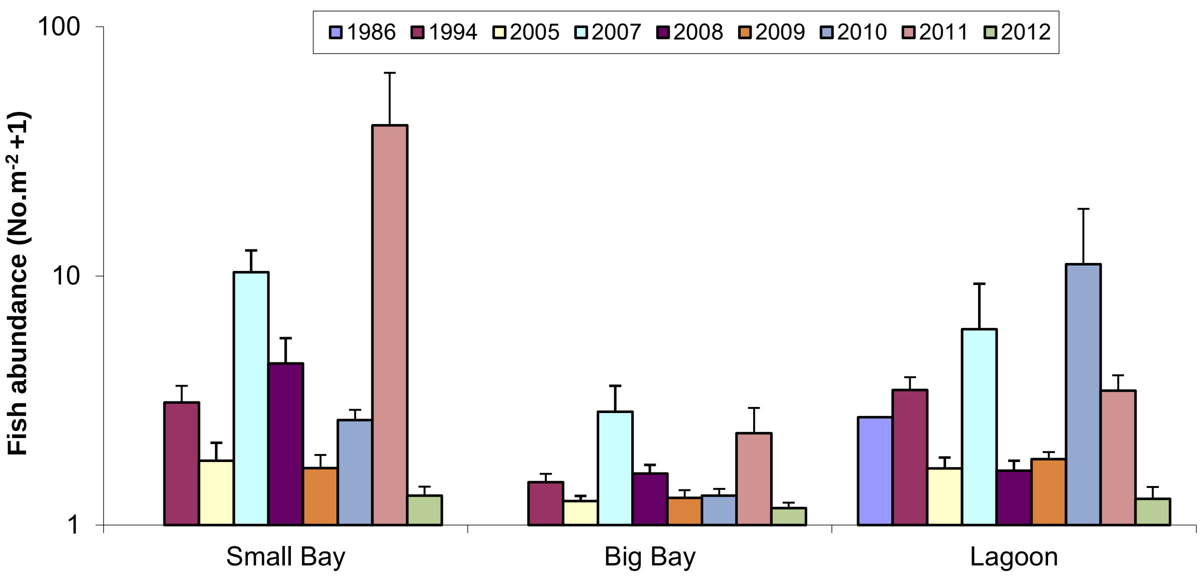


Figure 9.3. Average fish abundance (all species combined) during nine annual seine-net surveys conducted in Saldanha Bay and Langebaan lagoon. (Error bars show one Standard Error of the mean). The data are transformed (x + 1) and displayed on a logarithmic axis. Note: The abundance estimate for Langebaan lagoon during 2012 may be an artefact due to data loss.

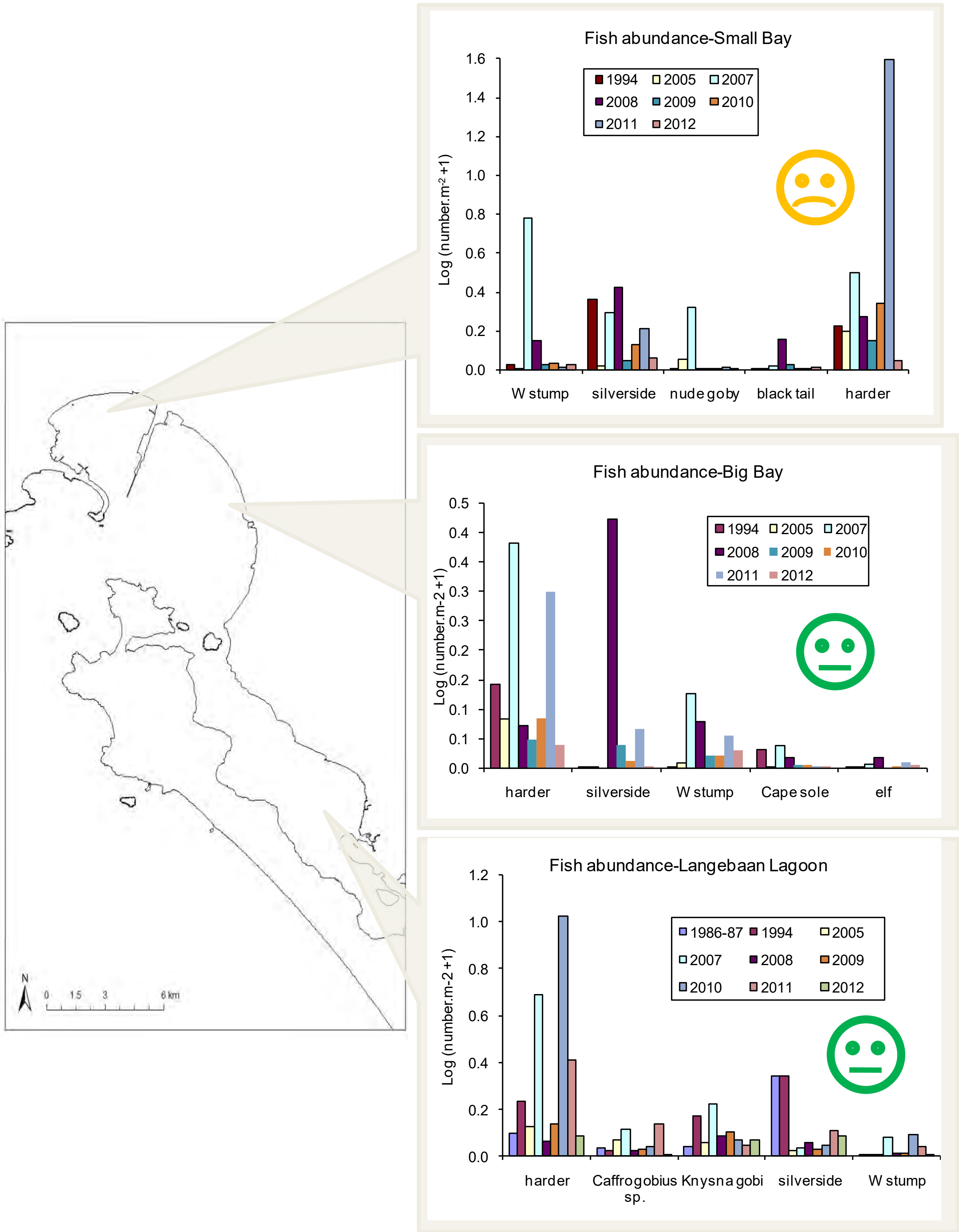


Figure 9.4. Abundance (log no.m^{-2} +1) of the most common fish species recorded in annual seine-net surveys within Saldanha Bay and Langebaan Lagoon (1986/87, 1994, 2005, 2007, 2010, 2011 &2012).

9.3.3 Status of fish populations at individual sites sampled during 2012

The average abundance of the four most common species in catches made during all earlier surveys and the most recent 2012 survey at each of the sites sampled is shown in Figure 9.5 , Figure 9.6 & Figure 9.7. These common fish species include two commercially important species (white stumpnose and harders), benthic gobies of the genus *Caffrogobius,* and the ubiquitous shoaling silverside (an important forage fish species). During earlier surveys, the generally higher abundance of these species within Small Bay compared to Big Bay is clear. During the 2012 surveys, substantial drops in the average abundance of these species at nearly all Small Bay sites was apparent (Figure 9.5). At the Big Bay sites, however, although there is some variation from the historical mean, it has not been unidirectional, and catches during 2012 are in general similar to those made in the past. Within each of the three main areas, there are also some differences in the fish communities between sites, with sites on the northern shore of Small Bay historically having consistently higher densities of these four species than the Small Craft Harbour Site on the western shore of Small Bay or the exposed Spreeuwalle and Lynch Point sites within Big Bay (Figure 9.5 & Figure 9.6). During the 2012 survey this was not the case, with exceptionally low catches made at the Hoedjiesbaai and the Caravan Park sites, whilst catches at the other two Small Bay sites were very similar to those made at the three sites along the eastern shore of Big Bay. The presence of large quantities of drifting weed at the Hoedjiesbaai and the Caravan Park site during 2012 did adversely affect sampling efficacy, indeed only a single successful haul was made at each of these sites and catches were low. Although the average densities of these more common species are highly variable between years, it is clear that at the time of the 2012 sampling, as was the case during 2011 sampling the average abundance of most species within Small Bay had decreased substantially (with the exception of harders at the small craft harbour site), but within Big Bay and Langebaan Lagoon, they were of a similar magnitude to the historical average (Figure 9.5 , Figure 9.6 & Figure 9.7). This may well reflect the difficulties experienced when sampling some of the Small Bay sites in 2012, rather than a fundamental change in the utilization of Small Bay by juvenile fish.

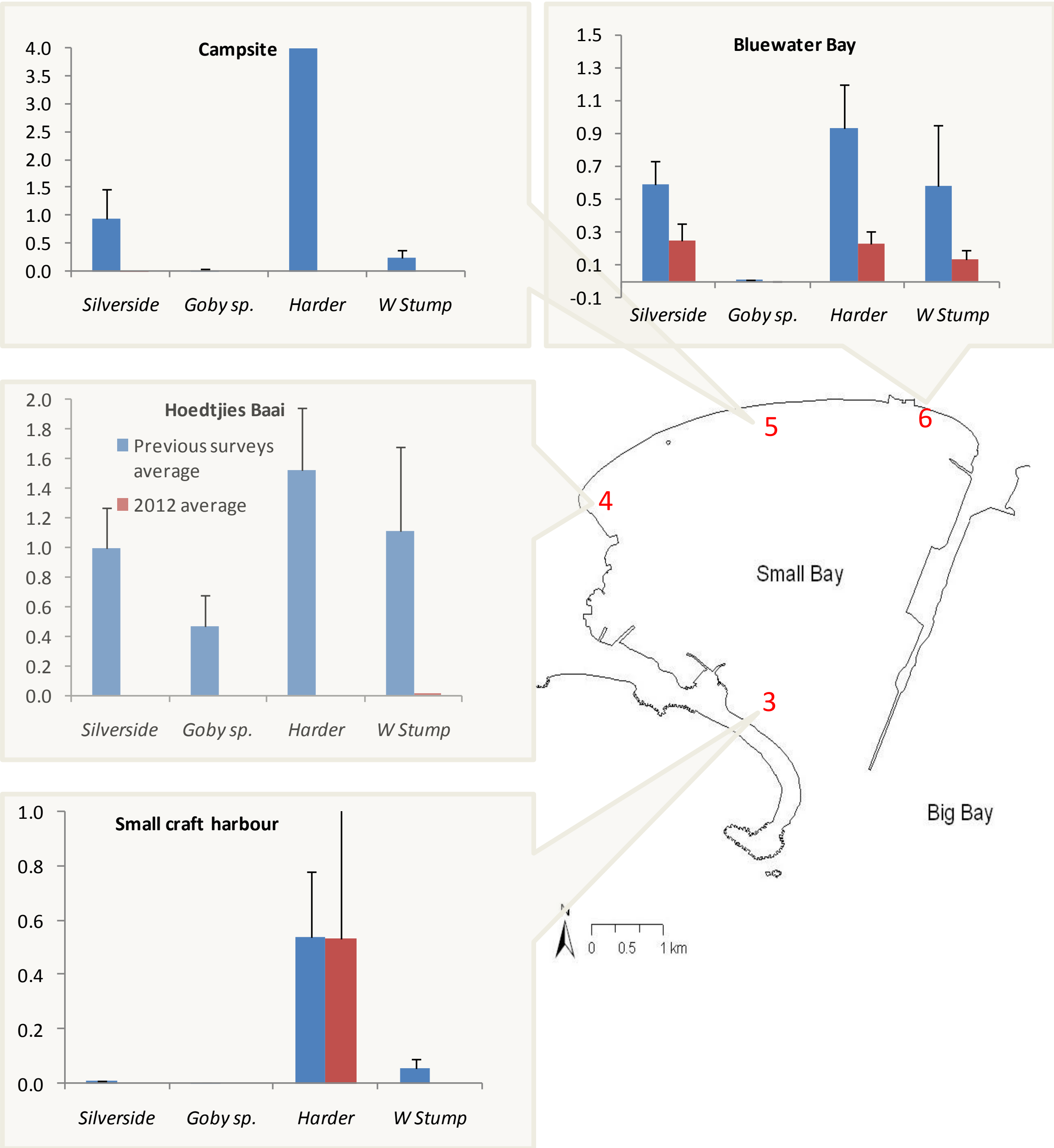


Figure 9.5. Average abundance of the four most common fish species at each of the sites sampled within Small Bay during the earlier surveys (1994, 2005, 2007-2011) and during the 2012 survey. Errors bars show plus 1 Standard error.

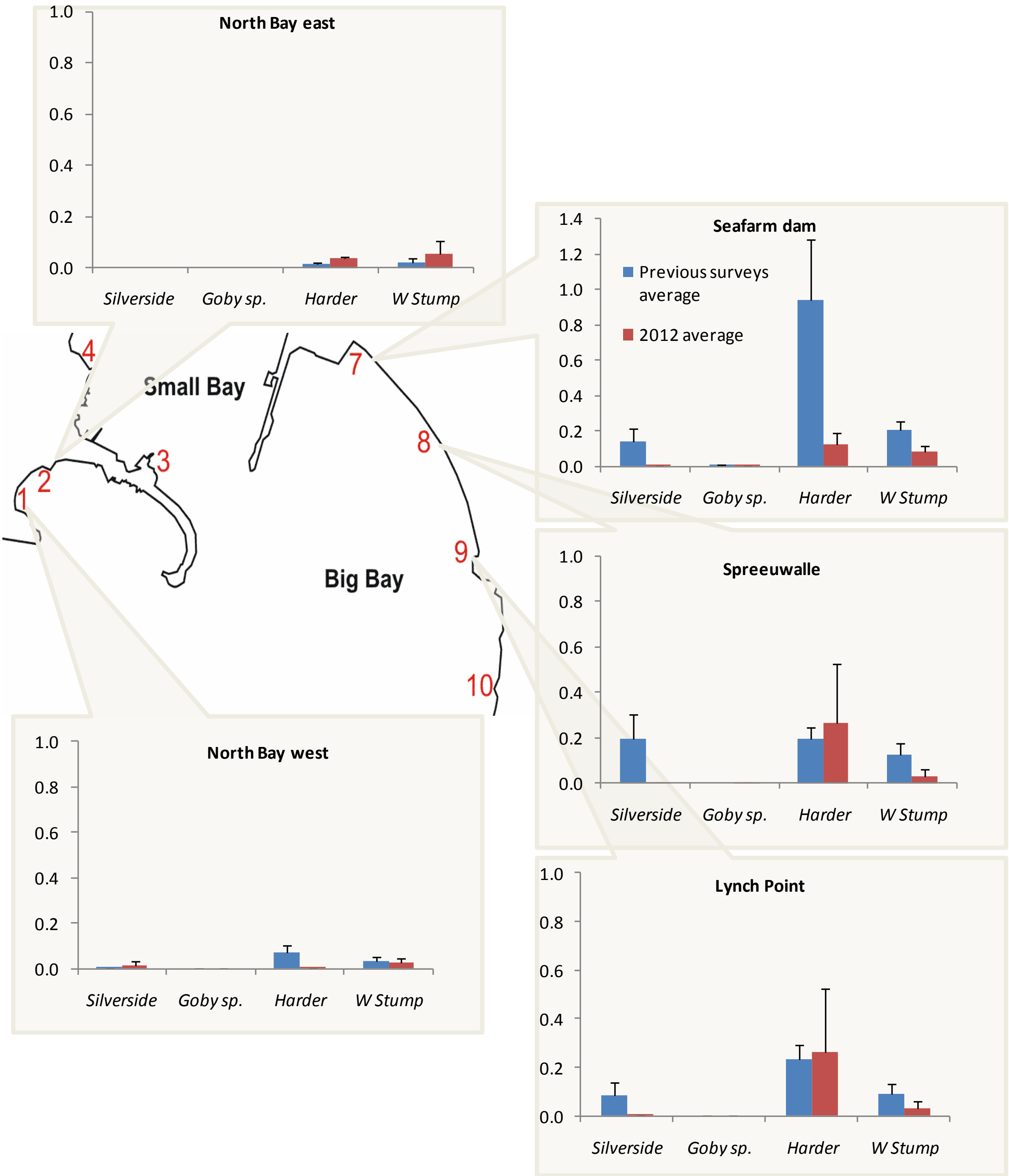


Figure 9.6. Average abundance of the four most common fish species at each of the sites sampled within Big Bay during the earlier surveys (1994, 2005, 2007-2011) and during the 2012 survey. Errors bars show plus 1 Standard error.

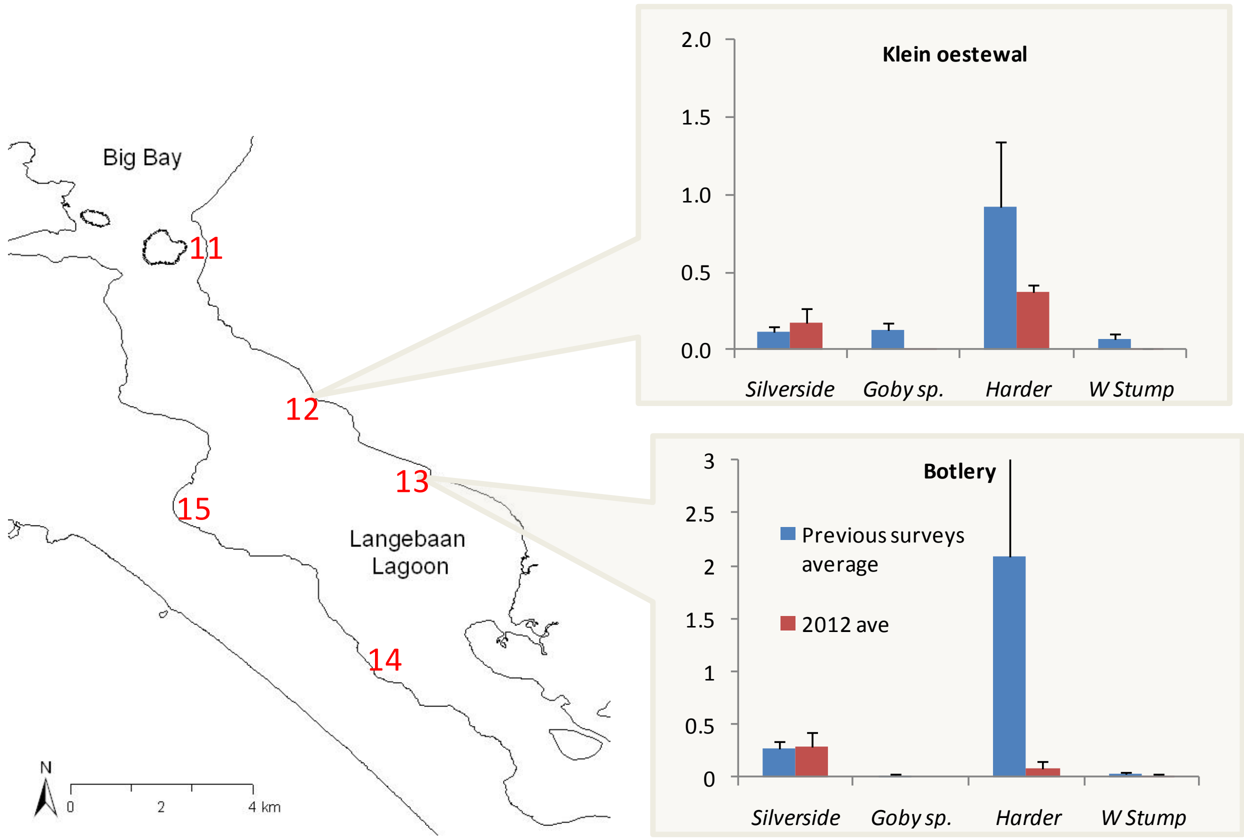


Figure 9.7. **Average abundance of the four most common fish species at two of the sites sampled within Langebaan lagoon during the earlier surveys (1994, 2005, 2007-2011) and during the 2012 survey. Errors bars show plus 1 standard error.**

9.3.4 Multivariate analysis of spatial and temporal trends in fish communities

The use of multivariate statistical techniques allows for the analysis of any patterns in the complete fish community, taking account of both the species composition of the assemblages as a whole, and the abundance of individual species. In the 2009 State of the Bay report, multivariate analyses showed that on average, the fish communities from each of the three areas (Small Bay, Big Bay and Langebaan Lagoon) were significantly different from each other. This was related to environmental differences between the three areas. It was concluded that although the whole Saldanha Bay- Langebaan Lagoon system is connected, the near-shore environment in one area (i.e. Small Bay, Big Bay or the Lagoon) on average, appears more suitable for the juveniles of particular species than the other areas.

The statistically significant differences in the fish communities found in the three main areas (Small Bay, Big Bay and Langebaan Lagoon), as well as the similarities between sites within each of these areas, supported the analysis of temporal trends (which provide information on changes in the health of the marine environment) on an area specific basis. The 2010 State of the Bay report also reported on the separation of the different sites within each area, based on dissimilarities in the fish community between sites. This separation is similar to the overall trend in fish communities throughout the Bay and Lagoon, a pattern relating to the degree of exposure of each site was evident, from the most exposed sites through to the most sheltered samples. In this report, analysis focussed on detecting any differences between years, taking account of the established inter-site variability by using a two factor (sites and years as factors) PERMANOVA design. Temporal changes in fish community from year to year are indicative of both natural variability in spawning and survival as well as possible changes in the environmental health of the habitat.

The MDS plot for Small Bay shows that samples from most years grouped centrally, suggesting little change in the fish community over time (Figure 9.8). Fish samples taken at some sites during 2005 and 2011 and two sites sampled during 2012 are however, outliers, indicating that these are dissimilar to the majority of other years. The two outliers from the 2012 survey are the Hoedjiesbaai and the Caravan Park sites where sampling was compromised due to the abundance of seaweed in the water. All other 2012 samples fall well within the central grouping, suggesting that the Small Bay fish community in 2012 was not significantly different from that sampled during the majority of earlier years.

A two way PERMANOVA indicated significant differences in the fish community between sample years (Pseudo $F = 2.468$, $P< 0.001$) and between sites (Pseudo $F = 10.491$, $P< 0.001$) and a significant interaction effect (Pseudo $F = 3.3156$, $P< 0.0001$). Pairwise tests indicate that there were significant differences between all years sampled and at least one of the other annual sampling events (Table 9.4). This is indicative of the high natural variability in the surf zone fish community inhabiting Small Bay. We suspect, given the orientation of Small Bay facing into the prevailing southerly wind, that short term meteorological changes (such as a wind change to a northerly or westerly) that are common during April and strongly influence the nature of the surf zone, are the primary drivers of this observed variability. The only way to account for this natural variability is to sample more intensively, by replicating the survey within years, sampling the same sites on different days within each survey and repeating it over several weeks. This is unfortunately not logistically possible, but trends in the ecological health of the Bay (for fish at least) can still be inferred from any long term consistent trends over time. Pairwise tests only identified the 1994 samples as being significantly different from the 2012 samples (Table 9.4). It is clear from the MDS plot that only two of the 2012 samples collected in Small Bay were the most dissimilar from the other annual samples and there is no consistent trend evident from the multivariate analysis that may be indicative of increasing or decreasing ecosystem health (Figure 9.8). It must be noted that aside from the two outliers that represent the Hoedjiesbaai and the Caravan Park site, where seaweed interfered with sampling, there is low inter-sample variability (spread of data in the MDS plot) within the 2012 samples and they all group with samples from earlier survey periods. This suggests that there is no evidence of declining ecosystem health within Small Bay, despite the decreases in overall fish abundance within Small Bay (shown in Figure 9.3).

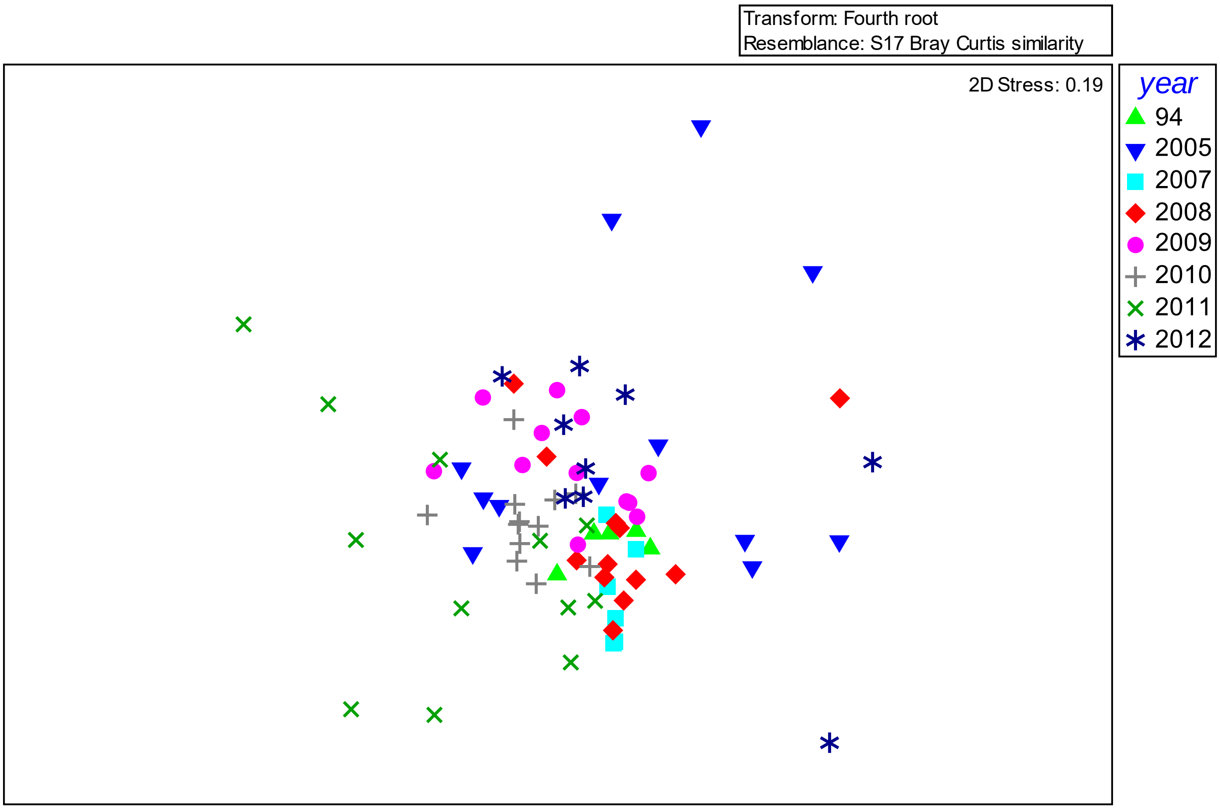


Figure 9.8. Multidimensional scaling plots showing similarities between the fish communities sampled at four sites within Small Bay during 1994, 2005, 2007, 2008, 2009, 2010 and 2011 sampling events.

SIMPER analyses identified decreased average abundance of harders, silversides, white stumpnose, gobies, pipefish and klipvis in the 2012 samples as the dominant causes (>80%) of dissimilarity between the 2012 and the 1994 samples. Although none of these species had disappeared from catches in Small Bay during 2012, they were on average substantially less abundant than in nearly all of the earlier surveys and this is somewhat concerning.

Table 9.4. Results of the multivariate PERMANOVA pairwise tests between Small Bay fish samples collected in different years. NS: not significant, *: P < 0.05, **: P < 0.01

	1994	2005	2007	2008	2009	2010	2011
1994							
2005	*						
2007	**	NS					
2008	NS	*	NS				
2009	**	NS	NS	*			
2010	NS	*	NS	*	*		
2011	*	NS	*	NS	*	NS	
2012	**	NS	NS	NS	NS	NS	NS

Within Big Bay too, little grouping of sampling years in the MDS plot is evident with the 2008, 2005 and 2012 outliers representing a few of Plankiesbaai, North Bay samples, and one Lynch Point 2012 sample (Figure 9.9). With the exception of two North Bay west samples and one Lynch Point sample, all the remaining 2012 samples are distributed well within the range of samples collected in earlier years, indicating no substantial changes in the Big Bay fish communities overall at sampled sites. The mixed model PERMANOVA test did, however, indicate significant differences between sites (Pseudo F = 7.3869, P< 0.001), between sampling events (Pseudo F = 1.8677, P< 0.01) and a significant interaction effect (Pseudo F = 3.428, P< 0.001). Pairwise testing showed that only the Big Bay fish samples collected during 1994 were significantly different from those collected during 2007 and 2009 and 2012, and the 2011 samples were significantly different from the 2012 samples (P<0.05). SIMPER analysis identified the lower abundance of white stumpnose and harders, and higher abundance Cape sole, silversides of sand sharks in the 1994 samples as the principal contributors to differences in similarity with the 2007, 2009 and 2012 samples. The main contributors to differences between 2011 and 2012 samples were decreased abundance of harders, silversides and elf and increased white stumpnose abundance in 2012 samples. Big Bay fish samples collected during all other years were statistically similar, indicating no consistent change in the Big Bay surf zone fish community over time.

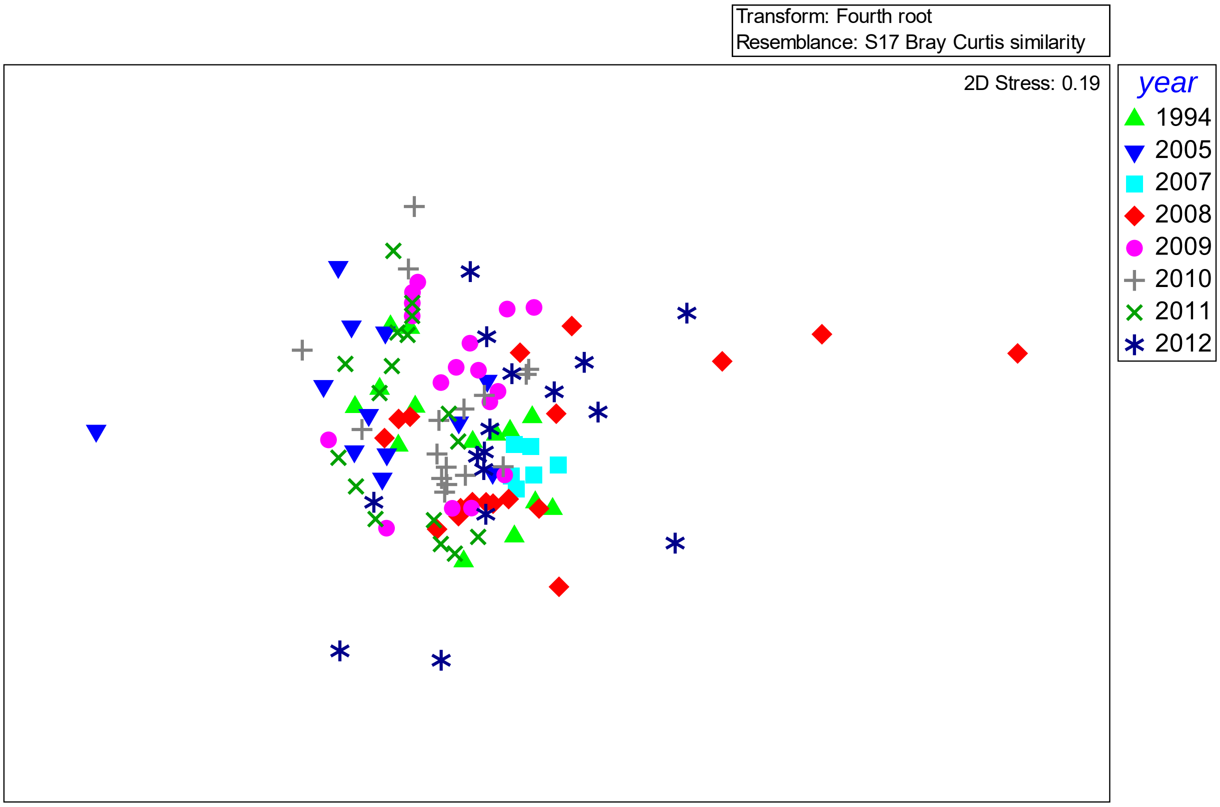


Figure 9.9. Multidimensional scaling plot showing similarities between the fish communities sampled at seven Big Bay sites during 1994, 2005, 2007 -2012 annual sampling events.

An MDS plot of Langebaan Lagoon fish samples shows some evidence of separation between sampling years , but four of the 2012 samples from the Klein Oostewal and Bottelary sites overlapped with samples from earlier surveys (Figure 9.10). Two of the 2012 Bottelary samples were slight outliers and this appears to be caused by low or zero harder catch in the last two hauls conducted at this site (sampling was conducted at low tide and the low water levels meant most harders were caught in the first haul). A PERMANOVA test was not conducted due to the loss of data for three out of the five lagoon sites during 2012. Nonetheless there does not appear to be a notable change in the fish fauna at the two Lagoon sites for which data are presented.

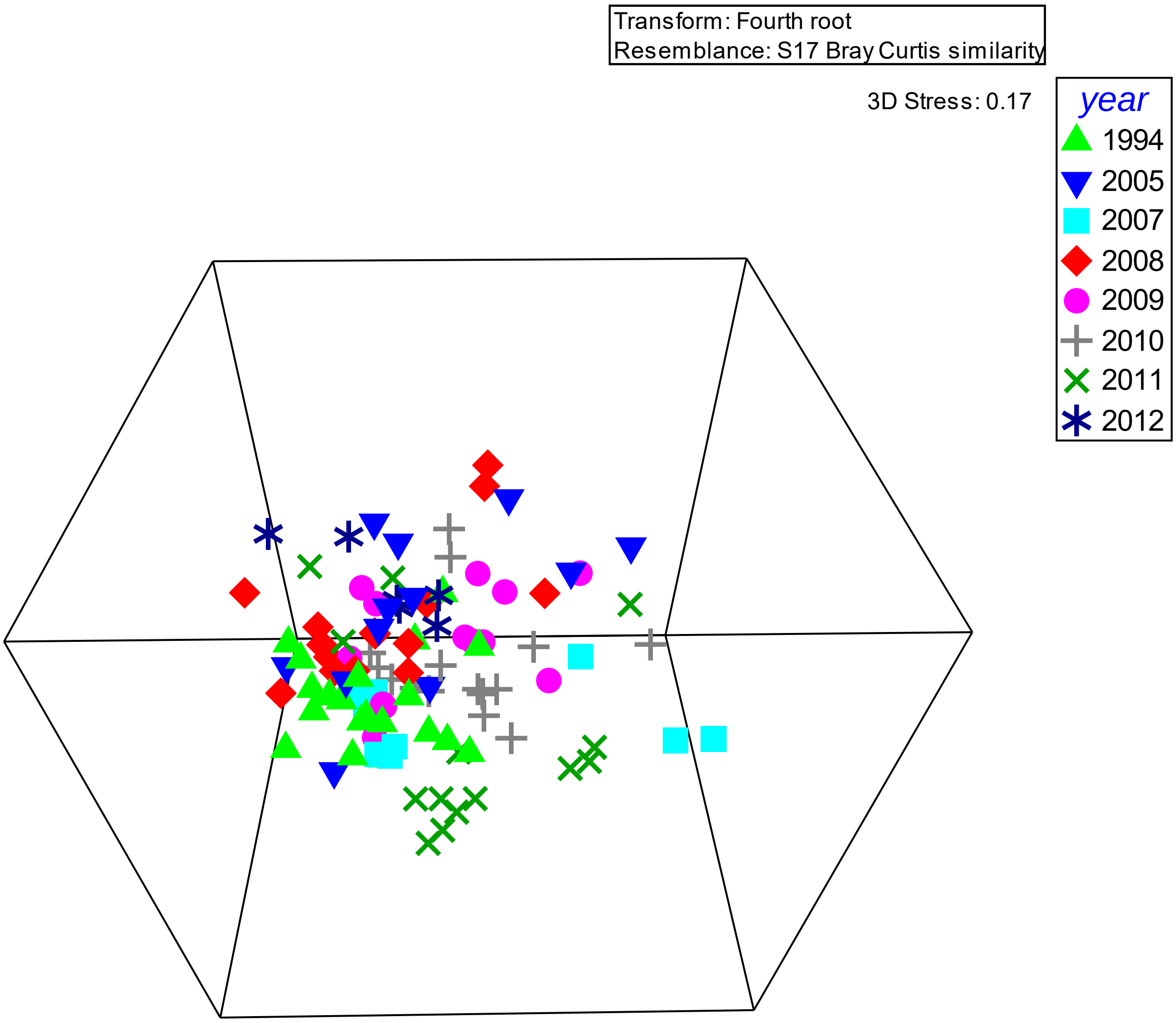


Figure 9.10. Multidimensional scaling plots showing similarities between the fish communities sampled at six Lagoon sites during 1994, 2005, 2007-2011 and 2012 sampling events.

9.3.5 Status of the commercial harder fishery

The annual effort expended in the Saldanha/Langebaan commercial harder gill net fishery has remained fairly consistent at around 1500 boat days/year over the period 2006-2012 (Figure 9.11). This period overlaps with the long-term rights allocation in this fishery (2004-2014) and the number of participants was not expected to vary much. A number of interim relief permits (three net rights to be used by up to 15 different operators) were however issued in 2009. This appears to have had little influence on the reported fishing effort, which actually decreased in 2010, but this may be due to poor reporting of fishing activity. During the 2006-2009 period, however, as effort increased, total reported catch and catch-per unit-effort (CPUE) decreased, but then recovered to 2006 levels thereafter (Figure 9.12). The response of CPUE to fairly moderate changes in fishing effort does suggest a fairly closed harder stock with little influence of broader demographic factors via immigration and emigration of fish to and from the bay.

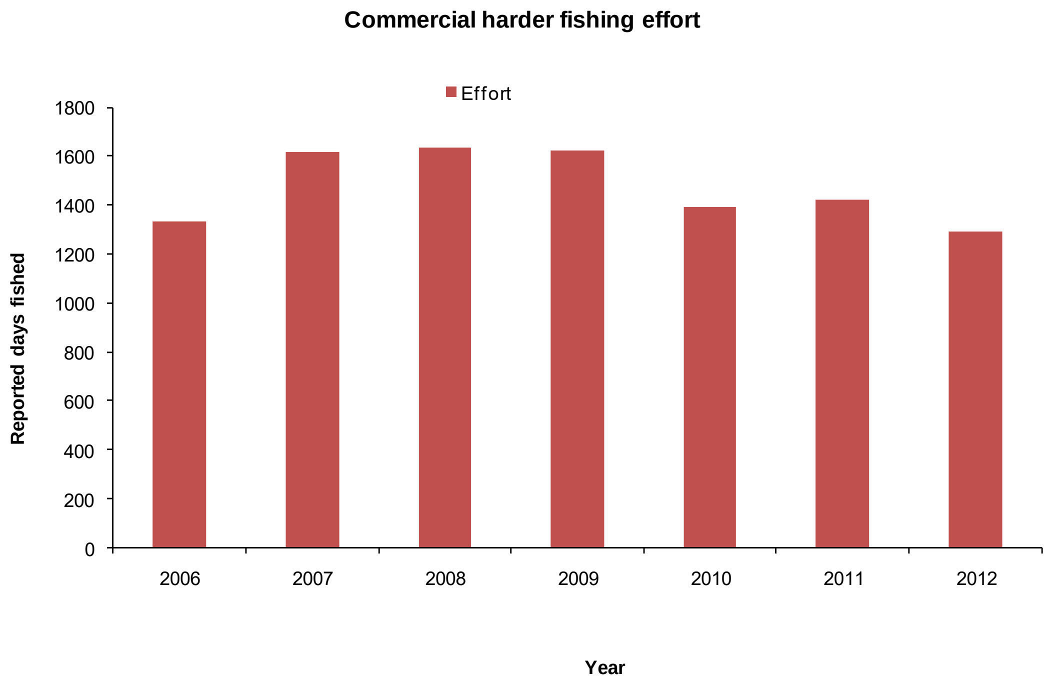


Figure 9.11. Reported annual fishing effort (boat days) by commercial harder gill net permit holders within Saldanha Bay and Langebaan lagoon (2006-2012).

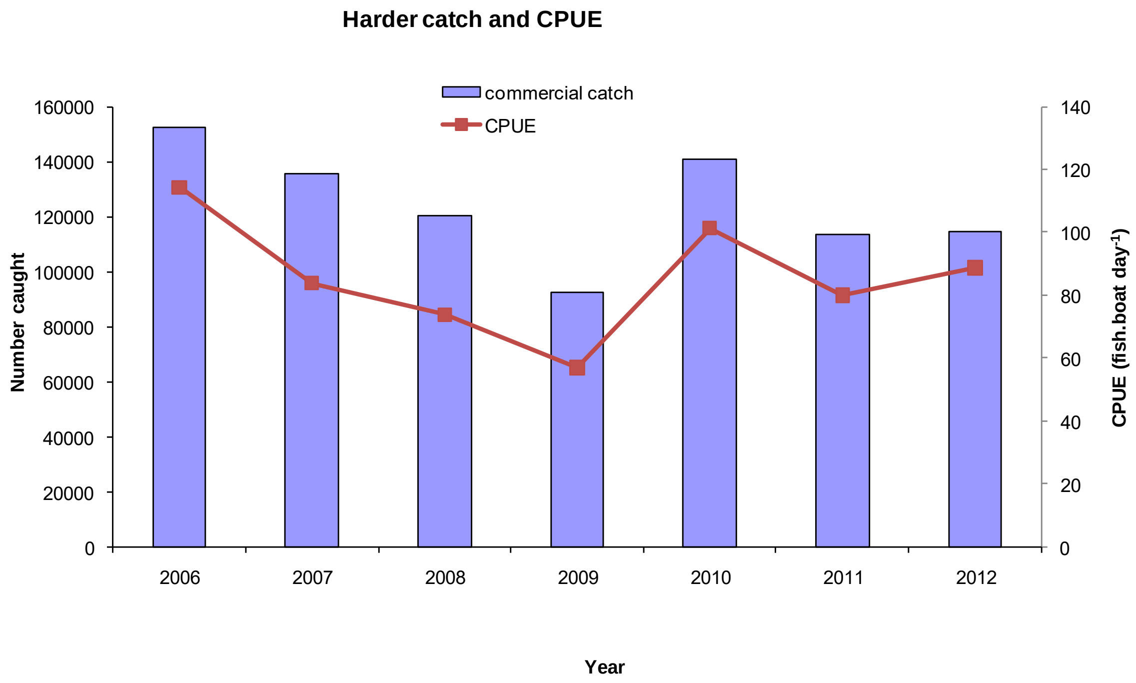


Figure 9.12. Reported annual fishing catch (number) and CPUE (number per boat day) by commercial harder gill net permit holders within Saldanha Bay and Langebaan lagoon (2006-2012).

9.3.6 Comparisons of harder catch rates with the seine net survey data

Higher average catch rates, large average size and year round availability of harders within the Saldanha Bay, Langebaan system compared to other areas along the West Coast suggests a degree of residency within the Bay (Hutchings & Lamberth 2002). Emigration and immigration of harders is, however, known to occur with shoals observed entering and leaving the bay seasonally. Links between the spawner biomass and juvenile abundance in the identified surf zone nursery habitats may, however, still be expected if the harder population is largely self-recruiting. On the other hand broader regional scale fluctuations in the spawner biomass may mask any relationship between juvenile abundance estimated from seine net surveys and catches of adult harders. Relationships between spawner biomass (the mass of adults) and juvenile recruitment are, however, notoriously difficult to show empirically. Indeed, some fisheries scientists go as far as to state there is no relationship other than "in the absence of spawning adults, recruitment will fail". This is due to two main factors- one is the very high fecundity of most broadcast spawning marine fish (including harders) where a single female can spawn hundreds of thousands of eggs every few weeks throughout the spawning season; and the other is the extremely high mortality that occurs during the egg and larval phases. This means that few adult females can produce strong recruitment under favourable environmental conditions that enhance egg and larval survival; or that a large female spawner biomass can produce very poor recruitment due to unfavourable environmental conditions.

Unfortunately the degree of overlap in the two sets of data is too short to interpret signals with any confidence and there is exceptionally high inter annual variability in the experimental seine net data that confounds such interpretation. Nevertheless, high adult abundance as indicated by the elevated catch rate (e.g. in 2006 and 2010) does appear to result in above average juvenile recruitment in the same and following year. This suggests that harder recruitment is positively related to the size of the adult stock within the BAY at the time (i.e. a largely self-recruiting population). Forecasting from estimated surf zone densities to commercial catch rates some two years later (when harders are ~25cm total length and should contribute to the commercial catches) does not appear possible at this stage, however. For example the low juvenile densities in 2008 and 2009 actually resulted in high average CPUE in 2010 and 2011. This indicates that either the CPUE is influenced by factors other than relative fish abundance (e.g. weather, market price, and other fisheries etc.) and/or movement of adult stock into and out of the Bay plays a bigger role than local recruitment in influencing catch rates. This analysis has shown that there does appears to be a link between the relative abundance of adult harders as estimated from catch rates, and estimates of juvenile harders utilizing the surf zone nursery habitats in the area. The potential to use the annual seine net surveys as a predictor of future fishery productivity within the Bay and thereby enabling adaptive management to be implemented, however, appears limited. On the other hand, the nursery value of the bay for the harder stock on a broader regional scale should not be discounted.

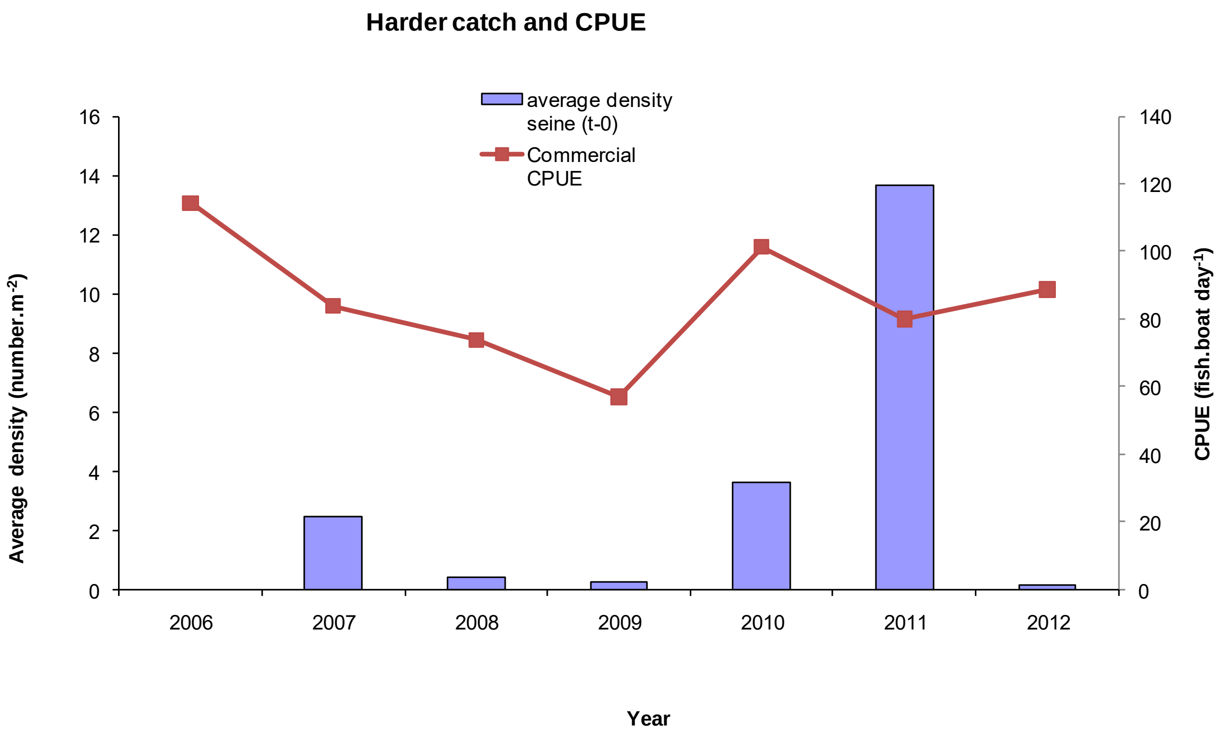


Figure 9.13. Comparison between the average annual juvenile harder abundance as estimated from seine net surveys and the commercial (catch returns) catch-per-unit-effort

9.4 Conclusion

The current status of fish and fisheries within Saldanha Bay-Langebaan appears satisfactory. Long term monitoring by means of experimental seine-netting has revealed statistically significant differences in fish community structure between different sampling sites within years and between sampling years. A consistent long-term negative trend, since fish sampling began in 1986-87 has however, not been detected. In fact, fish abundance of key species at sites within or in close proximity to the Langebaan Marine Protected Area appears to be increasing. This reflects natural and human induced impacts on the adult population size, recruitment success and use of the near shore habitat by fish species; but may also be a result of the benefits of protection from exploitation and reduced disturbance at some sites due to the presence of the Langebaan MPA. Certainly, the study by Kerwath *et al*. (2009) demonstrated the benefits of the MPA for white stumpnose, and the protection of harders from net fishing in the MPA undoubtedly benefits this stock in the larger Bay area.

The 2012 sampling event recorded poor recruitment of key species such as harders, white stumpnose, gobies and silversides throughout the Saldanha Bay-Langebaan system. The estimated abundance of fish within Big Bay and two of the Langebaan Lagoon sites are nonetheless comparable with data from earlier surveys. In Small Bay, however, estimated abundance of key species was well below average, with the lowest yet recorded harder and goby density to date. This follows the trend observed in the 2010 and 2011 report and it is somewhat concerning that the estimated abundance of some key species is decreasing in the areas of maximum anthropogenic disturbance within Small Bay, whilst they are stable or increasing in other less disturbed areas of Big Bay. Multivariate analysis, however, indicates no significant differences in the Small Bay fish community sampled during 2012 from that sampled in earlier years (with the exception of 1994). It appears that logistical difficulties in sampling two of the Small Bay sites (Hoedjiesbaai and the Caravan Park site) strongly influenced density estimates for Small Bay as a whole, but catches at the remaining two Small bay sites were well within the normal range.

In the data set collected to date, the average density of commercially important fish such as white stumpnose was much higher at Small Bay sites compared to Big Bay and Lagoon sites. The opposite trend was observed in 2011, however, and estimated densities of these species were similar and low in both Big Bay and Small Bay in 2012. Nonetheless, the average white stumpnose density calculated from all seine net surveys to date is 0.7 fish.m^{-2} in Small Bay, compared with 0.1 fish.m^{-2} in Big Bay and 0.07 fish.m^{-2} in Langebaan lagoon. The juveniles of other species were historically also more abundant in Small Bay. This gives an indication of the importance of Small Bay as a nursery habitat for the fish species that support the large and growing fisheries throughout the Bay. Small Bay is often viewed as the more developed or industrialised portion of the Bay and is considered by many as a 'lost cause'. These data provide a strong argument to stamp out such negative thinking and to continue lobbying strongly for enhanced protection of this portion of the Bay.

The monetary value of the recreational fishery in Saldanha-Langebaan should not be regarded as regionally insignificant as a lot of the expenditure associated with recreational angling is taking place within Langebaan and Saldanha itself. Furthermore the popular white stumpnose fishery is undoubtedly a major draw card to the area and has probably contributed significantly to the residential property market growth the region has experienced. Despite the decreased density estimates for the last two years surveys, the value of Small Bay as a fish nursery and the economic value of the resultant fisheries should not be disregarded when considering the environmental impacts of the proposed future industrial developments within Small Bay. The monitoring record from the annual seine net surveys will prove increasingly valuable in assessing and mitigating the impacts of future developments on the regions ichthyofauna. Extending the seine net monitoring record would also facilitate analysis of the relationship between recruitment to the surf zone nursery habitat and future catches in the commercial fisheries in the Bay. A preliminary investigation of this relationship was undertaken for white stumpnose and harders in the 2011 and 2012 reports, respectively. Should this relationship prove robust and quantifiable as more years of data become available, this will allow for adaptive management of the fisheries in the future as fishing effort continues to increase and at some point fishing mortality will need to be contained, if the fisheries are to remain sustainable.

10 BIRDS

10.1 Introduction

Together with the five islands within the Bay and Vondeling Island slightly to the South, Saldanha Bay and Langebaan Lagoon provide extensive and varied habitat for waterbirds. This includes sheltered deepwater marine habitats associated with Saldanha Bay itself, sheltered beaches in the Bay, islands that serve as breeding refuges for seabirds, rocky shoreline surrounding the islands and at the mouth of the Bay, and the extensive intertidal salt marshes, mud- and sandflats of the sheltered Langebaan Lagoon. Langebaan Lagoon has 1 750 ha of intertidal mud- and sandflats and 600 ha of salt marshes (Summers 1977). Sea grass *Zostera capensis* beds are more extensive at the southern end of the lagoon. Beds of the red seaweed *Gracilaria verrucosa* are mainly found at the mouth and patchily distributed over the sandflats. There are also small saltpans and drainage channels which add habitat diversity around the lagoon. Most of the plant communities bordering the lagoon belong to the West Coast Strandveld, a vegetation type which is seriously threatened by agricultural activities and urban development. Twelve percent of this vegetation type is conserved within the park (Boucher and Jarman 1977, Jarman 1986). Although there is no river flowing into the Lagoon, it has some estuarine characteristics due to the input of fresh groundwater in the southern portion of the lagoon.

Saldanha Bay and Langebaan Lagoon are not only extensive in area but provide much of the sheltered habitat along the otherwise very exposed West Coast of South Africa. There are only four other large estuarine systems which provide sheltered habitat comparable to Langebaan Lagoon for birds along the West Coast – the Orange, Olifants and Berg and Rietvlei/Diep. There are no comparable sheltered bays and relatively few offshore islands. Indeed, these habitats are even of significance at a national scale. While South Africa's coastline has numerous estuaries (about 290), it has few very large sheltered coastal habitats such as bays, lagoons or estuaries. Indeed, the Langebaan-Saldanha area is comparable in its conservation value to systems such as Kosi, St Lucia and the Knysna estuary.

Saldanha Bay, and particularly Langebaan Lagoon, are thus of tremendous importance in terms of the diversity and abundance of waterbird populations supported. A total of 283 species of birds have been recorded within the boundaries of the West Coast National Park, of which 11 are seabirds, known to breed on the islands within the Bay (Birdlife International 2011).

10.2 Birds of Saldanha Bay and the Islands

10.2.1 National importance of Saldanha Bay and the islands for birds

Saldanha Bay and the islands are important not so much for the diversity of birds they support, but for the sheer numbers of birds of a few species in particular.

The islands of, Vondeling (21 ha), Schaapen (29 ha), Malgas (18 ha) and Jutten (43 ha), Meeuw (7 ha) and Marcus (17 ha), support important seabird breeding colonies and forms one of only a few such breeding areas along the West Coast of South Africa. They support nationally-important breeding populations of African Penguin (recently up-listed to Endangered under IUCN's red data list criteria), Cape Gannet (Vulnerable), Cape Cormorant (Near-threatened), White-breasted Cormorant, Crowned Cormorant (Near Threatened), and Bank Cormorant (Vulnerable), Kelp and Hartlaub's gulls and Swift Tern.

In addition to seabird breeding colonies, the islands also support important populations of the rare and endemic African Black Oystercatcher (Near-threatened). These birds are resident on the islands, but are thought to form a source population for mainland coastal populations through dispersal of young birds.

10.2.2 Ecology and status of the principle bird species

The African Penguin *Spheniscus demersus* is endemic to southern Africa, and breeds in three regions: central to southern Namibia, Western Cape and Eastern Cape in South Africa (Whittington *et al*. 2005a). The species has recently been up-listed to Endangered, under IUCN's 'red data list' due to recent data revealing rapid population declines as a result of competition with commercial fisheries for food and shifts in prey populations (Birdlife International 2011; Pichegru *et al*. 2009). The Namibian population collapsed in tandem with the collapse of its main prey species, the sardine (*Sardinops sagax*; Ludynia 2010). In South Africa the penguins breed mainly on offshore islands in the Western and Eastern Cape with strongly downward trends at all major colonies (Whittington *et al*. 2005b).

The changes in population sizes at islands in Saldanha is believed to be partially linked to patterns of immigration and emigration by young birds recruiting to colonies other than where they fledged, with birds tending to move to Robben and Dassen Islands in recent years (Whittington *et al*. 2005b). However, once they start breeding at an island, they will not breed anywhere else. Penguin survival and breeding success is closely tied to the availability of pelagic sardines *S. sagax* and anchovies *Engraulis encrasicolus* within 20-30 km of their breeding sites (Pichegru *et al*. 2009). Diet samples taken from penguins at Marcus and Jutten Islands showed that the diet of African penguins in the Southern Benguela from 1984 to 1993 was dominated by anchovy (Laugksch and Adams 1993). During periods when anchovy are dominant, food is more consistently available to penguins on the western Agulhas Bank than at other times (older anchovy remain there throughout the year and sardines are available in the region in the early part of the year). Penguin colonies closest to the Agulhas Bank would benefit during periods of anchovy dominance while those colonies between Lüderitz and Table Bay (including Saldanha Bay) would be faced with a diminished food supply as the anchovy population contracts to the north off Namibia and the south off South Africa (Whittington *et al.* 2005b). The reduced abundance of anchovy may explain the decrease in the African penguin population evident from 1987 to 1993 clearly reflected in Saldanha (Figure 10.1). Furthermore, both prey species are exploited by purse-seine fisheries which together with the eastward displacement of the pelagic fish off the South African coast between 1997 and 2005, further reduced food availability for the penguins.

The number of African penguins breeding in the Western Cape decreased from some 92 000 pairs in 1956, to 18 000 pairs in 1996, there was a slight recovery to a maximum of 38 000 pairs in 2004, before another dramatic collapse to 11 000 pairs in 2009, equating to a total decline of 60.5% in 28 years (Crawford *et al*. 2008a, b, R. Crawford unpubl. data). In Saldanha Bay the population has decreased from 2 049 breeding pairs in 1987 to 518 breeding pairs in 2012, representing a 75% decrease in 24 years (Figure 10.1). Penguin numbers in Saldanha Bay in 2012 are slightly down on that in 2011 (518 vs. 614 pairs). This reduction in numbers is consistent with the overall downward trend evident since 2002 and strongly reinforces the argument that immediate conservation action is required to prevent further losses of these birds.

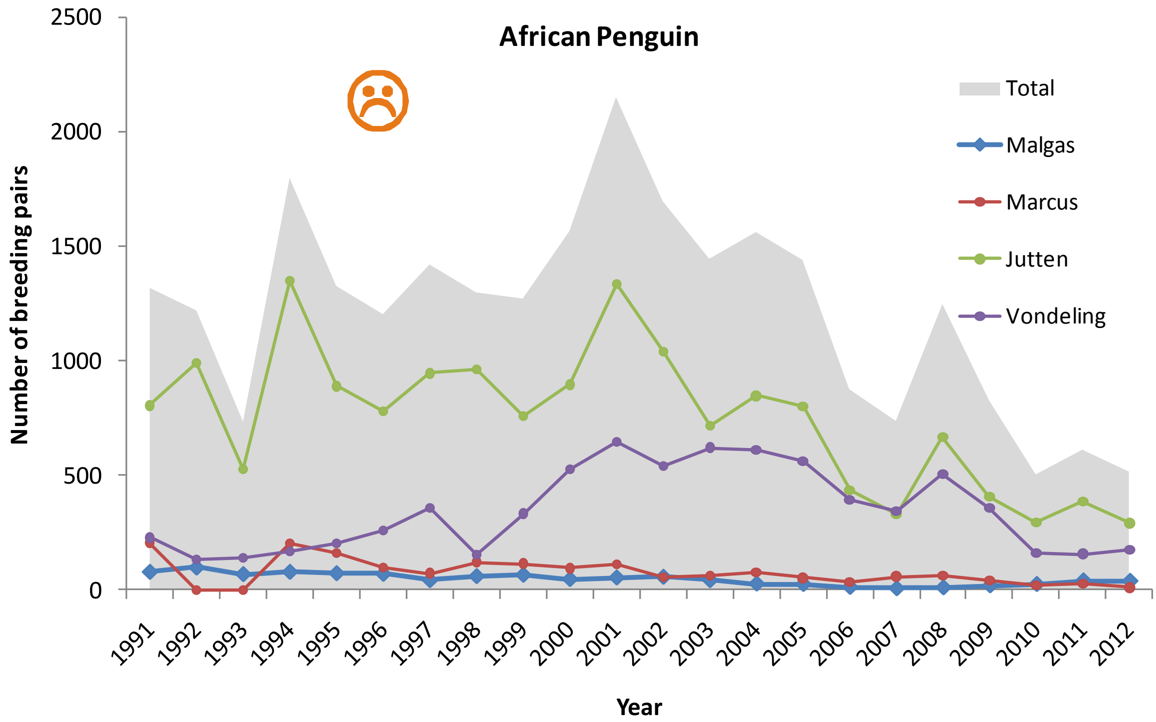


Figure 10.1. Trends in African Penguin populations at Malgas, Marcus, Jutten and Vondeling islands in Saldanha Bay (Data source: Rob Crawford, DEA: Oceans & Coasts).

There is considerable uncertainty around the cause of the decreases, however. One of the measures currently being employed to curb these declines is the use of no-take zones for purse-seine fishing. This strategy, recently tested at St Croix Island in the Eastern Cape, was effective in decreasing breeding penguins' foraging efforts by 30% within three months of closing a 20 km zone to purse-seine fisheries (Pichegru *et al*. 2010). In this case the use of small no-take zones has represented immediate benefits for a top predator dependent on pelagic prey, with minimum cost to the fishing industry, while protecting ecosystems within these habitats and important species. However, research at Dassen and Robben Islands has not delivered such positive results.

The reduction in colony sizes at most of the islands in Saldanha Bay will have had severe negative consequences for penguins. When Penguins breed in large colonies, packed close to one another, they are better able to defend themselves against egg and chick predation by Kelp gulls. Also, these losses are trivial at the colony level. However, the fragmented colonies and the massive rise in gull numbers associated with the rapidly expanding human settlements in the area, means that gull predation is increasingly problematic. Similarly, predation by seals (on land and around colonies) is having an increasingly negative impact on these dwindling colonies (Makhado *et al*. 2009). Additional stress, such as turbidity and increased vessel traffic, will not only impact penguins directly, but is likely to influence the location of schooling fish that the penguins are targeting and their ability to locate these schools. There are also concerns that toxin loads influence individual birds' health, reducing their breeding success and/or longevity (Game *et al*. 2009).

In summary, the initial collapse of the penguin colonies in the area is probably related to food availability around breeding islands and in areas where birds not engaged in breeding are foraging. However, now that colonies have shrunk so dramatically, the net effect of local conditions at Saldanha Bay are believed to be an increasingly important factor in the continued demise of African penguin colonies at the islands.

The Kelp Gull *Larus dominicanus* breeds primarily on offshore islands, as well as a small number of mainland sites. The Islands in Saldanha Bay support a significant proportion of South Africa's breeding population. Within this area, the majority breed on Schaapen, Meeuw and Jutten Islands, with additional small but consistent breeding populations on Vondeling and Malgas islands. Small numbers of breeding kelp gulls were recorded on Marcus Island in 1978, 1985 and 1990-92, but breeding has since ceased, probably due to the causeway connecting the island to the mainland allowing access to mammal predators (Hockey *et al*. 2005). Overall, the number of Kelp gulls on the islands increased until 2000 (Figure 10.2), probably due to the increase in availability of food as a result of the introduction and spread of the invasive alien mussel species *Mytilus galloprovincialis.* This was not particularly good news, however, as Kelp Gulls are known to eat the eggs of several other bird species (e.g. Cape Cormorants and Hartlaub's Gulls). However, since 2000, the populations on the islands have been steadily decreasing following large-scale predation by Great White Pelicans *Pelecanus onocrotalus* that was first observed in the mid-1990s (Crawford *et al*. 1997). During 2005 and 2006 pelicans caused total breeding failure of Kelp Gulls at Jutten and Schaapen Islands (de Ponte Machado 2007) the effects of which are still apparent (Figure 10.2). Recent counts suggest that numbers are now well below those at the start of the comprehensive counting period. Regrettably no new data are available for 2012.

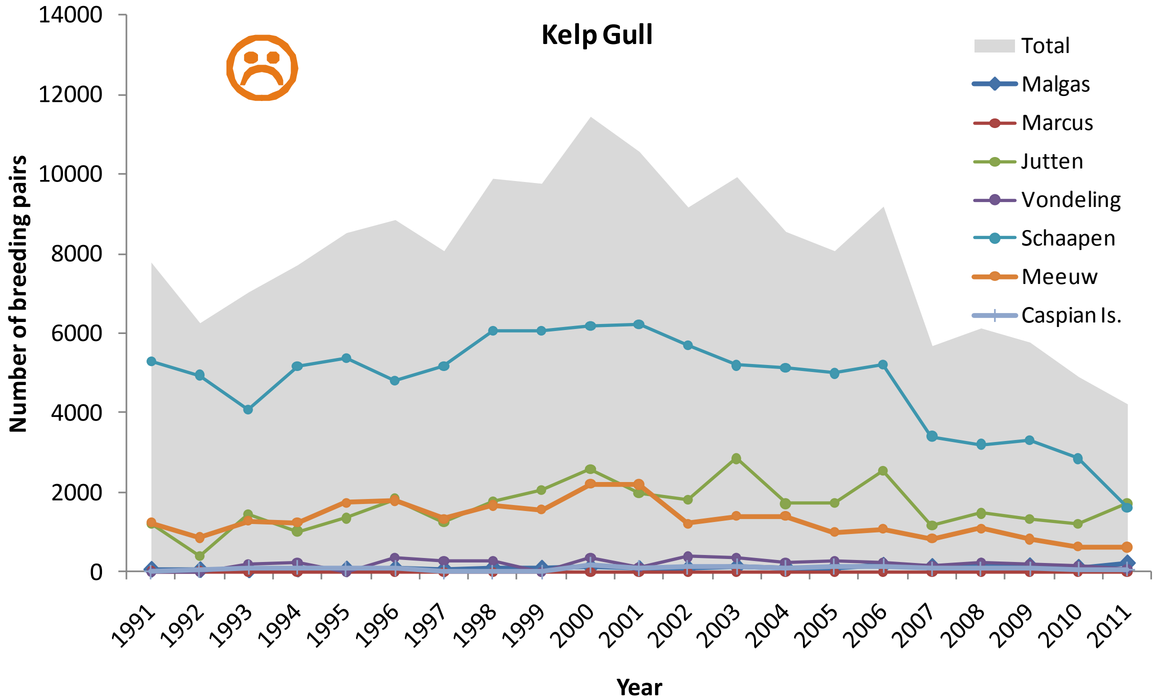


Figure 10.2. Trends in breeding population of Kelp gulls at Malgas, Jutten, Schaapen, Vondeling and Meeuw Islands in Saldanha Bay (Data source: Rob Crawford, DEA: Oceans & Coasts).

Hartlaub's Gull, *Larus hartlaubii,* is about the 10th rarest of the world's roughly 50 gull species. It is endemic to southern Africa, occurring along the West Coast from Swakopmund to Cape Agulhas. It breeds mainly on protected islands but has also been found to breed in sheltered inland waters. Hartlaub's Gulls are relatively nomadic, and can alter breeding localities from one year to the next (Crawford *et al.* 2003).

The numbers breeding on the different islands are highly erratic, as are the total numbers in the Bay. The highest and most consistent numbers of breeding birds are found on Malgas, Jutten and Schaapen islands, with a few birds breeding Vondeling Island between 1991 and 1999. They have also been recorded breeding on Meeuw Island in 1996 and from 2002 to 2004. There are substantial inter-annual fluctuations in numbers of birds breeding, suggesting that in some years an appreciable proportion of the adults do not breed (Crawford *et al*. 2003). Natural predators of this gull are the Kelp Gull, African Sacred Ibis and Cattle Egret, which eat eggs, chicks and occasionally adults (Williams *et al*. 1990). In Saldanha Bay there is no discernable upward or downward trend over time. Concern was recently expressed over the fact that breeding appeared to have ceased at Schaapen Island and that overall numbers have remained very low for several years. However, it is hoped that the recent resurgence in the numbers of breeding pairs on Schaapen, Malgas and Meeu Islands (925, 379 and 23 pairs recorded in 2012, respectively) represents a reversal in this trend (Figure 10.3).

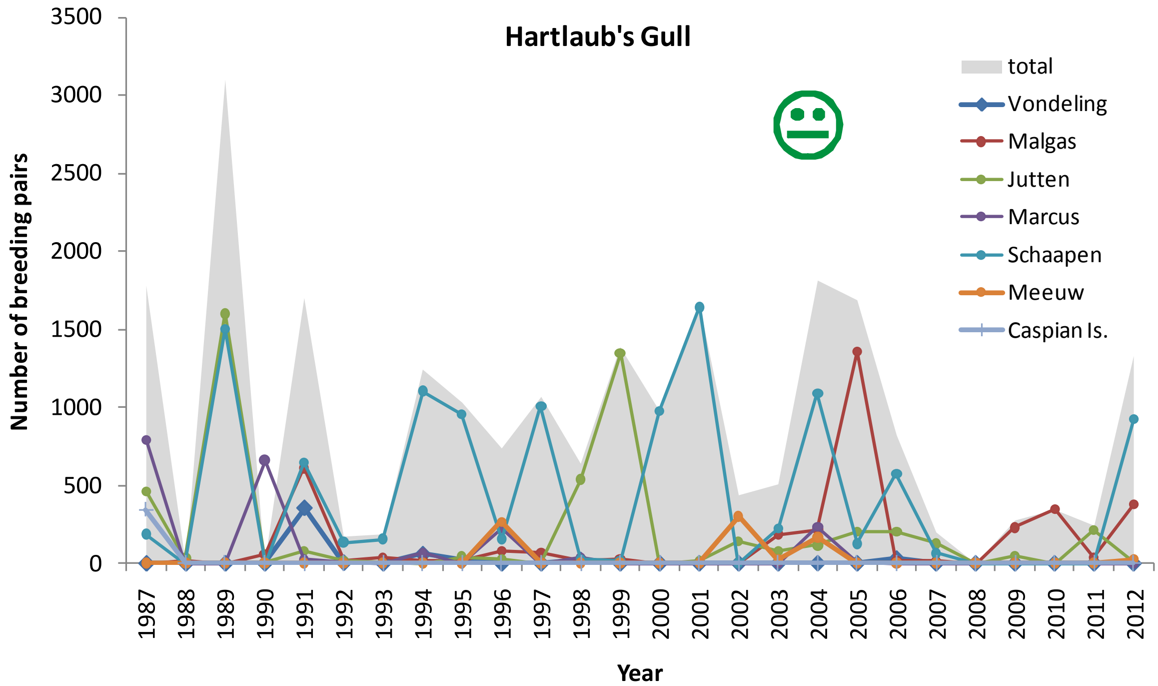


Figure 10.3. Trends in breeding population of Hartlaub's Gulls at Malgas, Marcus, Jutten, Schaapen and Vondeling Islands in Saldanha Bay (Data source: Rob Crawford, DEA: Oceans & Coasts).

The Swift Tern, *Sterna bergii,* is a widespread species that occurs as a common resident in southern Africa. Swift Terns breed synchronously in colonies, usually on protected islands, and often in association with Hartlaub's Gulls. Sensitive to human disturbance, their nests easily fall prey to Kelp Gulls, Hartlaub's Gulls and Sacred Ibis (Le Roux 2002). During the breeding season, fish form 86% of

all prey items taken, particularly pelagic shoaling fish, of which the Cape Anchovy (*Engraulis encrasicolus*) is the most important prey species. Since 2001 there has been an increase in the Swift Tern population number in South Africa. This increase coincided with a greater abundance of two of their main prey species, sardines and anchovies. However, since 2005, the population in the Western Cape has shifted south and eastward, coinciding with a similar shift of their prey species (Crawford 2009). In southern Africa, Swift Terns show low fidelity to breeding localities, unlike the African Penguin, Cape Gannet and Cape Cormorant, which enables them to rapidly adjust to changes in prey availability (Crawford 2009).

In Saldanha Bay, Jutten Island has been the most important island for breeding Swift Terns over the past 30 or more years, but breeding numbers are erratic at all the islands. The breeding population shifted to Schaapen Island in 2007, but no swift terns were reported breeding on islands in the Bay for the four years following this, the longest such period on record. It is encouraging therefore that the birds have retuned in numbers again in 2012, with 1438 pairs recorded on Malgas and 317 on Schaapen Islands (Figure 10.4).

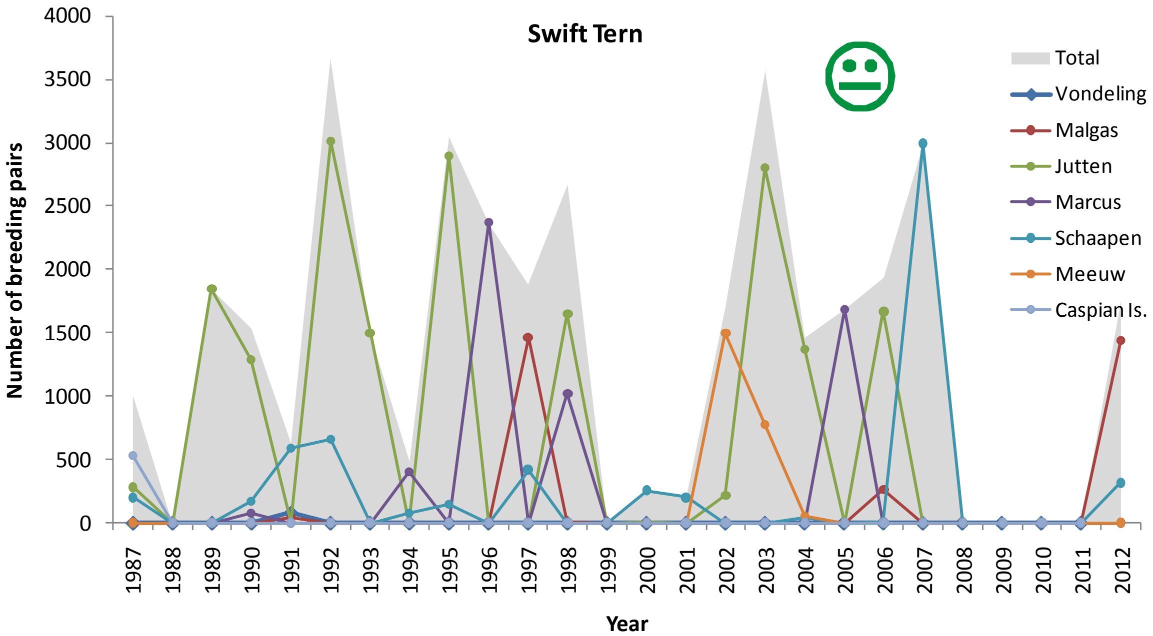


Figure 10.4. Trends in breeding population of Swift Terns at Malgas, Marcus, Jutten and Schaapen islands in Saldanha Bay (Data source: Rob Crawford, DEA: Oceans & Coasts).

Cape Gannets *Morus capensis* are restricted to the coast of Africa, from the Western Sahara, around Cape Agulhas to the Kenyan coast. In southern Africa they breed on six offshore islands, three off the Namibian coast, and two off the west coast of South Africa (Bird Island in Lambert's Bay and Malgas Island in Saldanha Bay), and one (Bird Island) at Port Elizabeth. The Cape Gannet is listed as Vulnerable on the IUCN's global Red Data List, due to its restricted range and population declines (Birdlife International 2011).

Cape Gannets breed on islands which afford them protection from predators. They feed out at sea and will often forage more than a hundred kilometres away from their nesting sites (Adams and Navarro 2005). This means that only a small proportion of foraging takes place within Saldanha Bay. The quality of water in Saldanha Bay should therefore not have a significant effect on the Cape Gannet population.

The bird colony at Malgas Island has shown population fluctuation since the early 1990's and a steady decline since 1996 (Figure 10.5). Regrettably there are no new data available for 2012. The decline in numbers at Malgas Island contrasts with population figures for Bird Island, off Port Elizabeth, where numbers have increased. A recent study suggested that Cape Gannet population trends are driven by food availability during their breeding season (Lewis *et al*. 2006). Pichegru *et al*. (2007) showed that Cape Gannets on the west coast have been declining since the start of the eastward shift of the pelagic fish in the late 1990s. This has resulted in west coast gannets having to increase their foraging efforts, during the breeding season, forage in areas with very low abundance of their preferred prey, and feed primarily on low-energy fishery discards (93% of total prey intake; Crawford *et al*. 2006, Pichegru *et al*. 2007). A bioenergetics model showed that enhanced availability of low-energy fishery discards does not seem to compensate for the absence of natural prey (Pichegru *et al*. 2007). In addition to the above, and of more concern at a local level, is the recent increase in predation by Cape fur seals *Arctocephalus pusilus pusillus* and the Great White Pelican *Pelecanus onocrotalus* (Makhado *et al*. 2006; Pichegru *et al*. 2007). Predation by seals caused a 25% reduction in the size of the colony at Malgas Island between 2001 and 2006 (Makhado *et al*. 2006). These added threats weigh heavily on an already vulnerable species.

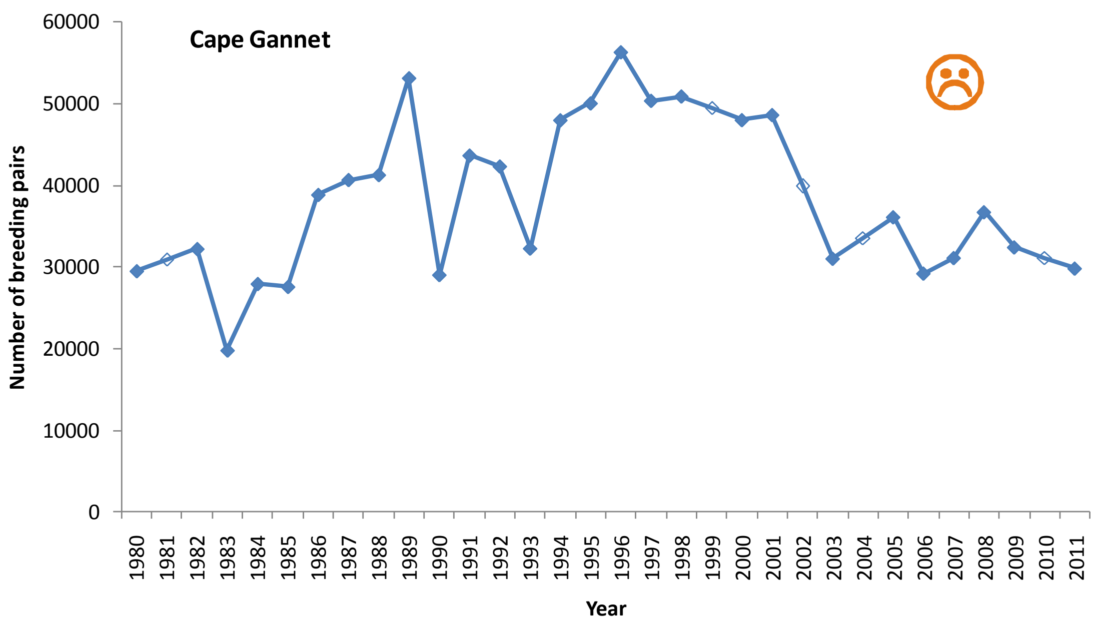


Figure 10.5. Trends in breeding population of Cape Gannets at Malgas Island, Saldanha Bay. Open data points are interpolated (no data). (Data source: Rob Crawford, DEA: Oceans & Coasts).

These recent findings have changed the overall health of the Gannet population on Malgas Island from Good to Fair based on the increase in predation by fur seals and recently observed predation by the Great White Pelican (Pichegru *et al*. 2007). Management measures were implemented between 1993 and 2001 and 153 fur seals seen to kill Gannets, were shot (Makhado *et al*. 2006). This practice has continued in an effort to improve breeding success (Makhado *et al*. 2009). The effects of this may be manifest in the slight recovery in Gannet numbers between 2006 and 2009, but numbers have declined since then.

Cape Cormorants *Phalacrocorax capensis* are endemic to southern Africa, where they are abundant on the west coast but less common on the east coast, occurring as far as Seal Island in Algoa Bay. They breed between Ilha dos Tigres, Angola, and Seal Island in Algoa Bay, South Africa. They generally feed within 10-15 km of the shore, preying on pelagic goby *Sufflogobius bibarbatus*, Cape anchovy *Engraulis capensis*, pilchard *Sardinops occelatus* and Cape horse mackerel *Trachurus trachurus* (du Toit 2004).

The Cape Cormorant is regarded as Near Threatened owing to a decrease in the breeding population during the late 1970s (Cooper *et al*. 1982). Numbers decreased again during the early 1990s following an outbreak of avian cholera, predation by Cape fur seals and White Pelicans as well as the eastward displacement of sardines off South Africa (Crawford *et al*. 2007). As a result there are large inter-annual fluctuations in breeding numbers due to breeding failure, nest desertion and mass mortality related to the abundance of prey, for which they compete with commercial fisheries. This makes it difficult to accurately determine population trends. In addition, during outbreaks of avian cholera, tens of thousands of birds die. Cape Cormorants are also vulnerable to oiling, and are difficult to catch and clean. Discarded fishing gear and marine debris also entangles and kills many birds. Kelp Gulls prey on Cape Cormorant eggs and chicks and this is exacerbated by human disturbance, especially during the early stages of breeding, as well as the increase in gull numbers (du Toit, 2004).

The Saldanha Bay population has been quite variable since the start of monitoring in 1988, with the bulk of the population residing on Jutten Island in recent years (Figure 10.6). Numbers of birds on this island have declined steadily over the last three years, however, but have increased slightly on Schaapen Island. Overall numbers are down nearly 60% since 2009 (down from 13 654 in 2009 to only 5644 pairs in 2012).

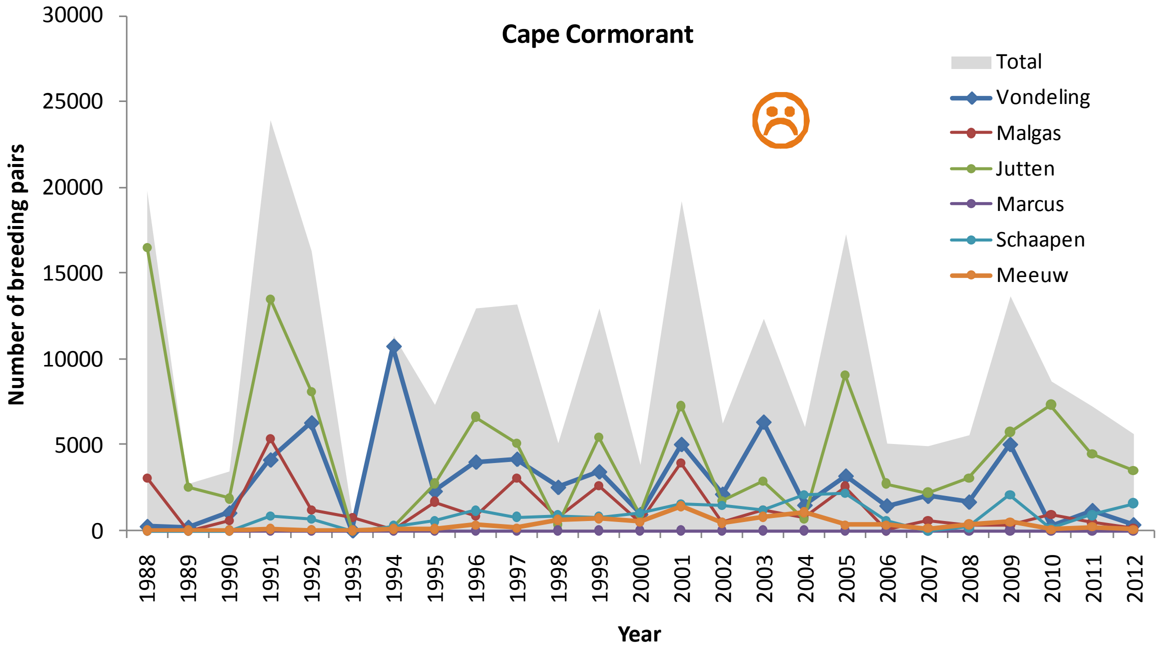


Figure 10.6. Trends in breeding population of Cape Cormorants at Malgas, Jutten, Schaapen, Vondeling and Meeuw islands in Saldanha Bay (Data source: Rob Crawford, Oceans & Coasts, Department of Environmental Affairs).

Bank Cormorants *Phalacrocorax neglectus* are endemic to the Benguela upwelling region of southern Africa, breeding from Hollamsbird Island, Namibia, to Quoin Rock, South Africa. They seldom range farther than 10 km offshore. Their distribution roughly matches that of kelp *Ecklonia maxima* beds. They prey on various fish, crustaceans and cephalopods, feeding mainly amongst kelp where they catch West Coast rock lobster, *Jasus lalandii* and pelagic goby *Sufflogobius bibarbatus* (du Toit 2004). The total population decreased from about 9000 breeding pairs in 1975 to less than 5000 pairs in 1991-1997 to 2800 by 2006 (Kemper *et al*. 2007). One of the main contributing factors to the decrease in the North and Western Cape colonies was a major shift in the availability of the West Coast rock lobster from the West Coast to the more southern regions, observed between the late 1980s and early 1990s to the turn of the century (Cockcroft *et al.* 2008). The abundance of lobsters was further severely affected by an increase in the number and severity of mass lobster strandings (walkouts) during the 1990s (Cockcroft *et al.* 2008). Ongoing population declines led to the Bank Cormorant's status being changed from Vulnerable to Endangered (Birdlife International 2011).

Count data from the Saldanha Bay area shows the dramatic decrease in the population at Malgas Island, which was previously the most important island for this species. This was accompanied by a slight increase in numbers on Marcus and Jutten islands. The population in Saldanha Bay has been more or less stable since 2009 (Figure 10.7).

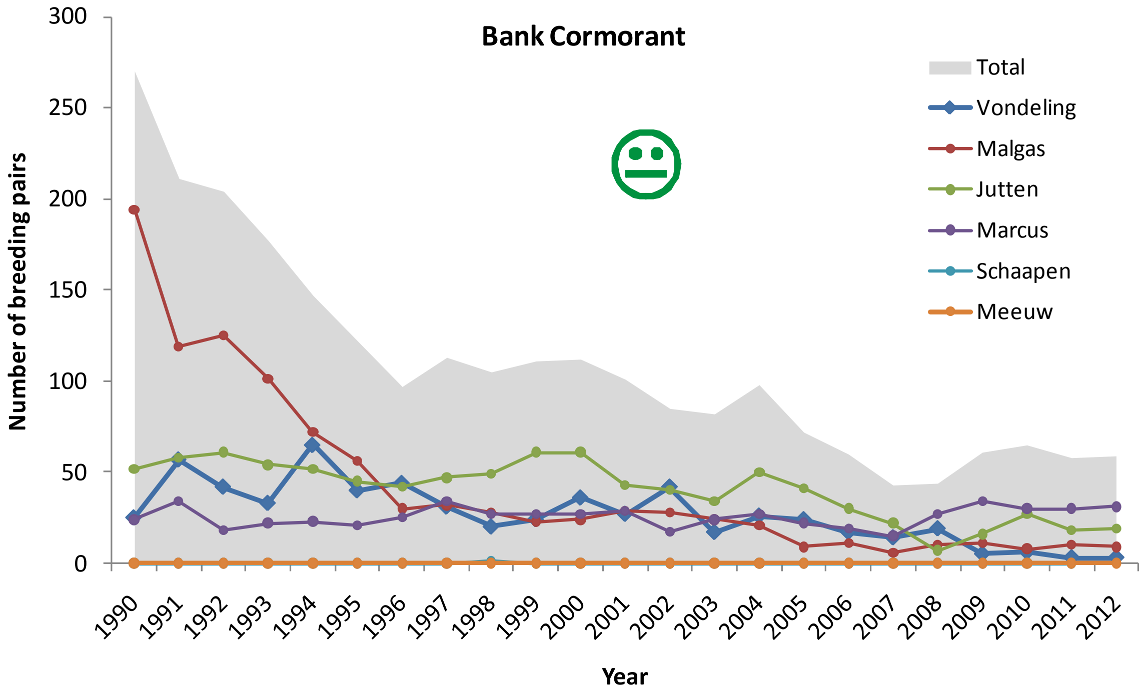


Figure 10.7. Trends in breeding population of Bank Cormorants at Malgas, Marcus, Jutten and Vondeling islands in Saldanha Bay (Data source: Rob Crawford, Oceans & Coasts, Department of Environmental Affairs).

In Saldanha Bay the declines are mainly attributed to scarcity of their main prey, the rock lobster which in turn has reduced recruitment to the colonies (Crawford 2007; Crawford *et al.* 2008c). Bank Cormorants are also very susceptible to human disturbance and eggs and chicks are taken by Kelp Gulls and Great White Pelicans. Increased predation has been attributed to the loss of four colonies in other parts of South Africa and Namibia (Hockey *et al*. 2005). Smaller breeding colonies are more vulnerable to predation which would further accelerate their decline. Birds are also known to occasionally drown in rock-lobster traps, and nests are often lost to rough seas.

The **White-breasted Cormorant** *Phalacrocorax carbo lucidus,* also known as Great Cormorant, occurs along the entire southern African coastline, and is common in the eastern and southern interior, but occurs only along major river systems and wetlands in the arid western interior. The coastal population breeds from Ilha dos Tigres in southern Angola, to Morgan Bay in the Eastern Cape. Along the coast, White-breasted Cormorants forage offshore, mainly within 10 km of the coast, and often near reefs. White-breasted Cormorants that forage in the marine environment feed on bottom-living, mid-water and surface-dwelling prey, such as sparid fishes (e.g. Steentjies and White stumpnose, du Toit 2004). This species forages in Saldanha Bay and Langebaan Lagoon, making it susceptible to local water quality (Hockey *et al*. 2005).

Within Saldanha Bay, breeding effort has occasionally shifted between islands. White-breasted Cormorant bred on Malgas Island in the 1920's, and low numbers of breeding pairs were counted on Marcus and Jutten Islands intermittently between 1973 and 1987 when they stopped breeding there and colonized Schaapen, Meeuw and Vondeling islands (Crawford *et al*. 1994). Most of the breeding population was on Meeuw in the early 1990s, but shifted to Schaapen in about 1995. By 2000, the breeding numbers at Schaapen had started to decline and the breeding population had shifted entirely back to Meeuw by 2004, where it has remained since (Figure 10.8). Overall numbers have been more or less stable in recent years, and there is no long term declining trend.

Human disturbance poses a threat at breeding sites. These cormorants are more susceptible to disturbance than the other marine cormorants, and leave their nests for extended periods if disturbed, exposing eggs and chicks to Kelp Gull predation. Other mortality factors include Avian Cholera, oil pollution, discarded fishing line and hunting inland (du Toit 2004). Due to Schaapen Islands' close proximity to the town of Langebaan, the high boating, kite-boarding and other recreational use of the area may pose a threat to these birds.

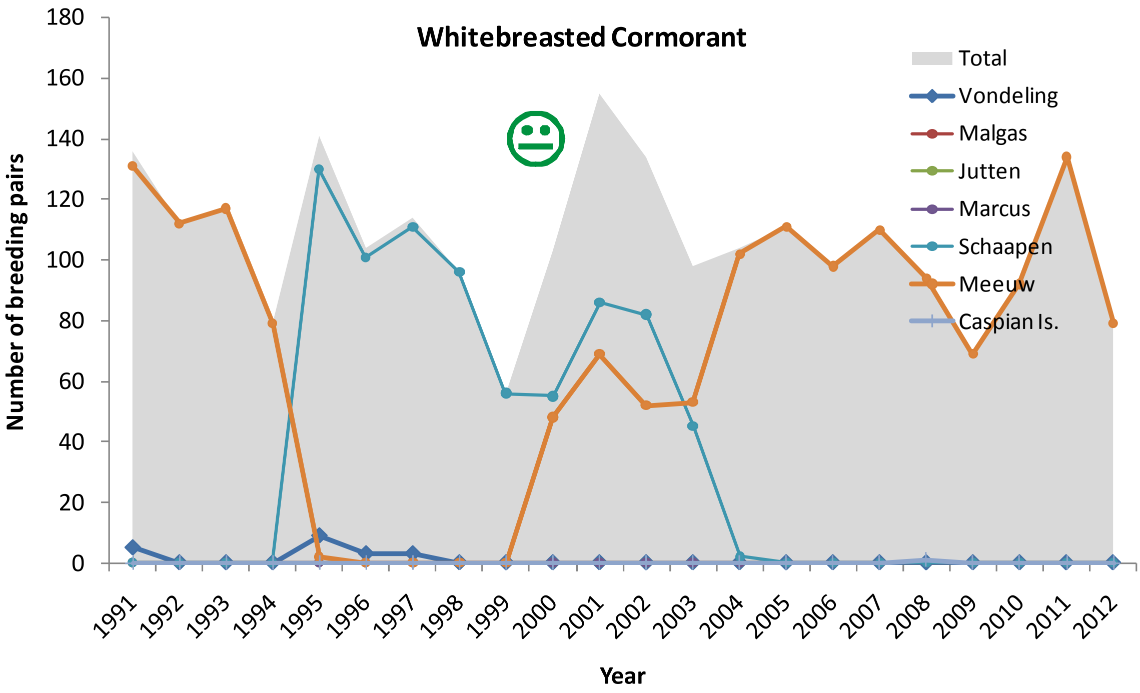


Figure 10.8. Trends in breeding population of White-breasted Cormorants on the islands in Saldanha Bay (Data source: Rob Crawford, DEA: Oceans & Coasts).

The **Crowned Cormorant** *Phalacrocorax coronatus* is endemic to Namibia and South Africa, occurring between the Bird Rock Guano Platform in southern Namibia and Quoin Rock, South Africa. It is listed as Near Threatened on the IUCN's Red Data List due to its small and range restricted population, making it very vulnerable to threats at their breeding colonies (Birdlife International 2011). This species is highly susceptible to human disturbance and predation by fur seals, particularly of fledglings. Crowned Cormorants generally occur within 10 km from the coastline and occasionally in estuaries and sewage works up to 500 m from the sea. They feed on slow-moving benthic fish and invertebrates, which they forage for in shallow coastal waters and among kelp beds (du Toit 2004).

Populations of this species have been comprehensively counted since 1991. Since then, numbers have shown considerable interannual variations without much cause for concern. Recently (the last three years), however, populations on almost all the islands in the Bay have been in decline, resulting a rather precipitous drop in the overall numbers of these birds in the area (down from more than 600 pairs in 2010 to fewer than 200 in 2012, Figure 10.9).

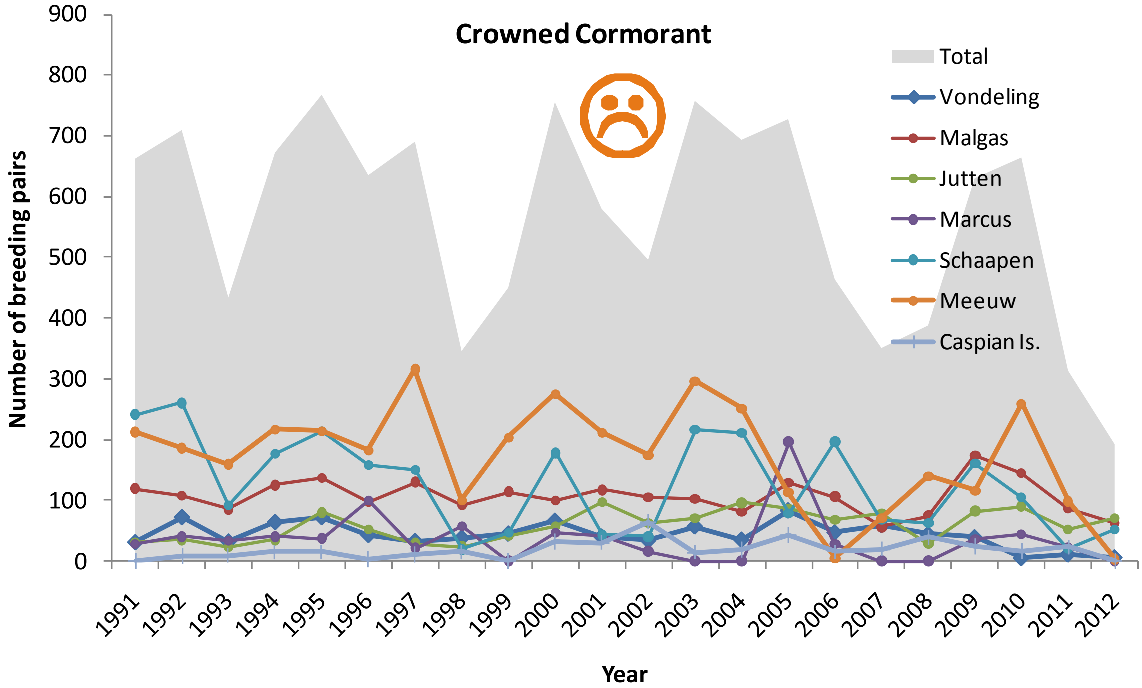


Figure 10.9. Trends in breeding population of Crowned Cormorants on the islands in Saldanha Bay (Data source: Rob Crawford, DEA: Oceans & Coasts).

The **African Black Oystercatcher** *Haematopus moquini* is endemic to southern Africa. It is listed as Near Threatened in the IUCN's a Red Data List, owing to its small population and limited range (Birdlife International 2011). It breeds in rocky intertidal and sandy beach areas from Namibia to the southern KwaZulu-Natal coast. The islands in Saldanha Bay support an important number of these birds. They are most numerous on Marcus, Malgas and Jutten Islands, where their populations currently fluctuate between 200 and 270, and between 100 and 160 birds, respectively. Their numbers have increased dramatically over the past 25 years. In the last 35 years (since 1980) the population has grown by 100 breeding pairs on the three main breeding islands in Saldanha Bay (Figure 10.10). This steady increase in Oystercatcher numbers over the past two decades is due primarily to the introduction and proliferation of the alien mussel *Mytilus galloprovincialis,* as well as due to the enhanced protection of this species throughout much of its range.

African Black Oystercatchers are resident on the islands, feeding in the rocky intertidal. While the invasive alien mussels proliferated and became important in the diet between the late 1980s and the early 1990s, the effects on population only began to show much later because of the age at first breeding and slow breeding rate of these birds (Hockey 1983). The population has stabilised in the recent years, suggesting that carrying capacity of the islands has been reached (Loewenthal in prep.). Oystercatchers are unlikely to be affected by water quality in Saldanha Bay except in as much as it affects intertidal invertebrate abundance. Like most of the birds described above, they are, however, vulnerable to catastrophic events such as oil spills.

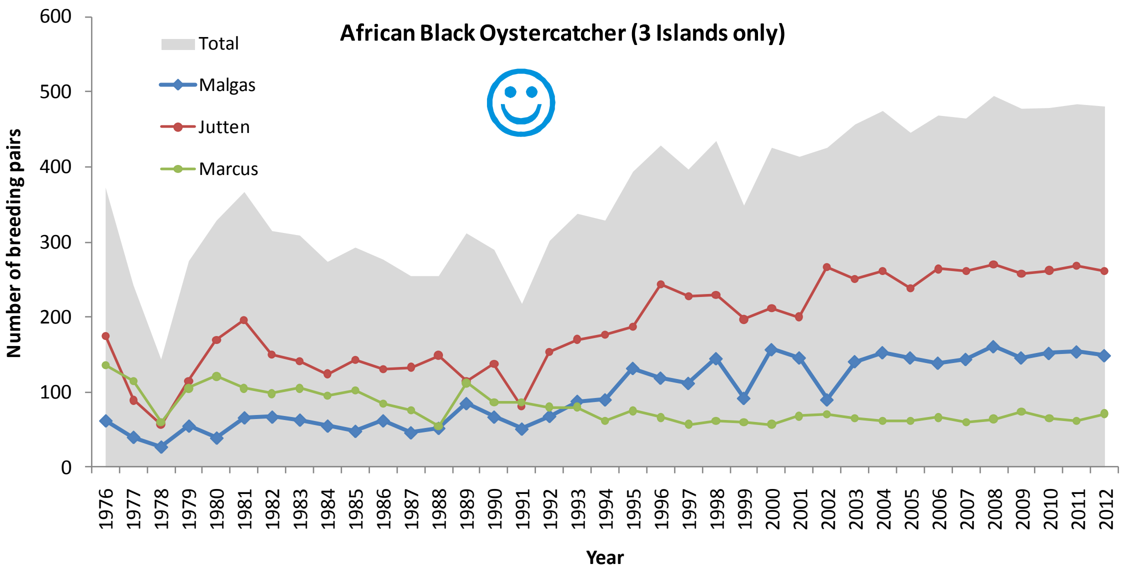


Figure 10.10. Trend in breeding population of African Black Oystercatchers older than 1 year, on Marcus, Malgas and Jutten Islands. (Data source: Douglas Loewenthal, Oystercatcher Conservation Programme).

10.3 Birds of Langebaan Lagoon

10.3.1 National importance of Langebaan Lagoon for birds

Langebaan Lagoon supports an average of about 50 000 waterbirds during summer and about 18 000 during winter. Fifty-five species of waterbirds are regularly recorded at Langebaan Lagoon. About two thirds of the waterbird species are waders, of which 18 species are regular migrants from the Palaearctic region of Eurasia; these make up 87% of the summer wader population by numbers. Important non-waders which utilise the system are Kelp and Hartlaub's Gulls, Greater Flamingo, Sacred Ibis and Common Tern. Resident waterbird species which utilise the rocky and sandy coastlines include the African Black Oystercatcher and the White-fronted Plover, both of which breed in the area.

The thousands of migratory waders visit Langebaan Lagoon during the austral summer making it the most important 'wintering' area for these birds in South Africa (Underhill 1987). Since Langebaan Lagoon regularly supports over 20 000 waders it is recognised as an internationally important site under the Ramsar Convention on Wetlands of International Importance, to which South Africa is a signatory. With regard to density and biomass of waders, Langebaan Lagoon compares favourably to other internationally important coastal wetlands in West Africa and Europe.

The true importance of Langebaan Lagoon for waders cannot be assessed without recourse to a comparison with wader populations at other wetlands in southern Africa. During the summer of 1976 to 1977, the wader populations at all coastal wetlands in the south-western Cape were counted (Siegfried 1977). The total population was estimated at 119 000 birds of which 37 000 occurred at Langebaan. Only one other coastal wetland, the Berg River estuary, contained more than 10 000 waders. Thus, Langebaan Lagoon held approximately one third of all the waders in the south-western Cape (Siegfried 1977). Studies were extended to Namibia (then South West Africa) in the summer of 1976-77. Walvis Bay Lagoon contained up to 29 000 waders and Sandvis had approximately 12 000 waders. Therefore, it was determined that Langebaan Lagoon was the most important wetland for waders on the west coast of southern Africa (Siegfried, 1977). Taking species rarity and abundance into account, Langebaan Lagoon has been ranked fourth of all South African coastal lagoons and estuaries in terms of its conservation importance for waterbirds (Turpie 1995).

In 1985, Langebaan Lagoon was declared a National Park, and recreational activities such as boating, angling and swimming have since been controlled within the Lagoon through zonation.

10.3.2 The main groups of birds and their use of habitats and food

The waterbirds of Langebaan Lagoon can be divided into nine different taxonomic orders (Table 10.1), the most species-rich being the Charadriiformes, which include the waders, gulls and terns. Table 10.1 also shows the more commonly used groupings of waterbirds, each of which is described in more detail below. Their relative contribution to the bird numbers on the estuary differs substantially in summer and winter, due to the prevalence of migratory birds in summer (Figure 10.11). Waders account for about 88% of the birds on Langebaan Lagoon during summer, nearly all of these being migratory. In winter, resident wader numbers increase slightly, and numbers of flamingos increase substantially.

Table 10.1. Taxonomic composition of waterbirds in Langebaan Lagoon (excluding rare or vagrant species).

Common groupings	Order	SA Resident	Migrant
Waterfowl	Podicipediformes (Grebes)	1	
	Anseriformes (Ducks, geese)	9	
	Gruiformes (Rails, crakes, gallinules, coots)	7	
Cormorants, darters, pelicans	Pelecaniformes (Cormorants, darters, pelicans)	7	
Wading birds	Ciconiiformes (Herons, egrets, ibises, spoonbill, etc.)	14	
	Phoenicopteriformes (Flamingos)	2	
Birds of prey	Falconiformes (Birds of prey)	4	
Waders	Charadriiformes: Waders	8	18
Gulls	Gulls	2	
Terns	Terns	3	4
Kingfishers	Alcediniformes (Kingfishers)	2	
Total		**59**	**22**

Waders are the most important group of birds on Langebaan Lagoon in terms of numbers. The influx of waders into the area during summer accounts for most of the seasonal change in community composition. Most of the Palaearctic migrants depart quite synchronously around early April, but the immature birds of many of these species remain behind and do not don the breeding plumage of the rest of the flock. The resident species take advantage of relief in competition for resources and use this period to breed. The migrants return more gradually in spring, with birds beginning to trickle in from August, and numbers rising rapidly during September to November.

Waders feed on invertebrates that mainly live in intertidal areas, at low tide, both by day and night (Turpie and Hockey 1995). They feed on a whole range of crustaceans, polychaete worms and gastropods, and adapting their foraging techniques to suit the type of prey available. Among the waders, plovers stand apart from the rest in that they have insensitive, robust bills and rely on their large eyes for locating prey visually. Oystercatchers have similar characteristics, using their strong bills to prise open shellfish. Most other waders have soft, highly sensitive bills and can locate prey by touch as well as visually. Those feeding by sight tend to defend feeding territories, whereas tactile foragers often forage in dense flocks.

Waders require undisturbed sandflats in order to feed at low tide and undisturbed roosting sites at high tide. In the 1970's it was determined that the most important sandflats, in terms of the density of waders they support, were in Rietbaai, in the upper section of Langebaan Lagoon, and at the mouth, near Oesterwal. The important roosting sites were the salt marshes, particularly between Bottelary and Geelbek (Summers 1977).

Gulls and terns are common throughout the area. Although their diversity is relatively low, they make up for this in overall biomass, and form an important group. Both Kelp Gulls and Hartlaub's Gulls occur commonly in the lagoon.

Cormorants, darters and pelicans are common as a group, but are dominated by the marine cormorants which breed on the Saldanha Bay islands. Great White Pelicans visit the bay and lagoon to feed, but they breed beyond the area at Dassen Island. African Darters *Anhinga rufa* are uncommon, and are more typical of lower salinities and habitats with emergent vegetation which is relatively uncommon in the study area.

Waterfowl occur in fairly large numbers because of the sheer size of the study area, but they are not as dense as they might be in freshwater wetland habitats or nearby areas such as the Berg River floodplain.

Other birds that commonly occur on the lagoon include birds of prey such as African Fish-Eagle *Haliaeetus vocifer*, Osprey *Pandion haliaetus* and African Marsh-Harrier *Circus ranivorus*, and species such as Pied Kingfisher *Ceryle rudis* and Cape Wagtail *Motacilla capensis*.

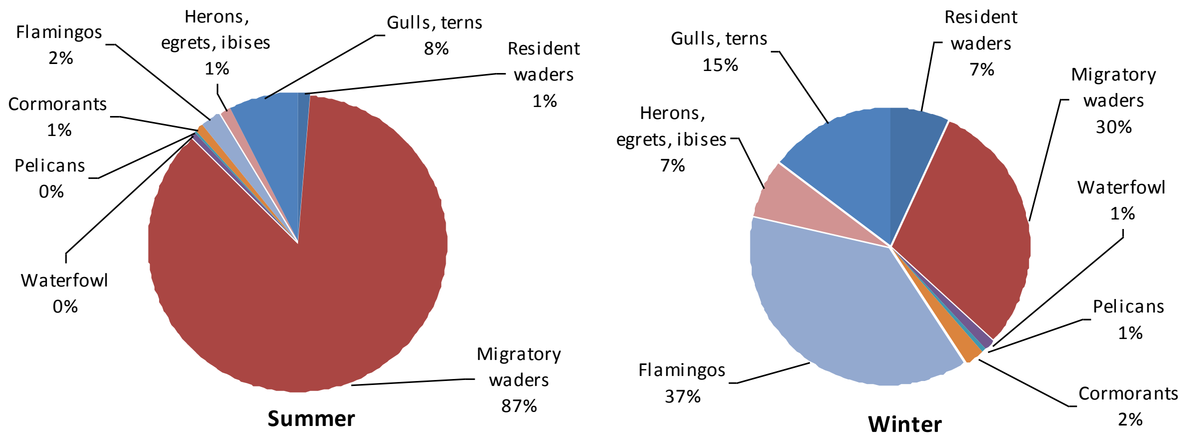


Figure 10.11. Average numerical composition of the birds on Langebaan Lagoon during summer and winter.

10.3.3 Inter-annual variability in bird numbers

Irregular waterbird surveys were conducted at Langebaan Lagoon from 1934, but, due to the large size of the lagoon, these early counts were confined to small areas. It was not until 1975 that annual summer (January or February) and winter (June or July) surveys of the total population of waders at high tide, when waders congregate to roost on saltmarshes and sand spits, were conducted by members of the Western Cape Water Study Group (WCWSG) (Underhill, 1987). An analysis of the numbers of waders over the period 1975 to 1980 showed stable summer populations, but large year to year variations in the number of Palearctic migrants that over-wintered (Robertson, 1981). The Western Cape Water Study Group monitored Langebaan continuously up to 1991, and since 1992, the Lagoon has been monitored bi-annually by the Co-ordinated Waterbird Counts (CWAC), organised by the Avian Demography Unity at the University of Cape Town.

The above data sets provide the opportunity to examine the long term trends in bird numbers at Langebaan Lagoon up to the present day. This reveals a dramatic downward trend in the numbers of Palearctic waders at the Lagoon, especially since 2008 (Figure 10.12). This is to some extent related to very low numbers of Curlew Sandpiper on the lagoon in 2011. Regrettably it has not been possible to obtain data for 2012.

The reasons for these declines are diverse and poorly understood, but seem to be a combination of loss and degradation of their breeding sites as well as of their over-wintering grounds during their non-breeding period (Dias *et al*. 2006). However, while the downward trend may echo global trends in certain wader populations, what is of more concern is that the trend appears to be echoed by resident waders, although in recent years populations numbers seem to be stabilizing (Figure 10.13). The absence of data from 2012, however, does not allow us to establish if this trend has remained the same or not. Whatever the case, it does suggests that conditions at Langebaan Lagoon are at least partially to blame for the decline in waders numbers (migrant and resident species). The most likely problems are that of siltation of the system reducing the area of suitable (e.g. muddy) intertidal foraging habitat, loss of seagrass beds with their associated invertebrate fauna (Pillay *et al.* 2011; see Chapter 6) and human disturbance, which has been shown to have a dramatic impact on bird numbers in other estuaries (Turpie and Love 2000).

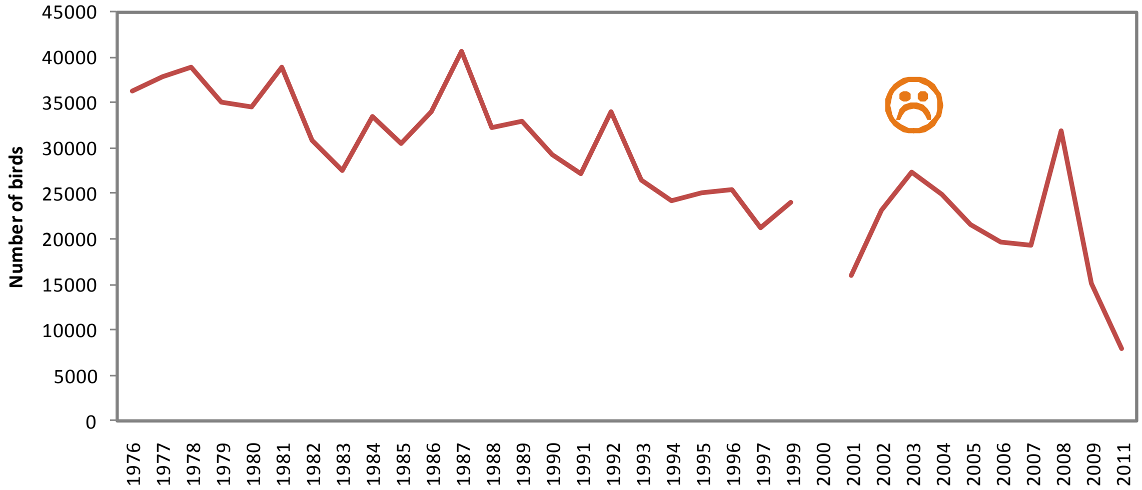


Figure 10.12. Long term trends in the numbers of summer migratory waders on Langebaan Lagoon. (Data source: CWAC data, Avian Demography Unity at the University of Cape Town).

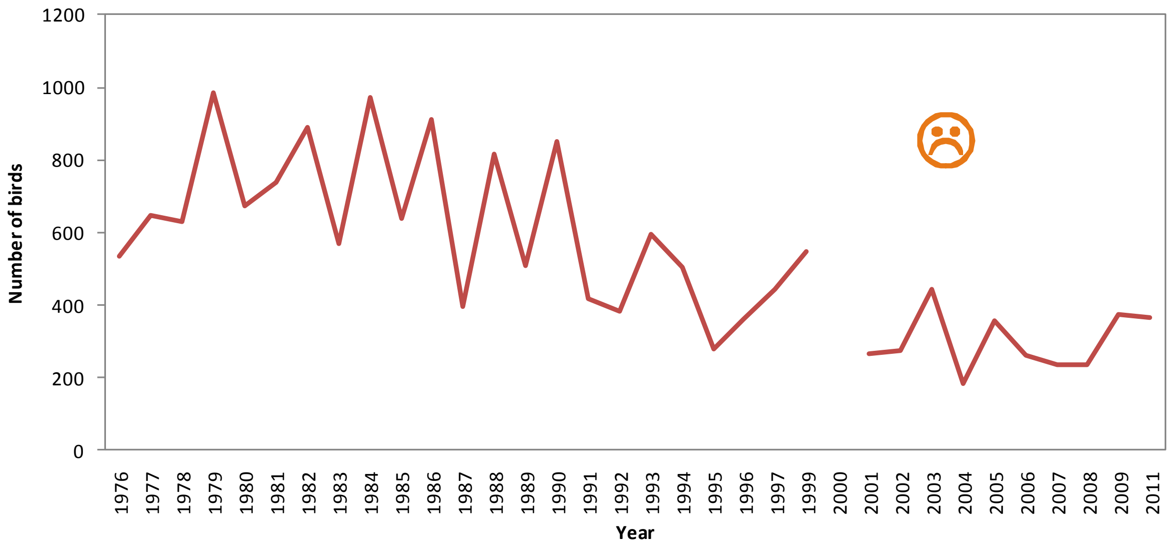


Figure 10.13. Long term trends in the numbers of winter resident waders on Langebaan Lagoon. . (Data source: CWAC data, Avian Demography Unity at the University of Cape Town).

10.4 Overall status of birds in Saldanha Bay and Langebaan Lagoon

Populations of two cormorant species, namely Bank Cormorants and White-breasted Cormorants, that utilise islands within the Saldanha Bay region for shelter and breeding, have decreased since early to mid-1990. This has been attributed to the construction of the causeway linking Marcus Island to the mainland, and to increased human disturbance. The Cape Gannet population on Malgas Island has also undergone increased decline due mainly to predation by Cape fur seals and more recently by Great White Pelicans. Predation by the seals was responsible for a 25% reduction in the size of the colony at Malgas Island, between 2001 and 2006. Management measures have been put in place, through selective culling of seals, which has improved conditions for the gannets at Malgas Island. The African Penguin populations are also under considerable pressure, partially due to causes unrelated to conditions on the island such as the eastward shift of the sardines, one of their main prey species. However, because populations are so depressed, conditions at the islands in Saldanha have now become an additional factor in driving current population decreases. Direct amelioration actions to decrease these impacts at the islands are difficult to find, however, support for conservation activities that improve penguin conservation, as a means to offset these impacts, should be considered. Most other species of seabirds investigated in this study in the Saldanha Bay region appear to have healthy populations with either stable or increasing numbers.

Decreasing numbers of migrant waders utilising Langebaan Lagoon reflects a global trend of this nature, largely due to increasing disturbance to breeding grounds of many species. The decreasing populations of resident waterbirds present in Langebaan Lagoon, a concern in itself, suggests that local conditions may be partly to blame for the decrease in migratory birds. This long-term trend is most likely due to unfavourable conditions persisting in Langebaan Lagoon as a result of anthropogenic impacts. Regrettably it has not been possible to obtain data on waterbirds numbers in the lagoon for 2012 even though such data have reportedly been collected. It is highly recommended that the status of key species continue to be monitored in future and that these data be made available and used as an indication of environmental conditions in the area.

11 ALIEN INVASIVE SPECIES IN SALDANHA BAY-LANGEBAAN LAGOON

To date, an estimated 85 marine species have been recorded as introduced to South African waters mostly though shipping activities or mariculture (Mead *et al.* 2011a). At least 62 of these are thought to occur in Saldanha Bay-Langebaan Lagoon (Table 11.1). Only a small number of these are considered invasive, but most of these occur or are suspected to occur in Saldanha Bay, including the Mediterranean mussel *Mytilus galloprovincialis,* the European green crab *Carcinus maenas* (Griffiths *et al.* 1992; Robinson *et al.* 2005), the barnacle *Balanus glandula* (Laird and Griffiths 2008), and the Pacific South American mussel *Semimytilus algosus (C.L. Griffiths, UCT, pers. comm.)*. An additional 25 species are currently regarded as cryptogenic (of unknown origin – i.e. potentially introduced) but very likely introduced. Comprehensive genetic analyses are required to determine their definite status, however (Griffiths *et al.* 2008).

Most of the introduced species in this country have been found in sheltered areas such as harbours, and are believed to have been introduced through shipping activities, for example ballast water discharge or hull fouling. As ballast water tends to be loaded in sheltered harbours, the species that are transported originate from these habitats and therefore have a difficult time adapting to South Africa's exposed coast. This might explain the low number of introduced species that have established along the coast (Griffiths *et al.* 2008) and the high number found in sheltered bays such as Saldanha.

Future surveys in the Bay will be used to confirm the presence of all listed species and will be used to ascertain if any additional or newly arrived introduced species are present. Current information on several key alien species in Saldanha Bay, some of which were identified through the State of the Bay monitoring programme, are presented below (Table 11.1).

Table 11.1. List of introduced and cryptogenic species from Saldanha Bay-Langebaan Lagoon. Occurrence is listed as confirmed or likely (not confirmed from the Bay but inferred from their distribution in the region). Region of origin and likely vector for introduction (SB = ship boring, SF = ship fouling, BW = ballast water, BS = solid ballast, OR = oil rigs, M = mariculture, F = Fisheries activities, I = intentional release) are also listed. (Data from Mead *et al.* 2011 a & b)

Taxon	Occurrence in Saldanha Bay	Origin	Vector
PROTOCTISTA			
Mirofolliculina limnoriae	Likely	Unknown	SB
Zoothamnium sp.	Likely	Unknown	SF
DINOFLAGELLATA			
Alexandrium tamarense-complex:	Likely	N Atlantic/N Pacific	BW
Alexandrium minutum	Likely	Europe	BW
Dinophysis acuminata	Likely	Europe	BW
PORIFERA			
Suberites tylobtusa	Likely	Red Sea	F
CNIDARIA			
Anthozoa			
Sagartia ornata	Confirmed	Europe	SF/BW
Metridium senile	Likely	N Atlantic/N Pacific	SF/OR
Hydrozoa			
Pachycordyle navis	Likely	Europe	SF/BW

Taxon	Occurrence in Saldanha Bay	Origin	Vector
Coryne eximia	Likely	N Atlantic/N Pacific	SF/BW
Pinauay larynx	Likely	North Atlantic	SF/BW
Pinauay ralphi	Likely	North Atlantic	SF/BW
Laomedea calceolifera	Likely	North Atlantic	SF/BW
Gonothyraea loveni	Likely	North Atlantic	SF/BW
Obelia bidentata	Confirmed	Unknown	SF/BW
Obelia dichotoma	Confirmed	Unknown	SF/BW
Obelia geniculata	Confirmed	Unknown	SF/BW
ANNELIDA			
Polychaeta			
*Boccardia proboscidea**	Likely	Eastern Pacific	SF/BW
Capitella sp. / spp. complex	Likely	Unknown	SF/BW
Polydora hoplura	Confirmed	Europe	SF/BW
Dodecaceria fewkesi	Likely	North American Pacific	SF/BW
Hydroides elegans	Likely	Indo-Pacific	SF/BW
Neodexiospira brasiliensis	Likely	Indo-Pacific	SF/BW
Janua pagenstecheri	Likely	Europe	SF/BW
Simplicaria pseudomilitaris	Likely	Unknown	SF/BW
CRUSTACEA			
Cirripedia			
Balanus glandula	Confirmed	North American Pacific	SF/BW
Isopoda			
Dynamene bidentata	Likely	Europe	SF/BW
Paracerceis sculpta	Likely	Northeast Pacific	SF/BW
Synidotea hirtipes	Confirmed	Indian Ocean	SF/BW
Synidotea variegata	Confirmed	Indo-Pacific	SF/BW
Ligia exotica	Confirmed	Unknown	SB
Limnoria quadripunctata	Confirmed	Unknown	SB
Limnoria tripunctata	Confirmed	Unknown	SB
Amphipoda			
Chelura terebrans	Confirmed	Pacific Ocean	SF/SB
Ischyrocerus anguipes	Confirmed	North Atlantic	SF/BW
Erichthonius brasiliensis	Confirmed	North Atlantic	SF/BW
Cymadusa filosa	Likely	Unknown	BS
Caprella equilibra	Confirmed	Unknown	SF/BW
Caprella penantis	Confirmed	Unknown	SF/BW
Paracaprella pusilla	Confirmed	Unknown	SF/BW
Jassa marmorata	Likely	North Atlantic	SF/BW
Jassa slatteryi	Confirmed	North Pacific	SF/BW
Orchestia gammarella	Confirmed	Europe	BS
Cerapus tubularis	Confirmed	North American Atlantic	BS
Decapoda			
Carcinus maenas	Confirmed	Europe	SF/BW/OR
INSECTA			

Taxon	Occurrence in Saldanha Bay	Origin	Vector
Coleoptera			
Cafius xantholoma	Likely	Europe	BS
MOLLUSCA			
Gastropoda			
Littorina saxatilis	Confirmed	Europe	BS
Catriona columbiana	Likely	North Pacific	SF/BW
Tritonia nilsodhneri	Likely	Europe	SF/BW
Kaloplocamus ramosus	Likely	Unknown	SF/BW
Thecacera pennigera	Likely	Unknown	SF/BW
Anteaeolidiella indica	Confirmed	Unknown	SF/BW
Bivalvia			
Mytilus galloprovincialis	Confirmed	Europe	SF/BW
Ostrea edulis	Confirmed	Europe	m
Semimytilus algosus	Confirmed	South Pacific	SF/BW
Teredo navalis	Likely	Europe	SB
Lyrodus pedicellatus	Likely	Unknown	SB
Bankia carinata	Likely	Unknown	SB
Bankia martensi	Likely	Unknown	SB
Dicyathifer manni	Likely	Unknown	SB
Teredo somersi	Likely	Unknown	SB
BRACHIOPODA			
Discinisca tenuis	Confirmed	Namibia	M
BRYOZOA			
Watersipora subtorquata	Confirmed	Caribbean	SF
Bugula neritina	Confirmed	Unknown	SF
Bugula flabellata	Confirmed	Unknown	SF
Conopeum seurati	Confirmed	Europe	SF
Cryptosula pallasiana	Confirmed	Europe	SF
CHORDATA			
Ascidiacea			
Ascidia sydneiensis	Likely	Pacific Ocean	SF
Ascidiella aspersa	Likely	Europe	SF
Botryllus schlosseri	Confirmed	Unknown	SF
Ciona intestinalis	Confirmed	Unknown	SF
Clavelina lepadiformis	Confirmed	Europe	SF
Cnemidocarpa humilis	Likely	Unknown	SF
Corella eumyota	Confirmed	Unknown	SF
Diplosoma listerianum	Confirmed	Europe	SF
Microcosmus squamiger	Likely	Australia	SF
Tridemnun cerebriforme	Confirmed	Unknown	SF
RHODOPHYTA			
Schimmelmannia elegans	Likely	Tristan da Cunha	BW
Antithamnionella ternifolia	Likely	Australia	SF/BW
Antithamnionella spirographidis	Confirmed	North Pacific	SF/BW

Taxon	Occurrence in Saldanha Bay	Origin	Vector
CHLOROPHYTA			
Codium fragile fragile (tomentosoides strain)	Confirmed	Japan	SF/BW
VASCULAR PLANTS			
Ammophila arenaria	Confirmed	Europe	I
Spartina maritima	Confirmed	Europe	BS

11.1 The occurrence and spread of marine alien species in Saldanha Bay

11.1.1 European mussel *Mytilus galloprovincialis*

Mytilus galloprovincialis was first detected in South Africa (in Saldanha Bay in fact) in 1979 (Mead *et al.* 2011b) but was only confirmed in 1984 (Grant *et al.* 1984, Grant and Cherry 1985). At this stage the population was already widespread in the country, being the most abundant mussel species on rocky shores between Cape Point and Lüderitz. This species has subsequently extended is distribution range as far as East London (Robinson *et al.* 2005). It is suspected that *Mytilus* was most likely first introduced to the country between the late 1970s and early 1980s (Griffiths *et al.* 1992) and that the reason for its late detection is that it is easily confused with the indigenous black mussel, *Choromytilus meridionalis*. *Mytilus* is, however, easily distinguished by the trained eye, being fatter, and having a pitted resilial ridge, and differs in habitat - occurring higher on the shore and away from sand-inundated sites – than *Choromytilus* (Figure 11.1). This species is commercially cultured in Saldanha Bay and elsewhere and is widely exploited by recreational and subsistence fishers (Robinson *et al.* 2005; 2007).

Figure 11.1 European mussel *Mytilus galloprovincialis. Photo: C.L. Griffiths.*

In its native countries in Europe, *M. galloprovincialis* is known to form dense subtidal beds directly on sandy bottoms (Ceccherelli and Rossi 1984) which stands in stark contrast to the sorts of areas it typically inhabits in southern Africa (viz. exposed rocky shores). Historically, *Mytilus galloprovincialis* has rarely if ever been found in heavily silted areas, which remain dominated by the indigenous *Choromytilus meridionalis* (Hockey and Van Erkom Schurink 1992). That said, *Mytilus* began establishing dense intertidal beds on the sandy center banks of Langebaan Lagoon in the mid-1990s (Hanekom and Nel 2002, Robinson and Griffiths 2002, Robinson *et al.* 2007). The biomass on the banks peaked at an estimated 8 tonnes in 1998 (Robinson and Griffiths 2002), but subsequently crashed, decreasing in size by 88% by early 2001 (Hanekom and Nel 2002) and had died off completely by mid-2001, leaving only empty shells and anoxic sand (Robinson *et al.* 2007). The reason for the die off is still not clear, and impacts on the macrobenthic infauna in the banks was evident for at least 6 month after most of the dead mussel shells had been removed by SANParks in late 2001.

Data from the State of the Bay surveys suggest that populations of *Mytilus* on rocky shores in Saldanha Bay seem to be growing rapidly (Figure 11.2). The proportion of the shore covered by this species has increased from an average of 3.0-5.4% in 2008/9 to around 7.8-11.1% in 2011/12. This species is by far the most dominant animal species on the rocks in the Bay now, and covers 100% of the available space across substantial portions of the shore. It reaches its highest densities low down on the shore, in areas exposed to high wave action.

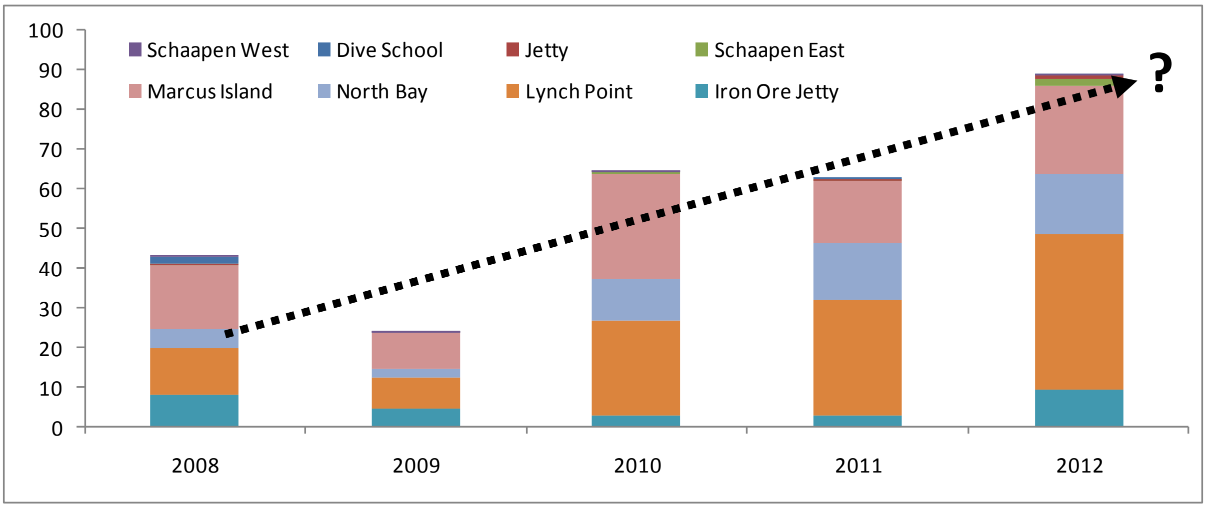


Figure 11.2. Changes in the abundance (% cover) of the Mediterranean mussel Mytilus *galloprovincialis* at eight rocky intertidal sites in Saldanha Bay over the period 2008-2012. Information of the locations of these sampling stations is provided in Chapter 8.

11.1.2 European shore crab *Carcinus maenas*

Carcinus maenas is a native European crab species that has been introduced on both the Atlantic and Pacific coasts of North America, in Australia, Argentina, Japan and South Africa (Carlton and Cohen 2003) (Figure 11.3). It is typically restricted to sheltered, coastal sites and appears thus far to have been unable to establish on the open wave-swept coastline in South Africa (Hampton and Griffiths 2007). In South Africa it was first collected from Table Bay Docks in 1983 and later in Hout Bay Harbour. It has established dense populations in both harbours where it has reportedly decimated shellfish populations (Robinson *et al.* 2005). Surveys in Saldanha Bay has not turned up any live specimens of this species to date, but a single dead specimen was picked up by Robinson *et al.* (2004) in Small Bay

Figure 11.3 European shore crab *Carcinus maenas. Photo: C.L. Griffiths.*

(the Small Craft Harbour). It is not clear whether there is in fact an extant population in the Bay at present or not.

11.1.3 Shell worm *Boccardia proboscidea*

Boccardia proboscidea is a small (20 mm long) tube-dwelling worm found in shallow sand-lined burrows on the surfaces of oysters, abalone and other shellfish. It occurs naturally on the Pacific coast of North America and Japan (Simon *et al.* 2009, Picker and Griffiths 2011). In South Africa it is known to occur on a number of oyster and abalone farms and has also recently been recorded in Saldanha Bay outside aquaculture facilities (Haupt *et al.* 2010).

11.1.4 Pacific South American mussel *Semimytilus algosus*

The Pacific South American mussel *Semimytilus algosus* is a small (up to 50 mm) elongated, relatively flat and smooth brown mussel, with a green tinged shell. This species has been long known from Namibia (since the 1930s, Kensley and Penrith 1970) but was only recently (2010) found in South Africa. It reportedly occurs in huge densities of thousands of individuals per square metre low on the shore, along most of the West Coast of South Africa. It is likely that it was transported southwards from Namibia either by shipping as a new invasion or through range expansion from the Namibian population (C.L. Griffiths, pers. comm.). This species show a strong preference for wave exposed shores (C.L. Griffiths pers. comm.) and thus is unlikely it reach high densities in Saldanha Bay. It has, however, been observed on the ropes of mussel farms in Saldanha Bay.

11.1.5 Acorn barnacle *Balanus glandula*

The presence of *B. glandula*, which originates from the Pacific coast of North America, has only recently been recognized (Simon-Blecher *et al.* 2008). It seems, however, that this species has been in South Africa since at least the early 1990s. It is now the most abundant intertidal barnacle in Saldanha Bay and indeed along the much of the southern west coast (Laird and Griffiths 2008). *B. glandula* looks very similar to the indigenous species, *Chthamalus dentatus,* which may account for the fact that it went undetected for so long (Figure 11.4). *B. glandula* has reportedly displaced populations of the indigenous and formerly abundant *C. dentatus* species which is now very rare on South African west coast shores (Laird and Griffiths 2008). *B. glandula* was first correctly identified in the State of the Bay surveys in Saldanha Bay in

Figure 11.4 Acorn barnacle *Balanus glandula*. *Photo: C.L. Griffiths.*

2008 but it is assumed, however, that it had been present during the baseline survey in 2005 but was identified as the indigenous barnacle species.

Initial records (2008/9) on the abundance of the acorn barnacle *Balanus glandula* in Saldanha Bay as evidenced by the State of the Bay sampling, suggested that populations were expanding. However, indications now suggest that this population may be shrinking again (Figure 11.5). Abundance peaked in 2009 when this organism accounted for around 7.5% of the biotic cover on the shore, but this has now declined to around 3.4%. Indications from studies conducted elsewhere (and indeed from the State of the Bay surveys – see Chapter 8 of this report) suggest that this species competes directly with another alien species – the Mediterranean mussel *Mytilus galloprovincialis* - for space on the shore and that expanding populations of *Mytilus* may be displacing this species. It still remains one of the most abundant species on the shore in Saldanha Bay, though, and thus still of significant concern.

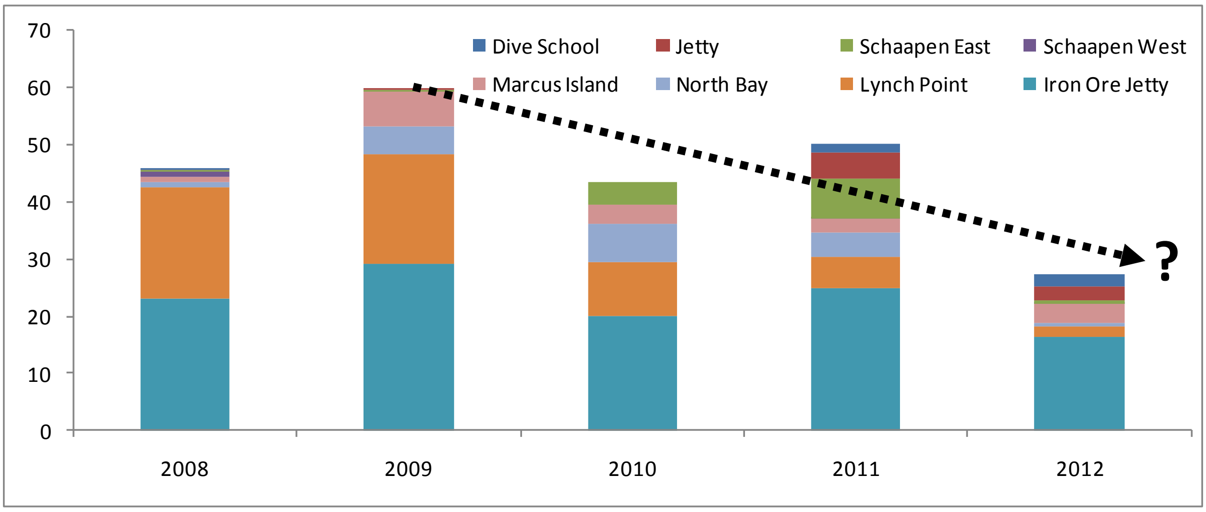


Figure 11.5. Changes in the abundance (% cover) of the acorn barnacle *Balanus glandula* at eight rocky intertidal sites in Saldanha Bay over the period 2008-2012. Information of the locations of these sampling stations is provided in Chapter 8.

11.1.6 Unnamed alien barnacle *Menesiniella regalis*

This species is known only by its scientific name *Menesiniella regalis* and as yet has not been assigned a common name. The presence of *M. regalis* in Saldanha Bay was first recognised in 2011 and was picked up as "an unfamiliar barnacle" at the Dive School in Saldanha Bay as part of the intertidal rocky-shore survey in that year. It constitutes the first known record of this barnacle species in South Africa. This species is included in the Sub-family, Concavinae (Pitombo, 2004) – animals an extended sheath and longitudinal abutment present on the inner surface of the radii and a bifid sutural edge present on the alae. Characters of the terga; a pronounced beak, closed spur-furrow and absence of longitudinal striations (Newman 1982, Zullo 1992) confirm the identification to species level (Figure 11.6).

This species originates from the Pacific coast of North America, with live material recorded intertidally from Baja California, Mexico (Pilsbry, 1916). It is difficult to tell when exactly it was reduced to Saldanha Bay in South Africa as, to the untrained eye based on external appearance, it can be easily confused with the local volcano barnacle, *Tetraclita serrata*. However, past reports from the annual State of the Bay monitoring programme have shown that Tetraclita serrata has never been recorded at the dive school in Saldanha Bay and that *Menesiniella regalis* appeared for the first time in April 2011. It is likely that the introduction of this species occurred via shipping given the high amount of shipping traffic in Saldanha Bay much like the alien acorn barnacle, Balanus glandula, which was also introduced from the Pacific coast of North America (Laird and Griffiths 2008).

Figure 11.6. Menesiniella regalis (Pilsbry, 1916) – photograph: Dr. Nina Steffani.

11.1.7 Disc lamp shell *Discinisca tenuis*

The disc lamp shell *Discinisca tenuis* is a small (20 mm diameter) disc shaped brachiopod with a semi-transparent, hairy, fringed shell (Figure 11.7). It was first recorded clinging on oysters grown in suspended culture in Saldanha Bay in 2008 (Haupt *et al.* 2010). More recently (2011) it has been reported as living freely outside of the oyster culture operation on Schaapen Island (G.M. Branch, pers. comm.). This species is endemic to Namibia and is thought to have been introduced to South Africa with cultured oyster imports from this country (Haupt *et al.* 2010). This species reportedly reaches very high densities in it home range and could become a significant fouling species in Saldanha Bay in the foreseeable future, although no previous history of invasion exists for this brachiopod.

Figure 11.7 Disc lamp shell *Discinisca tenuis.* Photo: *C.L. Griffiths.*

11.1.8 Lagoon snail *Littorina saxatilis*

Littorina saxatilis was first recorded in South Africa in 1974 (Day 1974), and the only known populations are those in Langebaan and Knysna lagoons (Hughes 1979, Robinson *et al.* 2004, Picker and Griffiths 2011). In its home range in the North Atlantic this species occurs in crevices on rocky shores (Gibson *et al.* 2001), but in South Africa it is restricted to sheltered salt marshes and lagoons, where it occurs on the stems of the cord grass *Spartina maritima* (Hughes 1979). It occurs only in the upper reaches of Langebaan Lagoon, between Bottelary and Churchhaven, and has not spread further afield than this in at least 20 years (Robison *et al.* 2004). It is not considered to be a major threat to the Lagoon or Bay ecosystems.

11.1.9 Brooding anemone *Sagartia ornata*

The only known records of the brooding anemone *Sagartia ornata* in South Africa are from Langebaan lagoon where it occurs in relatively high densities (hundreds per square meter) intertidally in beds of the spiky cord grass *Spartina maritima* and attached to rocks covered by sand (Acuña *et al.* 2004, Robinson *et al.* 2004, Picker and Griffiths 2011). Its presence in South Africa was first detected in 2002 (Acuña *et al.* 2004). Its home range extends throughout Western Europe, Great Britain and the Mediterranean (Manuel 1981), where it occur in crevices on rocky shores and on kelp holdfasts (Gibson *et al.* 2001). As such, it has the potential to spread more widely into Saldanha Bay and along the South African west coast, where conditions and habitats are similar to that in its home range, although it has not done so as yet. Impacts on local fauna are probably minimal and presumably restricted to small prey species.

11.1.10 Hitchhiker amphipod *Jassa slatteri*

Jassa slatteri is a small (9 mm) inconspicuous amphipod that constructs tubes of soft mud or crawls around on seaweeds, hydroids and other marine growth (Picker and Griffiths 2011, Colan 1990). It is common on piers, buoys and other structures in Saldanha Bay. It is suspected that it was introduced directly via ship fouling or ballast water transfer from its native habitat in Pacific North America or another infected temperate harbour where they are common. It is small and occurs in high densities and is probably a valuable food source for fish and other predators.

11.1.11 Dentate moss animal *Bugula dentata*

Bugula dentate is a bryzoan (lace animal) that forms colonies up to 50 mm tall and looks superficially like seaweed. It attaches to hard surfaces such as ship hulls, wharfs and rocks, hanging vertically in the water. It was introduced to South Africa from the Indo-Pacific region, very early on in our history (first report in 1852). It is common and a minor nuisance as a fouling species and occurs along much of the South African coast (Florence *et al.* 2007, Picker and Griffiths 2011).

11.1.12 Vase tunicate *Ciona intestinalis*

Ciona intestinalis is a tall (15 cm), cylindrical yellowish solitary ascidian with a soft floppy, transparent test. It forms large aggregations on submerged structures in harbours and lagoon from Saldanha Bay to Durban. It was originally introduced from North Atlantic prior to 1955. It is an economically important pest as it rapidly fouls hard marine surfaces. It is known to smother and kill mussels on aquaculture facilities, especially mussel ropes.

Figure 11.8. A typical aggregation of *Ciona intestinalis* (Photograph: National Museums Northern Ireland).

11.1.13 Jelly crust tunicate *Diplosoma listerianum*

Diplosoma listerianum is a colonial sea squirt that forms thin, fragile, yellow to dark grey jelly-like sheets up to 50 cm in diameter that grow over all types of substrata on sheltered shores between Alexander Bay and Durban (Monniot *et al.* 2001, Picker & Griffiths 2011). It is believed to have been accidentally introduced from Europe prior to the 1949, probably as a fouling organism.

11.1.14 Dirty sea squirt *Ascidiella aspersa*

Ascidiella aspersa is a medium sized (10 cm), solitary sea squirt that occurs on the west coast between Saldanha Bay and Table Bay (Monniot *et al.* 2001, Picker and Griffiths 2011). It was introduced from Europe and is normally found attached to ropes and floating pontoons in harbours. This species can form aggregations with others of the same species or other fouling species.

Figure 11.9. *Ascidiella aspersa* is often found covered in epibionts. (Photograph: Arjan Gittenberger).

11.1.15 Western pea crab *Pinnixa occidentalis*

Figure 11.10 Western pea crab *Pinnixa occidentalis*. Photo: C.L. Griffiths.

The Western Pea crab *Pinnixa occidentalis* (Figure 11.10) was originally described from California by M. J. Rathbun in 1893, but is presently reported to occur along the whole west coast of North America from Alaska to Mexico (Ocean Biogeographic Information System 2011). The depth range distribution for this species is reported to range from 11-319 m. This species was recently (in the latter part of 2010) identified in the collections from the Saldanha Bay: State of the Bay surveys (Clark *et al.* 2011), although previously listed as unidentified. It appears to have established itself in the Bay in the period between 1999 (at which time no specimens were recorded in a comprehensive set of samples from the Bay) and 2004 when it was recorded at four of the 30 sampling sites in the Bay with 10.1 individuals m^{-2}. Subsequent to this, both the abundance and range occupied by this species expanded fairly rapidly to a maximum of 8 sites and 19.0 individuals m^{-2} in 2009. Since then the range of sites at which this species has been recorded has varied between six and seven, spanning the deeper parts of Small Bay and Big Bay. The abundance and biomass (number of individuals and grams per square meter) also seem to have stabilised in this time, with numbers ranging from 15-39 individuals per square meter and biomass from 2.0-2.8 g per square meter (Figure 11.11). This species put in a brief appearance at one site in Langebaan Lagoon in 2009, but has not been recorded in this area since this time. This suggests that the habitat here may not be entirely suited to the species which favours deeper water (>10 m) in its native area (Ocean Biogeographic Information System 2011). It is highly likely that this species has expanded its range into deeper water outside of the Bay but has not yet been recorded there yet due to the lack of sampling effort.

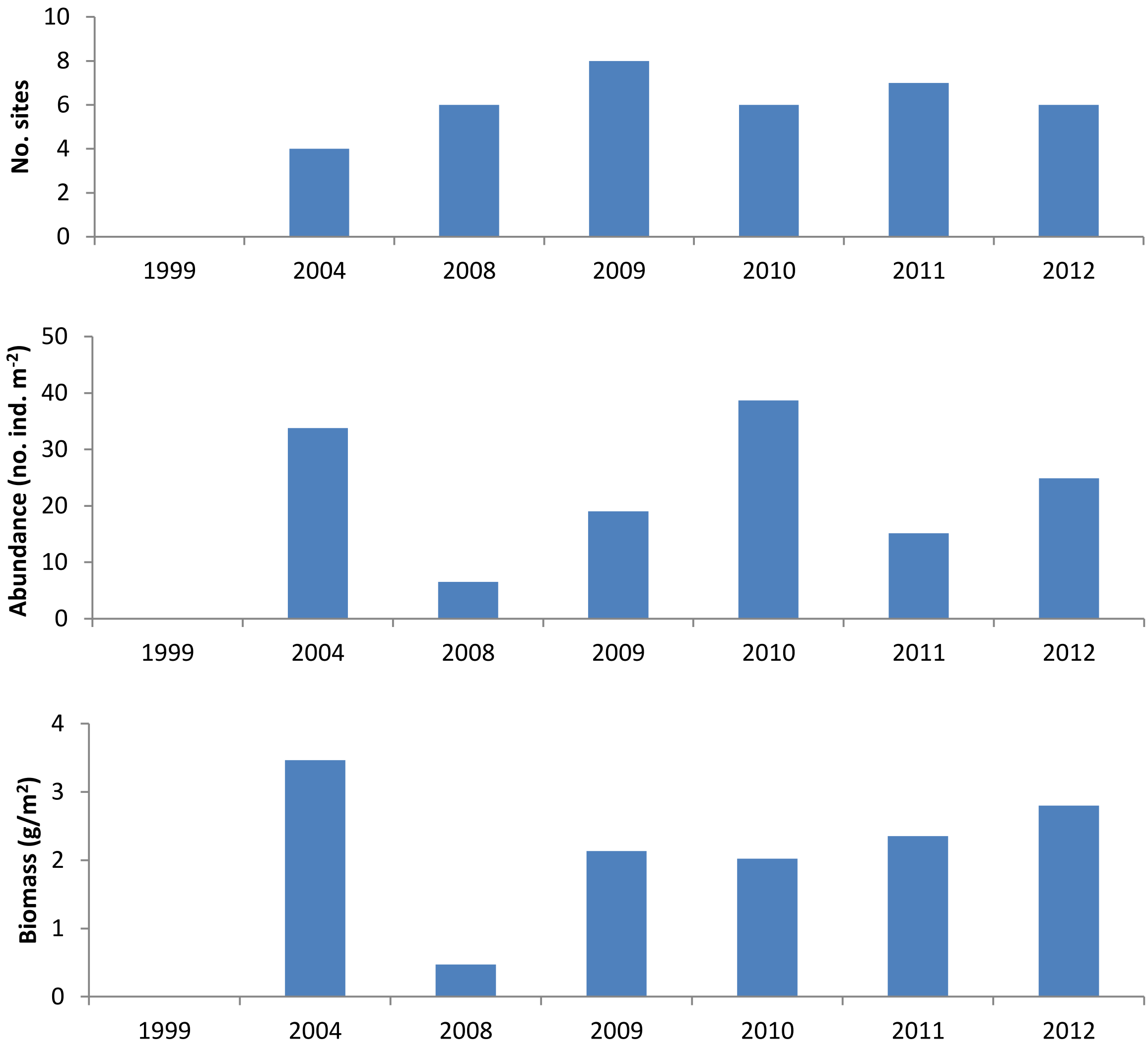


Figure 11.11 The number of sites (top) at which the Western Pea crab *Pinnixa occidentalis* has been recorded in Saldanha Bay and Langebaan lagoon in the period 1999-2012 and trend in abundance (middle) and biomass (bottom) of this organism.

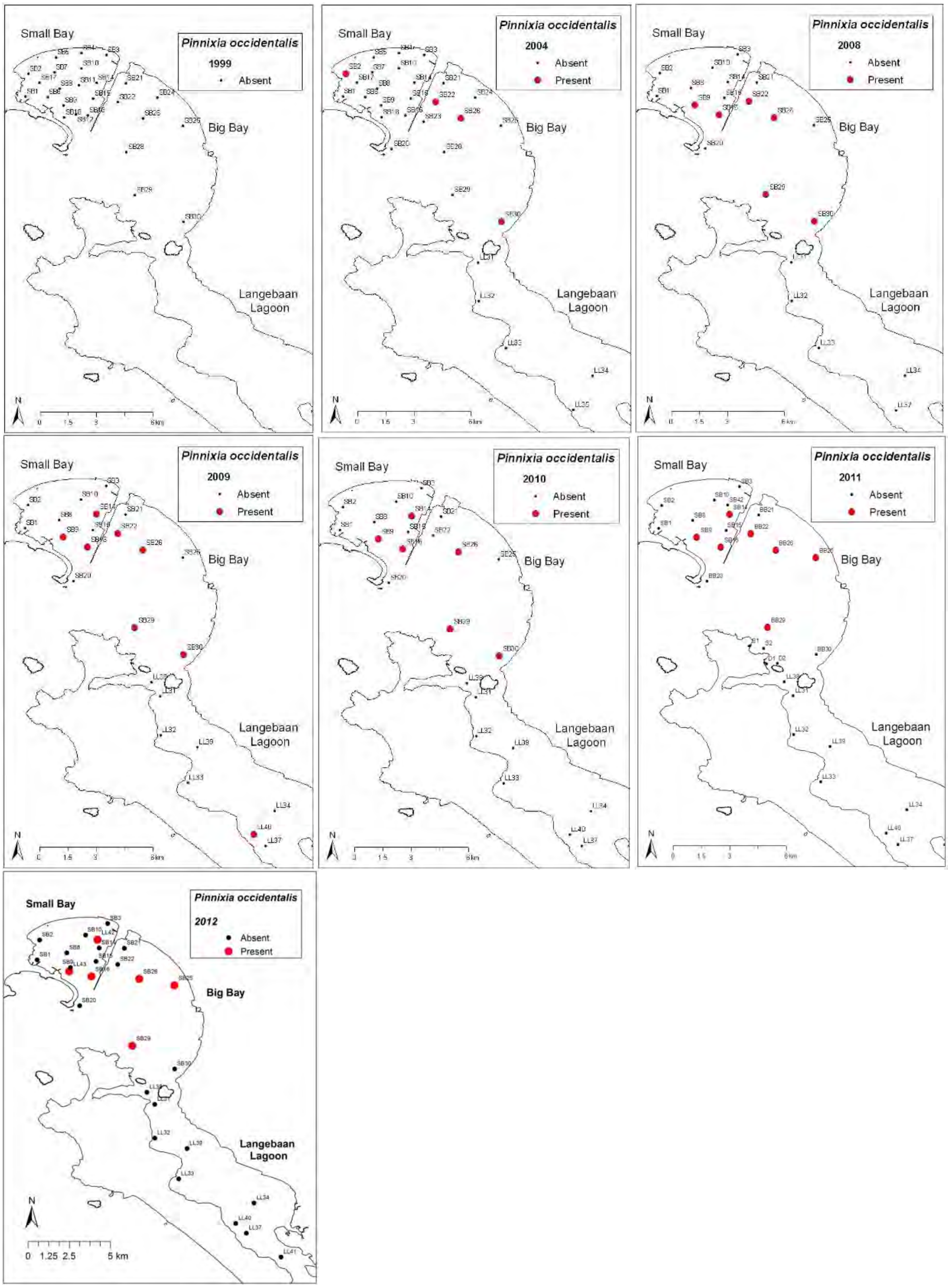


Figure 11.12. Map showing changes in the distribution of the Western Pea crab *Pinnixa occidentalis* in Saldanha Bay and Langebaan lagoon in the period 1999-2012.

12 MANAGEMENT AND MONITORING RECOMMENDATIONS

Monitoring of aquatic health and activities and discharges potentially affecting health of Saldanha Bay and Langebaan Lagoon has escalated considerably in recent years owing to concerns over declining health in the Bay. This section provides a summary of the state of health of Saldanha Bay and Langebaan Lagoon as reflected by the various environmental parameters reported on in this study. It also briefly describes current monitoring efforts and provides recommendations as to management actions that need to be implemented in order to mitigate some of the threats that have been detected. It also provides recommendations on how existing monitoring activities may need to be modified in the future to accommodate changes in the state of the Bay.

12.1 Activities and discharges affecting the health of the Bay

12.1.1 Human settlements, storm water and sewage

Human settlements surrounding Saldanha Bay and Langebaan Lagoon have expanded tremendously in recent years. This is brought home very strongly by population growth rates of over 9% per annum in Langebaan and nearly 7% in Saldanha over the period 2002 to 2004. This translates to a doubling in the population size every 8 years in the former case and every 10 years in the latter. Numbers of tourists visiting the area every year are increasing at a similarly rapid rate. This rapid rate in development translates to an equally rapid increase in the amounts of waste and waste water that is produced and has to be treated. Expansion and upgrades of treatment facilities have for the most part not been able to cope with such a rapid rate of expansion, with the result that much of the effluent produced is discharged to the environment without adequate treatment. The amount of hardened (as opposed to naturally vegetated) surfaces surround the Bay and Lagoon have also expanded at break-neck speed in recent years, with concomitant increases in volumes of contaminated storm water running off into the Bay. The contaminant loads in waste water running off into the Bay is not adequately monitored (e.g. there is no monitoring of storm water quality or run off from Saldanha or Langebaan, trace metals in ballast water have not been assessed since 1996, trace metals in bivalves assessed through the mussel watch programme was last available in 2007), nor is it adequately controlled at present (e.g. the Saldanha and Langebaan waste water treatments works still operate off an exemption issued under the old Water Act of 1956 in spite of the fact that the new Integrated Coastal Management Act with attendant water quality guidelines was enacted in 2009 and came into force in 2011). The contribution to trace metal and organic loading in the Bay from these sources is thus largely unknown, but is of concern.

Historically, insufficient provision has not been made for buffers zones around the Lagoon and Bay with the result that development encroaches right up to the waters' edge and is now widely threatened by coastal erosion. Disturbance from increasing numbers of people recreating in the Bay and lagoon of is taking its toll of sensitive habitats and species, especially seagrass, water birds and fish in Langebaan Lagoon. Small Bay in particularly is becoming increasingly industrialised and this is now threatening the vitally important nursery function of this area for important commercial and recreational fish species.

Urgent management intervention is required to limit further degradation of the environment from these pressures, and should focus on the following issues in particular:

- Ensuring that all discharges to the Bay are properly licensed and adequate monitored (both volume and water quality) and that the quality of the effluent is compliant with existing South African Water Quality Guidelines for the Coast Zone and any other legislative requirements;

- Development setback lines are established around the perimeter of the Bay and Lagoon that are compliant with new national legislation (specifically the Integrated Coast Management Act, 2009) and allow for adequate protection of the environment and infrastructure arising from current and future (i.e. climate change) pressures; and
- Sensitive habitats and fauna and flora in the Bay are assigned levels of protection that ensure minimal disturbance to these areas/populations.

12.1.2 Dredging

Dredging interventions in the Bay in the past, particularly those associated with the Iron Ore Terminal have been shown to have devastating impacts on the ecology of the Bay. Effects of the most recent major dredging event are still discernable in the sediments and faunal communities in the Bay more than a decade after their occurrence. Likely ecological impacts arising from any future proposed dredging programmes need to be carefully considered and these need to be weighed up very against social and economic benefits that may be derived from such programmes or projects. Where such impacts are unavoidable, mitigation measures applied must follow international best practice and seek to minimize and impacts to the ecology of the Bay. Even relative small dredging operations, such as those undertaken as part of the upgrade of the naval boatyard at Salamander Bay, can have very wide reaching impacts on the Bay and Lagoon.

12.1.3 Sewage

Effluent from two waste water treatment works (Saldanha and Langebaan) finds way into the Bay at present. The Saldanha WWTW operates on an exemption issued by the Department of Water Affairs (DWAF) in terms of the Water Act of 1956 which authorises the release of a total volume of 958 000 m^3 into the Bok river (and ultimately Saldanha Bay) per year. Until recently the Langebaan WWTW did not discharge any effluent into the sea as all of it was used it to irrigate the local golf course. However, increasing volumes of effluent received by this plant is yielding more water than is required for irrigation and some of this is now discharged into the Bay. There are also nine sewage pump stations in Saldanha Bay and two conservancy tanks, all of which are situated close to the coast. There are eighteen sewage pump stations in Langebaan situated throughout the town, many of which are near the edge of the lagoon, and three conservancy tanks spread around the edge of the lagoon at Oostewal, Stofbergsfontein and Oudepos. These pumpstations periodically malfunction (often due to power failures) with the result that raw untreated sewage is allowed to flow directly into the Bay threatening human health and mariculture operations. The effluent released by these two WWTW is compliant with regulations in respect of some but not all contaminants.

12.1.4 Fish factories

Data on effluent discharged from fish factory effluent discharged in to Saldanha Bay is patchy and not considered very reliable, particularly that available in recent years. Data on effluent quality is even scarcer, being restricted to data collected from two processing plants over a period of one year in 1996 and 2002, respectively. Data available for one of the principal processing factories in the Bay indicate that effluent volumes have, until recently at least, been increasing steadily each year. Given the high organic loading of these effluents, as indicated by the historic water quality data, these discharges have presumably contributed significantly to organic loading in the Bay, particularly in

Small Bay. One of the largest fish processing plants that historically discharged into the Bay has been out of operation for several years but has recently (2013) been granted permission by the authorities to reopen shop. Although the plant is now required to implement much more strict effluent management protocols than in the past and must now meet much more stringent effluent quality criteria there is still a risk that effluent from the plant could impact negatively on the Bay unless compliance with these requirements is carefully monitored and are adhered to. This is equally applicable to the other plants that discharge effluent into the Bay. Although the available data do not show this, it is quite likely that the volume of effluent discharged to the Bay from the other fish processing factories had also tailed off sharply in recent years owing to the fact that pelagic fish stocks (sardine and anchovy) had temporarily relocated eastwards beyond the reach of fishing vessels stationed in Saldanha Bay (now centered off Gansbaai). (Note that this was a major contributing factor for the temporary closure of one of these plants). Now that these fish stocks have returned to the West Coast, volumes of effluent discharged to the Bay from this source is set to increase again and it is strongly recommended that both the volume and quality of all effluent discharged from fish processing facilities in Saldanha be monitored, and that the quality of the effluent be made compliant with existing South African Water Quality Guidelines for the Coast Zone. All of the existing establishments still operate off exemptions issued under the old 1956 Water Act and need to be made compliant with the new 2009 Integrated Coastal Management Act.

12.1.5 Mariculture

Saldanha Bay is the only natural sheltered embayment in South Africa and as a result it is regarded as the major area for mariculture. A total area of approximately 145 ha has been allocated to seven mariculture operators within Saldanha Bay. All operators farm mussels and six of the operators also farm oysters. Abalone, scallops, red bait and seaweed are each cultured on one of the farms. These farms have been shown to cause organic enrichment and anoxia in sediments under the rafts owing to contamination by the farmed animals themselves, faeces, and fouling species. Monitoring of their impacts on benthic communities in the Bay is being undertaken by the Department of Agriculture Forestry and Fisheries (DAFF) but the results of this have yet to be made available to the public.

12.1.6 Shipping, ballast water discharges and oil spills

Shipping traffic and ballast water discharges to the Bay are currently monitored by the Port of Saldanha. Data indicate a steady growth in the numbers of vessels visiting the Bay and a concomitant increase in the volume of ballast water discharged to the Bay, especially since 2002 (up by about 75%). Associated with this increase in shipping traffic, is an increase in the incidence and risk of oil spills, an increased risk of introducing alien species to the Bay, increased volume of trace metals entering the Bay, and direct disturbance of marine life and sediment in the Bay. Of particular concern is the potential input of trace metals to the Bay from this source. Trace metal concentrations in ballast water discharged to Saldanha Bay have in the past (1996), been shown to exceed South Africa Water Guidelines. Whether this is still the case or not is unknown, given that the concentrations of these contaminants in ballast water discharges has not been assessed in recent years. It may well be that measures introduced to minimise risk from alien species' introduction (such as open ocean ballast water exchange) have gone a long way towards addressing water quality issues as well.

It is strongly recommended that shipping traffic and ballast water discharges continue to be monitored in the future and that this be accompanied by a contaminant monitoring programme.

12.1.7 Other development in and around the Bay

There are a range of other development that are planned (e.g. oil and gas terminals), commissioned and/or are under construction (e.g. reverse osmosis desalination plants) in and around the Bay that will add pressure on the ecological function and integrity of the system. Potential impacts from these activities need to be carefully considered and monitored especially in light of the existing pressures on the Bay which have already caused severe degradation in some areas.

12.2 Water Quality

12.2.1 Temperature, Salinity and Dissolved Oxygen

From a water quality perspective, key physico-chemical changes that have resulted from anthropogenic impacts on the Bay include modification in circulation patterns and wave exposure gradients in the Bay, leading to a reduction in water movement and exchange between the Bay and the adjacent marine environment.

There is currently no continuous monitoring of physico-chemical parameters (temperature, salinity and dissolved oxygen) taking place in Saldanha Bay whereby the data are readily accessible to the Saldanha Bay Water Quality Trust. It is strongly recommended that continuous (at least hourly) monitoring of temperature and (if possible) oxygen be implemented at a minimum of three locations in the Bay, including two stations in Small Bay (one specifically in the Yacht Club Basin), and one station in Big Bay using similar methodology and station locations to that employed by the CSIR (1999). It should be possible to download this data remotely and it should be analysed on a regular basis. Furthermore, it would be beneficial to obtain such data from both surface and bottom waters (i.e. 1 m and 10 m) to enable ongoing comparisons with historical data.

12.2.2 Chlorophyll a and Nutrients

There is currently no regular monitoring of chlorophyll a or nutrient concentrations (specifically nitrogen and ammonia) taking place in Saldanha Bay. It is strongly recommended that monthly monitoring of these parameters be implemented at a minimum of the same two stations identified for temperature, salinity and oxygen monitoring. This may require manual samples to be collected on a monthly basis and sent for laboratory analysis. Ongoing data analysis and interpretation should form a part of such monitoring programs. These data would be invaluable in calibrating existing hydrodynamic and biological production models that have been developed for the Bay.

12.2.3 Currents and waves

Long term changes in the patterns of current flow and wave energy should be quantified through a formal dedicated study to be conducted approximately every five years.

12.2.4 Trace metal concentrations in biota (DEA Mussel Watch Programme and Mariculture Operators)

The concentrations of metals in the flesh of mussels are currently monitored by the Mussel Watch Programme, which is conducted by the Department of Agriculture, Forestry, and Fisheries. Data are available for the period between 1997-2001 and 2005-2007 but not since this time apparently due to a backlog in processing of samples. The mussel samples collected from the shore are analysed for the metals cadmium (Cd), copper (Cu), lead (Pb), zinc (Zn), iron (Fe) and manganese (Mn), hydrocarbons and pesticides. No long term trends are evident in the data but it is clear that concentrations of trace metals in the mussels from some sites in the Bay are way in excess of guideline limits for foodstuffs for human consumption and are cause for considerable concern.

Data on trace metals concentrations in shellfish from the mariculture farms in the Bay were also obtained from DAFF (courtesy of the farm operators). These results show that trace metal concentrations away from the shore are much lower than those in nearshore water and mostly meet guidelines for foodstuffs for human consumption.

In the light of the fact that large qualities of shellfish are harvested and consumed by recreational and subsistence fishers from the shore of the Bay, it is imperative that this Mussel Watch Program is continued and possibly extended to cover other species as well (e.g. fish).

12.2.5 Microbiological monitoring (Faecal coliform)

Water samples are currently analysed fortnightly for faecal coliform and *E. coli* concentrations from 20 stations in Saldanha Bay and Langebaan Lagoon. Faecal coliform counts in Small Bay regularly exceed water quality guidelines for recreational and mariculture use. Despite guideline values being exceeded in Small Bay, there has been a general improvement in water quality over the last decade but these gains seems to be dropping off again now. Water quality (bacterial counts) for Big Bay fall mostly below guideline limits, however there has been a notable decline in water quality within Big Bay over time and this is of some concern. There appear to be limited bacterial contamination within Langebaan Lagoon, but levels are clearly increasing with time, and unmitigated erosion of Langebaan beach may increase the risk of sewage pollution via broken or leaking sewage holding tanks. It is imperative that management steps are taken to improve water quality within Small Bay, especially in the vicinity of the Bok River mouth (sewage outlet). The upgrading of sewage treatment and storm water facilities needs to match the rate of development in order to prevent any further degradation of water quality within the Bay. The current level of monitoring should continue as such with regular analysis and interpretation of data taking place.

The older DWAF water quality guidelines for recreational use have recently been revised following an international review of guidelines for coastal waters, which highlighted several shortcomings in those developed by South Africa. The revised guidelines (RSADEA 2011) are based on counts of intestinal *Enterococci* and *E. coli*, and require that both types of bacteria be enumerated at least every two weeks. It is highly recommended that enumeration of *Enterococci* be included in the Saldanha water sampling programme in place of faecal coliforms as several studies have shown faecal coliforms and *E.coli* to be relatively poor indicators of health risks in marine waters. These organisms are also less resilient than *Enterococci* (and other pathogenic bacteria) so if analysis is focussed on coliforms, risk can be underestimated due to mortality occurring in the time taken between collection and analysis. Guidelines state that samples should be collected 15-30 cm below the surface, on the seaward side of a recently broken wave. Samples to be tested for *E. coli* counts should be analysed within 6-8 hours of collection, and those to be tested for intestinal

Enterococci, within 24 hours. Analyses should be completed by an accredited laboratory, preferably one with ISO 17025 accreditation.

12.3 Sediments

12.3.1 Particle size, Particulate Organic Carbon and Trace metals

Sediment monitoring in the Bay has revealed that key heavy metal contaminants (Cd, Pb, Cu, and Ni) are high at a number of sites in the Bay, particularly in Small Bay, to the extent that they are almost certainly impacting on benthic fauna and possibly other faunal groups in the Bay. These contaminants are typically associated with the finer sediment fraction and are highest in the most quiescent areas of the Bay (i.e. In the Yacht basin and adjacent of the Multipurpose terminal).

Sediment monitoring (particle size, particulate organic carbon and trace metals) should continue to be conducted annually at the same suite of stations that have been monitored since 1999 along with additional stations added since this time (e.g. those in Langebaan Lagoon). Dredging in the Bay should be avoided if at all possible, and appropriate precautions need to be taken when dredging become necessary to ensure that suspended trace metals do not reach cultured organisms in the Bay.

12.3.2 Hydrocarbons

Poly-cyclic, poly-nuclear compounds and pesticides were considered to pose no threat during analysis conducted in 1999. Assessment undertaken on a small number of samples in 2010 and 2011 suggested that this was still the case, however the most recent batch of samples analysed (i.e. those collected in 2012) suggest that there has been a substantial increase in TPH levels such that the ERL threshold was exceeded at all 5 sites surveyed. It is not clear if this is a real result or reflects a change in methods used to analyse the samples. (Note that samples were analysed by CSIR Analytical Laboratories in 2011 and 2012 but reported detection levels have been reduced.) Future monitoring will hopefully confirm if there is indeed cause for concern or not and may require implementation of corrective management action.

12.4 Benthic macrofauna

A range of benthic community health indicators examined in this study over the period 1999 to 2012 has revealed that benthic health most likely deteriorated in the Bay as a whole from 1999 to 2008, recovered somewhat in the period 2009-2011, but may since have decline again (as indicated by the 2012 surveys). Localised improvements in health are however still evident at some stations (e.g. in the yacht club basin). Big Bay still remains in a much better state of health than Small Bay and has shown a much greater improvement in health since the start of the State of the Bay monitoring surveys than has the latter. Most notable is the return of the suspension feeding sea-pen *Virgularia schultzei* to Big Bay since 2004 as well as an increase in the percentage biomass of large, long lived species such as the tongue worm *Ochaetostoma capense*, and several gastropods. In order to ensure the continued improvement in the health of the Small Bay marine environment it is recommended that stringent controls are placed on the discharge of effluents into Small Bay to facilitate recovery of benthic communities in this extremely important area. The regularity (annually) and intensity of benthic macrofauna monitoring should continue at all of the current stations.

12.5 Rocky intertidal

Key changes in the rocky intertidal ecosystem reflect the regional invasion by the Mediterranean mussel *Mytilus galloprovincialis* and the North American barnacle *Balanus glandula* which compete for space on most of the rocky intertidal substrata in the bay at the expense of the native species. Their spread throughout the Bay has significantly altered natural community structure in the mid and lower intertidal, particularly in wave exposed areas.

The intertidal transects (and the quadrats along those transects) that were established in the survey initiated in 2005 should continue to be monitored annually for another year but could then be reduced in frequency to once every five years thereafter.

12.6 Fish

The current status of fish and fisheries within Saldanha Bay and Langebaan Lagoon appear to be satisfactory. Long-term monitoring by means of experimental seine-netting has revealed no statistically significant, negative trends since fish sampling began in 1986-87. If anything, abundance of key fish species at sites within or in close proximity to the Langebaan Marine Protected Area over the long term appear to be increasing which is very encouraging. Certainly, work by Kerwath *et al*. (2009) clearly demonstrated the benefits of the MPA for white stumpnose, and the protection of harders from net fishing in the MPA undoubtedly benefits this stock in the larger Bay area.

This notwithstanding, it is likely that the major changes reflected in the macrobenthos and concurrent reduction in the extent of eelgrass (*Zostera capensis*) in Langebaan lagoon since the 1970's (see Chapter 9 for more details on this) did have a dramatic impact on the ichthyofauna. These changes would have caused ecosystem wide effects that included changes in both the physical habitat (extent of eel grass, sediment structure etc.) and food sources (reductions in bivalves and polychaetes and increases in sand prawns) available to fish. This would have likely favoured some fish species and had a negative impact on others. The abundance of two species that tend to favour aquatic macrophytes habitats namely pipefish and super klipvis, does appear to have declined in Langebaan lagoon since the 1986/87 sampling. However, the major changes that probably occurred in the system would have taken place at the same time that the changes in benthos and eelgrass took place (i.e. 1970s-1980s), and as no fish sampling took place over this period, these are not reflected in the available data which only exists from the late 1980's.

Over the shorter term there are some indications that recruitment of key species such as harders, white stumpnose, gobies and silversides were lower than average in 2012. This was particularly clear in Small Bay, where the lowest harder and goby density recorded to date yet was reported. This follows the trend observed in the 2010 and 2011 reports and may be linked to high levels disturbance in this part of the Bay. This is disturbing, as Small Bay has always been disproportionately important as nursery site for the more important recreational and commercially caught fish in the Bay. The average white stumpnose density calculated from all seine net surveys to date, for example, is 0.7 fish.m^{-2} in Small Bay, compared with 0.1 fish.m^{-2} in Big Bay and 0.07 fish.m^{-2} in Langebaan lagoon. Small Bay is often viewed as the more developed or industrialised portion of the Bay and is considered by many as a 'lost cause'. These data provide a strong argument to stamp out such negative thinking and to continue lobbying strongly for enhanced protection of this portion of the Bay.

Fish sampling surveys should be conducted annually at the same sites selected during the 2005 study for as long as possible. This sampling should be confined to the same seasonal period each year for comparative purposes. Additional data on daily catch records from anglers (West Coast National Park and fishing clubs) was collected by the Department of Agriculture Forestry and Fisheries (DAFF) in the past. This initiative should be restarted and strongly supported as it will provide invaluable information that will contribute to an improved understanding of the overall health of fish populations in the Bay.

12.7 Birds

An alarming decrease in the abundance of both resident and migrant waders utilising Langebaan Lagoon is evident over the past decade and is believed to be a function of increased human utilisation of the area and possible reduction in available food. Similar declines are evident in some bird species breeding on the offshore islands in the Bay. This is believed to be a function of reductions in their food supply (largely pelagic fish e.g. pilchard) outside of the Bay and human disturbance within the Bay. Encouraging increases in numbers of African Black Oystercatchers have been observed on some of the islands in the Bay and is believed to be related to the proliferation of alien mussels on rocky shores in the area, which constitute an important food source for these birds.

Populations of key bird species are currently monitored annually on the offshore islands within the Saldanha Bay area, whilst bird populations in Langebaan Lagoon are monitored twice per annum. These bird counts are conducted as part of an ongoing monitoring programme, managed by the Avian Demography Unit of the University of Cape Town and Oceans and Coasts (Department of Environmental Affairs). Regrettably it was not been possible to obtain data on waterbirds numbers in the lagoon for 2012 even though such data were reportedly collected. It is highly recommended that the status of key species continue to be monitored in future and that these data be made available and used as an indication of environmental conditions in the area. .

12.8 Summary of environmental monitoring requirements

In summary, the environmental monitoring currently implemented in Saldanha Bay and Langebaan Lagoon (e.g. sediment, benthic macrofauna and birds) should continue with some small adjustments or additions, however, monitoring of other environmental parameters that are not currently assessed on a regular basis (e.g. temperature, oxygen, rocky intertidal and fish populations) require structured, maintained monitoring to be implemented.

Table 11.1. Tabulated summary of Environmental parameters reported on in the State of the Bay: Saldanha Bay and Langebaan Lagoon.

Parameter monitored	Time period	Anthropogenic induced impact	
Water Quality			
Physical aspects (temperature, salinity, dissolved oxygen, nutrients and chlorophyll)	1974-2000	No clear change attributable to development	
Current circulation patterns and current strengths	1977 vs. 1991	Reduced wave energy, and impaired circulation and rate of exchange in Small Bay Increased current strength alongside obstructions (e.g. ore terminal)	

Parameter monitored	Time period	Anthropogenic induced impact	
Microbiological (faecal coliform)	1999-2012	Faecal coliform counts in Small Bay frequently exceed safety levels. Big Bay and Langebaan Lagoon mostly remain within safety levels for faecal coliform pollution but coliform concentrations in these areas are increasing.	😐
Heavy metal contaminants in water	1997-2008	Concentrations of cadmium, copper, lead, zinc, iron and manganese in mussel flesh currently well below required safety levels, but this may change following any future dredging events owing to elevated metal concentration in sediments.	😐
SEDIMENTS			
Particle size (mud/sand/gravel)	1977-2012	Mud component of sediments has increased as a result of reduced water movement and dredging (negative impact), recovered somewhat in the periods 1999 to 2007, and 2008-2011 but was high in 2008 and again in the latest survey (2012). Elevated levels of mud at the near the mariculture rafts and ore terminal are of particular concern.	☹
Particulate Organic Carbon (POC)	1974-2012	Similar trends as for %mud. Elevated levels of POC at the Yacht Club basin and near the mariculture rafts (negative impacts) are of particular concern.	☹
Particulate Organic Nitrogen (PON)	1974-2010	Similar trends as for %mud and POC. Elevated levels of POC at the Yacht Club basin and near the mariculture rafts (negative impacts) are of particular concern.	☹
Trace metal contaminants in sediments	1980-2012	Cadmium, lead, copper and nickel are currently elevated considerably above historic levels. Concentrations were highest in 1999 following major dredge event. Pb, Cu, Ni elevated in 2008-2012 at Yacht Club and multipurpose terminal, which may be related to lead ore exports and maintenance dredging.	☹
BENTHIC MACROFAUNA			
Species abundance and biomass	1999-2012	Biomass increased from 1999-2004, decreased in 2008, increased again between 2008 and 2011 but decreased to lowest level ever in 2012.	☹
Species diversity	1999-2012	Steady increase in species richness between 1999 and 2011 (positive) but sharp declined again in 2012 (negative)	☹
ROCKY INTERTIDAL			
Impact of alien mussel and barnacle introductions	1980-2012	Displacement of local mussel and other native species from the lower shore leading to decreased species diversity (negative).	☹
FISH			
Community composition and abundance	1986-2012	Baseline conditions established against which to measure future changes. Causes of changes in fish communities not clearly discernable from natural variability, but some concern due to mounting anthropogenic pressures on fish stocks and the supporting environment especially in Small Bay.	😐

Parameter monitored	Time period	Anthropogenic induced impact	
BIRDS			
Population numbers of key species in Saldanha Bay and islands	1977-2012	Decreasing populations of Cape, Bank and White-breasted Cormorants are attributed to construction of causeway and increasing human disturbance. African Black Oystercatcher populations have recovered dramatically, now stabilising	☹
Population numbers of key species in Langebaan Lagoon	1976-2011	Sustained decrease in migrant and resident waders utilising Langebaan Lagoon, attributed to offsite impacts on breeding grounds and local impacts (habitat changes) and disturbance in the lagoon.	☹

13 REFERENCES

Acuna, F.H., Excoffon, & Griffiths, C.L. 2004. First record and redescription of the introduced sea anemone *Sagartia ornate* (Holdsworth 1855) (Cnidaria: Actinaria: Sargartiidae) from South Africa. African Zoology 39: 314-318.

Adams, N.J. and Navarro, R.A. 2005. Foraging of a coastal seabird: flight patterns and movements of breeding Cape gannets Morus capensis. African Journal of Marine Science, 27(1): 239-248.

Agency for Toxic Substances and Disease Registry (ATSDR). 2008. Toxicological Profile for Manganese (Draft for Public Comment). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

Anchor Environmental Consultants 2004. Saldanha Bay water quality monitoring programme: benthic macrofaunal monitoring: 2004. Prepared for: Saldanha Bay Water Quality Trust. Anchor Environmental Consultants, Cape Town, 27 pp.

Anchor Environmental Consultants 2006. State of the Bay 2006: Saldanha Bay and Langebaan Lagoon. Technical Report. Prepared for Saldanha Bay Water Quality Trust:93 pp. + Appendices.

Anchor Environmental Consultants 2008. State of the Bay 2008: Saldanha Bay and Langebaan Lagoon. Prepared for Saldanha Bay water quality monitoring programme: benthic macrofaunal monitoring: 2004. Prepared for: Saldanha Bay Water Quality Tust. Anchor Environmental Consultants, Cape Town, 174pp.

Anchor Environmental Consultants 2009. State of the Bay 2008: Saldanha Bay and Langebaan Lagoon. Prepared for Saldanha Bay water quality monitoring programme: Anchor Environmental Consultants, Cape Town, 174pp.

Anchor Environmental Consultants 2010. State of the Bay 2009: Saldanha Bay and Langebaan Lagoon. Prepared for Saldanha Bay water quality monitoring programme. Anchor Environmental Consultants, Cape Town, 213pp

Anchor Environmental Consultants 2011. State of the Bay 2010: Saldanha Bay and Langebaan Lagoon. Prepared for Saldanha Bay water quality monitoring programme. Anchor Environmental Consultants, Cape Town, 280pp

Anchor Environmental Consultants 2012. Re-commissioning of a Fishmeal Processing Plant, Saldanha Bay Marine Specialist Report. Prepared for SRK Consulting (South Africa) (Pty) Ltd.

Anderson M.J., Gorley R.N., Clarke K.R. 2008. PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods. PRIMER-E: Plymouth, UK, pp. pp. 214

Angel, A., Branch, G.M, Wanless, R.M. and Siebert T. 2006. Causes of rarity and range restriction of an endangered, endemic limpet, Siphonaria compressa. Journal of Experimental Marine Biology and Ecology 330: 245–260

AquaEco 2012. Final Scoping Report - Offshore salmon farming in Saldanha Bay. Report prepared for Southern Cross Salmon Farming (Pty) Ltd.

Archambault P., Bourget E. 1996. Scales of coastal heterogeneity and benthic intertidal species richness, diversity and abundance. *Mar Ecol Prog Ser* 136:111-121

Attwood, C.G., Naesje, T.F., Fairhurst, L. and S.E. Kerwath 2010 Life History parameters of white stumpnose *Rhabdosargus globiceps* (Pisces: Sparidae) in Saldanha Bay, South Africa, with evidence for stock separation. African Journal of Marine Science 32: 23-36.

Awad, A.A., Clarke, C., Greyling, L., Hillard, R., Polglaze, J. and Raaymakers, S. 2003. Ballast water risk assessment, Port of Saldanha Bay, Republic of South Africa, Final Report November 2003. Global Ballast Water Management Programme. Globallast Monograph Series 13. 64 pp.

Axelson, E. 1977. A summary of the history of human settlement at Saldanha Bay. Transactions of the Royal Society of South Africa 42: 215-221.

Baldwin, J. R. and Lovvorn, J. R. 1994. Expansion of seagrass habitat by the exotic Zostera japonica, and its use by dabbling ducks and brant in Boundary Bay, British Columbia. Marine Ecology Progress Series 103: 119-127

Bay, S., Jones, B.H., Schiff, K. and Washburn, L. 2003. Water quality impacts of storm water discharges to Santa Monica Bay. Marine Environmental Research 56 (1-2): 205-223.

BCLME. 2006. The development of a common set of water and sediment quality guidelines for the coastal zone of BCLME, South Africa. CSIR/NRE/ECO/2006/0011/C. CSIR. CSIR Report.

Beckley, L. E. 1981. Marine benthos near the Saldanha Bay iron-ore loading terminal. South African Journal of Zoology 16(4): 269-271.

Bickerton, I. B. 1999. Saldanha Bay Water Quality Programme: Benthic Macrofaunal Monitoring. CSIR, Cape Town, 18 pp.

Bird E. C. F. 1985. Coastline changes: a global review. Wiley and Sons, Chichester, UK.

Birdlife International 2004. Threatened Birds of the World 2004. CD Rom version. BirdLife international, Cambridge, UK.

BirdLife International 2011. IUCN Red List for birds. Downloaded from http://www.birdlife.org

Birdlife International. 2010. URL www.birdlife.org/datazone/species.

Blamey L.K., Branch G.M. 2009. Habitat diversity relative to wave action on rocky shores: implications for the selection of marine protected areas. Aquatic Conserv: Mar Freshw Ecosyst 19:645-657

Bonvicini Pagliai, A.M., Cognetti Varriale, A.M., Crema, R., Curini Galletti, M. and Vandini Zunarelli, R. 1985. Environmental impact of extensive dredging in a coastal marine area. Marine Pollution Bulletin 16 (12): 483-488.

Booth, D.B. and Jackson, C.R. 1997. Urbanization of aquatic systems: degradation thresholds, storm water detection, and the limits of mitigation. Journal of the American Water Resources Association 33 (5): 1077 – 1090.

Boruvka L., Vaceck O., and Jehlicha, J. 2005. Principal component analysis as a tool to indicate the origin of potentially toxic elements in soils. Geoderma 128: 289-300.

Bosman A.L., Du Toit J.T., Hockey P.A.R., Branch G.M. 1986. A field experiment demonstrating the influence of seabird guano on intertidal primary production. Estuarine, Coastal and Shelf Science, Volume 23, Issue 3, September 1986, Pages 283-294.

Bosman A.L., Hockey P.A.R. 1986. Seabird guano as a determinant of rocky intertidal community structure. Mar Ecol Prog Ser 32:247-257.

Bosman A.L., Hockey P.A.R. 1988. The influence of seabird guano on the biological structure of rocky intertidal communities on islands off the west coast of southern Africa. South African Journal of Marine Science Vol. 7, pp. 61-68.

Boucher C. and Jarman M.L. 1977. The vegetation of the Langebaan area, South Africa. Transaction of the royal Society of South Africa 42: 241 - 272.

Branch G.M, Odendaal F. & T.B. Robinson 2008. Long-term monitoring of the arrival, expansion and effects of the alien mussel Mytilus galloprovincialis relative to wave action. Mar Ecol Prog Ser 370:171-183

Branch G.M. & C.N. Steffani 2004. Can we predict the effects of alien species? A case-history of the invasion of South Africa by Mytilus galloprovincialis (Lamarck). Journal of Experimental Marine Biology and Ecology 300:189-215.

Branch G.M., Griffiths C.L., Branch M.L. & L.E. Beckley 2010. Two Oceans, David Philip Publishers, Cape Town, South Africa.

Branch G.M., Odendaal F., Robinson T.B. 2008 Long-term monitoring of the arrival, expansion and effects of the alien mussel *Mytilus galloprovincialis* relative to wave action. Mar Ecol Prog Ser 370:171-183

Branch G.M., Odendaal F. & T.B. Robinson 2010. Competition and facilitation between the alien mussel Mytilus galloprovincialis and indigenous species: Moderation by wave action. Journal of Experimental Marine Biology and Ecology 383:65-78

Branch G.M., Steffani C.N. 2004. Can we predict the effects of alien species? A case-history of the invasion of South Africa by *Mytilus galloprovincialis* (Lamarck). Journal of Experimental Marine Biology and Ecology 300:189-215.

Branch, G. M., & M.Branch. 1981. The Living Shores of Southern Africa. C. Struik, Cape Town.

Bruun, P. 1962. *Sea level Rise as a Cause of Shore Erosion* Journal of Waterways and Harbors Division, 117-130.

Buchman M.F. 1999. NOAA screening quick reference tables. 99-1, 1-12. Seattle WA, Coastal Protection and Restoration Division, National Oceanic and Atmospheric Administration. NOAA HAZMAT Report.

Bustamante R.H., Branch G.M. 1996. Large scale patterns and trophic structure of southern African rocky shores: the roles of geographic variation and wave exposure. Journal of Biogeography. 23:339-351.

Bustamante R.H., Branch G.M., Eekhout S. 1997. The influences of physical factors on the distribution and zonation patterns of South African rocky-shore communities. South African Journal of marine Science. 18:119-136.

Bustamante R.H., Branch G.M., Eekhout S., Robertson B., Zoutendyk P., Schleyer M., Dye A., Hanekom N., Keats D., Jurd M. & C.McQuaid 1995. Gradients of intertidal primary productivity around the coast of South Africa and their relationships with consumer biomass. Oecologia 102:189-201

C.E.F. 2008. Central Energy Fund –Newsroom: A state of the art oil spill protection, Tuesday, 22 April 2008. www.cef.org.za - Accessed 10 April 2009

Carlton J.T. & Cohen A.N. 2003. Episodic global dispersal in shallow water marine organisms: the case history of the European shore crabs *Carcinus maenas* and *Carcinus aestuarii*. *J. Biogeog.* 30: 1809-1820.

Carlton J.T. 1996. Pattern, process, and prediction in marine invasion ecology. Biological Conservation 78: 97– 106.

Carlton J.T. 1999. The scale and ecological consequences of biological invasions in the world's oceans. In: Sandlund, O.T., et al., (Ed.), Invasive Species and Biodiversity Management. Kluwer Academic Publishing, Netherlands, pp. 195– 212.

Carlton, J.T. & J.B Geller. 1993. Ecological roulette: the global transport and invasion of non indigenous marine organisms. Science 261: 78–82.

Carlton, J.T. 1992. Marine species introductions by ships' ballast water: an overview. In: DeVoe R (Ed) Introduction and Transfers of Marine Species. Williams College, Connecticut, 23–25 pp.

Carlton, J.T., Vermeij, G.J., Lindberg, D.R., Carlton, D.A. & E.C. Dudley 1991. The first historical extinction of a marine invertebrate in an ocean basin: the demise of the eelgrass limpet Lottia alveus. Biological Bulletin 180: 72–80.

Carr, G.M. & C.J. Rickwood 2008. Water Quality Index for Biodiversity Technical Development Document. Report prepared for Biodiversity Indicators Partnership, World Conservation Monitoring Center, 219 Huntingdon Road, Cambridge CB3 0DL, United Kingdom. 64 p.

Carter, R.A. 1996. Environmental impact assessment SSF Saldanha: the potential ecological impacts of ballast water discharge by oil tankers in the Saldanha Bay Langebaan lagoon System. CSIR report EMAS-C 96005D, Stellenbosch.

Ceccherelli, V.U. & Rossi, R. 1984. Settlement, growth and production of the mussel Mytilus galloprovincialis. *Mar Ecol Prog Ser* 16:173–184.

Cempel, M. and G. Nikel. 2006. Nickel: A Review of Its Sources and Environmental Toxicology. *Polish J. of Environ. Stud*. Vol. 15, No. 3, 375-382

Christie, N.D. and Moldan, A. 1977. Affects of fish factory effluent on the benthic macrofauna of Saldanha Bay. Marine Pollution Bulletin 8: 41-45.

Clark, B. M. 1997. Variation in surf-zone fish community structure across a wave-exposure gradient. Estuarine and Coastal Shelf Science 44(6): 659-674.

Clark, R.B. 1986. Marine Pollution. Claredon Press, Oxford, 215pp.

Clarke K.R., Gorley R.N. 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E: Plymouth, Plymouth

Clarke, K.R. & Warwick, R.M. 1994. Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. National Environmental Research Council, UK, 144pp.

Clarke KR, & Warwick RM 2001. Change in marine communities: an approach to statistical analysis and interpretation, 2nd Edition, Vol. PRIMER-E Ltd, Plymouth

Cockcroft A.C., van Zyl D. and Hutchings, L. 2008. Large-scale changes in the spatial distribution of South African West Coast rock lobsters: an overview. African Journal of Marine Science 30:149 — 159

Coetzee, M. 2007. Proposed Construction of Erosion Protection Measures on Paradise Beach, Langebaan, Environmental Impact Assessment. Common Ground URL: www.commonground.co.za.

Colan, K.E. 1990. Revision of the crustacean amphpod genus Jass Leach (Coroohioidea: Ischyroceridae). Canadian Journal of Zoology 68: 2031-2075.

Common Ground Consulting 2013a. Environmental Repair, Rehabilitation, Maintenance and Management Plan for Shoreline and Beach Areas Associated with the Langebaan Beach Groynes and Rock Revetment. Prepared for Saldanha Bay Municipality. 18 pp.

Common Ground Consulting 2013b. Environmental Repair, Rehabilitation, Maintenance and Management Plan for Shoreline and Beach Areas Adjacent to the Leentjiesklip Caravan Park, Alabama Street Slipway and the Melck Street Steps at Langebaan. Prepared for Saldanha Bay Municipality. 24 pp.

Compton, J. S. 2004. The rocks and mountains of Cape Town. Double Storey Books, Cape Town, South Africa.

Cooper, J. A. G. and Pilkey, O.H. 2004. Sea-level rise and shoreline retreat: time to abandon the Bruun Rule. Global and Planetary Change. Vol. 43, pp. 157-171.

Crawford R.J.M. 2009. A recent increase of swift terns Thalasseus bergii off South Africa – The possible influence of an altered abundance and distribution of prey. Progress in Oceanography 83:398–403

Crawford R.J.M., Cockcroft A.C., Dyer B.M. and Upfold L. 2008. Divergent trends in bank cormorants Phalacrocorax neglectus breeding in South Africa's Western Cape consistent with a distributional shift of rock lobsters Jasus lalandii. African Journal of Marine Science 30: 161–166

Crawford R.J.M., Dyer B.M. & R.K. Brooke 1994. Breeding nomadism in southern African seabirds – constraints, causes and conservation. Ostrich 65: 231–246.

Crawford R.J.M., Sabarros P.S, Fairweather T., Underhill L.G. & A.C. Wolfaardt 2008. Implications for seabirds off South Africa of a long-term change in the distribution of sardine. African Journal of Marine Science 30: 177–184

Crawford R.J.M., Underhill L.G., Coetzee J.C., Fairweather T., Shannon L.J. & A.C. Wolfaardt 2008. Influences of the abundance and distribution of prey on African penguins Spheniscus demersus off western South Africa. African Journal of Marine Science 30: 167–175

Crawford, R. J. M. & L. G. Underhill 2003. Aspects of breeding, molt, measurements and population trend of Hartlaub's gull Larus hartlaubii in Western Cape, South Africa. Waterbirds, 26: 139e149.

Crawford, R.J.M. 2007. Trends in the numbers of three cormorants Phalacrocorax spp. breeding in South Africa's Western Cape Province. In: Kirkman, S.P. (ed.) Final Report of the BCLME (Benguela Current Large Marine Ecosystem). Project on Top Predators as Biological Indicators of Ecosystem Change in the BCLME:173-178. Avian Demography Unit, Cape Town.

Crawford, R.J.M., Barham, P.J., Underhill, L.G., Shannon, L.J., Coetzee, J.C, Dyer, B.M., Mario Leshoro, T. and Upfold, L. 2006. The influence of food availability on breeding success of African penguins Spheniscus demersus at Robben Island, South Africa. Biological Conservation 132:119-125.

Crawford, R.J.M., Dundee, B.L., Dyer, B.M., Klages, N.T., Meyer, M.A., and Upfold, L. 2007. Trends in numbers of Cape gannets (Morus capensis), 1956/57–2005/06, with a consideration of the influence of food and other factors. ICES Journal of Marine Science 64: 169–177.

Crawford, R.J.M., Dyer, B.M. & L. Upfold 2000. Age at first breeding and change in plumage of Kelp gulls Larus dominicanus in South Africa. South African Journal of Marine Science 22: 27-32.

Crawford, R.J.M., Dyer, B.M., Kemper, J., Simmons, R.E. & L. Upfold 2007. Trends in numbers of Cape Cormorants (Phalacrocorax capensis) over a 50 year period, 1956-57 to 2006-07. Emu 107:253-261

Crawford, R.J.M., Nel, D.C., Williams, A.J. & A.Scott 1997. Seasonal patterns of abundance of Kelp Gulls Larus dominicanus at breeding and non-breeding localities in southern Africa. Ostrich 68: 37-41.

Cruz-Motta J.J., Underwood A.J., Chapman M.G. & F. Rossi 2003 Benthic assemblages in sediments associated with intertidal boulder-fields. Journal of Experimental Marine Biology and Ecology 285-286:383-401

CSIR 2012. Draft Scoping Report for the Proposed Construction, Operation and Decommissioning of a Seawater Reverse Osmosis Plant and Associated Infrastructure in the Saldanha Bay Region, Western Cape.

CSIR. 1999. The biogeochemical status of surface sediments in Saldanha Bay in 1999. CSIR Report ENV-S-C 99093A. 38 pp.

CSIR. 1999. Saldanha Bay Water Quality Monitoring Programme: Benthic macrofaunal monitoring 1999. CSIR Report ENV-S-C 99104. 18 pp.

CSIR. 2001. Saldanha Bay Sediment Monitoring Programme 1999 – 2001. CSIR report ENV-S-C 2001-116. 21 pp.

CSIR. 2002. Saldanha Bay marine water quality management plan. Phase I: Situation Assessment. Report to the Saldanha Bay Water Quality Forum Trust. CSIR Report ENV-S-C, Stellenbosch.

CSIR. 2004. The biogeochemical status of surface sediments in Saldanha Bay and Langebaan Lagoon 2004. CSIR Report ENV-S-C 2004080. 41 pp.

CSIR. 2012. Final Environmental Impacts Assessment Report for the Proposed Construction, Operation and Decommissioning of a Seawater Reverse Osmosis Plant and Associated Infrastructure in the Saldanha Bay Region, Western Cape.

Cubit J.D. 1984. Herbivory and the seasonal abundance of algae on a high intertidal rocky shore. Ecology 66:1904-1917

DAFF 2012. Department of Agriculture, Forestry and Fisheries Aquaculture Annual Report 2011 South Africa. ISBN: 973-1-868-71-355-4.

Davidson I.C., Crook A.C. & D.K.A. Barnes 2004. Quantifying spatial patterns of intertidal biodiversity: is movement important? Marine Ecology 25:15-34

Day J.H. 1959. The biology of Langebaan Lagoon: a study of the effect of shelter from wave action. Trans R Soc S Afr 35:475-547

Day, J.H. 1969. A guide to marine life on the South African shores. A.A. Balkema, Cape Town. Vol1-289pp.

Day, J.H. 1974. *A guide to the marine life on South African shores*. Cape Town: A.A. Balkema.

Denny M. & Gaylord B. 2002. The mechanics of wave-swept algae. The Journal of Experimental Biology 205:1355-1362

Denny MW & S.Gaines 2007. Encyclopedia of Tidepools and Rocky Shores. University of California Press, pp. 705

Department of Agriculture Forestry and Fisheries. 2011. South Africa's Aquaculture Annual Report 2011.

Department of Water Affairs & Forestry (DWAF). 1991. Water quality management policies and strategies in the RSA. Pretoria. 32 pp.

Department of Water Affairs & Forestry (DWAF). 1995a. South African water quality guidelines for coastal marine waters. Volume 1. Natural Environment. Pretoria.

Department of Water Affairs & Forestry (DWAF). 1995b. South African water quality guidelines for coastal marine waters. Volume 2. Recreation. Pretoria.

Department of Water Affairs & Forestry (DWAF). 1995c. South African water quality guidelines for coastal marine waters. Volume 3. Industrial use. Pretoria.

Department of Water Affairs & Forestry (DWAF). 1995d. South African water quality guidelines for coastal marine waters. Volume 4. Mariculture. Pretoria.

Desideri D., Meli, M.A., Roselli C. and L. Feduzi, A biomonitoring study: 210Po and heavy metals in mussels. J Radioanal Nucl Chem 2009; 279: 591-600.

Dias M.P. 2009. Use of salt ponds by wintering shorebirds throughout the tidal cycle. Waterbirds 32: 531–537.

Dias M.P., Granadeiro J.P., Lecog M., Santos C.D., Palmeirim J.M. 2006. Distance to high-tide roosts constrains the use of foraging areas by dunlins: implications for the management of estuarine wetlands. Biological Conservation 131: 446–452.

Du Toit, M. 2004. Avian Demography Unit, Dept of Statistical Sciences, University of Cape Town. http://web.uct.ac.za/depts/stats/adu/species/bankcormorant.htm ; http://web.uct.ac.za/depts/stats/adu/species/capecormorant.htm ; http://web.uct.ac.za/depts/stats/adu/species/crcormorant.htm and http://web.uct.ac.za/depts/stats/adu/species/wbcormorant.htm

Dyer K. R. 1986. Coastal and Estuarine Sediment Dynamics. Wiley and Sons, Chichester, UK.

Eckman J.E. 1990. A model of passive settlement by planktonic larvae onto bottoms of differing roughness. Limnology and Oceanography 35:887-901

Engledow H.R., Bolton J.J. 1994. Seaweed a-diversity within the lower eulittoral zone in Namibia: the effects of wave action, sand inundation, mussels and limpets. Botanica Marina 37:267-276.

EPA. 2003. After the storm. US Environmental Protection Agency. EPA 833-B-03-002. http://epa.gov/weatherchannel/storm water.html.

Erftemeijer, P.L.A and Lewis R.R. R. 2006. Environmental impacts of dredging on seagrasses: A review. Marine Pollution Bulletin, 52: 1553-1572.

ERM 2008. Environmental Impact Assessment (Basic Assessment) Process: Background Information Document. Proposed dredging (caissons 3 and 4) on the Saldanha side of the iron ore handling facility and scour hole protection works, Port of Saldanha. Environmental Resources Management, April 2008. ERM Ref: 0080265, DEAT Ref: 12/12/20/1143.

ERM 2008. Saldanha phase 2 screening study: Port zoning and operational opportunities and constraints. report no. 1026/01/01 rev. 04.

ERM. 2010. Saldanha LPG Facility: Environmental Impact Assessment November 2010. Presentation to the Saldanha Bay Water Quality Forum Trust, November 2010.

Flemming, B. W. 1977. Distribution of recent sediments in Saldanha Bay and Langebaan Lagoon. Transactions of the Royal Society of South Africa 42 (3&4): 317-340.

Florence, W.K., Hayward, P.J. & Gibbons, M.J. 2007. Taxonomy of shallow0water Bryozoa from the west coast of South Africa. *African Natural History* 3: 1-58.

Fuggle. R. F. 1977. A review of a symposium on research in the natural sciences at Saldanha Bay and Langebaan Lagoon. Transactions of the Royal Society of South Africa 42 (3&4):211-214.

Galil B.S., Occhipinti-Ambrogi A., Gollasch S. 2008. Biodiversity impacts of species introductions via marine vessels. In: Abdulla A, Linden O (eds) Maritime traffic effects on biodiversity in the Mediterranean Sea Volume 1 - Review of impacts, priority areas and mitigation measures, Malaga, Spain: IUCN Centre for Mediterranean Cooperation, Chapter 4: 117-158

Game, E.T., Grantham, H.S., Hobday, A.J., Pressey, R.L., Lombard, A.T., Beckley, L.E., Gjerde, K., Bustamante, R., Possingham, H.P., Richardson, A.J., 2009. Pelagic protected areas: the missing dimension in ocean conservation. Trends in Ecology & Evolution 24, 360-369

Ganter B. 2000. Seagrass (Zostera spp.) as food for brent geese (Branta bernicla): an overview. Helgol Marine Research 54: 63–70

Gericke, J. 2008. Analysis of Four Decades of Changes to Sedimentary Features by means of Historical Aerial Photographs: Langebaan Lagoon and Saldanha Bay. Unpbl. Honours Thesis University of Cape Town. Department of Environmental and Geographical Science

Gibbons, M.J. 1999.The taxonomic richness of South Africa's marine fauna: a crisis at hand. South African Journal of Science 96:8–12

Gibbs R.J. 1994. Metals in sediments along the Hudson River Estuary. Environmental International 20, 507-516.

Gibson, R., B. Hextall & A. Rogers 2001. *Photographic guide to the sea and shore life of Britain and north-west Europe*. New York: Oxford University

Gollasch, S., Macdonald, E., Belson, S., Botnen, H., Christensen, J. T., Hamer, J.P., Houvenaghel, G., Jelmert, A., Lucas, I., Masson, D., Mccollin, T., Olenin, S., Persson, A., Wallentinus, I., Wetsteyn, L.P.M.J., and Wittling, T. 2002. Life in Ballast tanks In: Invasive Aquatic Species of Europe: Distribution, Impacts and Management. LEPPÄKOSKI, ERKKI; GOLLASCH, STEPHAN; OLENIN, SERGEJ (Eds.), Academic Publishers, Netherlands. 217-231 pp.

Goss-Custard J.D. and Yates M.G. 1992. Towards predicting the effect of saltmarsh reclamation on feeding bird numbers on the Wash. Journal of Applied Ecology 29: 330-340.

Grall, J. and Glemarec, M. 1997. Using biotic indices to estimate macrobenthic community perturbations in the Bay of Brest. Estuarine, Coastal and Shelf Science 44: 43-53.

Grant, W. S. & Cherry, M. I. 1985. Mytilus galloprovincialis Lmk in southern Africa. J. Exp. Mar. Biol. Ecol. 90 (2): 179-162.

Grant, W. S., Cherry, M. I. & A. T. Lombard 1984. A cryptic species of Mytilus (Mollusca: Bivalvia) on the west coast of South Africa. *S. Afr. J. mar. Sci*. 2: 149–162.

Griffin, N.J., Bolton, J.J. and Anderson, R.J. 1999. Distribution and population dynamics of Porphyra (Bangailes, Rhodophyta) in the southern Western Cape, South Africa. Journal of Applied Phycology 11: 429-436.

Griffiths C., Robinson T., Mead A. 2011. The alien and cryptogenic marine Crustaceans of South Africa. In: Galil BS, Clark PF, Carlton JT (eds) In the Wrong Place - Alien Marine Crustaceans: Distribution, Biology and Impacts Invading Nature - Springer Series in Invasion Ecology 6. Springer Science+Business Media B.V. 2011

Griffiths C.L., Robinson T.B., and Mead A. 2009. The status and distribution of marine alien species in South Africa. Biological Invasions in Marine Ecosystems. Ecological Studies 204:393-408

Griffiths, C. L., Hockey, P.A.R., Van Erkom Schurink, C. and Roux. P. J. L. 1992. Marine invasive aliens on South African shores: implications for community structure and trophic functioning. South African Journal of Marine Science 12:713-722.

Griffiths, C.L. 1999. Crustacean systematics in South Africa: status and historical overview. Transcripts from the Royal Society of South Africa 54:43–52.

Griffiths, C.L., Robinson, T.B. and Mead, A. 2008. The status and distribution of marine alien species in South Africa. In: Rilov, G. & Crooks, J. Marine Bioinvasions: Ecology, Conservation and Management Perspectives. Springer, Heidelberg. 204: 393-408.

Griffiths C.L., Robinson T.B., Mead A. 2009. The status and distribution of marine alien species in South Africa. Biological Invasions in Marine Ecosystems. Ecological Studies 204:393-408

Griffiths, C.L., van Sittert, L., Best, P.B., Brown, A.C., Clark, B.M., Cook, P.A., Crawford, R.J.M., David, J.H.M., Davies, B.R., Griffiths, M.H., Hutchings, K., Jerardino, A., Kruger, N., Lamberth, S., Leslie, R.W., Melville-Smith, R., Tarr, R. and Van Der Lingen, C.D. 2004. Impacts of human activities on marine animal life in the Benguela: A historical overview. Oceanography and Marine Biology, an Annual Review 42: 303-392.

Grindley J.R. 1977. The zooplankton of Langebaan Lagoon and Saldanha Bay. Trans R Soc S Afr 42:341-369

Guarnieri G., Terlizzi A., Bevilacqua S., Fraschetti S. 2009. Local vs regional effects of substratum on early colonization stages of sessile assemblages, Biofouling: The Journal of Bioadhesion and Biofilm Research 25:593-604

Guerra-Garcia, J.M. and Garcia-Gomez, C.J. 2004. Polychaete assemblages and sediment pollution in a harbour with two opposing entrances. Helgol Marine Research 58: 183-191.

Guichard F., Bourget E. 1998. Topographic heterogeneity, hydrodynamics, and benthic community structure: a scale-dependent cascade. Marine Ecology Progress Series 171:59-70.

Hammond, W. and Griffiths, C. L. 2004. Influence of wave exposure on South African mussel beds and their associated infaunal communities. Marine Biology 144:547-552.

Hanekom, N. and Nel, P. 2002. Invasion of sandflats in Langebaan Lagoon, South Africa, by the alien mussel Mytilus galloprovincialis: size, composition and decline of the populations. African Zoology 37:197–208

Heck KL, Hays C and Orth RJ. 2003. A critical evaluation of the nursery role hypothesis for seagrass meadows. Marine Ecology Progress Series 253: 123-136.

Hellawell, J.M. 1986. Biological indicators of freshwater pollution and environmental management. Elsevier Applied Science Publishers, London.

Herbert R.J.H., Hawkins S.J. 2006. Effect of rock type on the recruitment and early mortality of the barnacle Chthamalus montagui. Journal of Experimental Marine Biology and Ecology 334:96-108

Hewitt C.L., Gollasch S. and Minchin D. 2009. The vessel as a vector – biofouling ballast water and sediments. In: biological Invasions in Marine Ecosystems,(eds) Rilov G. and Crooks J.A. pp. 117–131. Springer-Verlag, Berlin.

Hir M.L., Hily C. 2005. Macrofaunal diversity and habitat structure in intertidal boulder fields. Biodiversity and Conservation 14:233-250

Hockey P.A.R., Dean W.R.J. and Ryan P.G., (Eds.) 2005. Roberts Birds of Southern Africa, 7th ed. Trustees of the John Voelcker Bird Book Fund, Cape Town. 1,296 pp.

Hockey, P.A.R. & Van Erkom Schurink, C. 1992. The invasive biology of the mussel Mytilus galloprovincialis on the southern African coast. Transactions of the Royal Society of South Africa 48:123-139.

Hockey, P.A.R. 1983. Aspects of the breeding biology of the African Black Oystercatcher. Ostrich 54: 26-35.

Hughes J.E., Deegan L.A., Wyda J.C., Weaver M.J. and Wright A. 2002. The effect of eelgrass habitat loss on estuarine fish communities of Southern New England. Estuaries 25: 235-249.

Hughes, R.N. 1979. South African populations of Littorina rudis. *Zoological Journal of the Linnean Society* 65: 119–126.

Hutchings, K. and Lamberth, S. J. 2002b. Catch and effort estimates for the gillnet and beach-seine fisheries in the Western Cape, South Africa. South African Journal of Marine Science 24: 205-225

Hutchings, K. and Lamberth, S. J. 2002a. Bycatch in the gillnet and beach-seine fisheries in the Western Cape, South Africa, with implications for management. South African Journal of Marine Science 24: 227-241

Hutchings, K, Porter, S., Clark, B.M & Sink, K. 2011. Strategic Environmental Assessment: Identification of potential marine aquaculture development zones for fin fish cage culture. Report prepared for Directorate Sustainable Aquaculture Management: Aquaculture Animal Health and Environmental Interactions Department of Agriculture, Forestry and Fisheries.

Integrated Development Plan. 2006 – 2011. Saldanha Bay Municipality. http://www.saldanhabay.co.za/

International Wader Study Group, 2003. Waders are declining worldwide. Wader Study Group Bulletin 101 (102): 8–12.

IUCN 2009. Marine Menace. Alien invasive species in the marine environment. http://wwwvlizbe/imisdocs/publications/153100pdf

Jackson, L.F. and McGibbon, S. 1991. Human activities and factors affecting the distribution of macrobenthic fauna in Saldanha Bay. South African Journal of Aquatic Science 17 (1/2): 89-102.

Jarman, M.L. (Ed) 1986. Conservation priorities in lowland regions of the fynbos biome. South African national scientific Programme Report No 87. CSIR, Pretoria: 55 pp.

Kalejta B. 1993. Diets of shorebirds at Berg River estuary, South Africa: spatial and temporal variation. Ostrich 64: 123-133.

Kemper J., Underhill L.G., Crawford R.J.M. and Kirkman S.P. 2007. Revision of the conservation status of seabirds and seals breeding in the Benguela Ecosystem. In Kirkman S.P. (ed.). Final Report of the BCLME (Benguela Current Large Marine Ecosystem) pp. 325-342

Kensley, B. & Penrith, M-L. 1970. New recordof Mytilidae from the Northern South West African coast. *Annals of the South African Museum* 57 (2): 15-24.

Kerwath Se. Thorstad EB.., Næsje T.F., Attwood C.G., Cowley P.D., Økland F & C Wilke 2009. Crossing Invisible Boundaries: The Effectiveness Of The Langebaan Lagoon Marine Protected Area As A Harvest Refuge For A Migratory Fish Species In South Africa. Conservation Biology 23 (3): 653-661.

Kerwath, S.E., Thorstad, E.B., Naesje, T.F., Attwood, C.G., Wilke, C., Okland, F. and Cowley, P. D. 2008. Can a Marine Protected Area protect mobile fish? A South African case study. Oral presentation at the South African Marine Science Symposium29-June-3rd July 2008, University of Cape Town, Cape Town.

Kljaković-Gašpić, Z., N. Odžak, I. Ujević, T. Zvonarić and A. Barić. 2006. Biomonitoring of trace metals (Cu, Cd, Cr, Hg, Pb, Zn) in the eastern Adriatic using the Mediterranean blue mussel (2002-2005). Fresenius Environ. Bull., 15 (9a): 1041-1048.

Knowles, R. 1982. Denitrification. *Microbiological Reviews* 46 (1), 43-70

Kostylev V.E., Erlandsson J., Ming M.Y., Williams G.A. 2005. The relative importance of habitat complexity and surface area in assessing biodiversity: Fractal application on rocky shores. Ecological Complexity 2:272-286.

Kruger, N. 2002. Long term changes in the benthic macrofauna of Saldanha Bay. MSc Thesis. University of Cape Town. 1-96pp.

Kruger, N., Branch, G.M., Griffiths, C.L. & Field, J.G. 2005. Changes in the epibenthos of Saldanha Bay, South Africa, between the 1960s and 2001: an analysis based on dredge samples. African Journal of Marine Science 27 (2): 471-477.

Laird, M. C. and Griffiths, C. L., 2008. Present distribution and abundance of the introduced barnacle *Balanus glandula* Darwin in South Africa. *Afr. J. Mar. Sci*., 30: 93-100.

Laugksch, R.C. and Adams, N.J. 1993. Trends in pelagic fish populations of the Saldanha Bay region, Southern Benguela upwelling system, 1980-1990: A predator's perspective. South African Journal of Marine Science 13: 295-307.

Le Roux, J. 2002. Avian Demography Unit, Dept of Statistical Sciences, University of Cape Town. http://web.uct.ac.za/depts/stats/adu/species/sp324_00.htm

Lewis S., Grémillet D., Daunt F., Ryan P.G., Crawford R.J.M. and Wanless S. 2006. Using behavioural variables to identify proximate causes of population change in a seabird. Oecologia 147:606–614

Lewis, J. R. 1964. The Ecology of Rocky Shores. English Universities Press, London

Londoño-Cruz E, Tokeshi M. 2007. Testing scale variance in species-area and abundance-area relationships in a local assemblage: an example from a subtropical boulder shore. Popul Ecol 49:275-285

Long E.R., MacDonald D.D., Smith S.L. and Calder F.D. 1995. Incidence of adverse biological effects within ranges of concentrations in marine and estuarine sediments. Environmental Management 19: 81-97.

Lowenthal D., Hockey P.A.R. and Haupt P. (in prep). African Black Oystercatcher Haematopus moquini 25 years on: Causes of population recovery.

Ludynia K., Roux J-P, Jones R., Kemper J. and Underhill L.G. 2010. Surviving off junk: low-energy prey dominates the diet of African penguins Spheniscus demersus at Mercury Island, Namibia, between 1996 and 2009. African Journal of Marine Science 32: 563–572

Luger, S., Van Ballegooyen, R. and Monteiro. 1999 . A Modelling-driven environmental baseline assessment for the proposed New Hood Point outfall in East London: Hydrodynamic and water quality modelling study. CSIR Report ENV-S-C 99109B. CSIR Environmentek, Stellenbosch, South Africa.

Lwandle Technologies (Pty) Ltd. 2012. Proposed LPG bulk importation into Saldanha Bay, Western Cape, South Africa: Marine Ecology Assessment. Unpublished report prepared for ERM (PTY) LTD.

Makhado A.B., Crawford R.J.M. and Underhill L.G. 2006. Impact of predation by Cape fur seals Arctocephalus pusillus pusillus on Cape Gannets Morus capensis at Malgas Island, Western Cape, South Africa. African Journal of Marine Science 28: 681–687

Makhado, A.B., Meÿer, M.A., Crawford, R.J.M., Underhill, L.G., Wilke, C., 2009. The efficacy of culling seals seen preying on seabirds as a means of reducing seabird mortality. African Journal of Ecology 47: 335-340

Maneveldt GW, Eager RC, Bassier A. 2009. Effects of long-term exclusion of the limpet Cymbula oculus (Born) on the distribution of intertidal organisms on a rocky shore. African Journal of Marine Science 31:171-179

Mann, B. Q. 2000. Southern African Marine Linefish Status Reports. Special Publication. Oceanographic Research Institute 7: 257 pp.

Marangoni, C. 1998. The potential for the introduction of alien phytoplankton by shipping ballast water: observations in Saldanha Bay. MSc thesis for the Faculty of Science, University of the Witwatersrand, Johanesburg 1998. Volume 1 – Text.

Mark W. Denny, Steven Dean Gaines (2007) Encyclopedia of tidepools and rocky shores. University of California Press, pp. 705

Mather, A. A., Stretch, D. D., & Garland, G. 2010. A simple empirical model for extreme wave run-up on natural beaches. International conference on Coastal Engineering, Shanghai. China.

McClintock JB, Angus RA, McClintock FE (2007) Abundance, diversity and fidelity of macroinvertebrates sheltering beneath rocks during tidal emersion in an intertidal cobble field: Does the intermediate disturbance hypothesis hold for less exposed shores with smaller rocks? Journal of Experimental Marine Biology and Ecology 352: 351-360

McCook LJ, Chapman ARO (1997) Patterns and variations in natural succession following massive ice-scour of a rocky intertidal seashore. Journal of Experimental Marine Biology and Ecology 214:121-147

McCoy ED, Bell SS (1991) Habitat structure: the evolution and diversification of a complex topic. In: Bell SS, McCoy ED, Mushinsky HR (eds) Habitat structure, the physical arrangement of objects in space. Chapman & Hall, New York, NY, p 3-27

McGuinness K.A. 1984. Species-area relations of communities on intertidal boulders: testing the null hypothesis. Journal of Biogeography 11:439-456

McGuinness K.A. 1987. Disturbance and organisms on boulders II. Causes of patterns in diversity and abundance. Oecologia 71:420-430

Mcguiness, K. A. and Underwood, A. J. 1986. Habitat structure and the nature of communities on intertidal boulders. Journal of Experimental Marine Biology and Ecology 104:97-123.

Mcquaid, C. D. and Branch, G. M. 1984. Influence of sea temperature, substratum and wave exposure on rocky intertidal communities: an analysis of faunal and floral biomass. Marine Ecology Progress Series 19:145-151.

Mcquaid, C. D. and Branch, G. M. 1985. Trophic structure of rocky intertidal communities: response to wave action and implications for energy flow. Marine Ecology Progress Series 22:153-161.

Mcquaid, C. D., Branch, G. M. and Crowe, A.A. 1985. Biotic and abiotic influences on rocky intertidal biomass and richness in the southern Benguela region. South African Journal of Zoology 20:115-122.

Mead, A., Carlton, J. T., Griffiths C. L. & Rius, M. 2011a. Introduced and cryptogenic marine and estuarine species of South Africa. Journal of Natural History 45: 2463–2524.

Mead, A., Carlton, J. T., Griffiths C. L. & Rius, M. 2011b. Revealing the scale of marine bioinvasions in developing regions: the South African example. Biological Invasions 13:1991-2008.

Meager JJ, Schlacher TA, Green M 2011. Topographic complexity and landscape temperature patterns create a dynamic habitat structure on a rocky intertidal shore. Mar Ecol Prog Ser 428:1-12

Meglen, R.R. 1992. Examining large databases: a chemometric approach using principal component analysis. Marine Chemistry 39: 217-237.

Menconi M, Benedetti-Cecchi L, Cinelli F (1999) Spatial and temporal variability in the distribution of algae and invertebrates on rocky shores in the northwest Mediterranean. Journal of Experimental Marine Biology and Ecology 233:1-23

Menge, B.A, Branch, G.M 2001 Rocky Intertidal Communities. In: Burtness MD, Gaines S, Hay ME (eds.) Marine Community Ecology. Sinauer Associates, Sunderland, p 221-251.

Menge B.A., Daley B.A., Wheeler P.A., Dahlhoff E., Sanford E., Strub P.T. 1997. Benthic-pelagic links and rocky intertidal communities: Bottom-up effects on top-down control? Proceedings of the National Academy of Sciences USA 94:14530-14535

Moldan, A. 1978. A Study of the Effects of dredging on the benthic macrofauna in Saldanha Bay. South African Journal of Science 74: 106-108.

Monniot, C., Monniot, F., Griffiths, C.L. & Schleyer, M. 2001. South African ascidians. Annals of the South African Museum 108: 1-141.

Monteiro, P.M.S & Brundrit, G. B. 1990. Interannual chlorophyll variability in South Africa's Saldanha Bay system, 1974-1979. South African Journal of marine Science 9: 281-288.

Monteiro, P.M.S & Kemp, A. 2004. Water quality management plan for Saldanha Bay: Phase III: Setting of critical loads using a modelling based ecosystem approach. CSIR Report ENV-S-C 2004-083.

Monteiro, P.M.S & Largier, J.L. 1999. Thermal stratification in Saldanha Bay (South Africa) and subtidal, density-driven exchange with the coastal waters of the Benguela Upwelling System. Estuarine and Coastal Shelf Science 49: 877-890.

Monteiro, P.M.S, Anderson, R. J. and Woodbourne, S. 1997. ^{15}N as a tool to demonstrate the contribution of fish-waste-derived nitrogen to an Ulva bloom in Saldanha Bay, South Africa. South African Journal of marine Science 18: 1-10.

Monteiro, P.M.S, Warwick, P. A., Pascall, A. and Franck, M. 2000. Saldanha Bay Water Quality Monitoring Programme. Parts 1 & 2. CSIR.

Monteiro, P.M.S. et al. 1999. The Biogeochemical Status of Near-Surface Sediments in Saldanha Bay in 1999. CSIR Report ENV-S-C 99093A.

Monteiro, P.M.S., Mcgibbon, S. and Henry, J.L. 1990. A decade of change in Saldanha Bay: natural or anthropogenic? South African Journal of Science 86: 454-456.

Næsje, T.J., Attwood, C.G., Kerwath, S., Cowley, P.D., Keulder, F. and Arendse, C. 2008. Patterns and volumes of commercial and recreational harvest of white stumpnose in Saldanha Bay: an assessment of the fishery. Oral presentation at the South African Marine Science Symposium; 29-June-3rd July 2008, University of Cape Town, Cape Town.

National Ports Authority. 2007. Environmental specification for the dredging activity at Mossgas quay and multipurpose terminal. Transnet National Ports Authority of South Africa, Port of Saldanha, Saldanha. 19pp.

NERSA. 2010. Application for a License to Construct a Loading and Storage Facility for Liquefied Petroleum Gas (LPG). Public Copy after NERSA Hearing 8 Feb 2010.

Newell, R.C., Seiderer, L.J. and D.R. Hitchcock. 1998. The impact of dredging works in coastal waters: A review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. Oceanography and Marine Biology: an Annual Review. 36: 127-78

Newman, W. A. 1982. A review of the extant taxa of the "Group of *Balanus concavus*" (Cirripedia, Thoracica) and a proposal for genus-group ranks. *Crustaceana*, 43:25-36.

Newman, W.A. and Abbott, D.P. 1980. Cirripedia: the barnacles. In: Morriss R.H., Abbott D.P., Haderlie E.C. (Eds) Intertidal Invertebrates of California. Stanford University Press, California, 504–535 pp.

Nikolaou, A., Kostopoulou, M., Lofrano, G., Meric, S., Petsas, A. and Vagi, M. 2009. Levels and toxicity of polycyclic aromatic hydrocarbons in marine sediments. Trends in Analytical Chemistry 28, 653-664

Nishihara GN, Terada R (2010) Species richness of marine macrophytes is correlated to a wave exposure gradient. Phycological Research 58: 280-292

Occhipinti-Ambrogi A. 2007. Global change and marine communities: Alien species and climate change. Marine Pollution Bulletin 55:342-352

Occhipinti-Ambrogi A., Galil B. 2010. Marine alien species as an aspect of global change. Advances in Oceanography and Limnology 1:143-156

Ocean Biogeographic Information System 2011. www.iobis.org. Accessed 28 July 2011

O'Donnell, M.J, Denny, M.W 2008. Hydrodynamic forces and surface topography: Centimeter-scale spatial variation in wave forces. Limnology and Oceanography 53:579-588.

Olivier, D. & Heinecken, L. & Jackson, S. 2013. Mussel and oyster culture in Saldanha Bay, South Africa: potential for sustainable growth, development and employment creation. Food Security 5: 251–267.

Orth R.J., Carruthers T.J.B., Dennison W.C., Duarte C.M., Fourqurean J.W., Heck K.L., Hughes A.R., Kendrick G.A., Kenworthy W.J., Olyarnik S., Short F.T., Waycott M. and Williams S.L. 2006. A global crisis for seagrass ecosystems. BioScience 56: 987–996.

OSPAR Commission. 2004. Biodiversity Series: Environmental impacts to marine species and habitats of dredging for navigational purposes. ISBN 1-904426-50-6. 1-22 pp.

OSPAR. 2010. Quality Status Report 2010: Status and Trend of marine chemical pollution. Access at OSPAR.org on 13 June 2012.

PDNA and SRK Consulting. 2006. Proposed phase 2 expansion of the Transnet iron ore handling facility, Saldanha: Background information document. 15 pp.

Petraitis, P.S. 1991. Recruitment of the mussel Mytilus edulis L. on sheltered and exposed shores in Maine, USA. Journal of Experimental Marine Biology and Ecology 147:65-80.

Pfaff MC, Branch GM, Wieters EA, Branch RA, Broitman BR (2011) Upwelling intensity and wave exposure determine recruitment of intertidal mussels and barnacles in the southern Benguela upwelling region. Mar Ecol Prog Ser 425:141-152

Phillips, D.J.H. 1980. Quantitative aquatic biological indicators: their use to monitor trace metal and organochlorine pollution. Applied Science Publishers, London.

Phillips, D.J.H. and Rainbow, P.S. 1994. Biomonitoring of trace aquatic contaminants. Chapman & Hall, London.

Pichegru L, Grémillet D., Ryan P.G. and Crawford R.J.M. 2010. Marine no-take zone rapidly benefits endangered penguin. Biology Letters 6: 498-501.

Pichegru L, Ryan P.G., Le Bohec C., van der Lingen C.D., Navarro R., Petersen S., Lewis S., van der Westhuizen J. and Grémillet D. 2009. Overlap between vulnerable top predators and fisheries in the Benguela upwelling system: implications for marine protected areas. Marine Ecology Progress Series 391: 199–208

Pichegru L., Ryan P.G., van der Lingen C.D., Coetzee J., Ropert-Coudert Y. and Grémillet D Foraging behaviour and energetics of Cape gannets Morus capensis feeding on live prey and fishery discards in the Benguela upwelling system. Marine Ecology Progress Series 350: 127–136

Picker, M. & Griffiths, C. Alien and Invasive Animals. A South African Perspective. Random House Struik, Cape Town. 240 pp.

Pillay D, Branch GM, Griffiths CL, Williams C and Prinsloo A (2010). Ecosystem change in south African marine reserve 1960-2009): role of seagrass loss and anthropogenic disturbance. Marine Ecology Progress Series 415:35-48

Pilsbry, H. A. 1916. The sessile barnacles (Cirripedia) contained in the collections of the U.S. National Museum; including a Monograph of the American species. *Bull. of the United States Nat. Mus*., Washington, 93: 1-366.

Pinedo S, Garcia M, Satta MP, de Torres M, Ballesteros E (2007) Rocky-shore communities as indicators of water quality: A case study in the Northwestern Mediterranean. Marine Pollution Bulletin 55:126-135

Poggenpoel, C. E. 1996. The exploitation of fish during the Holocene in the south-western Cape, South Africa. M. A. thesis, University of Cape Town: xxii+225p.

PRDW. 2007a. Prestige Retief Dresner Wijnberg (Pty) Ltd; Port of Saldanha Development Framework Plan. Report No. 491/01/006 Rev 01; December 2007.

PRDW. 2007b. Prestige Retief Dresner Wijnberg (Pty) Ltd; Port of Saldanha Iron Ore Berth Location Assessment. Report No. 491/01/003 Rev 01; May 2007.

Pullen, T. A. 2008. Eurotop – overtopping and methods for assessing discharge.

Quammen M.L. 1982 Influence of subtle substrate differences on feeding by shorebirds on intertidal mudflats. Marine Biology 71: 339-343.

Quick, L. 2006. The Geomorphic Changes to a Dune System in the Cape Peninsula: Fish Hoek – Noordhoek Dune Corridor. Unpbl. Honours Thesis University of Cape Town. Department of Environmental and Geographical Science.

Raffaelli, D. Hawkins, S. J. (1996) Intertidal Ecology, Chapman and Hall, London, 356p.

Rainbow P. S. 1995. Biomonitoring of heavy metal availability in the marine environment. Mar. Pollut. Bull. 31, 183-192.

Republic of South Africa, Department of Environmental Affairs (2011). South African Water Quality Guidelines for Coastal MarineWaters. Volume 2: Interim guidelines for recreational waters. Final. Cape Town.

Riuz, G.M, Fofonoff, P., Hines, A.H. 1999. Non-indigenous species as stressors in estuarine and marine communities: assessing invasion impacts and interactions. Limnology and Oceanography. 44: 950–972.

Robertson, H.G. 1981. Annual summer and winter fluctuations of Palearctic and resident waders (Charadrii) at Langebaan Lagoon, South Africa, 1975-1979. In: COOPER, J. (Ed.) Proceedings of the Symposium on Birds of the Sea and Shore, 1979. Cape Town: African Seabird Group. Pp.335-345.

Robinson, T. 2010. Marine Ecology Report. Prepared for the Department of Public Works as part of the New Boat Park at the Langebaan 4 Special Forces Base 24 G Process and Public Participation Report (JW de Jager, Arcus GIBB Pty Ltd).

Robinson, T.B., Branch, G.M. Griffiths, C.L., Govender, A. and Hockey, P.A.R. 2007a. Effects of the invasive mussel Mytilus galloprovincialis on rocky intertidal community structure in South Africa. Marine Ecology Progress Series 340:163–171.

Robinson, T.B. and Griffiths, C.L. 2002. Invasion of Langebaan Lagoon, South Africa, by Mytilus galloprovincialis—effects on natural communities. African Zoology 37:151–158

Robinson, T.B., Griffiths, C.L., Branch, G.M. and Govender, A. 2007. The invasion and subsequent die-off of Mytilus galloprovincialis in Langebaan Lagoon, South Africa: effects on natural communities. Marine Biology 152: 225-232

Robinson T.B., Griffiths C.L. and Kruger, N. 2004. Distribution and status of marine alien invasive species in and bordering the West Coast National Park. Koedoe 47: 79-87.

Robinson T.B., Griffiths C.L., Mcquaid, C.D. and Rius, M. 2005. Marine alien species of South Africa – status and impacts. African Journal of Marine Science 27: 297-306.

Robles C. 1982. Disturbance and predation in an assemblage of herbivorous Diptera and algae on rocky shores. Oecologia 54:23-31

Rogers D.I., Piersma T. and Hassell C. 2006. Roost availability may constrain shorebird distribution: exploring the energetic costs of roosting and disturbance around a tropical bay. Biological Conservation 133: 225–235.

Roughgarden J, Gaines S, Possingham H (1988) Recruitment dynamics in complex life cycles. Science 241:1460-1466

Ruiz GM, Fofonoff P, Hines AH (1999) Non-indigenous species as stressors in estuarine and marine communities: assessing invasion impacts and interactions. Limnol. Oceanogr. 44, 950–972.

Saldanha Bay Municipality. 2004. Water services development plan 2005/2006: Executive summary. 2005-07-07/206320KSO. 7 pp http://www.saldanhabay.co.za/

Schils, T, Clerck, O.D., Leliaert, F., Bolton, J.J., Coppejans, E. 2001. The change in macroalgal assemblages through the Saldanha Bay/Langebaan Lagoon ecosystem (South Africa). Botanica Marina 44:295-305.

Schoonees, J.S., Huizinga, P. and Taljaard, S. 1995. Saldanha Bay: turbidity caused by dredging, shipping and storms. Appendix 11 In TNPA Saldanha: Proposed extension of the general Cargo Quay. CSIR Report EMAS-C 94095D, CSIR, Stellenbosch. 87pp.

Schumacher, B.A. 2002. Methods for the Determination of Total Organic Carbon (TOC) in Soils and Sediments. United States Environmental Protection Agency.

Shannon, L.V. 1966. Hydrology of the south and west coasts of South Africa. Investigational Report, Sea Fisheries Research Institute, South Africa 58: 1-52.

Shannon, L.V. and Stander, G.H. 1977. Physical and chemical characteristics of water in Saldanha Bay and Langebaan Lagoon. Transactions of the Royal Society of South Africa 42: 441-459.

Siebert T. and Branch G.M. 2006. Ecosystem engineers: Interactions between eelgrass Zostera capensis and the sandprawn Calianassa kraussi and their indirect effects on the mudprawn Upogebia africana. 338: 253-270.

Siebert T. and Branch G.M. 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

Siebert T. and Branch G.M., 2005. Interactions between Zostera capensis, Callianassa kraussi and Upogebia africana: deductions from field surveys in Langebaan Lagoon, South Africa. South African Journal of Marine Science 27: 357–373.

Siegfried, W.R. 1977. Wading Bird Studies at Langebaan Lagoon. Interim Report submitted March 1977.

Simeonov V., Massart D.L., Andreev G., and Tsakovski S. 2000. Assessment of metal pollution based on multivariate statistical modelling of 'hot spot' sediments from the Black Sea. Chemosphere 41: 1411-1417.

Simon, C.A., Thornhill, D.J., Oyarzun, F. & Halanych, K.M. 2009. Gnetic similarity between *Boccardia proboscidae* from Western North America and cultured abalone, *Haliotis midae*, in South Africa. Aquaculture 294: 18-24.

Simon-Blecher, N., Granevitze, Z., Achituv, Y. 2008. Balanus glandula: from North-West America to the west coast of South Africa. African Journal of Marine Science 30(1):85-92

Simons, R.H. 1977. The algal flora of Saldanha Bay. Trans. Roy. Soc. South Africa 42: 461-482.

Skinner L.F., Coutinho R. 2005. Effect of microhabitat distribution and substrate roughness on barnacle Tetraclita stalactifera (Lamarck, 1818) settlement. Brazilian Archives of Biology and Technology 48:109-113

Slott J.M., Murray A.B., Ashton A.D., Crowley T.J. 2006. Coastline responses to changing storm patterns. Geophysical Research Letters 33, L18404.

Sousa W.P. 1979a. Disturbance in marine intertidal boulder fields: the non-equilibrium maintenance of species diversity. Ecology 60:1225-1239.

Sousa W.P. 1979b. Experimental investigations of disturbance and ecological succession in a rocky intertidal algal community. Ecological Monographs 49:227-254

Sousa W.P. 1984. Intertidal mosaics: patch size, propagule availability, and spatially variable patterns of succession. Ecology 65:1918-1935

Sousa W.P. 1985. Disturbance and patch dynamics on rocky intertidal shores. In: Pickett STA, White PS (eds) The Ecology of Natural Disturbance and Patch Dynamics. Academic Press, New York, p 101-124

SRK Consulting 2009. Saldanha Air Quality Permit Basic Assessment: Air Quality Specialist Baseline Study and Impact Assessment. SRK Project Number 399449.

Steffani, C. N. and Branch, G. M. 2003a. Spatial comparisons of populations of an indigenous limpet Scutellastra argenvillei and the alien mussel Mytilus galloprovincialis along a gradient of wave energy. African Journal of marine Science 25:195-212.

Steffani, C. N. and Branch, G. M. 2003b. Temporal changes in an interaction between an indigenous limpet Scutellastra argenvillei and an alien mussel Mytilus galloprovincialis: effects of wave exposure. African Journal of marine Science 25:213-229.

Stenton-Dozey, J. M. E., Jackson, L. F. and Busby, A. J. 1999. Impact of mussel culture on macrobenthic community structure in Saldanha Bay, South Africa. Marine Pollution Bulletin 39: 357-366.

Stenton-Dozey, J., Probyn, T. and Busby, A. 2001. Impact of mussel (Mytilus galloprovincialis) raft-culture on benthic macrofauna, in situ oxygen uptake and nutrient fluxes in Saldanha Bay, South Africa. Canadian Journal of Fisheries and Aquatic Sciences 58: 1021-1031.

Stephenson T.A., Stephenson A. 1972. Life between tidemarks on rocky shores. Publishers WH Freeman and co., pp. 425

Stroud D.A., Baker A., Blanco D.E., Davidson N.C., Delany S., Ganter B., Gill R., González P., Haanstra L., Morrison R.I.G., Piersma T., Scott D.A., Thorup O., West R., Wilson J. and Zöckler C., 2006. The conservation and population status of the world's waders at the turn of millennium. Waterbirds around the world. In: Boere G.C., Galbraith C.A., Stroud D.A. (Eds.). The Stationery Office. Edinburgh, UK, pp. 643–648.

Summers J.K., Wade T.L., Engle V.W., and Malaeb Z.A. 1996. Normalization of metal concentrations in estuarine sediments from the Gulf of Mexico. Estuaries 19, 581-594.

Summers, R.W. & Kalejta-Summers, B. 1996. Seasonal use of sandflats and saltmarshes by waders at low and high tide at Langebaan Lagoon, South Africa. Ostrich 67:72-79.

Summers, R.W. 1977. Distribution, abundance and energy relationships of waders (Aves: Charadrii) at Langebaan Lagoon. Transactions of the Royal Society of South Africa 42 (3&4): 483 - 495.

Summers, R.W., Cooper, J. and Pringle, J.S. 1977. Distribution and numbers of coastal waders (Charadrii) in the South-western Cape, South Africa, Summer 1975-76. Ostrich 48: 85-97.

Takada, Y. 1999. Influence of shade and number of boulder layers on mobile organisms on a warm temperate boulder shore. Marine Ecology Progress Series 189:171-179

Taljaard, S. and Monteiro, P.M.S. 2002. Saldanha Bay Marine Water Quality Management Plan. Phase I: Situation Assessment. Report to the Saldanha Bay Water Quality Forum Trust. CSIR Report ENV-S-C

Tinley, K L 1985. Coastal dunes of South Africa. *South African National Sciences Programmes Report*. No. 109, 300 pp.

Transnet National Ports Authority 2006. Port of Saldanha Oil spill contingency plan. National ports Authority. 51pp. http://www.transnet.co.za/BusinessWithUs/EnvPubDoc/saldanhaironore/DraftEnvironmentalManagementProgramme/5.%20Draft%20EMP%20_%20Annexure%20C.pdf

Transnet National Ports Authority 2009. http://www.transnetnationalportsauthority.net/NPA_ports_saldana_overview.html (Accessed March 2009).

Tunley KL, Attwood, CG, Moloney, CL and L Fairhurst 2009 – Variation in population structure and life history parameters of steentjies Spondyliosoma emarginatum: effects of exploitation and biogeography. African Journal of Marine Science 31: 133-143.

Turpie, J.K. & Love, V.C. 2000. Avifauna and human disturbance on and around Thesen Island, Knysna estuary: implications for the island's marina development and management plan. Report to Chris Mulder & Associates.

Turpie, J.K. 1995. Prioritizing South African estuaries for conservation: a practical example using waterbirds. Biological Conservation 74: 175-185.

Tyrrell, T. & M. Lucas. 2002. Geochemical evidence of denitrification in the Benguela upwelling system. *Continental Shelf Research*, 22, 2497-2511

Underhill, L.G. 1987. Waders (Charadrii) and other waterbirds at Langebaan Lagoon, South Africa, 1975-1986. Ostrich 58(4): 145-155.

Unit for Marine Studies 2000. South Africa's maritime industries. Published by M.E.R.I.T.

Van Ballegooyen, N. Steffani and A. Pulfrich 2007. Environmental Impact Assessment: Proposed Reverse Osmosis Plant, Iron –ore Handling Facility, Port of Saldanha – Marine Impact Assessment Specialist Study, Joint CSIR/Pisces Report, CSIR/NRE/ECO/ER/2007/0149/C, 190pp + 198pp App.

Van der Merwe, I.J., Ferreira, S.L.A. & H.L. Zietsman 2005. Growth Potential of towns in the Western Cape. Centre for Geographical Analysis, Stellenbosch University.

van Erkom Schurink C., Griffiths C.L. 1991. A comparison of reproductive cycles and reproductive output in four southern African mussel species. Marine Ecology Progress Series 76:123-134

van Erkom Schurink C., Griffiths C.L. 1993. Factors affecting relative rates of growth in four South African mussel species. Aquaculture 109:257-273 van Katwijk, M.M., Vergeer L.H.T., Schmitz G.H.W., & J.G.M. Roelofs 1997. Ammonium toxicity in eelgrass Zostera marina. Marine Ecology-Progress Series 157: 159-173.

Viljoen, R., Silomntu, M., Reuther, S. and S. Jones (2010). Transnet Port Terminal - Bulk Terminal Saldanha: Draft Environmental Management Programme for Air Quality Permit Amendment Application.

Visser, D, Goes, M & P Rosewarne 2007. Environmental Impact Assessment: Port Of Saldanha Proposed Reverse Osmosis Water Desalination Plant Groundwater Resources Impact Assessment.SRK Consulting Report.

Warwick, R.M. 1993. Environmental impact studies on marine communities: Pragmatical considerations. Australian Journal of Ecology 18: 63-80.

Watling, R.J. 1981. Manual of methods for use in the South African Marine Pollution Monitoring Programme, South African National Scientific Programmes, Report no. 44.

Waycott M., Duarte C.M., Carruthers T.J.B., Orth R.J., Dennison W.C., Olyarnik S., Calladine A., Fourqurean J.W., Heck K.L., Hughes A.R., Kendrick G.A., Kenworthy W.J., Short F.T. and Williams S.L. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. PNAS 106: 12377-12381

Weeks, S. J., Monteiro, P. M. S., Nelson, G. and Cooper, R. M. 1991a. A note on wind-driven replacement flow of the bottom layer in Saldanha Bay, South Africa: implications for pollution. South African Journal of Marine Science 11: 579-583.

Weeks, S.J., Boyd, A.J., Monteiro, P.M.S. and Brundrit, G.B.. 1991b. The currents and circulation in Saldanha Bay after 1975 deduced from historical measurements of drogues. South African Journal of marine Science 11: 525-535.

Wenchuan, Qu., Dickman, M. and Sumin, W. 2001. Multivariate analysis of heavy metals and nutrient concentrations in sediments of Taihu Lake, China. Hydrobiologia 450: 83-89.

Whitfield A.K., Beckley L.E., Bennett B.A. Branch, G.M. Kok, H.M. Potter, I.C. and van der Elst R.P. 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.

Whitfield, A. K. 1998. Biology and ecology of fishes in Southern African estuaries. Ichthyological Monographs of the J. L. B. Smith Institute of Ichthyology 2: 233pp.

Whitfield, A. K. 2005. Langebaan – A new type of estuary? African Journal of Aquatic Science. Vol. 30(2), pp. 207-209.

Whittington, P.A., Randall, B.M. Wolfaardt, A.C., Crawford, R.J.M., Klages, N.T.W., Bartlett, P.A., Chesselet, Y.J. and Jones, R. 2005a. Patterns of movements of the African penguin in South Africa and Namibia. African Journal of Marine Science 27(1): 215-229.

Whittington, P.A., Randall, R.M., Wolfaardt, A.C., Klages, N.T.W., Randall, B.M., Bartlett, P.A., Chesselet, Y.J. and Jones, R. 2005b. Patterns of immigration to and emigration from breeding colonies by African penguins. African Journal of Marine Science 27(1): 205-213.

Williams, A. J., Steele, W. K., Cooper, J. and Crawford, R. J. M. (1990) Distribution, population size and conservation of Hartlaub's Gull Larus hartlaubii. Ostrich 61: 66-76.

Windom, H.L. 1988. A Guide to the Interpretation of Metal Concentrations in Estuarine Sediments. Office of Water Policy. Florida Department of Environmental Protection.

WSP Africa Coastal Engineers 2010a. Development of a methodology for defining and adopting coastal development setback lines. Volume 1. Main report. Report prepared for Department of Environmental Affairs and Developing Planning, Western Cape Government, 81 pp.

WSP Africa Coastal Engineers 2010b. Development of a methodology for defining and adopting coastal development setback lines. Volume 2. Appendices. Report prepared for Department of Environmental Affairs and Developing Planning, Western Cape Government, 81 pp.

Zhang K, Douglas BC, and Leatherman SP. 2002. Do storms cause long-term beach erosion along the US East Barrier Coast? Journal of Geology. Vol. 110, pp. 493-502.

Zmarzly, D.L. 1992. Taxonomic review of pea crabs in the genus Pinnixa (Decapoda: Brachyura: Pinnotheridae) occurring on the California Shelf, with descriptions of two new species. Journal of Crustacean Biology 12 (4): 677–713.

Zullo, V. A., (1992). Revision of the Balanid Barnacle Genus *Concavus* Newman, 1982, with the Description of a New Subfamily, Two New Genera, and Eight New Species. The Paleontological Society. 27: 1-46.

Zuncknel, M. 2010 Dust Flux Monitoring Bulk Terminal Saldanha Phase IV: October 2009 –September 2010 Presentation to Saldanha Bay Forum – 18 November 2010.

Saldanha Bay Water Quality Trust

KUMBA RESOURCES

SFF

SA Lobster Exporters
a division of
FOODCORP
Consumer Brands

PPC

LANGEBAAN
COUNTRY ESTATE
GOLF & LEISURE

Black Mountain

FRONTIER
RARE EARTHS
FRONTIER RARE EARTHS LIMITED

Sea Harvest

SALDANHA BAAI BAY
MUNISIPALITEIT - MUNICIPALITY - UMASIPALA

METSEP
SALDANHA

Live Fish Tanks
WEST COAST

MITTAL

BLUE BAY
AQUAFARM

CAH
CHLOR-ALKALI HOLDINGS

TRANSNET
national ports authority

Duferco

SOUTH AFRICAN PORT OPERATIONS
A DIVISION OF TRANSNET LTD.

TRONOX

South African
NATIONAL PARKS