Saldanha Bay Water Quality Trust

THE STATE OF
SALDANHA BAY AND LANGEBAAN LAGOON
2013/2014

Technical Report
September 2014

ANCHOR environmental

Anchor Environmental Consultants Report No. AEC/1581/1

THE STATE OF
SALDANHA BAY AND LANGEBAAN LAGOON
2013/2014

TECHNICAL REPORT

Barry Clark, Megan Laird, Ken Hutchings, Vera Liebau, Aiden Biccard, Jane Turpie & Nausheena Parker-Mallick

Report prepared by:

8 Steenberg House, Silverwood Close, Tokai 7945, South Africa
www.anchorenvironmental.co.za

September 2014

Citation: Clark BM, Laird M, Hutchings K, Liebau V, Biccard A, Turpie J, & Parker-Mallick N. 2014. *The state of Saldanha Bay and Langebaan Lagoon 2013/2014.* Technical Report. Report no. 1581/1 prepared by Anchor Environmental Consultants for the Saldanha Bay Water Quality Trust.

FOREWORD

"I think I first fell in love with Saldanha Bay as a schoolboy studying maps of South Africa.
It appeared such a uniquely wonderful place."
(The late Dr. Martin Fourie, 2001)

As we enter our fifteenth year of monitoring of the Saldanha Bay/Langebaan Lagoon ecosystem, it is also a time for reflection. Where did this start, what have we achieved and where are we going?

Concerns were initially raised by the Department of Water Affairs (DWA) relating to water quality in Small Bay and specifically discharge of waste by-products by the fishing industry into the bay. They in turn pointed out that although willing to be part of a monitoring programme, they were not the only impactors and therefore should not be required to carry the costs alone.

The net was thrown far and wide and today we can proudly state that our contributors represent various sizes and types of industries, as well as local government. All of whom are impactors to a greater or lesser degree.

These entities contribute to the Trust on a purely voluntary basis and are to be commended for their commitment to our better understanding and management of this fragile environment.

The Trust was formally established in June 1996 thanks to the tireless efforts of the late Dr. Martin Fourie, (Langebaan resident), Mr Malcolm McGregor, (Sea Harvest) and Mr. Christo van Wyk, (Then of the DWA and currently the Chairperson.).

Although monitoring began in 1999, on the 1st of November 2007 a ten year monitoring programme was work shopped, proposed and adopted. For the first three years the Council for Scientific and Industrial Research (CSIR) did the monitoring but subsequently Anchor Environmental has been contracted to do so. Their obvious passion for this project has helped to develop a meaningful and healthy working relationship over the years.

The Trust undergoes an annual financial audit and is run on a day to day basis by the Chairman, assisted by a part-time Operations Manager and overseen by a Board of Trustees who meets every second month.

The meetings are also regularly attended by a number of other entities such as, for example, the West Coast District Municipality, the Department of Agriculture Fisheries and Forestry (DAFF), the South African Navy etc.

Over the years the Trust has strived to better understand and therefore influence the management of this unique system. To the best of my knowledge no other water body in South Africa has achieved the depth and broad based scientific knowledge that we have developed over the last fifteen years. (Although, the model has been copied in Angola, Australia and parts of Europe.).

Opposed to making decisions on a whim, we strive to build bridges, partnerships, better understanding and passion, by means of unadulterated science.

In the last twelve months major inroads have been made towards better management of this environment but I would not want to pre-empt the outcome of any of these activities at this stage, suffice to say that meetings have occurred with all three tiers of government and that these have been very positive to date.

I would like to thank the present Board of Trustees for their regular input and guidance. Special mention needs to be made of the Chairperson, Christo van Wyk, however, who hatched this idea fifteen years ago and today still drives it with an unrivalled commitment and passion, “Baie dankie!”

See you on the water,

Jimmy Walsh
Operations Manager
Saldanha Bay Water Quality Forum Trust

Figure i: SBWQFT Trustees. Top row (from left) Pierre Nel (SANParks), Andre Kruger(Saldanha Bay Municipality Councillor), Jan Cillie (Saldanha Bay Municipality Councillor), Frank Hickley (Sea Harvest); Bottom row (from left): Elmien de Bruyn (Duferco) Christo van Wijk (Metsal), and Nicole Abrahams (Transnet National Port Authority).

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.

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, Total organic carbon (TOC) 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 2014 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 wastewaters), water quality in the Bay itself (temperature, oxygen, salinity, nutrients, and pH), sediment quality (particle size, trace metal and hydrocarbon contaminants, TOC 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. Key findings for each of the major parameters in the State of the Bat monitoring are summarised below.

For the first time in 2014 sampling of sediments, benthic macrofauna and fish was undertaken in Danger Bay, an open coast bay directly west of Saldanha town. This represents the first year of baseline data collection prior to the construction of the proposed Saldanha Regional Marine Outfall, which when operational will discharge approximately 8-9 Mega litres per day of treated effluent (predominantly brine with trace levels of other elements generated from the various sources) into Danger Bay. It was deemed prudent to initiate monitoring in 2014 so as to develop a comprehensive baseline that captures natural variability prior to the commissioning of the pipeline (anticipated to be 2020). The results of the Danger Bay baseline sampling are included in the sediment, benthic macrofauna and fish chapters of the main report but key findings of all three aspects are summarized separately below.

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 2.66% per annum in Saldanha and 9.24% in Langebaan over the period 2001 to 2011. Numbers of tourists visiting the area every year has also increased by 13% per annum since 2005. This rapid population growth translates to corresponding increases in the amounts of infrastructure required to house and accommodate these people and also in the amounts of waste and wastewater that is produced and has to be treated and disposed of.

Major developments in the Bay itself over the last 50 years include the development of the Port of Saldanha (construction of the Marcus Island causeway and the iron ore terminal and associated infrastructure), the establishment of a three small craft harbours, mariculture farms and several fish processing factories. Extensive industrial and residential development has also 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 water’s edge. The impact of shoreline erosion on existing development in the Saldanha and Langebaan area is being managed by means of two Environmental Management and Maintenance Plans (EMMP) but the lack of sufficient funding for the implementation of some of these measures has been problematic. Coastal management/set-back lines and overlay zones (designed to cater for short, medium and long term storm events) for the West Coast District Municipality (WCDM) are currently in draft form and will soon be published in the *Government Gazette* for public comment. While ensuring the protection of coastal property and infrastructure in future, it is also hoped that these interventions will also afford greater protection to the marine environment by limiting coastal erosion, trampling and habitat loss. 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.

Several dredging events have occurred in Saldanha Bay to facilitate the development of the commercial 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 (Transnet-NPA 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 is also proposing upgrading the existing General Maintenance Quay and Rock Quay in Saldanha. Construction is expected to commence at the beginning of 2015 and is estimated to be completed just over a year later. Transnet has also proposed a Phase 2 expansion of the Iron Ore Terminal (Big Bay side) to increase its holding capacity, which will require the dredging of sediment and removal of hard material in the navigation channel near the proposed berth and will require an Environmental Impact Assessment (EIA) process. Other recent developments that have been implemented in and around the Bay include a reverse-osmosis desalination plant which has been constructed at the Iron Ore Terminal in Big Bay (operational since August 2012) and the refurbishment and expansion of the small craft harbour at Salamander Bay in Langebaan Lagoon. Environmental Authorisation (EA) has recently been granted for a new Liquid Petroleum Gas terminal in the bay and the EA is pending for a land-based gas storage facility in Saldanha.

The Saldanha Bay Industrial Development Zone (SBIDZ) was declared on 13 October 2013 and the Operator Permit was granted to the SBIDZ licensing Company (Saldanha Bay Industrial Development Zone LiCo). The SBIDZ is envisioned to provide services in maintenance and repair fabrication as well as communal and supply services to various industrial sectors in Saldanha. A new desalination plant has been proposed by the WCDM, for which EA was granted in August 2013. Effluent from this plant will be discharged into Danger Bay. Frontier Saldanha Utilities (Pty) Ltd. have also proposed a regional marine outfall project, which if implemented, will direct effluent from at least three sources (Rare Earth Elements Separation Plant, Chlor-Alkali Production Facility and the Regional Waste Water Treatment Plant proposed by the Saldanha Bay Municipality (SBM)) into Danger Bay.

Ships entering the port of Saldanha take up and discharge large volumes of ballast water when offloading and loading cargo, respectively. 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. The average size and number of vessels in use has also increased over the years, and as a result, the volume of ballast water discharged to the Bay has doubled since 2004, with almost 23 million tons of ballast water being discharged in 2013. Historical measurements suggest that the concentrations of the trace metals in ballast water discharged into Saldanha Bay exceeds the South African Water Quality Guidelines, indicating that ballast water discharges may also contribute significantly to metal contamination within the Bay. The introduction of new approaches to ballast water management such as open ocean exchange may, however, that mitigated this to some extent, but this remains to be confirmed.

Storm water enters Saldanha Bay/Langebaan Lagoon via multiple storm water drains and tarred surfaces. Storm water is a major potential source of pollutants in the Bay as it 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 Council for Scientific and Industrial Research (CSIR) indicate that the concentrations of several contaminants (nitrate, ammonia, metals and faecal coliforms) in Saldanha Bay storm water runoff are well above accepted guideline limits. More coordinated storm water management is now under way in Langebaan and a Stormwater

Management Master Plan is currently being drafted and may contribute to addressing some of these concerns.

Three fishing companies currently discharge land-derived wastewater into Saldanha Bay: SA Lobster Exporters (Marine Products), Live Fish Tanks (West Coast) – Lusitania (CSIR 2002) and Sea Harvest. Premier Fishing is currently in the process of upgrading their fish processing plant for which EA was issued in June 2013. Long term data for effluent volume and quality is available for the Sea Harvest factory, and it is evident from these data that their effluent contains significant quantities of organic material (suspended solids, ammonia and other nitrogenous compounds) and may be contributing to poor water quality conditions in Small Bay. No information is available on effluent discharged by SA Lobster Exporters and Live Fish Tanks, or whether their discharges are authorised in terms of the National Environmental Management: Integrated Coastal Management Act (No. 24 of 2008) (ICMA).

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 150 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.

Water Quality

Aspects of water quality (temperature, salinity and dissolved oxygen, nutrients and chlorophyll concentrations) are often measured in an attempt to understand the health of the environment. Regional oceanographic processes appear to be driving much of 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 Saldanha Bay, which are ascribed to the construction of the ore terminal and causeway. These changes have also contributed to the deterioration in water quality in Small Bay in particular. 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 has continued since this time with the assistance of the SBM. These data indicate that chronic problems with faecal coliform pollution were present in the early parts of the record but that conditions have improved considerably since this time. Currently, the situation in Small Bay remains a concern, with three sites exceeding the 80th percentile levels and five sites exceeding the 95th percentile levels for safe mariculture practices, and two sites exceeding the 80th percentile levels for safe recreational activities in 2014. An increasing trend in faecal coliform counts in Langebaan is also cause for concern, and although microbial counts are still within the recreational use guidelines, this is the only site outside of Small Bay that exceeded the mariculture guidelines. 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.

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 mariculture farm owners. DEA discontinued mussel watch programme in Saldanha Bay in 2007, but this has now been incorporated into the State of the Bay surveys. Data suggest that concentrations of trace metals are high along the shore (particularly for lead near the Multipurpose Quay) and are frequently or even consistently above published guidelines for foodstuffs. Concentrations of trace metals in the cultured mussel in the Bay offshore are much lower though, and are currently not of concern. 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. The high concentrations of trace metals along the shore points to the need for management interventions to address this issue, as metal contamination poses a very serious risk to the health of people harvesting mussels from the shore. It is vitally important that this monitoring continues in the future and that data are made available to the public for their own safety.

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 have flushed fine sediment and mud particles out the bay, leaving behind the heavier, coarser sand and gravel fractions. However, 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) tend to associate with the mud component of the sediment and can have a negative impact on the environment when they are re-suspended. 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 have been observed following dredging events. In between these events, mud tends to be flushed out or re-buried beneath sand and gravel, and the sediment composition starts reverting 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. However, despite these overall encouraging trends, the sediment at several deeper or more sheltered sites within Small and Big Bay still have elevated mud fractions. Areas most significant affected in this way are all located in the vicinity of the ore terminal the mussel rafts and the yacht club basin.

Levels of TOC and Total organic nitrogen (TON) are presently elevated in the muddy sediments in the more sheltered and deeper areas of the bay, notably near the Yacht Club Basin and the mariculture rafts. Phytoplankton production is still considered to be the dominant natural source of organic matter in sediments in the Bay but is greatly augmented by anthropogenic inputs of TOC and TON associated with waste discharge from the fish factories, faecal waste from the mussel rafts, sewage effluent and storm water runoff. Accumulation of organic waste, especially in sheltered areas where there is limited water flushing, is causing hypoxia (reduced oxygen) in these areas and is negatively impacting on benthic communities. Data collected between 1999 and 2011 mostly indicate a trend of declining levels of TON and TOC, one that was unfortunately abruptly reversed at many sites in 2012. Samples collected during 2013 and 2014 showed encouraging declines in TOC levels at many sites to amongst the lowest recorded since 1990. TON levels were fairly high at some sites in 2013 but markedly in 2014 to amongst the lowest levels recorded since 2000. Sites where TOC and TON levels are still somewhat elevated include the area around the multipurpose quay, the ore jetty and the mussel rafts in Small Bay where concentrations have remained elevated since 2008.

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 with the exceptions of a few sites in Small Bay where thresholds were exceeded in 2013 and 2014 samples. Key areas of concern regarding trace metal pollution within Small Bay include the Yacht Club basin where Cadmium and Copper exceeded recommended thresholds in 2013 and the multipurpose terminal where levels of cadmium 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, 2012, 2013 and 2014. The data from 2010 and 2011 indicated no cause for concern but the most recent (2012-2014) 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. Levels at three sites in the vicinity of the multipurpose quay and the base of the ore jetty were found to be exceptionally high in 2013 and 2014. The chemical composition of the hydrocarbons found in sediments at these sites suggests that the contaminant is weathered diesel. The most likely explanation for the high observed total petroleum hydrocarbon (TPH) contamination levels is that a pollution incident associated with shipping activities took place. Alternatively, a pollution incident or routine operational activities on the jetty itself could be the cause of this contamination. This warrants further investigation and appropriate remedial action to prevent further 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 an important 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. This is largely because these species are short lived and, as a consequence, their community composition responds rapidly to environmental changes. Monitoring of benthic macrofaunal communities over the period 1999-2014 has revealed a relatively stable situation in most parts of the Bay and Lagoon with the exception of 2008 when a dramatic shift in benthic community composition occurred at all sites. This shift involved a decrease in the abundance and biomass of filter feeders and an increase in shorter lived opportunistic detritivores. This was attributed to the extensive dredging that took place during 2007-2008. Filter feeding 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.

Aside from this Bay-wide phenomenon, localised improvements in health have been detected in the yacht club basin and at Salamander Bay following construction of the boat dock. 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 (TOC, 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.

Notable improvements in the health of benthic communities include the return of the suspension feeding sea-pen *Virgularia schultzei* to Big Bay and Langebaan Lagoon 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. Certain areas of Small Bay that experience reduced water circulation patterns in (e.g. base of the ore jetty, near the Small Craft Harbour and near mussel rafts) which results in the accumulation of fine sediment, organic material and trace metals (aggravated by anthropogenic inputs) still have impoverished macrofauna communities.

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 2014 survey, a total of 128 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 25 species of filter-feeders, 27 species of grazers, and 23 species of predators and scavengers combined. The algal component comprised 39 corticated (foliose) seaweeds, seven ephemerals, five species of encrusting algae, and two species of kelp. 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. During the present survey, it was confirmed that two new alien barnacle species (*Amphibalanus amphitrite amphitrite* and *Menesiniella regalis)* have become established in the Bay.

The most important factor responsible for community differences among sites remains exposure to wave action and to a lesser extent shoreline topography. 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. Exceptions are the alien species introduced by hull fouling, ballast water or mariculture.

Fish

With the exception of white stumpnose, the current status of fish and fisheries within Big 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 (MPA) over the long term appears to be increasing which is very encouraging. Certainly, work by Kerwath *et al.* (2009), Hedger *et al.* (2010) and da Silva *et al.* (2013) has clearly demonstrated the benefits of the Langebaan MPA for white stumpnose, elf and smooth houndsharks and the protection of harders from net fishing in the MPA undoubtedly benefits this stock in the larger Bay area.

The significant declines in white stumpnose abundance at all sites throughout the system in recent years, however, suggests that the protection afforded by the Langebaan MPA may not be enough to sustain the fishery at the current high effort levels. The low white stumpnose abundance in recent years may simply be a result of natural variability in recruitment strength (possibly at decadal time scales greater than the monitoring record). However, given the findings of Arendse (2011) who found the adult stock to be overexploited using data collected during 2006-08 already, this could indicate that recruitment overfishing is occurring and a precautionary approach is warranted. The annual seine net surveys can act as an early warning system that detects poor recruitment and allows for timeous adjustments in fishing regulations to reduce fishing mortality on weak cohorts and preserve sufficient spawner biomass to sustain catches in future. The consistent declining trend in juvenile white stump abundance in the nursery surf-zone habitats since 2007, with the two lowest abundance estimates emanating from the last two annual surveys, strongly supports the implementation of the harvest control measures recommended by Arendse (2011); namely a reduction in bag limit from 10 to 5 fish per person per day and an increase in size limit from 25 cm TL to 30 cm TL.

In Small Bay, with the exception of harders, estimated abundance of key species was well below average, with the lowest yet recorded blacktail and white stump density, and the 2nd and 3rd lowest silverside density to date. This follows the trend observed since 2010/11 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 and Langebaan Lagoon. 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 0.05 fish.m^{-2} in Langebaan lagoon. Small Bay is often viewed as the more developed or industrialized portion of the Bay and is considered by many as a 'lost cause'. These data provides a strong argument to stamp out such negative thinking and to continue lobbying strongly for enhanced protection of this portion of the Bay. The concerning trend in decreasing white stumpnose recruitment throughout the Bay makes it even more critical that the environmental health of Small Bay, that is demonstrably the most important white stump nursery habitat, is maintained.

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, Caspian 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 (particularly Dyer, St Croix and Bird Islands) and a reduced availability of sardines and anchovy along the west coast, which is the primary food source for these birds. In Saldanha Bay the population initially grew from 552 breeding pairs in 1987 to a peak of 2 156 breeding pairs in 2001 and then underwent a severe decline to just 314 breeding pairs in 2014. 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. Recent 2011-2013 counts suggest that numbers are now well below (less than half) those at the start of the comprehensive counting period (1991).

Hartlaub's Gull and Swift Tern populations vary erratically, with numbers fluctuating widely each year. The total number of breeding pairs of Hartlaub's Gull recorded in 2014 (622) is close to the midpoint of the substantial inter-annual variation observed. Breeding pairs were recorded on Malgas, Meeuw, Jutten and Vondeling Islands in 2014. Similarly, Swift terns bred in numbers on several of the islands in Saldanha Bay in 2012-2014, after being completely absent for several years. A total of with 543breeding pairs were recorded on Malgas , Jutten and Schaapen Islands in 2014.

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. The 2012 and 2013 data reveal that the Cape Gannet breeding population on Malgas Island has fallen to record low levels.

The Saldanha Bay Cape Cormorant 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. Numbers of birds on this island have declined substantially on Jutten, Schaapen and Vondeling Islands since 2009. Overall numbers are down 90% since 2009 (down from 13 655 in 2009 to only 1 268 pairs in 2013) and are at the lowest level ever recorded (when counts were conducted on all five islands). This is a concerning trend for this Near Threatened coastal bird species.

Bank Cormorant numbers in Saldanha Bay has declined drastically approximately by approximately 80% since 1990. Numbers dropped as low as 22 pairs in 2013 and have since increased slightly to 50 breeding pairs in 2014. 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. Bank Cormorants are also very susceptible to human disturbance and eggs and chicks are taken by Kelp Gulls and Great White Pelicans.

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 have been more or less stable in recent years, and there is no long term declining trend.

Populations of crowned cormorants have been comprehensively counted since 1991. Since then, numbers have shown considerable inter-annual variations without much cause for concern.

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. The regular censuses of oystercatchers in Saldanha Bay have unfortunately stopped. Consideration should be given to reviving oyster catcher counts in order to maintain this valuable long-term data series.

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. The 2013 and 2014 data however, show some limited recovery in numbers of Palaearctic waders, although the total estimate of 9 120 birds is still 74% down from the pre 1990 average of ~34 000 birds. 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. In recent years (2005-2012) resident wader numbers appear to have stabilized and as with migrants, some recovery was evident during 2013 and 2014, (although resident wader estimates do still remain at ~50% of the pre 1990 average). 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, 92 marine species have been recorded as introduced to South African waters, mostly though shipping activities or mariculture. At least 70 of these are thought to occur in Saldanha Bay and/or Langebaan Lagoon. Many of these are considered invasive, including the Mediterranean mussel *Mytilus galloprovincialis,* the European green crab *Carcinus maenas* and the recently detected barnacle *Balanus glandula*. An additional 39 species are currently regarded as cryptogenic (of unknown origin) 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.

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. This species made a brief incursion into Langebaan Lagoon in 2009 and was absent from this area until this year. 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 *Balanus 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* grew rapidly from an average of 5.4% cover in 2005 to 7.8-11.1% in 2012, but have since decreased again to 6.1% in 2014. Populations of Balanus also seems to be declining, after peaking in 2009. Abundance (% cover) of this species has declined from a peak of around 7.5% in 2009 to around 3.4% in 2014. These two species compete directly with one another for space on the shore, with expanding populations of *Mytilus* displacing those of *Balanus*.

Menesiniella regalis was again positively identified from Saldanha Bay. This barnacle originates from the Pacific coast of North America and was most likely introduced by ballast water or hull fouling. *Amphibalanus amphitrite amphitrite* was identified from the Bay for the first time, which is cause for concern. 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. Thus, changes in the population of these species in Saldanha Bay will be carefully monitored in future to see what impacts they will have on the local biota.

Danger Bay

Sediment and benthic macrofauna samples were collected from 14 sub tidal sites (7-20 m depth) in the vicinity of the options for the proposed regional marine outfall pipe end (the northern half of

Danger Bay), whilst seine net hauls were conducted at three sites within the surf zone in this area. In contrast to sediments within Saldanha Bay, Danger Bay sediments comprised almost entirely sand (>99%) with an extremely low mud fraction (on average 0.02%). Consequently organic matter concentrations (total organic carbon and total organic nitrogen) in these sediments were also very low. Concentrations of trace metals in the sandy Danger Bay sediment samples were very low relative to sites with anthropogenic impacts and muddy sediments collected within Saldanha Bay. Cu and Ni were not detectable at nearly all Danger Bay sites, whilst Cd and Pb concentrations were well below all sediment quality guidelines. These differences are attributed to the much higher wave exposure of Danger Bay, compared to sites within Saldanha Bay and are indicative are high flushing rates as opposed to the depositional environment found in many of the deeper and more sheltered parts of Small Bay and Big Bay.

Reflecting these habitat differences, the benthic macrofauna community in Danger Bay is significantly distinct from that found within Saldanha Bay and Langebaan Lagoon. Average macrofauna biomass at Danger Bay sites was an order of magnitude lower that that found within Saldanha Bay and Langebaan Lagoon during 2014 and the community was dominated by small crustaceans (mostly amphipods), polychaetes and gastropods. These taxa are mostly short lived R-selected species that are predominantly detritivores and scavengers in contrast to sites within Saldanha Bay and Langebaan Lagoon, where filter feeders are the dominant functional group. The absence of large crustaceans such as the mud prawn *Upogebia capensis* and associated commensal species (e.g. *Spiroplax spiralis*) and the crown crab *Hymenosoma orbiculare*, and the abundance of a small amphipod *Urothoe coxalis* found only in Danger Bay, were the main causes of dissimilarity between Danger Bay and the Saldanha Bay and Langebaan Lagoon samples.

Surf zone fish diversity at Danger Bay was low compared with catches made at most sites within the Saldanha Bay, and reflects the less sheltered, cooler and cleaner water found on the more exposed coast. These conditions are less suitable as a nursery area for many fish species in that they do not offer the increased turbidity, temperature and food availability found within the Bay. Indeed two of the three species caught at Danger Bay, False Bay Klipvis (78 individuals) and Sand Sharks (2 individuals) are adults, whilst seven of the 10 harders caught were around 10 cm total length, nearly double the average size harder (6 cm) sampled within Saldanha Bay- Langebaan in 2014.

The significant difference in physical habitat and biota found in Danger Bay compared to that within Saldanha Bay reflects a more exposed and dynamic environment that does suggest that this site is far more suitable for a regional marine outfall. Discharge of organically and chemically enriched effluent from the proposed regional marine outfall is still expected to have a discernable impact on the physical environment and biological communities within a zone of impact. Ongoing collection of comprehensive baseline data on macrobenthic communities in Danger Bay to capture the natural variability is essential for objective and quantitative assessment of expected impacts.

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 a considerable degree of negative impact having occurring over the last few decades. Long term decreases in populations of fish (e.g. white stumpnose) and many bird species in Saldanha Bay and Langebaan Lagoon are of particular concern of course. These most likely reflect long term changes in exploitation levels (fish) and habitat quality (sediment and water quality, and also increasing levels of disturbance) and also in important forage species (e.g. benthic macrofauna). Recent improvements in some of these underlying indicators (e.g. sediment quality and macrofauna abundance and composition) are very encouraging, though, and will hopefully translate into improvements in the higher order taxa as well. There remains considerable work to be done in maintain and restoring the health of the Bay, especially in respect of the large volumes of effluent that are discharged to the Bay, very little of which is compliant with the existing effluent quality standards. 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

GLOSSARY

Alien species	An introduced species that has become naturalized.
Articulated coralline algae	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	Algae that have a secondarily formed outer cellular covering over part or all of an algal thallus. Usually relatively large and long-lived.
Crustose coralline algae	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.

LIST OF ABBREVIATIONS

AOU	apparent oxygen utilization
BA	Basic Assessment
BCLME	Benguela Current Large Marine Ecosystem
CBA	Critical Biodiversity Area
COD	chemical oxygen demand
CSIR	Council for Scientific and Industrial Research
CWAC	Co-ordinated Waterbird Counts
CWDP	Coastal Water Discharge Permit
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DEA&DP	Western Cape Department of Environmental Affairs & Development Planning
DWA	Department of Water Affairs
EA	Environmental Authorisation
EIA	Environmental Impact Assessment
EMMP	Environmental Management and Maintenance Plan
EMPr	Environmental Management Programme
ICMA	National Environmental Management: Integrated Coastal Management Act (No. 24 of 2008)
LPG	liquid petroleum gas
MLRA	Marine Living Resources Act (No. 18 of 1998)
MPA	Marine Protected Area
NEMA	National Environmental Management Act (No. 107 of 1998)
NEMBA	National Environmental Management: Biodiversity Act (No. 10 of 2004)
NOAA	National Oceanic and Atmospheric Administration
NWA	National Water Act (No. 36 of 1998)
PAH	Poly-aromatic hydrocarbons
TOC	total organic carbon
TON	total organic nitrogen
RWQO	Receiving Water Quality Objectives approach
SBIDZ	Saldanha Bay Industrial Development Zone
SBM	Saldanha Bay Municipality
SBWQT	Saldanha Bay Water Quality Trust
TPH	total petroleum hydrocarbon
TSS	total suspended solids
WCDM	West Coast District Municipality
WWTW	Wastewater Treatment Works

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, Jutten and Vondelig).

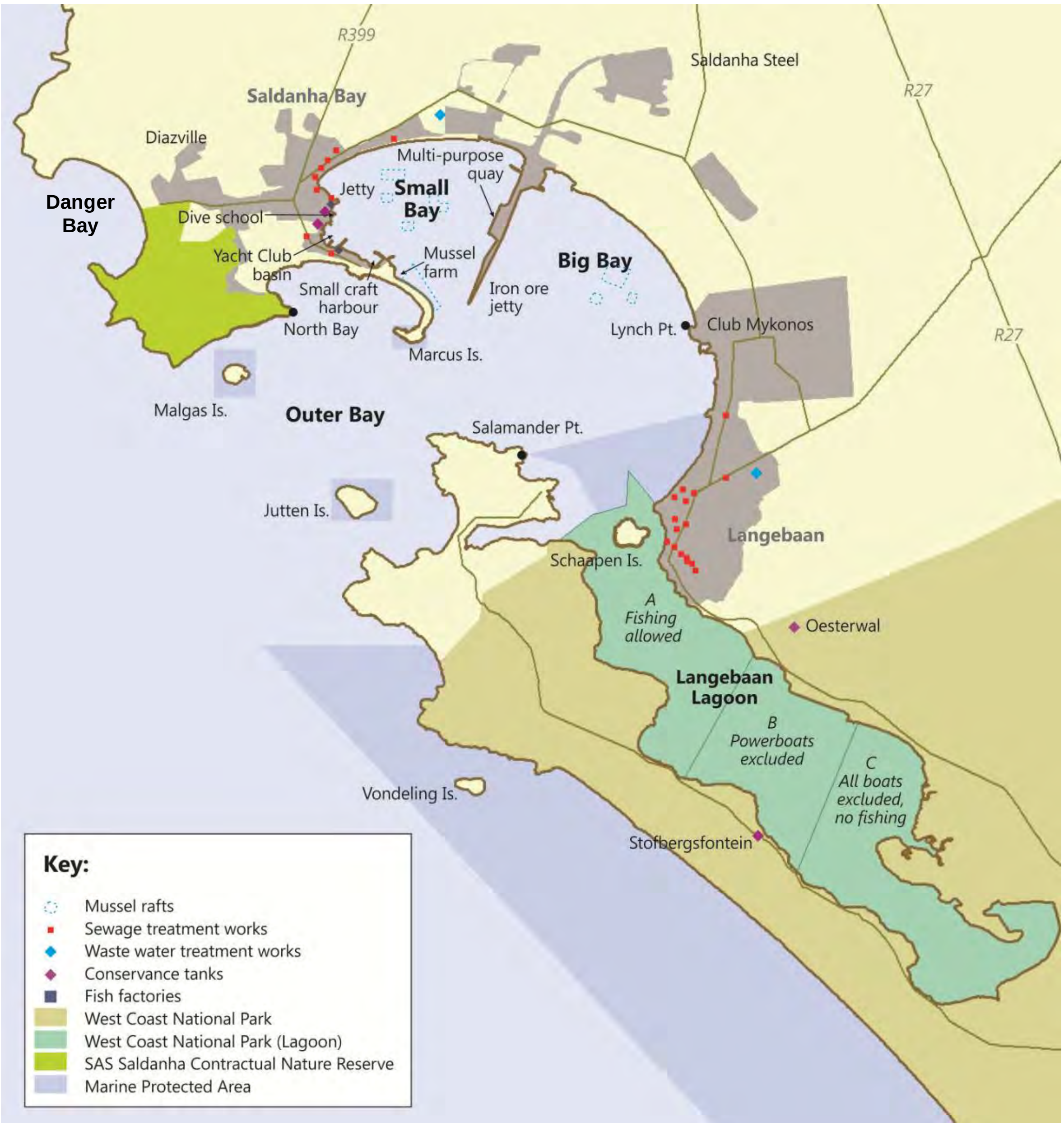


Figure 1.1. Regional map of Saldanha Bay and Langebaan Lagoon and Danger Bay showing development (grey shading) and conservation areas.

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, Total organic carbon (TOC) 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, trace metal and hydrocarbon contaminants, TOC 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 then annually from this time onwards. This (2014) report is the 8th 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 (2012), and includes information on trends in all of the parameters reported on in the previous reports (2006, 2008, 2009, 2010 2011 and

2012). It is somewhat different from the previous reports as it presents data on two years' worth of monitoring work (2013 and 2014) and reflects a new approach, which is to publish the State of the Bay report in the year that the bulk of the survey work has been done (i.e. each annual report will be published in the year covered by that report). Going forward, each annual report will not incorporate the full years' worth of monitoring data for that year but will still reflect the state of the Bay in that year inasmuch as it will incorporate all relevant data and information that has been collected in the preceding 12 months.

This 2014 report also for the first time includes data on sediment, benthic macrofauna and fish sampled in Danger Bay (Figure 1.1). This extension of the spatial coverage of the annual monitoring came about in response to the proposed development of a regional marine outfall pipe that will discharge into Danger Bay and the addition of a new Saldanha Bay Water Quality Trust (SBWQT) member, Frontier Rare Earths (TSX: FRO) a mineral exploration and development company. TSX: FRO have entered into an agreement with the West Coast District Municipality (WCDM) and Chlor-Alkali Holdings for the development of a regional marine outfall that will be able to accommodate waste from the TSX: FRO and Chlor-Alkali Holdings processing plants, the WCDM Regional Wastewater Treatment Works (WWTW), the WDCM Regional desalination plant, as well as from any other interested parties. The proposed Saldanha Regional Marine Outfall (will discharge approximately 8-9 Mega litres per day (Mℓ/day) of treated effluent generated from the various sources (CSIR 2013). The effluent to be discharged from the outfall will be predominantly brine with trace levels of other elements. The projected date for the commissioning of the outfall is also highly relevant to the design of the monitoring programme. The project is currently in pre-feasibility stage, will move into a feasibility stage within the next year but is only likely to be commissioned in approximately 6 years' time (i.e. around 2020). It was deemed prudent to initiate monitoring in 2014 so as to develop a comprehensive baseline that captures natural variability prior to the commissioning of the pipeline. The 2014 Danger Bay data presented herein represents the first year of phase 1 monitoring, which is to be expanded to included water quality monitoring and additional benthic stations (phase 2) no more than 2 years prior to the projected date of commissioning.

This annual report 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 on-going 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, Danger 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 and provides the first baseline data for Danger Bay.

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. In 2014 this survey was expanded to include Danger Bay.

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 2014 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 SBWQT 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
- New and updated information on new and existing development proposals for Saldanha (the Saldanha Bay Industrial Development Zone, the Transnet-NPA port expansion programme, the Sishen-Saldanha Oreline expansion project, Sunrise Energy Liquid Petroleum Gas (LPG) Facility, Oil Tanking MOGS Saldanha crude oil storage facility, and the Salamander Bay Boatyard expansion project)
- New and updated information on shipping traffic and ballast water discharges, and potential impacts of noise from shipping traffic in the Bay
- New and updated information on the Transnet-NPA and WCDM Desalination Plants, updated information on effluent volumes and quality discharged by the Saldanha and Langebaan Water Treatment Works, new and updated data on volumes and quality of effluent discharged by fish processing establishments in Saldanha, and new developments in the mariculture industry in Saldanha; and
- New developments pertaining to how development in the coastal zone surrounding the Bay will be managed and controlled in future.

Chapter 4: Water Quality

- New information on variations in temperature, salinity, dissolved oxygen and turbidity in the Bay.
- New updated information on levels of microbial indicators (faecal coliforms and *E. coli.*) in the Bay.
- New updated information on levels of trace metals in mussels on the shoreline and in farmed oysters and mussels in the Bay.

Chapter 5: Sediments

- New updated information on grain size composition and health of benthic sediment in Saldanha Bay (TOC and Nitrogen, Trace metal and hydrocarbon content).
- New information on sediment composition from 14 stations sampled in Danger Bay, including particle size composition, TOC and organic nitrogen 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.

- First baseline information on the benthic macrofauna community inhabiting soft sediments in Danger Bay.

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.

Chapter 10: Birds

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

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 wastewater. 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 trace 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.

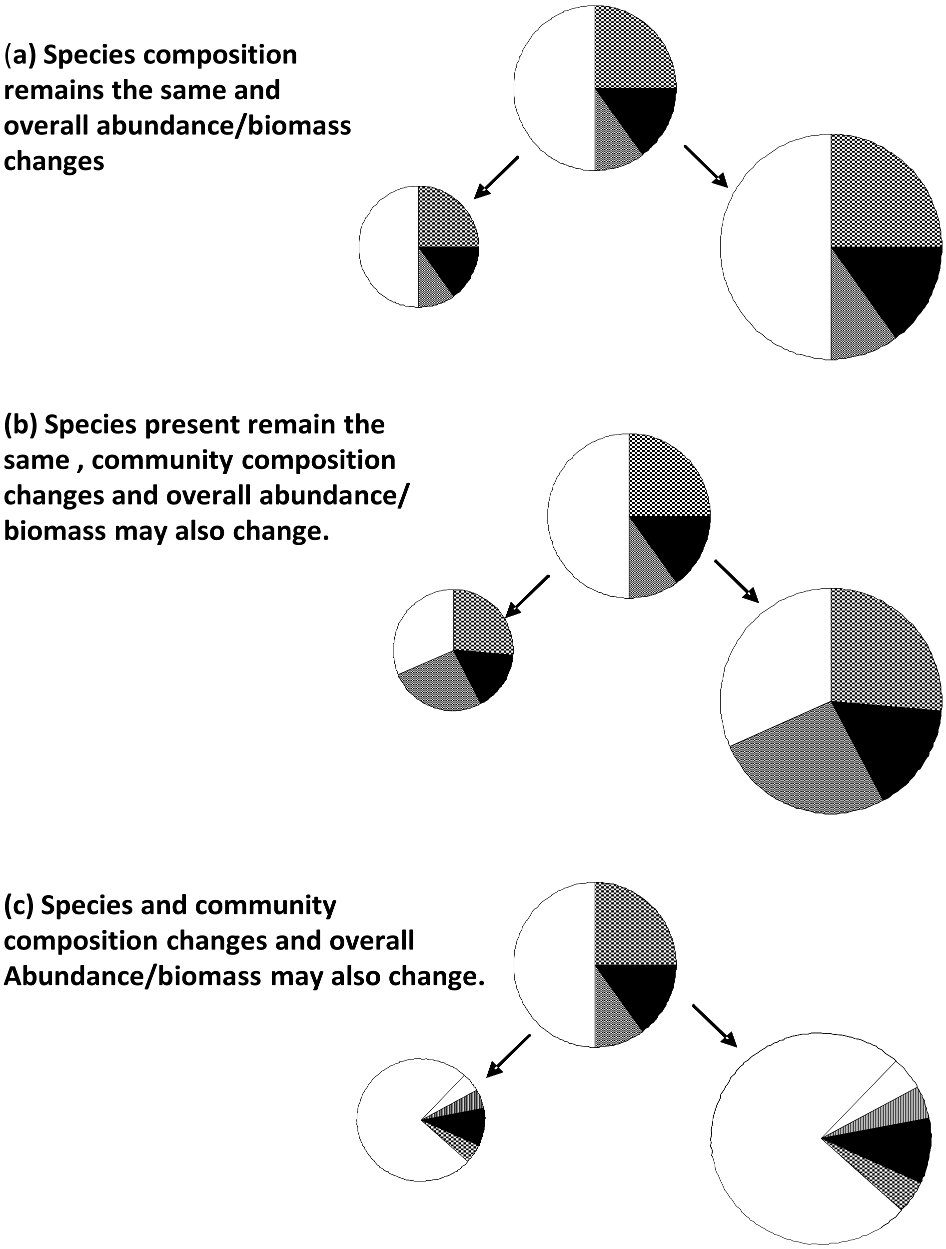


Figure 2.1. Possible alterations in abundance/biomass and community composition. Overall abundance/biomass is represented by the size of the circles and community composition by the various types of shading. After Hellawell (1986).

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 trace 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.

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 trace 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.

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.

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 a population of 28 135 and 8 294, in Saldanha and Langebaan respectively. 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. 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.

A reverse osmosis desalination plant for dust control at the iron ore terminal has been operational since August 2012 and an expansion to total a capacity of 3600 m^3/day of potable water is envisioned in the foreseeable future. Development of the port is expected to increase dramatically in the near future with the establishment of the Saldanha Bay Industrial Development Zone (SBIDZ) in October 2013. Other projects that are close to the implementation phase include the upgrade of the General Maintenance Quay and Rock Quay as well as new infrastructure to support import of liquid petroleum gas. Further proposed developments include the expansion of the iron ore terminal, a breakwater in Salamander Bay and potentially and if sufficient funds are available a new municipal reverse osmosis desalination plant.

Concerns have been raised that cumulative impacts on the marine environment in Saldanha Bay have not been adequately addressed by some of the recent development proposals. This applies especially to the cumulative impacts that will arise from future development within the Saldanha Bay IDZ. Furthermore, the impact on the Saldanha Bay marine environment by land-based projects such as storage facilities for crude oil and liquid petroleum gas has generally been underestimated. It was proposed that a more holistic management strategy was needed to deal with the piece meal Environmental Impact Assessments (EIA) and the solution was presented in form of a generic Environmental Management Programme (EMPr) which will become a requirement for every development that can be linked to the marine environment.

Disposal of wastewater is a major problem in the region, and much of it finds its way into the Bay as partially treated sewage, storm water, industrial effluent (brine, cooling water discharges and fish factory effluent) and ballast water. Sewage discharge is arguably the most important waste product that is discharged into Saldanha Bay in terms of its continuous environmental impact. Sewage is harmful to biota due to its high concentrations of nutrients which stimulate primary production 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.

Ballast water discharges are by far the highest in terms of volume and also continuous due to constant and increasing shipping traffic. Ballast water often includes high levels of contaminants such as trace metals and hydrocarbons, and, along with the vessels that carry the ballast water, serves to transport alien species from other parts of the world into Saldanha Bay. Ballast water discharges can, however, be effectively managed and the remit of the International Maritime Organisation (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 surface water containing pesticides, trace metals and hydrocarbons into the Bay during the rainy season, which can, in turn, be harmful to the environment and 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, as particles suspended in the water column kill suspension feeders like fish and zooplankton. It also limits the penetration of sunlight in the water column and causes die offs of algae and phytoplankton. The damage caused by dredging is generally 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 generally return in time.

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.

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 & Moldan 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 3.2). 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, 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.* 1991b) in the Bay. This led to reduced water exchange and increased nutrient loading of water within the Bay.

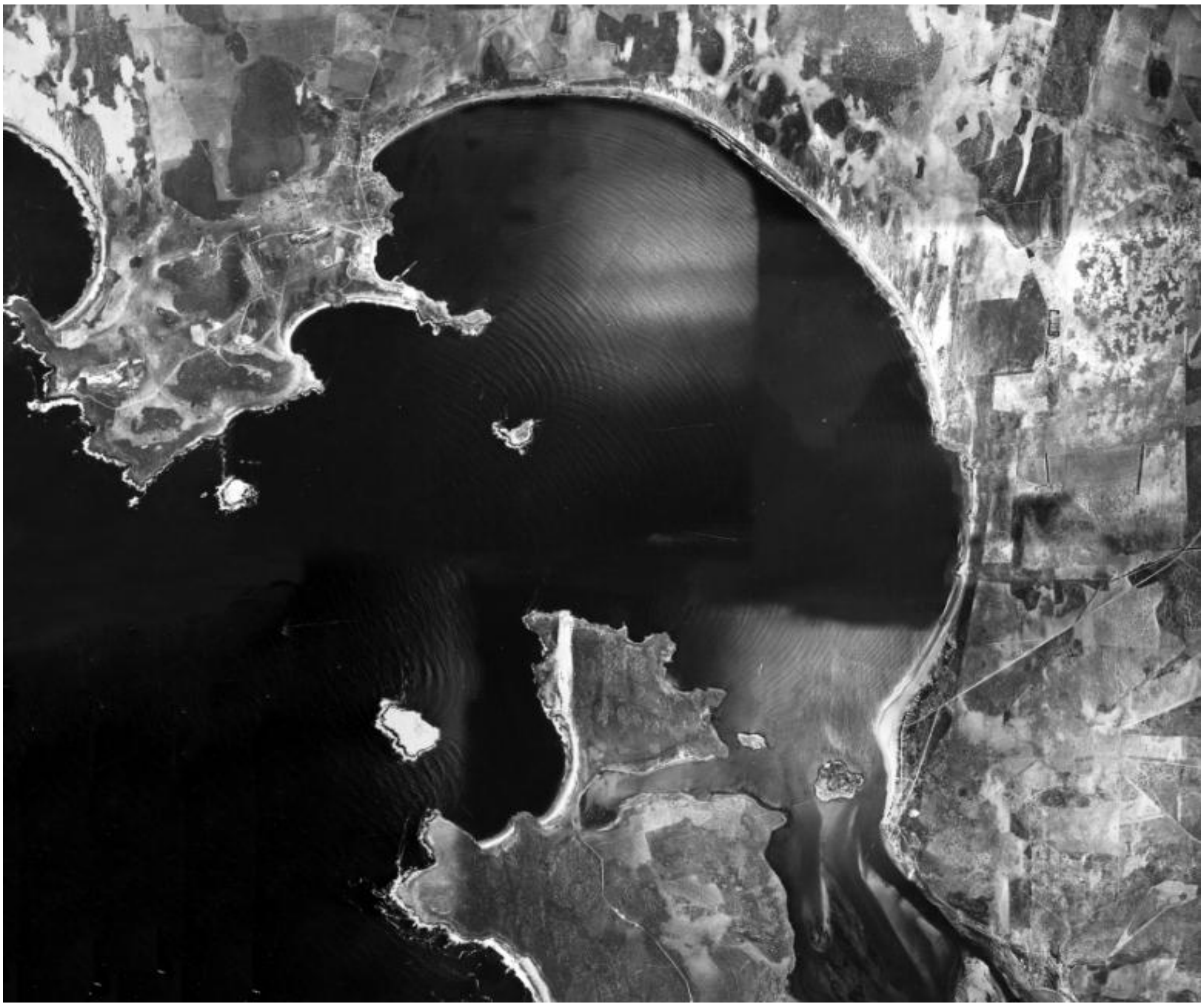


Figure 3.1. Composite aerial photo of Saldanha Bay and Langebaan Lagoon taken in 1960. (Source Department of Surveys and Mapping). Note the absence of the ore terminal and causeway and limited development at Saldanha and Langebaan.

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 3.1), 1989 (Figure 3.2) and in 2007 (Figure 3.3) clearly show the extent of development that has taken place within Saldanha By over the last 50 years.

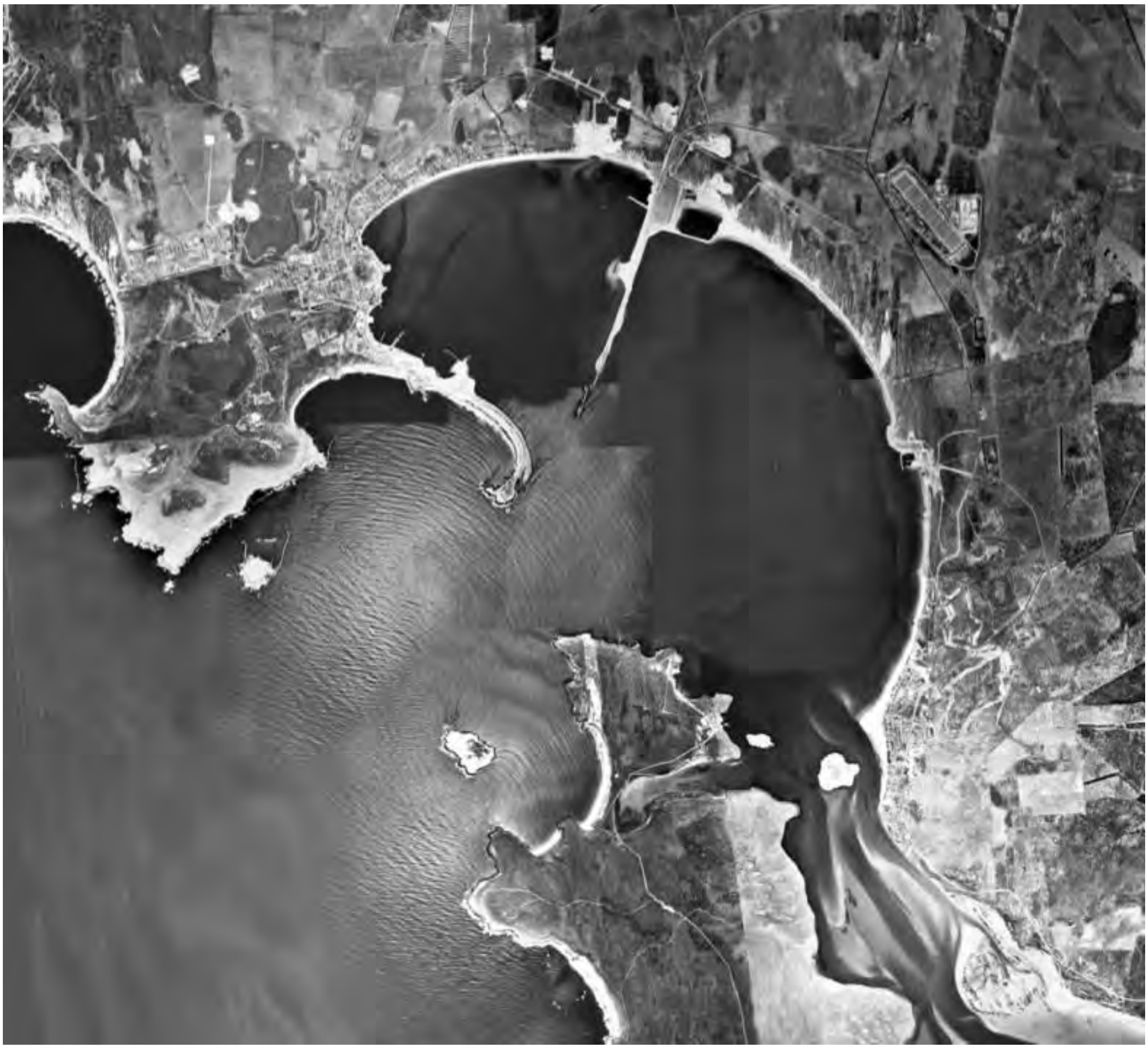


Figure 3.2. Composite aerial photo of Saldanha Bay and Langebaan Lagoon taken in 1989. (Source Department of Surveys and Mapping). Note the presence of the ore terminal, the causeway linking Marcus Island with the mainland, and expansion of settlements at Saldanha and Langebaan.

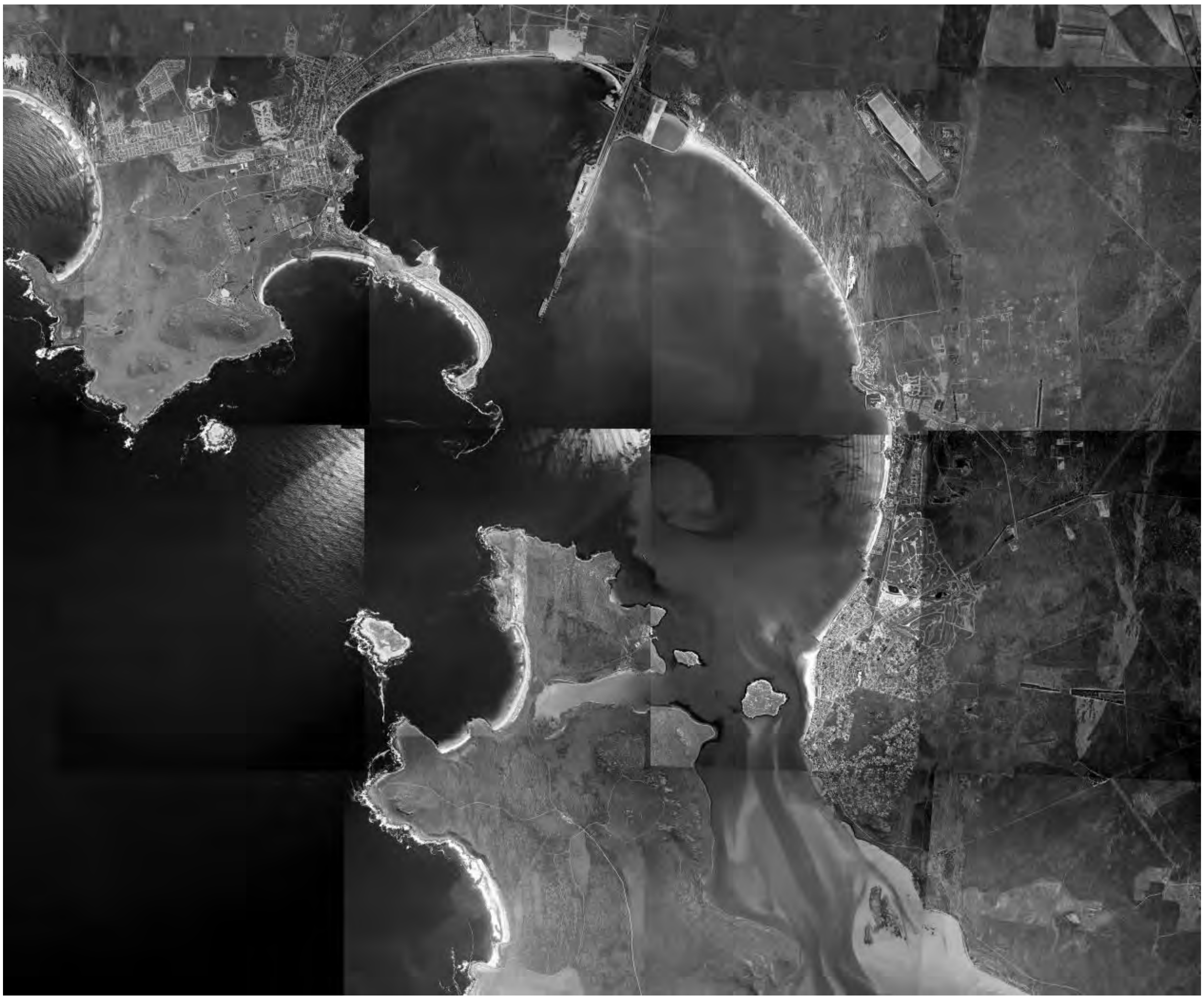


Figure 3.3. Composite aerial photo of Saldanha Bay and Langebaan Lagoon taken in 2007. (Source Department of Surveys and Mapping). Note expansion in residential settlements particularly around the town of Langebaan.

The National and Western Cape Provincial governments have great aspirations for the further expansion of the Port of Saldanha. A great variety of projects are in the planning phase or in the process of obtaining Environmental Authorisation (EA). Current and future projects planned for Saldanha Bay are described briefly in the Section 3.4. The current layout of the Port of Saldanha is shown in Figure 3.4. Future plans, including short term (2019) and long-term goals for the development of the bay are shown in Figure 3.5 and Figure 3.6.

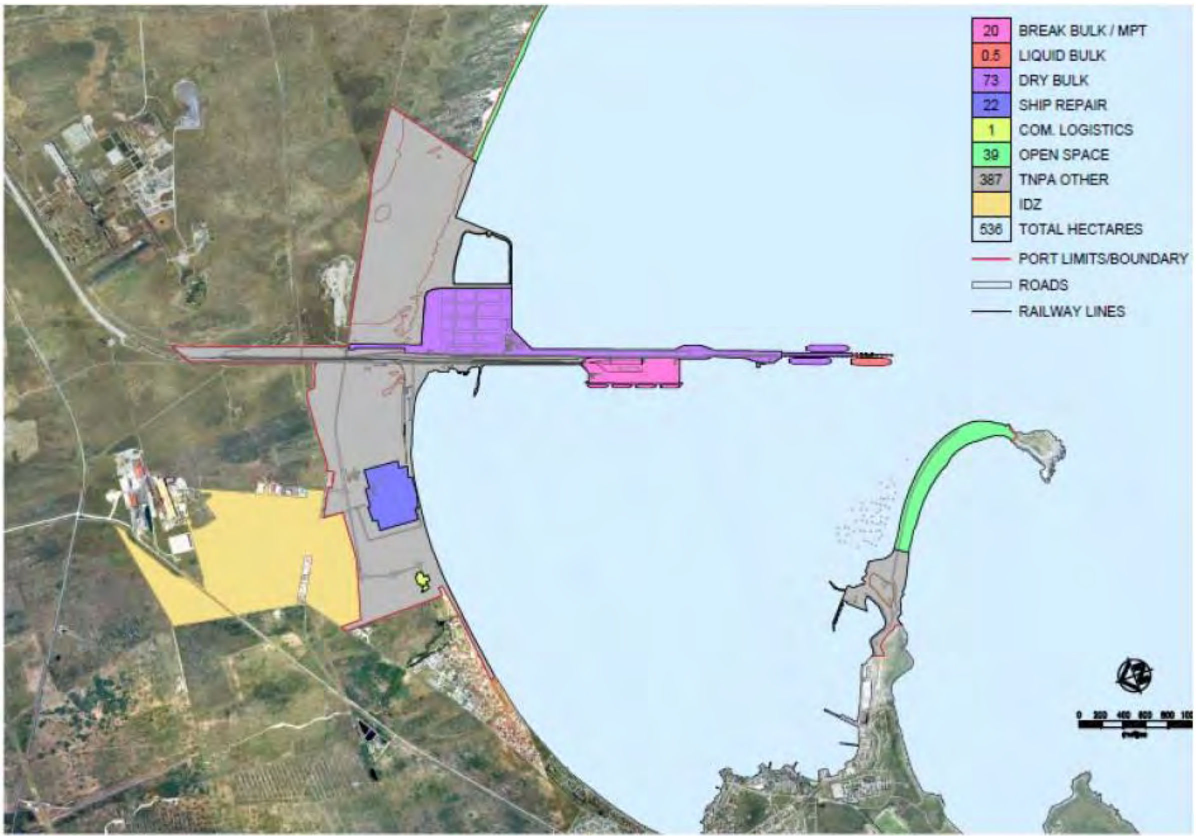


Figure 3.4. **Current layout of Transnet Saldanha Bay Port (Source: Transnet National Port Authority 2013, Port Development Framework Plans).**

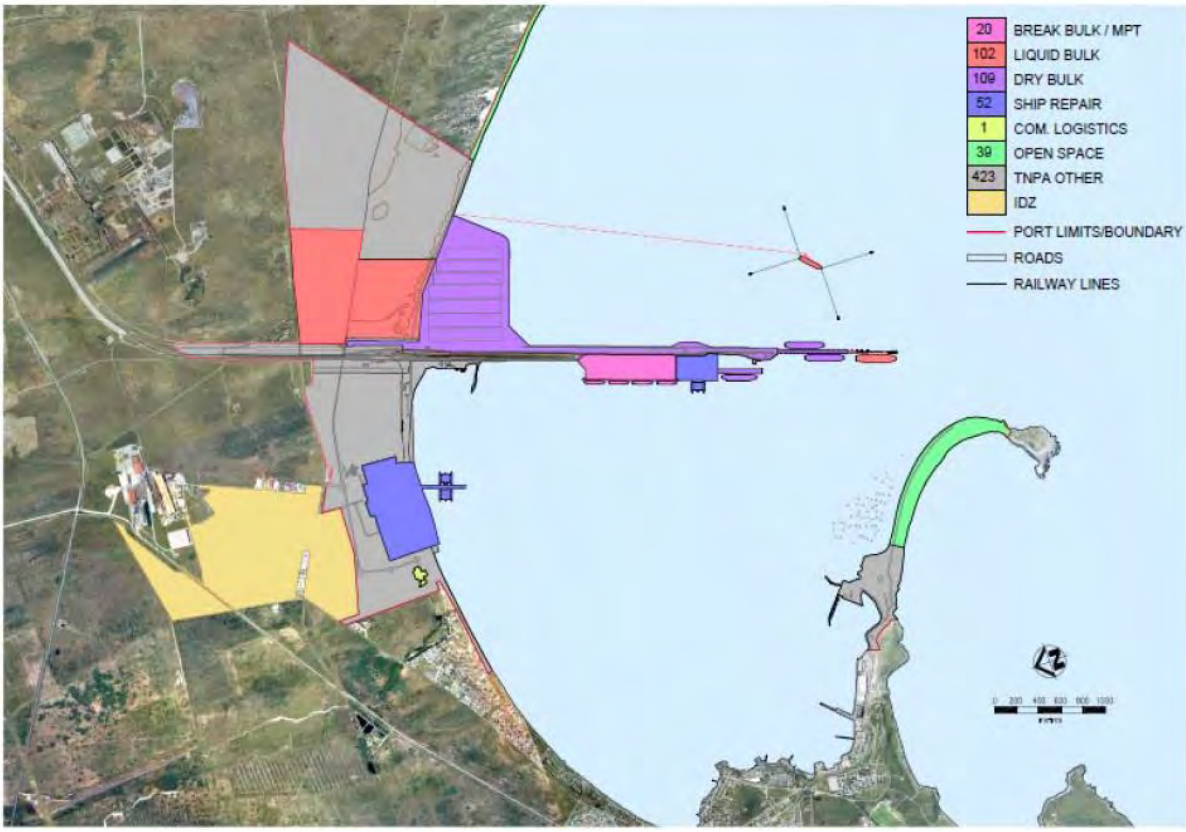


Figure 3.5. **Short term layout (2019) of Transnet Saldanha Bay Port (Source: Transnet National Port Authority 2013, Port Development Framework Plans).**

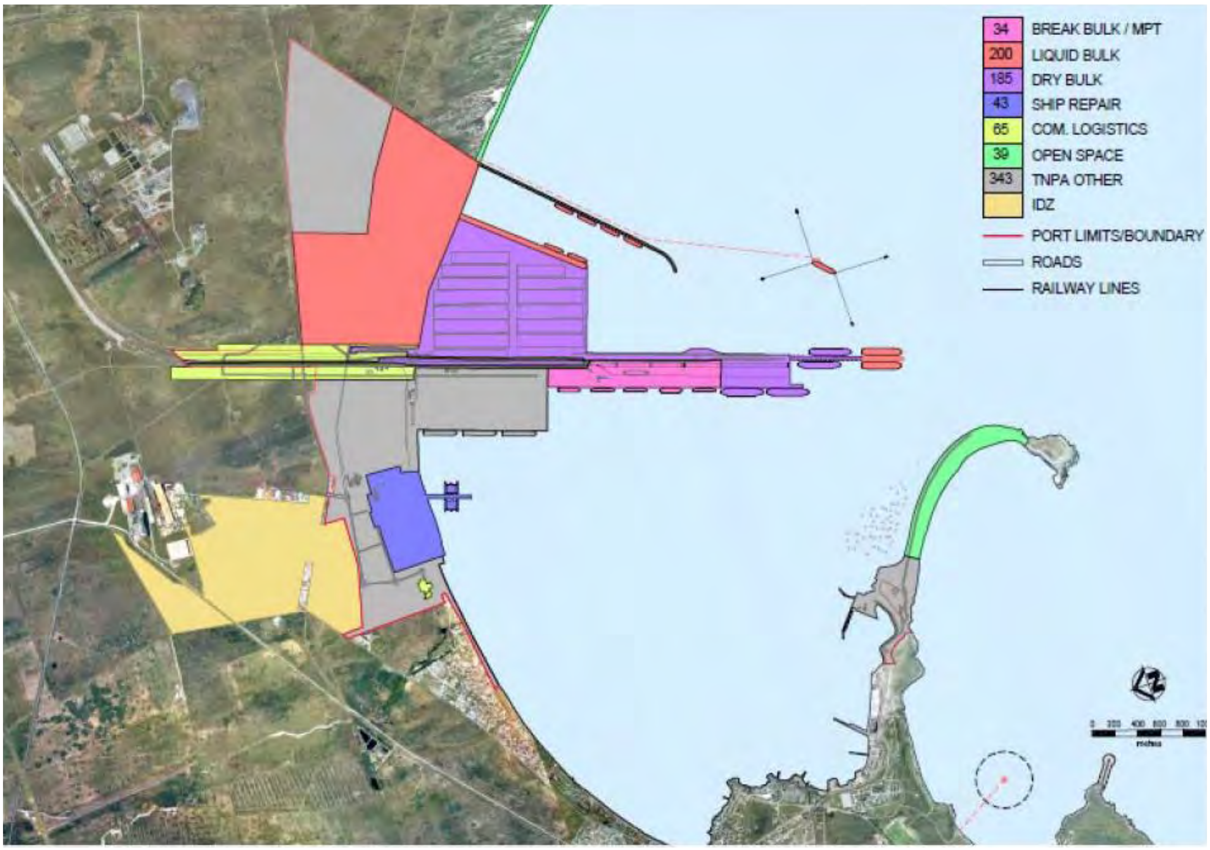


Figure 3.6. Long term layout of Transnet Saldanha Bay Port (Source: Transnet National Port Authority 2013, Port Development Framework Plans).

Data on population growth in the town of Saldanha and Langebaan Lagoon are available from the 1996, 2001 and 2011 census data. The population of Saldanha increased from 16 820 in 1996 to 21 636 in 2001 and to 28 135 in 2011, growth slowing from an initial rate of 5.7% per year in the first period to just 2.7%/yr in the second (Statistics South Africa 2014). In contrast, the Langebaan population increased from 2 735 to 3 428 between 1996 and 2001 (2.5% per year), and rapidly from there up to 8 294 in 2011 (a growth rate of 9.24%/yr) (Table 3.1) (Statistics South Africa 2014). The human population in Saldanha Bay, particularly that in Langebaan Village, is thus expanding rapidly, which has been attributed to the immigration of people from surrounding municipalities in search of real or perceived jobs (Saldanha Bay Municipality 2011). 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 3.7 and Figure 3.8). 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 3.4).

Table 3.1. Total human population and population growth rates for the towns of Saldanha and Langebaan from 2001 to 2011 (Statistics South Africa, 2014).

Location	Total Population 1996	Total Population 2001	Total Population 2011	Growth 2001-2011 (%/yr.)
Saldanha	16 820	21 363	28 135	2.66
Langebaan	2 735	3 428	8 294	9.24

Figure 3.7. Satellite image of Saldanha (Small Bay) showing little or no set-back zone between the town and the Bay. Source: Google Earth.

Figure 3.8. Composite aerial photograph of Langebaan showing absence of development set-back zone between the town and the lagoon. Source: Department of Surveys & Mapping, South Africa.

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 both strong seasonal trends in numbers of people visiting the park, peaking in the summer months and during the flower season, and a strong overall increase in the numbers of visitors over time (Figure 3.9). Overall, the total numbers of tourists visiting the park has been increasing at an average rate of 13% per annum since 2005[1], peaking in the 2012-2013 period with a total of 223 689 visitors (Figure 3.10).

[1] The average annual growth rate was calculated from the data reflecting the total numbers of tourists entering the West Coast National park in a rolling 12 month period from July 2005 until June 2014.

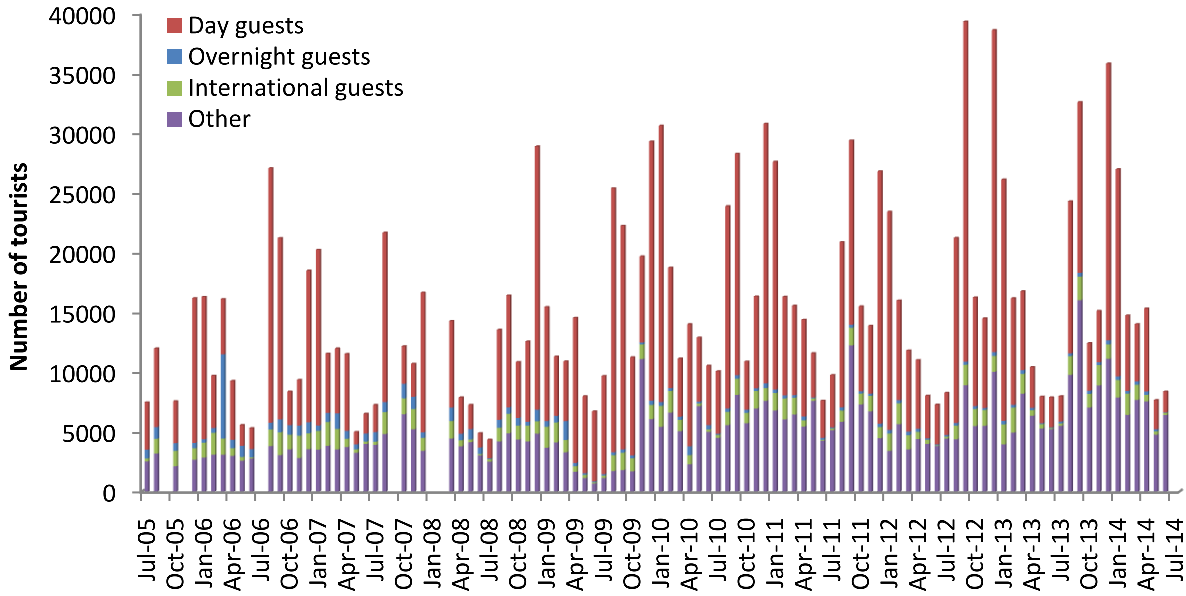


Figure 3.9. Monthly numbers of tourists visiting the West Coast National Park since 2005 (Source: Pierre Nel, WCNP). Day guests include all South African visitors (adults and children) while Overnight guests refer to those staying in SANPARK accommodation. International guests include all SADC and non-African day visitors (adults and children) while the category 'Other' includes residents, staff, military, school visits, etc.

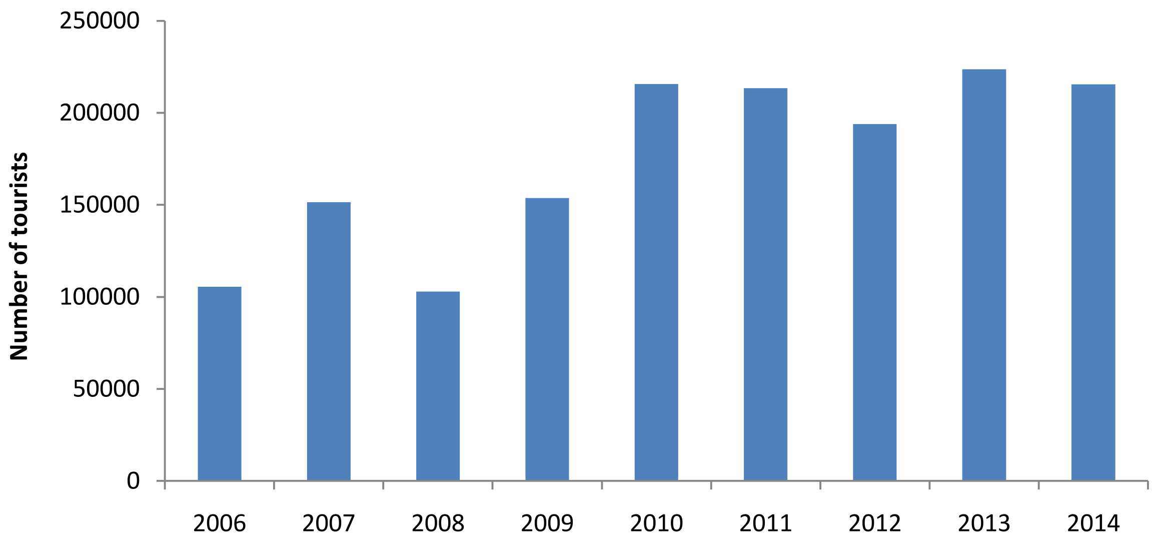


Figure 3.10. Total numbers of tourists visiting the West Coast National Park in a rolling 12 month period from July 2005 until June 2014 (Source: Pierre Nel, WCNP).

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 on-going 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 (SBM) 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.

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.

3.2.1 The Saldanha Bay Industrial Development Zone

Saldanha Bay has long been recognised as a strategically important industrial centre in the Western Cape, having great potential to promote sustainable development of the country as a whole. The suggestion to establish an Industrial Development Zone (IDZ) in Saldanha became increasingly stronger over time. IDZs are designated in terms the Industrial Development Zone Programme Regulations (R.1224 of the Manufacturing Development Act (no. 187 of l 993) which provide in Regulation 3 that:

(a) *The Minister may identify an area as suitable for development of an Industrial Development Zone by notice in the Gazette if the Minister is satisfied that designation of the area as an Industrial Development Zone will –*
   (1) facilitate the creation of an industrial complex having strategic economic advantage;
   (2) provide the location for the establishment of strategic investments;
   (3) enable the exploitation of resource-intensive industries;
   (4) take advantage of existing industrial capacity, promote integration with local industry and increase value-added production;
   (5) create employment and other economic and social benefits in the region in which it is located; and
   (6) be consistent with any applicable national policies & law, as determined by appropriate environmental, economic and technical analyses.

In 2008, the Western Cape Department of Economic Development and Tourism (DEDT), through Wesgro (the official Investment and Trade Promotion Agency of the Western Cape) appointed Demacon Consulting to conduct 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. This pre-feasibility study (completed in October 2009) was followed shortly by a more detailed feasibility study (Wesgro 2011) which culminated in an application from the Provincial Government of the Western Cape (PGWC) and SBM to the Department of Trade and Industry (DTI) for the designation of an IDZ within the Saldanha Bay area (Wesgro 2011).

On 13 October 2013, the Minister of Trade and Industry promulgated the IDZ at Saldanha Bay and granted the Operator Permit to the SBIDZ licensing Company (Saldanha Bay Industrial Development Zone LiCo) (Notice 1081 of 2013). The SBIDZ is intended as an Oil and Gas Marine Repair engineering and logistics services complex. The designation of the IDZ provides a contiguous customs-free area, designed to facilitate international investment in the area. The SBIDZ Licencing Company (LiCo) (a subsidiary of Wesgro) was assigned the responsibility for the promotion, management and marketing of the SBIDZ. The SBIDZ is envisioned to provide services in maintenance and repair fabrication as well as communal and supply services (Table 3.2). Proposed first phase developments that form part of the SBIDZ are described in Section 3.4. It appears that the impacts of the SBIDZ on the marine environment were insufficiently addressed, considering the likely impacts of increased vessel traffic on underwater noise and invasive alien species transfer; increased pollution of the Saldanha Bay through maintenance and repair activities; additional storm water runoff; and added pressure on the already regularly overflowing sewage works (Section 3.4.2) in Saldanha (Please refer to Chapter 12 Section 12.1 how this issue was addressed).

Table 3.2. Overview of the planned activities in the Saldanha Bay Industrial Development Zone (Adapted from Wesgro 2012)

Maintenance & Repair Services	Fabrication Services
• Maintenance, repair, upgrade and conversion of rigs and other vessels (floating repairs, dry docking) • Repair of parts and structures • Inspection, certification	• Structures, subsea manifolds • Spare parts
Communal Services	**Supply & other Services**
• Property development • Customs clearance • Marketing & administrative functions • Security, medical, food & retail • Utilities, waste management, transport • Road and quay access	• Bonded warehousing / storage - • Scheduling & forecasting • Logistics and transport – sourcing and forwarding (air, ship, rail and road) • Lifting, stacking, moving • Fuel bunkering • Pipe coating & upsetting • Tugging / piloting • Project and engineering services (e.g. EPC)

3.2.2 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 & 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 environment 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 & Lewis 2006, Bonvicini Pagliai *et al.* 1985, OSPAR Commission 2004, Transnet-NPA 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 & Mogensen 2000 in Erftemeijer & 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 3.11) (Port of Saldanha, Environmental Manager Nicole Abrahams, *pers. comm.* 2011). The environmental impact assessment for the proposed dredge event was undertaken by Environmental Resources Management Southern Africa (Pty) Ltd (ERM Southern Africa) in April 2008. The aim of the dredging was to increase the export capacity of the iron ore terminal through 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 Southern Africa 2008). It was considered a successful operation (Port of Saldanha, Environmental Manager Nicole Abrahams, *pers. comm.* 2012).

Figure 3.11. Location of the maintenance dredging site between Caissons 3 and 4 on the ore terminal.

In 2012, Transnet-NPA proposed an upgrade of the existing General Maintenance Quay and the Rock Quay in Saldanha Bay. This allows 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 General Maintenance Quay 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 are
- Reclamation (using dredged material) of the area between the Rock Quay and General Maintenance Quay to create an additional section of quay wall

An engineering report prepared by Prestidge 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 Transnet-NPA to conduct the required Basic Assessment (BA) in terms of the National Environmental Management Act (No. 107 of 1998) (NEMA). 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 -5 m 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 General Maintenance Quay. 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).

Environmental authorisation for this project was granted and the Draft EMPr was approved on 3 September 2013 (SRK Consulting, *pers. comm.* 2014). Construction companies have been invited to tender for this project and have been requested to submit their proposals by September. Construction will commence at the beginning of 2015 and is estimated to be completed just over a year later (PRDW, Project Engineer, Shaun Hayes, *pers. comm.* 2014).

3.2.3 The Sishen-Saldanha oreline expansion project

Currently, 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. In 2013, 308 iron ore ships arrived and departed from the Port of Saldanha.

In 2013, Transnet appointed GIBB engineering consultants to conduct a BA for the installation of a third iron ore tippler, which was completed in September 2013 (GIBB 2013b). A tippler unloads open bulk freight by rotating the rail wagon. It was motivated that this installation is required to back-up the other two tipplers, which are reaching the end of their life spans, such that 60 million tons per annum of iron ore can continue to be exported. EA was granted on 14 February 2014 and amended on 24 February 2014 to include an additional listed activity.

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 to 88 million tonnes/annum by 2017 in order to satisfy the global demand for iron ore. The Sishen-Saldanha oreline expansion project has three major components, namely a facility for emerging miners (mine-side ore loading), iron ore rail and a port iron ore terminal (GIBB 2013). The facility for emerging miners is envisaged to connect smaller mines directly to the railway and provide a platform for the off-loading, blending and stockpiling of iron ore. This project is currently in the pre-feasibility stage.

The iron ore rail expansion component aims to optimise the upgrade for the railway system. Environmental Resource Management Southern Africa (Pty) Ltd (ERM Southern Africa) were appointed to conduct a pre-feasibility study for the iron ore railway expansion component of the project, which was completed in 2012 (ERM Southern Africa, M. January, *pers. comm.* 2014). The pre-feasibility study was focused on stakeholder engagement and consultation with various engineers. Transnet is now conducting the feasibility stage with GIBB engineering consultants and this is due to be completed in 2015 (GIBB, J. Ball, *pers. comm.* 2014). Preliminary results show that the railway system can remain a single track, but the lengthening of existing and construction of new maintenance loop rail sections would be required (GIBB 2013). An EIA has not been conducted at this point in time (ERM Southern Africa, Tanja Swanepoel, *pers. comm.* 2014).

The iron ore terminal expansion component of the project proposed by Transnet SOC Limited is necessary to support an offloading and loading structure that can process larger volumes of iron ore as well as facilitating enhanced traffic of vessels for the export of the goods. GIBB engineering consultants were appointed by Transnet SOC Limited to conduct the pre-feasibility study and proposed main structures include the fourth tippler unit, the expansion of the stockyard (to 7 million tons), two additional stacker-reclaimers, one additional berth and two additional ship loaders. The conveyance, electrical and other associated infrastructure will also require upgrading. While most of the structures lie within the boundaries of the iron ore port, the berth and 4th tippler will be located outside the existing terminal footprint (GIBB 2013). The proposed project will involve the dredging of sediment and removal of hard material in the navigation channel near the proposed berth and will require an EIA process.

3.2.4 Development of a liquid petroleum gas facilities in Saldanha Bay

Liquid Petroleum Gas (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. The LPG industry is currently expanding to provide an alternative energy source in South Africa and to reduce the pressure on South Africa's electricity grid. In line with the National LPG Strategy (DEA&DP 2014), 1.5 million households are aimed to convert to LPG over the next five years. These new developments will contribute cumulatively to existing impacts in Saldanha Bay such as stormwater runoff and increased vessel traffic. The offloading of imported LPG in the harbour poses an additional pollution risk to the Saldanha harbour. Adherence to the approved Operational Phase EMP compiled for the offloading terminal is aimed at reducing this risk substantially.

Sunrise Energy (Pty) Ltd is currently building an LPG import facility in the Saldanha Bay Harbour and is scheduled to be completed in mid-2016 (Sunrise Energy (Pty) Ltd, Janet Barker, *pers. comm.* 2014*)*. This development aims to supplement current LPG refineries and distributors in the Western Cape and ensure that industries dependant on LPG can remain in operation. The information presented below is based uTON the information contained in the License Application to the Western Cape Department of Environmental Affairs & Development Planning (DEA&DP) (NERSA 2010), and conveyed in a presentation to the Saldanha Bay Water Quality Forum Trust in 2010. The project includes the following components (Figure 3.12) (ERM Southern Africa 2011):

(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.

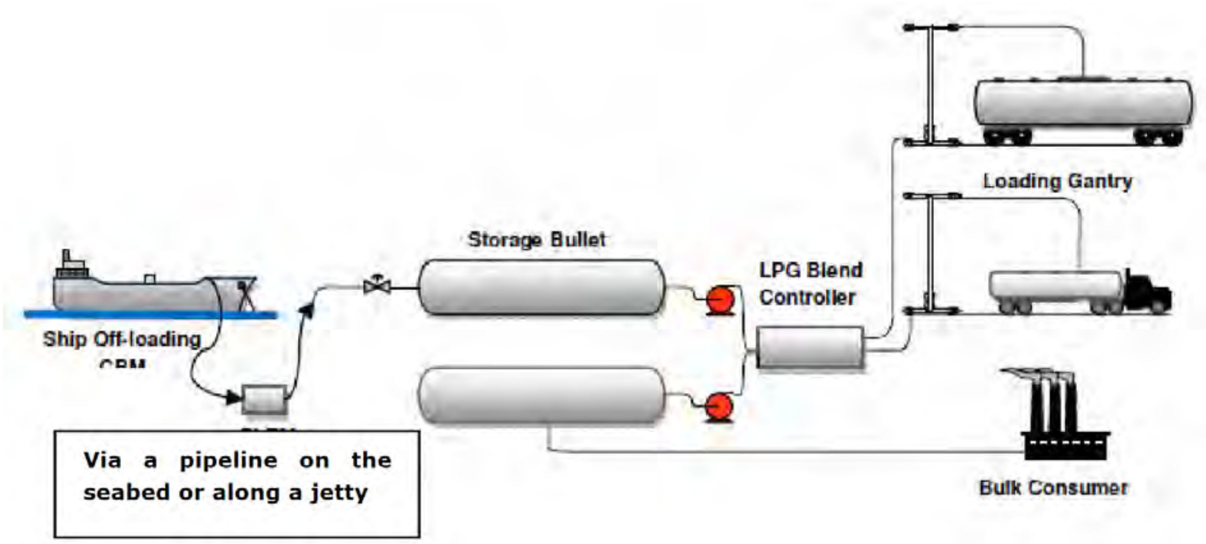


Figure 3.12. An illustration of a Liquid Petroleum Gas transfer scheme (Source: ERM Southern Africa, 2011).

An EIA process in terms of section 24 of the NEMA was initiated by ERM Southern Africa in 2012. 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 Southern Africa 2010). EA was granted on 13 May 2013 by the DEA&DP for the preferred alternative. The Draft EMPr 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. The bulk earthworks and site clearance on land commenced in January 2014 and is near completion, but the installation of infrastructure in the marine environment has not yet begun (Sunrise Energy (Pty) Ltd, Janet Barker, *pers. comm.* 2014*)*.

Avedia Energy has proposed developing a land based liquid petroleum gas storage facility on Portion 13 of Farm Yzervarkensrug No. 127 in Saldanha. The storage facility will include 16 mounded bullet tanks with a storage capacity of 250 metric tons each. The development will also entail the construction of a road tanker gantry, a cylinder storage facility for small commercial distribution and a water reservoir with a capacity to hold 500 m^3. Pipes for transporting LPG to the facility will also be constructed and the approximately 1000 m pipeline will be lead through 250 m of Critical Biodiversity Area (CBA). However, the construction will be restricted alongside a jeep track in the disturbed area of the CBA. The main development is situated on disturbed land. An approved stormwater management plan is in place to ensure treatment of stormwater by means of a bioretention area south of the proposed storage facility. EA was granted on 6 January 2014 and re-zoning of this portion from agricultural to industrial was recently approved. The Records of Decision of the EA were appealed and the outcome is still pending. The completion of the project was originally planned for March 2015, which could however be delayed by the appeal process (Frans Lesch, ILF Consulting Engineers, Project Manager at Avedia Energy Saldanha LPG plant, *Pers. Comm.* 2014).

3.2.5 Crude oil storage facility

The Port of Saldanha reportedly represents an excellent strategic location to receive, store process and distribute crude oil from West Africa and South America (SouthAfrica.info 2013). Oil tanking MOGS Saldanha (RF) (Pty) Ltd (OTMS), a joint venture between MOGS (Pty) Ltd and OTGC Holdings (Pty) Ltd, is in the final planning stage of a project to construct and operate a commercial crude oil blending and storage terminal with a total capacity of 13.2 million barrels, comprising twelve 1.1 million barrel in-ground concrete tanks in Saldanha Bay. The terminal will be situated on a portion of the farm Osfontein 194/0 in Saldanha Bay. The terminal will be linked to the existing port infrastructure by a 3 km long pipeline.

EA for this project was granted on 6 February 2013 after eight specialist studies had been undertaken by independent specialists. In addition to the EIA, OTMS decided to also conduct a maritime oil pollution control study to ensure that any and all of its environmental risks were adequately understood and addressed. This phase of the project lasted over two years. The tanks have been designed in such a manner that should an oil leak develop in one of the tanks, the oil will be collected in a separate layer underneath the tanks and relayed to a special collection point from where it will be pumped back into the tanks. This layer will be continuously monitored. In addition, ground water boreholes will be drilled around and between the tanks. The water from these holes will be analysed regularly to provide further monitoring. Construction is expected to start in 2015 once all required licences have been received and regulatory requirements met.

3.2.6 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 3.13). 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 3.13. The Salamander Bay boat park in Saldanha (central strip of the picture).

The construction activities commenced before an EIA had been conducted. An EIA was commissioned retrospectively in terms of section 24G of the National Environmental Management Amendment Act (NEMAA). 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 (Robinson 2010). 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 (Robinson 2010).

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 Chapter 5 and Chapter 7 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 3.14). Greenminded Environmental has been appointed to conduct the required basic assessment in terms of the NEMA. The BA Report has not yet been submitted to the Department of Environmental Affairs (DEA).

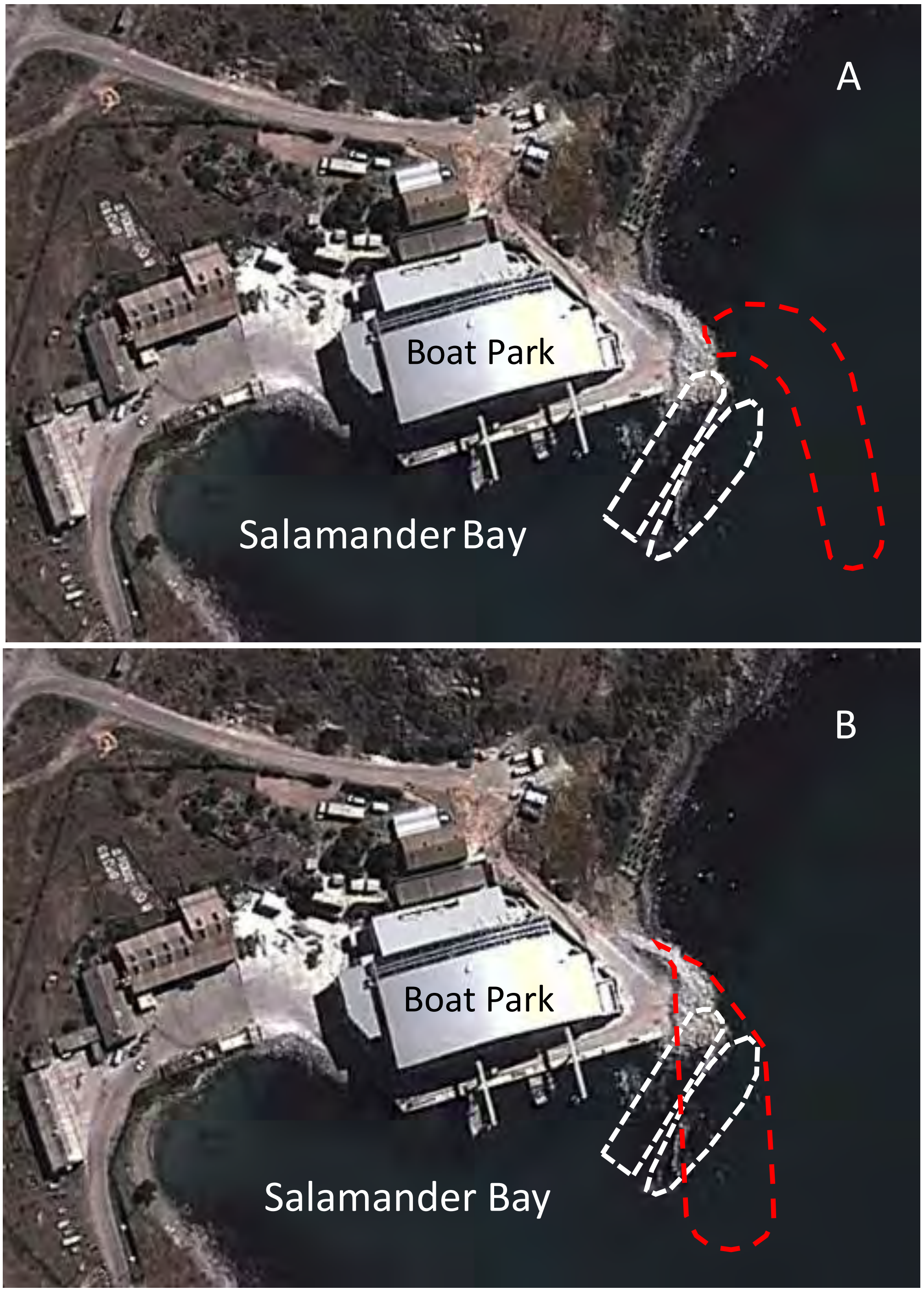


Figure 3.14. **Bird's eye view image of Salamander Bay showing the existing boat park, the two shipwrecks (white) and the site of the proposed breakwater (red). The breakwater may either be positioned A) on the outside of the two shipwrecks, or B) on top of sections of the shipwrecks (Anchor Environmental Consultants 2013a).**

3.3 Shipping, ballast water discharges, and oil spills

3.3.1 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 close to 500 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 3.4). There are also facilities for small vessel within the Port of Saldanha including the Government jetty used mostly by fishing vessels, the Transnet-NPA small boat harbour used mainly for the berthing and maintenance of Transnet-NPA 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 & 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 & Geller 1993). Carlton & 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 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 86 marine species (Peters *et al.* 2014) 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.* 2011a). 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 & Griffiths 2008). Recently, Peters *et al.* (2014) established that the brachiopod *Discinisca tenuis,* previously only known to occur in aquaculture facilities, has spread into the port of Saldanha and on the leeward side of Schaapen Island (Peters *et al.* 2014). Most of the introduced species are found in sheltered areas such as harbours and 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). More detail on alien invasive species in Saldanha Bay is provided in Chapter 11 of this report.

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 3.3). These discharges are almost certainly contributing to trace metal loading in the water column and are indicated by their concentration in filter-feeding organisms in the Bay (refer to Section 4.10).

Table 3.3. 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 uTON 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 2013, there were 475 ships which visited the port (Figure 3.15). 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 doubled since 2004, with almost 23 million tons of ballast water being discharged in 2013 (Figure 3.16). Overall, Iron ore tankers contributed 60% to the observed vessel traffic and 96% to the total water discharged in 2013 (Figure 3.16).

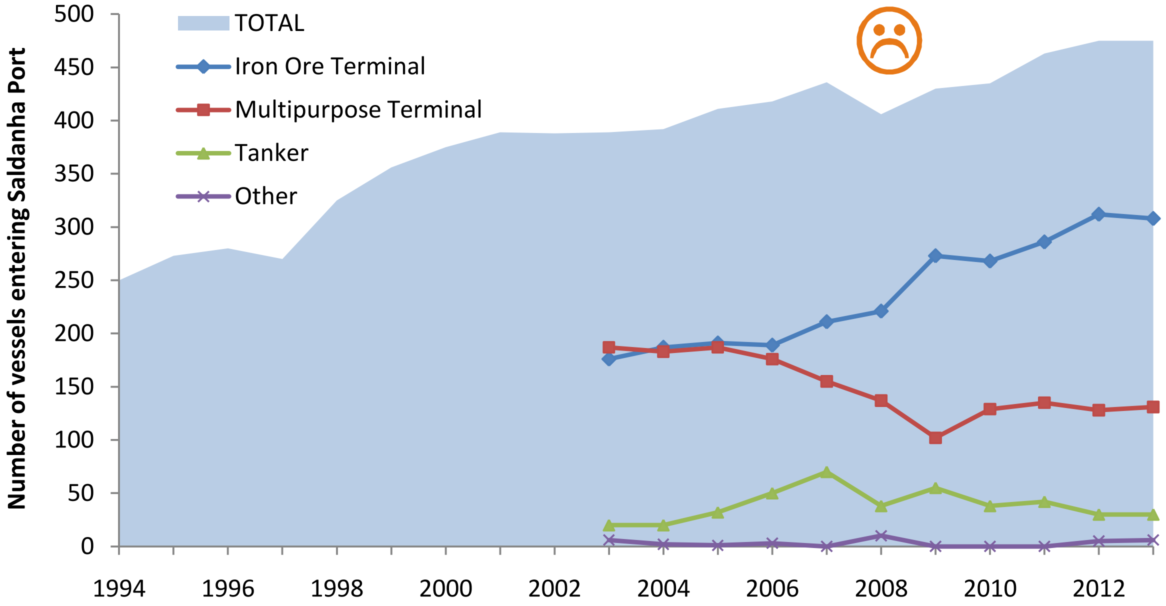


Figure 3.15. **The number and type of vessels entering Saldanha Port. The total number of vessels entering Saldanha Port between the years 1994 and 2013 is shown as the blue area. The numbers of vessels docking at the iron ore terminal, the multipurpose terminal, tankers and other vessels are shown in blue, red, green and purple respectively. Data for the different types of vessels is only available from 2003 to 2013 (Sources: Marangoni 1998, Awad *et al.* 2003, Transnet-NPA unpublished data 2003-2013).**

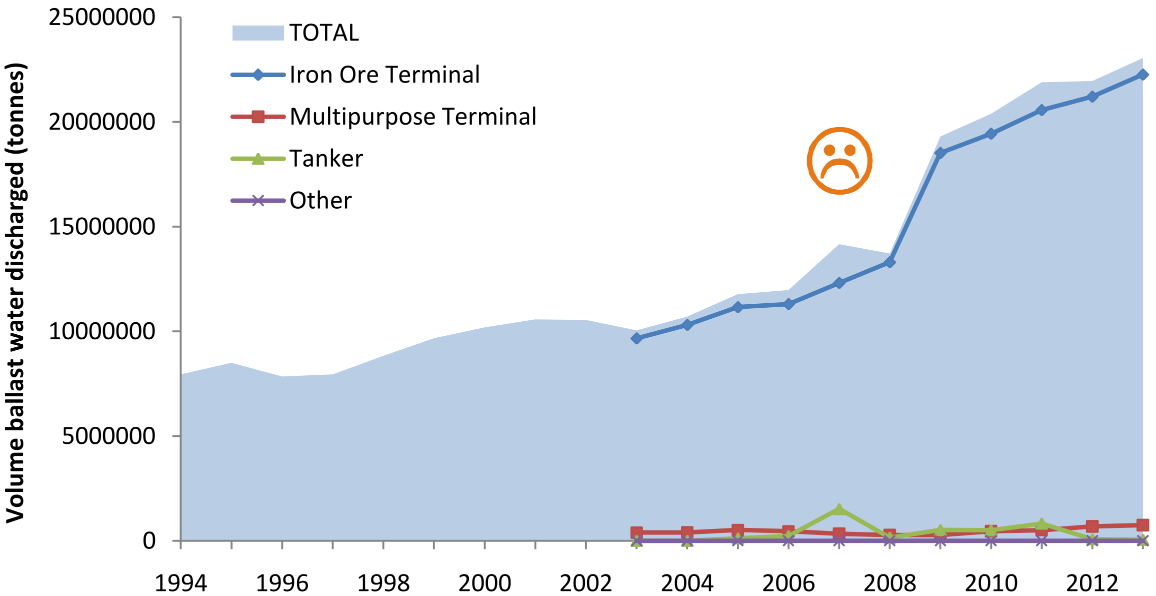


Figure 3.16. **Volumes of ballast water discharge in tonnes in Saldanha Port. The total amount of ballast water discharged in Saldanha Port between the years 1994 and 2013 is shown as the blue area. Ballast water discharged by vessels docking at the iron ore terminal, the multipurpose terminal, tankers and other vessels are shown in blue, red, green and purple respectively. Data for the different types of vessels is only available from 2003 to 2013 (Sources: Marangoni 1998, Awad *et al.* 2003, Transnet-NPA unpublished data 2003-2012).**

3.3.2 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 five major oil spills, two off Cape Town (1983 and 2000), one in the vicinity of Dassen Island (1994), one close to the St. Lucia estuary in KwaZulu-Natal (2002) and one in the Goukamma Nature Reserve (2013). In Saldanha Bay there have to date been no comparable oils spills (SAMSA, Martin Slabber *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 National Ports Authority 2007). 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.

UTON entry to the port, all vessels undergo an inspection by the Pollution Control Officer 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. Immediate containment of any minor spills is thereby ensured (SAMSA, Martin Sabber, *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).

3.3.3 Noise

A variety of noises are produced in the coastal underwater world, including short and high intensity sounds that are generated by underwater construction activities (for example pile driving) (Popper & Hastings 2009) as well as noise produced by shipping vessels which is characterised in wide spread and prolonged low frequency noise (Slabberkorn *et al.* In Press).

Impacts of noises in the coastal environment on fish behaviour and physiology have received a good deal of attention in recent years. For example Bregman (1990) described the 'auditory scene' of fishes which provides information from great distances or information at night for navigation, predator avoidance and prey detection. Consequences of a disturbance in the 'auditory scene' of fishes have been shown in captive three-spined sticklebacks (*Gasterosteus aculeatusI*) (Purser & Radford 2011). Foraging efficiency was significantly reduced when subjected to brief as well as prolonged noise, as more time was spent on attacking their prey due to a shift in attention. Several published studies have demonstrated the importance of sound in predator avoidance and prey detection (Knudsen *et al.* 1997, Konings 2001). Reproductive efficiency can also be affected as more than 800 fish species are known to produce sounds when spawning (Aalbers 2008) and during courtship (McKibben & Bass 1998). It has been suggested that entire fish assemblages in very noisy environments might be impacted by noise through reduced reproductive efficiency, thereby affecting number of individuals. For example, roach (*Rutilus rutilus*) and rudd (*Scardinius erythrophthalmus*) showed an interruption of spawning in the presence of noise produced by speed boats (Boussard 1981). Impacts of sound waves on fish physiology were investigated in controlled experiments where pile driving was lethal to some fish species (Caltrans 2001) but not for others (Abbot *et al.* 2005). The examination of dead and fatally injured fish revealed damaged and bleeding swim bladders (Caltrans 2001).

It appears that not all fish species respond to noise in the same way (Voellmy *et al.* 2014) and current research is insufficient to successfully predict the effects of noise on fish in the marine environment. It is recommended that a precautionary approach be adopted and that impacts of sound, especially future construction of infrastructure in the Port of Saldanha are mitigated. An air bubble curtain around a piling operations is commonly cited as an effective mitigation measure to reduce the sound transmission (Abbott & Bing-Sawyer, 2002, Bellmann & Remmers 2013). Producing bubbles around the noise source prevents transmission of sound due to the reflection and absorption of sound waves (Würsig *et al.* 2000).

3.4 Wastewater disposal

Management of water quality in inland and coastal water bodies around the world is generally achieved through a Receiving Water Quality Objectives (RWQO) approach where the physical, chemical and biological processes and uses of a particular (receiving) water body dictate the 'limits of discharge' for a particular operator or outfall. This differs from the effluent limit values (ELVs) approach in which fixed maximum concentrations or loads are applicable for contaminants in wastewater discharges for all users or outfalls, irrespective of where they are located. The "Water Quality Objectives Approach" requires the establishment of objectives and measurable targets for water quality depending on the requirements of the aquatic ecosystem and the beneficial uses of that water body (i.e. variable contaminant concentrations dictated by the use of the water body in question). Such beneficial uses can include human consumption (i.e. drinking water), aquaculture, irrigation, recreational use (e.g. bathing), industrial use (e.g. for cooling) or protection of biodiversity and ecosystem functioning (e.g. conservation areas). With the RWQO approach there is also recognition that effluent (and its associated contaminants) is rapidly diluted by the receiving waters as it enters the environment. In order to take advantage of this beneficial effect, allowance is generally made for a "mixing zone" which extends a short distance from the outfall point (or pipe end) and is an area in which contaminant levels are "allowed" to exceed the established water quality standards (or guidelines) for the receiving environment. The magnitude of the "mixing zone" should, in theory, vary in accordance with the sensitivity and significance of the receiving environment and the location of the outfall point in the environment, but in practice is usually set at a distance of around 100 m from the pipe end for marine systems.

South Africa has adopted the RWQO approach for the management of water quality in both inland (freshwater) and marine water bodies but also uses the ELV approach as a "fall-back" position. Receiving water quality guidelines have thus been published for the full range of beneficial uses for inland water (human consumption, aquaculture, irrigation, recreational use, industrial use, and protection of biodiversity and ecosystem functioning) and also for the marine environment (aquaculture, recreational use, industrial use, and protection of biodiversity and ecosystem functioning, Table 3.4), while *general and special standard*s have also been developed and are applicable to any effluent that is discharged into inland or marine water bodies (Table 3.5). The reason for the fall-back position is, in part, related to the challenges that have been experienced with the management of water quality management in coastal waters in recent years. Up until 1999, the Department of Water Affairs (DWA) was tasked with managing the disposal of land-derived effluent into the coastal environment in terms of the National Water Act (No 36 of 1998) (NWA). However, with the promulgation of the National Environmental Management: Integrated Coastal Management Act (No. 24 of 2008) (ICMA), responsibility for regulating land-derived effluent discharges into coastal waters was transferred to the DEA. In terms of this Act, exemptions were issued to proponents who, at the time of promulgation, were discharging effluent into the surf zone and estuaries in terms of permits issued under the NWA, provided that the effluent was treated to meet the *General and Special Standard* (Government Gazette No. 20526, 8 October 1999), and provided that they applied for a Coastal Waters Discharge Permit (CWDP) within three years of this date. New operators wishing to discharge effluent to coastal waters were required to apply for a CWDP before commencing and were also required to comply with the applicable RWQO guidelines, or as a minimum, the *General and Special Standard* from the date of commencement. Applications for CWDP are expected to include data on contaminant levels in the effluent to be discharged, as well as results of dilution and dispersion model studies indicated maximum expected levels for the same contaminants at the edge of the defined mixing zone. (These levels are of course expected to comply with published guideline levels as defined by other existing, or potential, beneficial uses of the receiving environment.)

Table 3.4. South African Water Quality Guidelines for Coastal Marine Waters (1995, 2012): Natural Environment, Industrial Use, Mariculture and Recreational Use

	Natural Environment	Industrial Use	Mariculture	Recreational Use
		PHYSICO-CHEMICAL PROPERTIES		
Temperature (°C)	The maximum acceptable variation in ambient temperature is ±1 °C			For prolonged exposure, temperatures should be in the range 15-35°C
Salinity (ppt)	33-36	33-36		
pH	7.3-8.2	7.3-8.2		pH of water should be within the range 5.0–9.0, assuming that the buffering capacity of the water is low near the extremes of the pH limits.
Floating matter including oil and grease **(Listed as Objectionable Matter in DEA 2012)**	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; Water should not contain submerged objects and other subsurface hazards which arise from non-natural origins and which would be a danger, cause nuisance or interfere with any designated/recognized use			Water should not contain litter, 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 objectionable deposits. Water should not contain submerged objects and other subsurface hazards which arise from non-natural origins and which would be a danger, cause nuisance or interfere with any designated/recognized use. Water should not contain substances producing objectionable colour, odour, taste, or turbidity.
Colour/turbidity/ clarity	Should not be more than 35 *Hazen units* above ambient concentrations (colour) Should not reduce the depth of the euphotic zone by more than 10 % of ambient levels measured at a suitable control site (turbidity)			
Suspended solids	Should not be increased by more than 10 % of ambient concentrations			
Dissolved -Oxygen	For the west coast, the dissolved oxygen should not fall below 10 % of the established oxygen - natural variation. For the south and east coasts the dissolved oxygen should not fall below 5 mg l^{-1} (99 % of the time) and below 6 mg l^{-1} (95% of the time)	-	For the west coast, the dissolved oxygen should not fall below 10 % of the established oxygen - natural variation. For the south and east coasts the dissolved oxygen should not fall below 5 mg l^{-1} (99 % of the time) and below 6 mg l^{-1} (95% of the time)	
		NUTRIENTS		
Ammonium	600 (NH_3 plus NH_4^+)	Waters should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing dissolved oxygen concentrations below the target range indicated for *Dissolved oxygen*		N/A
Nitrite **Nitrate** **Reactive phosphate** **Reactive silicate**	Waters should not contain concentrations of dissolved nutrients that are capable of causing excessive or			

	nuisance growth of algae or other aquatic plants or reducing dissolved oxygen concentrations below the target range indicated for *Dissolved oxygen*			
INORGANIC CONSTITUENTS				
Ammonia	20 µg N l^{-1} (as NH_3) 600 µg N l^{-1} (as NH_3 plus NH_4^+)	-	20 µg N l^{-1} (as NH_3) 600 µg N l^{-1} (as NH_3 plus NH_4^+)	
Cyanide	12 µg l^{-1}	-	12 µg l^{-1}	
Fluoride	5000 µg l^{-1}	-	5 000 µg l^{-1}	
Chlorine	-	-	-	
Hydrogen sulphide	-	-	-	
Arsenic	12 µg l^{-1}	-	12 µg l^{-1}	
Cadmium	4 µg l^{-1}	-	4 µg l^{-1}	
Chromium	8 µg l^{-1}	-	8 µg l^{-1}	
Copper	5 µg l^{-1}	-	5 µg l^{-1}	
Lead	12 µg l^{-1}	-	12 µg l^{-1}	
Mercury	0.3 µg l^{-1}	-	0.3 µg l^{-1}	
Nickel	25 µg l^{-1}	-	25 µg l^{-1}	
Silver	5 µg l^{-1}	-	5 µg l^{-1}	
Tin	-	-	-	
Zinc	25 µg l^{-1}	-	25 µg l^{-1}	
ORGANIC CONSTITUENTS				
Organotins (Tributyltin)	-	-	-	N/A
Total petroleum hydrocarbons	-	-	-	
Polycyclic aromatic - hydrocarbons	-	-	-	
MICROBIOLOGICAL INDICATOR ORGANISMS				
Faecal coliforms (including *E. coli.*)	-	-	Maximum acceptable count per 100 ml: • 20 in 80 % of the samples • 60 in 95 % of the samples	
Intestinal Enteroccoci[1]				
• **Excellent (2.9% gastrointestinal illness risk)**				≤ 100 CFU/100 ml (95 percentile)
• **Good (5% GI illness risk)**				≤ 200 CFU/100 ml (95 percentile)
• **Sufficient or Fair (minimum requirement) (8.5% GI illness risk)**				≤ 185 CFU /100 ml (90 percentile)
• **Poor (unacceptable) (>8.5% GI illness risk)**				≤ 185 CFU /100 ml (90 percentile)
Escherichia coli[1]				
• **Excellent (Excellent 2.9% gastrointestinal illness risk)**				≤ 250 CFU (95 percentile)
• **Good (5% GI illness risk)**				≤ 500 CFU (95 percentile)

• **Sufficient or Fair (minimum requirement) (8.5% GI illness risk)**				≤ 500 CFU (90 percentile)
• **Poor (unacceptable) (>8.5% GI illness risk)**				> 500 (90 percentile)
Clostridium perfringens[2]				Geometric mean ≤5 counts per 100 ml
Toxic substances				Consult South Africa's drinking water quality guidelines (e.g. SANS 2005) taking account of the fact that recreational exposure may result in an intake of 200 ml and not 2000 ml/day as is generally assumed for these guidelines

1. Note that a number of different methods are available for calculation of percentiles for bacterial counts. RSADepartment of Environmental Affairs (2011) recommend using the non-parametric Hazen method (i.e. using data ranking) for this purpose but indicate that the Excel spreadsheet method can also be applied where users do not have access to a suitable Hazen template.
2. Only applicable in tropical waters

In the case of Saldanha Bay, which is extremely important for biodiversity conservation (there are several Marine Protected Areas (MPAs) in the Bay), is also an important regional centre for aquaculture (mussels, oysters, finfish), is important for recreation (swimming, kite surfing, windsurfing, etc.), and an area from where water is abstracted for industrial purposes (cooling water and desalination), the most stringent receiving environment water quality guidelines should be applicable. In practice though, very few operations that discharge wastewater into the Bay have applied for a CWDPs (even though 5 years has elapsed since the promulgation of the ICMA, even fewer have completed the requisite hydrodynamic dilution and dispersion modelling studies required to estimate concentrations of contaminants at the edge of the mixing zone, and even fewer still, actually take measurements at the edge of the mixing zone. As a result, compliance checking is usually undertaken in respect of general or special effluent quality standards, for which at least some data exist.

Table 3.5. General Limit as specified in the revised general limit for general authorisation specified under the National Water Act (No. 36 of 1998)

Substance/parameter	General limit as specified in the general and special standards 1999 (government gazette no. 20526, 8 October 1999)
Temperature	-
Faecal Coliforms (per 100 ml)	1000
Electrical Conductivity measured in milliSiemens per meter (mS/m)	70 mS/m above intake to a maximum of 150 mS/m
pH	5.5-9.5
Chemical oxygen demand (mg/l)	75 (after removal of algae)
Suspended Solids (mg/l)	25
Soap, oil or grease (mg/l)	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)	3
Fluoride (mg/l)	1
Chlorine as Free Chlorine (mg/l)	0.25
Dissolved Cyanide (mg/l)	0.02
Dissolved Arsenic (mg/l)	0.02
Dissolved Cadmium(mg/l)	0.005
Dissolved Chromium (VI) (mg/l)	0.05
Dissolved Copper (mg/l)	0.01
Dissolved Iron (mg/l)	0.3
Dissolved Lead (mg/l)	0.01
Dissolved Manganese (mg/l)	0.1
Mercury and its compounds (mg/l)	0.005
Dissolved Selenium (mg/l)	0.02
Dissolved Zinc (mg/l)	0.1
Boron (mg/l)	1
Phenolic compounds as phenol (mg/l)	-

3.4.1 Reverse osmosis desalination plants

Desalination refers to a water treatment process whereby salts are removed from saline water to produce fresh water. Reverse Osmosis 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. Water is relatively scarce in the West Coast District Municipality (WCDM). The rapidly developing industry in Saldanha Bay, especially the transport of iron ore to from the mines to the Port of Saldanha, require vast quantities of potable water to mitigate impacts on air quality by iron dust in the Saldanha area. Building reverse osmosis desalination plants is a solution to reduce dependency of the industry on municipal water supplies. One desalination plant was built in Saldanha by Transnet-NPA and is operational while a second has been proposed by WCDM.

Transnet-NPA Desalination Plant

The Transnet-NPA Desalination Plant was required to produce freshwater for dust mitigation during the loading and offloading of iron ore (Figure 3.17). Initially, an additional 1200 m^3/day (1 RO unit) of fresh water was considered to supplement the current municipal allocation. However, Transnet chose to install two RO module instead to double the capacity to 2400 m^3/day. 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 units) to reduce dependency on municipal water as far as possible. EA was granted for this project on 11 November 2008. Subsequently, the project which involved the design, manufacture, supply, delivery to site, installation, testing and commissioning of two RO units with 1200 m^3/day capacity, was awarded to Veolia (Membrane Technology 2013). Transnet-NPA obtained a Water Use License from the DWA in January 2012. Construction and a performance test were completed in August 2012 and the RO desalination plant has since been operational (Membrane Technology 2013).

Figure 3.17 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.

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.

Approximately 45% of sea water taken in by the intake system is converted to potable water, while 55% is returned to the sea as brine and backwash waste. The seawater is passed through a pre-treatment process to remove suspended solids, biological matter and other particles that may clog the RO membranes. Pre-treatment also entails 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 is passed through a dual media filter to remove suspended solids and organics, which must be backwashed periodically. The pre-treated sea water is then 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 is then discharged into the sea and the potable water is diverted to the storage reservoir(s), with a capacity of 5 000 m^3, for use in dust mitigation. The flocculant and non-oxidising biocide used during the pre-treatment process as well as the anti-scalant are blended and discharged with the brine into the sea. So called Cleaning In Place chemicals are used for the cleaning of the reverse osmosis membranes, and the wash water containing these chemicals is disposed of either via the municipal sewer system (with approval from the municipality) or at a suitable disposal site, and is not contained in the brine discharged back into the ocean.

A BA for the reverse osmosis plant 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 in the effluent;
- the effects of co-discharged wastewater 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 to ensure that impacts in the marine environment are such that the beneficial uses of the potentially impacted area are considered. 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 of the physical and chemical characteristics of the receiving environment were conducted during the period June 2010 to March 2011 in order to establish a baseline prior to the RO plant coming into operation (van Ballegooyen *et al.* 2012). No follow-up monitoring has been done at this point in time.

West Coast District Municipality Desalination Plant

The WCDM has proposed the construction of an additional RO plant in the Saldanha Bay area, intended as a long-term sustainable alternative water source. 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. This is clearly evidenced by the fact that the WCDM has exceeded its water allocation for the last six years. In the financial year 2012/2013, abstractions for the WCDM exceeded allocation by 3.6 million m^3 (DWA 2013). 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 identified as a 25 500 m^3/day sea water desalination plant. 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. A Scoping and EIA Process was required in order to ensure compliance with the NEMA as amended and the EIA Regulations of June 2010. The Council for Scientific and Industrial Research (CSIR) was commissioned by WorleyParsons South Africa (Pty) Ltd to prepare an environmental screening study which identified potential impacts with ten alternative locations and associated infrastructure routes for power and pipelines. Taking into account technical, financial and environmental concerns, two were identified as the most feasible with minimal impacts. These sites were investigated in further detail during the EIA phase and are included in the Final EIA Report (CSIR 2012a).

EA was granted on 13 August 2013 for the preferred location for the RO plant, which will be situated on the farm Klipdrift at Danger Bay on a portion of municipal owned land. Both the intake and discharge lines will be located in Danger Bay (Figure 3.18). 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 threatened (vulnerable) 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 impacts are likely to have medium significance (CSIR 2012a).

The alternative scenario involved the construction of the RO plant on the property of the ArcelorMittal Smelter situated in the Saldanha Bay IDZ, where the marine feed water intake would have operated in Big Bay, while the brine discharge was considered to be situated in either Big Bay or Danger Bay. This alternative was less suitable for several reasons. Firstly, long-term access to the Transnet iron ore jetty would have been required and was not granted by Transnet during the EIA process. Secondly, quality of the intake water may be of concern in future. For example the presence of sediment, organic nutrients, bacteria, trace 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 2012a). Finally, discharging concentrated brine from such a large RO facility into Big Bay would add considerable pressure to the system in Saldanha Bay.

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 installation of the 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 3.18. Map showing location of intake and discharge points for the West Coast District Municipality desalination plant in Danger Bay (Source: CSIR 2012a).

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 wastewater 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.

Given the “no-go” alternative with predicted severely limited water supplies for the WCDM, the mitigation of these impacts is seen to be the most logical way forwards.

According to international guidelines (WHO 2007, UNEP 2008), a study of the physical, microbial and chemical characteristics, meteorological and oceanographic data should be collected at all alternative sites considered for the development. Technically, this information should have informed the choice of the preferred alternative. However, the operation of such a pilot plant requires EA as well as a CWDP and the latter was not issued within the time frame of the EIA process of the RO plant (CSIR 2012b). After EA was granted for the RO plant in Danger Bay, a pilot plant was constructed and operated in Danger Bay by WorleyParsons South Africa (Pty) Ltd to test methods for the pre-treatment of seawater (CSIR 2012b). A report of the pilot study is currently not available.

It is estimated that the proposed desalination plant and bulk infrastructure will cost R500 million, which is more than double the initially estimated cost. As a result, funding is currently a major challenge for the WCDM. Should funds become available, construction of this RO plant is planned to be executed in three phases, with the initial capacity of 8.5 million litres and leading up to achieving a final capacity of 25.5 million litres. Alternatively, a recent revision of the feasibility study revealed that the Berg River may have surplus water that could be extracted for the WCDM and an application for additional allocation of water sourced from the Berg River was submitted by the WCDM. In the event that this additional allocation is granted to the WCDM, the desalination plant will be put on hold for the next ten years.

3.4.2 Sewage and associated wastewaters

Environmental impacts

Sewage is by far the most dominant waste product discharged into rivers, estuaries and coastal waters worldwide. However, sewage is not the only organic constituent of wastewater, 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 wastewaters 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 wastewater 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 & Duarte 2008, Howarth *et al.* 2011). Vaquer-Sunyer & 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 & 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 & 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 & 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 & McGibbon 1991, Stenton-Dozey *et al.* 2001, Kruger 2002, Kruger *et al.* 2005). Tourism and mariculture are both important growth industries in and around Saldanha Bay, and both are dependent on good water quality (Jackson & McGibbon 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 & Largier 1999).

Treatment of effluent is pivotal in reducing the environmental impacts described above. However, the side effects of treating effluent with chlorine have been well established in the literature. 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 revised General and Special Standard (Government Notice No. 20526 –8 October 1999) promulgated under the NWA. Furthermore, chlorine, while disinfecting the effluent, produces a range of toxic disinfection by-products (DBPs) through its reactions with organic compounds (Richardson *et al.* 2007, la Farré *et al.* 2008, Sedlak & von Gunten, 2011).

Management of treated effluent in Saldanha Bay

There are two Wastewater Treatment Works (WWTW) that release treated effluent into Saldanha/Langebaan marine environment, namely the Saldanha WWTW and the Langebaan WWTW (Figure 3.19). Twenty seven sewage pump stations in Langebaan are situated throughout the town, many of which are near the edge of the lagoon and 16 sewage pump stations are located in Saldanha Bay (Figure 3.19). Problems have been encountered when pump stations in Saldanha Bay overflow due to malfunction or power failures and raw sewage is released directly into Saldanha Bay. This was particularly dangerous to human health and also damaging to the sea-based mariculture sector in Saldanha, which relies on good water quality in the Bay. To address this issue, upgrades to the pump stations in Saldanha Bay commenced in 2012 and thus far ten pump stations have been upgraded. This year, final upgrades will be implemented for the main pump station and several of the smaller ones will also be refurbished. Reportedly, the pump station in Pepper Bay recently overflowed several times due to electrical issues. Apart from improvements to this pump station, a backup generator will also be provided to further reduce the risk of overflow in the future (SBM, Gavin Williams, *pers. comm.* 2014).

There are approximately 200 conservancy tanks in Langebaan, east of Club Mykonos (SBM, Elmi Pretorius, *pers. comm.* 2014). Seepage or overflow from these septic or conservancy tanks has also contributed to the pollution of the Saldanha/Langebaan marine environment in the past. However, overflow of these tanks is considered an unlikely event today, as the municipality empties these tanks on a regular basis (SBM, Gavin Williams, *pers. comm.* 2014).

Details on the two WWTW are provided below, which present data on monthly trends in the effluent discharged by the WWTWs. Data was provided by the SBM and water quality parameters recorded as “trace”, “less than” or “greater than” was adjusted in accordance with the following standard international convention:

- “trace” = half the detection limit
- “less than” = half their detection limit
- “greater than” = detection limit multiplied by a factor of three

Concentrations of contaminants in the effluent are compared with the General Discharge Limits of the revised General and Special Standard (Government Notice No. 20526 –8 October 1999) promulgated under the NWA (Table 3.5).

Figure 3.19. **Location of wastewater treatment works, sewage pump stations and sewer pipes in the Saldanha and Langebaan area in 2014 (Source: Saldanha Bay Municipality, Elmi Pretorius 2014).**

Saldanha Wastewater Treatment Works

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 wastewater from a range of industries in Saldanha:

- Sea Harvest
- Hoedtjiesbaai Hotel
- Protea Hotel
- Bongolethu Fishing Enterprises
- SA Lobster
- Cape Reef Products
- Transnet Port Authority
- 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). The effective functioning of WWTW is largely dependent on the quality of sewage that is directed into the plant by the industry. Local by-laws are utilised to control the extent to which industries have to treat their effluent before it is directed into municipal wastewater treatment works. These by-laws were found to be not sufficient in regulating wastewater received from the industries and it has been suggested that regulatory standards should be determined on a national level (Eddy 2003).

The Saldanha WWTW was issued an exemption under the NWA section 21(f) and (g), provided that the effluent volume does not exceed 958 000 m^3 per year and that the water quality of the treated effluent is compliant with the General Discharge Limits of the revised General and Special Standard (Government Notice No. 20526 –8 October 1999) promulgated under the NWA (Table 3.5). The SBM submitted an application for a new water use licence in 2012, which is projected to be finalised during the course of this year (SBM, Gavin Williams, *pers. comm.* 2014).

Before 2008, the average daily volume discharged never exceeded the average daily limit of 2625 m^3, but volumes of effluent released have subsequently been increasing steadily over time (Figure 3.20.). Between the years 2008-2012, the Saldanha WWTW was non-compliant only during the winter months. However, the average daily limit was exceeded 65% of the time since February 2013, reaching unprecedented levels of 3363 m^3 effluent in June 2014.

Concentrations of faecal coliforms in the effluent from the WWTW exceeded the allowable limit of 1000 org/100 ml on 22 occasions since 2003 (16% of the time) (Figure 3.21). The frequency of non-compliance increased dramatically in 2008, although at a lower concentration (3000 org/100 ml) than previously recorded. Congruent with the consistently higher effluent volumes discharged since February 2013, allowable limits for faecal coliforms in the effluent were exceeded on five occasions, reaching an all-time estimated high of 7257 org/100ml (maximum detectable limit 2419 org/100ml multiplied by 3). Furthermore, faecal coliform measurements below the allowable limit are generally higher. This is cause for concern, as it appears that Saldanha WWTW is unable to adequately process the ever increasing volumes of wastewater generated in the area.

Allowable limit for total suspended solids (TSS) of 25 mg/l were exceeded on 9% of the occasions on which measurements were made since April 2003 (Figure 3.22). Compliance has clearly improved since the last quarter in 2008 where the allowable limit was only exceeded once in December 2012. Chemical oxygen demand (COD) in filtered effluent exceeded the allowable limit of 75 mg/l 20% of the time since April 2003 (Figure 3.23). COD is commonly used to indirectly measure the amount of organic material in water. COD was highest from June-October 2008 peaking at 260 mg/l in July 2008. This trend roughly coincided with the high faecal coliform counts in the effluent over the same period. Overall, as observed for TSS, compliance has improved substantially since the beginning of 2009, where the allowable limit was only exceed on five occasions at a much lower magnitude than in 2008 (<80 mg/l).

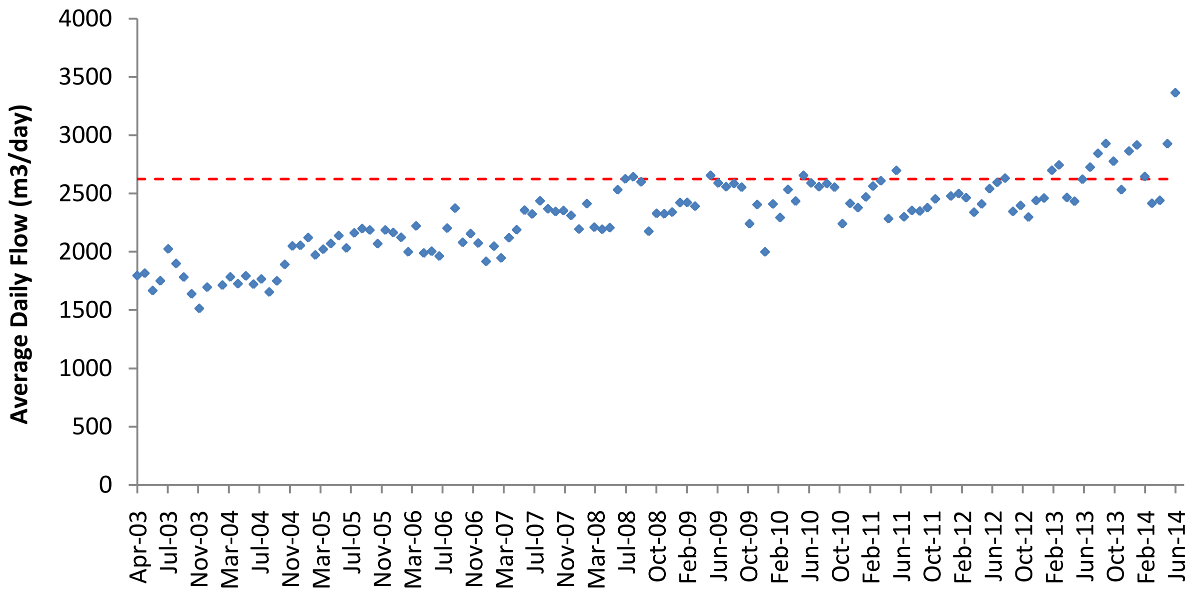


Figure 3.20. Monthly trend in effluent (m^3/day) released from the Saldanha Wastewater Treatment Works, April 2003-June 2014. Allowable discharge limits in terms of the exemption issued by DWAF under the National Water Act (No. 36 of 1998) are represented by the dashed red line.

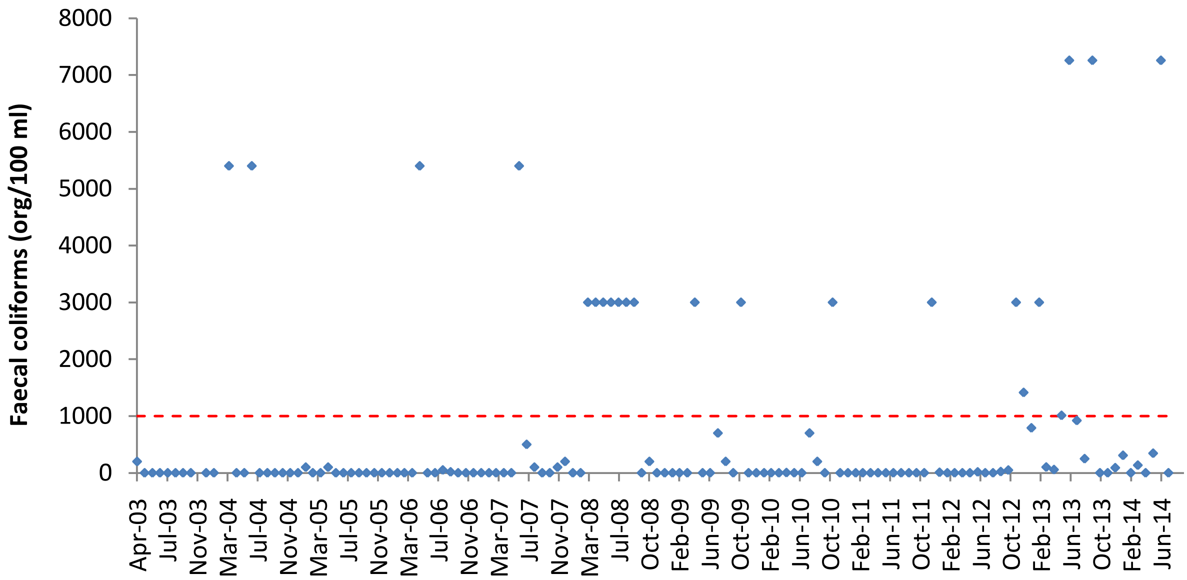


Figure 3.21. **Monthly trend in Faecal Coliforms (org/100ml) in effluent released from the Saldanha Wastewater Treatment Works, April 2003-July 2014. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line.**

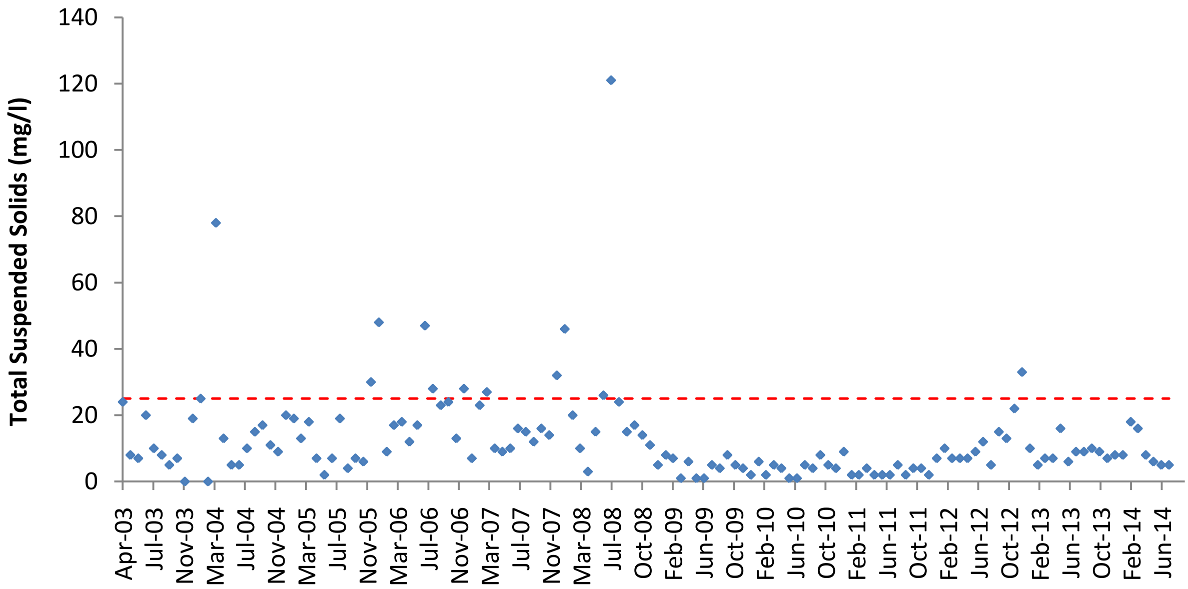


Figure 3.22. **Monthly trend in total suspended solids (mg/l) in effluent released from the Saldanha Wastewater Treatment Works, April 2003 – July 2014. Allowable limits as specified in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line.**

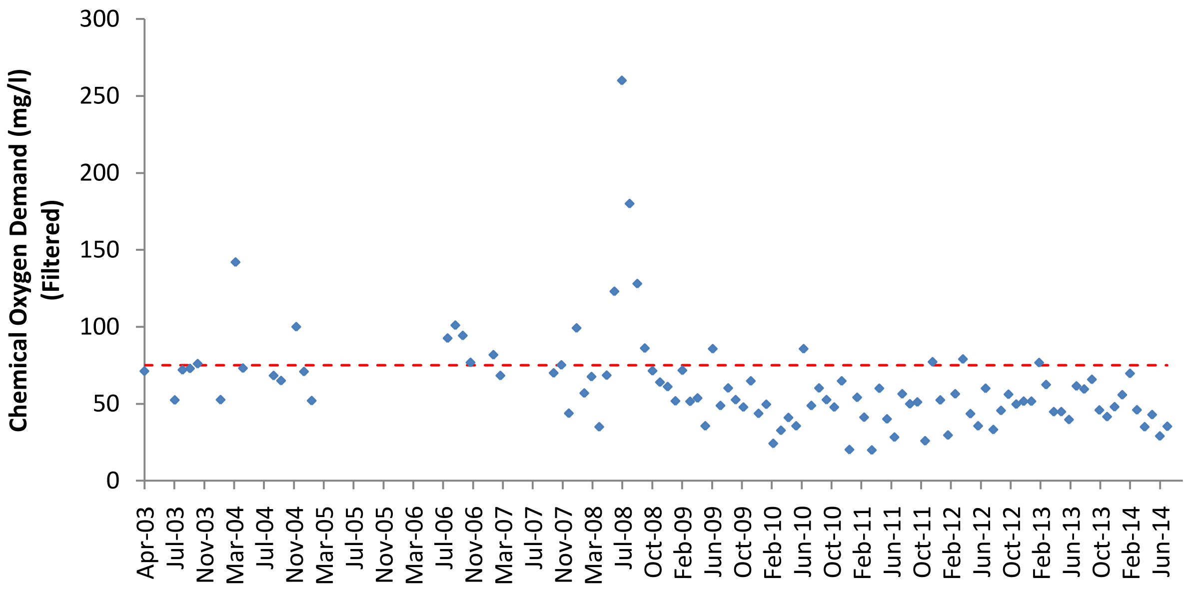


Figure 3.23. **Monthly trends of chemical oxygen demand (mg/l filtered) in effluent released from the Saldanha Wastewater Treatment Works, April 2003-July 2014. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line.**

Levels of Ammonia-Nitrogen (mg/l as N) are of great concern in the effluent discharged by the Saldanha WWTW as this water quality parameter exceeds the allowable limit of 3 mg/l 95% of the time (Figure 3.24). Overall, the degree of non-compliance has decreased substantially since the highest values were recorded in the winter of 2006 (58.8 mg/l). However, more drastic mitigation measures are clearly required to lower Ammonia Nitrogen levels to within the allowable limit.

The Nitrate-Nitrogen limit of 15 mg/l was exceeded 19% of time (Figure 3.25). Overall, compliance has improved since 2010 with values exceeding the allowable limit only seven occasions between April and November 2013.

The concentration of orthophosphate 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. Similar to TSS and DOD, orthophosphate levels have dropped since February 2013 and values have remained mostly below the allowable limit of 10 mg/l (Figure 3.26).

Permissible chlorine levels of 0.25 mg/l have been exceeded 56% of the time (Figure 3.27). Overall, the amount of free chlorine has not decreased over the last few years and the data shows that chlorine gas always peaks shortly after a high count of faecal coliform in the effluent. For example, chlorine gas was measured as 3.2 mg/l in October 2013, a month after faecal coliform numbers peaked at 7257 org/100ml (i.e. 2419 multiplied by a factor of three). In January 2008, chlorine levels were measured at 12 mg/l but this data point was removed from the graph such that the pattern could be demonstrated more clearly.

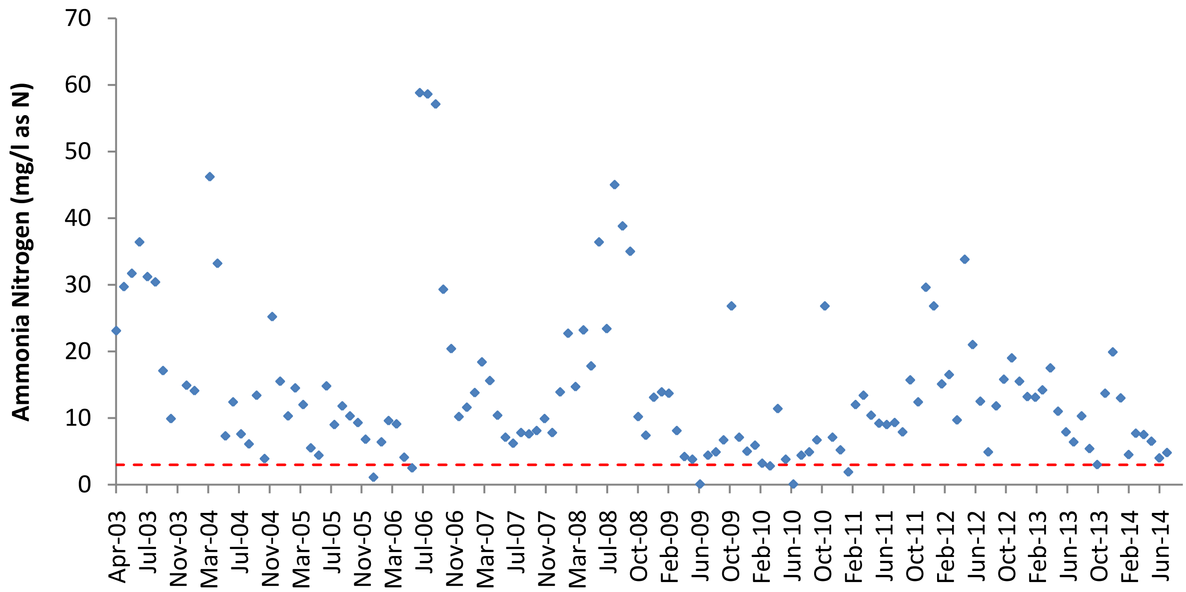


Figure 3.24. **Monthly trends of Ammonia Nitrogen (mg/l as N) in effluent released from the Saldanha Wastewater Treatment Works April 2003-July 2014. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line.**

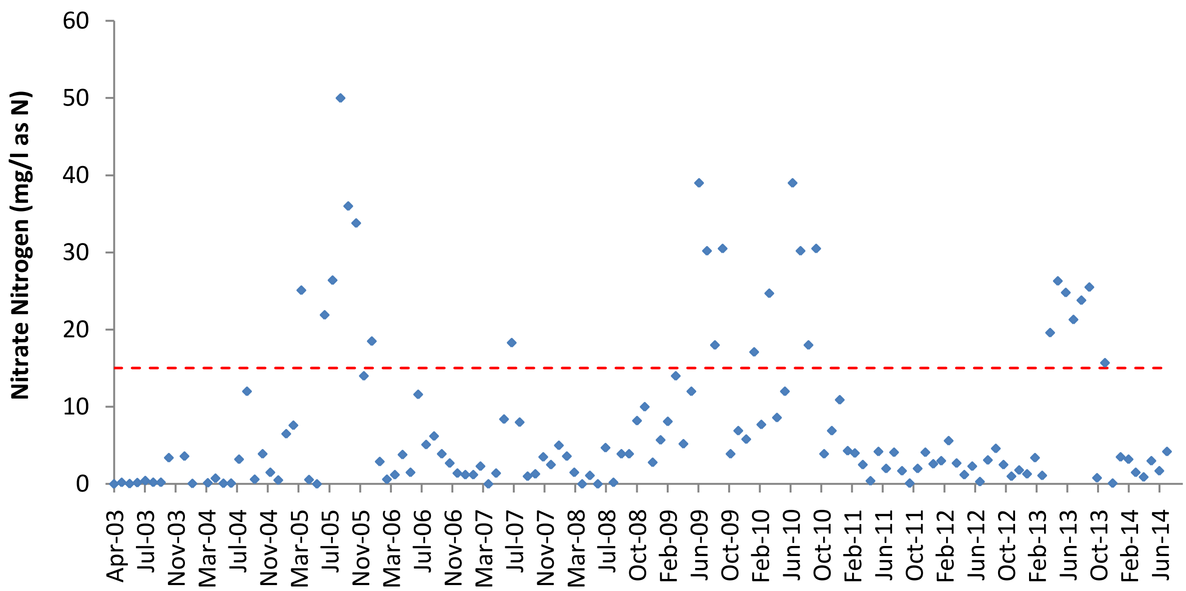


Figure 3.25. **Monthly trends of Nitrate Nitrogen (mg/l as N) in effluent released from the Saldanha Wastewater Treatment Works April 2003-July 2014. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line.**

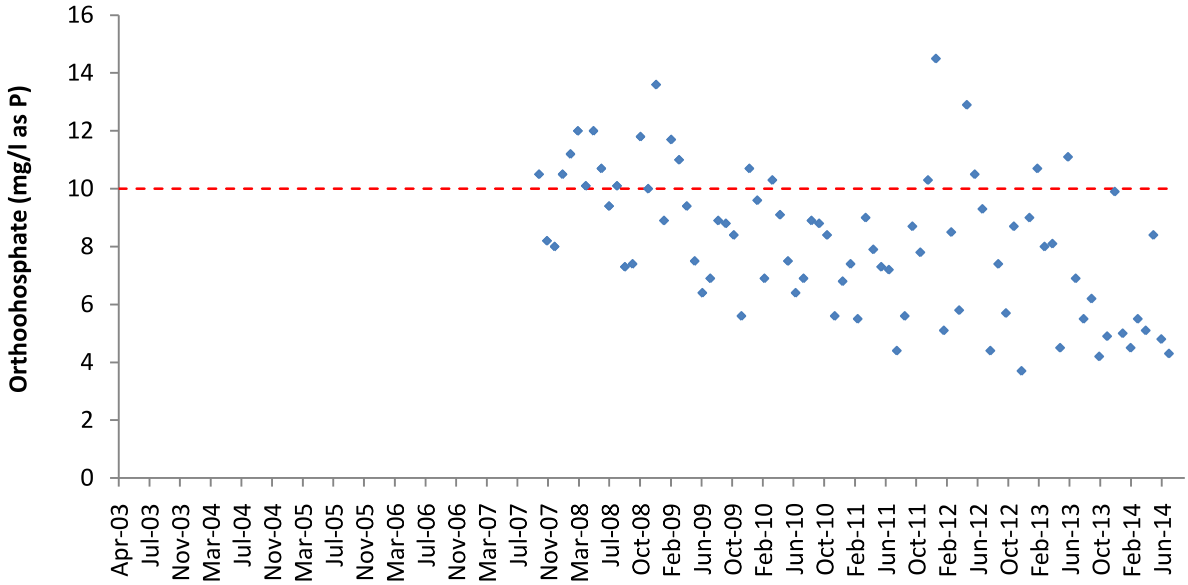


Figure 3.26. **Monthly trends of Orthophosphate (mg/l as P) in effluent released from the Saldanha Wastewater Treatment Works April 2003-July 2014. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line.**

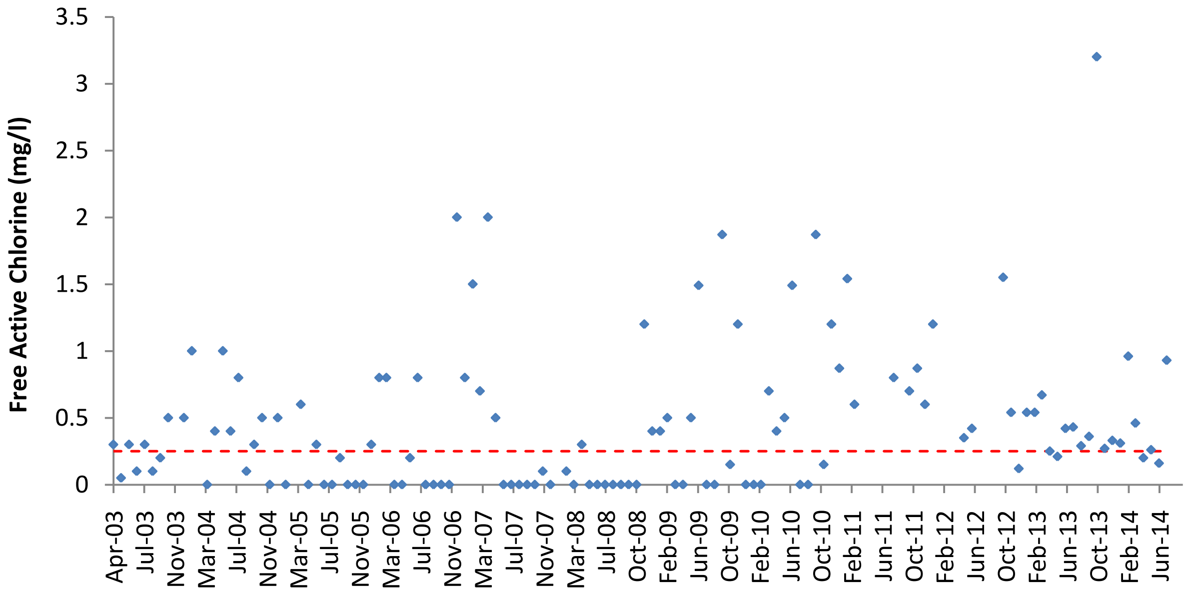


Figure 3.27. **Monthly trends of Free Active Chlorine (mg/l) in effluent released from the Saldanha Wastewater Treatment Works April 2003-July 2014. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line. An outlier of 12 mg/l measured for January 2008 was removed to show the trend more clearly.**

Langebaan Wastewater Treatment Works

Until recently the Langebaan WWTW did not discharge any effluent into the sea as all of it was used to irrigate the local golf course. The Langebaan WWTW was issued an exemption under the NWA section 21(f) and (g), provided that the effluent volume did not exceed 588 000 m^3 per year for the irrigation of the local golf course and that the water quality of the treated effluent is compliant with the General Discharge Limit of the revised General and Special Standard (Government Notice No. 20526 –8 October 1999) promulgated under the NWA (Table 3.5).

However, increasing volumes of effluent received by this plant is yielding more water than is required for irrigation and increasing volumes have been discharged into the Langebaan Lagoon MPA. This is an illegal activity in terms of the National Environmental Management: Protected Areas Amendment (Act No 21 of 2014) (NEMPAAA) section 48A *(d),* which prohibits the discharging or depositing of waste or any other polluting matter into an MPA, unless a CWDP is granted by the Minister of Environmental Affairs in terms of the ICMA. A directive has been issued to the SBM to stop releasing effluent into the Langebaan Lagoon MPA.

The SBM submitted an application for a General Authorisation in 2012, which is predicted to be finalised during the course of this year (SBM, Gavin Williams, *pers. comm.* 2014). Trends of water quality parameters in the effluent released into the Langebaan Lagoon MPA between 2009 and 2014 are shown in Figure 3.28**,** Figure 3.35 and Figure 3.28-Figure 3.35.

Water quality parameters associated with effluent from the Langebaan WWTW have only been measured since June 2009. The exemption permits the irrigation of the local golf course with 1611 m^3 treated effluent per day, which is exceeded 90% of the time (Figure 3.28). Although the average daily flow at Langebaan WWTW has decreased by approximately one third since the measurement of the highest levels in 2010, excess effluent has been illegally released into the Langebaan Lagoon MPA. Consequently, the magnitude of non-compliance for the remaining water quality parameters described below is of great concern.

Concentrations of faecal coliforms in the effluent from the Langebaan WWTW exceeded the allowable limit of 1000 org/100ml on 13 occasions since June 2009 (21% of the time) (Figure 3.29). The frequency and magnitude of non-compliance events increased dramatically in 2013, where the allowable limit for faecal coliforms were exceeded on eight occasions since December 2012, reaching an all-time estimated high of 7257 org/100ml (maximum detectable limit 2419 org/100ml multiplied by 3). Furthermore, faecal coliform measurements below the allowable limit are generally higher. This is cause for concern, as it appears that Langebaan WWTW is unable to adequately process effluent volumes above the allowable limit.

TSS values only twice exceeded the allowable limit of 25 mg/l (Figure 3.30). Overall, TSS levels were lowest in 2012 and increased steadily in 2013 and 2014 but remaining below the allowable limit. TSS levels roughly follow the trends observed in average daily flow volumes where TSS values are higher when flow is greater.

COD in filtered effluent exceeded the allowable limit of 75 mg/l 23% of the time since June 2009 (Figure 3.31). COD was highest from January 2010 until August 2011 peaking at 112 mg/l in May 2011. Overall, compliance has improved since August 2011 and the allowable limit was only exceeded on four occasions at lower magnitude (<105mg/l).

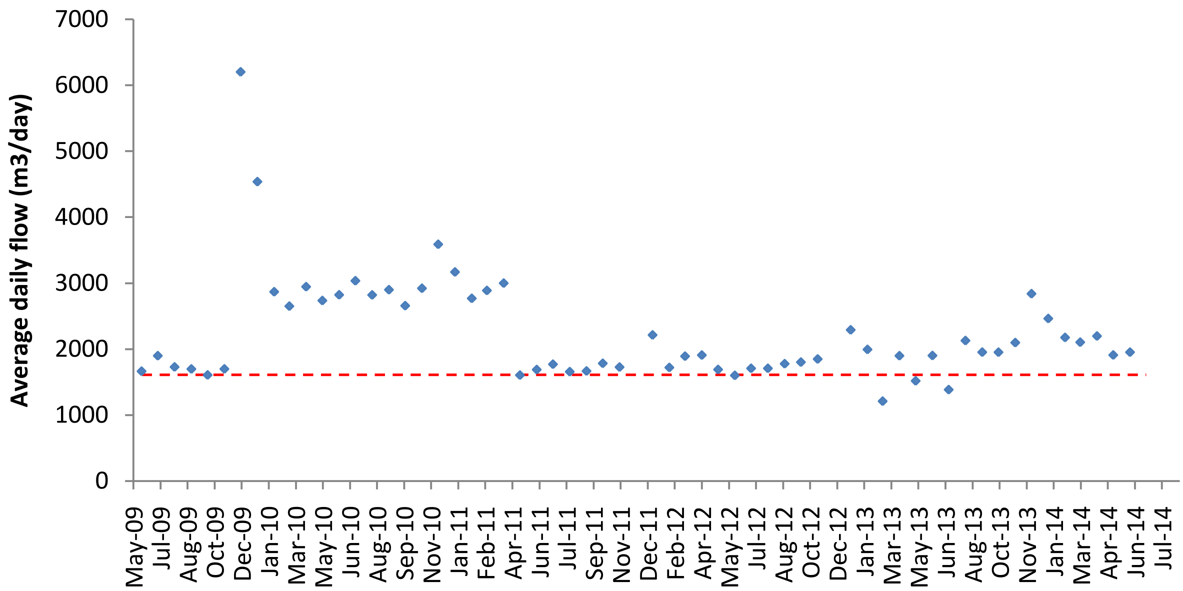


Figure 3.28. **Monthly trends of effluent (m^3/day) released from the Langebaan Wastewater Treatment Works, April 2003 - June 2014. Allowable discharge limits in terms of the exemption issued by DWAF under the National Water Act (No. 36 of 1998) are represented by the dashed red line.**

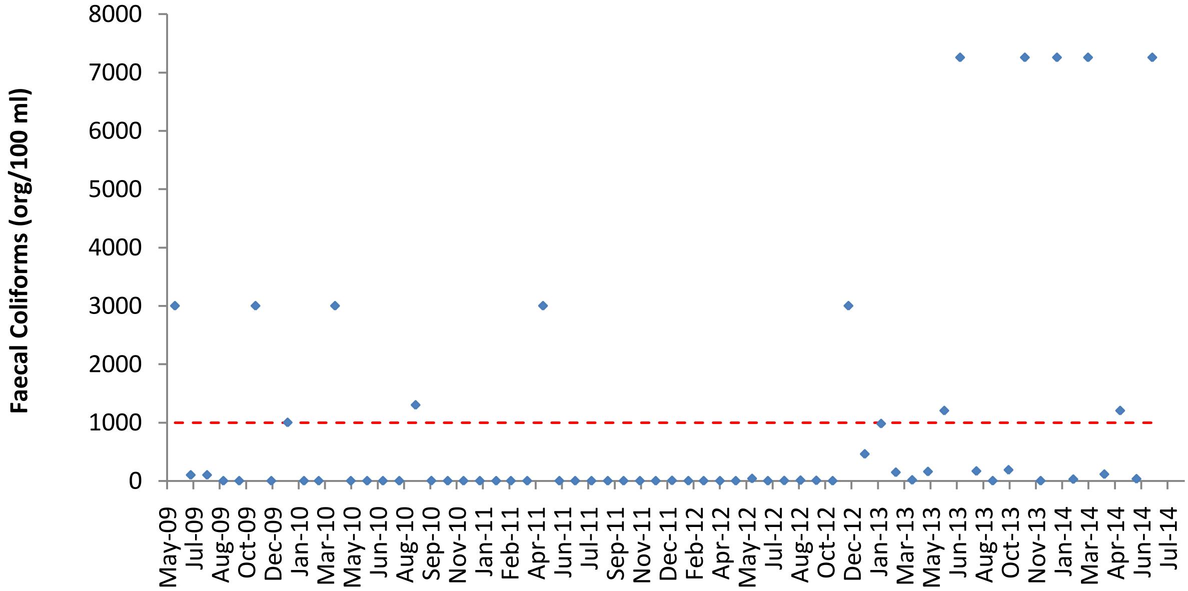


Figure 3.29. **Monthly trends in Faecal Coliforms (org/100ml) in effluent released from the Langebaan Wastewater Treatment Works, April 2003 - July 2014. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line.**

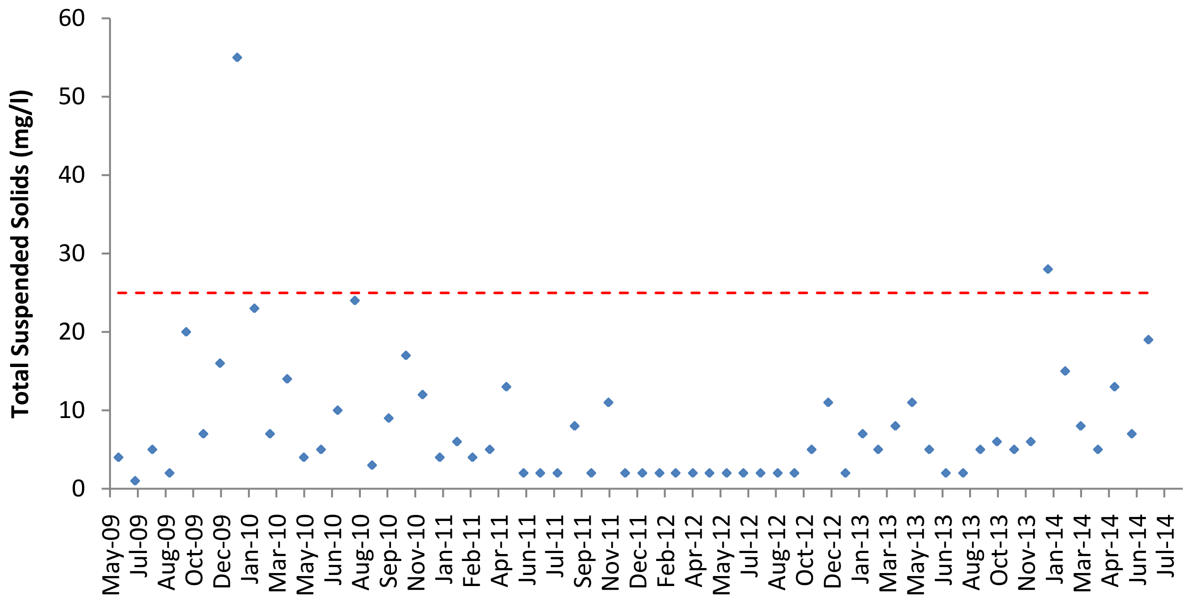


Figure 3.30. **Monthly trends of total suspended solids (mg/l) in effluent released from the Langebaan Wastewater Treatment Works, April 2003 – July 2014. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line.**

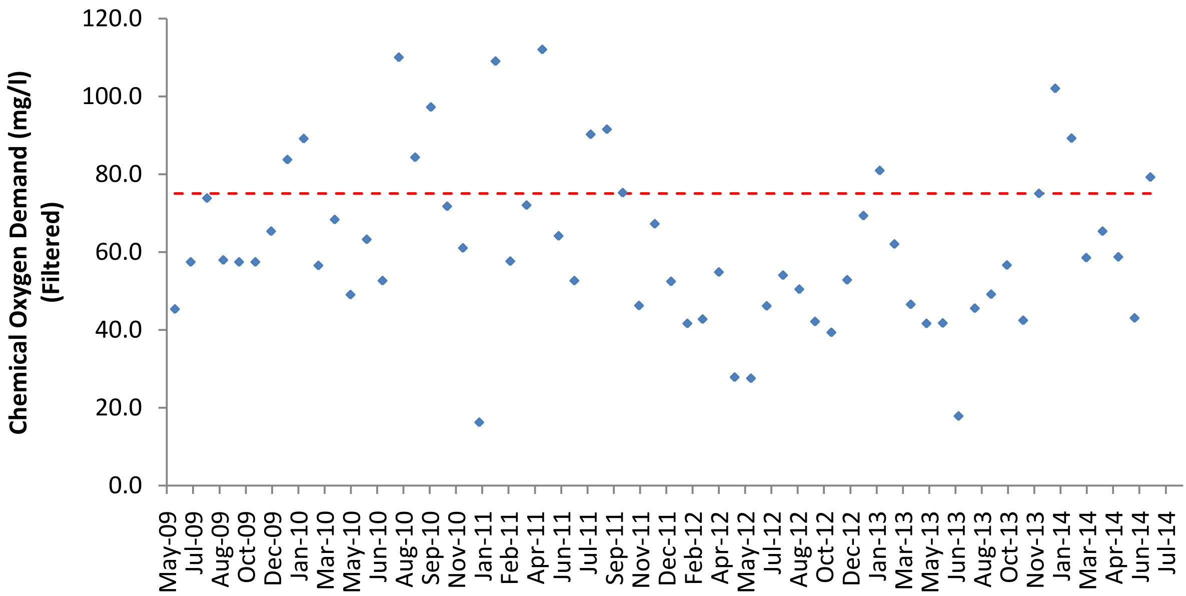


Figure 3.31. **Monthly trends of chemical oxygen demand (mg/l filtered) in effluent released from the Langebaan Wastewater Treatment Works, April 2003 – July 2014. Allowable limits as specified in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line.**

Ammonia Nitrogen levels discharged from the Langebaan WWTW have exceeded the allowable limit of 3 mg/l 90.3% of the time since June 2009 (Figure 3.32). Although Ammonia Nitrogen levels decreased to below the allowable limit in October 2011, levels have been increasing steeply since October 2012, reaching the highest value of 99.6 mg/l in January 2014. This trend follows closely the trend observed for faecal coliforms, which indicates that the Langebaan WWTW is unable to adequately process the effluent that it receives.

Nitrate Nitrogen levels have only exceeded allowable limits once since June 2009 (Figure 3.33). Nitrate Nitrogen levels increased steadily from June 2009 up to June 2012, peaking at 10.7 mg/l. Thereafter, levels decreased to nearly zero, with only high measurement recorded on January 2014 (19.3 mg/l as N), which coincided with the peak in Ammonia Nitrogen, COD and faecal coliform numbers.

Orthophosphate concentrations fluctuate in a seasonal pattern similar to that seen at the Saldanha WWTW (Figure 3.34). Orthophosphate levels decreased from June 2009, reaching a minimum of 0.4 mg/l in April 2012 and have largely remained below the allowable limit of 10 mg/l since January 2013. High orthophosphate levels were recorded in February and November 2013, however, with values of 11.6 and 10.1 mg/l respectively.

Levels of free active chlorine have exceeded allowable limits of 0.25 mg/l 69.4% of the time since monitoring commenced in 2009 (Figure 3.35) with a maximum of 6.6 mg/l recorded in November 2012. As observed at the Saldanha WWTW, free active chlorine levels above the allowable limit are always detected immediately after a rise in faecal coliforms.

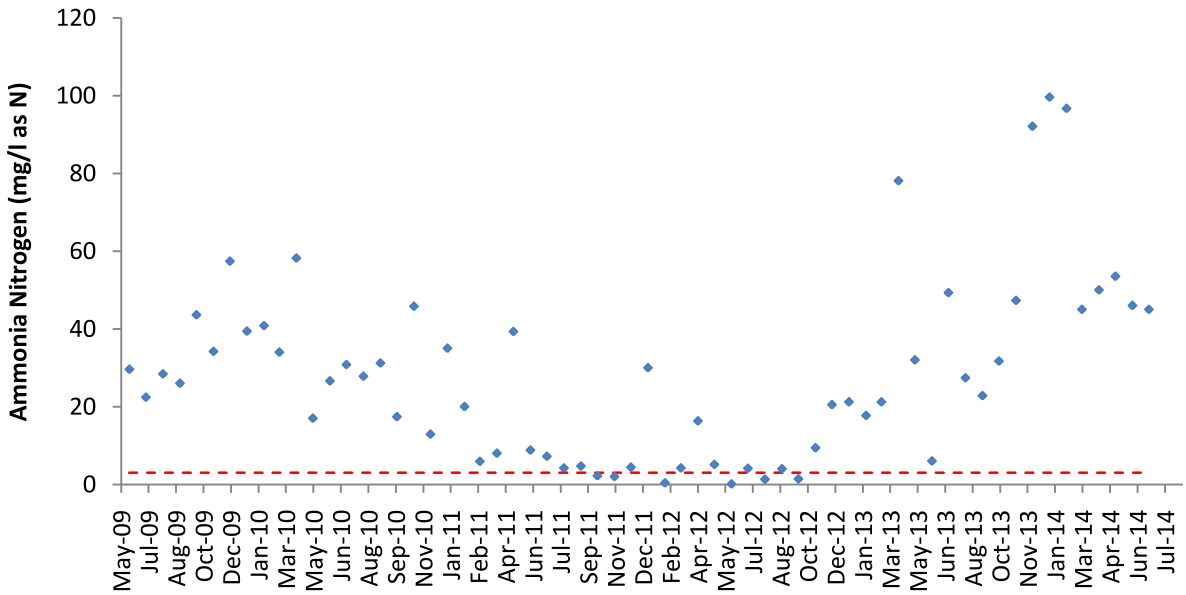


Figure 3.32. Monthly trends of Ammonia Nitrogen (mg/l as N) in effluent released from the Langebaan Wastewater Treatment Works April 2003 - July 2014. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line.

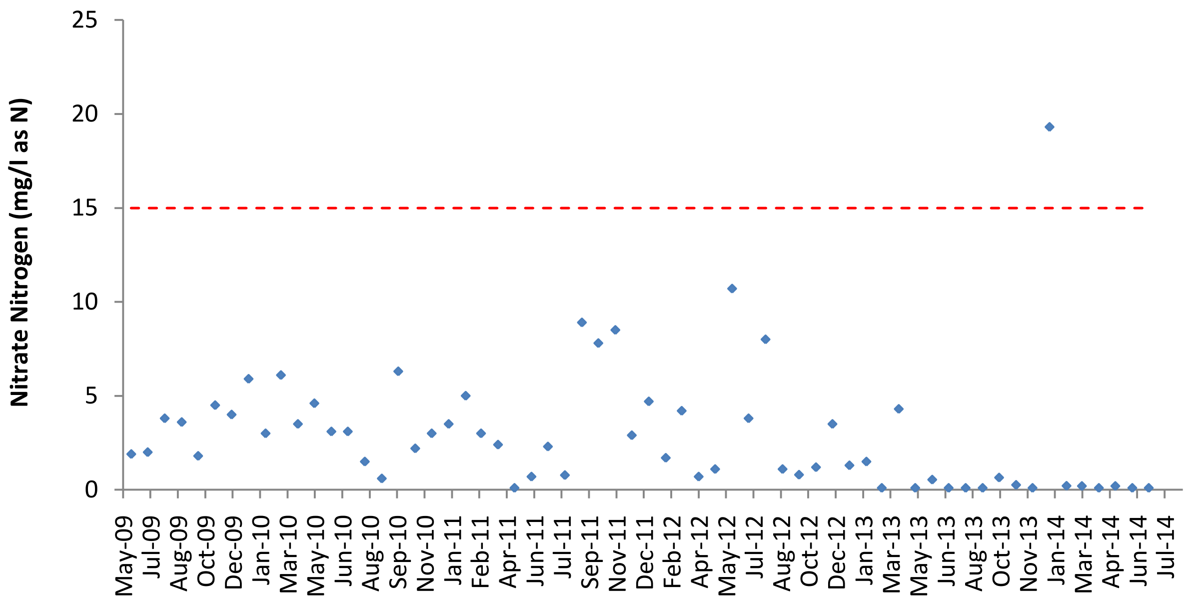


Figure 3.33. Monthly trends of Nitrate Nitrogen (mg/l as N) in effluent released from the Langebaan Wastewater Treatment Works April 2003 – July 2014. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line.

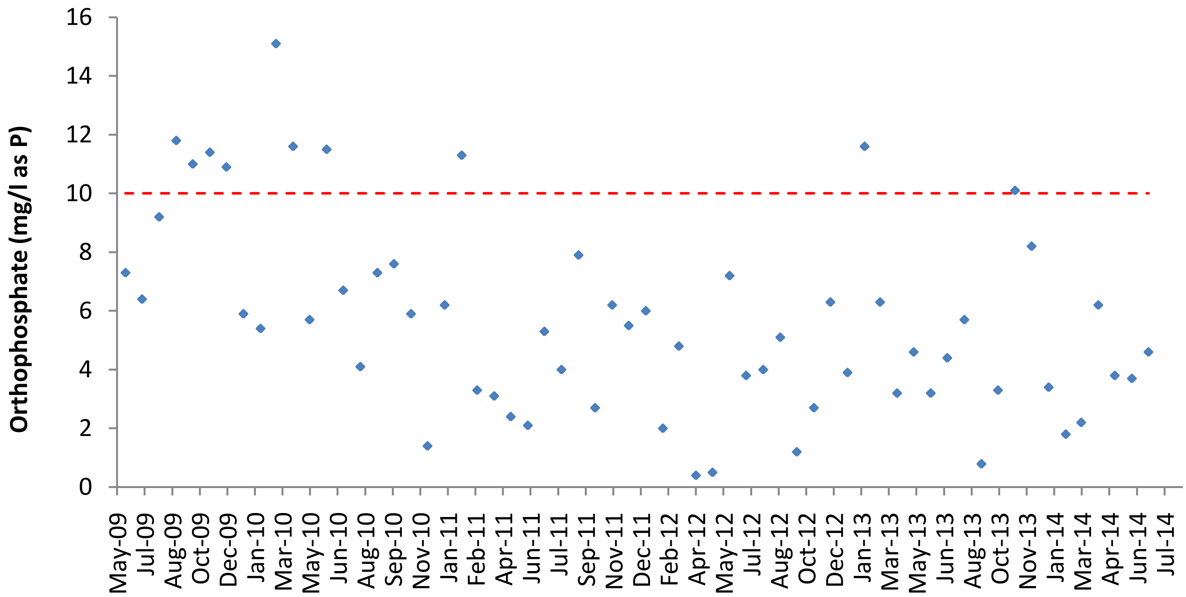


Figure 3.34. Monthly trends of Orthophosphate (mg/l as P) in effluent released from the Langebaan Wastewater Treatment Works April 2003 – July 2014. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line.

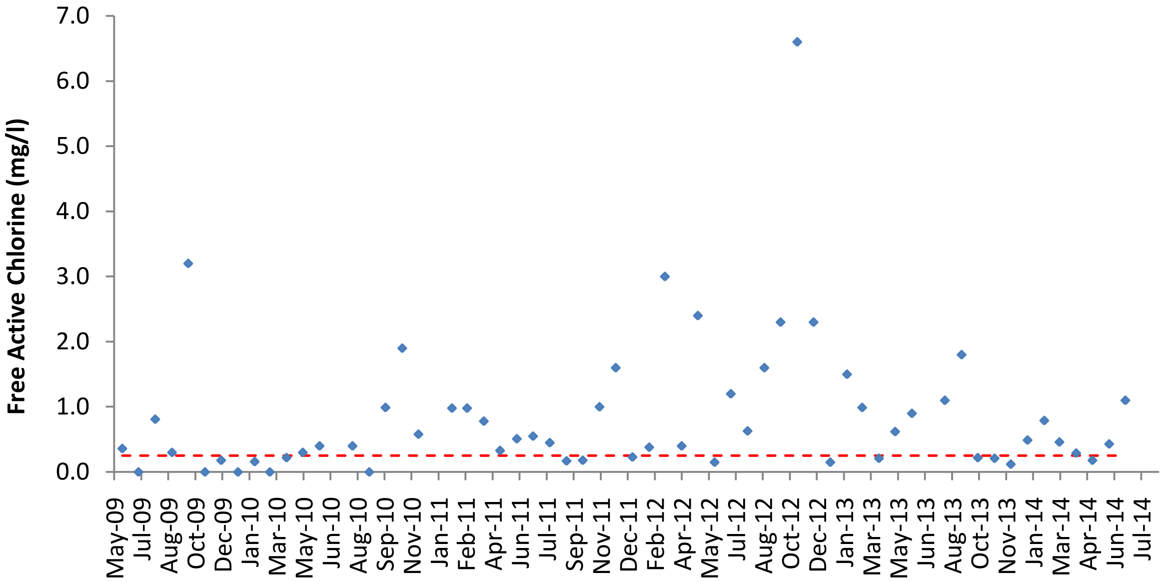


Figure 3.35. Monthly trends of Free Active Chlorine (mg/l) in effluent released from the Langebaan Wastewater Treatment Works June 2009 – July 2014. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line.

Summary

The data shows that the WWTW at Saldanha and Langebaan are experiencing difficulties in keeping effluent levels and water quality parameters within allowable limits and conditions as set out in the NWA (Government Gazette No. 20526, 8 October 1999) (Table 3.5). The data shows that both the Saldanha and Langebaan WWTW are receiving greater volumes of effluent for treatment than permitted. The consequences of this are clearly shown in their lack capacity to process the effluent adequately. The frequency and magnitude of non-compliance with regard to faecal coliform counts have increased dramatically and as a result, require liberal application of chlorine gas to sterilise the effluent.

Excessive ammonia nitrogen levels at both WWTWs are also of great concern. Although ammonia nitrogen levels at Saldanha WWTW have dropped in recent years, a drastic improvement is required to ensure compliance. In contrast, the Langebaan WWTW shows a steep increase in ammonia nitrogen levels since October 2012 peaking at >30 fold the permissible level. Management interventions are urgently needed to reduce ammonia nitrogen in this effluent.

TSS, DOD, nitrate nitrogen and orthophosphate levels have dropped at both WWTWs in recent years, however, both have yet to ensure compliance in terms of DOD levels. Although TSS levels at the Langebaan WWTW is within the allowable limit, a steady increase in 2013 and 2014 is evident, which should be monitored closely to maintain compliance.

3.4.3 Saldanha Regional Marine Outfall Project

Frontier Rare Earths is a mineral exploration and development company that is focused on rare earth elements. Frontier's flagship asset is the Zandkopsdrift rare earth deposit, located in the Northern Cape Province of South Africa. Ore from this deposit will be partially processed on site at Zandkopsdrift where after it will be transported to a separation plant in Saldanha in the Western Cape for further processing. Processing at the separation plant in Saldanha will generate brine effluent that will need to be disposed of. The preferred option for disposal is to sea through a deepwater marine discharge. Frontier Saldanha Utilities (Pty) Ltd. has proposed the Saldanha Regional Marine Outfall Project at Danger Bay in the Saldanh Bay region (Figure 3.36). This project has been proposed to discharge treated effluent of up to 8-9 mega litres per day into Danger Bay from three sources (CSIR 2013a):

(1) Rare Earth Element Separation plant proposed by Frontier Separation (Pty) Ltd.
(2) Chlor-Alkali Production Facility proposed by Chlor-Alkali Holdings (Pty) Ltd.
(3) Regional WWTW proposed by SBM.

The preferred alternative relies on the construction of the West Coast Districty Municipality desalination plant (refer to Page 90 for more detail on this development). In this scenario, the effluent will be disposed via the brine return disposal infrastructure of the desalination plant. However, alternatives have been considered in the event that the construction of the WCDM desalination plant is postponed.

It is envisioned that the proposed outfall structure will also be utilised by other, future developments in the Saldanha Bay area. This is a crucial step towards deflecting some of the future wastewater disposal away from the poorly circulated and highly impacted Saldanha Bay (Small Bay/Big Bay) to the adjacent Danger Bay, which has a much greater capacity to disperse effluent (refer to Section 12.1.8 for more detail on the importance of this project). It must be noted that future development is required to undergo separate feasibility studies and EIAs to consider the capacity of the receiving environment to assimilate additional effluent.

The effluent will largely be comprised of sodium chloride but will also contain biocides, co-pollutants and rare earth elements. Rare earth elements contain radioactive metals (thorium and uranium), which will be removed from the effluent prior to discharge. Nonetheless, accidental contamination is considered in the EIA. It is poorly understood how rare earth elements interact with organic compounds (i.e. whether or not they form bonds with organic compounds to become unavailable/nontoxic to organisms in the receiving environment). As a result it is unknown whether trace amounts of rare earth potentially elements can harm marine organisms. Furthermore, the discharged effluent is likely to have a higher temperature than the receiving environment and as a result dissolved oxygen levels are likely to be lower in the discharge plume.

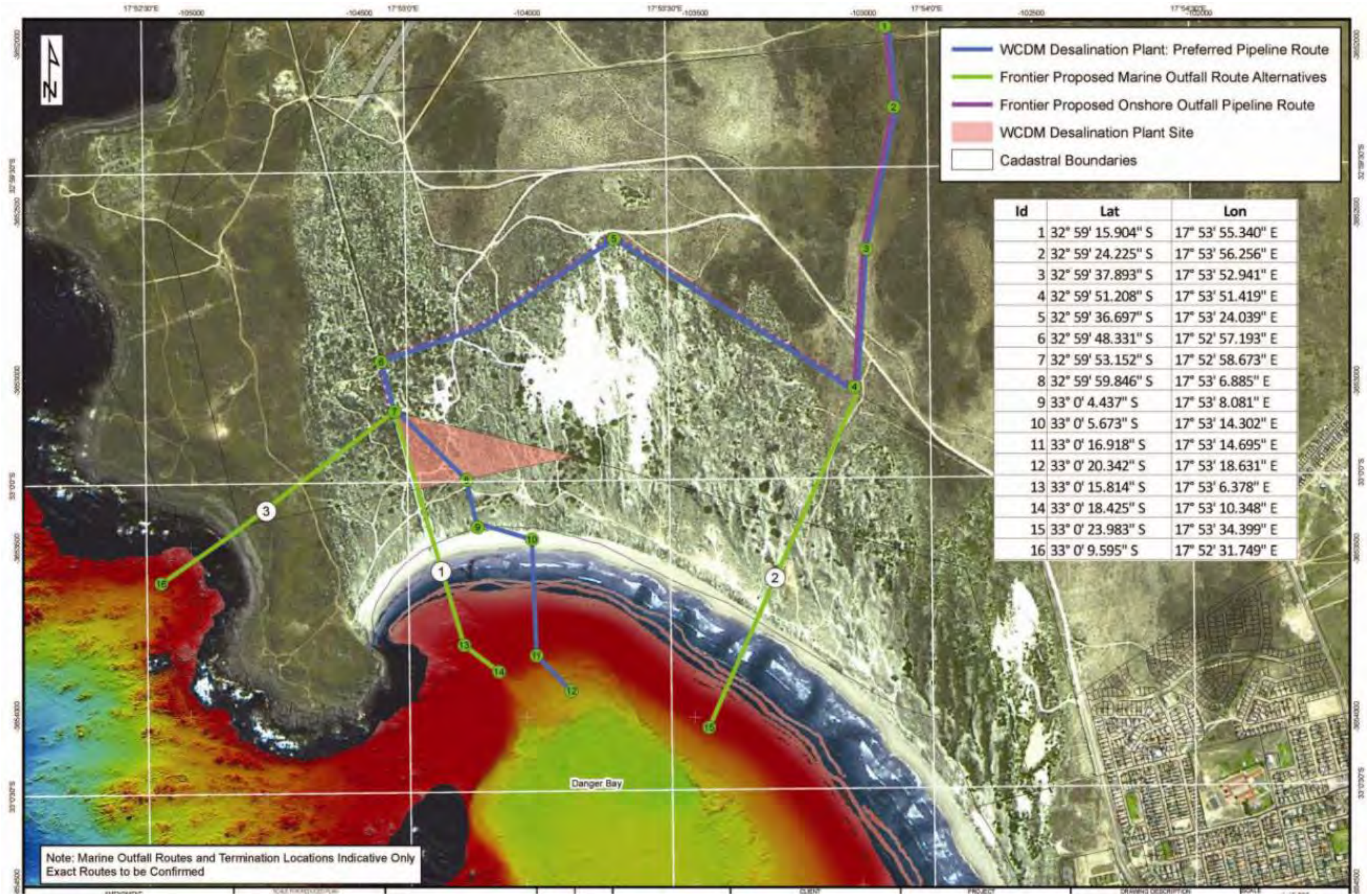


Figure 3.36 **Alternative options for the routing of the Saldanha Regional Marine Outfall project pipelines and West Coast District Municipality Plant outfalls (Source CSIR 2013b).**

3.4.4 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 & 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 3.37). All residential and industrial storm water outlets drain into the sea.

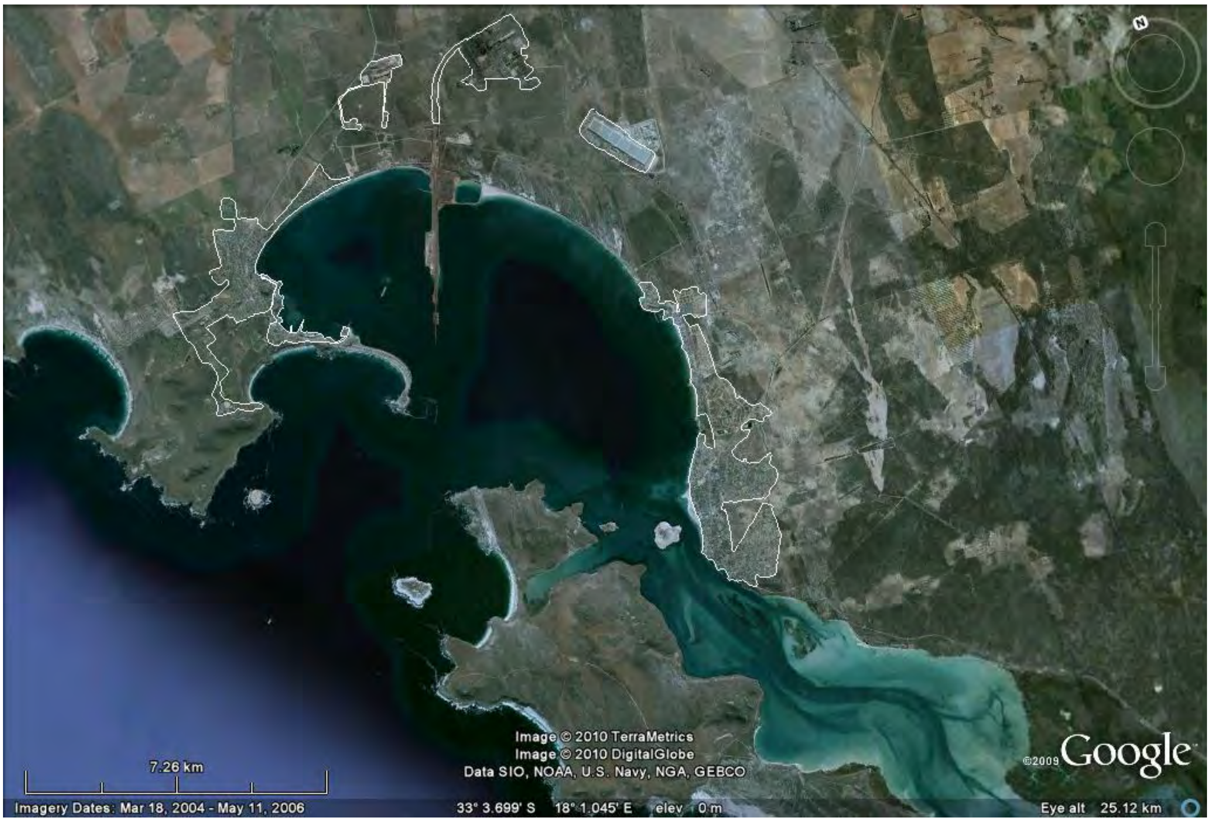


Figure 3.37. Spatial extent of residential and industrial areas surrounding Saldanha Bay and Langebaan Lagoon from which storm water runoff is likely to enter the sea (areas outlined in white). Note that runoff from the Port of Saldanha and ore terminal have been excluded as this is now reportedly all 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 3.37 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. 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. 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.

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

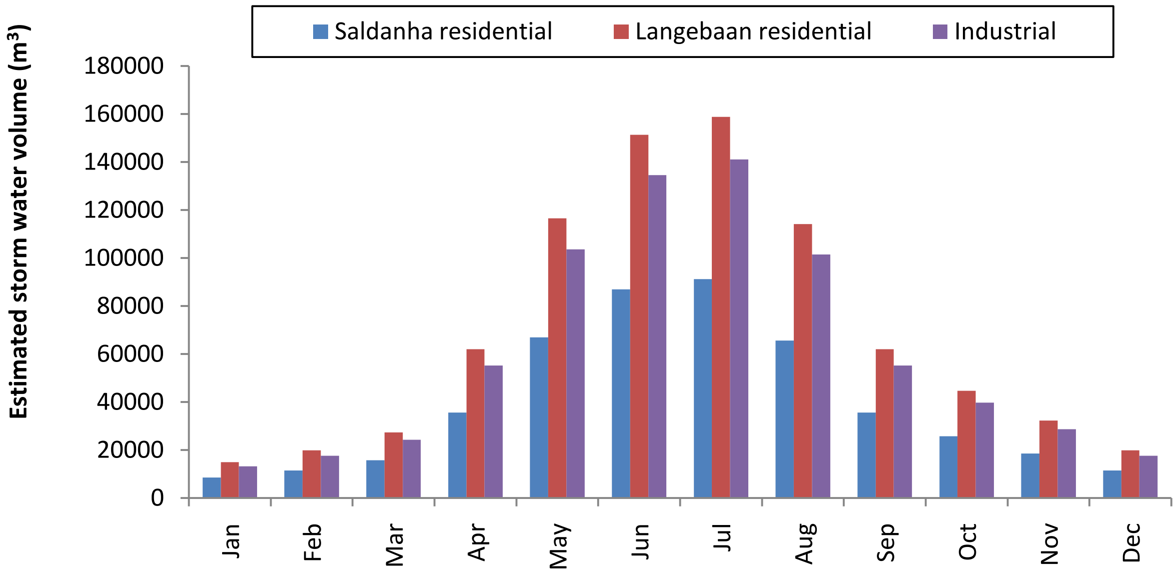


Figure 3.38. Monthly estimated storm water volume (m^3) for Saldanha and Langebaan residential areas and industrial area. Note that runoff from the Port of Saldanha and ore terminal have been excluded as this is now reportedly all diverted to storm water evaporation ponds.

Stormwater management in Saldanha

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) is currently unknown.

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**

Despite the efforts by the iron ore industry to reduce dust emission and to divert and store stormwater in evaporation ponds, Saldanha Bay experiences frequent and considerable pollution when the terminals are washed down with hosepipes (Figure 3.39). It has been brought to attention that current mitigation measures are insufficient and that the Air Emission Licence conditions are not adequate. There is growing concern that this will become worse with the expansion of the iron ore export industry from 60 to 88 million tonnes per annum as proposed by Transnet (Section 3.2.3).

A report on the impacts of iron on the marine environment in Saldanha Bay was produced by Anchor Environmental Consultants in 2012 (Anchor Environmental Consultants 2012c). This report distinguished between the impacts of iron on the marine environment in its solid and hydrated state. Iron in the solid phase affects the organism by either smothering or physical damage, thereby reducing the survival fitness of the affected organism. For example, high concentration of iron dust was shown to inhibit photosynthesis of the primary producers (Woolsey & Wilkinson 2007) and reduce fitness of intertidal organisms by changing the rate of heat absorption and reflective properties of shells (Erasmus & De Villiers 1982). If iron is dissolved through chemical reactions with organic matter and oxygen, it becomes available to organisms in the marine environment. Dissolved iron is a micronutrient and shortage of this element can limit primary productivity in certain areas, while excess dissolved iron can result in unusual phytoplankton blooms. It has been shown that toxin levels in phytoplankton responsible for red tides are increased as a response to enhanced dissolved iron levels (He *et al.* 2009). Furthermore, accumulation of iron in tissue of bivalves can be harmful to humans when ingested and high levels of iron in tissue is recognised as an indicator for readily bioavailable iron (Rainbow 2002) (refer to Section 4.10).

Figure 3.39 **Pollution of Saldanha Bay by particulate iron carried by stormwater runoff (Source: Jaco Kotze, September 2014, Langebaan Rate Payers Assosiation)**

Stormwater management in Langebaan

Concerns and complaints have been publically raised by the residents of Langebaan with regard to the poor stormwater management in Langebaan. Some parts of Langebaan are situated below the sea level and in the winter months, water becomes trapped on the roads in these areas. As a result, residents struggle to access their properties and to commute on flooded roads (Saldanha Bay Municipality 2014). Furthermore, the following concerns have been registered by the SBM:

- Deterioration/destructions of wetlands as well as canalisation of streams and rivers reduce the assimilative and dissipative capacity of the natural environment.
- Inadequate capacity of stormwater retention facilities east of Oostewal Street.
- Impact of stormwater effluent containing pollutants from roads, private properties and businesses discharging into the Langebaan Lagoon.
- Lack of maintenance of conveyance systems with large sediment deposits.
- Impact on tourism market due to deteriorating aesthetic value.

As a result, a Stormwater Management Master Plan is currently being drafted (Saldanha Bay Municipality 2014). A Stormwater Management Plan is a necessary precursor to an action plan for improving stormwater management in Saldanha. However, the importance of drafting and implementing a policy for the maintenance of existing and future stormwater management structures has also been recognised. Langebaan currently has approximately 30 existing ponds of various sizes for the collection of stormwater and three additional large ponds are currently proposed. (Note that these numbers may change as the Stormwater Master Plan is amended). There are about 20 outlets for stormwater that drain directly into the Langebaan Lagoon. Three types of structural stormwater controls are proposed for Langebaan, namely stormwater wet extended detention ponds, enhanced swale and litter/silt traps. The former will control the volume and quality of stormwater to be released into the Lagoon. The enhanced swale will encourage groundwater recharge and litter/silt traps will enable separation of refuse and larger debris at the entrance to chosen stormwater structures.

3.4.5 Fish processing plants

Three fishing companies currently discharge land-derived wastewater into Saldanha Bay: SA Lobster Exporters (Marine Products), Live Fish Tanks (West Coast) – Lusitania (CSIR 2002) and Sea Harvest. The latter is dealt with in more detail in below. The locations of the fish factory intake and discharge points are shown in Figure 3.40. Premier Fishing is currently in the process of re-commissioning and upgrading their fish processing plant.

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). It was not possible to obtain more updated information or data for effluent volume and quality. It must be ensured that this organisation is compliant with the revised General Discharge Limit and that an application for a CWDP has been submitted.

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). It is therefore unknown if this organisation is compliant with the revised General Discharge Limit. Furthermore, municipal water is released on a regular basis into the sea after cleaning of concrete slabs without cleaning agents (Live Fish Tanks, *pers. comm.* 2014). It must be determined how much freshwater is released into Small Bay by Live Fish Tanks (West Coast)-Lusitania in order to assess whether it significantly impacts the receiving environment. It is currently unknown whether an application for a CWDP has been submitted to the DEA.

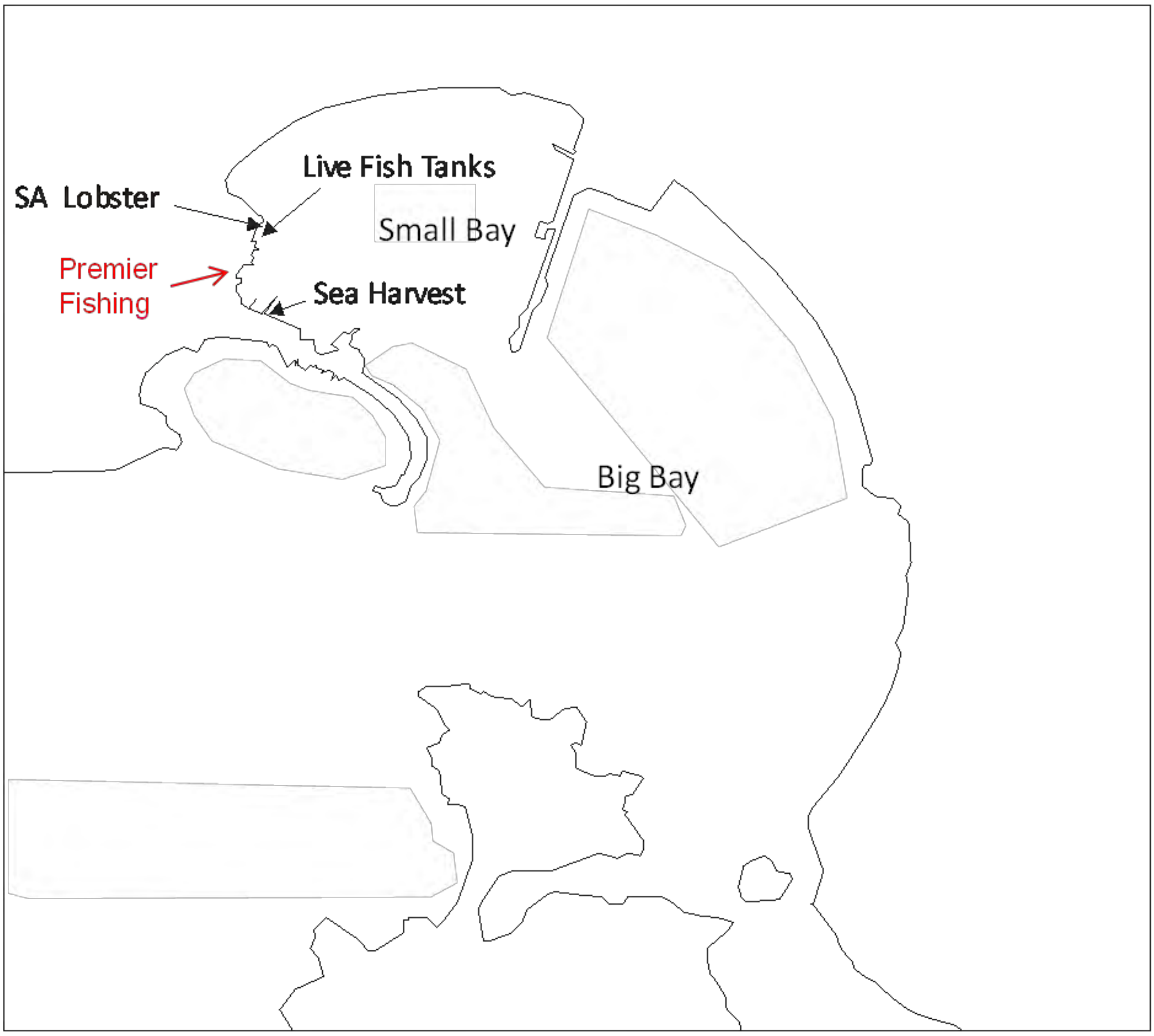


Figure 3.40. Location of seawater intakes and discharges for current and proposed seafood processing factories in Saldanha Bay. Current factories are indicated in black while the proposed Premier Fishing Fish Processing Plant is indicated in red.

Sea Harvest Fish Processing Plant

Sea Harvest is a predominantly demersal trawl fishing company which was established in 1964. The fish processing factory is situated near the base of the causeway to Marcus Island in Saldanha Bay and primarily processes hake (*Merlucius paradoxus and M. capensis*) into a variety of primary fish products including fillets, cutlets, steaks and loins. Previously, fish waste was processed into fish meal by an independent contractor, but EA was granted on 14 October 2013 for the establishment of a fish meal processing facility on the same premises and construction will commence during the course of 2015. A public participation process is currently underway to address a proposed increase from a 5-day to a 7-day work week (Frank Hickley, Environmental Management, Sea Harvest, *pers. comm.* 2014).

Prior to the promulgation of the ICMA, Sea Harvest Fish Processing Plant was granted an exemption under the NWA, provided that the effluent was treated to comply with the General Discharge Limits of the revised General and Special Standard (Government Notice No. 20526 –8 October 1999) promulgated under the NWA (DEA 2014).

Sea Harvest is currently operating under a water use licence in terms of section 21(h) of the NWA which was granted in January 2012 and authorises the disposal of industrial effluent into the Saldanha Bay harbour through an existing marine outfall. Unfortunately, the Saldanha Bay Municipal Water Treatment Works does not have the capacity to process the effluent volume generated by this operation and therefore the effluent is directly disposed into the sea. Since the promulgation of the ICMA, Sea Harvest Fish Processing Plant was given 36 months to submit an application for a CWDP to the DEA. This application was submitted on 12 July 2012. The CWDP application did not, however, include dispersion modelling for the effluent to be discharged. According to the guidelines released by DEA: Oceans and Coasts, dispersion modelling is required for such an outfall to determine likely concentrations of key contaminants at the edge of the mixing zone. Additional information for this application, as well as a public participation process was requested by the DEA at the beginning of 2014.

Until such time that the CWDP has been issued, effluent quality is only recorded at the outfall and not at the edge of the mixing zone in the receiving waters as required by current legislation, policies and guidelines. Therefore, in this report, the water quality data is compared to the General Standard as prescribed in the revised General and Special Standard (Government Notice No. 20526 – 8 October 1999) promulgated under the NWA. The General Discharge Limit can be considered as the minimum requirement for compliance with the ICMA. It must be emphasised that in future, more conservative limits are likely to be required by the CWDP due to the nature of the effluent (volume, concentration and constituents), poor circulation at the outfall point and stringent targets that should be achieved in the receiving environment (mariculture and biodiversity as the beneficiaries requiring most conservative targets).

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. The composition of the effluent from Sea Harvest was surveyed by the CSIR in 2001 and 2012 (Entech 1996 in CSIR 2002, Sea Harvest, F. Hickley, *pers. comm*.) (Table 3.8). The effluent is highly concentrated and contains suspended and combustible solids (flammable solids, fat, oil and grease; ammonia nitrogen, protein, phosphate and faecal coliforms, including *E.coli.* From 2001 to 2012, suspended solids and ammonia nitrogen decreased slightly while estimated protein content as well as faecal coliforms increased. Faecal coliforms almost doubled, of which *E.coli* appears to be responsible for most of the increase. Monthly discharge for the Sea Harvest factory was in the region of 70 000 m^3/month in 2001. No data for the discharge volume, combustible solids; fat oil and grease; and phosphate was obtained in 2012.

Prior to 2014 effluent plant consisted of a concrete sump into which two streams of effluent from the fresh fish processing facilities flowed. A sump pump controlled by level switches pumped the water from the sump across a rotating contrashear screen. The underflow of the screen flowed directly down the discharge channel into a concrete distribution box underneath the jetty and into the sea. The screen discharge was deposited into a container for transport to a fish meal producer.

The bulk of the major solids (fish frames, skins, etc.) went directly into a truck from the processing facility via a screw conveyor. The measurement of the flow was done in the discharge channel (flow restrictor with level measurement) to determine the flow rate and cumulative flow. This system never worked well due to foaming, aeration and turbulent flow, resulting in inaccurate volume readings. Furthermore, the solids handling capability of this system was very limited and pump blockages was a continuous problem. Most of the time, the sump overflowed into the discharge channel, with no treatment taking place.

In 2014, the plant was changed and improved to ensure continuous operation and better solids handling capabilities (Sea Harvest, Site Engineer Nico Van Houwelingen, *Pers comm* 2014). The two effluent streams are now directed through a screw conveyor sieve (mesh size 20 mm) to ensure that all solids larger than 20 mm are removed from the effluent stream before entering the distribution sump. Any particulate matter captured by the screw conveyor sieve is now transported off-site for disposal. The water containing solids <20 mm is then pump into the contrashear screen for further screening (x Salsness SF2000 belt filters with 300 micron screens). The filtered water passes through a flow meter before being discharged into the sea via the discharge channel and distribution box.

In order to limit the possibility of system faults, the following has been done:

- ✓ Two sump pumps have been installed to provide a back-up in case of failure.
- ✓ An alarm was installed to alert the plant operator should any part of the plant stop functioning
- ✓ The contrashear screen, filters and sump are cleaned out every second weekend

Daily checks on components of the plant are also conducted. Furthermore the plant is manned 24/7 by semiskilled staff to ensure quick reaction to deviations that occur mostly due to issues inside the processing area. This ensures that the effluent quality is constant. Currently, residual hygiene chemicals in the effluent are not removed or measured. The existing sanitizer is a quaternary ammonia compound which can resilt in high NH_4 levels in the effluent (clearly reflected in the the water quality monitoring data Figure 3.44). This issue will be addressed through the use of a different sanitizing process. Furthermore, the reduction of particulate matter in the effluent through the new effluent processing technology should also reduce ammonia levels.

It is evident that effluent quality up to June 2014 is still drastically higher than the General Standards of the General and Special Standard promulgated under the Water Act (Act No. 53 of 1956). However, improvements are expected in the second half of 2014 due to the drastic technological and management improvements made by Sea Harvest.

Monthly monitoring data of effluent volumes as well as effluent quality are available since 2007 and 2010, respectively, and are discussed in more detail below.

Table 3.8. Effluent constituents from Sea Harvest Fish Processing Plant (Data from CSIR 2002 and F. Hickley, Environmental Officer for Sea Harvest) compared to the General Discharge Limit of the revised General and Special Standard (Government Notice No.20526 – 8 October 1999)

	Sea Harvest (2001)	Sea Harvest (2012)	General Standard
Effluent volume (m^3/month)	69 595	-	-
Suspended solids(mg/l)	164	158	25
Combustible solids (mg/l)	144	-	-
Fat, Oil and grease(mg/l)	212	-	2.5
Ammonia-N (mg/l)	164	147	3
Kjeldahl Nitrogen-N (mg/l)	83	99	-
Phosphate-P (mg/l)	34	-	10
Faecal coliform (CFU/100 ml)	751	1347	1000
E. coli. (CFU/100ml)	5	789	-

Average fresh fish processing effluent volumes discharged into Small Bay per day by Sea Harvest is shown in Figure 3.41. No data is available for the period April 2007 to December 2012. Overall, measurements show that on average, effluent volumes discharged into Small Bay have decreased substantially since 2004. During the period of August 2006 to November 2007, the volume of effluent disposed by Sea Harvest increased peaked at unusually high levels. It is not clear why this increase occurred, but data reporting and environmental monitoring at Sea Harvest have suffered irregularities due to high staff turnover (Sea Harvest, F. Hickley, *pers. comm.*). Average effluent discharged per day was 4350 m^3 in 2004, increased to 6738 m^3 in 2006 and dropped to 703 m^3 in 2013. Thus far, measurements obtained for the period January-April 2014 show that 1236 m^3 of effluent has been released into Small Bay on a daily basis. Total effluent discharged from the facility could not be determined, as readings are taken irregularly due to a frequently broken flow meter. Furthermore, the fish processing plant is often operational on weekends and measurements are not taken on these days (Sea Harvest, Environmental Officer, Fulufhedzani Ramashia, *pers. comm.* 2014). On average, 155 measures are taken per year, reporting on an average of 240 working days per year.

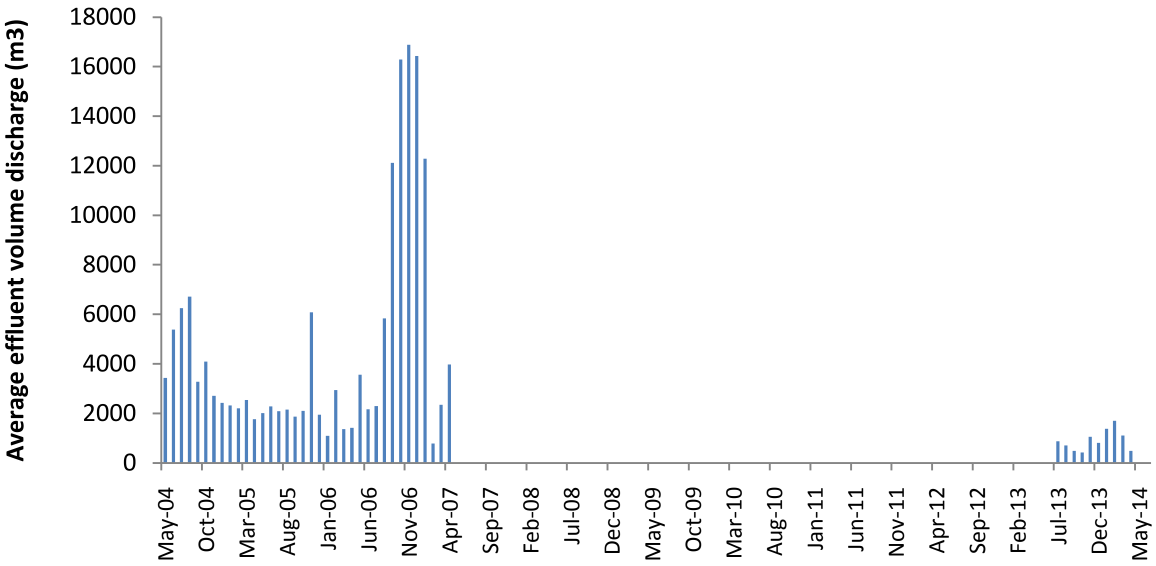


Figure 3.41. Average fresh fish processing effluent volume discharged into Small Bay per day by Sea Harvest from May 2004 - March 2014. Data was not available for the period May 2007 – August 2013 (Source: Frank Hickley, Environmental Manager at Sea Harvest fish Processing Plant).

As expected, faecal coliforms concentrations in the effluent are mostly compliant with the revised General Discharge Limit of 1000 CFU/100 ml (Figure 3.42). Until the beginning of 2013, concentrations were highest during the summer months, reaching a maximum of 3300 CFU/100 ml (>1100 detection limit multiplied by three). A decrease in frequency and magnitude of peaks in faecal coliform concentrations is evident since February 2013, with a maximum of 500 CFU/100ml in June 2014. 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 TSS are extremely high and since measurements commenced in 2010, compliance with the revised General Discharge Limit of 25 mg/l could only be observed in October 2013 (14 mg/l) (Figure 3.43). Trends in TSS since 2010 suggest that concentrations peak in late summer to beginning of autumn each year (February-April). Overall concentrations have remained very high since 2010.

The revised General Discharge Limit for ammonia nitrogen is 3 mg/l, which is exceeded 96% of the time at very high concentrations. In 2010, ammonia nitrogen concentrations were lower, averaging 13.2 ±10 mg/l but have increased dramatically since then, reaching a maximum of 474 mg/l in September 2012. Towards the end of 2013 concentrations dropped substantially, but since then have increased to reach 175 mg/l in June 2014.

Total Kjeldahl Nitrogen (TKN) (mg/l) provides an indication of the protein content in the effluent. Protein content stayed constant between February 2010 and August 2012 with an average concentration of has 76±27 mg/l (Figure 3.45). Since then TKN concentrations have increased steadily, averaging on 129±176 mg/l.
A salinity limit at the end of the pipe is not specified in the revised General Discharge Limits. Fish processing involves the use of freshwater and therefore, conductivity (mS/m) as an estimate of

salinity is markedly lower that what seawater (~5400 mS/m) (Figure 3.46). It is evident that conductivity has increased since May 2011, approaching the conductivity expected in the receiving environment.

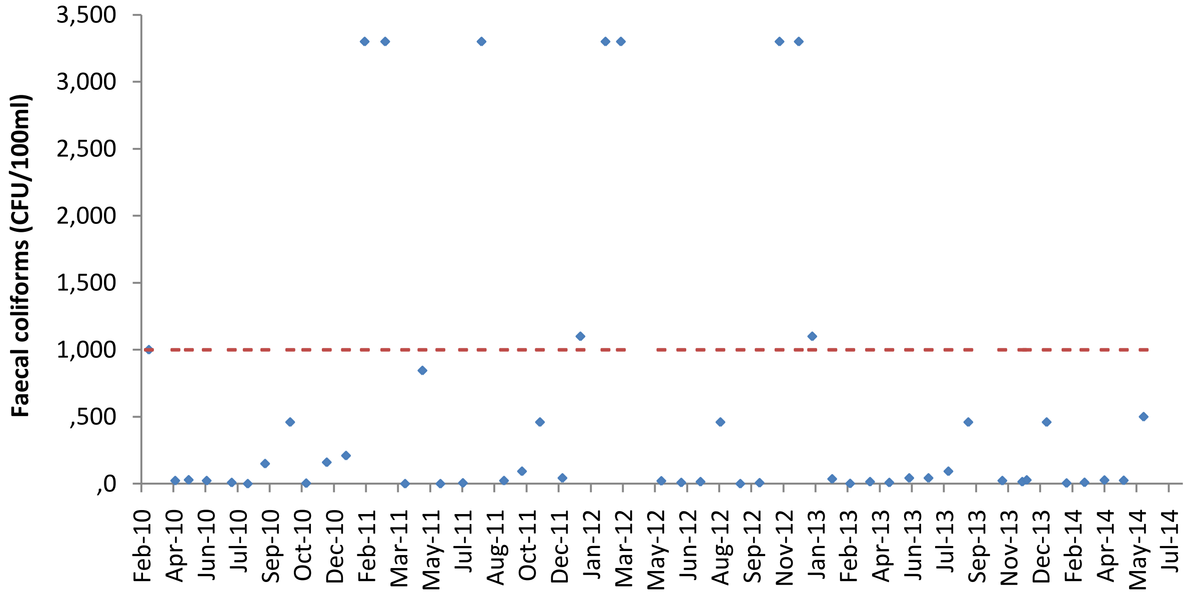


Figure 3.42. **Monthly trends in the numbers of faecal coliforms (CFU/100 ml) in the effluent discharged from the Sea Harvest fresh fish processing (FFP) plant into Small Bay in the period March 2010 to June 2014. The red dashed line indicates the limit prescribed by the General Discharge Limit of the revised General and Special Standard (Government Notice No.20526 – 8 October 1999).**

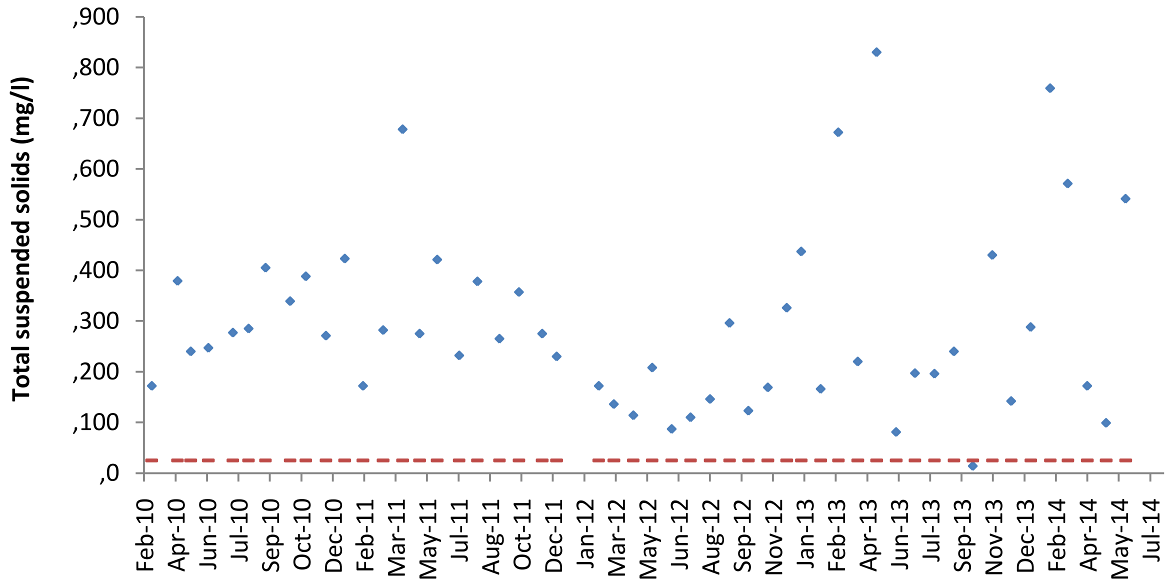


Figure 3.43. **Monthly trends in total suspended solids (mg/l) in the effluent discharged from the Sea Harvest fresh fish processing (FFP) plant into Small Bay in the period March 2010 to June 2014. The red dashed line indicates the limit prescribed by the General Discharge Limit of the revised General and Special Standard (Government Notice No.20526 – 8 October 1999).**

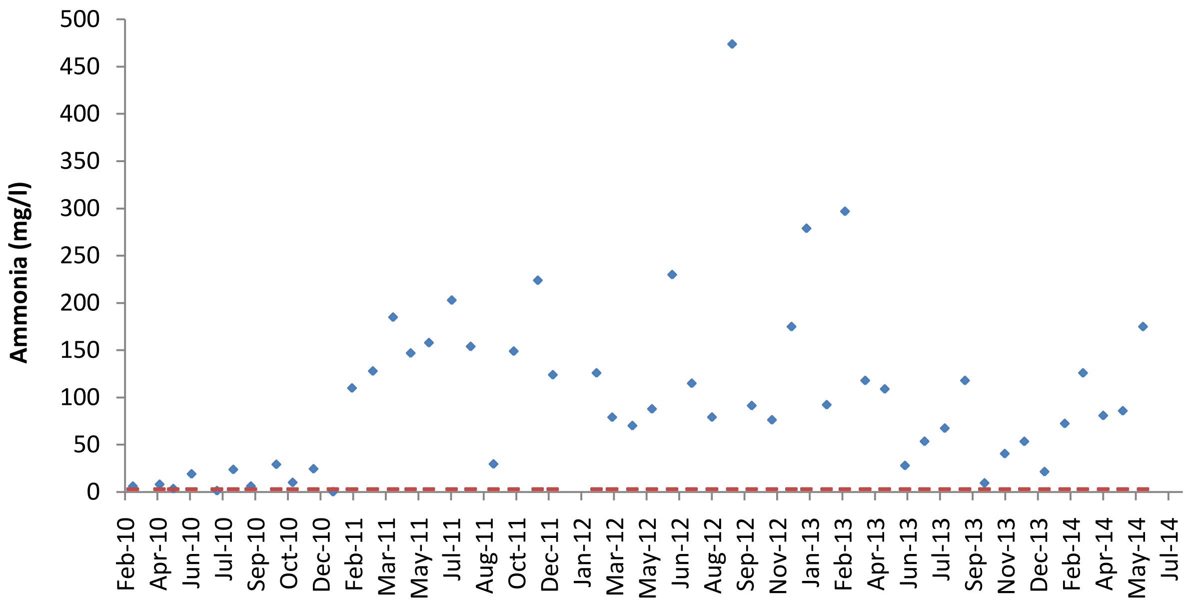


Figure 3.44. **Monthly trends in ammonia nitrogen (mg/l) in the effluent discharged from the Sea Harvest fresh fish processing (FFP) plant into Small Bay in the period March 2010 to June 2014. The red dashed line indicates the limit prescribed by the General Discharge Limit of the revised General and Special Standard (Government Notice No.20526 – 8 October 1999).**

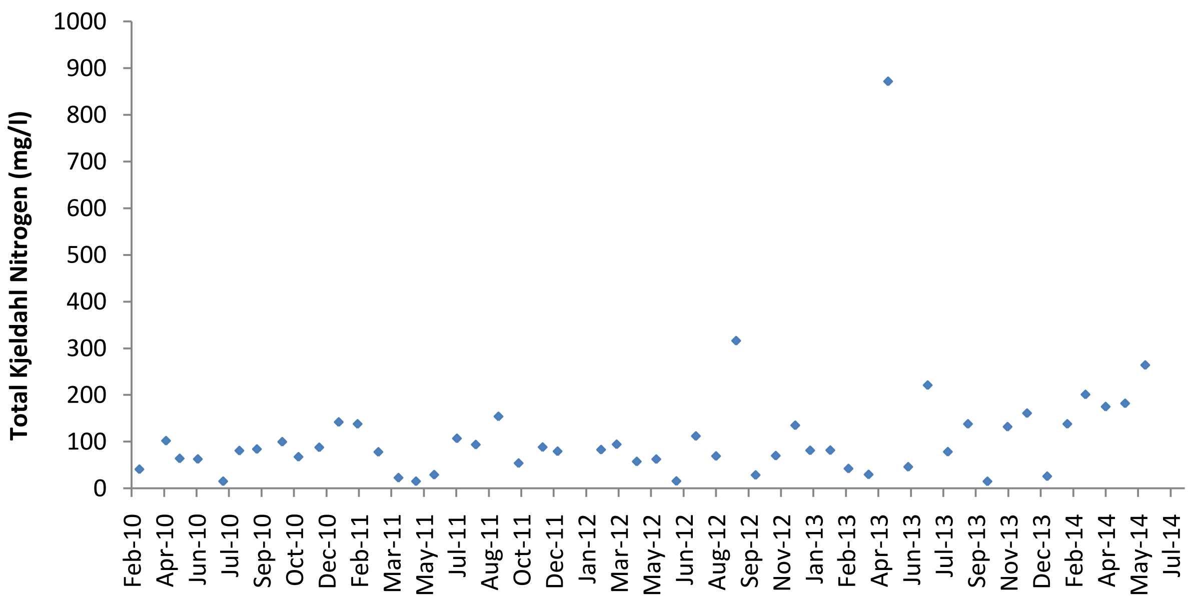


Figure 3.45. **Monthly trends in Total Kjeldahl Nitrogen (mg/l) in the effluent discharged from the Sea Harvest fresh fish processing (FFP) plant into Small Bay in the period March 2010 to June 2014. Note that no limit is prescribed for this effluent constituent in the General Discharge Limit of the revised General and Special Standard (Government Notice No.20526 – 8 October 1999).**

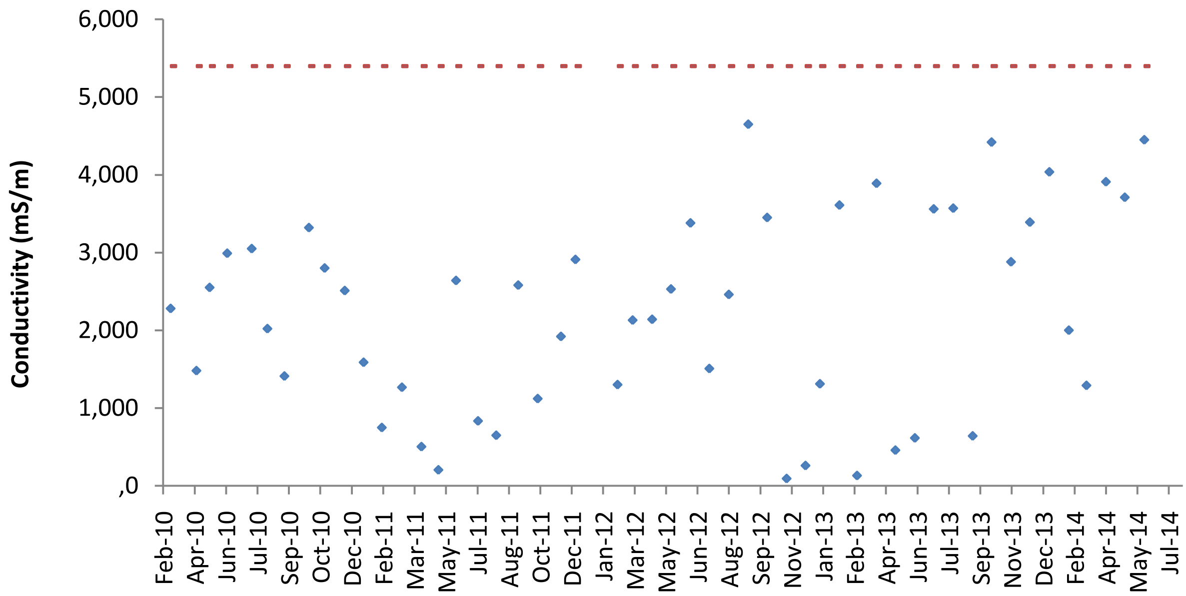


Figure 3.46. Monthly trends in Conductivity (mS/m) in the effluent discharged from the Sea Harvest fresh fish processing (FFP) plant into Small Bay in the period March 2010 to June 2014. The red dashed line indicates approximate Conductivity (mS/m) expected in sea water.

In conclusion, it appears that despite a substantial decrease in effluent volumes since 2004, the effluent at the Sea Harvest Fish Processing Plant is not treated adequately to ensure minimum impact to the receiving environment. Sea Harvest fish Processing Plant is non-compliant in terms of the revised General Discharge Limit for faecal coliforms, TSS and ammonia nitrogen. The latter two effluent constituents can have severe impacts on the ecology of the receiving environment by reducing light penetration for photosynthesis and toxicity to marine organisms. Conductivity as an estimate of salinity is clearly lower than what is expected in the receiving environment.

Re-commissioning of the Premier Fishing fish processing plant

Southern Seas Fishing (now trading as Premier Fishing) previously discharged wastewater into the Bay but closed its factories in 2008 after being operational for 50 years. Premier Fishing is in the process of re-commissioning and upgrading the existing fishmeal and fish oil processing plant situated in Pepper Bay, the western side of Saldanha Bay.

For the upgrade and re-commissioning of the Premier Fishing plant, a Scoping and EIA process is required in terms of the NEMA, the EIA 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 (Pty) Ltd 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 (Anchor Environmental Consultants 2012a). 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 wastewater 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 wastewater 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 to be discharged to the marine environment (cooling water and condensed liquids only) must not exceed 30 m3/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 DEA 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; and
- 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.

Taking into account the above potential environmental impacts and proposed mitigation methods, EA was granted in June 2013. The Atmospheric Emission Licence was approved in April 2014, but has been appealed. Discharges from the fish factories are subject to the ICMA and the jurisdiction of the DEA and require a CWDP. An application for a CWDP in terms of the ICMA was also submitted to the Department of Environmental Affairs: Oceans and Coasts Branch (DEA:OC) for the discharge of cooling water containing condensate from the plant's scrubber to the sea. The permit application was provided for public review in Appendix H of the Revised Final EIA Report for the project (SRK Report 431676/10). On 24 April 2014 DEA:OC requested additional information for the CWDP application and that the application be subjected to another round of public participation.

3.5 Marine aquaculture

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 180 ha has been allocated to ten mariculture operators within Saldanha Bay (Table 3.8, Figure 3.47). All operators except for Southern Atlantic Sea Farms hold rights to farm mussels (although only six of them currently exercise this) and six of the operators also farm oysters. Abalone, scallops, red bait and seaweed are not cultured on any of these farms, although some of the farms have the right to do so.

Blue Bay Aquafarm (Pty) Ltd. was the largest and oldest of the current farms and had rights to approximately 50 hectares of water at the entrance of Small Bay since 2002 for the farming of oysters and mussels. Blue Bay Aquafarm (Pty) Ltd was assimilated into Blue Ocean Mussel and now only farms mussels in Saldanha Bay. The other six operators have had rights to smaller areas in both Small Bay and Big Bay since 2010. West Coast Seaweeds is an oyster nursery operation and grown oysters are sold to Saldanha Bay Oyster Company.

Southern Atlantic Sea Farms is the first mariculture operator in Saldanha Bay to hold a right for the cage culture of finfish (Atlantic salmon). Details of this operation are provided in Section 3.5.2.

Table 3.9. Details of marine aquaculture rights issued in Saldanha Bay (BB and SB refer to Big Bay and Small Bay respectively (source: Personal communications with the respective farms). 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**	**Finfish**	**Area (Location*)**	**Duration of right**
Blue Ocean Mussel (previously trading as Blue Bay Aquafarm (Pty) Ltd.	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						15 ha (SB)	2010-2024
West Coast Seaweeds (Pty) Ltd	x	x						5 ha (SB) 5 ha (BB)	2010-2024
African Olive Trading 232 (Pty) Ltd	x							5 ha (SB) Port of Saldanha	2013-2028
Aqua Foods SA (Pty) Ltd	x	x						Port of Saldanha 10 ha (SB)	2014-2030
Southern Atlantic Sea Farms							x	15 ha (SB) Port of Saldanha	2014-2029

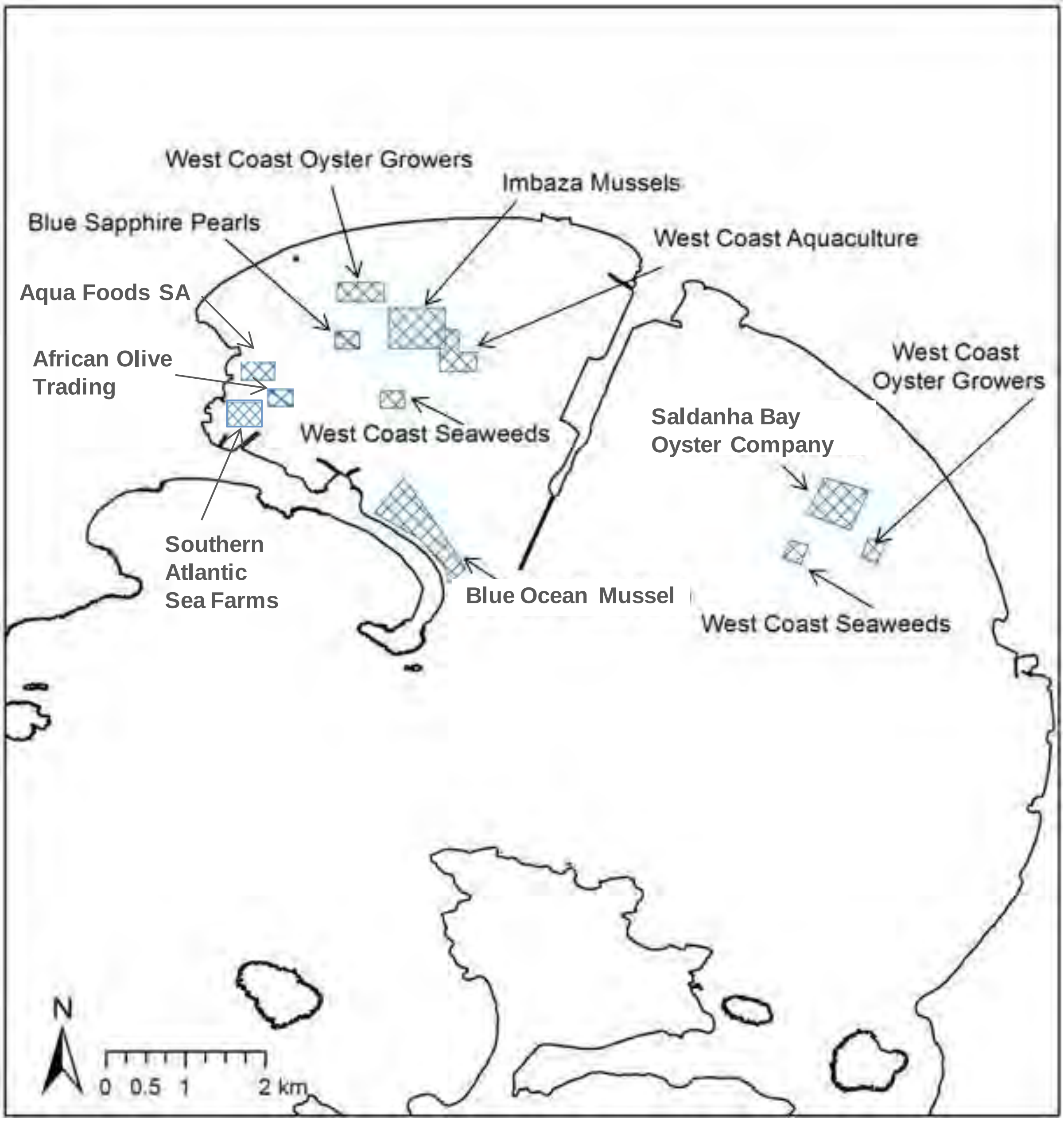


Figure 3.47. Allocated mariculture concession areas in Saldanha Bay 2012.

3.5.1 Shellfish, seaweed and redbait marine aquaculture

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.

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 has been increasing steadily since peaking in

2012 at 859.77 tons following a lull in productivity between 2005 and 2007 (Figure 3.48). In 2012 the mussel sub-sector (based in Saldanha Bay) was the second highest contributor to the overall mariculture productivity for the country (DAFF 2014).

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).

On-going environmental impact monitoring surveys undertaken in Saldanha Bay by the Department of Agriculture, Forestry and Fisheries (DAFF) 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.

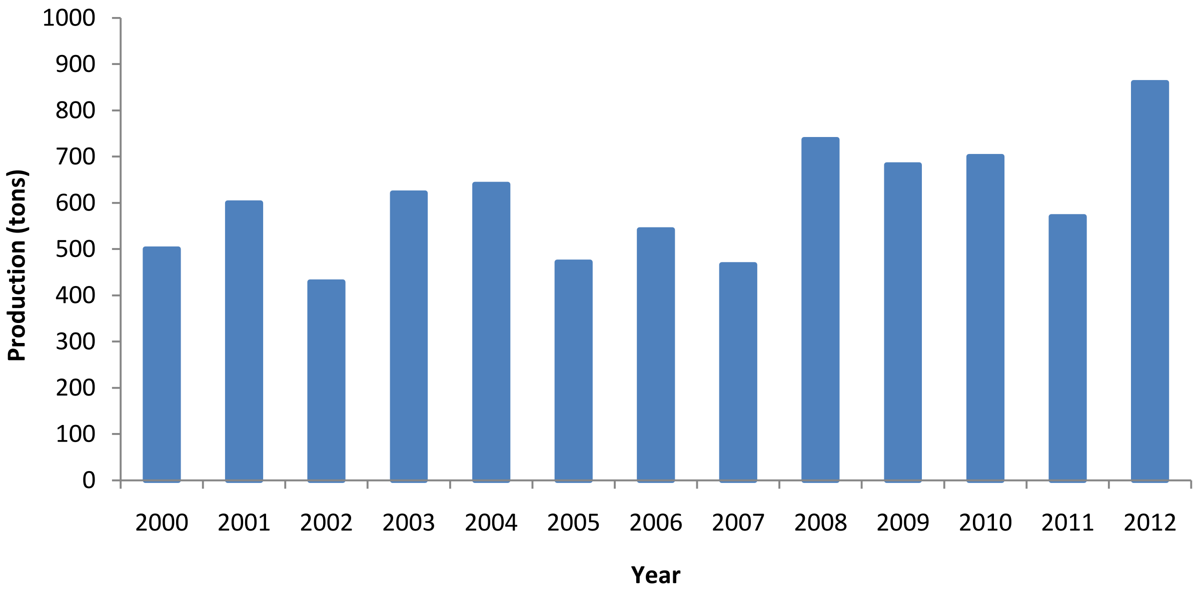


Figure 3.48. Overall annual mussel production (tonnes) in Saldanha Bay between 2000 and 2011 (source: Department of Agriculture, Forestry and Fisheries 2014)

3.5.2 Finfish cage farming

Finfish culture is is currently pioneering in Saldanha Bay. The Southern Cross Salmonid Farm is in the process of applying for EA for the cage culture of salmon or trout. Southern Atlantic Seafarms has recently gone to sea with two trial cages stocked with Atlantic Salmon (*Salmo* salar) amounting to a total production of less than 50 000 kg per year. Details of both developments are provided below.

Operational phase environmental impacts of finfish cage culture have been well reported in international literature and include:

- Incubation and transmission of fish disease and parasites from captive to wild populations.
- Pollution of coastal waters due to the discharge of organic wastes.
- Escape of genetically distinct fish that compete and interbreed with wild stocks that are often already depleted.
- Chemical pollution of marine food chains (& potential risk to human health) due to the use of therapeutic chemicals in the treatment of cultured stock and antifouling treatment of infrastructure.
- Physical hazard to cetaceans and other marine species that may become entangled in ropes and nets.
- Piscivorous marine animals (including mammals, sharks, bony fish and birds) attempt to remove fish from the cages and may become tangled in nets, damage nets leading to escapes and stress or harm the cultured stock. Piscivorous marine animals may also be attracted to the cages that act as Fish Attractant Devices (FADs) and in so doing natural foraging behaviors and food webs may be altered. Farmers tend to kill problem predators or use acoustic deterrents.

The above impacts can largely be mitigated by the implementation of an EMPr (as required in Regulation 33 in the EIA regulations R543 of 2010). The aim of such a Programme would be to document and plan the management approach that will best achieve the avoidance and minimisation of potential environmental impacts in the construction, operation and decommissioning phase of a finfish cage culture operation.

New Alien and Invasive Species Regulations and Invasive Species Lists were promulgated on 1 August 2014 in terms of the National Environmental Management: Biodiversity Act (No. 10 of 2004) (NEMBA). These regulations and lists specify that any restricted activities related to an alien species legally introduced prior to the promulgation of these regulations and lists are exempted from the requirement of a permit (and therefore a risk assessement). These new regulations raise concerns with regards to the introduction of alien species into new environments. For example, it is of concern that salmon, previously only farmed on land (low risk) can now be introduced into the marine environment (higher/unknown risk) without a permit/risk assessment in terms of NEMBA.

Southern Cross Salmonid Farm

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 DEA and the DEA&DP in June 2012, as part of the 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 28. The 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 3.49). 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).

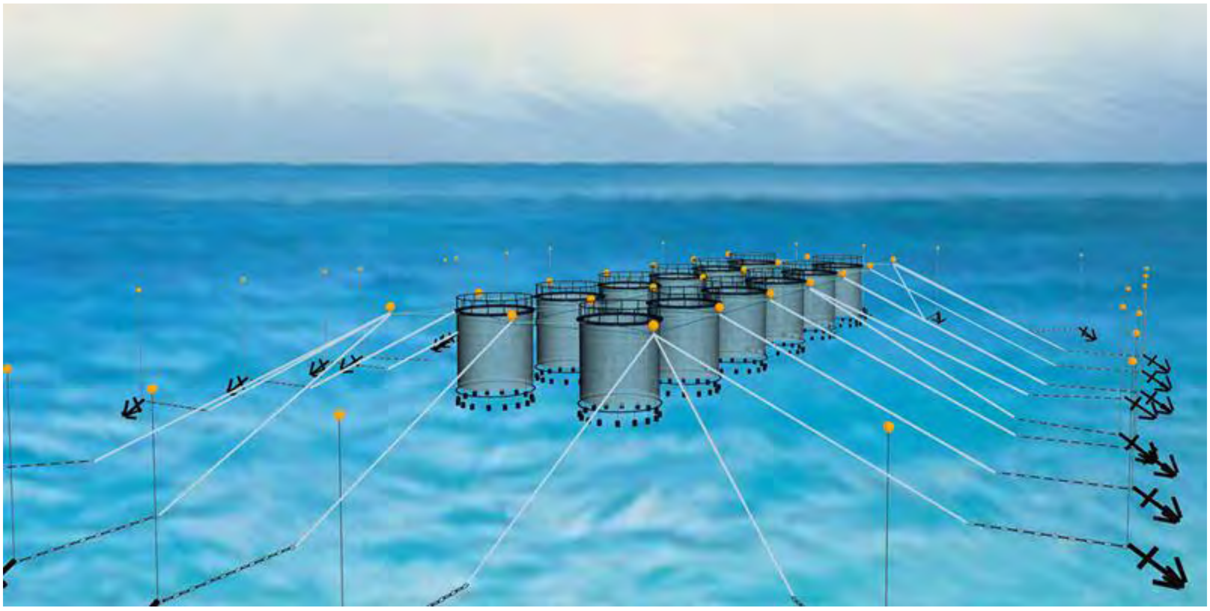


Figure 3.49. Proposed setup of the Southern Cross offshore salmonid farm.

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. The EIA process is still on-going as many aspects have been raised and extensive additional oceanographic modelling was performed since the project was first proposed. It is expected that this EIA will be completed early next year and if approved the project will commence as soon as possible (Aqua Eco, E. Hinrichsen, *pers. comm.* 2014).

Southern Atlantic Sea Farms

Southern Atlantic Sea Farms is a research and development company with the aim to pioneer salmon and wild marine finfish in the Saldanha Bay area (SalmonBar 2013). Southern Atlantic Sea Farms (Pty) Ltd is a joint venture company between Three Streams Holdings (Pty) Ltd and Andrew MacLachlan. The company obtained a Right to Engage in Marine Aquaculture in terms of Section 18 of the Marine Living Resources Act (No. 18 of 1998) (MLRA) (Southern Atlantic Seafarms, Director Gregory Stubbs, *Pers. comm.* 2014). The right is for the production of Atlantic Salmon (*Salmo salar*) for a period of 15 years and commenced on 1 January 2014. The company also has a long-term lease with Transnet National Ports Authority for the 15 hectare site in Small Bay (Figure 3.47.

Currently the project is in Pilot Phase with two floating cages deployed and approximately 10 000 Atlantic salmon in on-growing trials. The salmon were introduced end May and early June this year. The cages are 15 m in diameter and have a rearing space of 1 980 cubic metres. The definition of "Pilot" allows Southern Atlantic Sea Farms not to exceed 50 000 kg of production per annum, sufficient to trial this enterprise before launching into a commercial phase, if indeed it proves viable. It is planned that a further two cages will be deployed in the near future and stocked with a second batch of Salmon in early December (Southern Atlantic Seafarms, Director Gregory Stubbs, *Pers. comm.* 2014).

The company has not undergone an environmental impact assessment as current annual production amounts to less than 50 000 kg (NEMA, R.544 Listing Notice 1, Activity number 7). An environmental monitoring plan was approved by the DAFF prior to the issuing of the right (Southern Atlantic Sea Farms, Andrew McLachlan, *pers. comm.*). This monitoring plan includes analysis of sediment samples (baseline and follow up) and analysis of video footage of the seabed by an independent party. Furthermore, bio-security is controlled and monitored by Amanzi Biosecurity. Best available hardware from Europe has been deployed and cages, moorings, nets and fish behaviour are inspected on a daily basis. Southern Atlantic Sea Farms ensures that to date, no interaction of seals, sharks or other mammals has been observed (Southern Atlantic Sea Farms, Andrew McLachlan, *pers. comm.*). The current operation has the objective to establish the financial viability of farming Salmon in this area. The results of the pilot project will lead to a full environmental impact assessment prior to going commercial and the results of these will determine possible size of the project.

3.6 Shoreline erosion in Saldanha Bay and Langebaan lagoon

3.6.1 Background

Beach erosion in Saldanha Bay, particularly at Langebaan Beach, has been the subject of much controversy in recent years. On-going 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). This issue has been addressed in some detail in previous versions of the State of the Bay report (see for example Anchor Environmental Consultants 2010, 2011 and 2013b), as have the various ad hoc responses to these erosion problems (e.g. construction of groynes and rock revetments along Langebaan Beach, and gabion walls on Paradise Beach). Recently, two Environmental Management and Maintenance Plans (EMMP) were drafted by Common Ground Consulting and approved by the DEA&DP (Common Ground Consulting 2013a and b) (for more detail refer to Anchor Environmental 2013b). Updates with regards to the implementation of these management recommendations are provided below.

Although management and maintenance of structures to prevent further shoreline erosion in build-up areas of Langebaan are necessary, future impact of shoreline erosion due to storm events and climate change have to be anticipated in order to ensure sustainable development instead of ad hoc reactive management. Some innovative solutions in this respect are currently being trialled in the WCDM (which includes Saldanha Bay), which are summarised in Section 3.6.3.

Current status of Langebaan beach erosion management measures

Much needed maintenance is required to prevent further degradation of the groynes at Langebaan North beach and other erosion protection infrastructure in the Bay. While such interventions would normally require environmental authorisation (i.e. BA of Scoping and EIR), agreement was recently reached between the SBM and DEA&DP that such works could be undertaken in terms of an EMMP. Such an EMP was drafted and approved by DEA to provide the necessary management and reporting procedures for the contractor appointed to undertake the works. However, due to the lack of funding at the SBM no contractor has been assigned for the above repairs and maintenance suggestions and none of the recommended monitoring has been implemented to date (SBM, Environmental Officer, Nazema Duarte 2014, *pers. comm.*).

Upgrading and maintenance is also needed the Leentjiesklip Caravan Park, the Alabama Street slipway and the terraced concrete walkway at the end of Uitsig Street/Melck Street and a separate EMMP was prepared for this purpose by Common Ground Consulting (Common Ground 2013b). Recommendations for the Leentjiesklip Caravan Park included various short term interventions not requiring engineering solutions of which some have so far been implemented. A low fence was erected to direct pedestrian traffic onto the wooden path accompanied by notices that prohibit people to walk in the dunes. Unfortunately, neither dune rehabilitation nor the redirecting of stormwater was implemented due to the lack of financial funds. Furthermore, the nature of these mitigation strategies is not desirable within a National Park. No awareness was created about the impacts of dumping of coals in dunes (SBM, Environmental Officer, Nazema Duarte 2014, *pers. comm.*). This is despite the low financial cost associated with for example the distributing of flyers, emails or small signboards. Two different engineering solutions were proposed by the EMMP to stop further shoreline retreat in this area, which both included the reshaping of the foredune, removal of the access road and construction of a submerged barrier. It was found that this project would require EA and would be financially demanding and no progress has been made for the implementation of this recommendation. Managed retreat has not yet been considered by the SBM (SBM, Environmental Officer, Nazema Duarte 2014, *pers. comm.*).

Maintenance at the Alabama street slip way was not considered urgent and other sites have therefore been prioritised. In the case of the Melck Street/Uitsig Street Walkway it was recommended that the existing structure be demolished and rebuilt to ensure the repair of all hidden cavities. This project was perceived with a sense of urgency because of a sewer line which is situated near the deteriorating concrete steps. No leakage was detected then, but this collapsing concrete structure certainly had the capacity to cause damage to the sewer line. DEA&DP authorised the replacement of concrete steps based on the EMMP and consent from SANParks was also granted. Once construction had commenced, SANParks intervened and suspended construction in terms of the MLRA. It was argued that the original EMMP had not indicated the actual amount and depth of digging that would be required for the re-construction of the concrete steps. It became apparent that more sand than initially anticipated had to be excavated in order to remove the foundation. Furthermore, an increased footprint was required to ensure the drying out of the area before the insertion of a new foundation. Although it was not possible to negotiate a smaller footprint SBM and SANParks agreed on a depth of 300 mm instead of 600 mm for the new foundation. Construction has since commenced and is due to be completed in the near future (SBM, Environmental Officer, Nazema Duarte 2014, *pers. comm.*).

Beach erosion in Saldanha Bay, particularly at Langebaan Beach, has been the subject of much controversy in recent years. On-going 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). This issue has been addressed in some detail in previous versions of the State of the Bay report (see for example Anchor Environmental 2010, 2011 and 2012), as have the various ad hoc responses to these erosion problems (e.g. construction of groynes and rock revetments along Langebaan Beach, and gabion walls on Paradise Beach). The authorities have realised that these piecemeal responses are not really the solution and ultimately better planning is required. Some innovative solutions in this respect are currently being trialled in the WCDM (which includes Saldanha Bay). These developments are summarised in the subsections that follow.

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. BA of Scoping and EIR), agreement was recently reached between the SBM and DEA&DP that such works could be undertaken in terms of an EMPr.

Figure 3.50. Groynes and rock revetment at Langebaan North beach. Source: Google Earth.

3.6.2 Integrated coastal management

The ICMA, which came into effect in December 2009, aims to ensure the integrated management of the coastline and the sustainable use of its resources. The 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 the 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 National Environmental Management: Protected Areas Act (No. 57 of 2003). MPAs declared under the MLRA 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 the ICMA. The following aspects of the ICMA will affect future development activities in Saldanha and Langebaan:

- Section 15 of the 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 the 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 set-back 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 the ICMA or coastal management objectives. Designated coastal set-back lines will help to protect biodiversity and heritage sites, ensure the safety of developments while minimizing maintenance issues. The National Environmental Management Integrated Coastal Management Amendment Bill (Bill no 8 of 2013) proposes that 'coastal set-back lines' be renamed to 'coastal management lines' to avoid confusion with EIA development set-back lines.

3.6.3 Defining and adopting Coastal Management/Set-back Lines

Historically, development in the coastal zone has been controlled largely through the EIA regulations (Government Notice R543 published in terms of the 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 has changed dramatically in recent years. This is particularly pertinent in the light of climate change where rising sea-levels and potential increases in the frequency and intensity of storm events are upping the stakes even further. These changes are being implemented through the ICMA which calls for coastal development set-back lines to be determined for all coastal areas. Specifically, section 25 of the ICMA indicates the priority for set-back 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 set-back 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.*

Set-back lines are to be plotted on maps as part of zoning and made available to public, as indicated in the ICMA:

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.

Provinces have been experiencing difficulties in changing coastal setback/management lines once they have been promulgated. Therefore, the National Environmental Management: Integrated Coastal Management Act Amendment Bill (Bill no 8 of 2013) (ICMAA) proposes the amendment of section 25(1) such that the MEC can publish, amend and withdraw a notice in the *Government Gazette* instead.

In response to the above motivation and legal requirements, the DEA&DP commissioned WSP Africa Coastal Engineers (Pty) Ltd to develop a methodology for defining and adopting coastal development set-back lines in the Western Cape and to test the methodology in the Cape Town Metropolitan area (Milnerton) and in the Saldanha 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 set-back 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’) set-back line** which demarcates the set-back 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 set-back line** demarcating the set-back 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 set-back 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 set-back line), and (iv) changes in policy regarding an established set-back line. Furthermore, it was recommended that the set-back lines be scientifically determined regardless of existing development, that they apply equally to mining operations and development.

The process for determining set-back 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.

3.6.4 Coastal management/set-back lines of the West Coast District Municipality

Royal HaskoningDHV (previously SRK Consulting) was appointed by the DEA&DP to delineate coastal set-back lines for the WCDM. Using the provincial methodology, the approach by the City of Cape Town to manage development in the coastal urban space, as well as the recommendations produced in a pilot study in the Overberg Municipality, coastal management/set-back lines and overlay risk zones were produced for the WCDM. The coastal management/set-back lines were determined in the following way (van Weele *et al.* 2014):

1. Urban areas are comprised of existing development, existing development rights and/or land set aside for future municipal development. This was taken into account during the demarcation of the coastal management/set-back line.
2. Long-term risk projections (1:100 year risk zone) were used in rural areas and expanding into the littoral active zone. Existing development was taken into account where necessary to preserve development rights. The coastal management/set-back line was drawn around the developments to create 'development islands'.
3. Coastal management/set-back lines were determined for estuaries along a 5 m contour in undeveloped/rural areas. The lower (water side) boundary of properties was considered where development occurred along the banks of an estuary. Development islands were delineated around isolated existing developments and development rights.
4. Apart from taking into account existing development, development rights and areas set aside for future municipal development, environmental (biophysical sensitivities), heritage (areas of preservation), social (coastal access) and economic (activities which are reliant on proximity to the sea) aspects were also considered in the delineation of coastal management/set-back lines.

The modelled physical process/hazard lines were used as overlay zones which reflect three risk scenarios (as recommended by the Overberg pilot study), namely low (20 years or 200 mm), medium (50 years or 500 mm) and high (100 years or 1000 mm). The modelling of these three scenarios is a five-step process, and relies on wave run-up modelling (van Weele & Breetzke 2013):

Step 1:	Offshore wave height	The 1:10 (current high water mark), 1:20 (short term), 1:50 (medium term) and 1:100 (long term) year storm wave heights and periods.
Step 2:	Wave run-up heights	Current wave run up (HWM), 1:20 (short term), 1:50 (medium term) and 1:100 (long term) wave run up
Step 3:	Future shoreline regression due to sea level rise	The amount of shoreline retreat for short, medium & long term sea level rise
Step 4:	Determine the short-term storm erosion risk along the coastline	Average short term shoreline retreat
Step 5:	Determine long-term beach retreat due to natural sand movement	Available historical aerial photography for sandy shorelines

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 including the current (1:10 year, HWM), short term (1:20 year), medium term (1:50 year) and long term (1:100 year) for sandy and rocky shoreline were determined using the models of Mather *et al.* (2010) and the Eurotop manual (Pullen 2008) respectively. 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) 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 pointed 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. No shoreline surveys were available for the study area and therefore, a short term storm erosion risk along the coastline was assessed as being 20 m on average for sandy shorelines. Due to poor and differing quality of aerial photographs, featureless beaches (difficult to detect common features), unclear position of the wet line and the lack of tidal information, no clear trend of long-term beach retreat due to natural sand movement could be detected. 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.

These overlay zones must be superimposed onto the coastal management/set-back line, and together, these two management tools recognise existing development and development rights while directing development into the lower risk areas and informing how the development should be undertaken such that property, people and the integrity of the coast can be protected. Excerpts of the draft coastal management/set-back lines and overlay zones are shown in Figure 3.51., Figure 3.52, and Figure 3.53. Currently, this information is in preparation to be published in the *Government Gazette* for public comment. It is important to note that this product is therefore subject to change if the outcomes of the formal public participation process should require such changes. There has been a delay in the promulgation of the ICMAA as a result of the elections and change in cabinet in May 2014, which is why the coastal management/set-back lines are to be promulgated as regulations in terms of the ICMA. Should the ICMAA be promulgated before the public participation period is completed, the coastal management/set-back lines will be published as a notice. Unlike the coastal management/set-back lines, the overlay zones have no legal standing under the ICMA and therefore the overlay zones will be published in the *Government* Gazette in form of supporting documentation (DEA&DP, *pers. comm.*, 2014). Once the regulations/notices have been promulgated/adopted, the overlay zones are given effect by incorporation into the municipal planning schemes under Municipal Systems Act (No. 32 of 2000).

Figure 3.51. **The draft coastal management/set-back line and overlay zones for the area due south of the small craft harbour. The green line represents the coastal management/set-back line, the purple polygon outlines development islands within the 1:100 year risk zone. The green area shows the general risk zone in rural areas (1:100 year risk zone) and for estuaries. The red, orange and yellow areas represent the high (1:20), medium (1:50) and low (1:100 year) risk zones for the urban/developed areas respectively (Source: DEA&DP, Caren George).**

Figure 3.52. **The draft coastal management/set-back line and overlay zones for Paradise Beach in the Mykonos development. The green line represents the coastal management/set-back line; the green area shows the general risk zone in rural areas (1:100 year risk zone) and for estuaries. The red, orange and yellow areas represent the high (1:20), medium (1:50) and low (1:100 year) risk zones for the urban/developed areas respectively (Source: DEA&DP, Caren George).**

Figure 3.53. The draft coastal management/set-back line and overlay zones for the Langebaan lagoon and town. The green line represents the coastal management/set-back line; the green area shows the general risk zone in rural areas (1:100 year risk zone) and for estuaries. The red, orange and yellow areas represent the high (1:20), medium (1:50) and low (1:100 year) risk zones for the urban/developed areas respectively (Source: DEA&DP, Caren George).

4 WATER QUALITY

4.1 Introduction

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 physical and biological processes impacting on, or occurring within a body of seawater. Historical long-term data series exist for these three variables for Saldanha Bay spanning the period 1974-2000 and have recently been augmented by monitoring studies undertaken by the Council for Scientific and Industrial Research (CSIR) (van Ballegooyen *et al.* 2012) on behalf of Transnet for their newly constructed reverse osmosis desalination plant (data for the period 2010-2011). These data are presented in this chapter together with a summary of the main natural driving forces influencing water quality in the Bay (currents and waves). Some recent data is also available on other physico-chemical parameters from the Bay including turbidity and bromide, as well as for faecal coliforms and trace metals (introduced to the Bay through wastewater discharges). These data are also presented in this chapter.

4.2 Circulation and current patterns

Circulation patterns and current strengths prior to 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 appear 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 4.1). 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. 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 (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 & 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 4.1).

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 & 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.

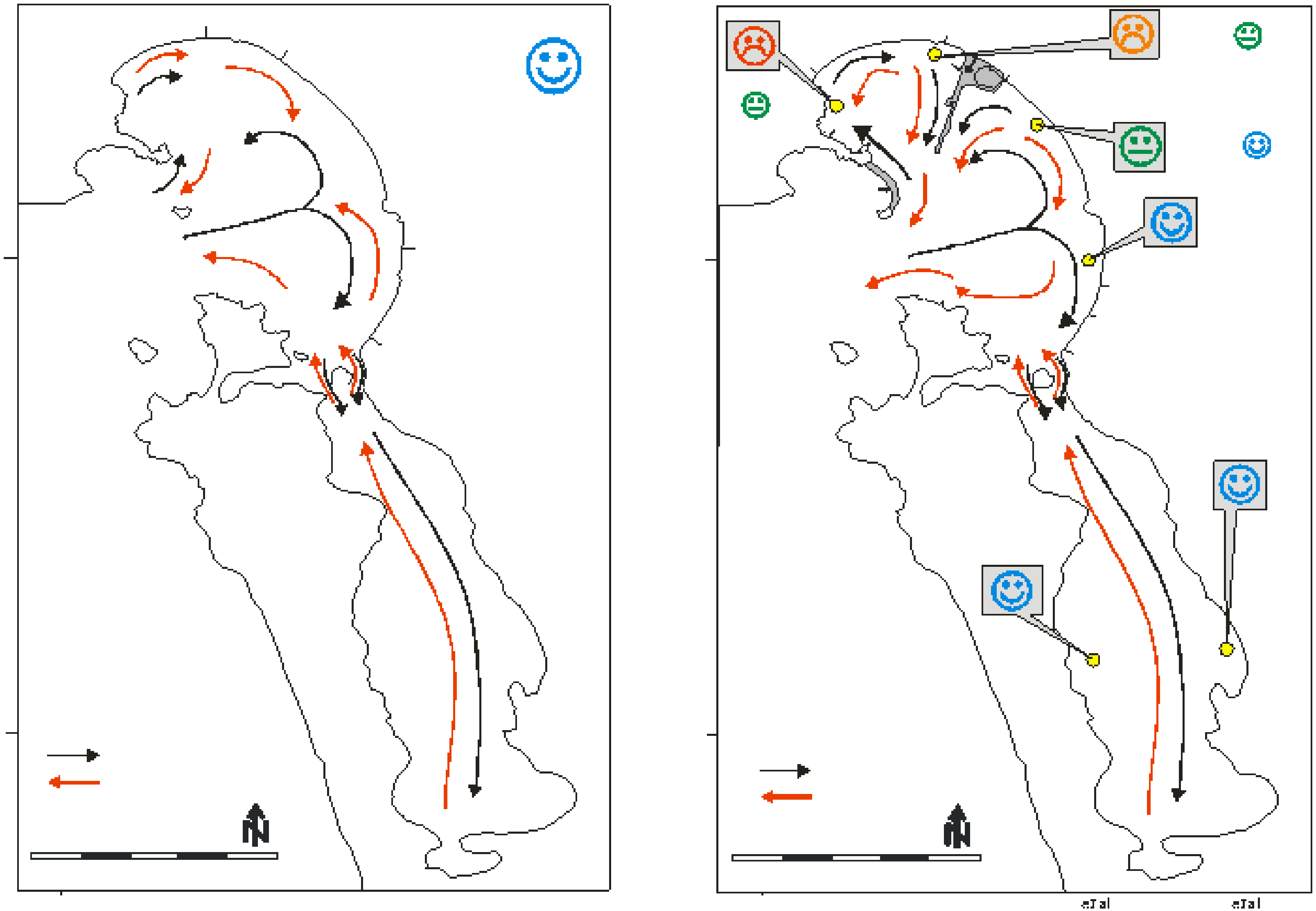


Figure 4.1. Schematic representation of the surface currents and circulation of Saldanha Bay (A) prior to the harbour development (Pre-1973) and (B) after construction of the causeway and iron-ore terminal (Present). (Adapted from Shannon & Stander 1977 and Weeks *et al*. 1991a).

4.3 Wave action

Construction of the Iron Ore Jetty and the Marcus Island causeway 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 4.2). The iron ore terminal essentially divided the Bay into two parts, eliminating much, if not all, the semi-exposed area in Small Bay, greatly increasing the extent and degree of shelter in the north-western part of Small Bay, and subtly altering wave exposure patterns in Big Bay (Figure 4.3). Wave exposure in Big Bay was altered less dramatically, however, the extent of sheltered and semi-sheltered wave exposure areas increased after harbour development (Luger *et al.* 1999).

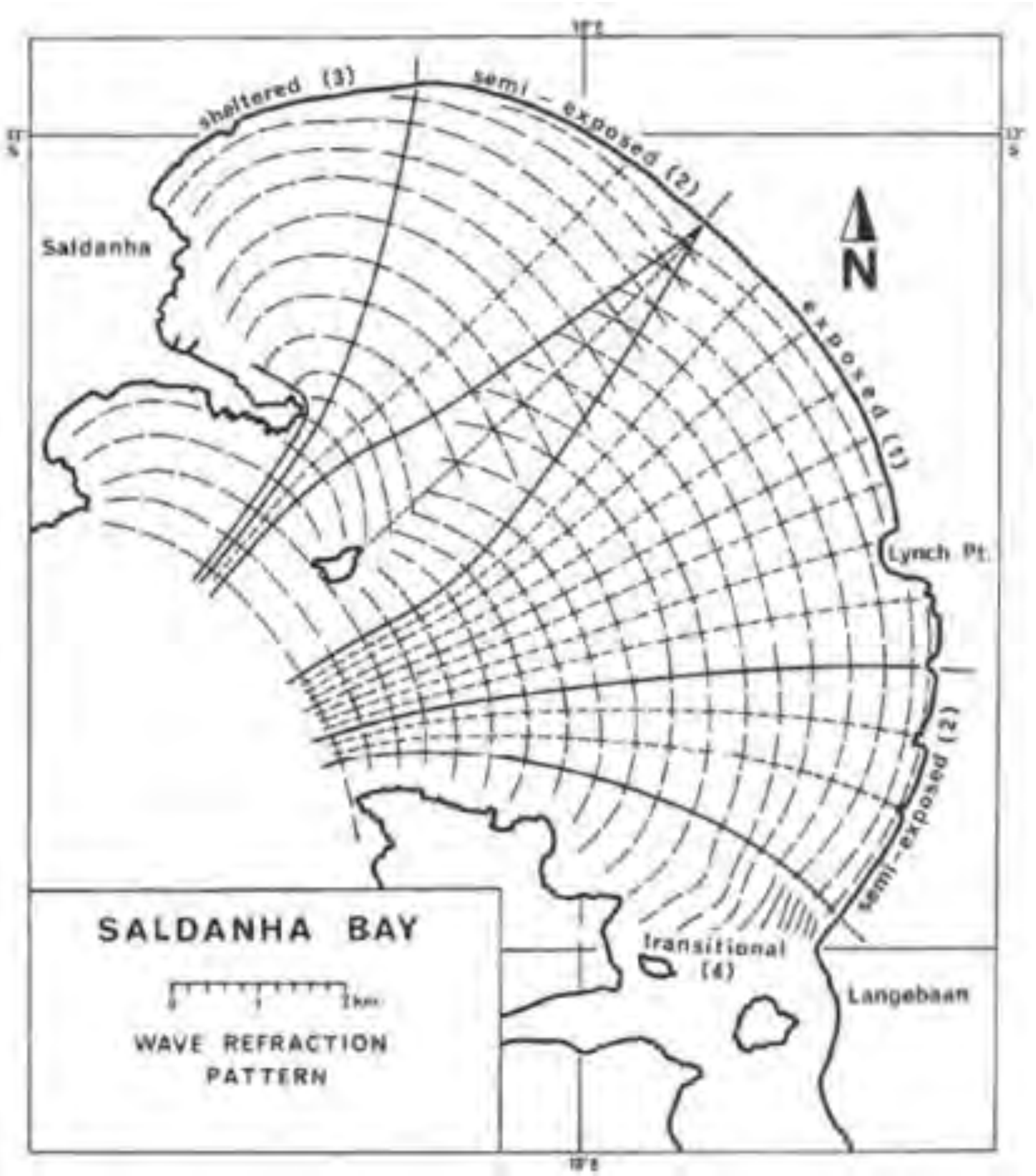


Figure 4.2. Predicted wave field in Saldanha Bay showing wave height and direction. (Source: Flemming (1977).)

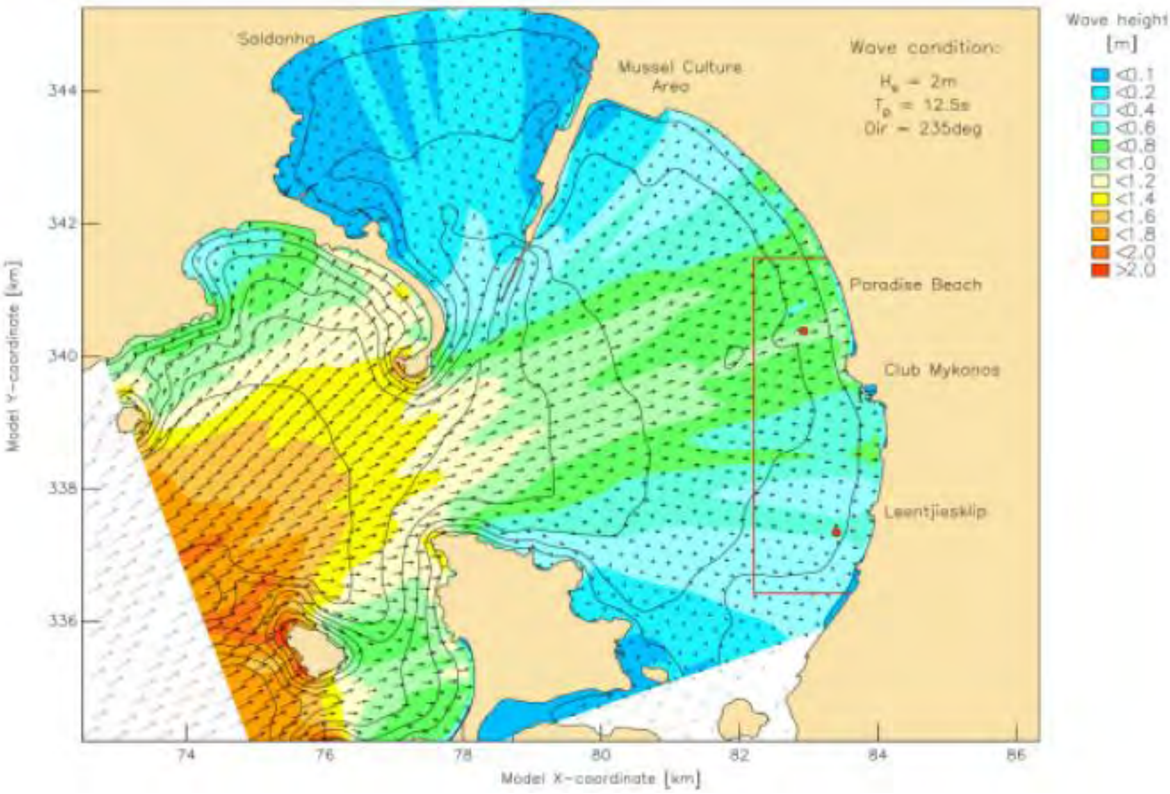
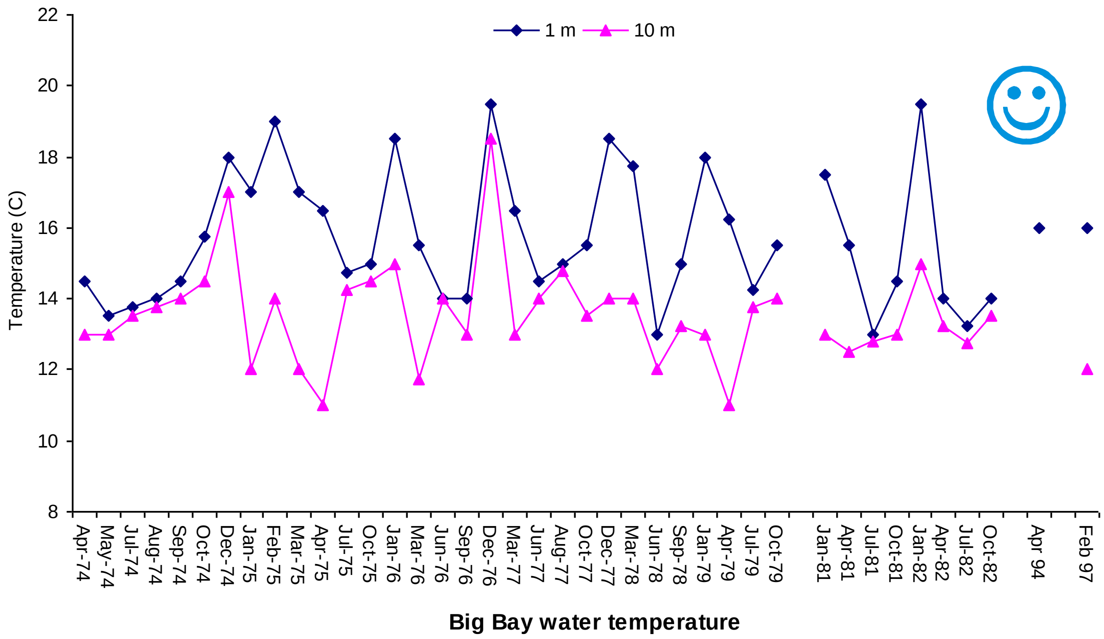


Figure 4.3. Predicted wave field in Saldanha Bay showing wave height and direction. (Source: WSP Africa Coastal Engineers (2010)).

4.4 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 (later renamed Marine and Coastal Management (MCM) - Department of Environmental Affairs and Tourism and now known as Oceans and Coasts – Department of Environmental Affairs). 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 & 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 & 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 & Brundrit (1990). The temperature time series for Small Bay and Big Bay is shown in Figure 4.4. 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 4.4). 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 4.4). 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 4.4).



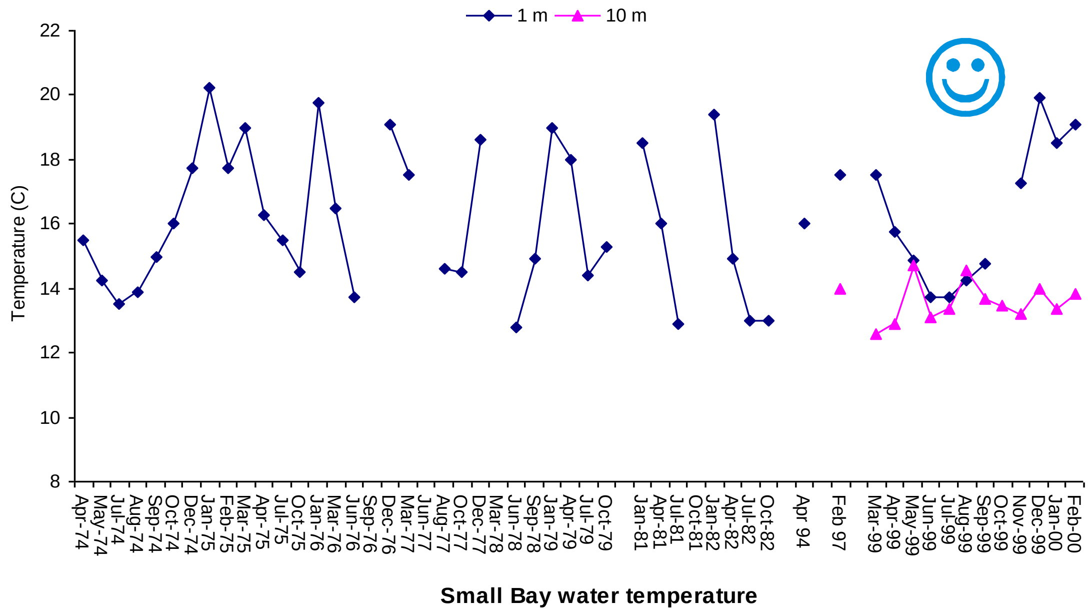


Figure 4.4. Water temperature time series at the surface and at 10m depth for Big Bay and Small Bay, Saldanha Bay (data sources: Monteiro *et al.* 1990, Monteiro & Brundrit 1990. Monteiro *et al.* 2000 and Shannon & Stander 1977).

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 4.8), and low nitrate and chlorophyll concentration (a measure of phytoplankton production) measurements taken at the same time (Monteiro & 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 4.4) and although the pre-construction data record is limited to only one year, Shannon & 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 Outer Bay.

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, 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 close 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 & 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.

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 (1 m) and bottom (10 m) for this period is shown in Figure 4.4. 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 4.4). The continuous monitoring of temperature also identified a three 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).

The CSIR undertook baseline monitoring in Saldanha Bay on behalf of Transnet before the implementation and operation of the Transnet reverse osmosis desalination plant in 2012 (van Ballegooyen *et al.* 2012). Monitoring of sea water temperature, salinity and dissolved oxygen included continuous monitoring over a period of 10 months (July 2010 to March 2011) at one site immediately adjacent to proposed outfall from the desalination plant (an underwater mooring) and also water column profiling undertaken at nine stations at discrete intervals during the course of the year. Locations of the sampling stations are listed in Table 2.1 and indicated on Figure 4.5. The combination of continuous monitoring and discrete profiling measurements was designed to address the different scales of temporal variability in the Bay: seasonal, event (3 to 10 days) and diurnal scales.

Table 4.1 Location and details of sites sampled during the water column profiling surveys undertaken by the Council for Scientific and Industrial Research between July 2010 and March 2011.

Site	Latitude	Longitude	Depth (m)	Distance from discharge (m)	In/Out channel
North Buoy (NB)	33° 1.114'S	17°58.130'E	12.5	1875	Out
Mussel Farm (MF)	33° 1.794'S	17° 58.247'E	16.0	1 400	Out
Intermediate Dredge site (IDS)	33° 1.889'S	17° 58.642'E	16.0	880	Out
WRO3	33° 1.935'S	17° 59.030'E	26.5	525	In
WRO4	33° 1.721'S	17° 59.127'E	28.5	105	In
WRO2	33° 1.651'S	17° 59.094'E	23.0	85	On slope
Brine Discharge Site (BDS)	33° 1.679'S	17° 59.147'E	17.3	30	On slope between the dredge channels berthing areas
WRO1	33° 1.688'S	17° 59.215'E	18.0	85	Out
East Buoy (Big Bay)	33° 3.188'S	18° 0.433'E	15.5	3450	Out

Sites were selected in an effort to address the following issues/aspects:

- Brine Discharge Site (BDS): to provide a measure of brine plume impacts in the immediate vicinity of the proposed brine discharge at caisson 3
- WRO3 and WRO4: to measure the brine plume extent along the dredged shipping channel. (Should a dense plume develop it is expected “drain” seawards along the axis of the shipping channel);
- WRO1 and WRO2: to monitor potential plume excursions out of the dredge channel and towards Small and Big Bay, respectively.
- Mussel Farm (MF) and Intermediate Dredge site (IDS): to couple WRO1 and WRO2 to data measured previously. The MR site was also considered to be a sensitive location, while the ID site lies roughly on a line between the proposed RO Plant discharge and the Mussel Raft site.
- North Buoy (NB): to create a baseline to complement both past and potential future long-term mooring at North buoy
- Big Bay (BB): to provide a baseline station in Big Bay even though the RO plant is not predicted to cause impacts at a site that is so remote from the discharge as is the Big Bay site.

Figure 4.5. Water quality monitoring stations adopted for the RO plant baseline survey undertaken by the Council for Scientific and Industrial Research. (Source: van Ballegooyen *et al.* 2012).

Examples of the temperature data from the water column profiling exercises undertaken at North Buoy are shown in Figure 4.6. In general the profiles at all sites indicated a well-mixed column in winter, becoming increasingly stratified in spring and early summer, and highly stratified in late summer/autumn. The temperature variability in the lower water column was very high during spring and early summer when strong wind events change the water column from being moderately to highly stratified to a well-mixed water column under strong wind conditions. This variability was much lower in Summer due to the presence of cold upwelled waters that help to stratify the water column and in so doing, increase the resistance of the water column to vertical mixing. Stratification was less pronounced at East Buoy in Big Bay than at the more sheltered stations in and around Small

Bay (van Ballegooyen *et al.* 2012). This was ascribed to the generally more turbulent conditions in Big Bay compared to Small Bay. A strong thermocline was also evident in the shipping channel which is more accessible to the cold bottom waters associated with upwelling that enter the Bay.

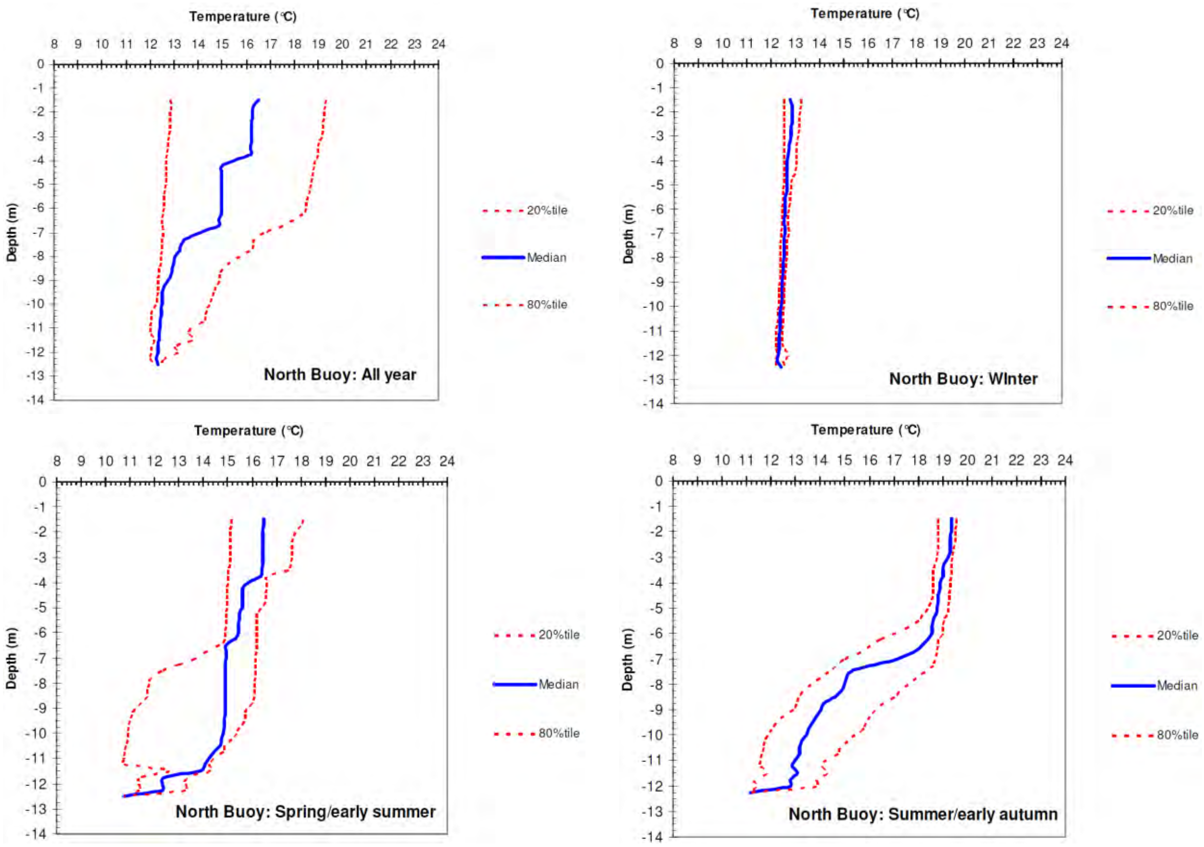


Figure 4.6. Seawater temperature median profiles at North Buoy for all seasons (winter, spring/early, summer and summer/early autumn). The 20 and 80 percentile limits of the profiles are indicated by the dotted red lines (Source: van Ballegooyen *et al.* 2012).

The in situ mooring installed by the CSIR in 2010/2011 as part of the baseline monitoring for the RO plant yielded temperature, salinity and dissolved oxygen times series for the period 09 July 2012 to 23 March 2012 at a temporal resolution of 10 minutes (van Ballegooyen *et al.* 2012). Observations highlighted by the CSIR (van Ballegooyen *et al.* 2012) from this data include the fact that the most obvious variability in the Bay is that which occurs over synoptic (weather) time scales, and was described as follows:

- south-easterly to southerly winds result in upwelling that adverts cold, lower salinity and oxygen deficient waters into the Bay;
- If the winds continue to blow, then a degree of vertical mixing takes place, resulting in a slow increase in temperature, salinity and dissolved oxygen in the bottom waters;
- When the wind drops or reverses to NW, then the water column develops a high degree of stratification shortly followed by a relaxation of upwelling that leads to the colder, less saline

and low oxygen bottom waters exiting the bay. This, coupled with vertical mixing results in the warmer, more oxygenated surface waters being mixed downwards, sometimes to the depth of the mooring.

- As summer progresses, the bottom waters are more and more insulated from the surface waters and the variability in temperature, salinity and dissolved oxygen of the bottom waters decreases compared to spring and early summer;
- The dissolved oxygen in the bottom waters decreases throughout summer to early autumn when the winter storms and vertical mixing of the water column alleviated these low oxygen conditions.

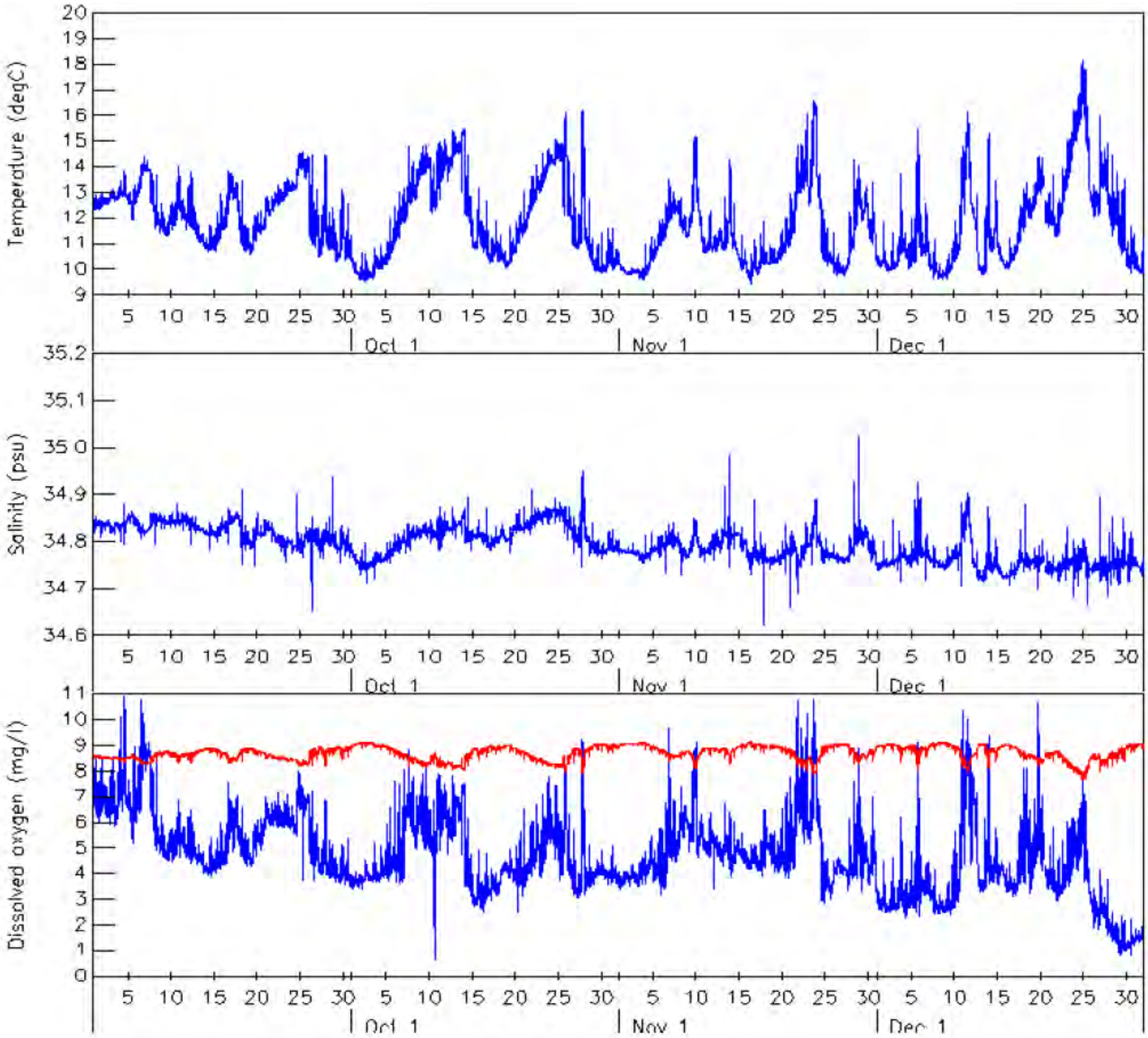


Figure 4.7. Time series of water temperature, salinity and dissolved oxygen concentration from the mooring site (33° 01.679'S: 17° 59.143'E) for spring/early summer. (Source: van Ballegooyen *et al.* 2012).

4.5 Salinity

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).

The historic salinity data time series covers much of the same period as that for water temperature and salinity data were extracted from the studies of Shannon & Stander (1977), Monteiro & Brundrit 1990, Monteiro *et al.* (1990) and Monteiro *et al.* (2000) (Figure 4.8). 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 4.8. 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.

The salinity time series shows salinity peaks in December 1974 and 1976 which reflects the warm water inflows that occurred at this time (Figure 4.8). Higher than normal salinity values were also recorded in August 1977 and July 1979. 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). The 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 & Brundrit 1990) (Figure 4.9). 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 & 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.

Examples of the salinity data from the water column profiling exercises undertaken at North Buoy by the CSIR in 2010/2011 are shown in Figure 4.10 (van Ballegooyen *et al.* 2012). In general, the profiles at all sites were found to be consistent with the notion that lower salinity bottom waters enter the bay during the upwelling season (summer), and higher salinity surface waters are present in late summer/autumn. The low salinity "spikes" observed in the profile data are reportedly spurious (instrument error) and can be ignored (van Ballegooyen *et al.* 2012).

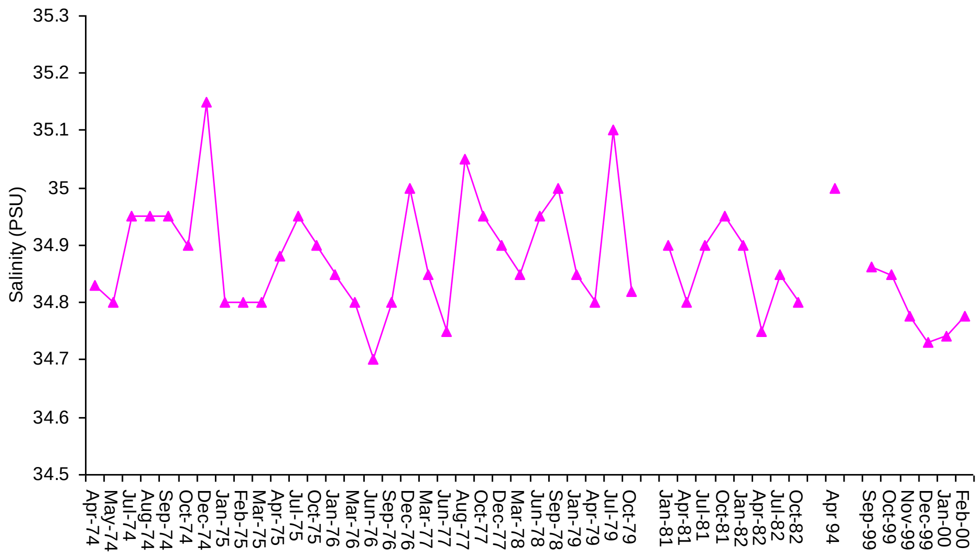


Figure 4.8. **Time series of salinity records for Saldanha Bay (data sources: Shannon & Stander 1977, Monteiro & Brundrit 1990, Monteiro *et al.* 1990 and Monteiro *et al.* 2000).**

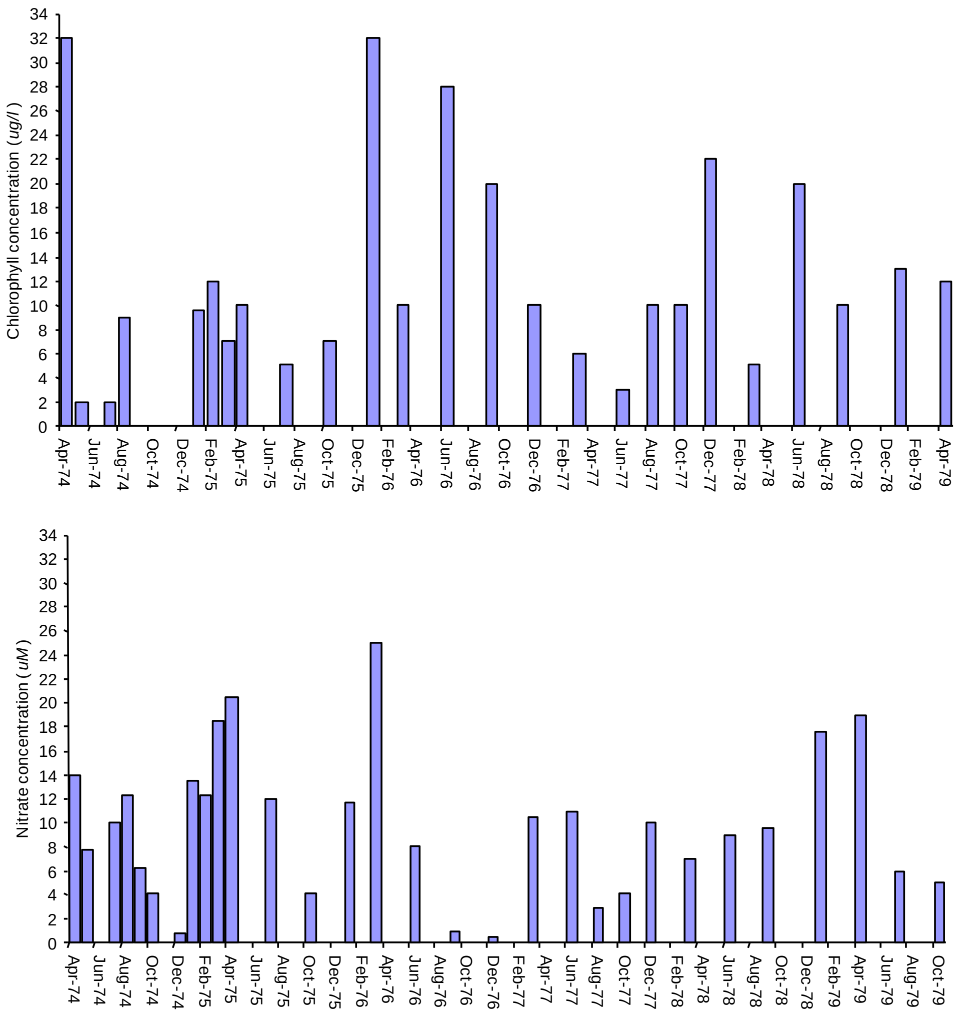


Figure 4.9. **Time series of chlorophyll and nitrate concentration measurements for Saldanha Bay (Data source: Monteiro & Brundrit 1990).**

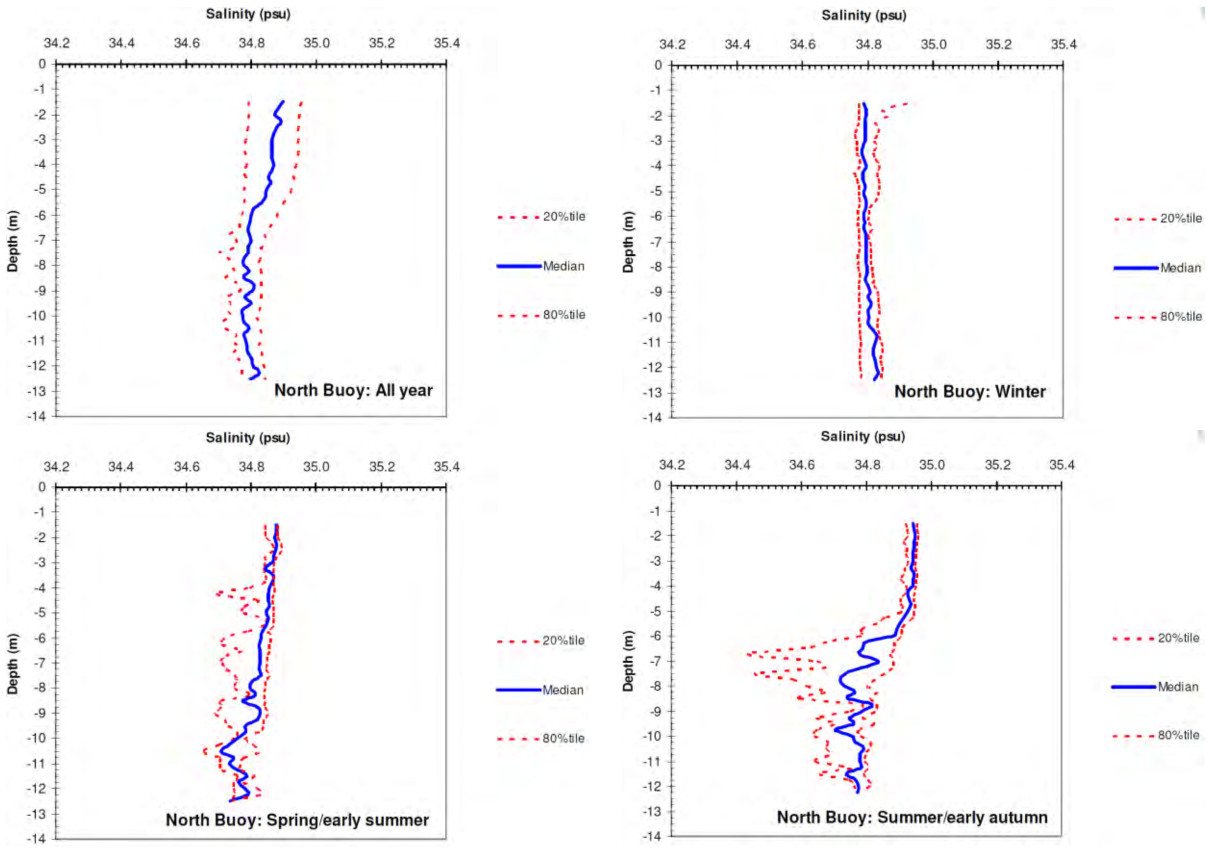


Figure 4.10. Salinity median profiles at North Buoy in Small Bay for all seasons (winter, spring/early, summer and summer/early autumn). The 20 and 80 percentile limits of the profiles are indicated by the dotted red lines (Source: van Ballegooyen *et al.* 2012).

4.6 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 4.11). 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 4.9.

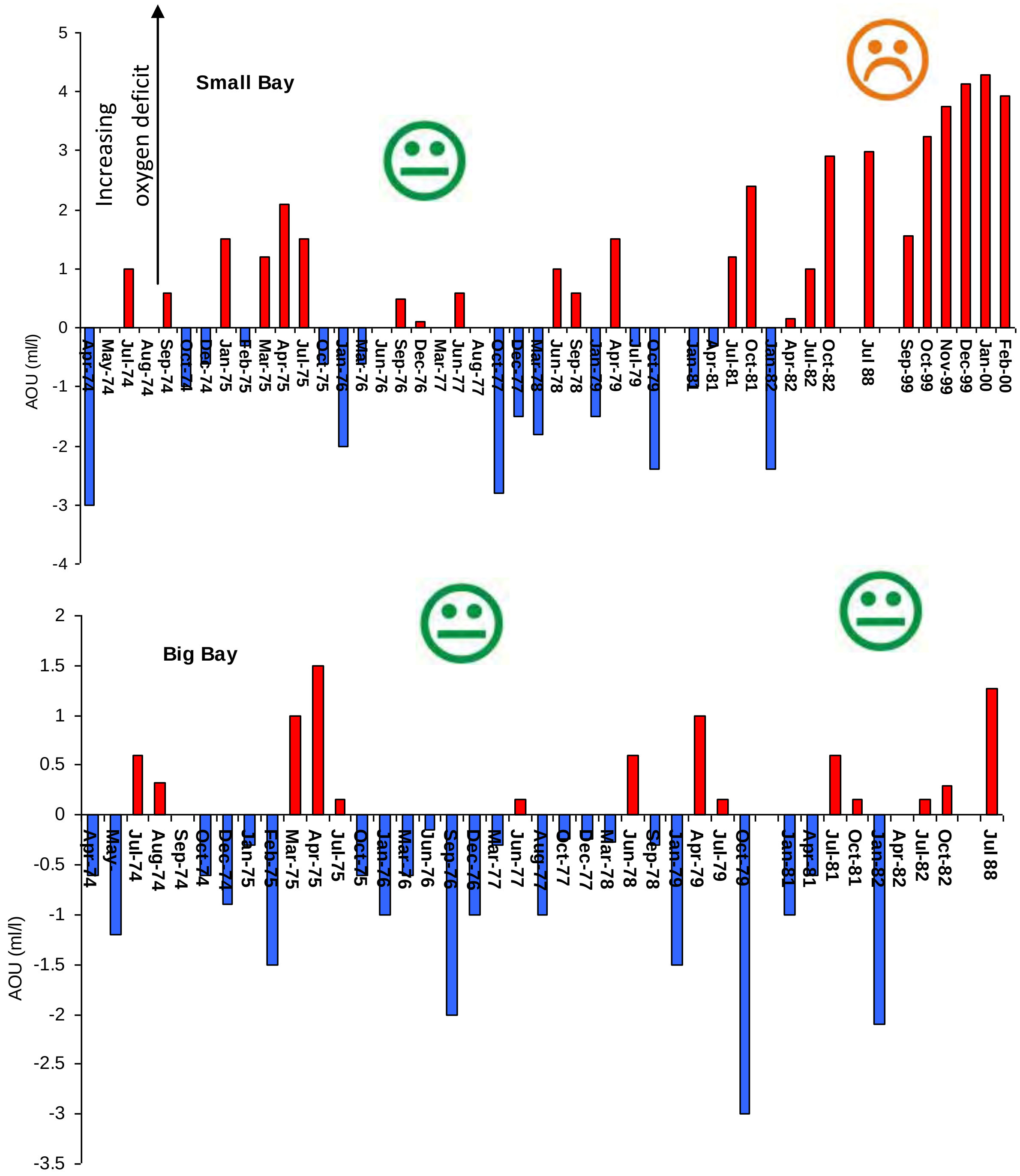


Figure 4.11. Apparent oxygen utilization time series for Small Bay and Big Bay in Saldanha Bay. Positive values in red indicate an oxygen deficit. (Data sources: Monteiro *et al.* 1990 and 2000).

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 4.11). 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 4.11). 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 and 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. Examples of the dissolved data from the water column profiling exercises undertaken by the CSIR at North Buoy in 2010/2011 are shown in Figure 4.12 (van Ballegooyen *et al.* 2012). The profiles indicated that dissolved oxygen concentrations are high in winter but very low in the bottom waters and near the seabed in summer, late summer and early autumn. These low oxygen concentrations in the near bottom waters are considerably lower than those reported by Shannon & Stander (1977) for the period prior to the development of the port, but those in the upper water column are similar. Shannon & Stander's results indicated dissolved oxygen concentrations at the surface of 8.60 ± 1.86 (std dev) mg/l, 7.96 ± 1.63 mg/l at -5m, 6.85 ± 1.54 mg/l at -10 mm, and 5.13 ± 1.80 mg/l at -20m for period April 1974 to October 1975.

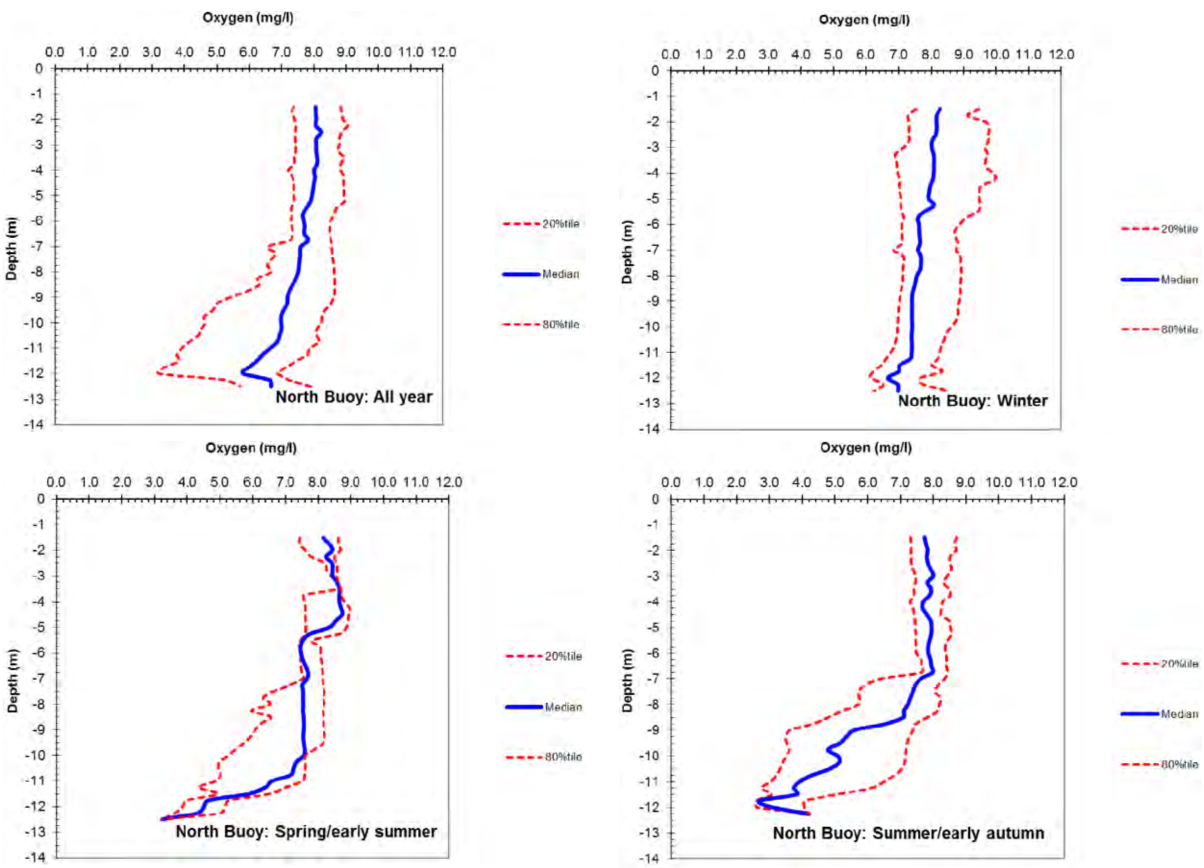


Figure 4.12. **Dissolved oxygen concentration median profiles at North Buoy for all seasons (winter, spring/early, summer and summer/early autumn). The 20 and 80 percentile limits of the profiles are indicated by the dotted red lines (Source: van Ballegooyen *et al.* 2012).**

4.7 Turbidity

The CSIR describe the water of Saldanha Bay as being "fairly turbid", the turbidity comprising both organic and inorganic particulates that are suspended in the water column (van Ballegooyen *et al.* 2012). Turbidity in the Bay generally peaks under strong wind conditions (due to wind and wave action that suspend particulate matter in the water column, particularly Big Bay). Langebaan Lagoon, however, typically remains very clear even when the winds are very strong. Phytoplankton blooms and shipping movements have also been observed to cause significant increases in turbidity in the Bay. Historic measurements (n = 90) made by Carter and Coles (1998) indicate that average levels of total suspended solids (TSS) in the Bay are in the order of 4.08 mg/l (± 2.69 mg/l SD) and peak at around 15.33 mg/l. Higher values than this (162 mg/l), caused by shipping movements, have, however been recorded by the CSIR (1996). Variations in turbidity caused by these different driving forces are clearly demonstrated in Google Earth images presented by CSIR (van Ballegooyen *et al.* 2012).

Data on turbidity (a measure of light conditions in the water column) and TSS (a measure of the mass per unit volume of TSS in the water column) were collected at their water column profiling stations sampled for the RO plant baseline in in 2010/2011 (van Ballegooyen *et al.* 2012). Turbidity data for the North Buoy site in Small Bay are shown here (Figure 4.14). In general the TSS concentrations are greatest near the seabed, particularly at the shallower sites in and around Small Bay. The TSS concentrations generally did not exceed approximately 10 mg/l, except for a few occasions where higher TSS of between 10 mg/l and 40 mg/l were observed (typically in the near bottom waters at the Mussel Farm site, at East Buoy in Big Bay and in the immediate vicinity of the berths along the iron-ore jetty). A few values above 100 mg/l were recorded in the vicinity of the iron ore jetty, and were reportedly related to shipping activities. The water column turbidity data reflected the same general trends as the TSS data, with turbidity in winter generally in the range of 5-12 NTU while in the other seasons the turbidity typically lay between 5 and 8 NTU (van Ballegooyen *et al.* 2012).

Figure 4.13. Turbidity generated under high wind conditions (top) and by propeller wash (bottom) in Saldanha Bay. (Source: van Ballegooyen *et al.* 2012).

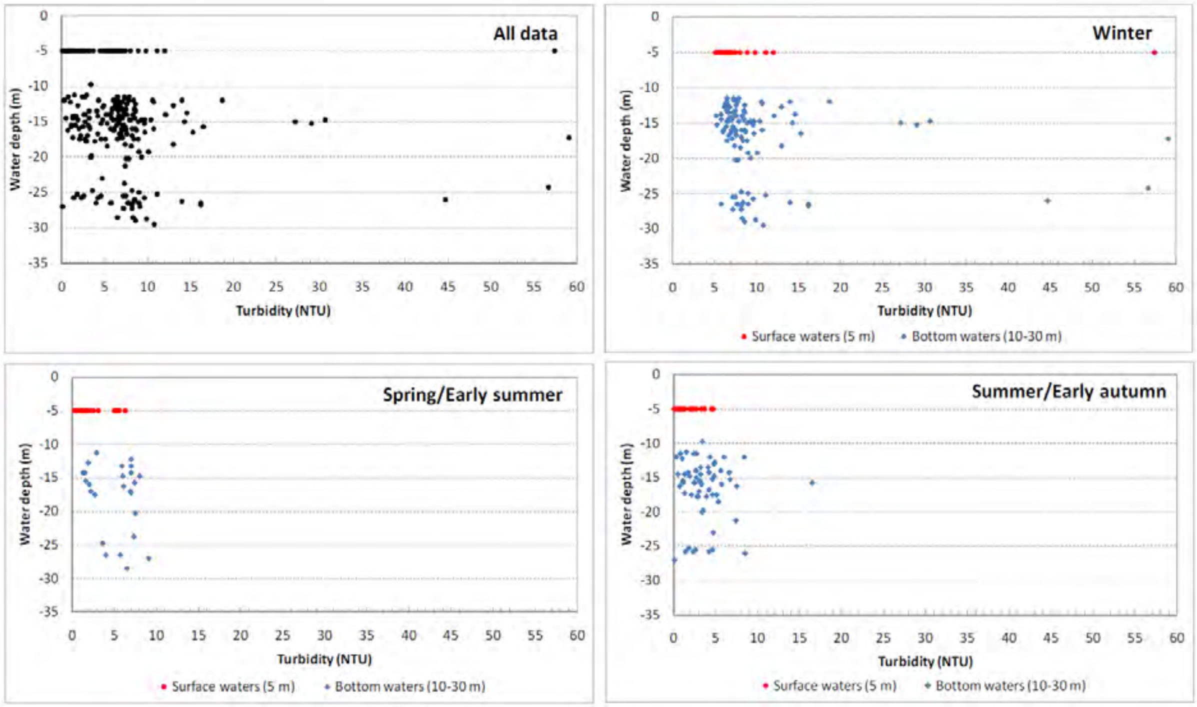


Figure 4.14. Turbidity (NTU) plotted as a function of depth and season (red –surface; blue – bottom). (Source: van Ballegooyen *et al.* 2012).

4.8 Bromide

Measurements of Bromide concentrations were collected at their water column profiling stations sampled for the RO plant baseline in in 2010/2011 (van Ballegooyen *et al.* 2012). Measurements were taken at the surface and near the bottom at each station to provide a measure of its natural occurrence in the marine environment of Saldanha Bay. The purpose was to ensure that the biocide proposed to be used in the RO plant, 2,2-dibromo-3-nitrilopropionamide or its break-down products, do not change these natural distributions. Bromide concentrations in seawater are generally in the range of 65 mg/l to well over 80 mg/l in some confined sea areas. Data presented by the CSIR were consistent with these observations, variability being higher in summer than in winter (van Ballegooyen *et al.* 2012). Variability was particularly high in spring/early summer and it was suggested that this may be related to maintenance dredging that occurred close to the sample sites around the iron-ore jetty at the time.

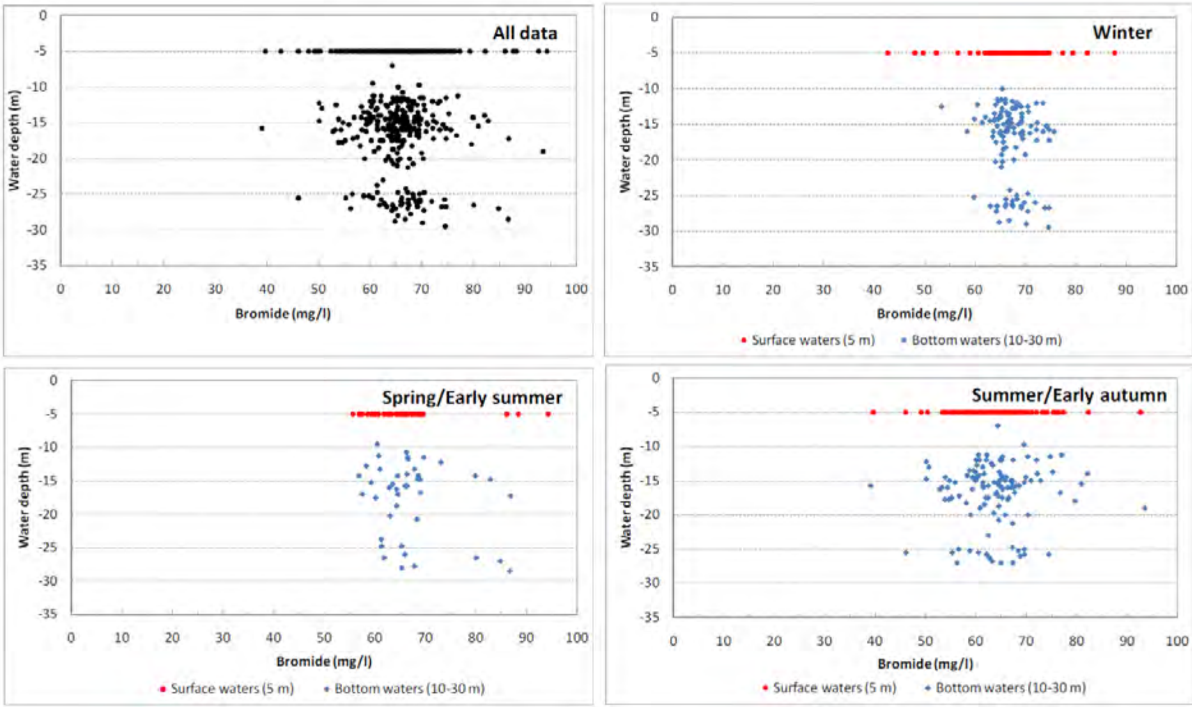


Figure 4.15. Bromide concentrations as measured at all stations (all year, winter, spring/early summer and summer/early autumn). (Source: van Ballegooyen *et al.* 2012).

4.9 Faecal coliforms

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 (1995a-d) guidelines for inland and coastal waters respectively, have been used to assess compliance in respect of human health criteria. In 2012, the Department of Environmental Affairs (DEA) published revised South African Water Quality Guidelines for Coastal Marine Waters Volume 2: Guidelines for Recreational Waters (DEA 2012). Sampling in Saldanha Bay and Langebaan Lagoon is still undertaken in accordance with the 1995 DWAF protocol but in this report, the evaluation of these data is done in accordance with guidelines for recreational and mariculture use (DWAF 1995b and d) as well as in terms of the revised South African Water Quality Guidelines for Coastal Marine Waters Volume 2: Guidelines for Recreational Waters (DEA 2012).

4.9.1 DWAF 1995 and 1996 guidelines

The *Guidelines for Inland and Coastal Waters: Volume 2* Guidelines *for Recreational Use* (DWAF 1995b), 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 waterskiing, 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 4.2). 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 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 nine of the 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 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 4.2. Maximum acceptable count of faecal coliforms (per 100 ml sample) for mariculture and recreational use according to the DWAF 1995 guidelines (DWAF 1995b and d).

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 and is now undertaken by the Saldanha Bay Municipality (SBM). The available data covers the period February 1999 to June 2014 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 – Transnet-NPA) where no data were collected during 2003, 2004, 2008, 2010 and 2011. Regular data collection was initiated at some of the Langebaan sites in 2004. Samples were collected at Stations 19 and 20 (Kraalbaai North and South respectively) for the first time in 2012. Only faecal coliform limits were included in this analysis.

Data from the microbial monitoring programme suggest that nearshore coastal waters in Saldanha Bay have improved for recreational use since 1999 but decreased slightly in health from 2013 to 2014. The beach at Bok River Mouth (Site 9) exceeded the 80th percentile guideline limits for recreational use in 2013, while both Hoedjies Bay Beach and the beach at the Caravan Park (Sites 7 & 8 respectively) exceeded these limits in 2014 (Table 4.3). All of the sites met the 95th percentile limits in 2013, while the small quay at Pepper Bay (Site 6) exceeded these limits in 2014 (Table 4.4).

Levels of compliance in 2013 and 2014 show an increase in environmental health with respect to recreational water use when compared to the 1999-2004 period.

Guideline limits for mariculture are much stricter than the recreational guideline limits, thus levels of compliance for mariculture were predictably much lower. A total of five sites (Sites 3, 6, 7, 9 & 15) were not compliant in respect of the 80th percentile limits for faecal coliforms in terms of mariculture in 2013, while four sites (Sites 7, 8, 9 & 15) were not compliant in 2014 (Table 4.5). These data reveal a decrease in microbiological contamination at the Sea Harvest small quay (Site 3) and an increase in contamination at the Hoedjies Bay and Caravan Park beaches (Sites 7 & 8 respectively). Eight sites (Sites 1, 3, 6, 7, 8, 9, 15 & 17) were not compliant with respect to the 95th percentile limits in 2013, however, this improved to six sites (Sites 1, 6, 7, 8, 9 & 15) in 2014 (Table 4.6). Despite the improvement at the Sea Harvest small quay and the Langebaan Yacht Club (Sites 3 & 17 respectively), the water quality at the small quay at Pepper Bay (Site 6) deteriorated by two orders of magnitude. Many of the non-compliant sites exceeded the limit by quite a large margin (especially Site 9 in 2013 for the 80% limit and Site 6 in 2014 for the 95% limit). The site with the highest faecal coliform readings was the small quay at Pepper Bay with 45 000 per 100ml, and the beach at the Bok river mouth following second with 2 000 faecal coliforms per 100ml both in May 2014. Overall levels of compliance in 2014 showed an improvement in faecal coliform counts relative to the guidelines for mariculture from the previous year and a definite improvement since the earlier 1999-2005 period. It must be stressed that these samples are collected from the shore and are therefore much closer to sources of contamination (stormwater drains etc.) and are in relatively shallow water, hence concentrations of microbiological contaminants are likely to be higher than those near the mariculture rafts. Shore based sampling however, does provide good data on the input of microbiological contaminants into the Bay and measured concentrations are directly applicable to recreational contact limits.

Time series plots and linear regression analysis of the faecal coliform and *Escherichia coli* counts were carried out for selected sites within Small Bay, Big Bay and Langebaan Lagoon. A downward slope of the regression (solid red and blue lines) is generally indicative of improving water quality, while an upward slope in these lines is generally indicative of decreasing water quality. Faecal coliform counts from Small Bay and Big Bay were compared to the DWAF 1995 80th percentile mariculture limits as mussels and oysters are cultivated in these bays, while faecal coliform counts from Langebaan Lagoon were compared to the 80th percentile recreational limits. These limits are indicated by the dashed green line on the graphs. The trend of water quality health over time is illustrated by means of smiley faces in the figures. Nine of the 10 stations within Small Bay show a decrease in faecal coliform concentrations over the last ten years, although values at the beach at Hoedjies Bay Hotel, the beach at the Caravan Park and Bok River Mouth (Sites 7, 8 & 9) still remain relatively high. Saldanha Bay Yacht Club (Site 4) showed the greatest improvement in bacterial counts (Figure 4.16). Time series plots for the four sampling sites in Big Bay are shown in Figure 4.19. The levels of faecal coliforms at these stations are mostly lower than at stations in Small Bay, with the largest decrease over time at Leentjiesklip (Site 14). Microbial levels at the Langebaan sites are all below the recreational limits (Figure 4.20 and Figure 4.21), although noticeable deterioration has taken place at Langebaan North (Site 15) and slight deterioration at Tooth Rock (Site 18).

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 from 1999-2014. The average faecal coliform concentration of samples was calculated within the 80th percentile limit specified in South African Water Quality Guidelines for recreational use (100 organisms/100 ml). Numbers in black indicate compliance with regulations, while red numbers indicate non-compliance. A dash (-) indicates that no samples were collected that year (source: Saldanha Bay Water Quality Forum Trust). *Samples for 2014 are from January to July and do not represent a 12 month period.**

	Site	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014*
Small Bay	1. Beach at Mussel Rafts	157	2	0	4	0	0	0	0	2	0	3	0	0	2	0	1
	2. Small Craft Harbour	111	14	8	6	14	7	4	0	0	0	11	0	0	4	0	4
	3. Small Quay - Sea Harvest	476	89	37	93	93	93	15	7	13	5	23	4	16	5	21	14
	4. Saldanha Yacht Club	996	514	972	240	240	460	240	9	20	7	7	5	6	4	9	3
	5. Pepper Bay - Big Quay	834	172	2400	186	460	240	93	93	23	23	15	23	23	43	10	9
	6. Pepper Bay - Small Quay	758	182	240	43	83	93	23	15	15	4	7	240	6	11	28	6
	7. Hoedjies Bay Hotel - Beach	442	105	1052	240	222	181	150	27	128	43	240	240	186	328	43	162
	8. Beach at Caravan Park	94	38	201	62	83	43	75	9	41	93	93	168	51	328	15	161
	9. Beach - Bok River Mouth	938	190	692	1100	460	240	240	35	93	412	460	53	63	716	240	93
	10. General Cargo Quay - TNPA	8	2	4	0	0	0	0	0	0	0	0	0	0	0	0	2
Big Bay	11. Seafarm - TNPA	7	6	0	0	-	-	0	0	0	-	0	-	4	6	0	1
	12. Mykonos - Paradise Beach	3	6	0	0	0	0	9	0	0	0	7	0	0	2	0	1
	13. Mykonos - Harbour	18	21	3	7	9	0	0	4	9	9	23	4	22	5	10	13
	14. Leentjiesklip	-	-	240	93	36	15	10	9	15	4	9	9	18	15	9	9
Langebaan	15. Langebaan North	5	5	6	9	9	2	0	2	4	5	4	0	13	116	27	52
	16. Langebaan Main Beach	-	-	79	0	0	0	4	0	0	0	43	4	3	23	12	5
	17. Langebaan Yacht Club	-	-	-	-	-	17	4	2	12	1	23	4	6	9	9	9
	18. Tooth Rock	-	-	-	-	-	5	7	2	4	12	9	5	0	22	9	6
	19. Kraalbaai North	-	-	-	-	-	-	-	-	-	-	-	-	-	4	0	4
	20. Kraalbaai South	-	-	-	-	-	-	-	-	-	-	-	-	-	4	7	2

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 from 1999-2014. The average faecal coliform concentration of samples was calculated within the 95th percentile limit specified in South African Water Quality Guidelines for recreational use (2000 organisms/100 ml). Numbers in black indicate compliance with regulations, while red numbers indicate non-compliance. A dash (-) indicates that no samples were collected in that year (source: Saldanha Bay Water Quality Forum Trust). *Samples for 2014 are from January to July and do not represent a 12 month period.

	Site	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014*
Small Bay	1. Beach at Mussel Rafts	720	3	1	7	15	4	15	0	4	9	4	19	0	13	121	106
	2. Small Craft Harbour	330	16	110	23	28	41	240	9	4	15	81	9	4	52	8	13
	3. Small Quay - Sea Harvest	2374	279	240	230	240	237	43	41	23	11	240	9	86	25	69	47
	4. Saldanha Yacht Club	12831	1508	2400	1100	1100	1100	1100	40	23	46	67	9	22	4	40	7
	5. Pepper Bay - Big Quay	3312	324	4600	383	460	438	460	2360	88	155	43	93	86	262	23	33
	6. Pepper Bay - Small Quay	3565	642	612	189	449	231	93	43	85	34	76	460	21	130	928	13520
	7. Hoedjies Bay Hotel - Beach	1154	119	2400	799	460	438	240	429	460	155	1100	460	2500	1240	405	486
	8. Beach at Caravan Park	692	45	588	1945	233	225	150	85	220	1100	240	1820	427	2580	181	417
	9. Beach - Bok River Mouth	2794	216	2840	2400	2335	1036	1100	93	423	1100	1100	416	227	2580	940	674
	10. General Cargo Quay - TNPA	18	2	20	4	4	4	4	14	9	7	4	0	4	4	3	5
Big Bay	11. Seafarm - TNPA	13	20	21	3	-	-	23	4	4	-	8	-	4	48	8	3
	12. Mykonos - Paradise Beach	4	7	9	0	4	7	23	10	4	4	20	8	3	12	13	3
	13. Mykonos - Harbour	786	29	6	130	439	15	9	88	139	24	203	20	86	25	27	21
	14. Leentjiesklip	-	-	284	876	93	88	28	22	23	16	76	37	43	149	43	20
Langebaan	15. Langebaan North	35	9	212	93	23	86	4	9	9	15	349	6	34	1100	398	240
	16. Langebaan Main Beach	-	-	518	0	0	0	4	0	0	4	405	20	67	48	43	22
	17. Langebaan Yacht Club	-	-	-	-	-	723	23	40	41	23	405	173	210	36	79	41
	18. Tooth Rock	-	-	-	-	-	18	23	4	20	91	37	20	20	26	39	16
	19. Kraalbaai North	-	-	-	-	-	-	-	-	-	-	-	-	-	70	4	58
	20. Kraalbaai South	-	-	-	-	-	-	-	-	-	-	-	-	-	18	20	6

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 from 1999-2014. The average faecal coliform concentration of samples was calculated within the 80th percentile limit specified in South African Water Quality Guidelines for mariculture use (20 organisms/100 ml). Numbers in black indicate compliance with regulations, while red numbers indicate non-compliance. A dash (-) indicates that no samples were collected in that year (source: Saldanha Bay Water Quality Forum Trust). *Samples for 2014 are from January to July and do not represent a 12 month period.**

	Site	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014*
Small Bay	1. Beach at Mussel Rafts	157	2	0	4	0	0	0	0	2	0	3	0	0	2	0	1
	2. Small Craft Harbour	111	14	8	6	14	7	4	0	0	0	11	0	0	4	0	4
	3. Small Quay - Sea Harvest	476	89	37	93	93	93	15	7	13	5	23	4	16	5	21	14
	4. Saldanha Yacht Club	996	514	972	240	240	460	240	9	20	7	7	5	6	4	9	3
	5. Pepper Bay - Big Quay	834	172	2400	186	460	240	93	93	23	23	15	23	23	43	10	9
	6. Pepper Bay - Small Quay	758	182	240	43	83	93	23	15	15	4	7	240	6	11	28	6
	7. Hoedjies Bay Hotel - Beach	442	105	1052	240	222	181	150	27	127	43	240	240	186	328	43	162
	8. Beach at Caravan Park	94	38	201	62	83	43	75	9	41	93	93	168	51	328	15	161
	9. Beach - Bok River Mouth	938	190	692	1100	460	240	240	35	93	412	460	53	63	716	240	93
	10. General Cargo Quay - TNPA	8	2	4	0	0	0	0	0	0	0	0	0	0	0	0	2
Big Bay	11. Seafarm - TNPA	7	6	0	0	-	-	0	0	0	-	0	-	4	6	0	1
	12. Mykonos - Paradise Beach	3	6	0	0	0	0	9	0	0	0	7	0	0	2	0	1
	13. Mykonos - Harbour	18	21	3	7	9	0	0	4	9	9	23	4	22	5	10	13
	14. Leentjiesklip	-	-	240	93	36	15	10	9	15	4	9	9	18	15	9	9
Langebaan	15. Langebaan North	5	5	6	9	9	2	0	2	4	5	4	0	13	116	27	52
	16. Langebaan Main Beach	-	-	79	0	0	0	4	0	0	0	43	4	3	23	12	5
	17. Langebaan Yacht Club	-	-	-	-	-	17	4	2	12	1	23	5	6	9	9	9
	18. Tooth Rock	-	-	-	-	-	5	7	2	4	12	9	5	0	22	9	6
	19. Kraalbaai North	-	-	-	-	-	-	-	-	-	-	-	-	-	4	0	4
	20. Kraalbaai South	-	-	-	-	-	-	-	-	-	-	-	-	-	4	7	2

Table 4.6. **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 from 1999-2014. The average faecal coliform concentration of samples was calculated within the 95th percentile limit specified in South African Water Quality Guidelines for mariculture use (60 organisms/100 ml). Numbers in black indicate compliance with regulations, while red numbers indicate non-compliance. A dash (-) indicates that no samples were collected in that year (source: Saldanha Bay Water Quality Forum Trust). *Samples for 2014 are from January to July and do not represent a 12 month period.**

	Site	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014*
Small Bay	1. Beach at Mussel Rafts	720	3	1	7	15	4	15	0	4	9	4	19	0	13	121	106
	2. Small Craft Harbour	330	16	110	23	28	41	240	9	4	15	81	9	4	52	8	13
	3. Small Quay - Sea Harvest	2374	279	240	230	240	237	43	41	23	11	240	9	86	25	69	47
	4. Saldanha Yacht Club	12831	1508	2400	1100	1100	1100	1100	40	23	46	67	9	22	4	40	7
	5. Pepper Bay - Big Quay	3312	324	4600	383	460	438	460	2360	88	155	43	93	86	262	23	33
	6. Pepper Bay - Small Quay	3565	642	612	189	449	231	93	43	85	34	76	460	21	130	928	13520
	7. Hoedjies Bay Hotel - Beach	1154	119	2400	799	460	438	240	429	460	155	1100	460	2500	1240	405	486
	8. Beach at Caravan Park	692	45	588	1945	233	225	150	85	220	1100	240	1820	427	2580	181	417
	9. Beach - Bok River Mouth	2794	216	2840	2400	2335	1036	1100	93	423	1100	1100	416	227	2580	940	674
	10. General Cargo Quay - TNPA	18	2	20	4	4	4	4	14	9	7	4	0	4	4	3	5
Big Bay	11. Seafarm - TNPA	13	20	21	3	-	-	23	4	4	-	8	-	4	48	8	3
	12. Mykonos - Paradise Beach	4	7	9	0	4	7	23	10	4	4	20	8	3	12	13	3
	13. Mykonos - Harbour	786	29	6	130	439	15	9	88	139	24	203	20	86	25	27	21
	14. Leentjiesklip	-	-	284	93	93	88	28	22	23	16	76	37	43	149	43	20
Langebaan	15. Langebaan North	35	9	212	876	23	86	4	9	9	15	349	6	34	1100	398	240
	16. Langebaan Main Beach	-	-	518	0	0	0	4	0	0	4	405	20	67	48	43	22
	17. Langebaan Yacht Club	-	-	-	-	-	723	23	40	41	23	405	173	210	36	79	41
	18. Tooth Rock	-	-	-	-	-	18	23	4	20	91	37	20	20	26	39	16
	19. Kraalbaai North	-	-	-	-	-	-	-	-	-	-	-	-	-	70	4	58
	20. Kraalbaai South	-	-	-	-	-	-	-	-	-	-	-	-	-	18	20	6

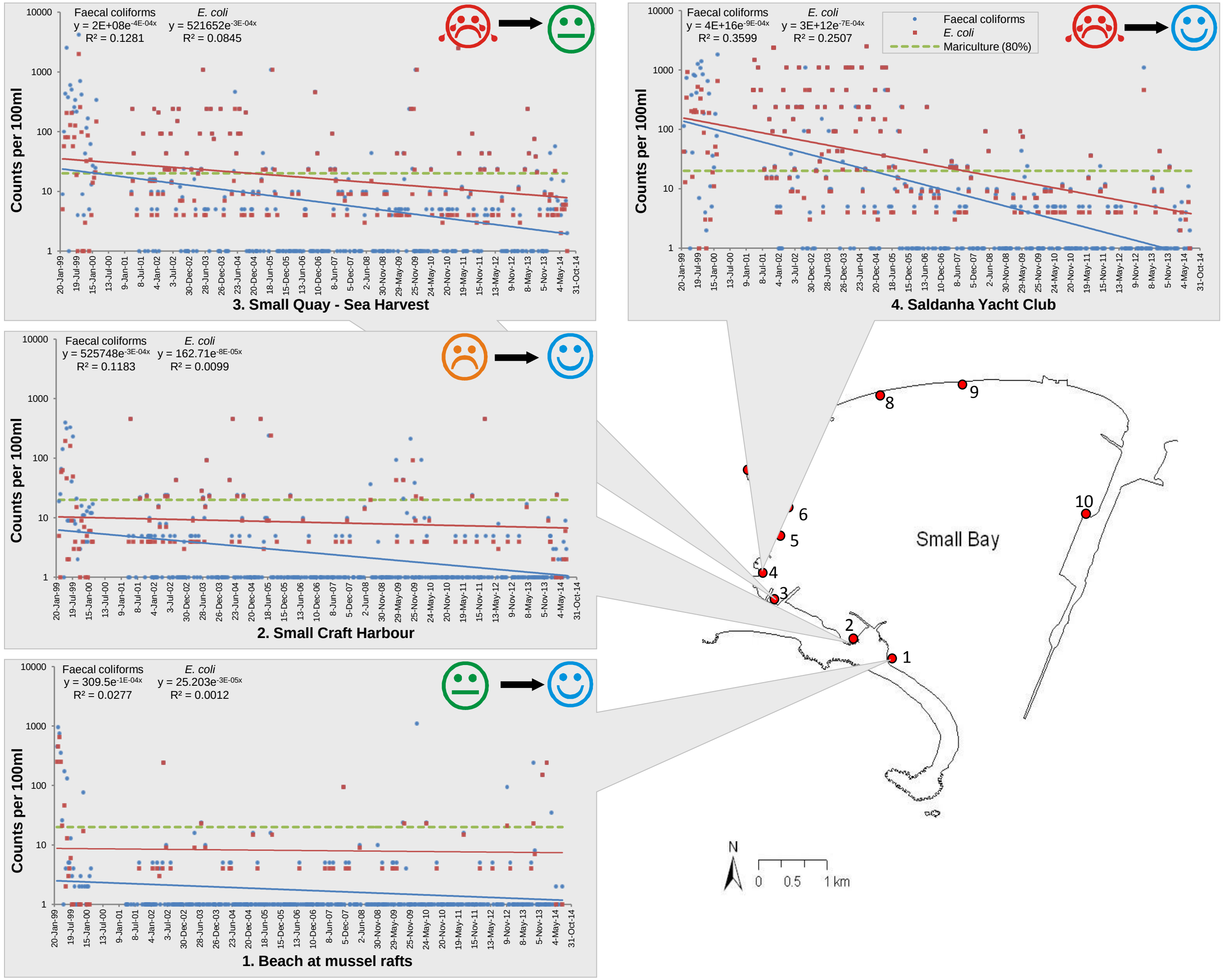


Figure 4.16. Faecal coliform and *E. coli.* counts at four of the 10 sampling stations within Small Bay (Feb 1999 – June 2014). The green dashes indicate the 80th percentile mariculture limit of faecal coliforms and the smiley faces correspond to changes in faecal coliform counts over time. The y-axis represents a log scale with y=counts per 100ml+1 allowing zero values to be plotted.

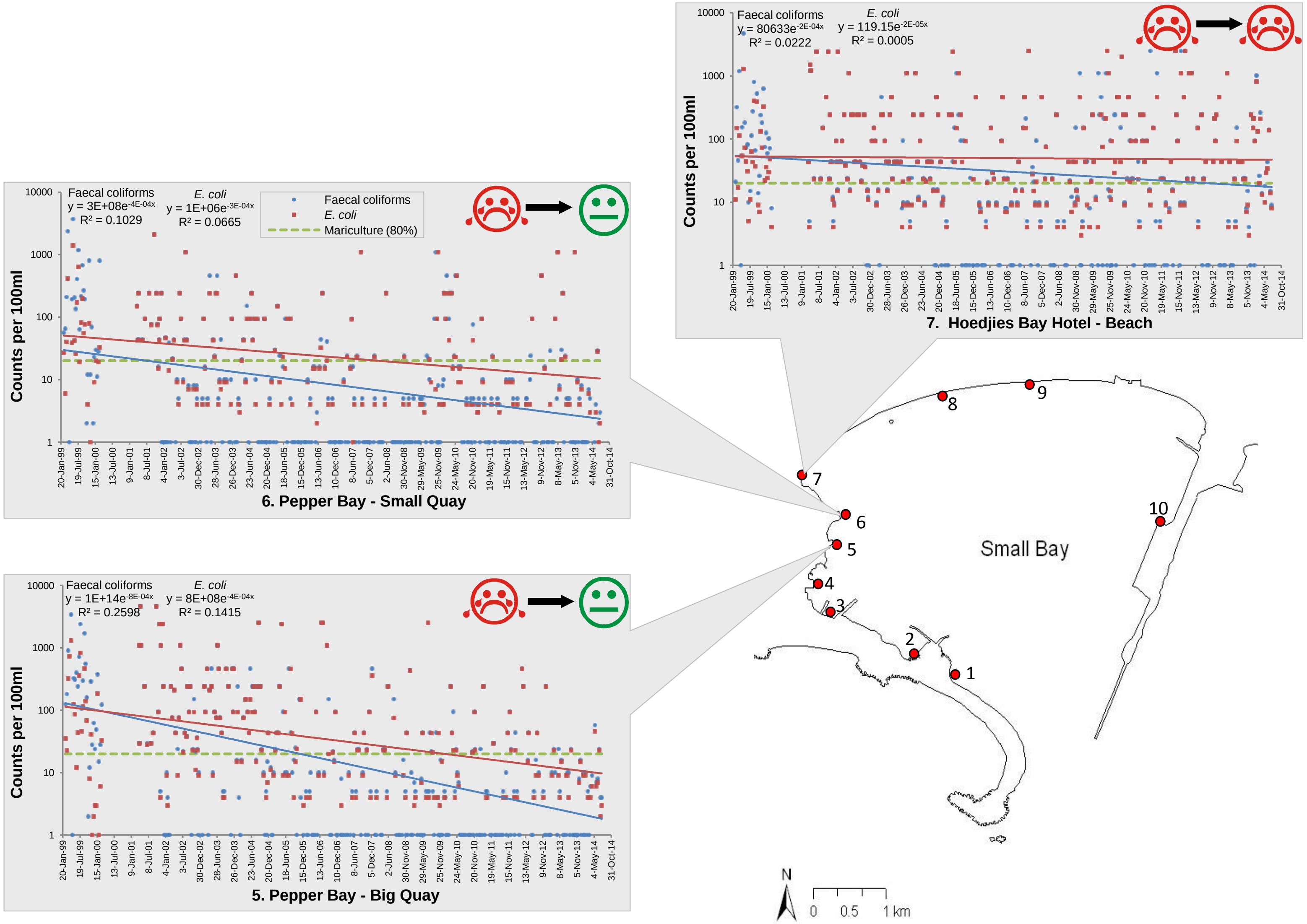


Figure 4.17. **Faecal coliform and *E. coli.* counts at three of the 10 sampling stations within Small Bay (Feb 1999 – June 2014). The green dashes indicate the 80th percentile mariculture limit of faecal coliforms and the smiley faces correspond to changes in faecal coliform counts over time. The y-axis represents a log scale with y=counts per 100ml+1 allowing zero values to be plotted.**

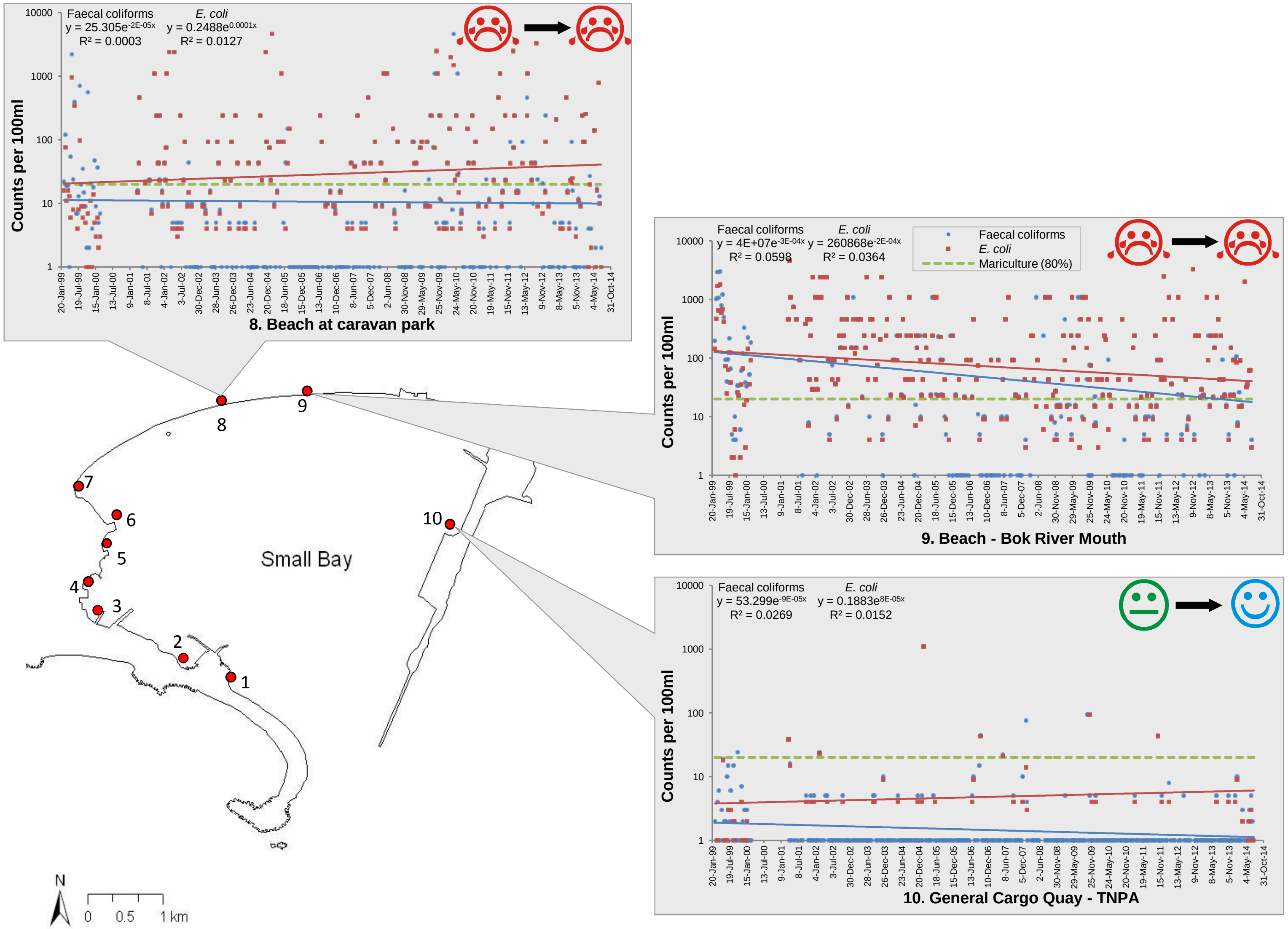


Figure 4.18. Faecal coliform and *E. coli.* counts at three of the 10 sampling stations within Big Bay (Feb 1999 – June 2014). The green dashes indicate the 80th percentile mariculture limit of faecal coliforms and the smiley faces correspond to changes in faecal coliform counts over time. The y-axis represents a log scale with y=counts per 100ml+1 allowing zero values to be plotted.

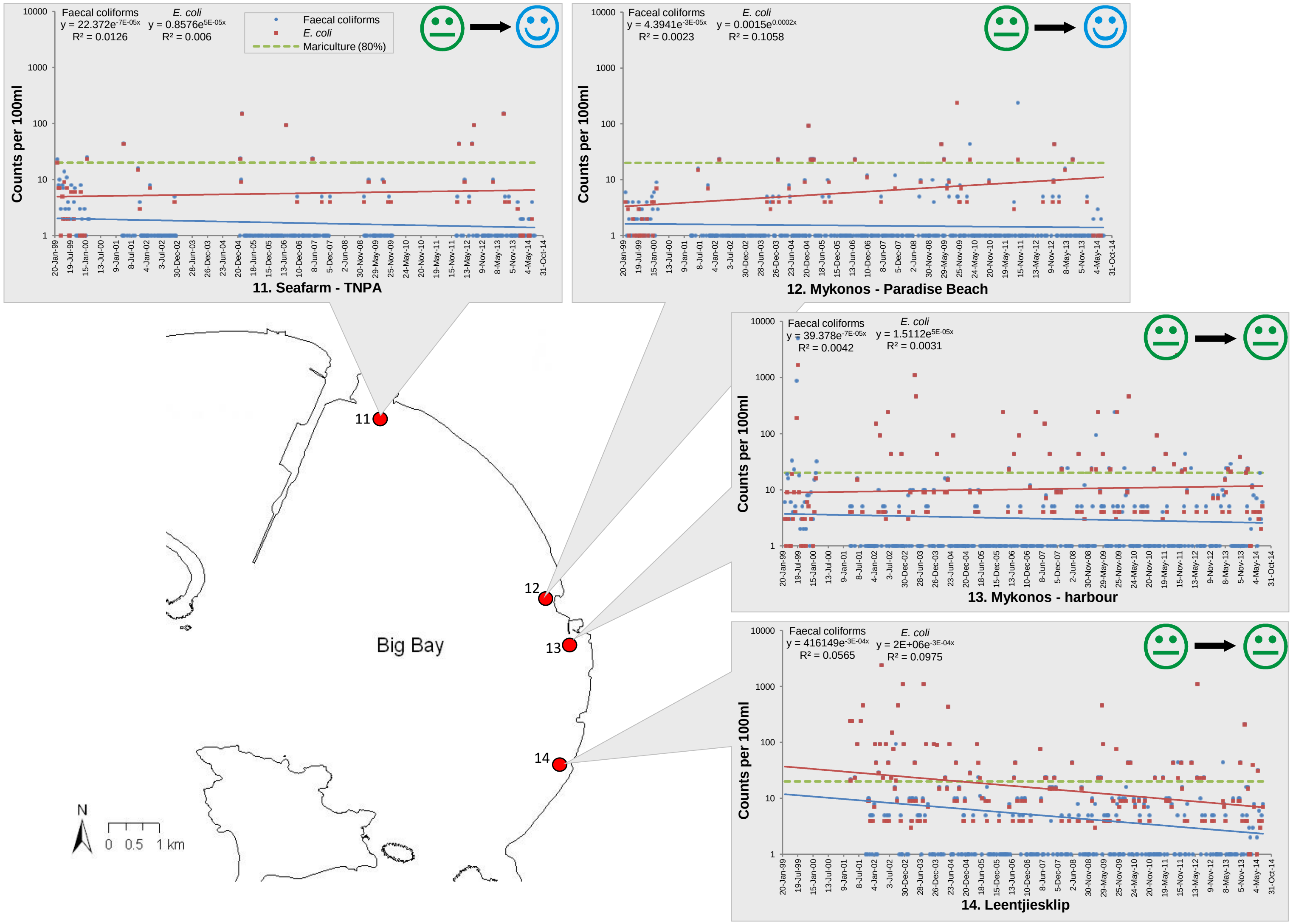


Figure 4.19. **Faecal coliform and *E. coli.* counts at all four sampling stations within Big Bay (Feb 1999 – June 2014). The green dashes indicate the <u>80th percentile mariculture limit</u> of faecal coliforms and the smiley faces correspond to changes in faecal coliform counts over time. The y-axis represents a log scale with y=counts per 100ml+1 allowing zero values to be plotted.**

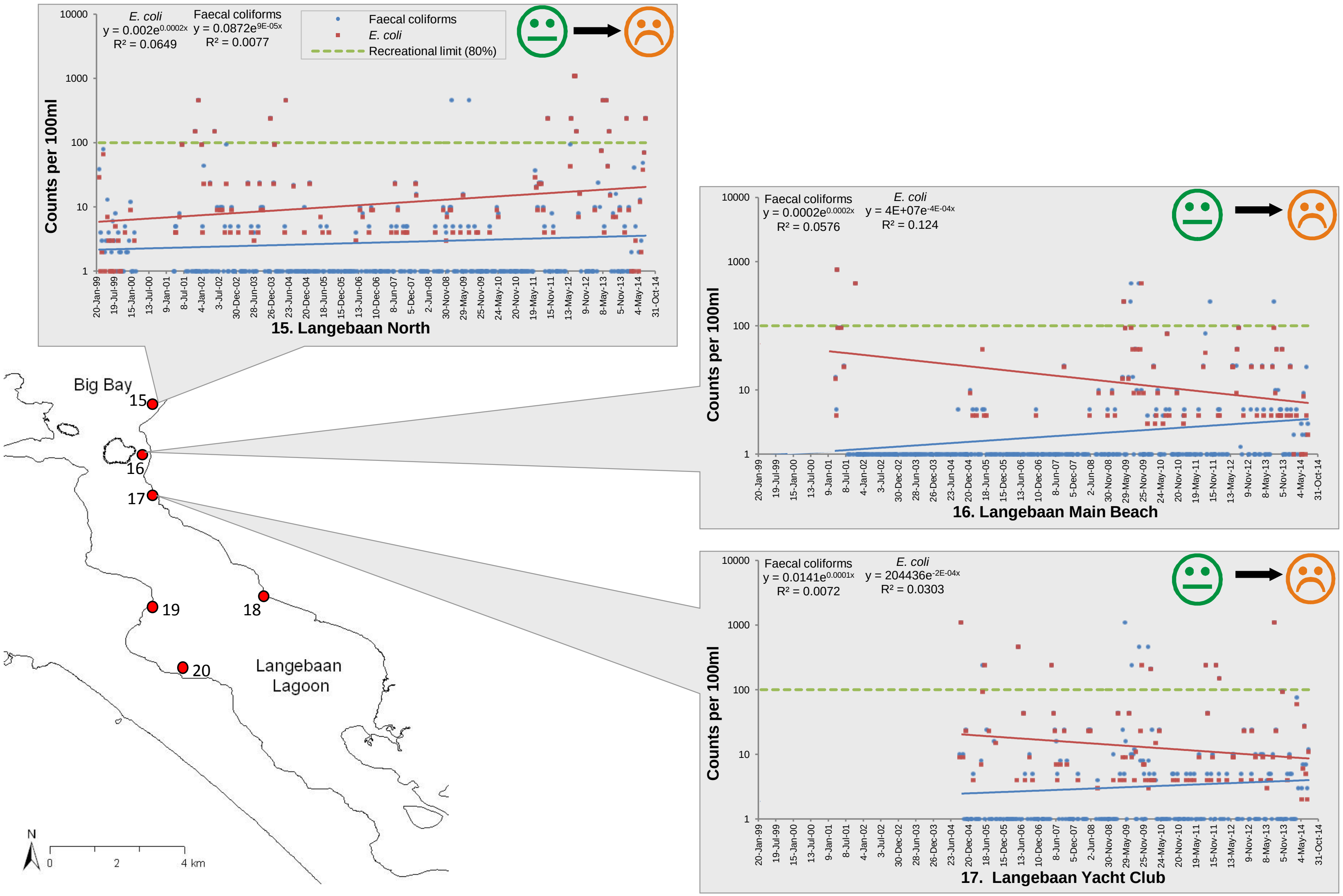


Figure 4.20. **Faecal coliform and *E. coli.* counts at three of the six sampling stations within Langebaan Lagoon (Feb 1999 – June 2014). The green dashes indicate the 80th percentile recreational limit of faecal coliforms and the smiley faces correspond to changes in faecal coliform counts over time. The y-axis represents a log scale with y=counts per 100ml+1 allowing zero values to be plotted.**

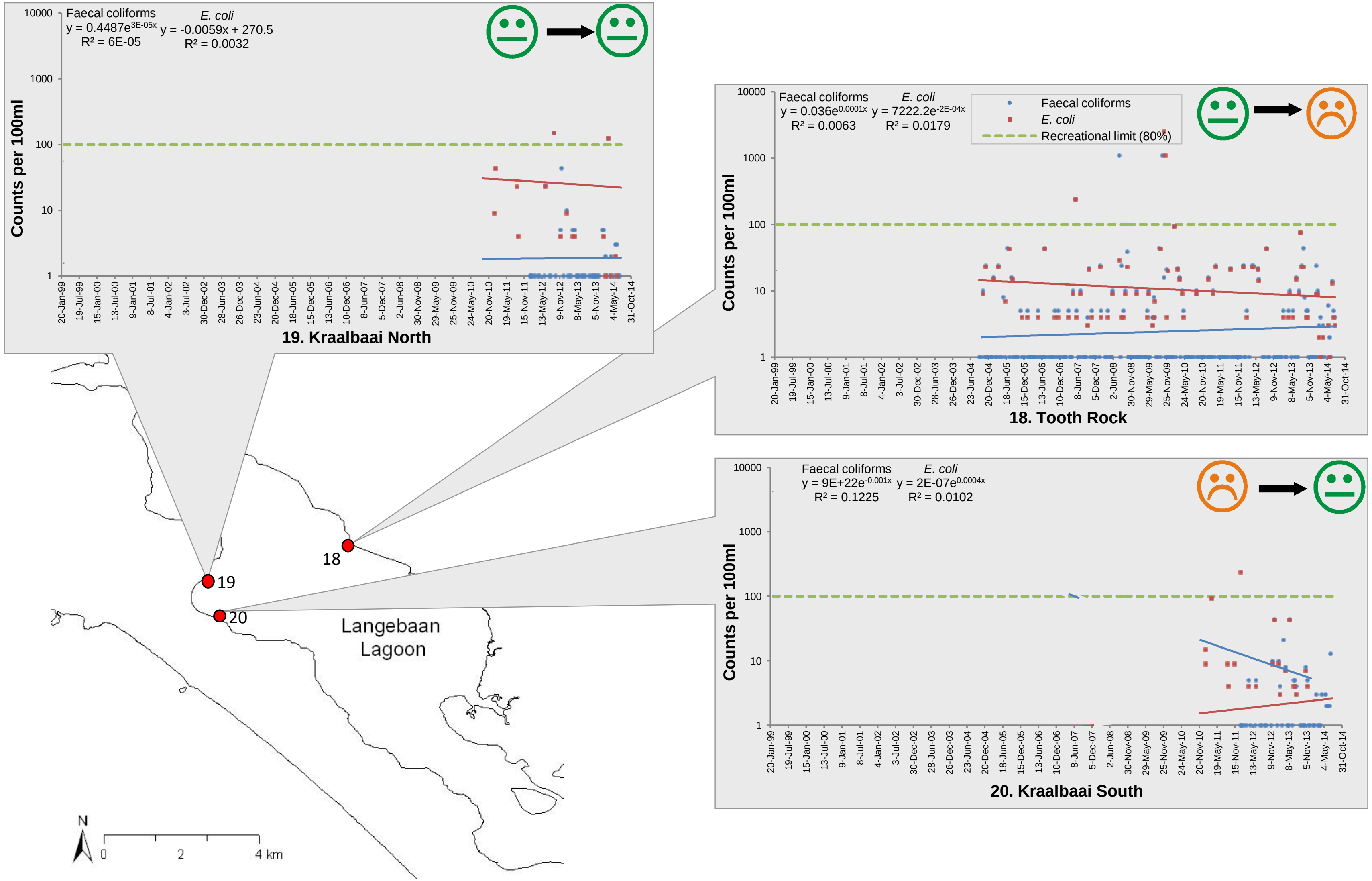


Figure 4.21. **Faecal coliform and *E. coli.* counts at three of the six sampling stations within Langebaan Lagoon (Feb 1999 – June 2014). The green dashes indicate the 80th percentile recreational limit of faecal coliforms and the smiley faces correspond to changes in faecal coliform counts over time. The y-axis represents a log scale with y=counts per 100ml+1 allowing zero values to be plotted.**

4.9.2 Microbiological water quality in terms of the revised guidelines for recreational waters of South Africa's coastal marine environment

In 2012 the revised DWAF guidelines were published following an international review of guidelines for coastal waters, which highlighted several shortcomings in those developed by South Africa. The revised guidelines (DEA 2012) 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 is used 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 & 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 the next few years to assess applicability and feasibility while determining target limits.

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 (DEA 2012). 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* sp. rather than for *E. coli.* Several studies have shown 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). Thus, if analysis is focused on coliforms, the risk could be underestimated due to mortality occurring in the time taken between collection and analysis.

In addition to this, an operational management process was recommended for South Africa, following *Enterococci* counts (Figure 4.22). A mode is assigned based on the levels of *Enterococci* in a single count (shaded green or amber) or on consecutive counts (shaded red). Each mode outlines a plan of action to be undertaken to deal with the problem.

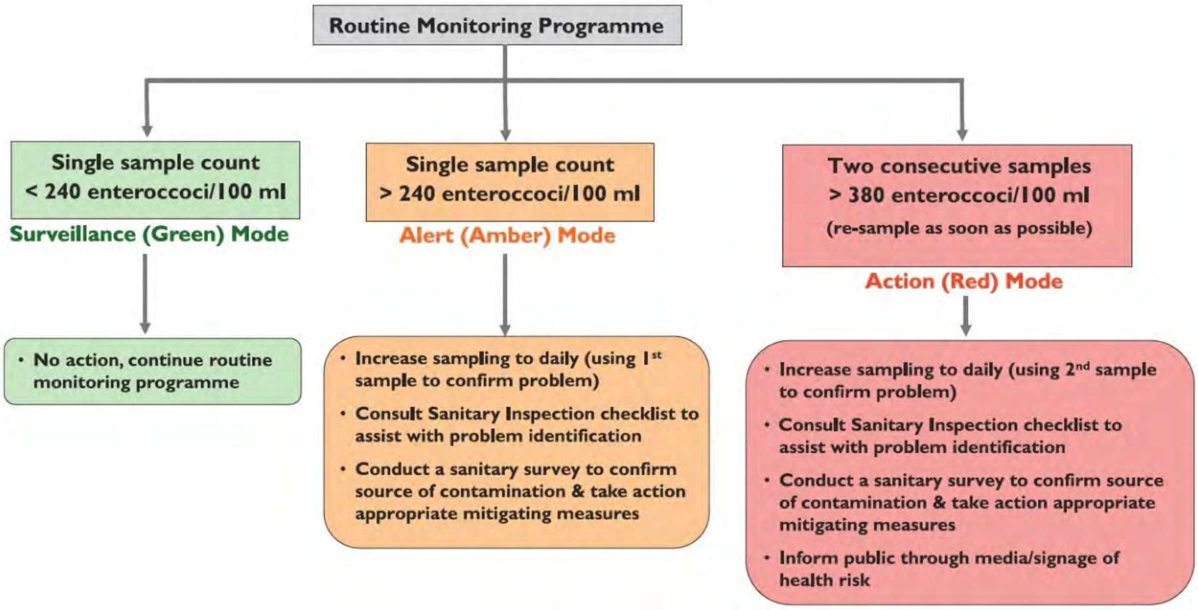


Figure 4.22. An illustration of the proposed routine monitoring programme to be trialled in South Africa. Source: South African Water Quality Guidelines for Coastal Marine Waters (DEA 2012).

The Hazen non-parametric statistical method is recommended for dealing with the microbiological data as it does not fit a normal (bell shaped) distribution. The data are ranked into ascending order and then percentile values are calculated using a formula. Target limits, based on counts of intestinal *Enterococci* sp. and *E. coli.* , for recreational water use are indicated below (Table 4.7). In order to calculate 95th percentiles, a minimum of 10 data points are required, while the calculation of the 90th percentile estimates require only five data points.

Table 4.7. Target limits for *Enterococci* sp. and *E. coli.* based on revised final guidelines for recreational waters of South Africa's coastal marine environment (DEA 2012). The probability of contracting a gastrointestinal illness (GI) is also listed.

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

Data from January 1999 to December 2013 have been analysed using the Hazen method (Table 4.8) to assess overall health rankings. Due to the absence of data on the concentrations of intestinal *Enterococci* sp. 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 were assessed for compliance by evaluating both the 90th and 95th percentiles, therefore 10 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'. Data were not collected for several of the sites 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 ranks of 20 sites around the Saldanha Bay area are presented in Table 4.8. In 2013, three of the sites in Small Bay were ranked as 'Fair', showing an improvement in water quality from 'Poor' to 'Fair' for Hoedjies Bay Hotel and Bok River Mouth (Sites 7 and 9) and a deterioration from 'Good' to 'Fair' at the small quay at Pepper Bay (Site 6). The beaches at the Caravan Park and Langebaan North (Sites 8 and 15) were ranked as 'Poor' in 2012 and improved to 'Good' in 2013. The Small Craft Harbour, the big quay at Pepper Bay and Leentjiesklip (Sites 2, 5 and 14) all improved by a category, while Langebaan Yacht Club (Site 17) deteriorated by a category. The rank of the remaining 11 sites remained 'Excellent'.

In 2014, the beach at the Mussel Rafts (Site 1) deteriorated from 'Excellent' to 'Good', as did Kraalbaai North (Site 19). The beach at Hoedjies Bay Hotel (Site 7) deteriorated from 'Fair' to 'Poor' and of particular concern was the large decline of health at the beach at the Caravan Park (Site 8) and Langebaan North (Site 15). Only the Langebaan Yacht Club improved between 2013 and 2014, thus the overall trend in 2014 showed a decline in water quality based on concentrations of *E. coli.*

Table 4.8. 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 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 and "Excl." indicates excellent water quality.

	Site	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Small Bay	1. Beach at Mussel Rafts	Fair	ID	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Good
	2. Small Craft Harbour	Excl.	ID	Good	Excl.	Excl.	Excl.	Good	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Good	Excl.	Excl.
	3. Small Quay - Sea Harvest	Fair	ID	Excl.	Excl.	Fair	Excl.	Fair	Excl.	Excl.	Excl.	Good	Excl.	Fair	Excl.	Excl.	Excl.
	4. Saldanha Yacht Club	Poor	Poor	Poor	Fair	Poor	Poor	Poor	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.
	5. Pepper Bay - Big Quay	Poor	ID	Poor	Fair	Fair	Fair	Fair	Poor	Excl.	Excl.	Fair	Excl.	Excl.	Good	Excl.	Excl.
	6. Pepper Bay - Small Quay	Poor	ID	Fair	Good	Excl.	Good	Excl.	Excl.	Good	Excl.	Good	Good	Excl.	Good	Fair	Fair
	7. Hoedjies Bay Hotel - Beach	Fair	ID	Poor	Fair	Good	Poor	Poor	Good	Fair	Excl.	Fair	Fair	Poor	Poor	Fair	Poor
	8. Beach at Caravan Park	Fair	ID	Fair	Poor	Excl.	Fair	Poor	Excl.	Good	Poor	Fair	Fair	Fair	Poor	Good	Poor
	9. Beach at Bok River Mouth	Poor	ID	Poor	Poor	Poor	Poor	Poor	Excl.	Fair	Poor	Poor	Good	Excl.	Poor	Fair	Fair
	10. General Cargo Quay - TNPA	Excl.	ID	Excl.	Excl.	Excl.	Excl.	Good	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.
Big Bay	11. Seafarm - TNPA	Excl.	ID	Excl.	Excl.	ND	ND	Excl.	Excl.	Excl.	ND	Excl.	ND	ND	Excl.	Excl.	Excl.
	12. Mykonos - Paradise Beach	Excl.	ID	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.
	13. Mykonos - Harbour	Fair	ID	Excl.	Excl.	Fair	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Fair	Excl.	Excl.	Excl.
	14. Leentjiesklip	ND	ID	Good	Fair	Good	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Fair	Excl.	Excl.
Langebaan	15. Langebaan North	Excl.	ND	Good	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Poor	Good	Poor
	16. Langebaan Main Beach	ND	ND	Fair	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Good	Excl.	Excl.	Excl.	Excl.	Excl.
	17. Langebaan Yacht Club	ND	ND	ND	ND	ND	Poor	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Excl.	Good	Excl.
	18. Tooth Rock	ND	ND	ND	ND	ND	ID	Excl.	Excl.	Excl.	Excl.	Fair	Excl.	Excl.	Excl.	Excl.	Excl.
	19. Kraalbaai North	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	Excl.	Excl.	Good
	20. Kraalbaai South	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	Excl.	Excl.	Excl.

4.10 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 impacts 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/trace metals are often regarded as pollutants of aquatic ecosystems. However, they are naturally occurring elements, some of which (e.g. copper & zinc) are 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 (presenting 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 and typically occur at higher concentrations than dissolved levels, but this 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 (Kljaković-Gašpić *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, Kljaković-Gašpić*et al.* 2010).

Elevated levels of cadmium 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, increased growth deficiencies and possibly mortality. Elevated levels of zinc are known to suppress growth of bivalves at levels between 470 to 860 mg/l and can result in mortality of the mussels (DEA 1995d).

In 1985 the MCM 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 were collected periodically from five stations in Saldanha Bay. According to DEA, challenges in processing the mussel samples have resulted in data from the Saldanha Bay Mussel Watch programme only being available between 1997-2001 and 2005-2007. No new data were received for the 2013/2014 period; however, the programme is due to resume in late 2014. In the interim, Anchor Environmental Consultants collected mussel samples from the same five sites during the field survey in April 2014.

The mussel samples were analysed for the metals lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), iron (Fe) and manganese (Mn). An automated method for sample preparation, including microwave digestion, was used to process these samples (Watling 1981; G. Kiviet *pers. comm*.). Data from the mussel watch programme and from the April 2014 collection by Anchor Environmental Consultants are represented in Figure 4.23 to Figure 4.29 below. 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 4.9).

Data showed that concentrations of lead in mussels at the Portnet site were consistently above guideline limits for foodstuffs, with values averaging more than 135 ppm (Figure 4.23). Values spiked to very high levels at this site in May 1999 (252.5 ppm) and October 2001 (714.6 ppm). This site is situated at the base of the iron ore terminal on the Small Bay side. The high levels of lead are almost certainly linked to the export of lead ore from the multipurpose quay, which is situated in close proximity to the Portnet site. The concentration of lead was generally below 10 ppm at the other sites, although values spiked to 250 ppm at the Mussel Raft in October 2000. Compared to the guideline limit of 0.5 ppm, these levels were extremely high; although concentrations dropped to an average of 1.3 ppm over all the sites in 2014, indicating that the situation is greatly improved.

Concentrations of cadmium frequently exceeded the guideline limits of 3 ppm at all sites (Figure 4.24). Levels of cadmium in mussels from Saldanha Bay fluctuate less than those of lead and range between 1-10 ppm, but occasionally exceed this level with a maximum reading of 49.3 ppm in April 2007 at the Mussel Rafts. Although the concentration dropped to 4.3 ppm in 2014, this value is still high relative to guideline levels, and presents a cause for concern for anyone who may be consuming these mussels.

Average zinc concentrations across the years were higher than the 150 ppm guideline limit listed by the Canadian Authorities (Table 4.9) at Portnet, Fish Factory and Saldanha Bay North, while those at the Mussel Raft and the Iron Ore Jetty were below this value (Figure 4.25). Concentrations spiked to 425.8 ppm at Fish Factory in October 200 and 427.8 ppm at Portnet in May 2001. Values were above guideline limits at two sites in 2014: Saldanha Bay North and Fish Factory, indicating that the situation has improved at Portnet. In contrast with lead, cadmium and zinc, concentrations of copper were well below the specified level of 70 ppm at all sites. The maximum value recorded was 18.1 ppm at the Mussel Raft in 2014. No guideline limits exist for manganese, which reached a maximum of 11.3 ppm at Saldanha Bay North in May 1999. All values measured in 2014 were below 5 ppm (Figure 4.28).

Iron poisoning is usually only associated with the over consumption of iron supplements with toxic effects evident with ingestion of 10–20 mg/kg body weight of elemental iron (http://www.webmd.com/a-to-z-guides/iron-poisoning). As there are no official guideline limits for the safe concentration of iron present in foodstuffs, it is not possible to comment on the suitability of these mussels for consumption based on this trace metal. Average values were highest at Saldanha Bay North and lowest at the Mussel Raft (ppm), with concentrations higher in 2014 than in recent years. There is no record of acute toxicity of iron ingested by humans in regular foodstuffs and excess iron is not stored by the body. As iron is not considered to be toxic to humans, there is no recommended guideline level for this trace metal. However, iron ore is processed in Saldanha Bay on a large scale and iron ore residue is apparent on all structures in vicinity of Saldanha Steel processing plant. Thus, it is recommended that the concentration of this substance in the flesh of bivalves continue to be monitored to flag any sharp increases over time. Overall, no clear trends of trace metal contamination in the flesh of bivalves in Saldanha Bay were evident over time.

Table 4.9. 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.

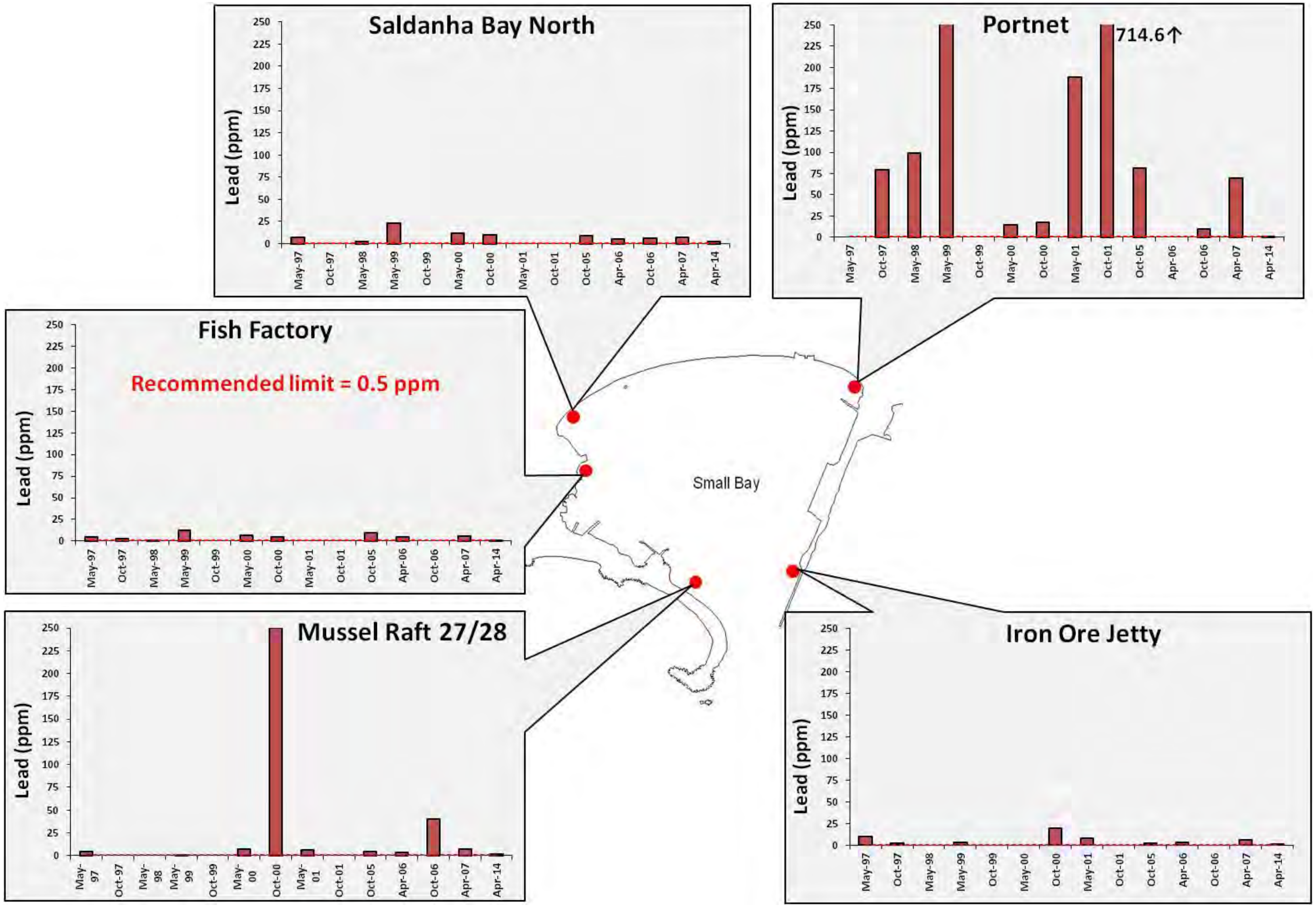


Figure 4.23. Iron concentrations in mussels collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (source: G. Kiviets, Department of Environmental Affairs) and by Anchor in 2014. Recommended maximum limits for trace metals in seafood are shown as a dotted red line.

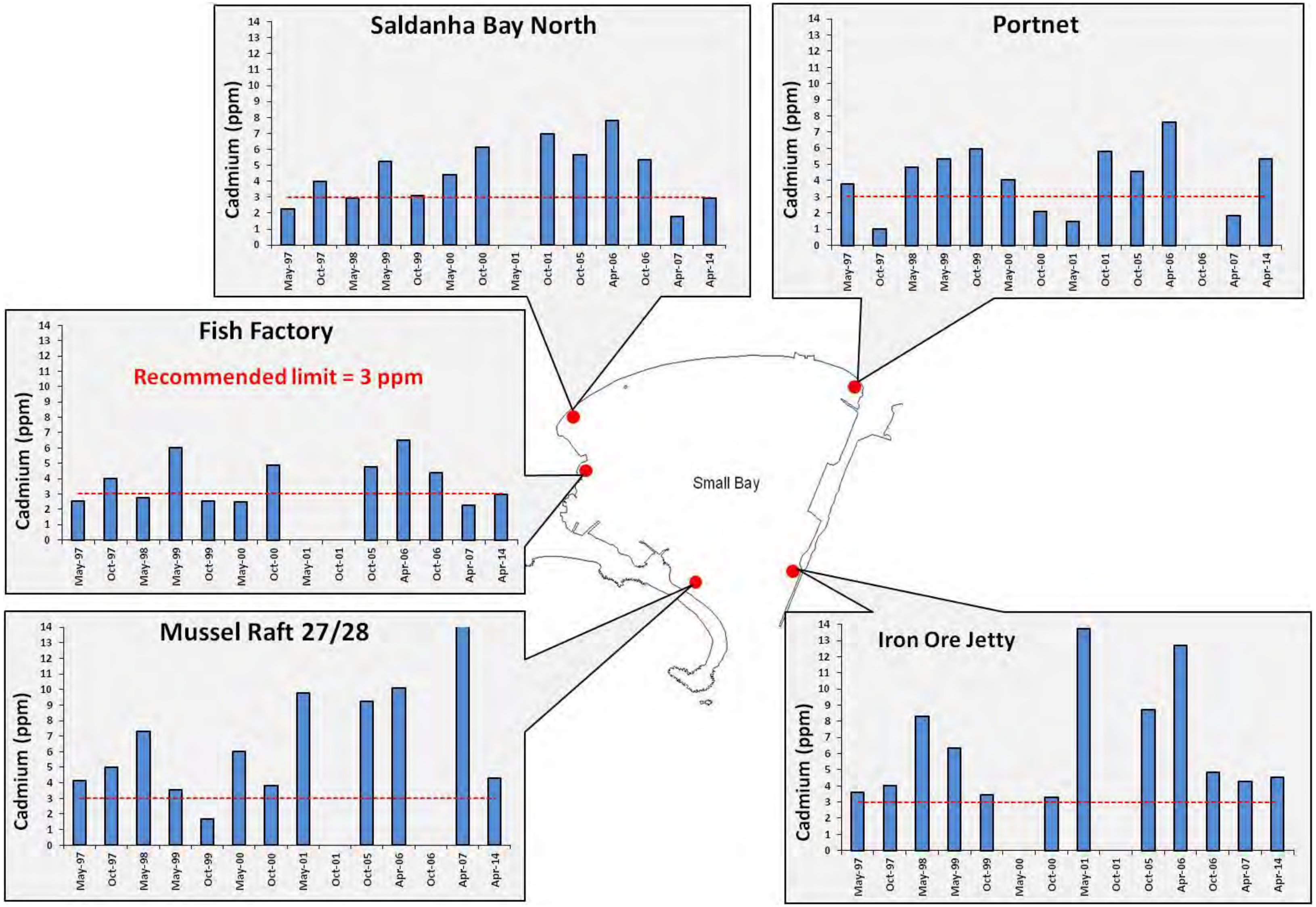


Figure 4.24. **Cadmium concentrations in mussels collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (source: G. Kiviets, Department of Environmental Affairs) and by Anchor in 2014. Recommended maximum limits for trace metals in seafood are shown as a dotted red line.**

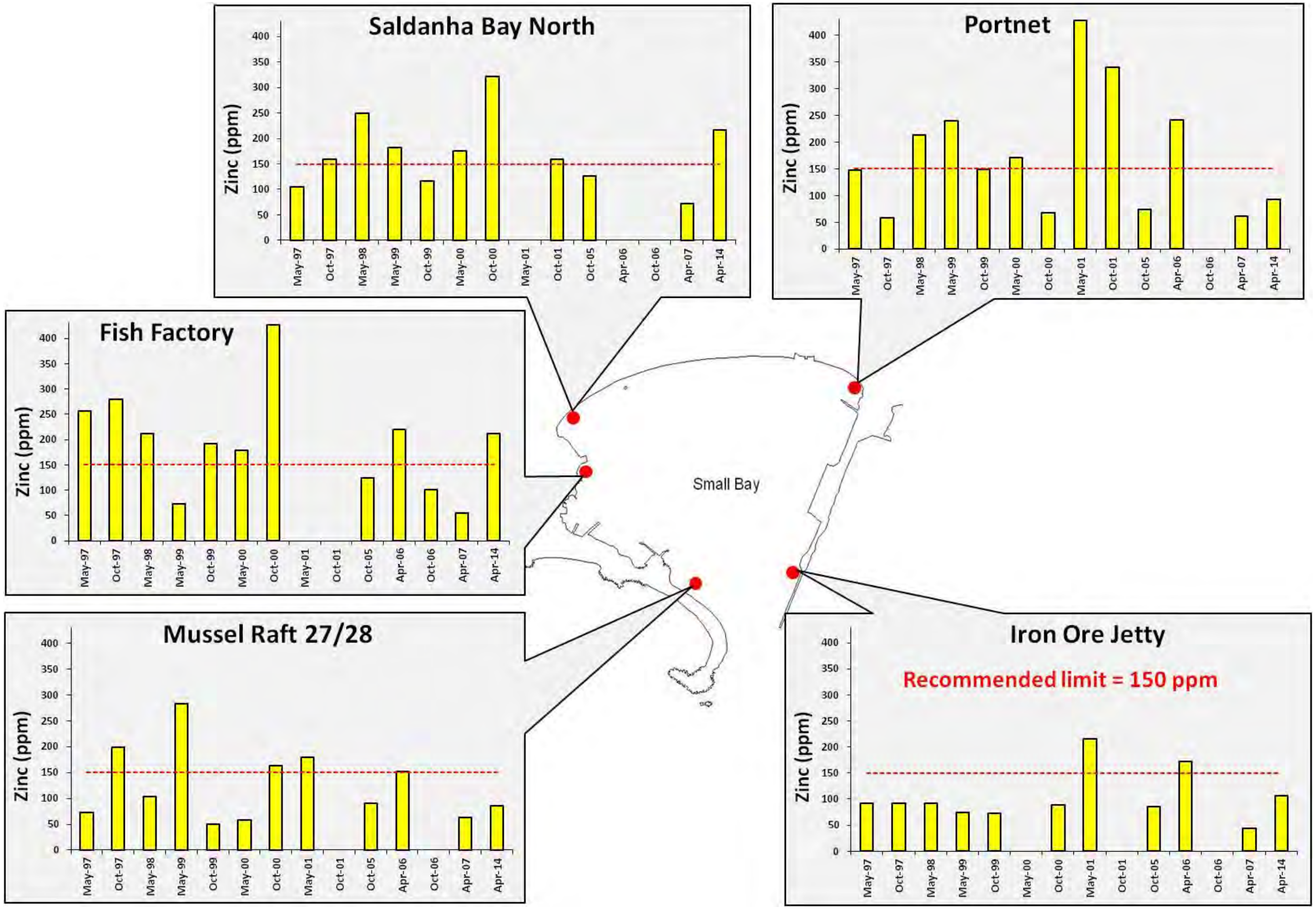


Figure 4.25. Zinc concentrations in mussels collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (source: G. Kiviets, Department of Environmental Affairs) and by Anchor in 2014. Recommended maximum limits for trace metals in seafood are shown as a dotted red line.

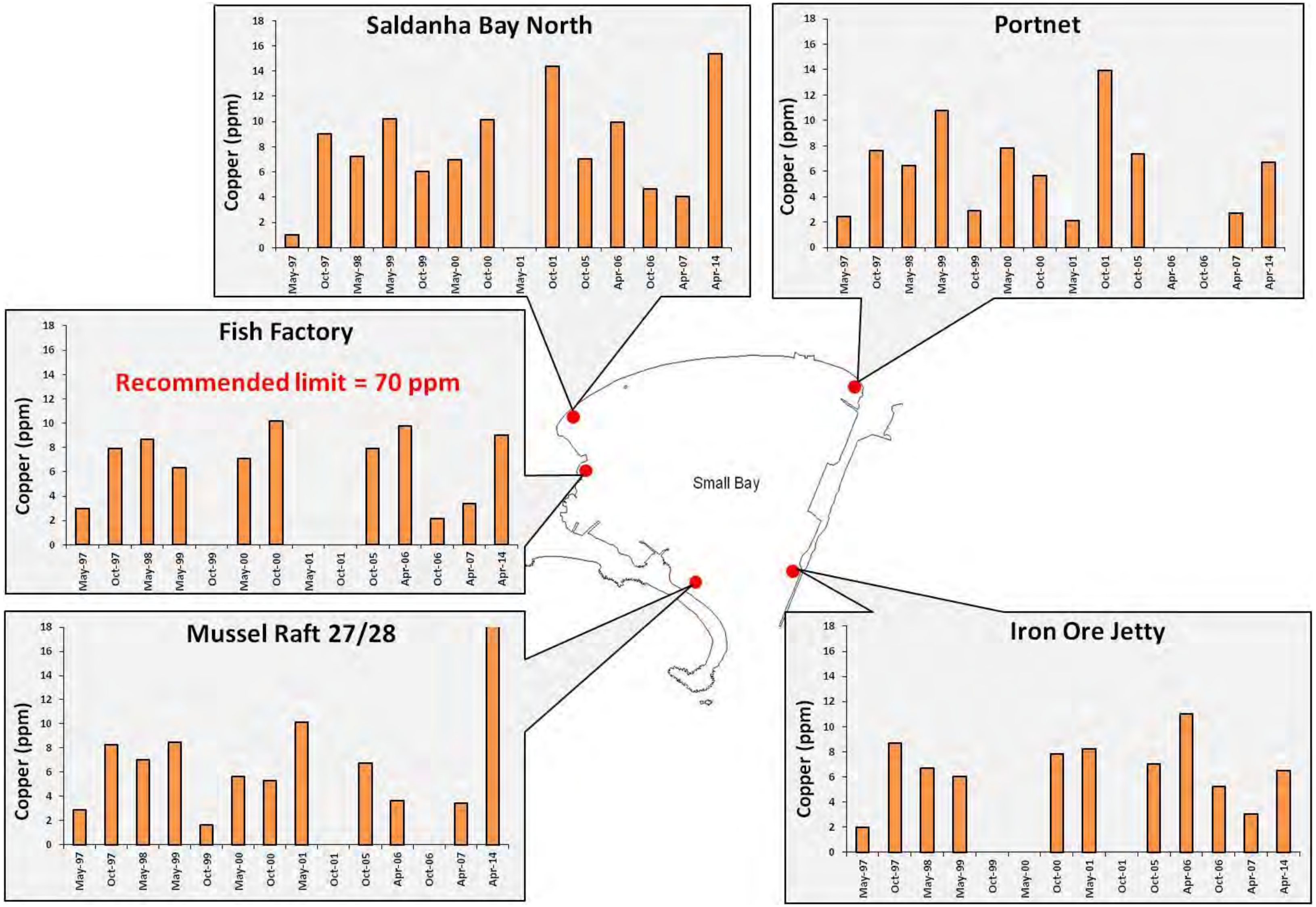


Figure 4.26. **Copper concentrations in mussels collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (source: G. Kiviets, Department of Environmental Affairs) and by Anchor in 2014. Recommended maximum limits for trace metals in seafood are shown as a dotted red line.**

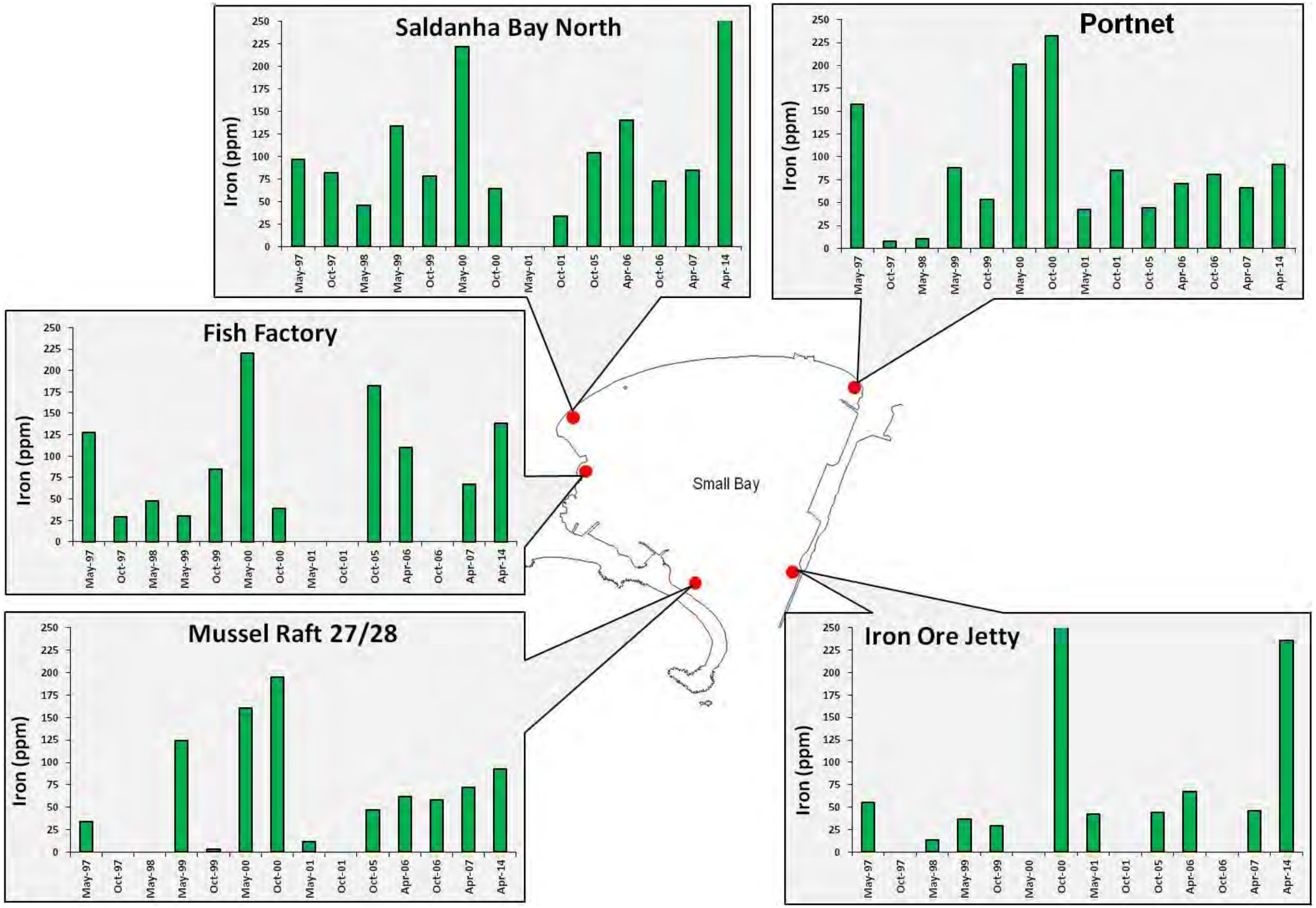


Figure 4.27. Iron concentrations in mussels collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (source: G. Kiviets, Department of Environmental Affairs) and by Anchor in 2014. Recommended maximum limits for trace metals in seafood are shown as a dotted red line.

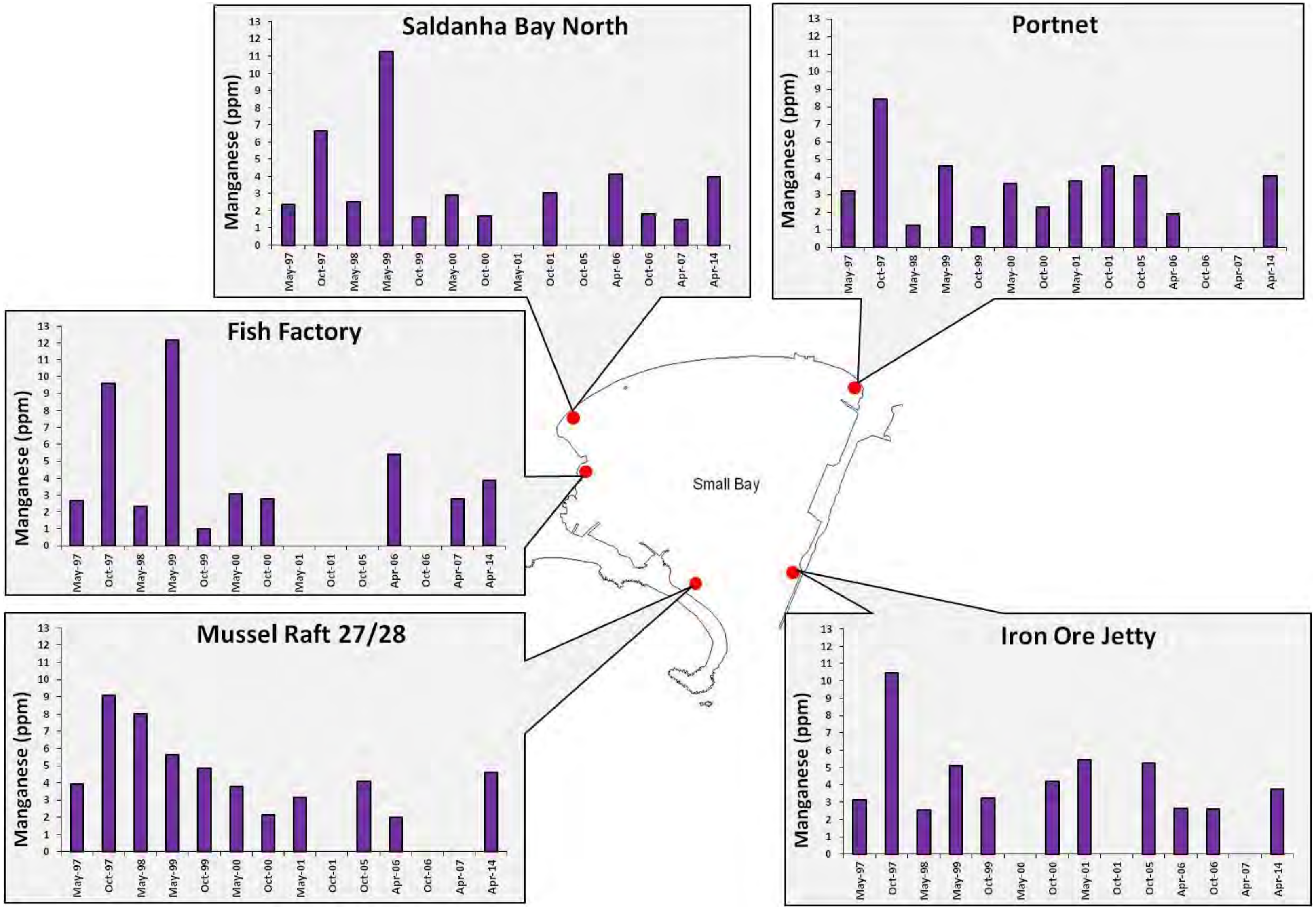


Figure 4.28. **Manganese concentrations in mussels collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (source: G. Kiviets, Department of Environmental Affairs) and by Anchor in 2014. Recommended maximum limits for trace metals in seafood are shown as a dotted red line.**

Rights holders engaged in bivalve culture of mussels and oysters in South Africa are required to report on concentrations in harvested organisms on an annual basis. Data were obtained for three trace metal indicators (Lead, Cadmium and Mercury) for eight farms in Saldanha Bay covering the period 1988-2013 (Figure 4.29). As the measurement of concentrations of trace metals in bivalves from farms in the area has been reduced to an annual occurrence, measurements for 2014 will only be taken in August and are not available for addition into this report.

Concentrations of lead were consistently above guideline levels in the period prior to 2000, and especially high in 1988 when concentrations were measured at 5.3 ppm, 14.1 ppm and 3.9 ppm at Blue Bay Aquafarm, West Coast Oyster Growers and Striker Fishing respectively. Although these values were high, they were still much lower than those measured in the nearshore mussel samples. From 2000 onwards, lead concentrations have been mostly within guideline limits (i.e. less than 0.5 ppm); although bivalves from West Coast Aquaculture and West Coast Oyster Growers exceeded these limits in 2010-2011 and 2007 respectively. None of the farms were above the guideline levels post 2011, with lab analyses reporting levels no higher than 0.12 ppm for these years.

Concentrations of cadmium from the flesh of farmed mussels and oysters in Saldanha Bay have not exceeded the guideline limits of 3 ppm for the duration of testing but have approached this level on occasion, with the maximum level recorded measuring 2.90 ppm at West Coast Oyster Growers in 2011. The highest concentration of Cadmium recorded since 2011 was measured at 2.29 ppm from oysters from West Coast Aquaculture (Figure 4.29). Mercury concentrations have largely been within the guideline limits of less than 0.5 ppm, apart from one or two spikes above this level, including readings of 1.7 ppm in 1994, 1.1 ppm in 2007 and 1.0 ppm in 2011. All farm samples collected during 2012 and 2013 contained less than 0.02 ppm of Mercury (Figure 4.29). Samples were analysed for Arsenic for the first time in 2012, and all farms were within the guideline limits of less than 3 ppm, except for the Saldanha Bay Oyster Company (3.5 ppm) and Striker Fishing in (3.15 ppm) in 2012 (Figure 4.29).

Data from these farms suggest that the situation in the deeper parts of Saldanha Bay, where the farms are located, is less of a problem than in the nearshore coastal waters, where the Mussel Watch Programme samples are collected. 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 experienced by the farmed mussels, as well as the fact that they are feeding on phytoplankton blooms in upwelled water that has only recently been flushed into Saldanha Bay. In contrast, mussels on the shore filter water that has been trapped in the Bay for a longer period and may contain a greater quantity of suspended sediment and associated contaminants.

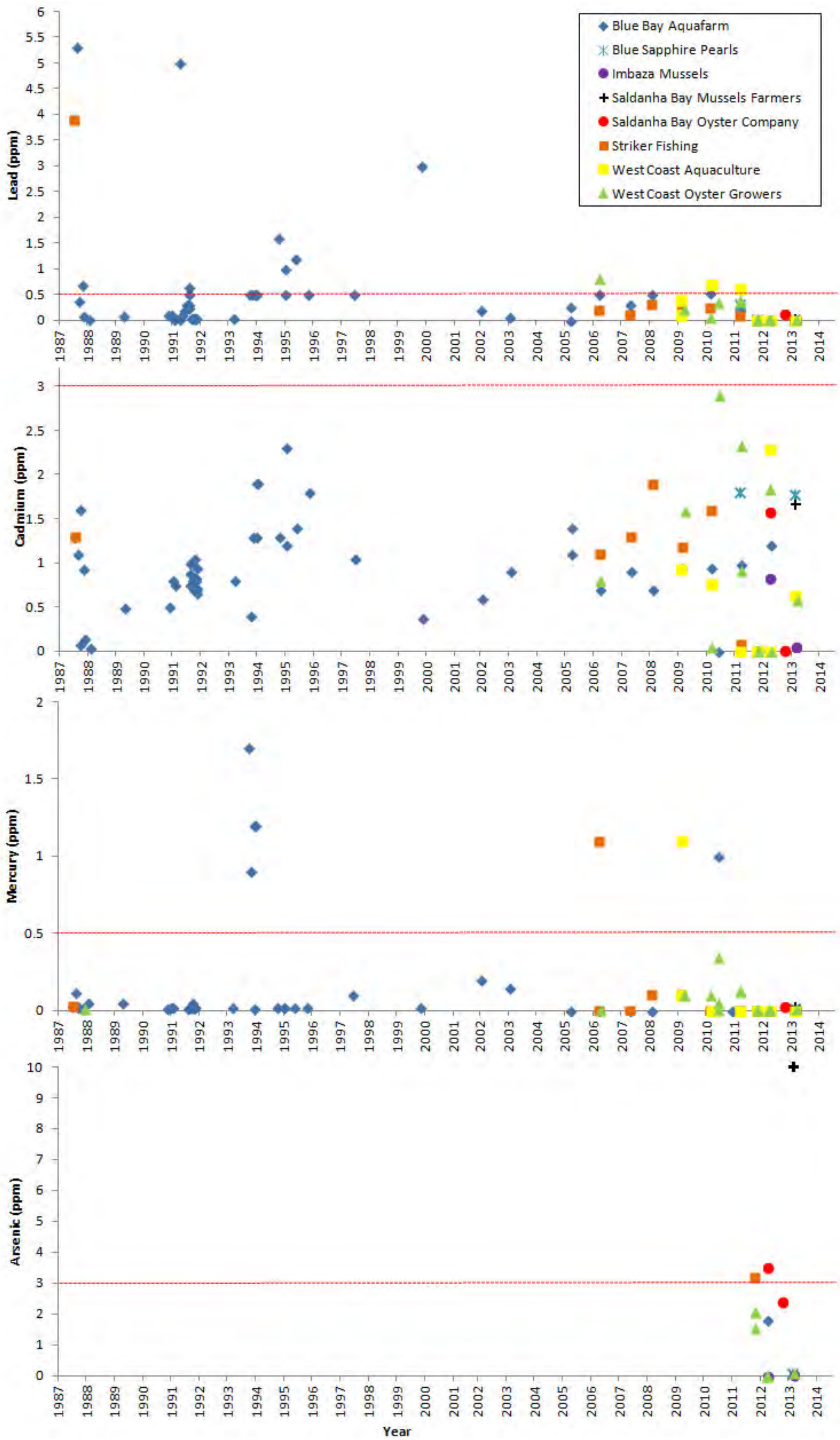


Figure 4.29. **Concentrations of Lead, Cadmium, Mercury and Arsenic in bivalves from six bivalve culture operations in Saldanha Bay from 1988 to 2013. Recommended maximum limits for trace metals in seafood as stipulated in South African legislation are indicated by a dotted red line.**

4.11 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 Saldanha 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). Although it is conceivable that construction of the causeway and ore/oil jetty 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 down welling and extensive coast to bay exchange), rather than internal, anthropogenic causes, appear to remain the major factors affecting physical water characteristics in Saldanha Bay. The construction of physical barriers (the iron ore/oil jetty and the Marcus Island causeway) do 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 microbial monitoring program provides evidence that while some 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 an overall trend of improving compliance for which the relevant authorities should be commended. However, the situation in Small Bay remains a concern, with three sites exceeding the 80th percentile levels and five sites exceeding the 95th percentile levels for safe mariculture practices, and two sites exceeding the 80th percentile levels for safe recreational activities in 2014. The increasing trend in faecal coliform counts at the Langebaan North site is also cause for concern, and although microbial counts are still within the recreational use guidelines, this is the only site outside of Small Bay that exceeded the mariculture guidelines. 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.

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 at the Portnet site) and are frequently or even consistently (in the case of lead) above published guidelines for foodstuffs. Concentrations offshore are clearly much lower and are less of a concern. The high concentrations of trace metals along the shore points to the need for management interventions to address this issue, as metal contamination poses a very serious risk to the health of people harvesting mussels from the shore.

5 SEDIMENTS

5.1 Sediment quality

5.1.1 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 influences 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 therefore of particular interest and are summarised in this section.

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 about deteriorating water quality in Saldanha Bay, sediment samples were collected again in 1989 and 1990 (Jackson & McGibbon 1991). At the time of the Jackson & McGibbon study, the iron ore terminal had been built 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 5.6). The Jackson & 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 5.6), 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 5.6). 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 5.6). 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 Section 3.2.2). 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 m^3 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 appears to have had a more significant impact and is discussed in detail below.

The percentage mud in sediments declined at most sites in Small Bay over the period 2008 to 2011. This bay-wide progressive reduction in mud content suggested 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 flushed 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- 2012 surveys are presented 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 Section 5.1.3 for more details on this).

Sediment particle size results for 2013 and 2014

Sediment samples were collected in both 2013 and 2014 and analysed for particle size composition, Total organic carbon (TOC), nitrogen and trace metals. During April 2013 sediment samples were collected from a total of 28 sites, 11 in Small Bay, eight in Big Bay, one in Salamander Bay and eight in Langebaan Lagoon (Figure 5.1). During April 2014 there were 49 sediment collection sites, 17 in Small Bay, nine in Big Bay, 14 in Danger Bay and nine in Langebaan Lagoon (Figure 5.1 & Figure 5.2).

Samples collected during 2013 and 2014 at sites throughout the system comprised predominantly sand (particle size ranging between 63 µm and 2000 µm). During 2013 the sites in Small Bay had on average the highest proportion of mud (12.4%), followed by Big Bay (4.6%), Salamander Bay (3.5%), and Langebaan Lagoon with the lowest average proportion of mud (0.9%). Samples collected in 2014 however, revealed a similar proportion of mud in sediment from Big Bay (5.29%) and Small Bay (5.27%), indicating a substantial reduction in the mud fraction of the Small Bay samples. The sediments collected from Langebaan Lagoon (0.56%) and Danger Bay (0.02%) had a much lower average proportion of mud. A very low proportion of gravel (particles exceeding 2000 µm) was found at most sites during both 2013 and 2014. In 2013 areas with the highest gravel content include LL37, over half-way into the lagoon (10.51%), Salamander Bay (4.13%) and at BB30 within Big Bay (3.16%). In 2014, sites with a notable gravel proportion included SB6, near the Mussel Farm (7.89%), SB15 adjacent to the Ore Jetty (6.26%) and LL38 (3.82%).

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) and Salamander Bay (S) in 2013. (Particle size analysed by Scientific Services, and total organic carbon (TOC) and total oranic nitrogen (TON) analysed by the Council for Scientific and Industrial Research).

	Sample	Gravel (%)	Sand (%)	Mud (%)	TOC (%)	TON (%)	C:N
Small Bay (SB)	SB1	0,00	84,48	15,52	3,37	0,61	6,48
	SB2	0,00	98,29	1,71	0,30	0,06	5,69
	SB3	0,00	96,46	3,54	0,40	0,12	3,90
	SB8	0,59	96,95	2,46	0,53	0,78	0,79
	SB9	2,16	91,53	6,32	1,17	0,87	1,57
	SB10	1,77	97,44	0,79	0,35	0,07	5,66
	SB14	0,26	86,88	12,87	1,93	0,62	3,63
	SB15	0,00	57,35	42,65	1,18	0,53	2,58
	SB16	1,50	89,51	8,99	0,70	0,36	2,27
	SB42	0,14	97,68	2,19	0.31	0.40	0.92
	SB43	2,03	55,57	42,40	1.79	1.03	2.03
	SB44	0,00	96,45	3,55	0,45	0,08	6,20
Big Bay (BB)	BB20	2,64	95,38	1,97	0,79	0,50	1,83
	BB21	0,00	93,41	6,59	0,50	0,30	1,95
	BB22	0,60	91,98	7,41	0,74	0,43	2,01
	BB25	0,15	99,08	0,77	0,19	0,14	1,61
	BB26	0,00	92,59	7,41	0,87	0,74	1,36
	BB29	0,11	94,17	5,72	0,73	0,31	2,76
	BB30	3,16	96,65	0,19	0,14	0,38	0,43
Salamander Bay	S1	4,13	92,38	3,50	0,99	0,31	3,77
Langebaan Lagoon (LL)	LL31	0,24	98,90	0,87	0,46	0,62	0,86
	LL32	0,32	99,34	0,34	0,20	0,22	1,04
	LL33	0,00	99,57	0,43	0,10	0,03	3,59
	LL34	0,68	97,67	1,65	0,18	0,04	4,73
	LL37	10,51	89,11	0,37	0,27	0,10	3,34
	LL38	1,37	95,57	3,06	0,36	0,08	5,29
	LL39	0,18	99,76	0,06	0,33	0,61	0,64
	LL40	0,59	98,80	0,61	0,21	0,06	4,14

Mud is the most important particle size component to monitor given that fine grained particles provide a larger surface area to which contaminants bind. The sites beneath the mussel farm, and in the shipping channels adjacent to the Ore Jetty, are the deepest and are expected to yield sediments with a higher mud fraction than elsewhere in the Bay (Figure 5.2). The 2012, 2013 and 2014 sampling confirms these expectations, with the highest proportion of mud recorded in the sediments in the vicinity of the Ore Jetty, multipurpose quay, the mussel farms and the Yacht Club Basin (Figure 5.3, Figure 5.4, & Figure 5.5). The remainder of sites in Big Bay had a relatively moderate to low mud content and Langebaan Lagoon had very low mud content in all recent surveys.

Mud content at sites for which historical data exists (1977- 2014) in Small Bay showed a declining trend from 1999-2010 where after it has remained relatively constant and at a much lower level than during the 1999-2009 period (Figure 5.6). A similar and more rapid decline was noted at the Big Bay site adjacent to the ore jetty over the period 2000-2004, however, the mud content in 2012 to 2014 was slightly elevated from the zero values recorded during 2009-2011 (Figure 5.6). The Mussel farm displayed a slight decrease in mud content in 2013 but increased again in 2014. The Yacht Club Basin however, displayed an increase in mud content in 2013 but decreased in 2014, to a level below that of 2012 (Figure 5.6). At both these Small Bay sites however the percentage mud in the sediments remains substantially reduced from that recorded during the 1999-2008 period. Despite these overall encouraging trends, the sediment at two sites within Small Bay, namely SB15 at the base of the ore jetty and SB 43 in the channel near the mussel raft, still had mud content exceeding 40% in 2013 samples (Table 5.1). Mud content in sediments sampled in 2014 at these, and adjacent sites (SB9, SB 14 & SB 15) remained elevated (>10%) (Table 5.2).

Table 5.2. Particle size composition and percentage organic carbon and nitrogen in surface sediments collected from Small Bay (SB), Big Bay (BB), Langebaan Lagoon (LL), Liquid Petroleum Gas (LPG) and Danger Bay (DB) in 2014. (Particle size analysed by Scientific Services, and total organic carbon (TOC) and total organic nitrogen (TON) analysed by the Council for Scientific and Industrial Research).

	Sample	Gravel (%)	Sand (%)	Mud (%)	TOC (%)	TON (%)	C:N
Small Bay (SB)	SB1	0,32	94,07	5,61	0,32	0,05	7,44
	SB2	0,30	98,65	1,05	0,24	0,04	7,13
	SB3	2,64	94,56	2,82	0,28	0,05	7,01
	SB4	0,64	98,74	0,62	0,15	0,03	6,73
	SB5	0,23	99,30	0,47	0,14	0,03	5,32
	SB6	7,89	86,47	5,64	0,89	0,12	8,42
	SB7	0,35	99,11	0,55	0,22	0,05	5,63
	SB8	0,13	97,30	2,56	0,33	0,04	9,91
	SB9	1,12	87,48	11,41	0,68	0,12	6,64
	SB10	0,77	98,09	1,11	0,38	0,07	6,85
	SB11	0,85	94,54	4,60	0,60	0,10	7,30
	SB12	0,21	91,19	8,60	1,03	0,15	7,85
	SB14	1,53	86,67	11,82	2,13	0,31	7,94
	SB15	6,26	78,02	15,71	3,34	0,51	7,66
	SB16	0,99	93,03	5,99	0,86	0,15	6,75
	SB18	1,89	88,69	9,42	5,80	0,88	7,67
	SB20	3,16	95,25	1,59	0,54	0,10	6,13
Big Bay (BB)	BB21	0,10	93,94	5,96	0,62	0,09	8,44

	Sample	Gravel (%)	Sand (%)	Mud (%)	TOC (%)	TON (%)	C:N
	SB22	2,34	89,10	8,57	0,41	0,06	7,38
	BB23	2,29	92,13	5,57	0,85	0,14	7,22
	BB24	0,29	90,71	9,01	0,82	0,13	7,67
	BB25	0,37	98,27	1,34	0,22	0,03	8,10
	BB26	0,99	87,34	11,67	0,41	0,06	7,85
	BB28	1,06	97,51	1,45	0,36	0,04	9,48
	SB29	0,59	95,38	4,03	1,00	0,17	6,99
	SB30	0,29	99,70	0,01	0,16	0,02	8,16
	LPG1	0,66	93,99	5,34	1,41	0,19	8,56
Danger Bay (DB)	DB1	0,00	99,98	0,02	0,30	0,04	9,88
	DB2	0,07	99,93	0,00	0,33	0,04	10,26
	DB3	0,00	100,00	0,00	0,60	0,08	8,83
	DB4	0,01	99,88	0,11	0,45	0,05	9,67
	DB5	0,57	99,43	0,00	0,37	0,05	8,62
	DB6	0,02	99,99	0,00	0,55	0,05	13,22
	DB7	0,05	99,95	0,00	0,60	0,07	9,59
	DB8	0,00	100,00	0,00	0,33	0,03	12,28
	DB9	0,64	99,35	0,00	1,31	0,07	23,52
	DB10	0,00	99,99	0,00	0,36	0,03	14,94
	DB11	0,00	99,86	0,14	7,59	0,43	20,64
	DB12	0,00	99,99	0,00	0,22	0,02	13,87
	DB13	0,00	99,97	0,04	0,21	0,02	13,99
	DB14	0,23	99,77	0,00	0,47	0,04	12,94
Langebaan Lagoon (LL)	LL31	0,18	99,43	0,39	0,17	0,02	12,82
	LL32	0,08	99,73	0,19	0,33	<0.0010	384,88
	LL33	0,00	99,38	0,62	0,32	<0.0010	372,52
	LL34	0,22	98,72	1,08	0,91	0,04	27,40
	LL37	0,00	99,71	0,29	0,36	<0.0010	425,13
	LL38	3,82	93,90	2,27	0,61	0,00	338,33
	LL39	0,26	99,76	0,00	0,61	0,03	21,16
	LL40	0,07	99,82	0,10	0,22	0,02	12,77
	LL41	1,63	98,29	0,06	0,11	0,03	4,39

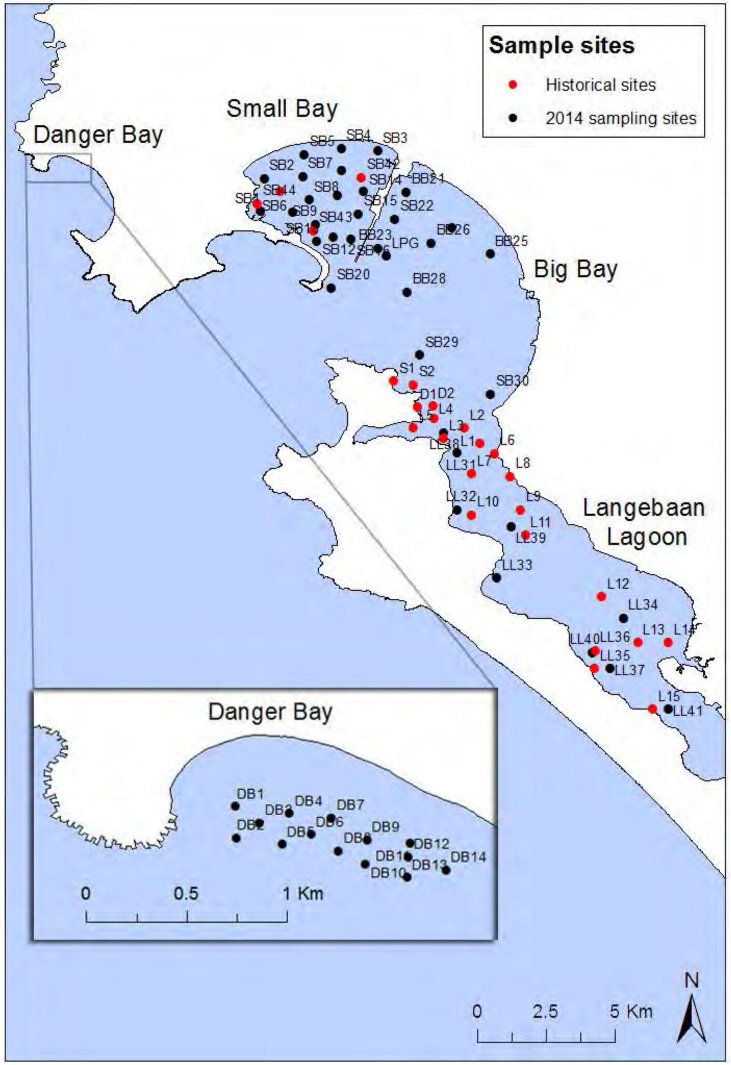


Figure 5.1 Sediment sampling sites in Saldanha Bay, Danger Bay and Langebaan Lagoon for 2014. Sites sampled from pre-1980 to 2013 are marked and labeled in red.

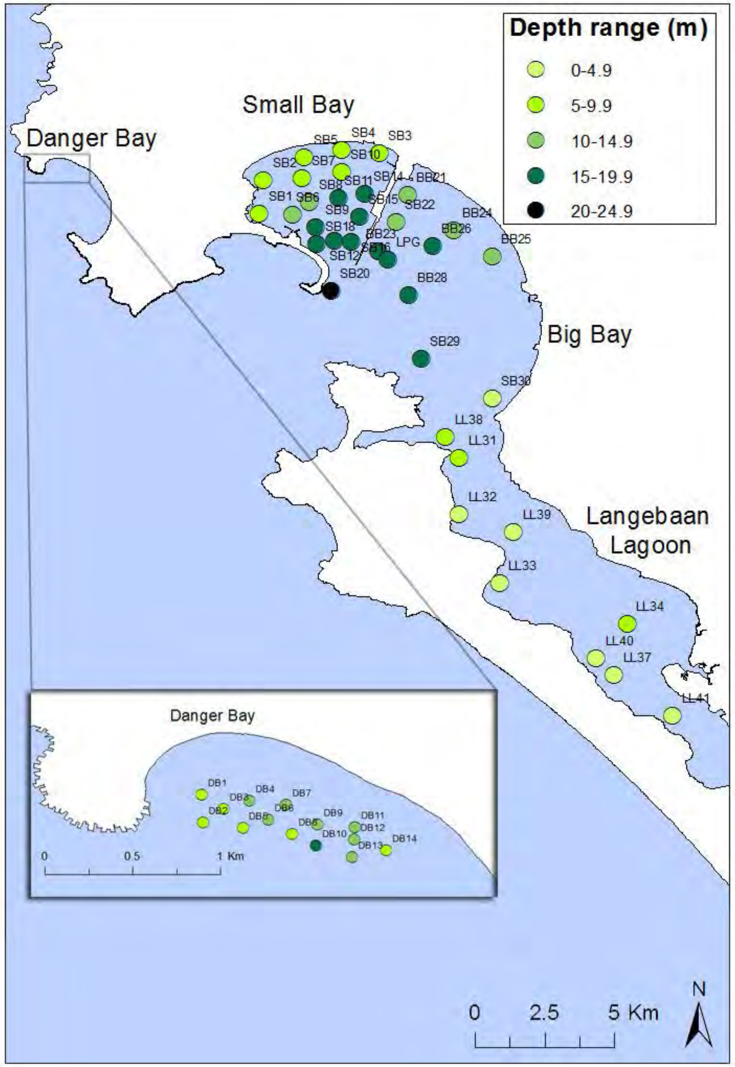


Figure 5.2 Depth of sites sampled in Saldanha Bay, Danger Bay and Langebaan Lagoon in 2014.

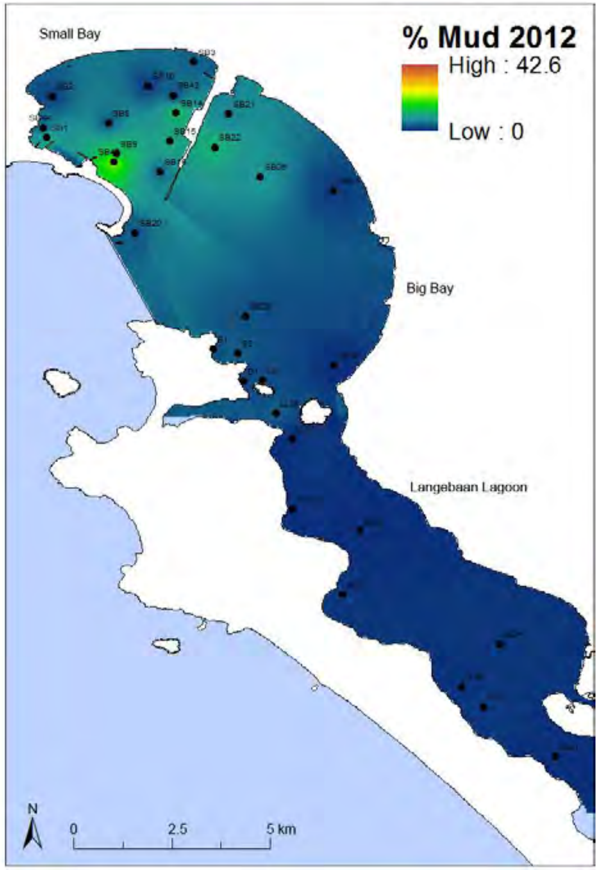


Figure 5.3 **Variation in the percentage mud in sediments in Saldanha Bay and Langebaan Lagoon as indicated by the 2012 survey results.**

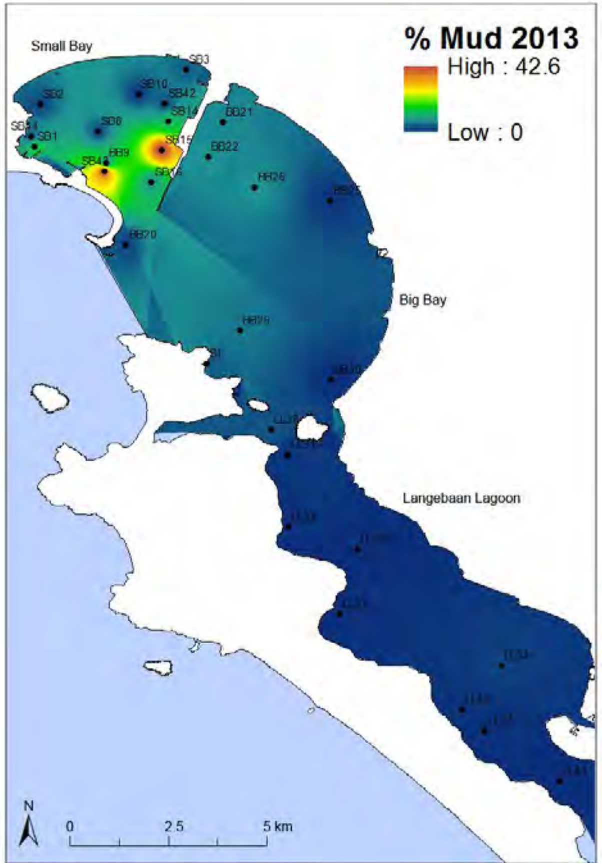


Figure 5.4 **Variation in the percentage mud in sediments in Saldanha Bay and Langebaan Lagoon as indicated by the 2013 survey results.**

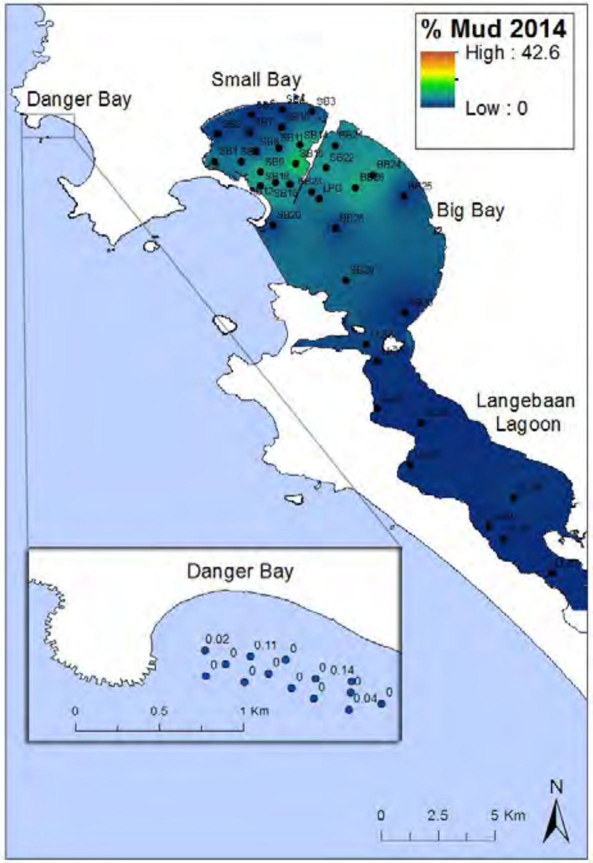


Figure 5.5 **Variation in the percentage mud in sediments in Saldanha Bay, Danger Bay and Langebaan Lagoon as indicated by the 2014 survey results.**

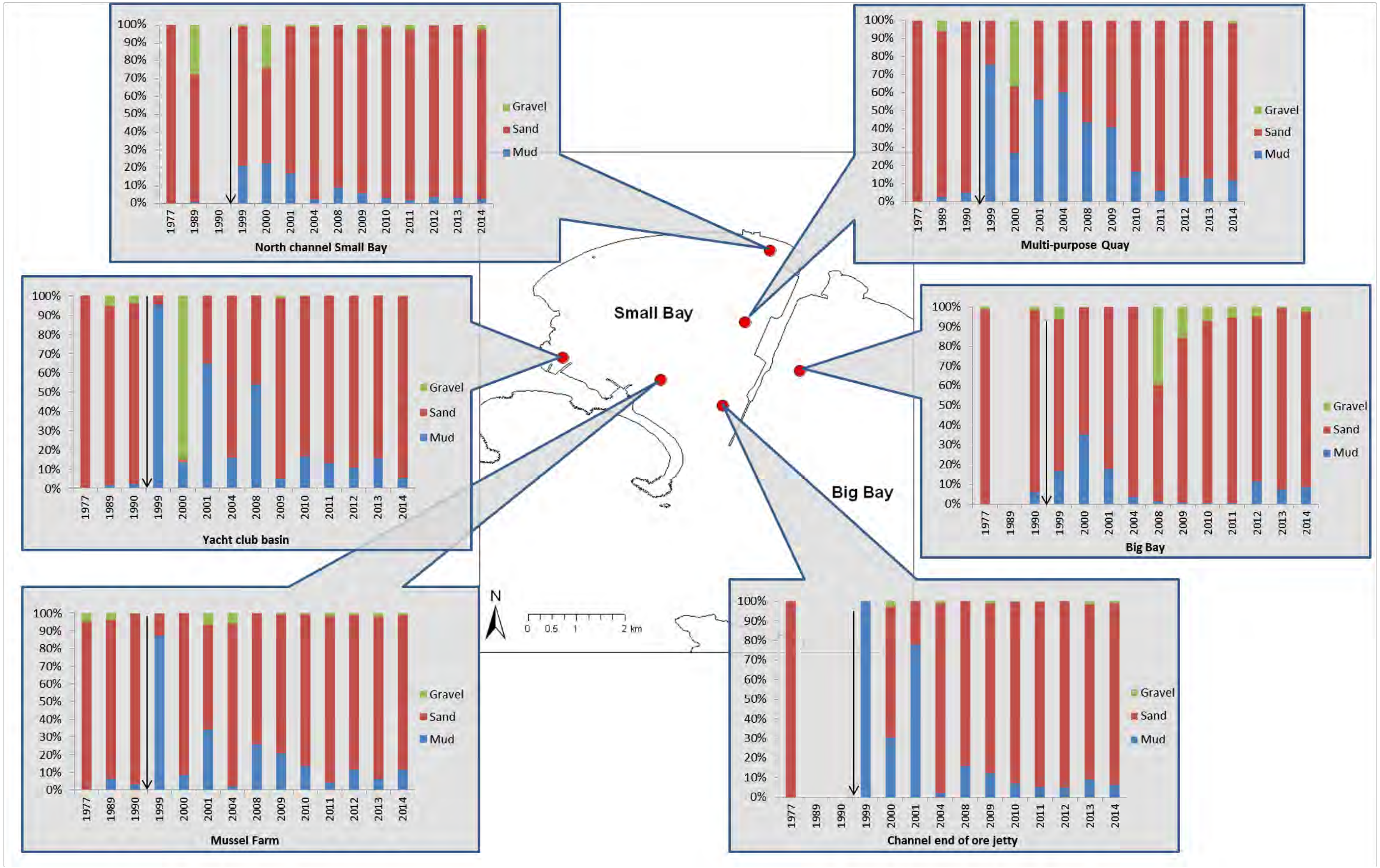


Figure 5.6. Particle size composition (percentage gravel, sand and mud) of sediments at six localities in the small bay area of Saldanha Bay between 1977 and 2014.

5.1.2 Total organic carbon (TOC) and nitrogen (TON) in sediment in the Bay

Total organic carbon (TOC) and Total organic nitrogen (TON) 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 TOC and TON 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. The accumulation of organic matter in the sediments doesn't necessarily directly impact the environment, but 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 wastewater 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.

TOC 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 TOC 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 TOC with the greatest increase occurring in the vicinity of the Mussel Farm. TOC levels peaked at 16.9% at this site in 1990. The reason for this extremely high TOC percentage is uncertain. Through all subsequent years of TOC monitoring (1990, 1999-2001, 2004, 2008-2010), levels have remained higher than those reported prior to development.

Spatial trends in TOC and TON

Spatial variation in the amount of TOC and TON recorded in the sediments in Saldanha Bay and Langebaan Lagoon in 2013 and 2014 are presented in Figure 5.7, Figure 5.8, Figure 5.9 and Figure 5.10. The concentration of TOC and TON in 2013 and 2014 was generally highest in Small Bay between the Mussel Farm and along the Ore Jetty. This pattern mirrors the distribution of muddy sediments in the bay. In addition both TOC and TON levels were elevated in the vicinity of the Liquid Petroleum Gas (LPG) site and across the entrance of Big Bay in 2013-2014 samples.

The Danger Bay sediments collected in 2014 mostly had low TOC and TON concentrations similar to those measured in Langebaan Lagoon and Big Bay (Figure 5.8, Figure 5.10 & Table 5.2). This is expected given the exposed nature of Danger Bay and the sandy sediments with very low mud content found there. The sediment sample collected at one site (DB 11) however, had the highest TOC (7.6%) and the third highest TON concentration (0.43%) of all sediment samples collected throughout Saldanha Bay during the 2014. The reasons for this apparent carbon and nitrogen enrichment in the absence of any elevation in mud content at this site are not known and may well reflect contamination of the sediment sample with biota. Future surveys in Danger Bay will reveal if this anomaly was a genuine result or an artefact of sampling or analytical error.

Spatial trends in the C:N ratio

The C:N ratio results for 2012, 2013 and 2014 were strikingly different. Most Small Bay and Big Bay sites in 2012 had values above that expected for marine productivity, suggesting terrestrial organic matter input or denitrification, whilst the Langebaan Lagoon sites were mostly within the values expected for marine production (Figure 5.11A). In 2013 all sites bar the yacht club basin had values below that expected from marine production, i.e. reflecting nitrogen enrichment (Figure 5.11B). In 2014 however, most sites within Langebaan Lagoon and four out of the nine Big Bay sites had C:N ratios above that expected from marine production, reflecting terrestrial nitrogen sources or (and more plausibly) nitrogen depletion in these areas, whilst most Small Bay sites had values expected from Marine Production. The exceptions in Small Bay in 2014, with below expected C:N ratios were in the vicinity of the Bok River, which is known to be enriched with processed sewage (Figure 5.11C).

There are two possible reasons for elevated C:N ratios; the first being that the organic matter found in these areas originated from terrestrial sources. 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 & 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 TOC content was recorded and stratification is possible. It is however highly unlikely that this process is responsible for the elevated C:N ratios at Langebaan sites in 2014, 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. An alternative hypothesis is that enhanced productivity with selectively greater recycling of nitrogen rich relative to carbon rich organic matter can lead to elevated C:N ratios (Twichell *et al* 2002).

The observed temporal variability of C:N ratios in Saldanha Bay may well reflect upwelling events and associated water column and benthic productivity over the summer period that precedes the annual surveys in April. Given the high inter-annual variability in the C:N ratios, interpretation that focuses on the outliers in any given year (e.g. Yacht club sites in 2013, Bok River sites in 2014) is probably more informative than a temporal analysis.

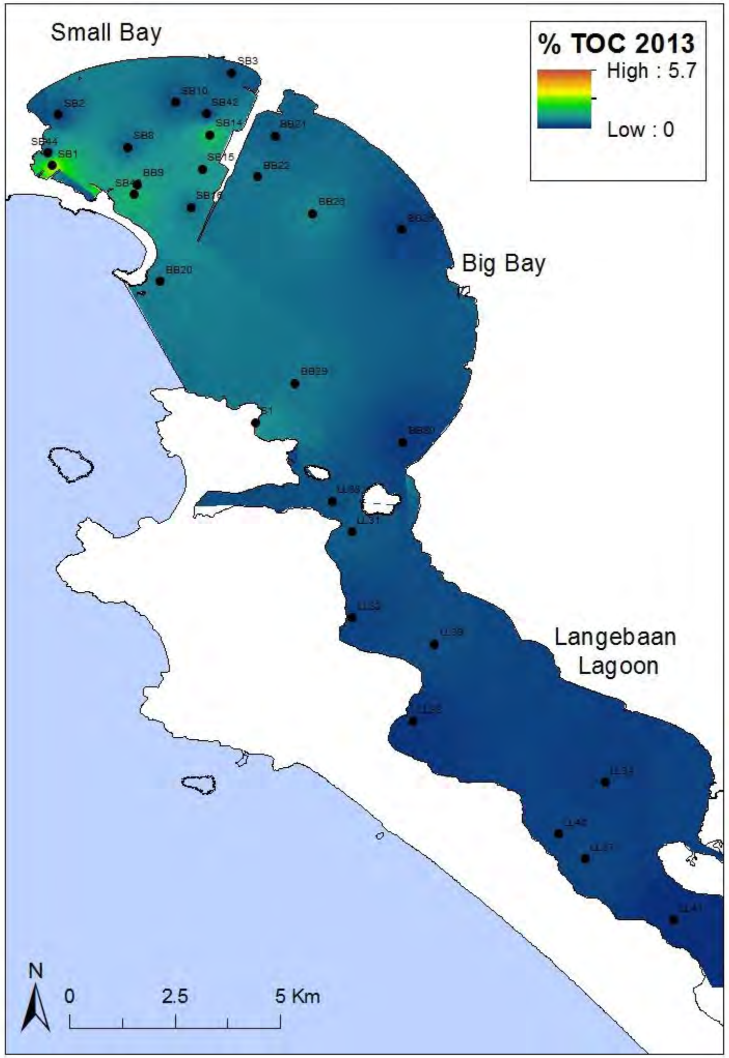


Figure 5.7 **Variation in the percentage total organic carbon in Saldanha Bay and Langebaan Lagoon as indicated by the 2013 survey results.**

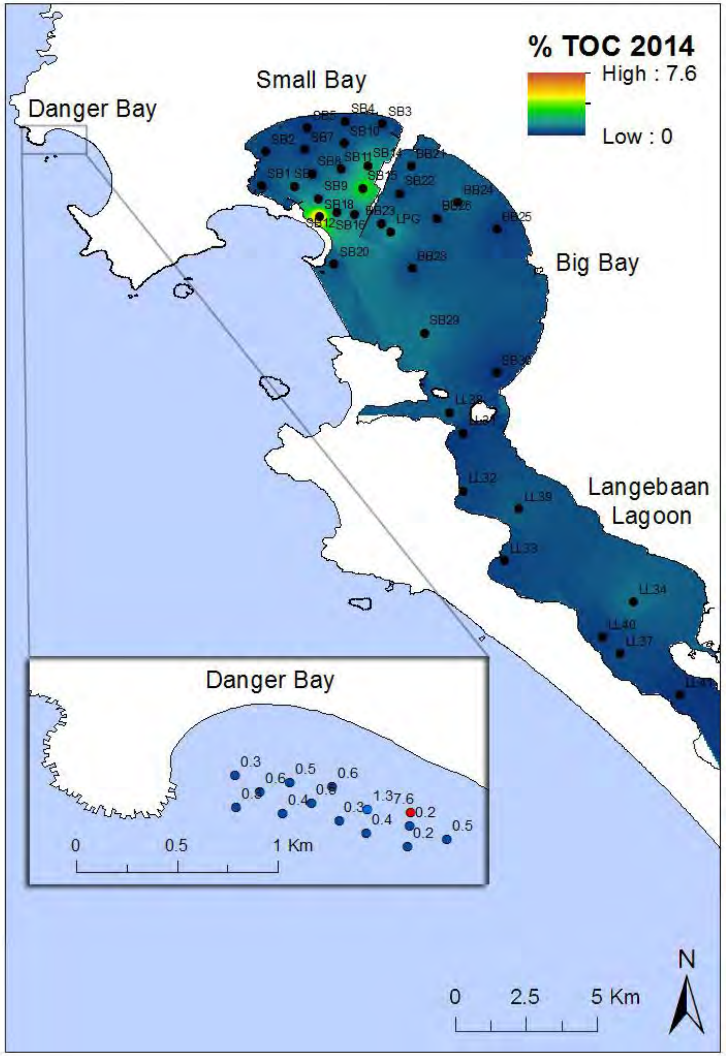


Figure 5.8 **Variation in the percentage total organic carbon in Saldanha Bay, Danger Bay and Langebaan Lagoon as indicated by the 2014 survey results.**

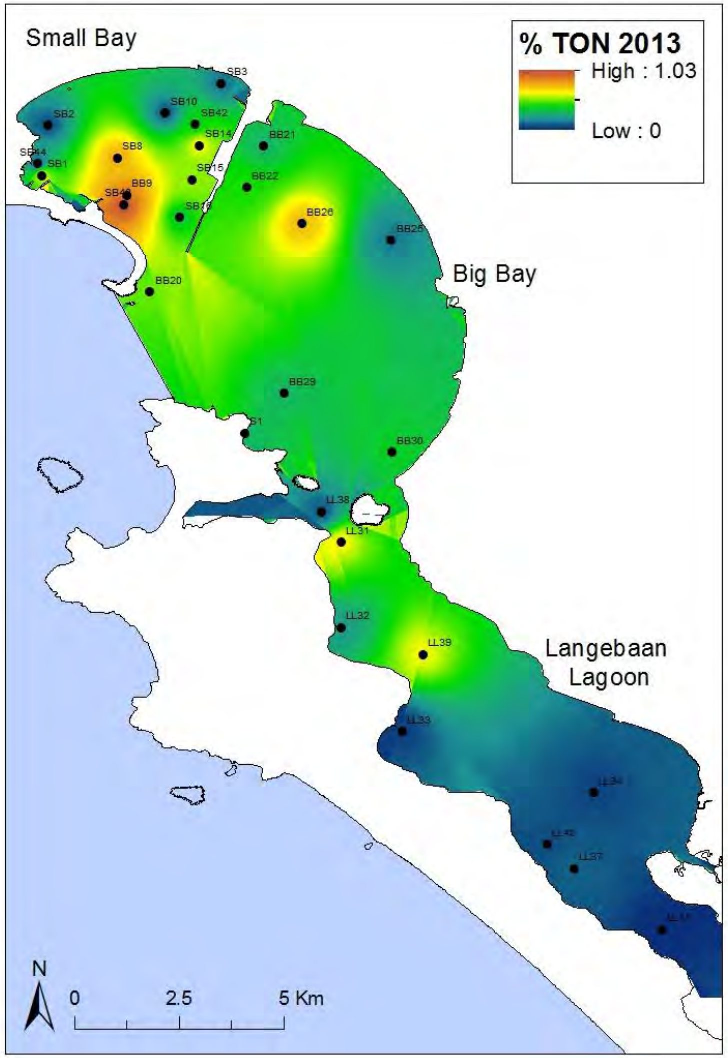


Figure 5.9 **Variation in the percentage total organic nitrogen in Saldanha Bay and Langebaan Lagoon as indicated by the 2013 survey results.**

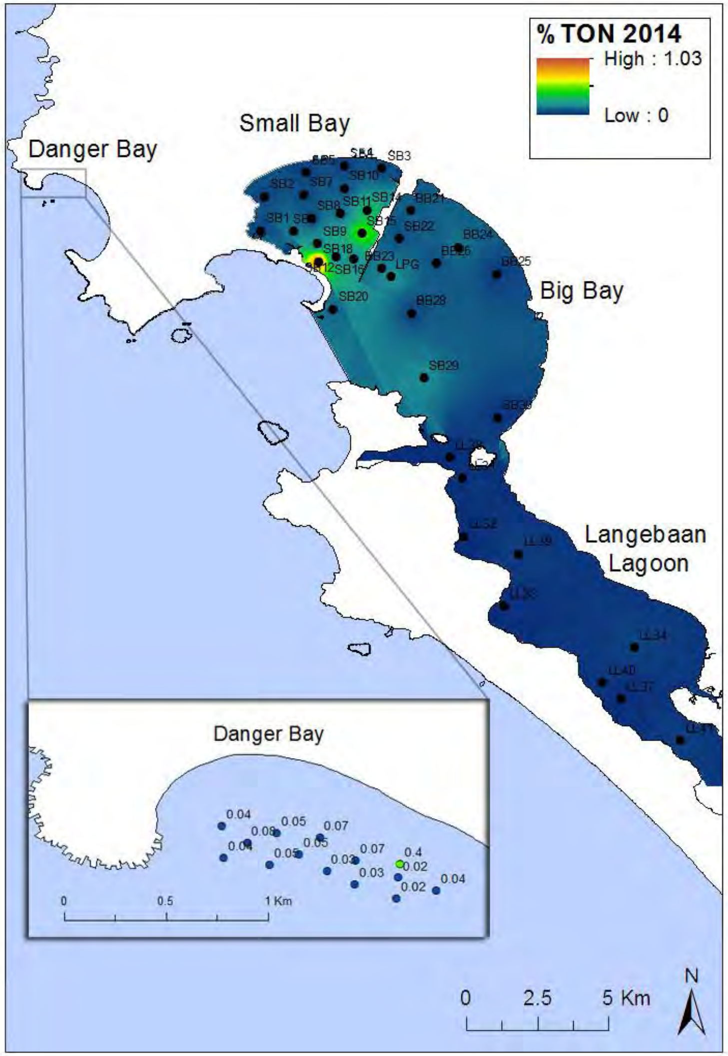


Figure 5.10 **Variation in the percentage total organic nitrogen in Saldanha Bay, Danger Bay and Langebaan Lagoon as indicated by the 2014 survey results.**

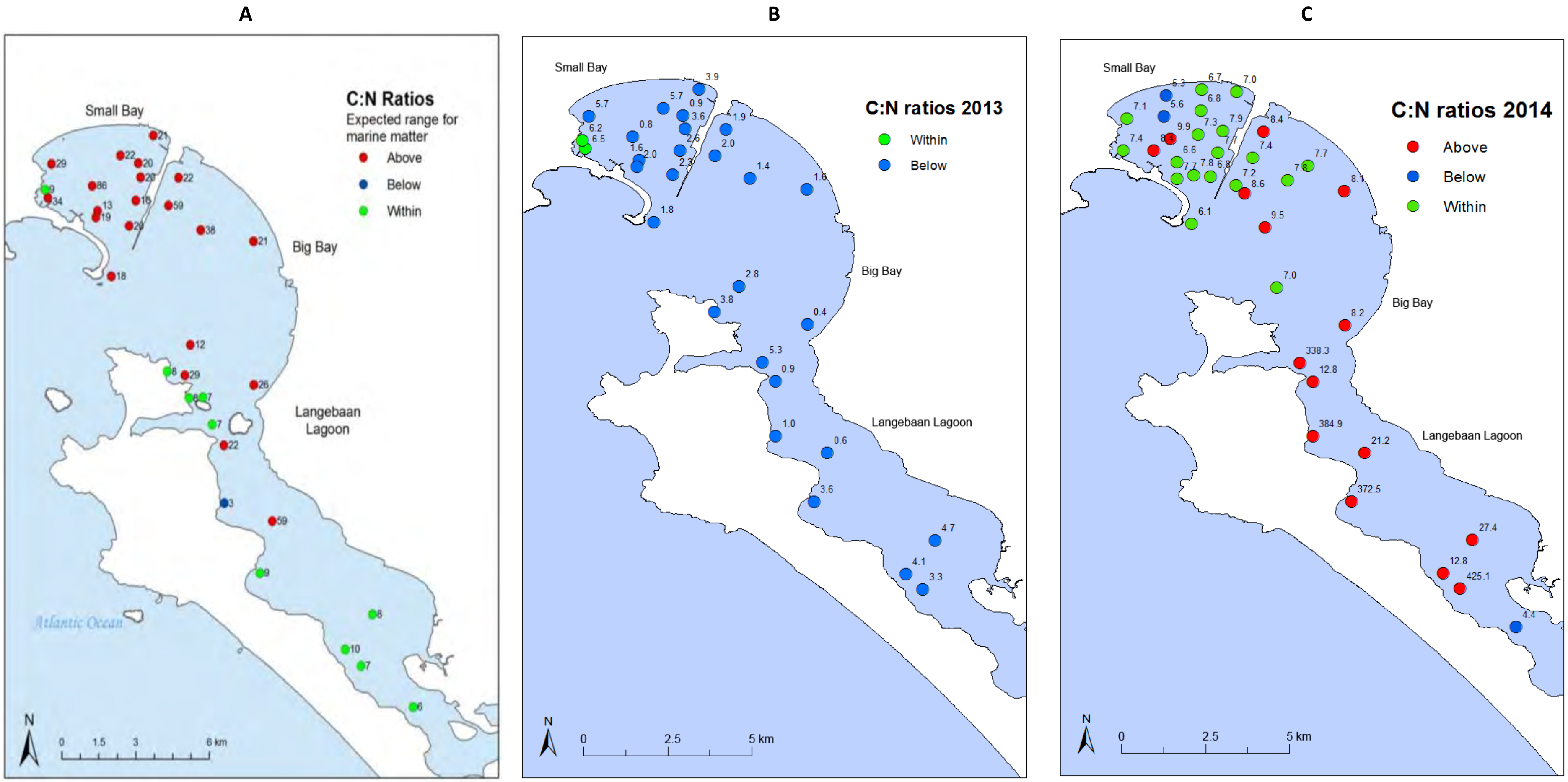


Figure 5.11 **Map showing C:N ration at different at sites surveyed in Saldanha Bay and Langebaan Lagoon in 2012, 2013 & 2014 (red = exceeds range expected for marine production, green = within range expected for marine production and blue = below range expected for marine production).**

Temporal trends

Total organic carbon

A total of six sites have been sampled and TOC compared at various stages between 1974 and 2014 (Figure 5.12). The sediments from the Yacht Club Basin (SB1) and Multi-purpose Quay (SB14) consistently had the highest TOC content of the six sites sampled since 1989. TOC at the Mussel Farm (SB9) historically had elevated TOC but since 2008 levels have been mostly low. The TOC at all six sites had increased in 2012, but decreased substantially in the subsequent years, particularly in 2014 at the Yacht Club Basin where the lowest % TOC was recorded since pre-1974.

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 were 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.

Total organic nitrogen

Sources of organic nitrogen in Small Bay include fish factory wastes, biogenic waste from mussel and oyster culture, sewage effluent from the wastewater treatment works and leaking of sewage from septic tanks. TON had not been measured in early (historic) studies of the Bay, and data are only available from 1999 onwards (Figure 5.13). Historically the TON concentrations have been greatest at the Yacht Club Basin, Multi-purpose Quay and near the Mussel rafts (Figure 5.13). 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 2013 data indicate an increase in the TON at all six sites except the North End of Small Bay. This increase was particularly great at the Yacht Club Basin, Mussel farm and Multi-Purpose Quay sites. However, in 2014 all six sites indicated a substantial decrease in TOC, with the Yacht Club Basin, Mussel Farm and Big Bay sites indicting some of the lower recordings of TON since 1999.

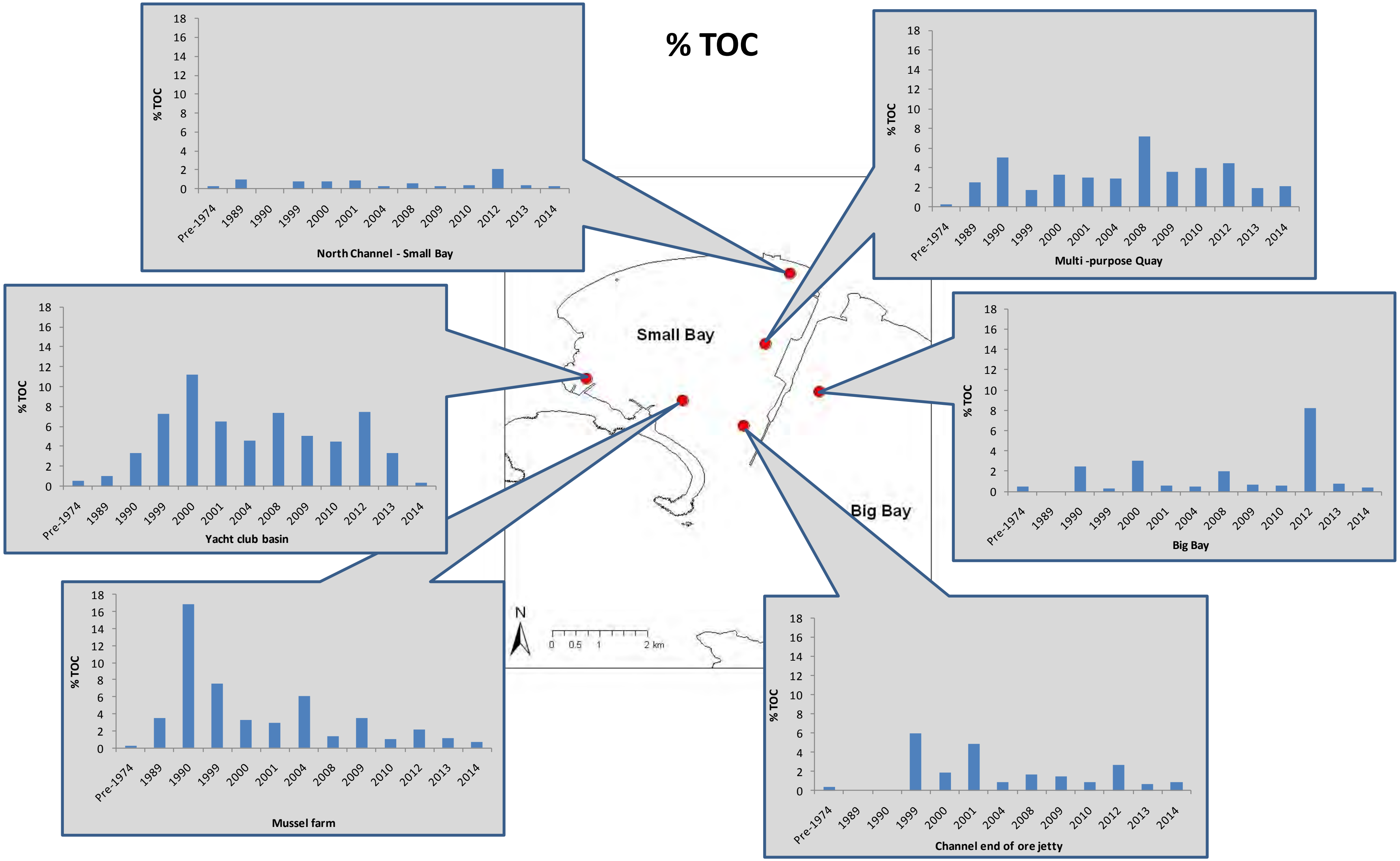


Figure 5.12. Total organic carbon percentage occurring in sediments of Saldanha Bay at six locations between 1999 and 2014.

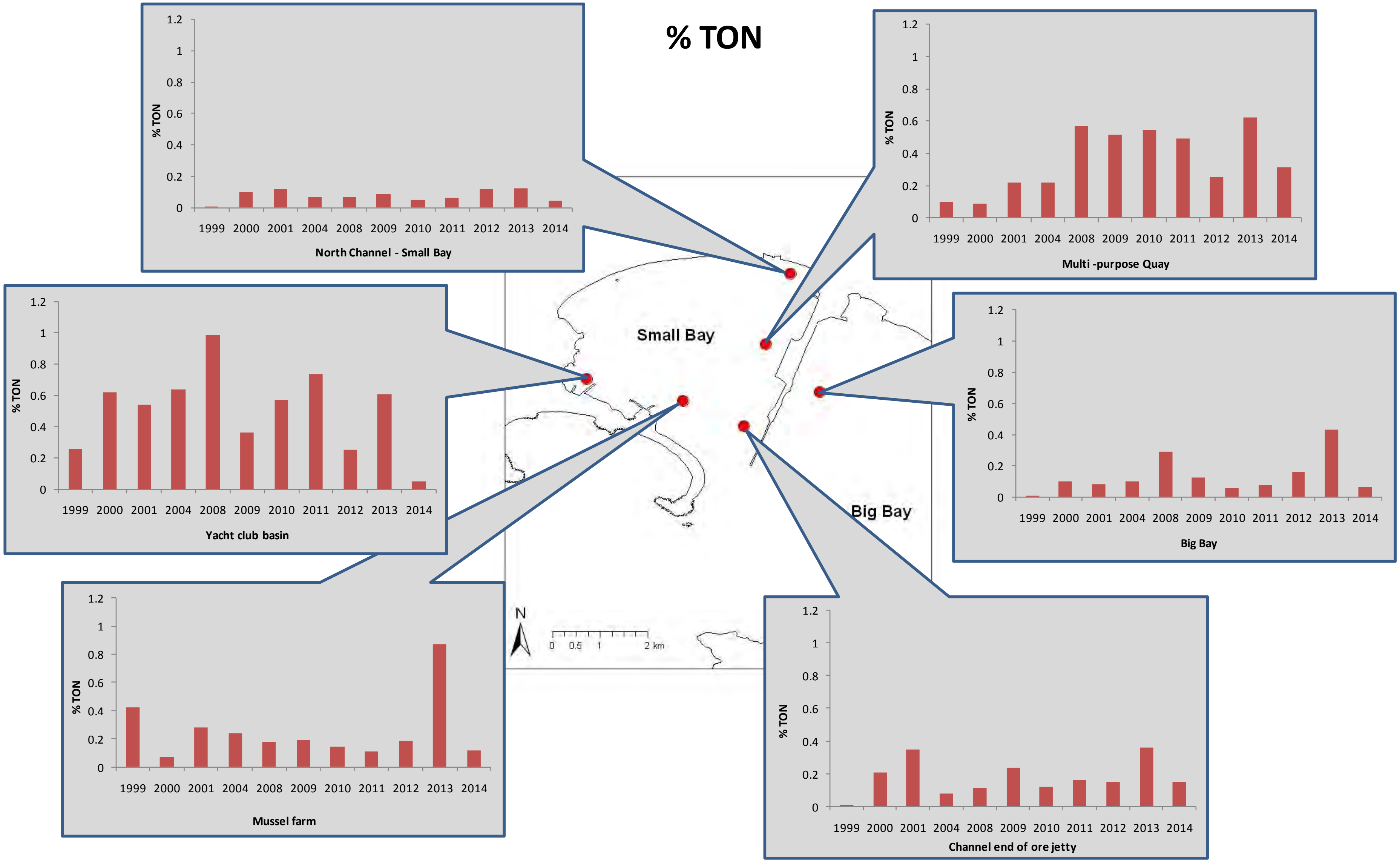


Figure 5.13. Total organic nitrogen percentage occurring in sediments of Saldanha Bay at six locations between 1999 and 2014.

5.1.3 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 TOC. 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 5.3). 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 (CSIR 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 5.3.

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 10th 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 50th 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 5.3. Summary of Benguela Current Large Marine Ecosystem and National Oceanic and Atmospheric Administration 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](CSIR 2006), [2] (Long *et al.* 1995, Buchman 1999)

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 2012 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.

Analysis and results for 2013 and 2014

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, Danger Bay and Langebaan Lagoon in 2013 are shown in Table 5.4 and in 2014 in Table 5.5.

Table 5.4. Concentrations (mg/kg) of metals in sediments collected from Saldanha Bay in 2013. Values that exceed sediment quality guidelines are highlighted in red font.

	Sample #	Al (ppm)	Fe (ppm)	Cd (ppm)	Cu (ppm)	Ni (ppm)	Pb (ppm)
***ERL Guideline (mg/kg)**		-	-	**1.2**	**34**	**20.9**	**46.7**
Small Bay	SB1	23949	10930	**3,1**	**52,7**	14,5	28,0
	SB2	5113	2836	0,2	32,6	3,6	5,0
	SB3	3171	2012	0,3	10,3	2,5	10,2
	SB8	3945	2548	0,5	7,7	3,1	1,5
	SB9	7480	4622	0,6	6,5	5,1	4,7
	SB10	3445	2353	0,3	13,8	3,1	3,2
	SB14	17689	9772	**1,7**	27,0	10,3	**47,2**
	SB15	10422	5258	0,9	5,6	5,3	12,2
	SB16	7444	4596	0,8	12,0	5,2	3,1
	SB42	3732	2180	0,6	13,9	3,3	0,8
	SB43	4581	3227	0,4	10,5	3,3	5,9
	SB44	21105	9762	**1,8**	19,2	11,5	11,7
	SB20	6790	4429	0,3	17,8	3,5	0,0
Big Bay	BB21	6192	3096	0,5	8,9	3,9	2,3
	BB22	8793	4785	0,7	17,2	5,0	2,2
	BB25	2633	1976	0,4	5,0	2,5	0,0
	BB26	7189	3628	0,6	6,2	4,0	1,4
	BB29	7324	3079	0,6	8,4	4,7	0,9
	BB30	1658	1006	0,1	11,4	1,9	2,6
Salamander Bay	S1	6911	4899	0,6	14,8	3,6	13,3
Langebaan Lagoon	LL31	6286	3215	0,5	16,8	4,3	3,2
	LL32	6000	3266	0,5	5,2	3,5	0,7
	LL33	3867	3833	0,3	9,7	2,7	0,9
	LL34	2187	2278	0,0	13,5	2,3	0,0
	LL37	5904	3855	0,4	9,4	3,5	4,2
	LL38	2537	2220	0,2	14,0	2,2	0,0
	LL39	9140	5246	0,7	16,5	5,2	2,9
	LL40	2875	2076	0,3	18,3	2,2	1,3
	LL41	3194	2291	0,1	16,3	2,5	0,0

Table 5.5. Concentrations (MG/KG) of metals in sediments collected from Saldanha Bay in 2014. . Values that exceed sediment quality guidelines are highlighted in red font.

	Sample #	Al (ppm)	Fe (ppm)	Cd (ppm)	Cu (ppm)	Ni (ppm)	Pb (ppm)
***ERL Guideline (mg/kg)**		-	-	**1.2**	**34**	**20.9**	**46.7**
Small Bay	SB1	4218	4002	1,0	4,0	3,4	8,3
	SB2	2585	3769	0,7	4,2	2,5	6,3
	SB3	2550	3828	0,7	4,1	2,2	12,5
	SB4	1726	2810	0,4	2,0	1,5	3,9
	SB5	1781	3811	0,5	2,9	2,3	4,1
	SB6	3388	3300	0,7	3,0	2,1	4,3
	SB7	2030	3929	0,5	2,7	2,5	3,4
	SB8	2786	3352	0,7	1,8	1,9	6,8
	SB9	4461	5738	1,0	3,5	3,4	8,4
	SB10	2264	4008	0,6	2,4	2,2	6,0
	SB11	4556	5350	0,9	3,4	3,6	8,6
	SB12	3842	3931	0,9	3,1	2,6	4,9
	SB14	9375	8974	**2,0**	16,8	7,3	45,3
	SB15	11601	11595	**2,4**	15,1	9,8	36,3
	SB16	4165	4459	1,0	3,8	3,3	4,9
	SB18	11678	10349	**3,4**	12,7	11,4	17,4
	SB20	2077	2505	0,8	1,4	1,9	2,2
	SB22	4393	5020	0,9	2,4	3,1	7,7
	SB29	1791	2285	0,6	1,0	1,2	2,7
	SB30	1237	2042	0,4	0,8	0,9	1,2
Big bay	BB21	3424	3961	0,7	2,1	2,5	4,8
	SB23	3273	4210	0,8	2,3	2,4	4,6
	BB24	4027	3925	1,0	2,4	3,0	5,3
	BB25	1528	2188	0,5	0,9	1,0	1,9
	BB26	3978	4210	0,9	1,9	3,0	4,5
	BB28	1043	1277	0,4	0,5	0,6	0,4
LPG	LPG 1	3598	3985	1,0	2,5	2,8	3,5
Danger Bay	DB1	412	555	0,3	0,0	0,0	1,9
	DB2	406	529	0,3	0,0	0,0	2,2
	DB3	296	366	0,3	0,0	0,0	0,0
	DB4	399	429	0,3	0,0	0,0	0,9
	DB5	421	611	0,3	0,0	0,0	1,1
	DB6	416	586	0,3	0,0	0,0	1,5
	DB7	466	592	0,3	0,0	0,0	0,9
	DB8	434	532	0,4	0,0	0,0	0,6
	DB9	397	552	0,3	0,0	0,0	0,8
	DB10	378	509	0,3	0,0	0,0	1,5
	DB11	387	549	0,4	0,0	0,2	0,3

	Sample #	Al (ppm)	Fe (ppm)	Cd (ppm)	Cu (ppm)	Ni (ppm)	Pb (ppm)
	DB12	444	566	0,4	0,0	0,0	0,5
	DB13	437	569	0,3	0,2	0,0	4,9
	DB14	411	590	0,3	0,0	0,0	1,6
Langebaan Lagoon	LL31	2775	3819	0,6	1,6	1,9	3,5
	LL32	2142	3994	0,6	0,9	2,0	2,4
	LL33	1775	3832	0,5	2,4	2,5	4,0
	LL34	2464	3564	0,6	2,5	2,1	4,6
	LL37	1570	3677	0,4	3,0	1,9	4,1
	LL38	4618	5422	1,1	3,5	4,3	7,9
	LL39	1591	2818	0,5	1,5	0,8	4,1
	LL40	959	2948	0,4	2,1	1,2	4,5
	LL41	1224	3876	0,4	2,2	1,7	3,9

The ERL guideline for Cd was exceeded at the Yacht Club Basin and at two sites on either side of the ore jetty in 2013 and at three sites on the Small Bay side of the ore jetty in 2014. 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 in 2013. 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. Concentrations of trace metals in the sandy Danger Bay sediment samples were very low relative to sites with anthropogenic impacts and muddy sediments collected within Saldanha Bay. Cu and Ni were not detectable at nearly all Danger Bay sites, whilst Cd and Pb concentrations were well below all sediment quality guidelines.

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.* 1996a). 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.* 1996a); and ratios of metal concentrations to Al or Fe concentrations are relatively constant in the earth's crust (Summers *et al.* 1996a). 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. Several studies have been conducted to determine the relative abundance of metals in crustal materials (Turekin & Wedepohl 1961, Taylor 1964, Taylor & McLennan 1981, Martin & Whitfield

1983). The results of these studies (summarized in Table 5.6) are useful for the assessment of the extent of metal contamination resulting from anthropogenic activity.

Table 5.6. 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

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 2013 and 2014 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 (Figure 5.14 - Figure 5.21).

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 5.7). 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.

Cadmium

The normalized Cd values measured in 2013 exceeded that which is expected for average crustal materials at nearly all the sites and was especially high within Small Bay, along the shore in Big Bay and at a site on the far end of the Lagoon (Figure 5.14). The normalized Cd values measured in 2014 at all sites exceeded that which is expected for average crustal materials (Figure 5.15). 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 and SB44 (near the Yacht Club Basin) and site SB14 (near the Multi-Purpose Quay) and 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 (Table 5.7).

Copper

The normalized Cu values measured in 2013 exceeded that which is expected for average crustal materials at most sites within the Bay and Lagoon (Figure 5.16). The values were highest at SB2 near the shore in Small Bay, along the far end of Big Bay and along the mouth of the Lagoon and well as within the Lagoon. The normalized Cu values measured in 2014 exceeded that which is expected for average crustal materials at most sites within Small Bay, particularly along the shore and Ore Jetty (Figure 5.17). Areas within the Lagoon also exceeded the exceeded the average crustal value. This suggests that there may be a source of copper pollution affecting most of the Bay and region and parts of the Lagoon. 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 exceeded the ERL guideline, the normalised value indicates the pollution source was anthropogenic and the enrichment factor was also alarmingly high in 2013, but was reduced greatly (although still high) in 2014 (Table 5.7).

Nickel

The normalized Ni values measured in 2013 exceeded that which is expected for average crustal materials at one site within the Lagoon and two sites within Big Bay (Figure 5.18). These sites were along the shore and near the mouth of the lagoon in Big Bay. The normalized Ni values measured in 2014 exceeded that which is expected for average crustal materials at various sites within Small Bay and the Lagoon (Figure 5.19). 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.

Lead

The normalized Pb values measured in 2013 exceeded that which is expected for average crustal materials at almost all sites in Saldanha Bay (with a few exceptions within Big Bay and the Lagoon) and extending much of the way south into the Lagoon (Figure 5.20). Similarly, in 2014 normalized Pb values exceeded that which is expected for average crustal materials at all sites within Saldanha Bay, except for one site in Danger Bay (Figure 5.21). This suggests that 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). In both 2013 and 2014, 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 during both 2013 and 2014 (59 and 56.7 fold respectively) and the concentration of lead at these site exceeded the ERL (Table 5.6, Table 5.7).

Table 5.7. Enrichment factors for Cadmium, Copper and Lead in sediments collected from Saldanha Bay in 2013 and 2014 relative to sediments from 1980.

	Sample	Cd		Cu		Pb	
	1980 average	0,075		0,41		0,8	
		2013	2014	2013	2014	2013	2014
Small Bay	SB1	41,2	12,7	128,5	9,8	35,0	10,4
	SB2	3,2	8,7	79,6	10,3	6,2	7,9
	SB3	3,9	9,7	25,1	10,1	12,8	15,6
	SB8	6,5	9,1	18,7	4,3	1,9	8,5
	SB9	7,9	13,1	15,8	8,6	5,9	10,5
	SB10	3,4	7,7	33,7	5,7	4,0	7,4
	SB14	22,2	26,1	65,9	41,1	59,0	56,7
	SB15	12,2	32,6	13,7	36,8	15,2	45,4
	SB16	10,4	13,1	29,3	9,3	3,9	6,1
	SB44	23,9		46,8		14,7	
Big Bay	BB20	3,8	10,1	43,5	3,4	0,0	2,7
	BB21	6,2	9,9	21,8	5,2	2,8	6,1
	BB22	9,1	11,4	42,0	5,9	2,7	9,6
	BB25	4,7	6,2	12,2	2,2	0,0	2,3
	BB26	8,3	12,0	15,0	4,7	1,7	5,7
	BB29	7,7	7,5	20,4	2,5	1,1	3,3
	BB30	0,9	5,7	27,8	1,9	3,3	1,5

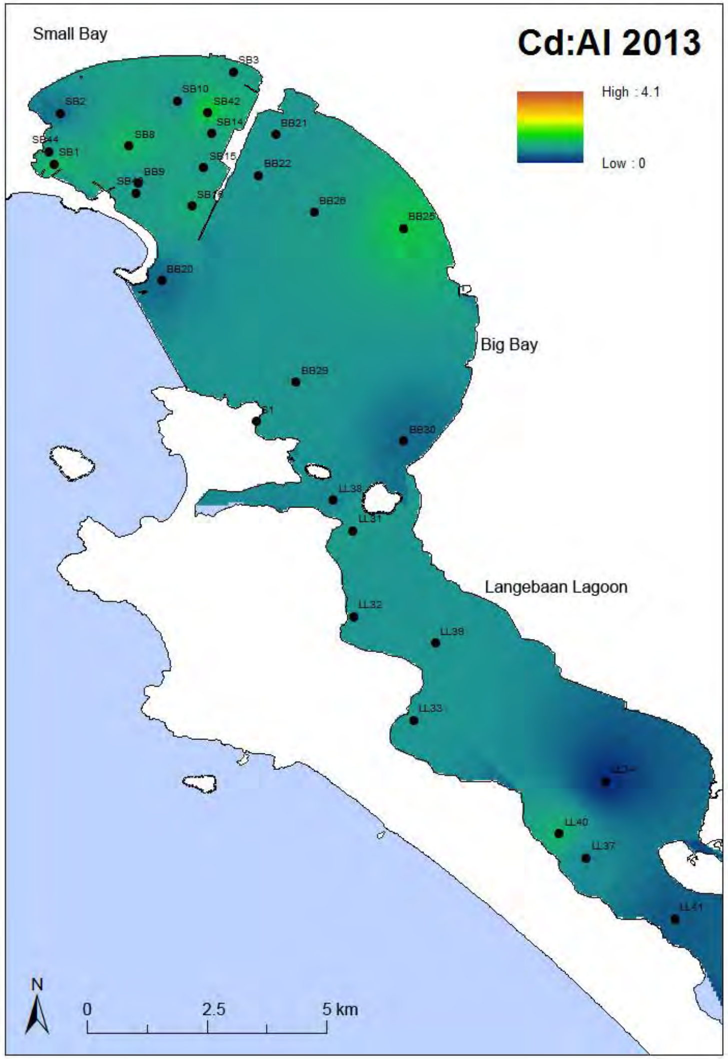


Figure 5.14 Spatial interpolation of normalized cadmium values based on values measured in Saldanha Bay and Langebaan Lagoon in 2013 (normalised using Al) (the average crust value = 0.24).

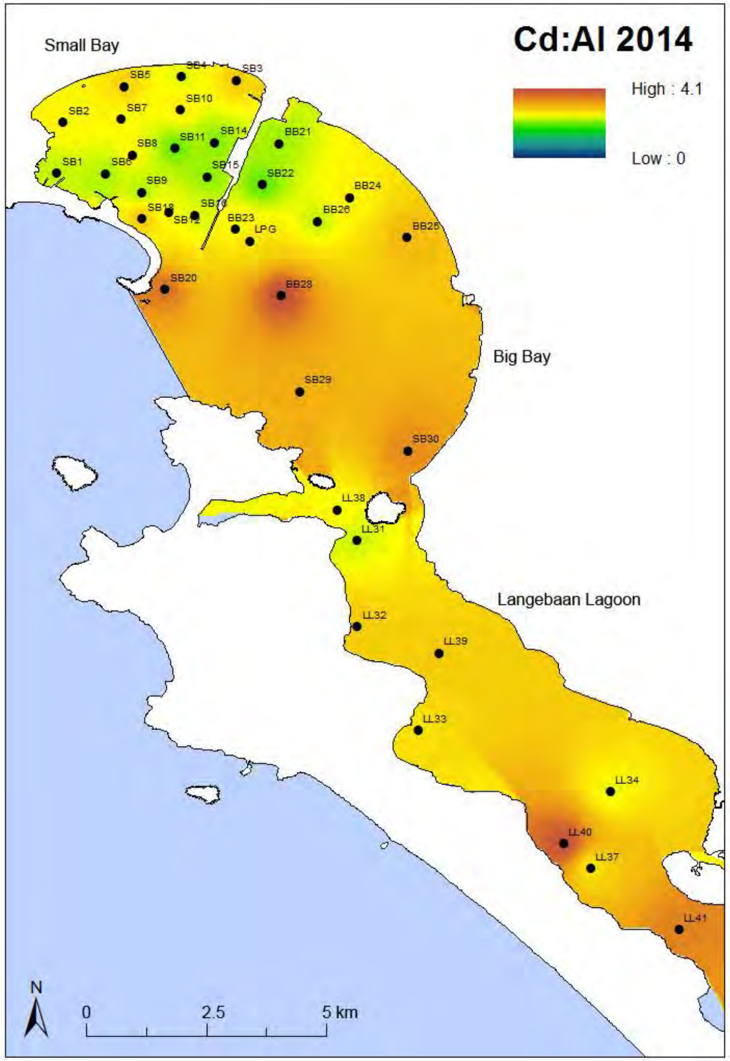


Figure 5.15 Spatial interpolation of normalized cadmium values based on values measured in Saldanha Bay and Langebaan Lagoon in 2014 (normalized using Al). (The average crust value = 0.24).

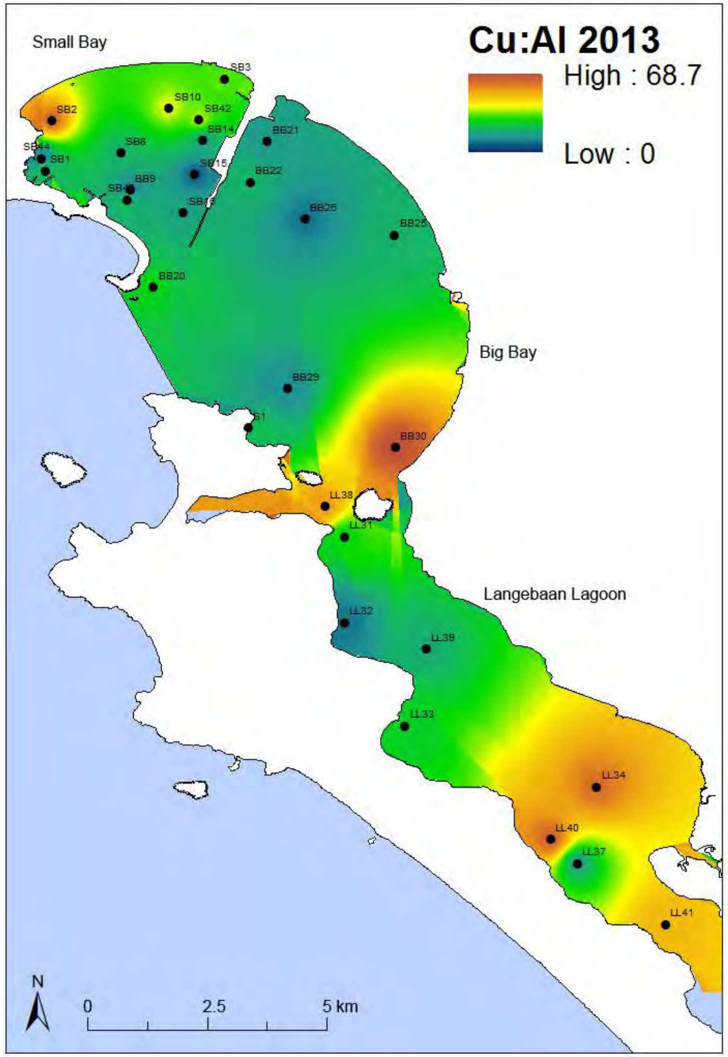


Figure 5.16 **Spatial interpolation of normalized copper values based on values measured in Saldanha Bay and Langebaan Lagoon in 2013 (normalised using Al). (The average crust value = 6.7).**

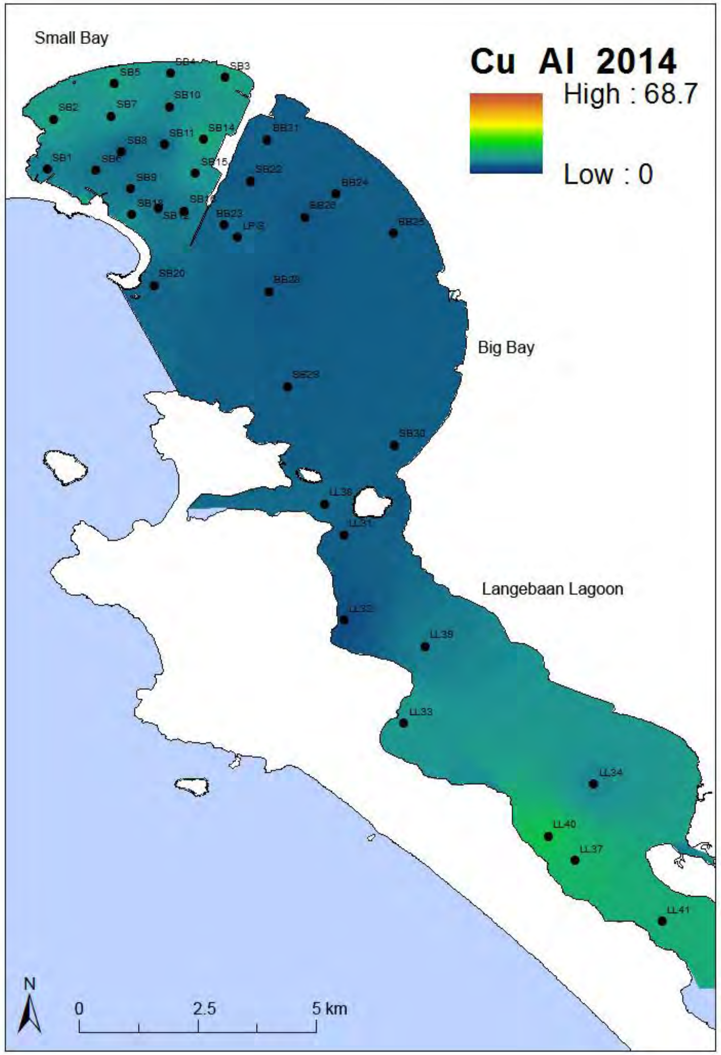


Figure 5.17 **Spatial interpolation of normalized copper values based on values measured in Saldanha Bay and Langebaan Lagoon in 2014 (normalised using Al). (The average crust value = 6.7).**

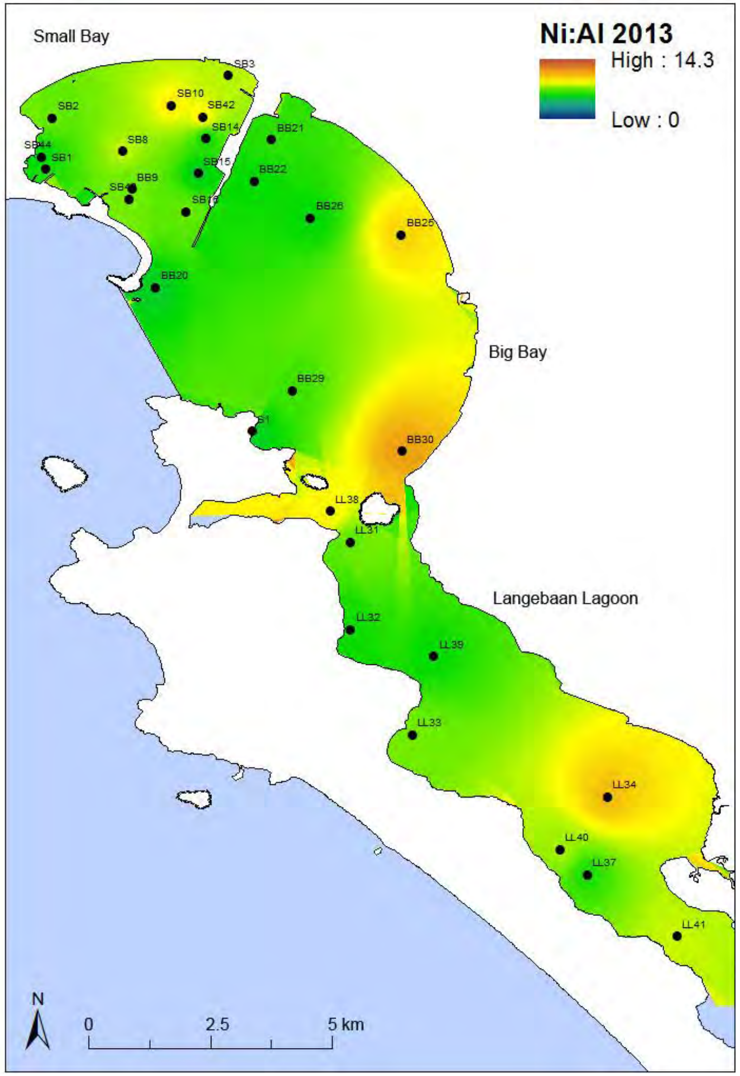


Figure 5.18 **Spatial interpolation of normalized nickel values based on values measured in Saldanha Bay and Langebaan Lagoon in 2013 (normalized using Al). (The average crust value = 9.1).**

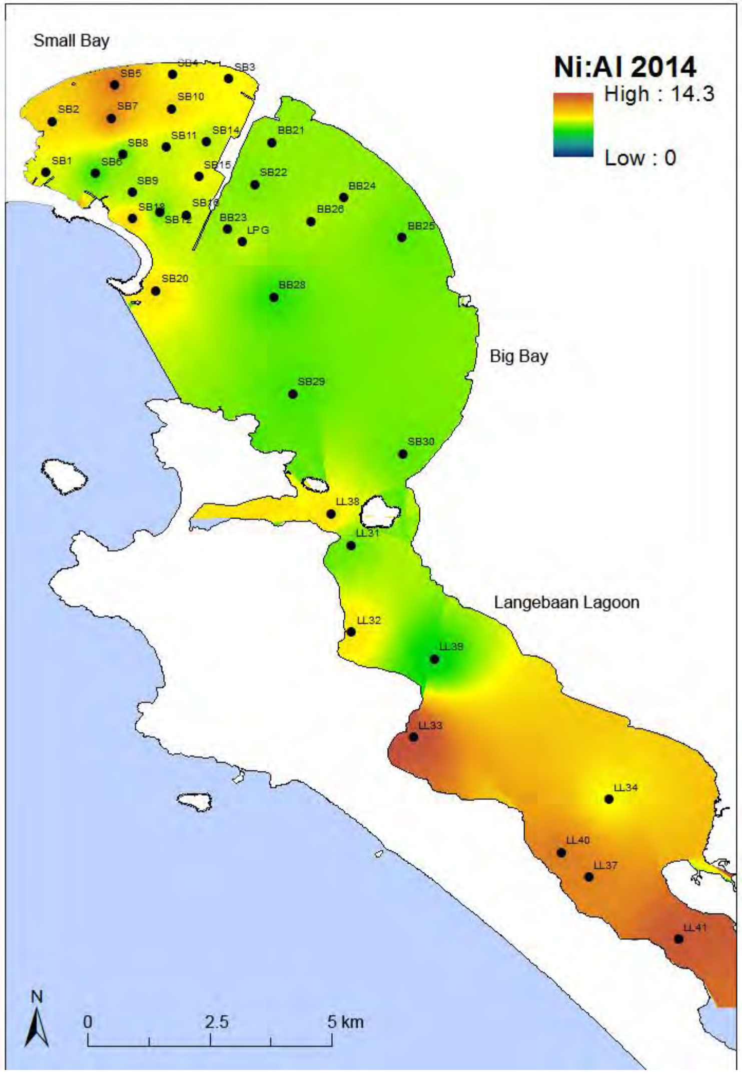


Figure 5.19 **Spatial interpolation of normalized nickel values based on values measured in Saldanha Bay and Langebaan Lagoon in 2014 (normalized using Al). (The average crust value = 9.1).**

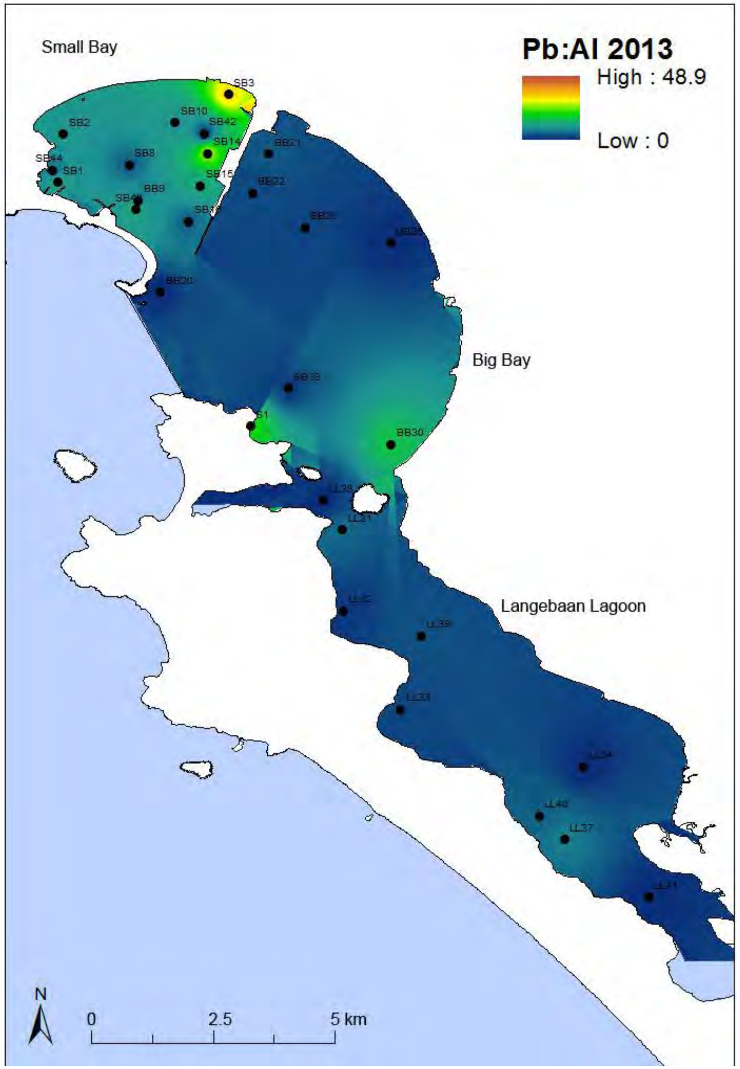


Figure 5.20 **Spatial interpolation of normalized lead values based on values measured in Saldanha Bay and Langebaan Lagoon in 2013 (normalized using Al). (The average crust value = 1.5).**

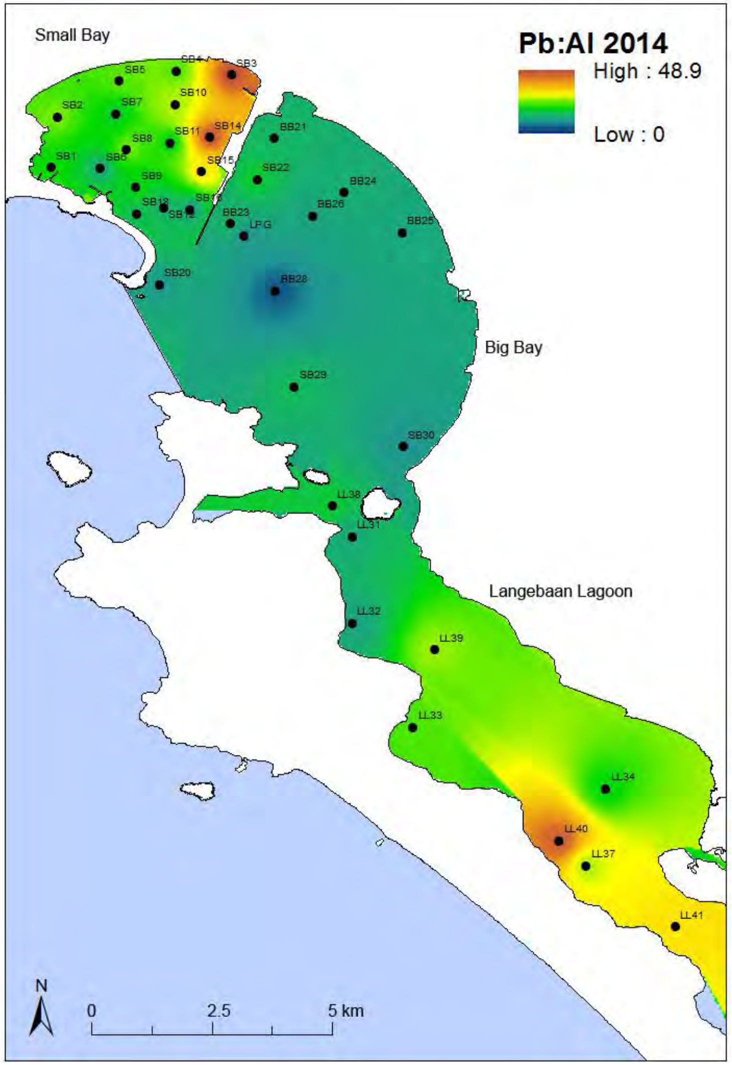


Figure 5.21 **Spatial interpolation of normalized lead values based on values measured in Saldanha Bay and Langebaan Lagoon in 2014 (normalized using Al). (The average crust value = 1.5).**

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.

Cadmium

There was a considerable increase in the concentration 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 5.22). Cadmium concentrations have shown a progressive and dramatic decrease in the period 1999-2010, however, the results between 2010 and 2013 indicated a steady increase again in the cadmium concentrations in the Yacht Club Basin. During the 2014 survey cadmium concentrations had decreased to below the ERL toxicity threshold within the Yacht Club Basin. Most of the other sites have displayed an increase in cadmium concentrations during 2013 and 2014, although still below the ERL toxicity threshold. The exception to this is at the Multi-purpose Quay, where the concentrations exceeded the ERL limit (Table 5.5).

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 2013 (Figure 5.23). All sites showed an increase in the copper concentration over the period 2004-2013. A decrease in copper concentration at all sites was observed during 2014, especially at the Yacht Club Basin with a dramatic decrease to below the ERL threshold.

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 (Figure 5.24). Since 1999, nickel concentrations have declined 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. In 2012 there was a slight increase in the concentration of nickel at all six sites, though it remains well below the ERL threshold value. The 2013 results displayed mostly similar concentrations to 2012, while the 2014 results indicated a decrease in nickel concentrations at all six sites.

Lead

The concentration of lead peaked and exceeded the ERL threshold at the yacht club basin and mussel farm site in 1999 (Figure 5.25). 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 14 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 13 years, with these concentrations exceeding the threshold in 2012 and 2013 and being just below the threshold in

2014. 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 continue to contaminate the adjacent marine environment with lead.

Iron

The temporal variation in the concentration of iron in sediments around the ore terminal in Saldanha Bay is shown in Figure 5.26). 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 five of the six sites between 2010 and 2014. 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 SB increased very dramatically in 2012, but decreased equally dramatically in 2013. In 2014 the concentration at SB14 increased again but not as high as in 2012. The reason for the increase at this site but not at any of the other sites is unclear. On-going 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.

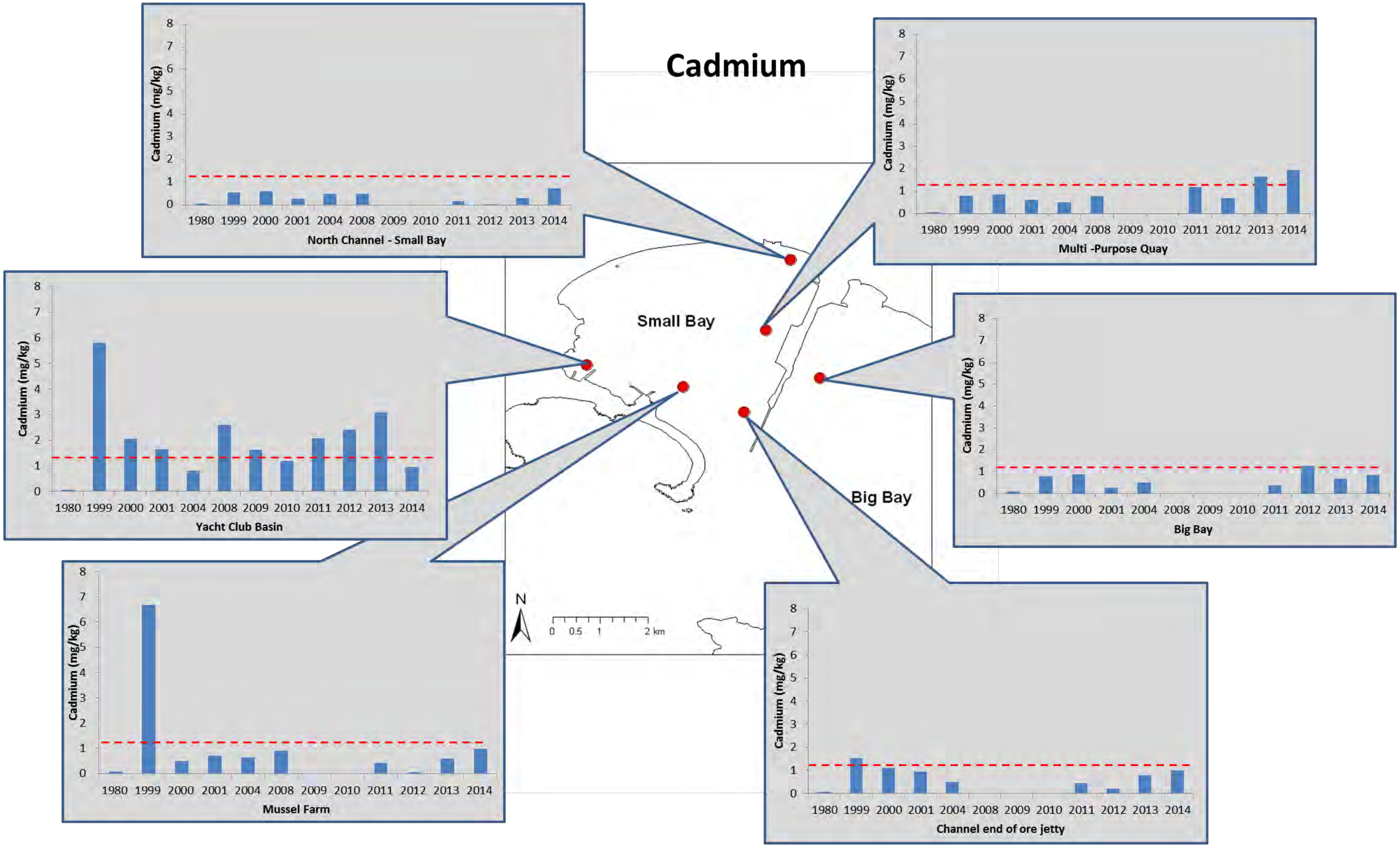


Figure 5.22. Concentrations of Cadmium (Cd) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2014. Dotted lines indicate Effects Range Low values for sediments.

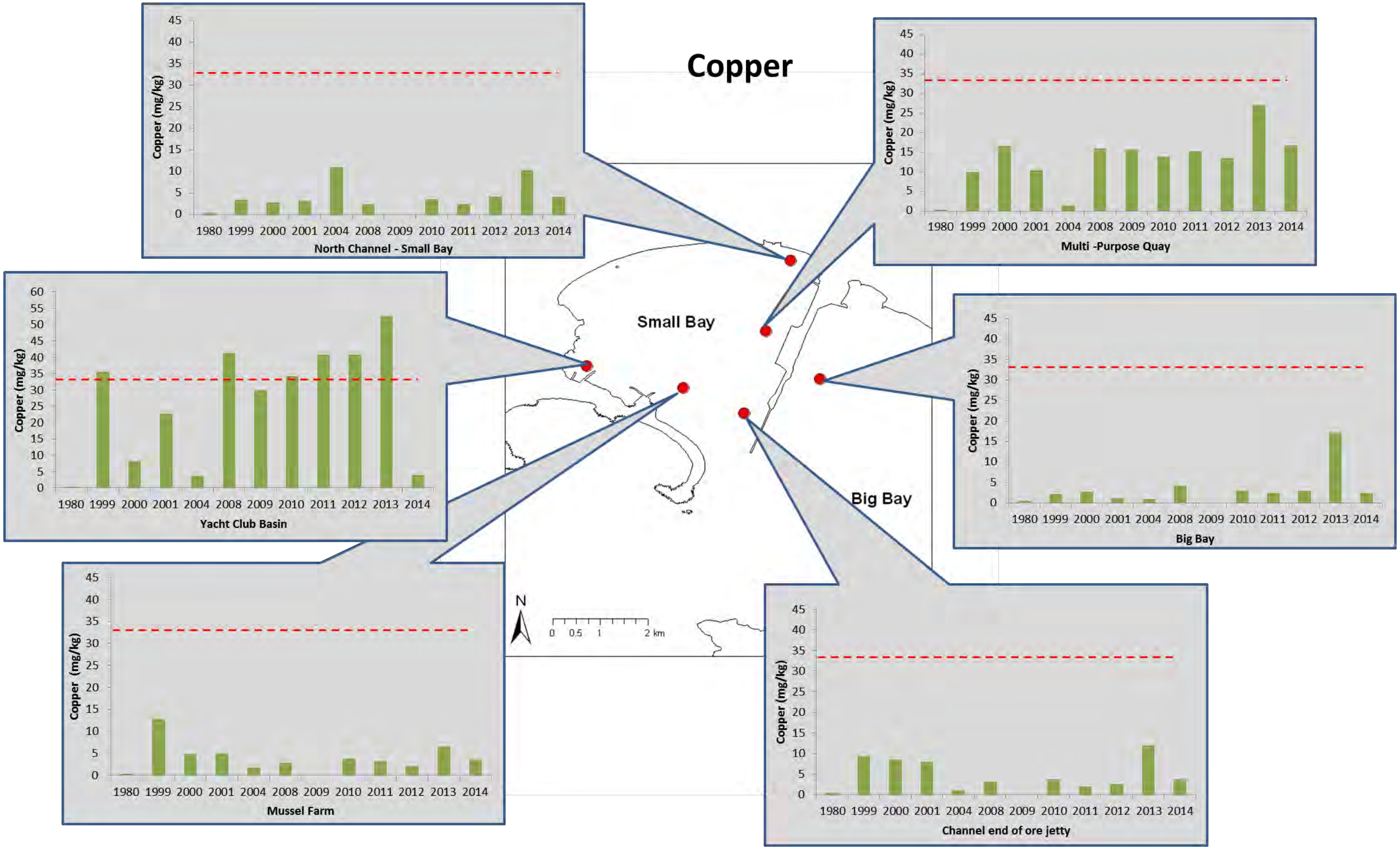


Figure 5.23. Concentrations of Copper (Cu) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2014. Dotted lines indicate Effects Range Low values for sediments.

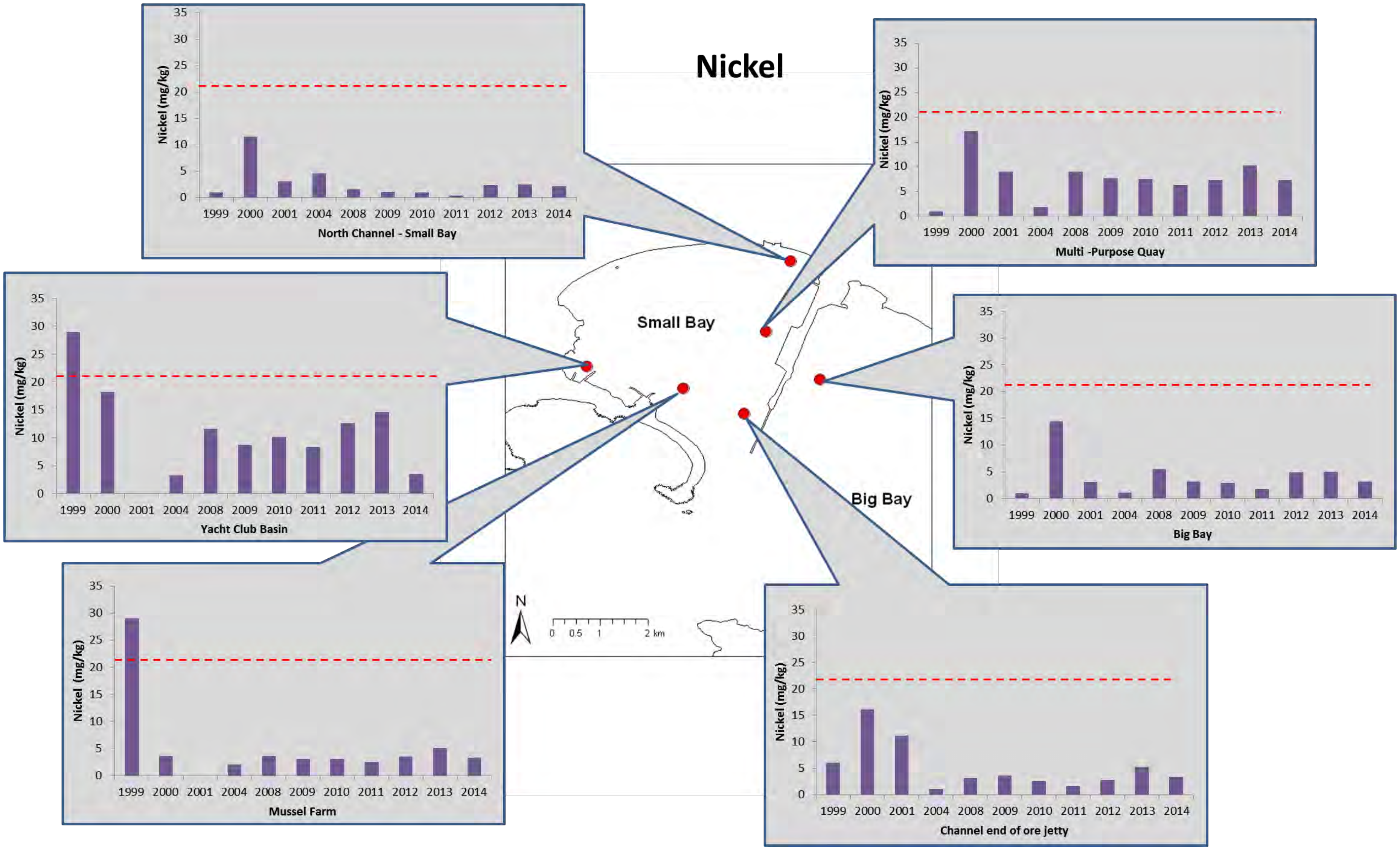


Figure 5.24. **Concentrations of Nickel (Ni) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2014. Dotted lines indicate Effects Range Low values for sediments.**

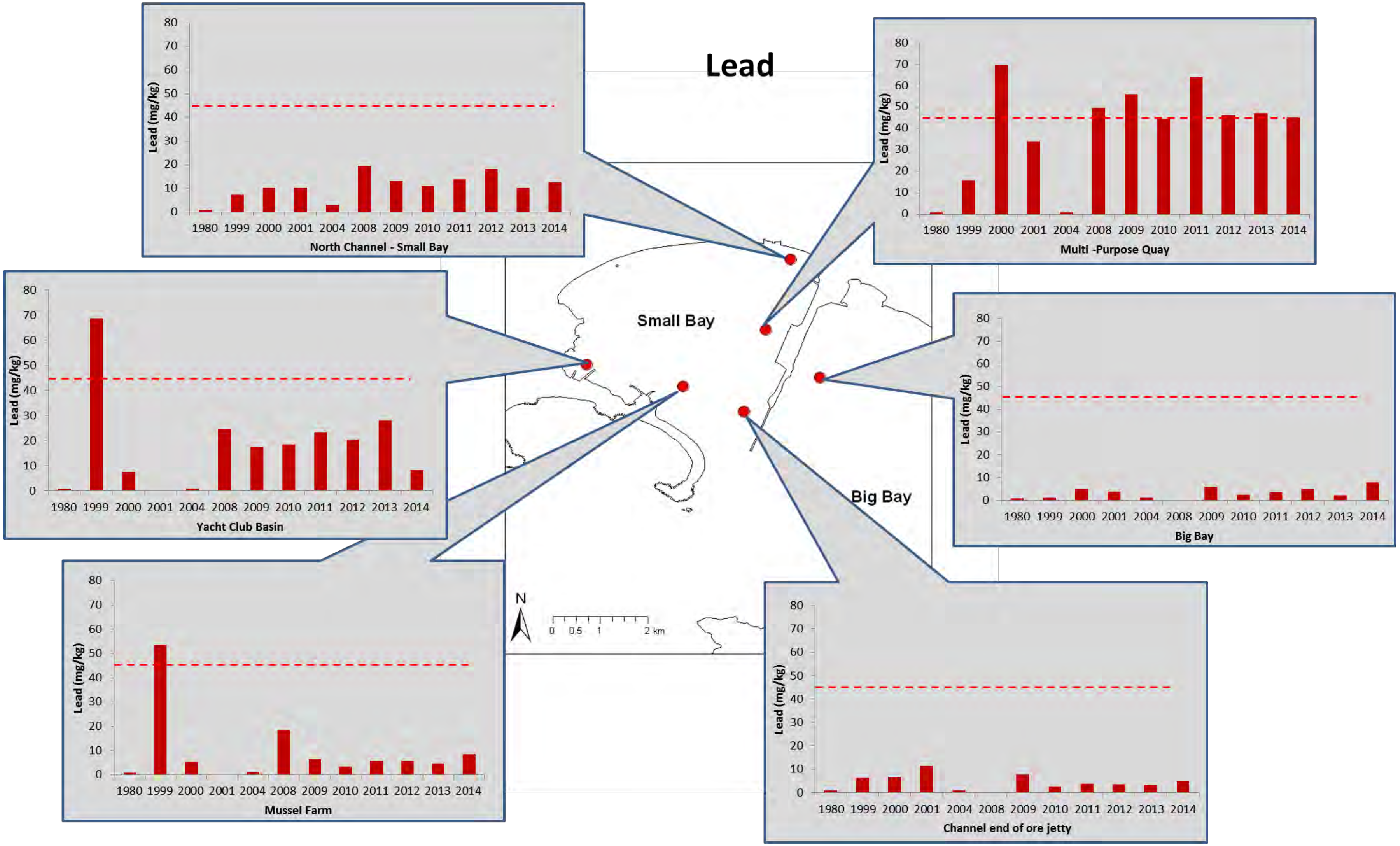


Figure 5.25. **Concentrations of Lead (Pb) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2014. Dotted lines indicate Effects Range Low values for sediments.**

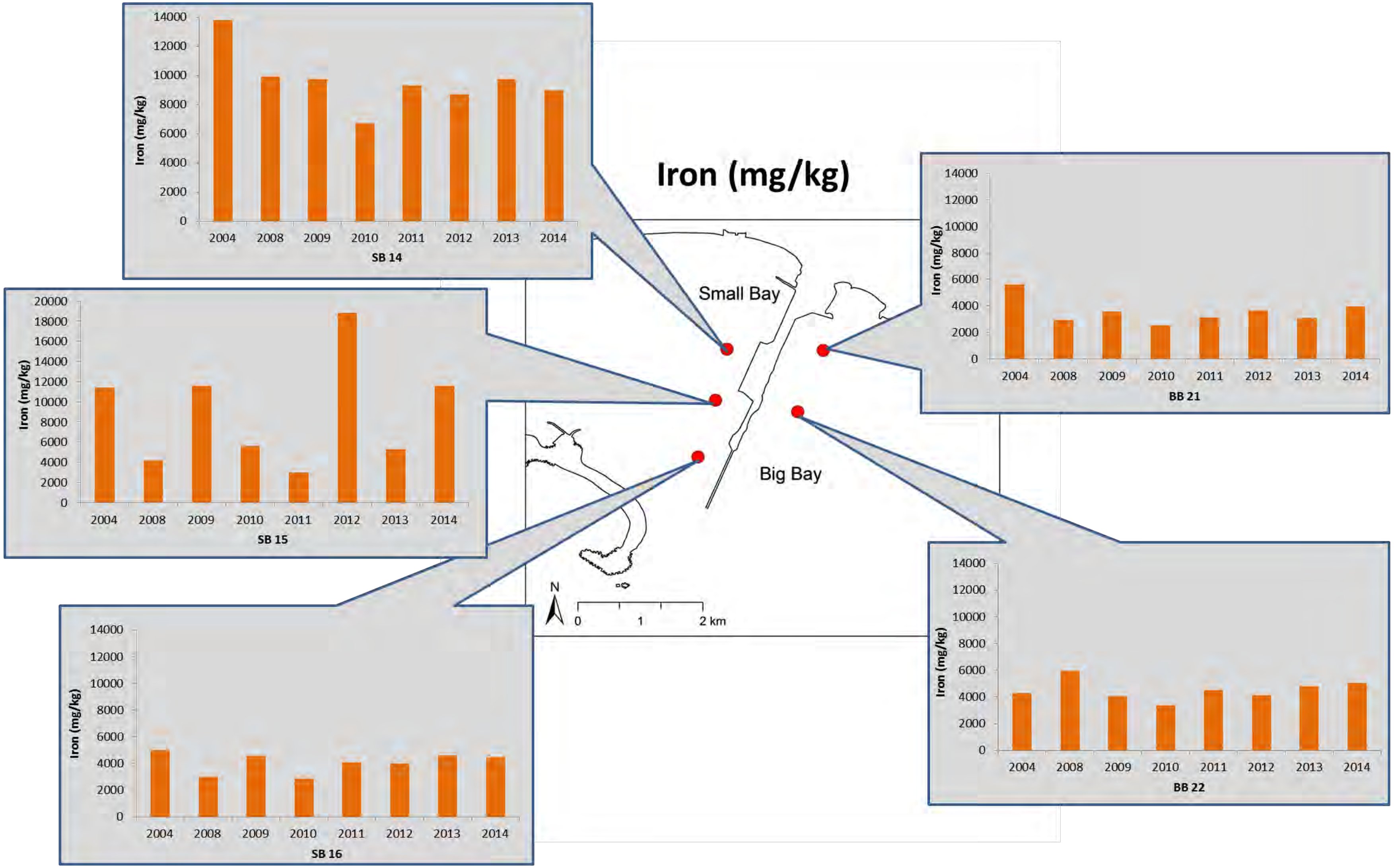


Figure 5.26. **Concentrations of Iron (FE) in mg/kg recorded at five sites in Saldanha Bay between 2004 and 2014.**

5.1.4 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).

Marine sediment samples from Saldanha Bay were analysed for the presence of hydrocarbons in 1999. 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 from five sites in the vicinity of the oil terminal in Saldanha Bay were tested for hydrocarbon contamination again in April 2010 (Table 5.8). The total petroleum hydrocarbon (TPH) contamination for all sites, with the exception of SB14, fell below the ERL guideline stipulated by the NOAA. TPH concentration at site SB14 was equal to the ERL value. These analyses were performed again in 2011 and hydrocarbon concentrations in these samples were all found to be below the detection limit of 20 mg/kg. Results from the 2012 survey, however, indicated that TPH levels had increased considerably such that measured values exceeded the ERL guideline at all five sites sampled (Table 5.9). Data from the 2013 survey indicated a further rise in TPH levels at all four sites where samples were collected (Table 5.9) and that levels at site SB14 (inside Small Bay) exceeded even the ERM (Effects Range Medium) level. This concerning finding was highlighted and it was recommended that the geographical scope of the TPH sampling campaign be increased in future surveys (i.e. extended to more stations in the Bay) in order to isolate the potential source of the contamination. Previously it was thought that the change in TPH levels might be linked to a change in the methods used to analyse the samples (note that detection limits were reduced between 2011 and 2012) but it seems that this was not the case given the sustained increase in measured TPH levels.

In light of the observed increase in TPH levels from recent surveys, the 2014 survey sought to answer two questions which have since been raised: (1) where is the source of contamination and what is the geographical extent of the contamination? (2) What kind of hydrocarbon(s) constitutes the majority of the contamination?

In order to answer the first of these two questions, the geographical extent of the TPH sampling campaign was increased to include an additional ten sites (now 15 in total) during the 2014 survey (Table 5.9). The second question was dealt with by screening the samples using a variety of tests, each of which is used to detect a specific range of hydrocarbons. It is important to note that petroleum-based hydrocarbons occupy various "carbon ranges" most of which overlap (Figure 5.27). For this reason it is impossible to identify a single petroleum-based hydrocarbon contaminant in the environment, one can only quantify the total amount which is found within a certain carbon range which would allow one to speculate what the contaminant is. For this study three carbon ranges were selected, C_6-C_{10} (mostly volatile light fuels such as commercially available gasoline or petrol), C_{10}-C_{28} (diesel fuels) and C_{28}-C_{40} (lubricants, motor oil and grease).

Table 5.8. Sediment quality guidelines and total petroleum hydrocarbons (mg/kg) in sediment samples collected over the period 2011-2014 from five stations in Saldanha Bay. Values in red indicate exceptionally high total petroleum hydrocarbon levels.

	2011	2012	2013	2014
ERL*	**4**	**4**	**4**	**4**
ERM**	**44.7**	**44.7**	**44.7**	**44.7**
SB14	<20	34	130	19
SB15	<20	35	NO DATA	53
SB16	<20	24	28	14649
BB21	<20	20	32	20
BB22	<20	17	27	<0.2

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

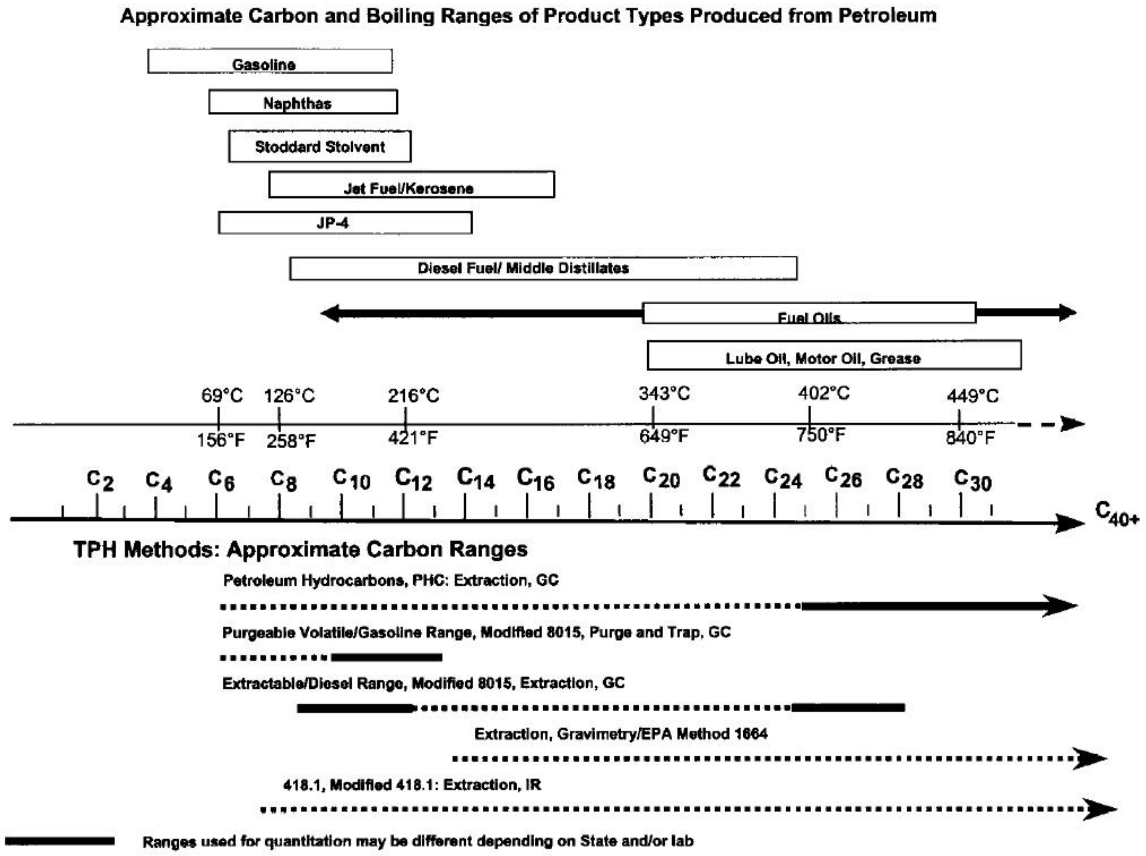


Figure 5.27. Approximate carbon ranges of petroleum-based hydrocarbons and the respective laboratory methods used to detect total petroleum hydrocarbon within each carbon range.

Results from the 2014 survey show that TPH levels at site SB14 have decreased from 130 mg/kg to 19 mg/kg. Although this has fallen below the ERM guideline, it remains above the ERL guideline and is therefore still of concern. More importantly however, is the elevation of TPH at SB15 to 53 mg/kg and the extreme elevation observed at site SB16 to 14 649 mg/kg. This is of major concern as such levels are considered to be toxic (Nikolaou *et al.* 2009). UTON closer inspection it can be seen that the majority (14 283 mg/kg) of this contamination falls within the C_{10}-C_{28} carbon range, that of diesel fuels, whilst the remainder (366 mg/kg) is within the C_{28}-C_{40} carbon range – that of lubricants, motor oil and grease (Table 5.9). The laboratory technician who analysed the samples was of the opinion that the contaminant was likely to be "very weathered diesel" (UIS Organic Laboratory, *pers. comm.*). SB14, SB15 and SB16 are all situated alongside the iron ore jetty and are in close proximity to bulk-shipping berths and associated mooring activities. The most likely explanation for the high observed TPH contamination levels is that a pollution incident associated with these shipping activities took place. Alternatively, a pollution incident or routine operational activities on the jetty itself could be the root of this contamination. This warrants further investigation and appropriate remedial action to prevent further contamination.

Table 5.9. Total petroleum hydrocarbon (TPH) sampling effort for 2014 in Saldanha Bay (SB = Small Bay, BB = Big Bay). Data presented are for the amount (mg/kg) of petroleum-based hydrocarbons within each of the three carbon ranges for which samples were analysed, C_6-C_{10} (mostly volatile light fuels such as commercially available gasoline or petrol), C_{10}-C_{28} (diesel fuels), C_{28}-C_{40} (lubricants, motor oil and grease) and the total amount of TPH. Values in red indicate exceptionally high TPH levels.

Site	C6-C10	C10-C28	C28-C40	Total
SB1	<0.2	<0.2	<0.2	<0.2
SB2	<0.2	<0.2	<0.2	<0.2
SB3	<0.2	<0.2	<0.2	<0.2
SB8	<0.2	<0.2	<0.2	<0.2
SB9	<0.2	<0.2	<0.2	<0.2
SB10	<0.2	6.7	<0.2	6.7
SB14	<0.2	19.1	<0.2	19.1
SB15	<0.2	46.7	6.4	53.1
SB16	<0.2	14283	366	14649
BB20	<0.2	<0.2	<0.2	<0.2
BB21	<0.2	20.3	<0.2	20.3
BB22	<0.2	<0.2	<0.2	<0.2
BB23	<0.2	32.4	1.5	33.9
BB26	<0.2	10	<0.2	10
BB29	<0.2	20.5	<0.2	20.5

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 & Branch 2005). 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 & Young 1970, Woodin 1976, Wynberg & Branch 1991, Siebert & Branch 2006). 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 & Branch 2005). 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 & Perez 1977, Whitfield *et al.* 1989, Hemmingra & 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 *et al.* 1989, Hemmingra & Duarte 2000, Heck *et al.* 2003, Orth *et al.* 2006, Siebert & Branch 2007). It is therefore surprising that recent research in the Langebaan Lagoon (Pillay *et al.* 2011) showed that the opposite was true when comparing sediment penetrability and species richness between habitats dominated by the sandprawn *Calianassa kraussi* and cordgrass *Spartina maritime.* Bioturbation by the sandprawn loosened the sediment, resulting in less anoxic conditions, enhanced organic content and colonisation of burrowing species. It is speculated that the sandprawn may aid in increasing food availability to higher trophic levels. 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 deterioration of water quality including coastal eutrophication, alterations to food webs caused by the overexploitation of predatory fish, modified sediment dynamics associated with coastal and harbour development (Waycott *et al.* 2009) and direct physical damage through bait collection (Pillay *et al.* 2010). Most recently, research has shown that warmer temperatures and longer exposure to air resulted in significantly lower biomass of seagrass in the Langebaan Lagoon (University of Cape Town, Cloverly Lawrence, *pers. comm.* 2014).

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). Loss of seagrass is also associated with increased fragmentation of large seagrass beds, which leads to the reduced species diversity. For example, Källén *et al.* (2012) demonstrated that large seagrass beds were home to significantly greater epifaunal richness and abundance of *Assiminea globules. A globules* is a gastropod which favours seagrass bed edges. Species composition was found to differ between the edges and the interior of seagrass beds and interestingly, it was shown that species composition converged in more fragmented seagrass beds (Källén *et al.* 2012).

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.* 2010). Most recent research in the Langebaan Lagoon shows that seagrass morphometric growth patterns are mainly controlled by temperature, followed closely by turbidity as a proxy for light levels. It was found that cooler temperatures and less tidal exposure time favoured higher seagrass biomass than warmer more exposed areas. This result could be linked to distribution patterns in the lagoon based on aerial photography (University of Cape Town, Cloverly Lawrence, *pers. comm.* 2014).

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 & 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.

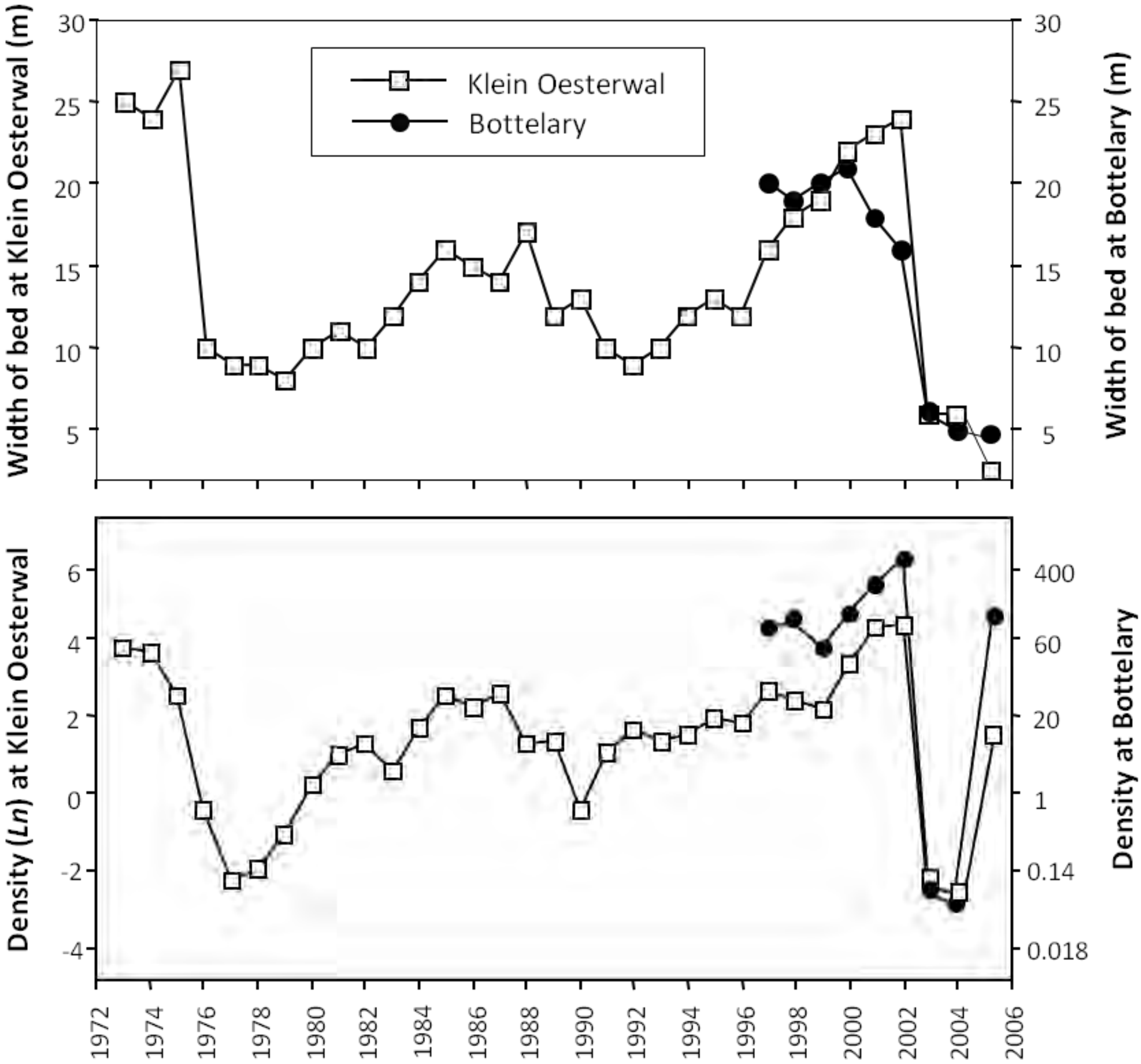


Figure 6.2. Width of the *Zostera* beds and density of *Siphonia* at Klein Oesterwal and Bottelary in Langebaan Lagoon, 1972-2006.

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, Gericke 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 (Adams *et al.* 1999).

Long term changes in salt marshes in Langebaan Lagoon were investigated by Gericke (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. Gericke (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).

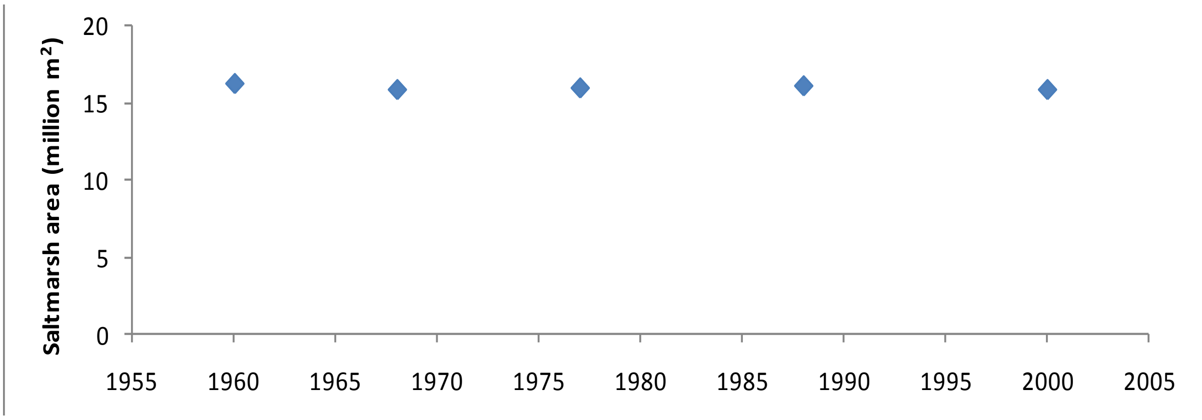


Figure 6.3. Change in saltmarsh area over time in Langebaan Lagoon. (Data from Gerricke 2008)

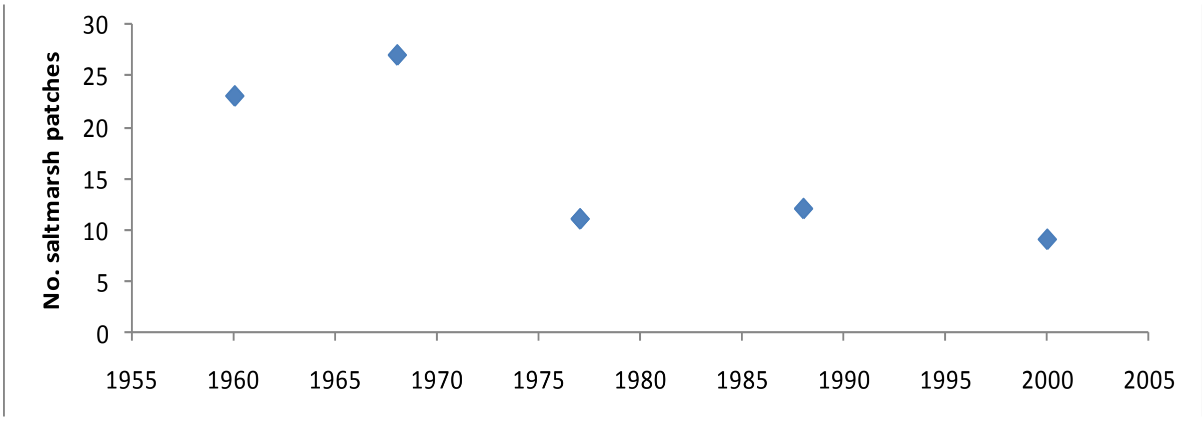


Figure 6.4. Change in the number of discrete saltmarsh patches over time in Langebaan Lagoon. (Data from Gerricke 2008).

7 BENTHIC MACROFAUNA

7.1 Background

It is important to monitor biological criteria in addition to physico-chemical and eco-toxicological 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, benthic community responses to a number of anthropogenic influences have 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 species 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 2013 and 2014, 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 Council for Scientific and Industrial Research (CSIR) in 1999 (Bickerton 1999) and Anchor Environmental Consultants in 2004 and 2008-2012 do, however, provide benthic macrofauna data from Saldanha Bay and Langebaan Lagoon that are comparable with those collected in 2013/2014. Direct comparisons to earlier studies are complicated owing to the fact that different equipment was used in the earlier surveys than those undertaken from 1999 to present. The 1975 study, for example, 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 within range of larger species such as prawns and crabs. 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 1999-2014 studies also differed (refer to Chapter 5), 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 2014

7.3.1 Sampling

A total of 28 sites were sampled for benthic macrofauna in 2013, 11 of which were in Small Bay, seven in Big Bay, nine in Langebaan Lagoon and one in Salamander Bay. Sampling effort was increased to 49 sites in 2014 with an additional five sites in Small Bay, three in Big Bay and 14 in Danger Bay. The Salamander Bay site was dropped from the survey. The water depth ranges of these sites are reported in Chapter 5 (Sediments) – the shallowest sites being those in Langebaan Lagoon. 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 2008-2012 and thus facilitate comparisons between these sets of data. Samples were stored in plastic bottles and preserved with 5% formalin.

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 2013 and 2014 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.

Community structure and composition

Changes in **benthic species composition** can be the first indicator of disturbance, 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 indication of the rate of recovery 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 benthic macrofauna abundance data. Data were root-root (fourth root) transformed and converted to a similarity matrix using the Bray-Curtis similarity coefficient. Multidimensional Scaling (MDS) plots were constructed in order to find 'natural groupings' between sites for the spatial assessment and between years for the temporal assessment. SIMPER analysis was used to identify species principally responsible for the clustering of samples. 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.

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 *Shannon-Weiner diversity index* (H') was calculated for each sampling location using PRIMER V 6:

The Shannon-Weiner diversity index (H'): $H' = -\Sigma ipi(\log pi)$ [2]

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. Alpha diversity (total number of species) was also then calculated for the three pre-designated locations for past surveys from 1999 to present: Small Bay, Big Bay and Langebaan Lagoon.

[2] 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.

7.4 Benthic macrofauna survey results: 2013 and 2014

7.4.1 Species diversity

Variations in species diversity (represented by the Shannon Weiner Index, H') for Saldanha Bay, and Langebaan Lagoon in 2013 and 2014 (including Danger Bay) are presented in Figure 7.1. Diversity was highest in Langebaan Lagoon in both 2013 and 2014, intermediate in Big Bay and Danger Bay, and lowest around the ore terminal and in Small Bay. This is most likely attributable to the higher levels of disturbance (mainly dredging) and a high proportion of fines (mud) in the sediment, which contains elevated levels of contaminants (trace metals, organic material, etc.) in the latter two areas. It is well known that high levels of disturbance associated with pollution can allow a small number opportunistic, short-lived or r-selected species to colonize the affected area and prevent a more diverse community comprising longer living k-strategist species from becoming established. The intermediate diversity recorded in Danger Bay was expected, given that Danger Bay is more exposed to wave action in comparison to Saldanha Bay and Langebaan Lagoon. This exposure results in dynamic and coarse, sandy sediments and a near complete absence of mud (for more detail refer to Chapter 5), creating a highly disturbed habitat which is unsuitable for benthic species that require more consolidated sediments (e.g. for burrow construction).

7.4.2 Community structure

Ordination plots prepared from the 2013 and 2014 macrofauna abundance data, are presented in Figure 7.2. These data show a very similar pattern as for the diversity data, with the Langebaan Lagoon and Danger Bay sites (for the 2014 survey) standing out as being clearly different to those in Big Bay and Small Bay. The sampling sites in Big Bay and Small Bay are also distinct from one another, but to a lesser extent than those in the lagoon. These differences are a function of differences in community structure (i.e. the abundance or presence/absence of different species at each site) and not just the total number of species present at a particular site. "Sensitive" species that cannot tolerate high levels of disturbance are present in abundance in the Lagoon and in moderate numbers at some of the Big Bay sites but are largely absent from sites in Small Bay and those surrounding the ore terminal. The community structure of benthic macrofauna present at Danger Bay is unique in comparison to that recorded at Small Bay, Big Bay and Langebaan Lagoon. This is directly attributable to the difference in the physical and environmental parameters present in Danger Bay (increased wave action and exposure on a sandy subtidal habitat) influencing the community structure of benthic macrofauna.

The "hardier" filter feeders such as *Upogebia capensis* were, for example, abundant in both Big Bay and Small Bay samples, but the "more sensitive" filter feeders such as the amphipods *Ampelisca spinimana* and *A. anomala*, the mollusc *Macoma odinaria* and the polychaete *Sabellides luderitzi* were notably more abundant in Big Bay, whilst the sea pen *Virgularia schultzei* was found only in Big Bay and Langebaan Lagoon. Species that contributed significanty to the dissimilarity between the Saldanha Bay and Langebaan Lagoon samples include the filter feeding amphipods *Ampelisca* sp. and the predatory whelks *Nassarius* sp. that were relatively abundant in Small Bay and Big Bay, but either rare or absent from lagoon samples. Other species such as the sand prawn *Callichirus kraussi*, the isopod *Natatolana hirtipes*, and the crown crab *Hymenosoma orbiculare* (detritivores, scavengers or predators) were more abundant in lagoon samples. The community structure of benthic macrofauna in Danger Bay was dominated by small crustaceans (mostly amphipods), polychaetes and gastropods. The absence of large crustaceans such as the mud prawn *Upogebia capensis* and associated commensal species (e.g. *Spiroplax spiralis*) and the crown crab, *Hymenosoma orbiculare*, and the abundance of a small amphipod *Urothoe coxalis* found only in Danger Bay, were the main causes of dissimilarity in community structure between Danger Bay and the Saldanha Bay and Langebaan Lagoon samples.

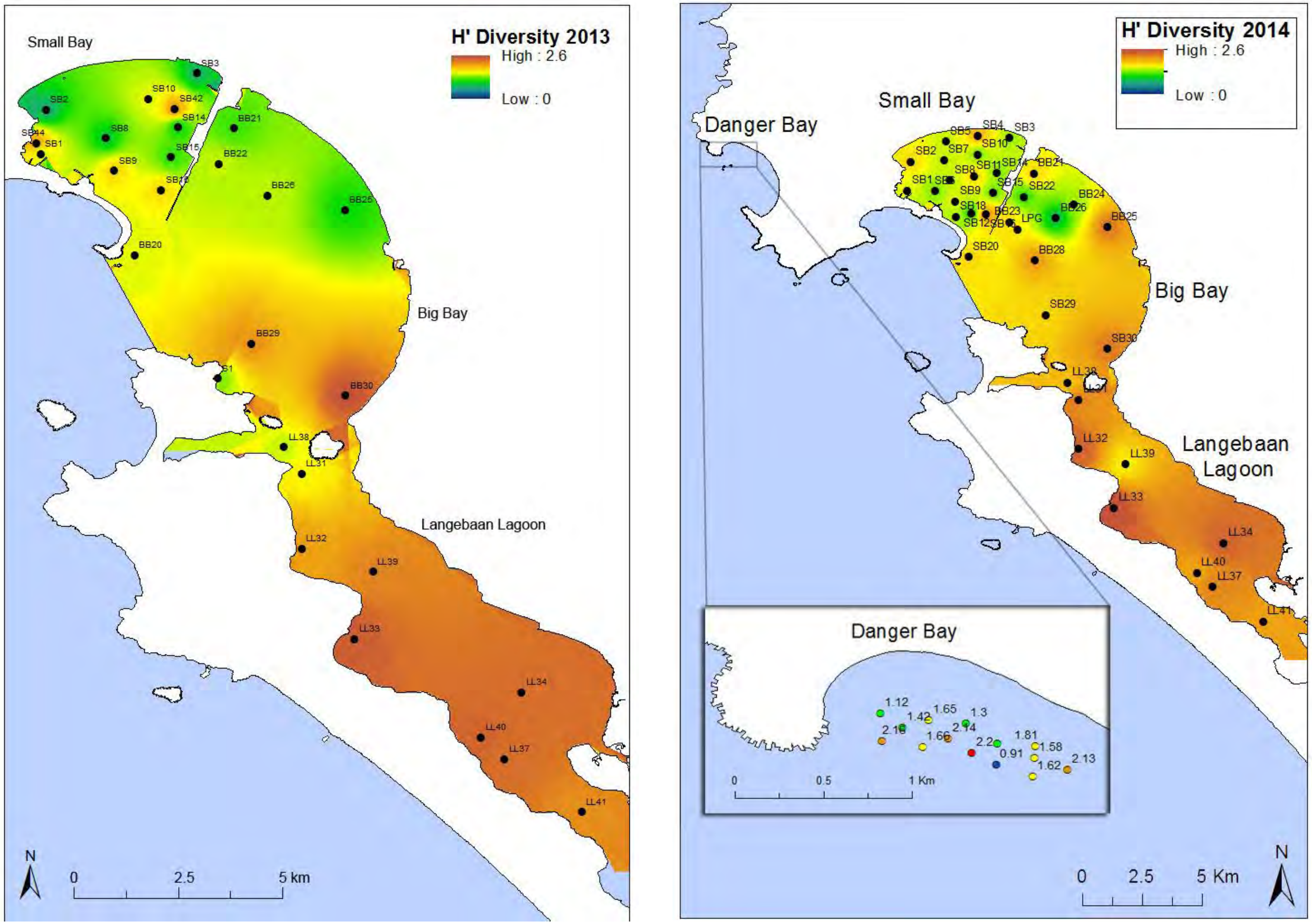
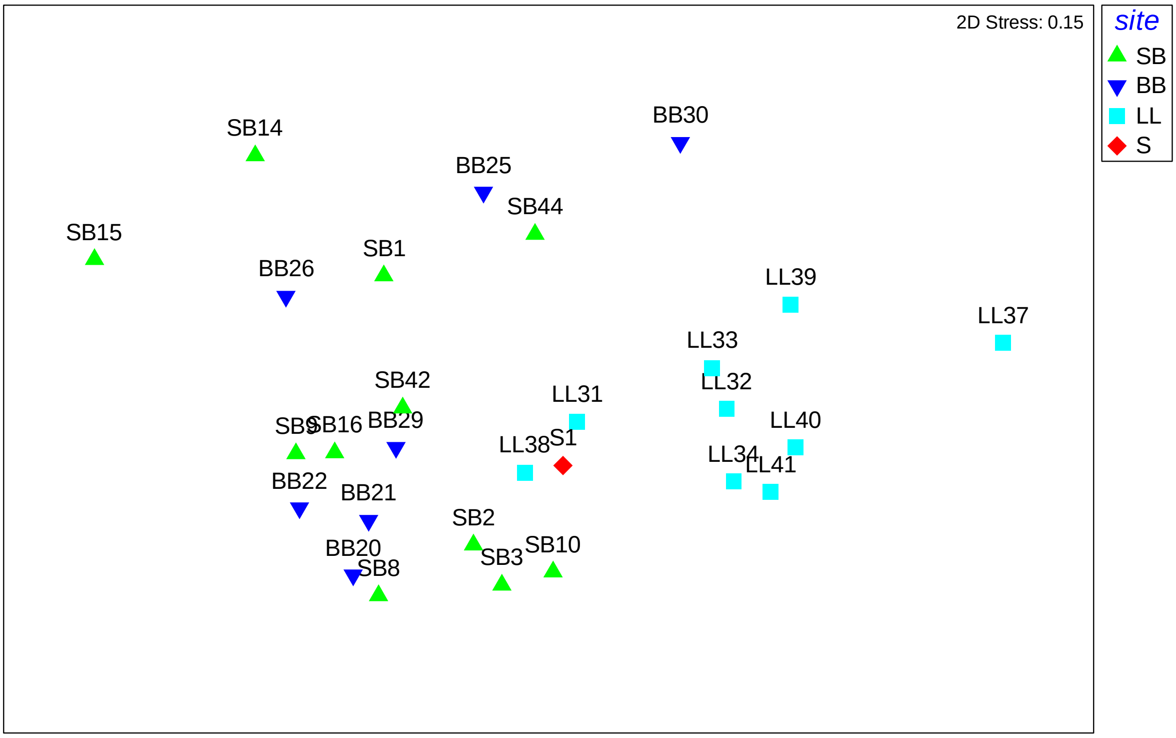


Figure 7.1 **Variation in the diversity of the benthic macrofauna in Saldanha Bay and Langebaan Lagoon as indicated by the 2013 (left) and 2014 (right) survey results. (H' = 1.5 indicates low diversity, H' = 3.5 indicates high diversity).**



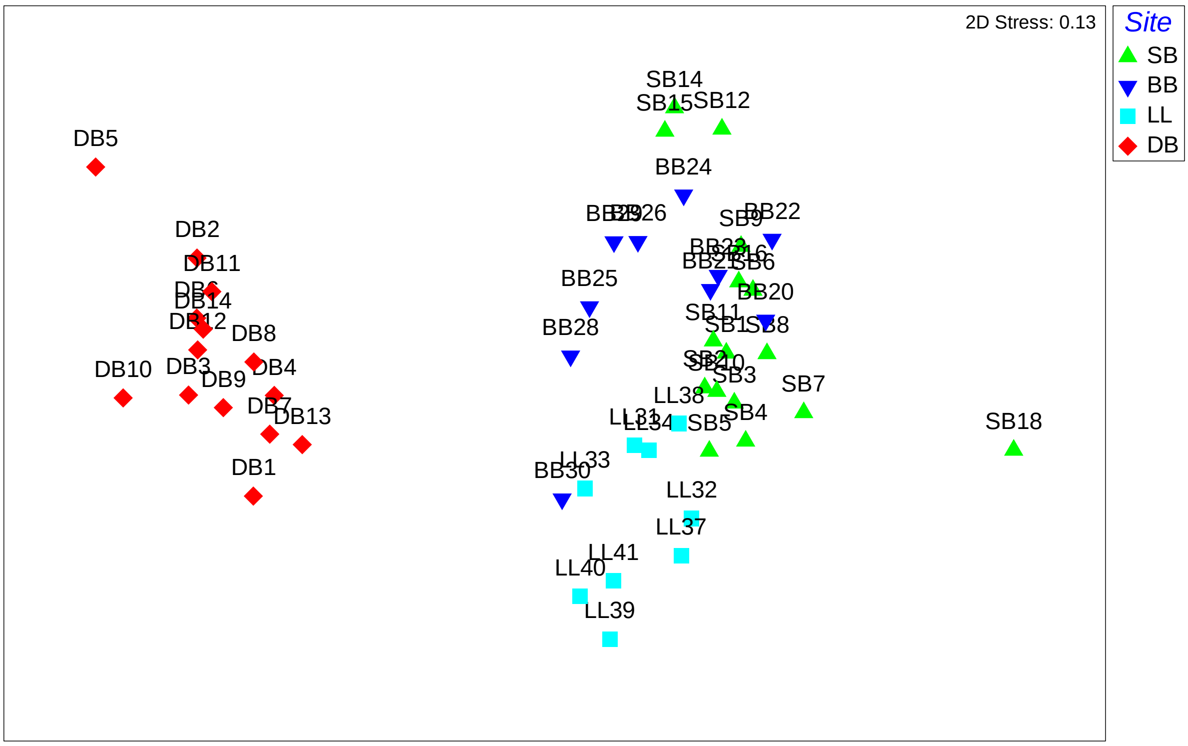


Figure 7.2. **Ordination plots showing similarity amongst sites based on benthic macrofauna abundance in 2013 (top) and 2014 (bottom). Symbols on the ordination plots are as follows: Small Bay (SB), Big Bay (BB) and Langebaan Lagoon (LL). Clusters of sites significantly similar are represented by the red dotted lines (SIMPROF).**

These differences in species composition between areas can be more easily understood at the taxonomic and functional group (essentially feeding mode) level (Figure 7.3). Crustaceans (this diverse group includes prawns, shrimps, mysids, crabs, amphipods and isopods) were the dominant taxonomic group in all areas. The next most abundant taxonomic group were polychaetes, and a relatively greater abundance of these worms were found in Langebaan Lagoon than in Small Bay and Big Bay (Figure 7.3). Filter feeders were by far the dominant functional group in Small bay and Big bay with a greater average abundance in the latter area (Figure 7.3). Detritivores were numerically the most abundant group in Langebaan Lagoon and Danger Bay, whilst predators were also more abundant in these two areas than in Small Bay and Big Bay (Figure 7.3). Average biomass of benthic macrofauna at Danger Bay sites was an order of magnitude lower that that found within Saldanha Bay and Langebaan Lagoon during 2014. This indicates that the fauna recorded in Danger Bay, despite their abundance, are mostly small, short-lived R-selected species, the total biomass of which is but a fraction in comparison to Saldanha Bay and Langebaan Lagoon.

These differences are attributable to physical habitat differences between the benthic environments found in the different areas (and many of these differences are attributable to past and present anthropogenic activities – e.g port construction, dredging, organic pollution). In contrast to sediments within Saldanha Bay, Danger Bay sediments comprised almost entirely sand (>99%) with and a extremely low mud fraction (on average 0.02%). Consequently organic matter concentrations (total organic carbon and total organic nitrogen) in these sediments were also very low. These differences are attributed to the much higher wave exposure of Danger Bay, compared to sites within Saldanha Bay and are indicative are high flushing rates as opposed to the depositional environment found in many of the deeper and more sheltered parts of Small Bay and Big Bay.

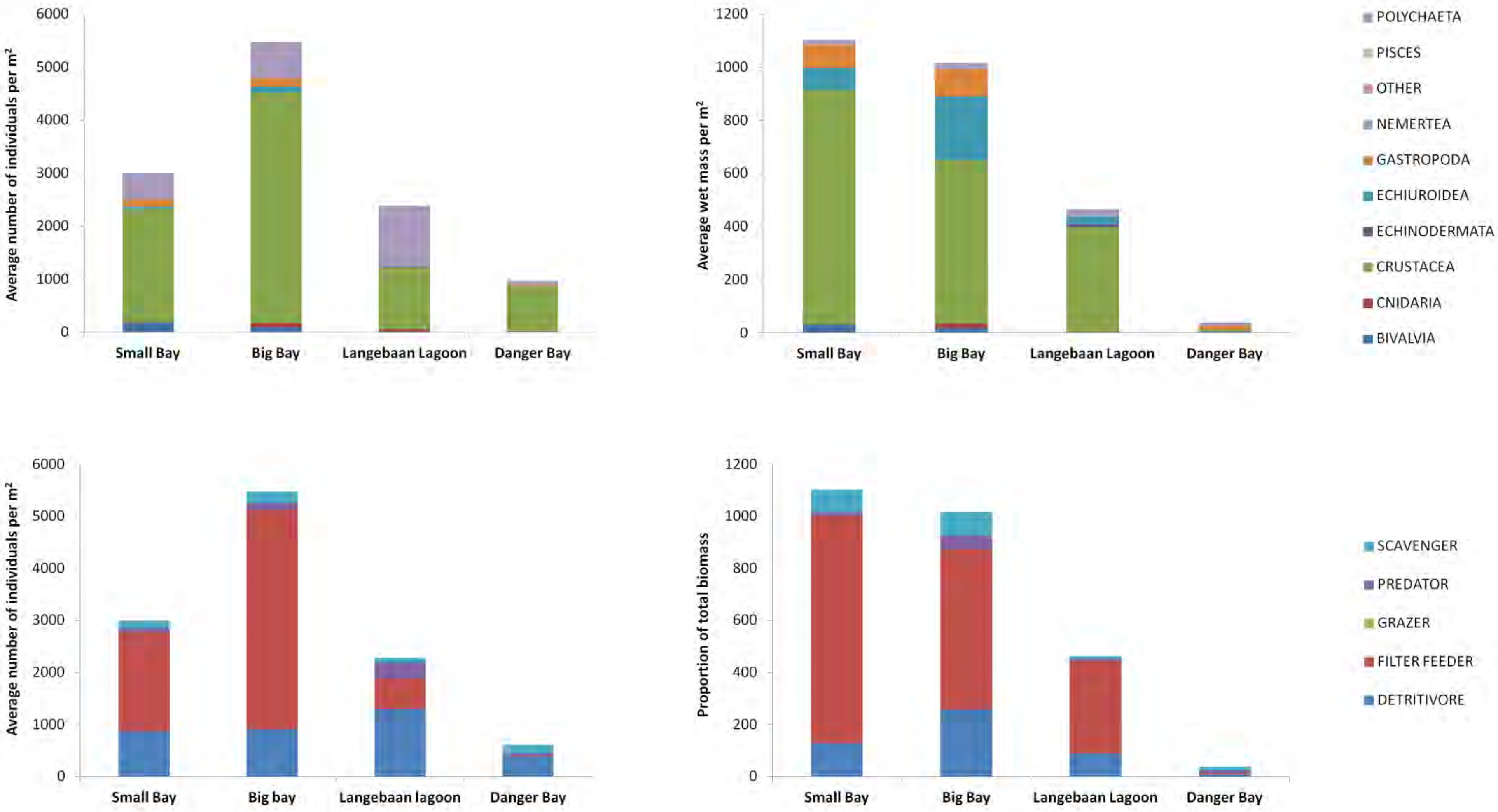


Figure 7.3 **Average abundance of benthic macrofauna by functional and taxonomic group in Big Bay, Small Bay, Langebaan Lagoon and Danger Bay in 2014.**

7.5 Changes in abundance, biomass and community structure over time

7.5.1 Species richness

Variations in the total number of macrofauna species recorded in Small Bay, Big Bay and Langebaan Lagoon during each annual survey from 1999 to 2014 is are shown in Figure 7.4. While there appears to be a slight increase in the numbers of species recorded over time, this is more likely to be related to improvements in taxonomic resolution rather than a real increase with time. In Small Bay and Big Bay species richness was lowest in 1999, 2008 and 2012, while in Langebaan Lagoon the lowest richness was recorded in 2004, 2008 and 2012 (note that no samples were collected from the Lagoon in 1999). If one considers these dates in the light of recent, major developments in the Bay, it is immediately clear that these changes may be linked to major dredging events in the Bay. Following the original construction of the original port in 1973, the most significant dredging events were implemented in 1996/7 (when 2 million m^3 of material was removed from the Small Bay side of the ore terminal for the construction of the Multipurpose Terminal), the second in 2007/2008 (when approximately 50 000 m^3 of seabed material was removed from the area of the Mossgas quay and the Multi-Purpose Terminal) and the third in 2009/2010, (when 7 300 m^3 of material was removed from the Saldanha side of the ore terminal). Species richness tends to drop (or starts off very low) immediately following these events (1999, 2008 and 2012) but tends to be higher (or even increase with time) in the intervening periods (2004, 2009-2011, 2013-2014).

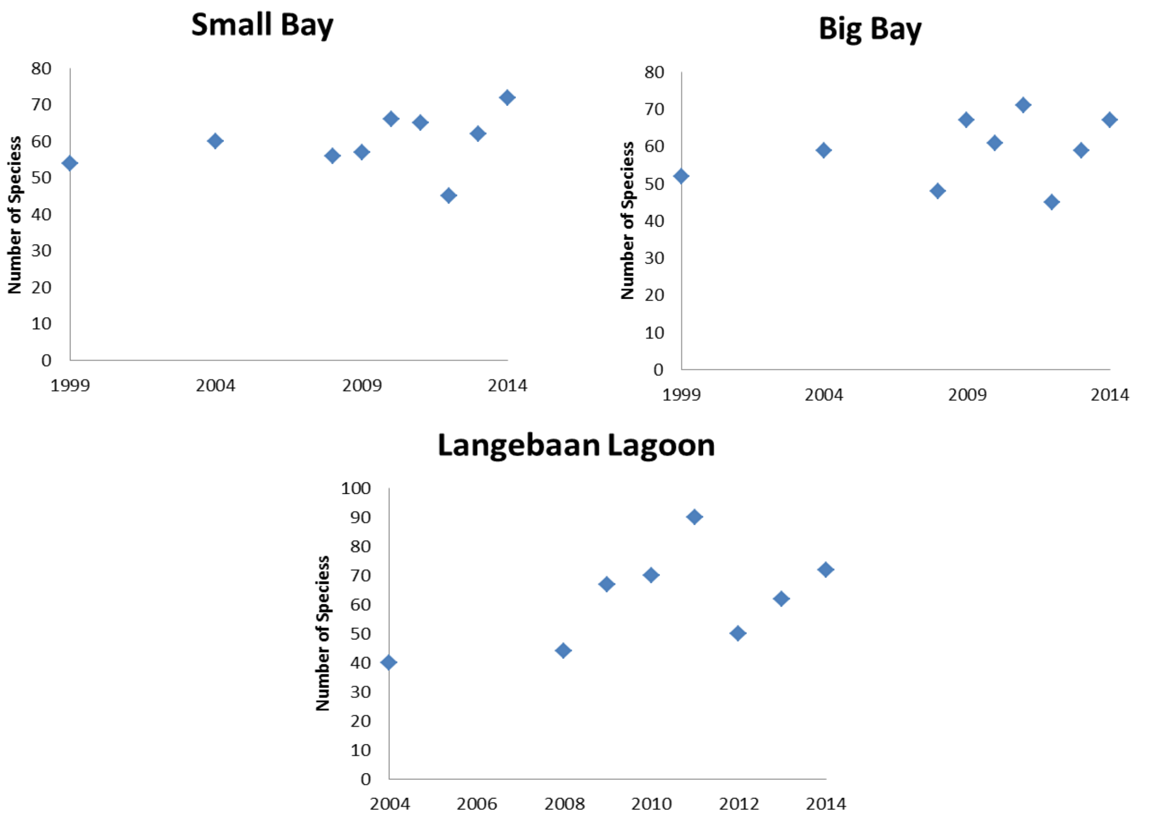


Figure 7.4. Variation in the number of species recorded at Small Bay, Big Bay and Langebaan Lagoon in the time period 1999-1014.

The low species richness in Langebaan Lagoon recorded during the 2004 sampling event may be related to an entirely different phenomenon. During the mid-1990s the 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). In early 2001, however, the mussels had started to die off and by mid-2001 only dead shells and anoxic sands remained. 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). 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). There is a high probability that the reduced macrofauna species richness in the 2004 State of the Bay samples may have been linked to a residual impact of the mussel invasion.

7.5.2 Abundance, biomass and community composition

Changes in the abundance and biomass of benthic macrofauna in Small Bay, Big Bay and Langebaan Lagoon are presented in Figure 7.5 - Figure 7.7. 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) in each year are also shown on the same graphs. In all three areas (Small Bay, Big Bay and Langebaan Lagoon), there is a suggestion that both abundance and biomass of benthic macrofauna has been increasing over time (top panels on all three figures) aside from a number of major perturbations (troughs) that are evident at the start of the monitoring period (1999, Small and Big Bay only), and 2008/2009 and 2012 (all three areas). There are some clear changes in the relative contribution of major taxonomic groups (Bivalvia, Crustacea, Gastropoda, etc.) in the periods of reduced abundance/biomass but the changes in the relative contributions by the different feeding groups is much more pronounced. The relative contribution by the group known as filter feeders (i.e. those that feed by filtering particulate matter out of the water column) dropped dramatically during these perturbations in all three areas of the Bay while the contribution by the group known as detritivores (those that feed on particulate organic matter in or on the surface of the sediment) tended to increase. Filter feeders tend to be more sensitive to levels of suspended sediment that the other feeding groups, and this certainly lends weight to the argument that these period of reduced abundance and/biomass may be linked to major dredging events that have taken place in the Bay. Filter feeders in the Bay consist mostly of the mud prawn (*Upogebia capensis*) and smaller amphipod species belonging to the genus *Ampelisca*. The Sea pen, *Virgularia schultzei,* is another important filter feeding species in the Bay. This species was reported very abundant in the period prior to port development, and was present throughout Big Bay and Small Bay. It is now completely absent from Small Bay but still present in Big Bay but only in small numbers. 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 or even dominate when conditions deteriorate.

7.5.3 Community structure

In this and previous reports, multivariate analysis has revealed clear differences in the macrofaunal communities inhabiting Small Bay, Big Bay and Langebaan Lagoon that are largely driven by physical habitat characteristics of each area (Figure 7.2). Investigation of any changes in macrofaunal communities over time, however, is useful as an ecosystem health monitoring tool as community scale perturbations outside of natural variability can indicate anthropogenic impacts on habitat quality. In order to do this without the confounding effects of the documented spatial structure, multivariate analysis of macrofaunal samples collected in all years since 2004 was undertaken separately for Small Bay, Big Bay and Langebaan Lagoon

7.6 Small Bay

The Small Bay ordination plot (that groups samples with similar macrobenthic communities close together and separates dissimilar samples), shows clear separation of all samples collected during 2008 from samples collected in all other years (Figure 7.8). Overall abundance in Small Bay was not notably low in 2008, but the macrobenthic community was different in that there were a high abundance of detritivores such as the shrimp *Betaeus jucundus*, the polychaetes *Mediomastus capensis* and *Maldanidae* sp., and crustaceans of the Family Cumacea that were not common in samples collected during other years. Conversely detritivorous crustaceans such *Spiroplax spiralis,* polychaetes *Polydora* sp. and *Orbinia angrapequensis*, the sea cucumber *Ochetostoma capense,* predatory whelks of the genus *Nassarius* and filter feeding amphipods *Ampelisca* sp. and the mud prawn *Upogebia capensis*, were common in samples collected in other years, but rare or absent in 2008 samples.

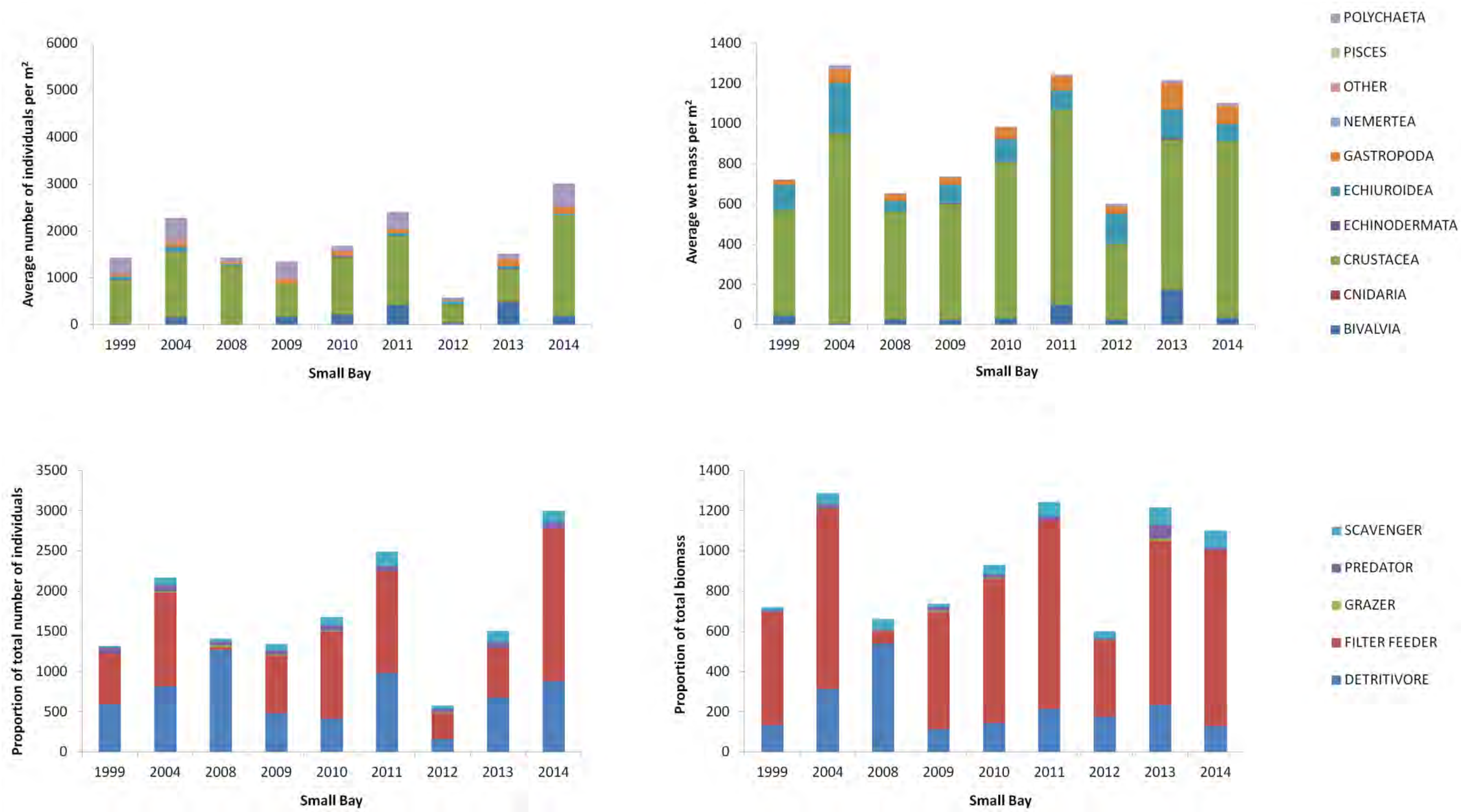


Figure 7.5. Overall trends in the abundance and biomass (g/m²) of benthic macrofauna in Small Bay as shown by taxonomic and functional groups.

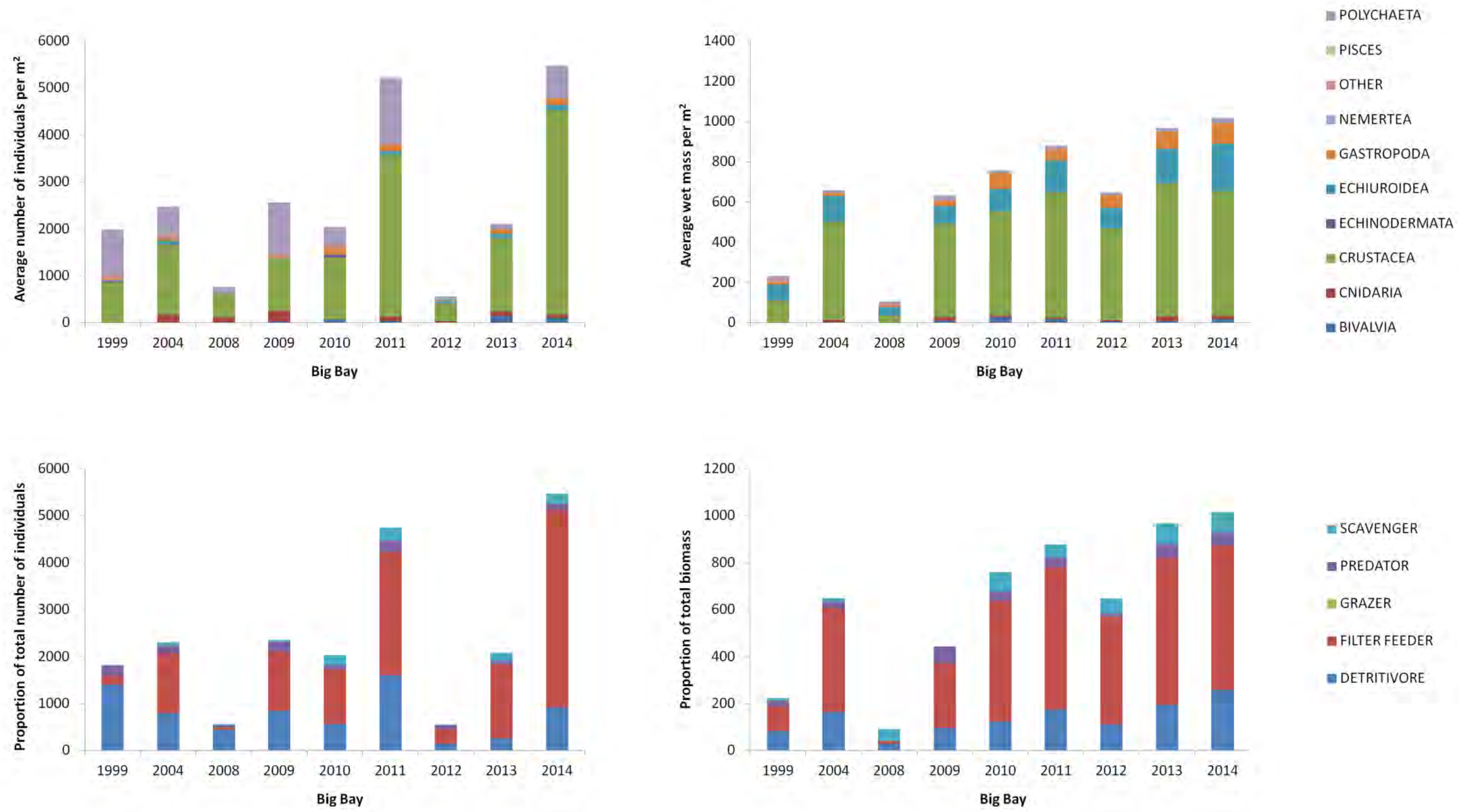


Figure 7.6. **Overall trends in the biomass and abundance (g/m^2) of benthic macrofauna in Big Bay as shown by taxonomic and functional groups.**

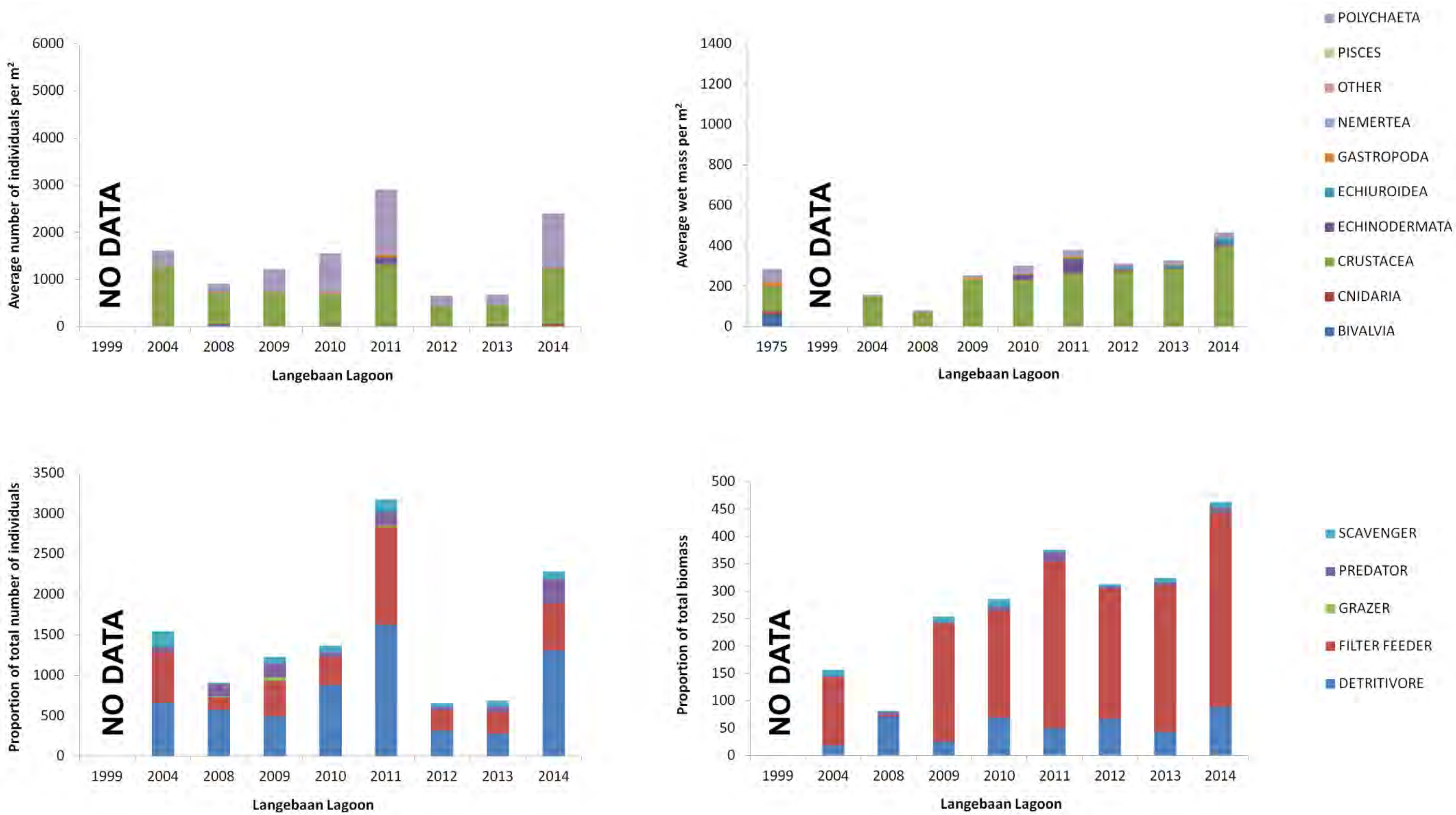


Figure 7.7. Overall trends in the biomass (g/m^2) and abundance of benthic macrofauna in Langebaan Lagoon as shown by taxonomic and functional groups.

7.7 Big Bay

The 2008 Big Bay macrobenthos samples were also separate from all other years on the ordination plot indicting that they were dissimilar (Figure 7.8). Species primarily responsible for the dissimilarity of 2008 samples from all other years include very low abundance or absence of detritivores*, Orbinia angrapequensis and Ochetostoma capense*, filter feeders such as *Upogebia capensis, Ampelisca* sp. and *Virgularia schultzei* and predators such as *Nassarius* sp. whelks in 2008 samples. The same resilient species that were abundant in Small Bay 2008 samples also dominated the macrofauna in Big Bay, e.g. *Betaeus jucundus*, *Mediomastus capensis* and *Platynereis australis*.

7.8 Langebaan Lagoon

The 2008 samples were also outliers in the Langebaan Lagoon ordination plot (Figure 7.8). Low abundance or absence of filter feeding mud prawns *Upogebia capensis*, the polychaete *Notomastus latericeus* and the isopod *Natatolana hirtipes*; and high abundance of *Betaeus jucundus* and the polychaetes *Marphysa sanguine* and *Eteone foliosa* in 2008 samples were the species consistently responsible for the dissimilarity of 2008 Lagoon samples from those collected in other years

As mentioned above, these changes in macrobenthic community structure in are thought to be related to the extensive dredging activities undertaken during 2007 and early 2008 that appeared to have had Bay-wide impacts, with a temporary loss of species that are less tolerant and the community composition shifting to a dominance of more tolerant species. Multivariate analysis of the macrobenthic samples collected over the period 2009-2014 suggests that the smaller 2009 dredging event had a limited impact with little change in macrobenthic community structure over the last five years.

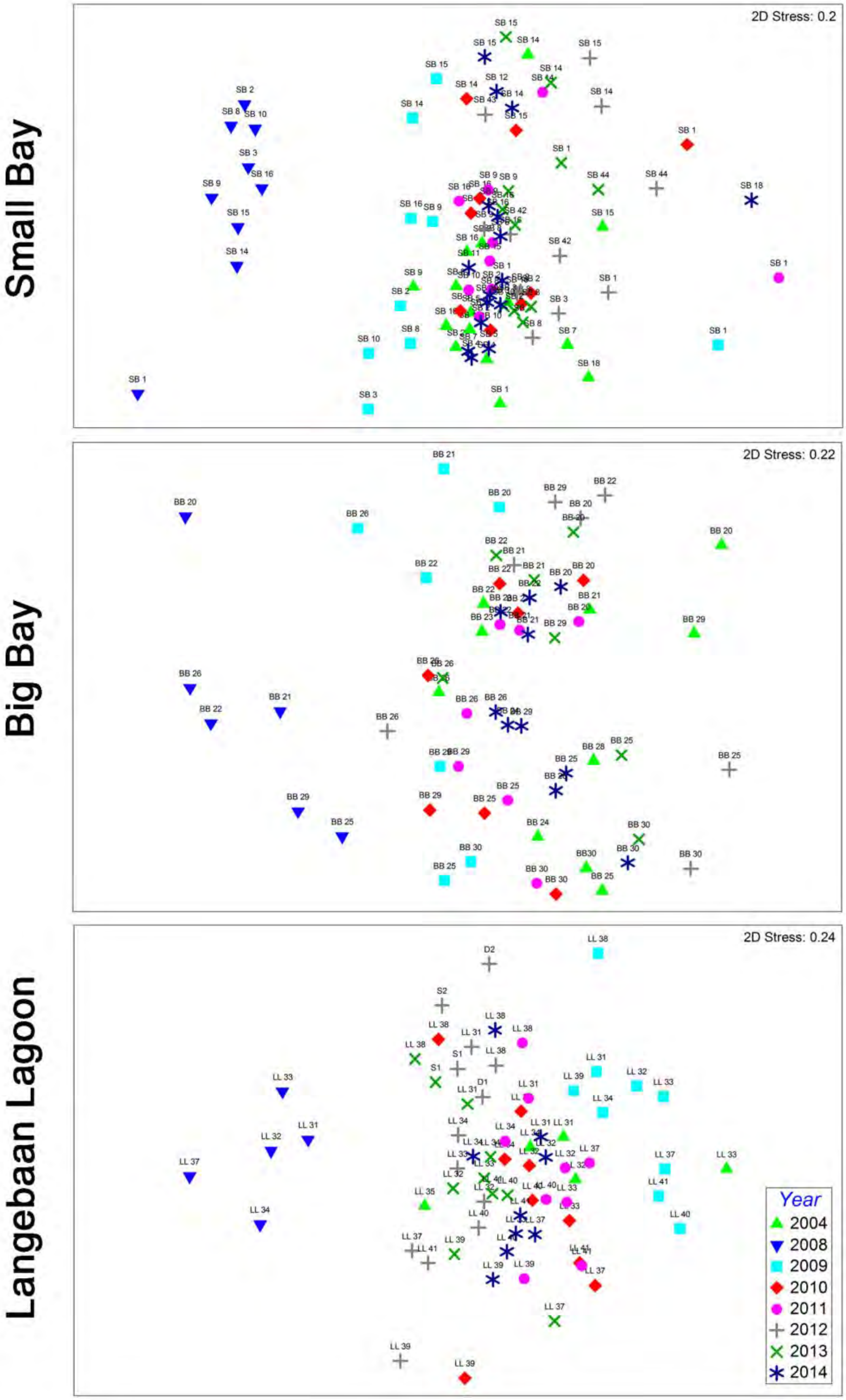


Figure 7.8. **MDS plots showing differences in community structure amongst macrofauna assemblages in Small Bay (top), Big Bay (middle) and Langebaan Lagoon (bottom) in the period 2004-2014.**

7.9 Summary of benthic macrofauna findings

Macrobenthic community structure within Saldanha Bay has been the subject of several studies in the past, most of which focus on anthropogenic impacts to benthic health. These earlier studies showed very clearly that there was a substantial change in benthic communities before and after harbour development in the early 1970s. At this time, approximately 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). Severe declines in a number of species were reported, along with a change in the relative abundance of different trophic (feeding) groups, with a reduction in the number of suspension feeders in particular and an increase in the numbers of opportunistic scavengers and predators (Moldan 1978, Kruger *et al.* 2005). 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). Dredging reportedly directly impacts benthic community structure in a variety of ways: 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). 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).

Methods for collecting macrofauna samples for the State of the Bay surveys, which commenced in 1999, are unfortunately very different to those that were employed for the earlier surveys, and thus data from these studies cannot be compared directly. Analysis of the data from these studies as reported in this chapter is thus focussed on changes that have occurred in this latter period only. Variations in species richness, abundance biomass, and community composition and community structure all show very similar patterns over this period. Starting off at modest levels in 1999, both abundance and biomass rose to fairly high levels in Small Bay and Big 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 (Langebaan Lagoon included) increased steadily year-on-year until 2011, before dropping dramatically again in 2012, and finally rising again in 2013 and 2014 (the latest survey). These changes in abundance and biomass were, to a large extent, driven by the loss of filter feeding species during period of low abundance (1999, 2008 and 2012). Filter feeding species are thought to be highly sensitive to changes in water quality (more so than detritivores or scavengers) and it is thought that reductions in abundance and biomass of these species may also be linked to a sequence of dredging events that have occurred in recent years (1996/, 2007/2008 and 2009/2010).

Other more localised factors are also clearly important in structuring benthic macrofauna communities in the Bay and the Lagoon (see previous versions of the State of the Bay Report – Anchor Environmental 2010, 2011, 2012) for more details on this. For example, reduced water circulation patterns in parts of Small Bay (e.g. near the Small Craft Harbour) and localised discharges of effluent from fish processing establishment in this area, contribute to the accumulation of fine sediment, organic material and trace metals, and results in macrofauna communities in this area being highly impoverished. Similarly, the impacts of dredging required for the expansion and refurbishment of the Salamander Bay boatyard at the entrance of the lagoon in 2010 had a very clear impact on macrofaunal communities in this area (Anchor Environmental 2012, 2013). Invasion of Langebaan Lagoon by the European mussel *Mytilus galloprovincialis* also had a major impact on the fauna in the affected areas of the Lagoon (Hanekom and Nel 2002, Robinson and Griffiths 2002, Robinson *et al.* 2007b) and presumably on the results of the earliest 2004 State of the Bay survey as well.

Overall, increases in abundance, biomass and diversity of macrofauna across all parts of the Bay (Small Bay, Big Bay and Langebaan Lagoon) over the last two years (2013 and 2014) is a very positive sign and points to an overall increase in the health of the Bay. The benthic macrofauna samples collected for the first time in Danger Bay during 2014 as the start of a baseline monitoring programme revealed a distinct community attributable to physical habitat differences between this open coast bay and the more sheltered Saldanha Bay and Langebaan Lagoon habitats. The Danger Bay macrofaunal community is dominated by crustaceans that are largely free living forms (as opposed to burrow forming animals) adapted to the dynamic, coarse sediments present at this site. The physical habitat and associated macrobenthic biota are indicative of an exposed, dynamic environment (suggesting high flushing rates), however, discharge of organically and chemically enriched effluent from the proposed regional marine outfall is still expected to have a discernable impact on macrobenthic communities within a zone of impact. Ongoing collection of comprehensive baseline data on macrobenthic communities in Danger Bay to capture the natural variability is essential for objective and quantitative assessment of expected impacts.

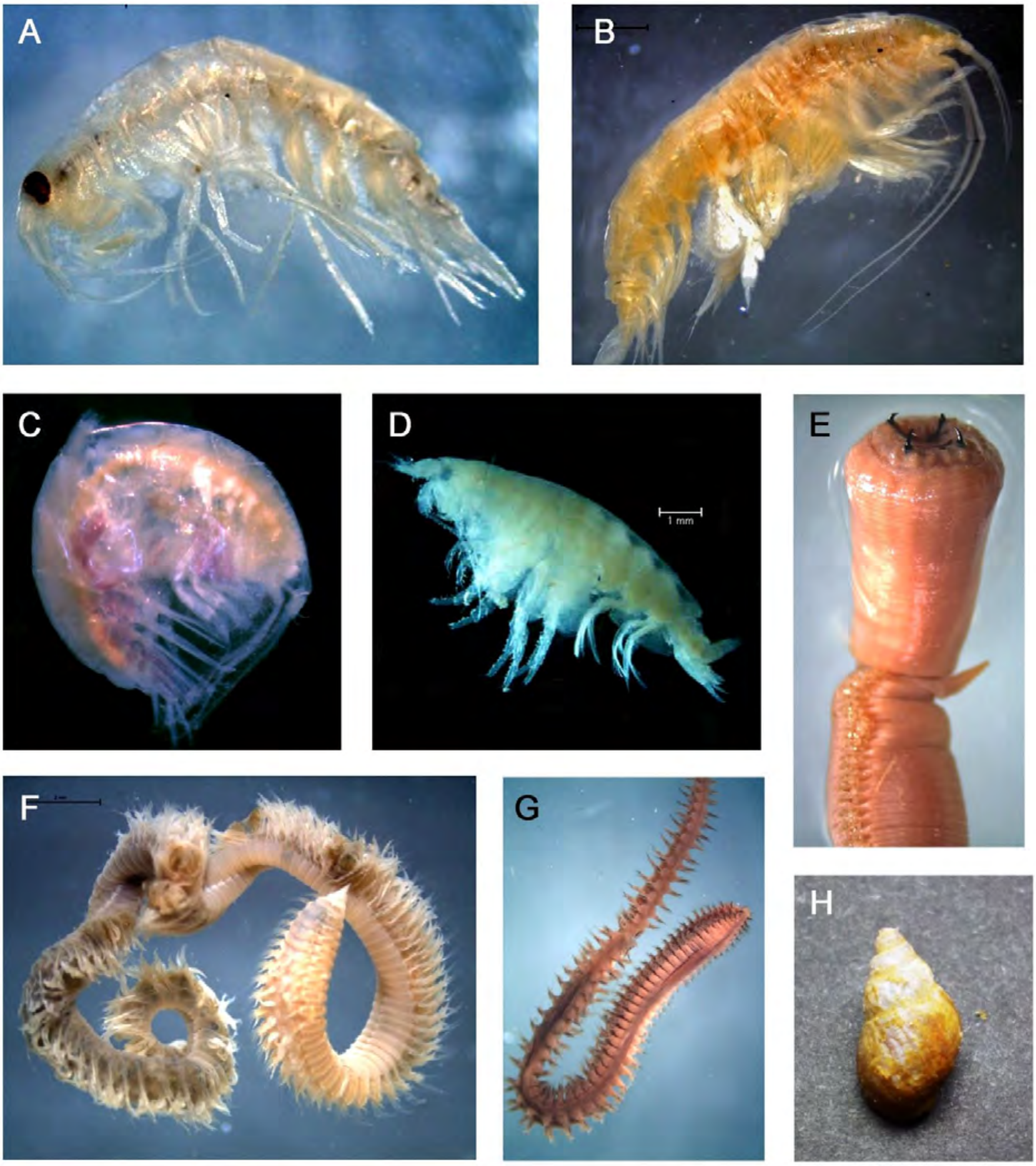


Figure 7.9. **Benthic macrofauna species frequently found to occur in Saldanha Bay and Langebaan Lagoon, photographs by: Nina Steffani and Aiden Biccard. A – *Paramoera capensis*, B – *Ampelisca brevicornis*, C – *Ampelisca palmata*, D – *Hippomedon normalis*, E – *Glycera tridactyla*, F – *Orbina angrapequensis*, G – *Nephtys hombergii,* H – *Nassarius vinctus*.**

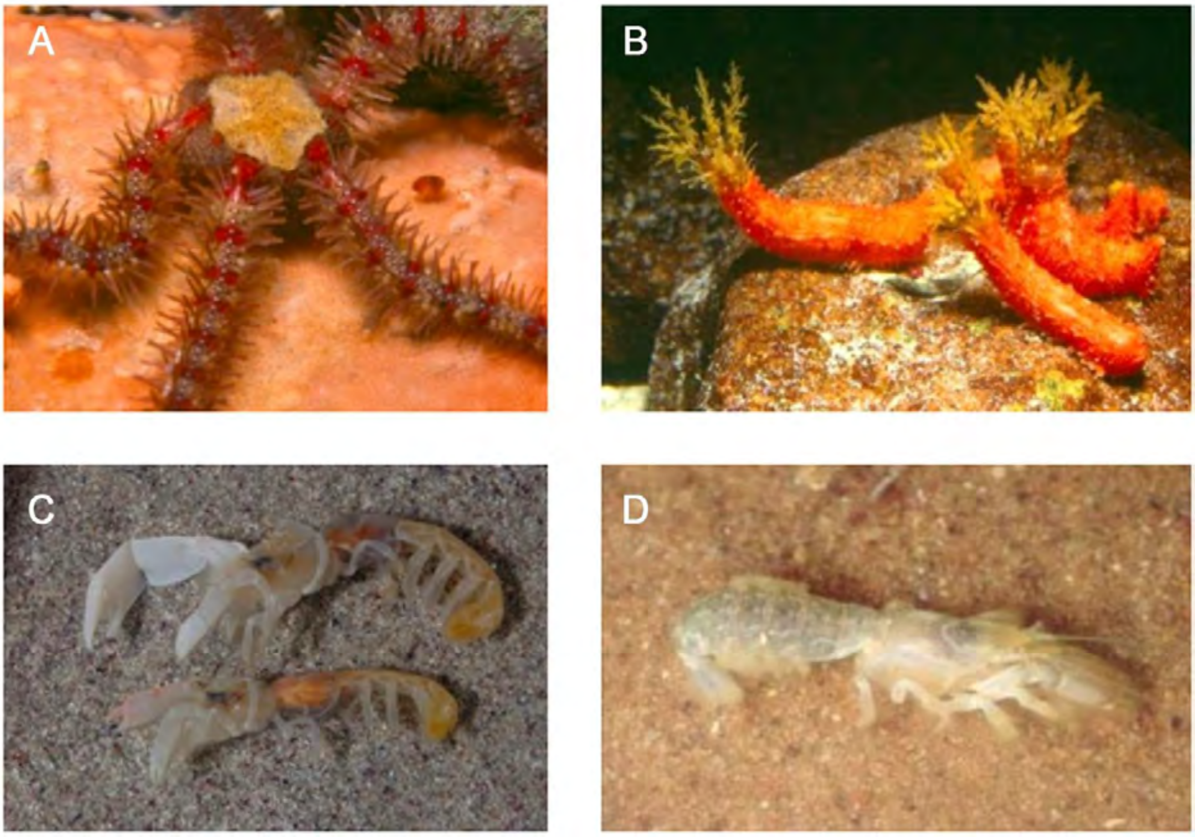


Figure 7.10. Benthic macrofauna species frequently found to occur in Saldanha Bay and Langebaan Lagoon, photographs by: Charles Griffiths. A – Ophiuroidea, B - *Pseudonella insolens*, C - *Callichirus kraussi* , D – *Upogebia capensis*.

8 ROCKY INTERTIDAL INVERTEBRATES

8.1 Background

Little historical data exists on the state of the rocky-shore habitats within the Saldanha Bay system. Species presence/absence data was collected by undergraduate students of the University of Cape Town at Lynch Point and Schaapen Island between 1965 and 1974 (University of Cape Town, Prof. C. Griffith, *pers. comm.*); however, the accuracy and reliability of these data is questionable, thus it is of limited value for monitoring changes in the health of the Saldanha Bay ecosystem. Historical studies by Simons (1977) and Schils *et al.* (2001) reported on the algal species assemblages, while Robinson *et al.* (2007b) examined the species composition of rocky intertidal communities in Saldanha Bay. The latter 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 Saldanha 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 Saldanha Bay and Langebaan Lagoon. 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 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 annually since 2008 (Anchor Environmental Consultants 2009, 2010, 2011, 2012b, 2013b). The baseline survey report concluded that wave exposure is the primary physical driver shaping the intertidal rocky shore communities across the study area. 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, and led to a change in community structure. The lack of historical data from these shores precludes confirmation of this hypothesis. The results further indicated that the topography and substratum type of the shore influences community structure as, for example, 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 but the presence of four alien invasive species, the Mediterranean mussel *Mytilus galloprovincialis*, and the three barnacles *Balanus glandula*, *Menesiniella regalis* and *Amphibalanus amphitrite amphitrite* were noted. This chapter presents results from the seventh and eighth annual monitoring surveys conducted in April 2013 and April 2014 respectively.

8.2 Approach and methodology

8.2.1 Study sites

The location of the eight rocky shore sampling sites is shown in Figure 8.1. The Dive School and Jetty sites are situated along the northern shore in Small Bay. The Marcus Island, Iron Ore Jetty and Lynch Point sites are in Big Bay, while the Schaapen Island East and West sites are located at the entrance to Langebaan Lagoon. The North Bay site 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 were specifically chosen to cover the different rocky shore habitats found in the Saldanha Bay system incorporating the full range 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. A&B). Schaapen Island East (SE) is situated in a little baylet and is relatively sheltered and mostly flattish with some rougher rock sections (Figure 8.2. C). Schaapen Island West (SW) is more exposed and mostly flat with some elevated topography (Figure 8.2. D).

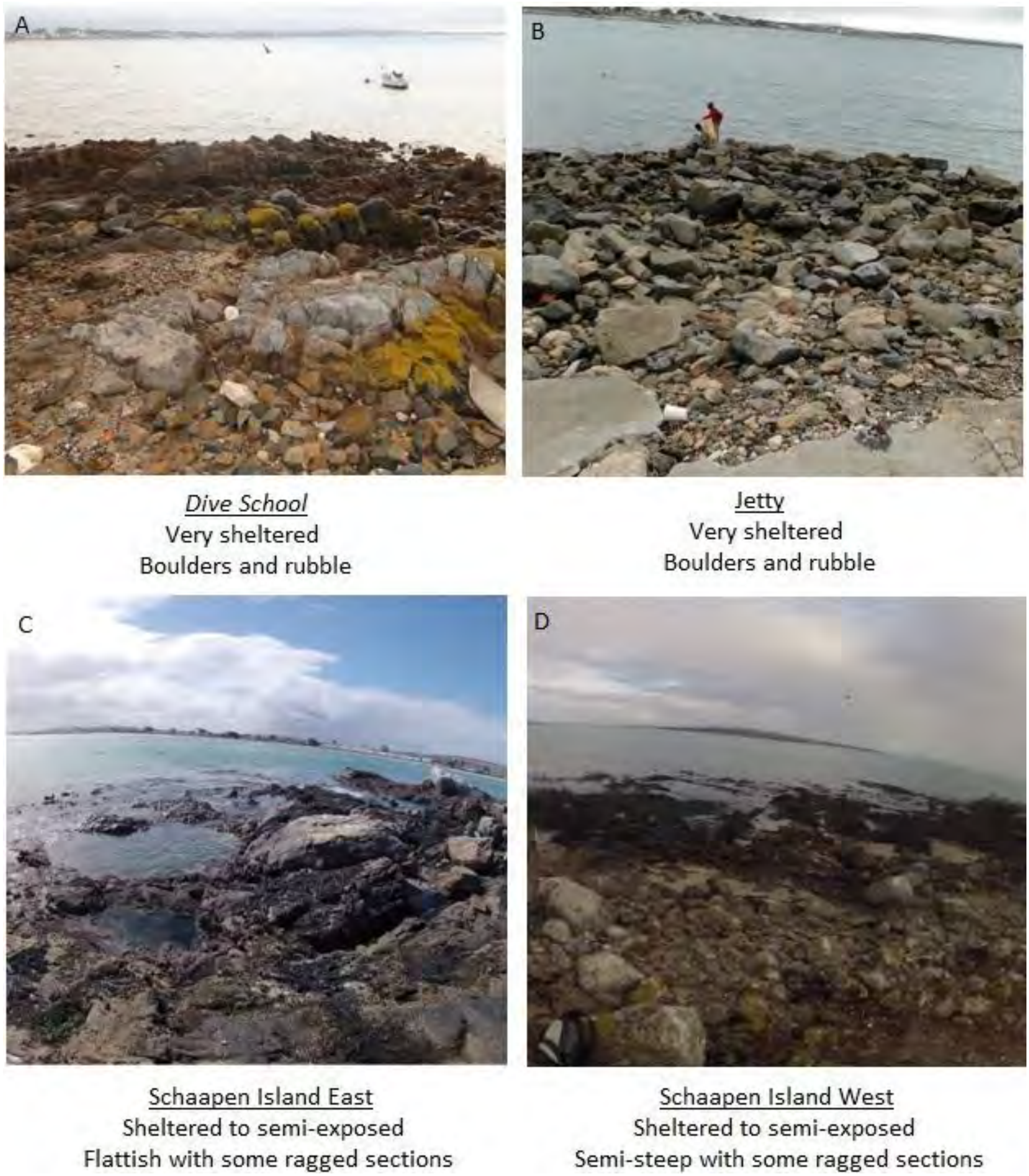


Figure 8.2. Rocky shore study sites in Saldanha Bay: A) Dive School, B) Jetty, C) Schaapen Island East, and D) Schaapen Island West (Photographs: Nina Steffani).

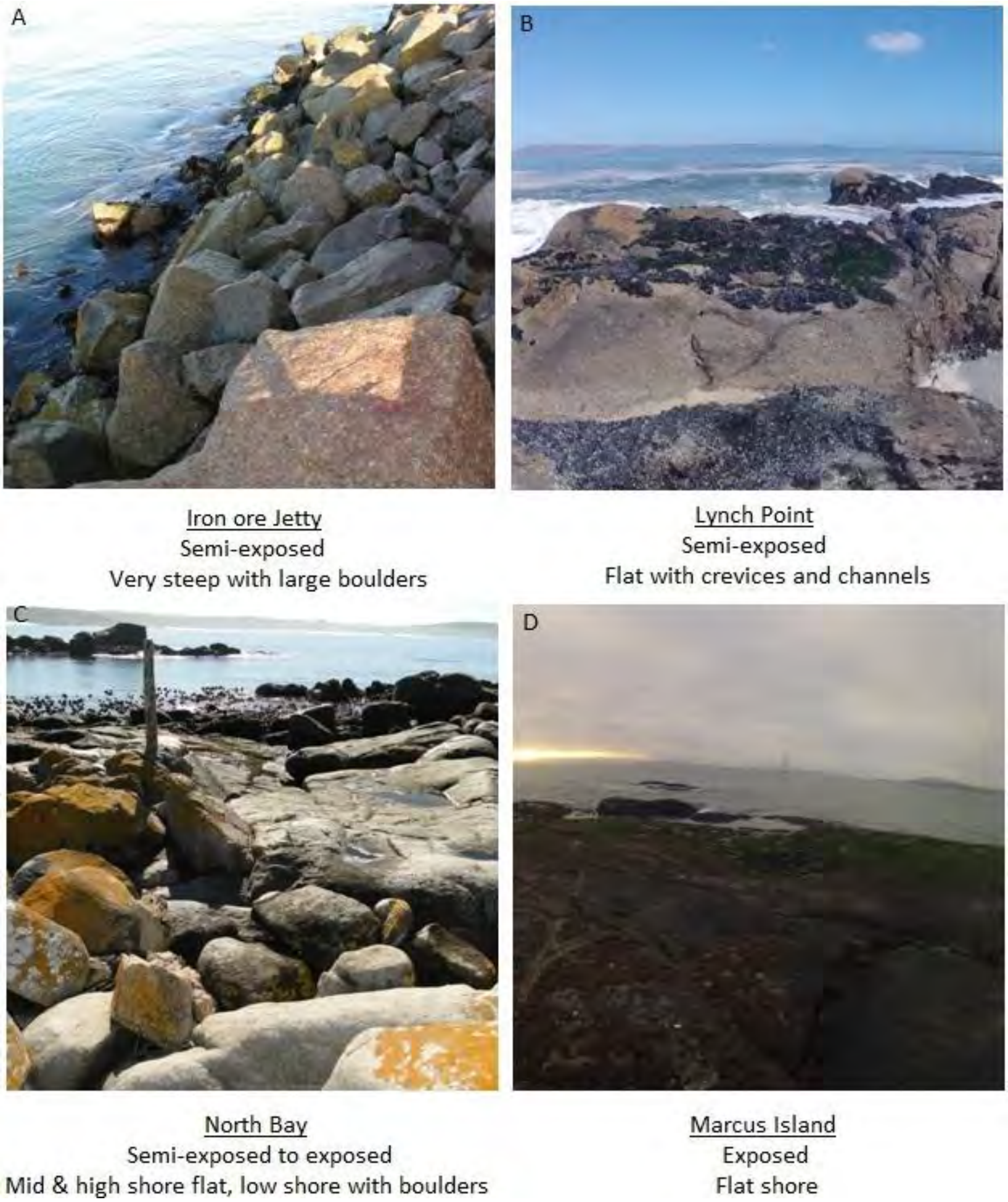


Figure 8.3. Rocky shore study sites: A) Iron ore Jetty, B) Lynch Point, C) North Bay, and D) Marcus Island (Photographs: Nina Steffani).

The site at the Iron Ore Jetty (IO) is 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 jetty (Figure 8.3. A), 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 occasional deep crevices (Figure 8.3. B). North Bay (NB) is semi-exposed to exposed with a relatively flat high and mid shore (Figure 8.3. C). The low shore consists of large unmovable square boulders separated by channels.

The rocky intertidal site on Marcus Island (M) is flat and openly exposed to the prevailing south-westerly swell (Figure 8.3. D).

8.2.2 Methods

Intertidal rocky shores are alternately submerged underwater and exposed to air by tidal action. This creates a steep vertical environmental gradient for the biota that inhabit these shores resulting in biota lower on the shore being mostly submerged and biota higher on the shore mostly exposed. 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 100x50 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. Individual mobile organisms were 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%. The survey protocol has remained consistent for all surveys.

Sampling was non-destructive, *i.e.* the biota was 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 not recorded by this survey protocol. 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 seven functional groups: grazers (mostly limpet species), filter-feeders (including sessile suspension feeders such as mussels and barnacles), predators and scavengers (such as carnivorous whelks and anemones), encrusting algae (crustose and articulated coralline algae), corticated algae, ephemeral foliose algae and kelps.

8.2.3 Data analysis

The rocky shore biota from the eight study sites were analysed with multivariate statistical 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. All percentage cover data were 4^{th}-root transformed and the Bray-Curtis resemblance matrix was used.

Statistical comparisons of *a priori* defined groups of samples (e.g. sites, treatments, years) were 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 $p < 0.05$ (i.e. a 95% probability that the finding is not due to chance).

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

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

- *Species number (S)* - total number of species present.
- *Percentage cover* - the percentage of intertidal rocky surface that is covered by biota (fauna and flora).
- *Evenness (J')* - 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 (d)* - 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 greater species evenness.

8.3 Results and discussion

8.3.1 Biotic communities and zonation

In 2014, a total of 128 taxa were recorded from all rocky shores, of which 75 taxa were invertebrates (58.6%) and 53 (41.4%) algae. The faunal component was represented by 25 filter feeding taxa, 27 grazers, and 23 predators and scavengers. The algal component comprised 39 corticated (foliose) seaweeds, 7 ephemerals, 5 encrusting algae, and 2 kelp species. This is likely a gross underestimation of coralline taxa as most species are not identifiable in the field and are thus lumped into larger groups.

The total number of taxa recorded at the study sites has remained relatively constant over the years (Anchor Environmental Consultants 2009, 2010, 2011, 2012b, 2013b). Most of the species have already been recorded during one or more of the previous monitoring years, and many are listed by other studies conducted in the Saldanha Bay area (e.g. Simons 1977, Schils *et al.* 2001, Robinson *et al.* 2007b). The species are generally common to the South African West Coast (e.g. Day 1974, Branch *et al.* 2010).

High shore

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 (McQuaid & Branch 1984). Within a site, shore height is the critical factor as a result of the increasing exposure to air from low to high shore, whereby the existence of distinct patterns of zonation of flora and fauna has been well described (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 accumulate amongst the boulders. A typical high shore species at the sheltered sites was the winkle *Oxystele variegata*, while at the exposed sites the anemone *Bunodactis reynaudi* and, in larger numbers, the tiny periwinkle *Afrolittorina knysnaensis* dominated this zone. The latter typically accumulates in moist cracks and crevices at Lynch Point, Marcus Island and North Bay, with maximum densities exceeding 900 individuals per 0.5 m^2 (Figure 8.4. B & Figure 8.5. B).

The alien barnacle *B. glandula* occurred in the high and mid shore zones at almost all sites, with the exception of Dive School; but with very low coverage of the entire shore (<1.5%) in 2013 and higher coverage in 2014 (>3%). Barren rock accounted for >80% at most high shores, while algal cover was extremely sparse. The exceptions were Schaapen Island, which had rock covered in diatoms and dense low carpets of the ephemeral algae *Ulva* spp., and Jetty, which had light sand inundation on the high shore (Figure 8.4. C). Ephemerals are opportunistic algae that have short life cycles and are usually the first settlers on a rocky shore after a disturbance event (Maneveldt *et al.* 2009).

Figure 8.4. **Species found on the high shore in Saldanha Bay. A) *Oxystele variegate* and sparse *Balanus glandula* cover, with gravel accumulation among the boulders at the Jetty site; B) *Afrolittorina knysnaensis* accumulations in crevices at Schaapen East; C); *Ulva spp.* and *P. capensis* patch at Schaapen East; and D) low growing *Ulva spp.* with *Porphyra capensis* tufts at Marcus Island (Photographs: Nina Steffani).**

Mid shore

The mid shores at the sheltered sites were also relatively barren. *Oxystele variegata* extended into the mid shore at Jetty, Iron Ore Jetty and Lynch Point, but also occurred in low numbers at other sites. A few specimens of the limpets *Cymbula granatina*, *Siphonaria capensis* and *S. serrata* and the winkle *Oxystele verigata* were also recorded. Algal cover was dominated by the encrusting red algae *Ralfsia verrucosa* and some patches of *Ulva* spp. (Figure 8.5. A).

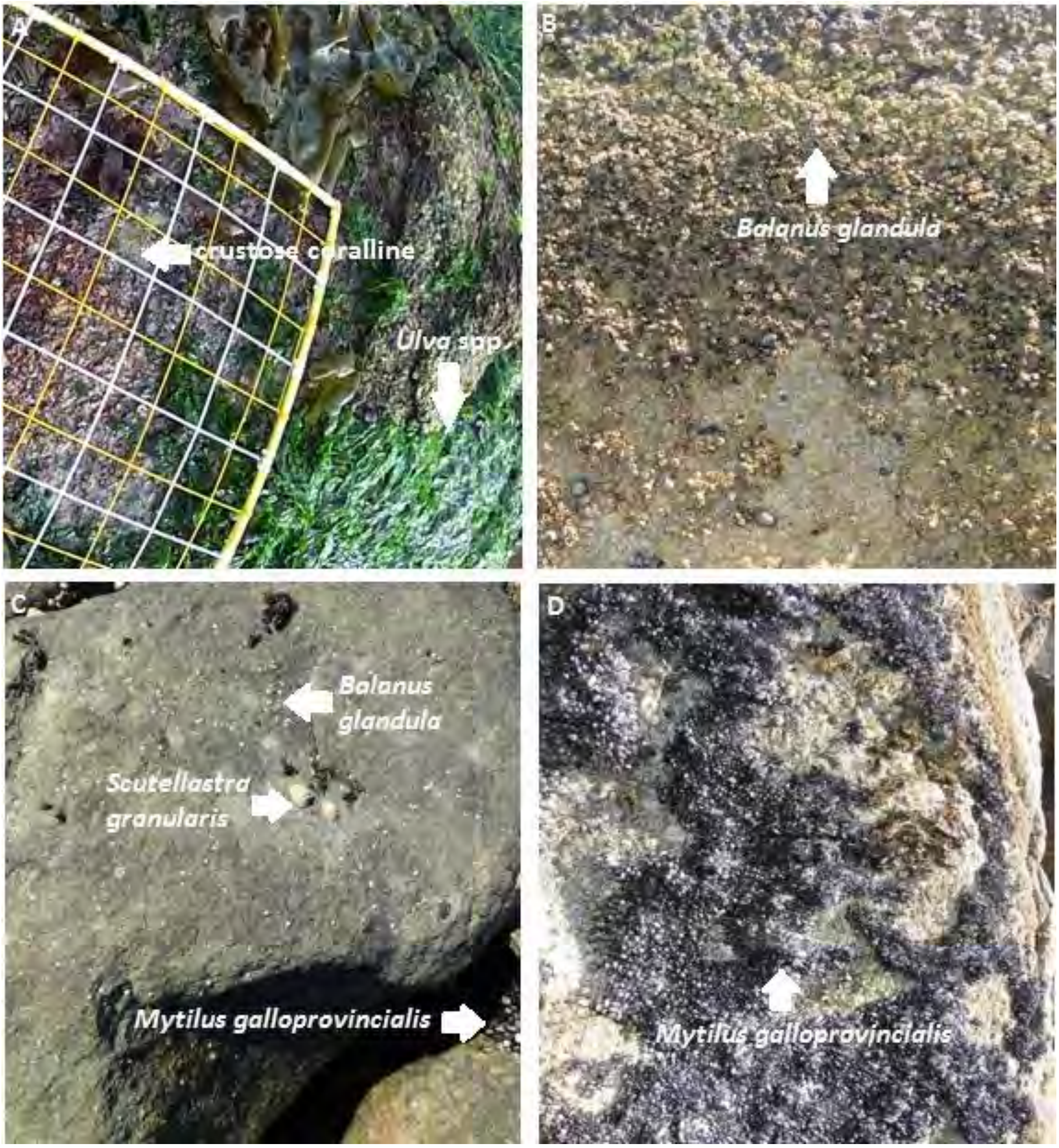


Figure 8.5. **Mid shore species in Saldanha Bay. A) *Ulva* spp. and crustose coralline cover at Schaapen Island West; B) dense *Balanus glandula* cover at Iron Ore Jetty; C) barren mid shore at North Bay with some *Balanus glandula*, a patch of *Mytilus galloprovincialis* as well as the limpet *Scutellastra granularis*; and D) dense cover of *Mytilus galloprovincialis* at Lynch Point (Photographs: Nina Steffani).**

At the Dive School and the Schaapen Island sites, the Dwarf cushion-star *Parvulastra exigua* was typically found in moist rock-depressions and small pools, while *Siphonaria serrata* was more prevalent at Schaapen Island West. In previous years, a tube-building polychaete living deeply cemented in a compact matrix of sand was very common at this site (see Anchor Environmental Consultants 2011), but in 2012 the sand/tubeworm mix had declined at the mid shore and was only recorded from lower down the shore albeit with low cover.

With increasing wave force, the mid shores were dominated by filter feeders, particularly the mussel *M. galloprovincialis* and the barnacle *B. glandula*. The barnacle was particularly abundant at the semi-exposed site Iron Ore Jetty with an average cover of 35% (Figure 8.5. B), whereas the mussel was more abundant at the exposed Marcus Island (>40%) (Figure 8.5. D) and to a lesser extent at Iron Ore Jetty (37%). In contrast, the mid shore at Schaapen Island was relatively barren with only small patches of *Mytilus* and *Balanus* (Figure 8.5. C). Algal presence was generally low in the mid shore with some cover by the ephemerals *Ulva* spp. and *Porphyra capensis*. Mobile animals included the limpets *Scutellastra granularis*, *Siphonaria serrata*, and the tiny snail *Afrolittorina knysnaensis* nestling in amongst the barnacles. The scavenging whelk *Burnupena* spp. was encountered in low numbers at most sites.

Low shore

Reflecting known zonation patterns, total biotic cover generally increased from high to low shore, for example, total cover on the high shore at Lynch Point was only 4% compared to 56% at the low shore. Biotic cover, however, also increased among the shores with intensifying wave force, for example from 40% at the low shore at Jetty to 87% at North Bay. Differences in community structure are thus most pronounced at the low shore where the wave energy is greatest. At the very sheltered sites, faunal cover was very low with some mussel and barnacle cover. Algal cover was only slightly higher, consisting primarily of encrusting alga, *Ralfsia verrucosa*, the foliose seaweed *Gigartina polycarpa*, and the green ephemeral alga *Ulva* spp. (Figure 8.6. A). Mobile animals included the limpet *Cymbula granatina*, the winkle *Oxystele tigrina*, the cushion star *Parvulastra exigua*, and the sea urchin *Parechinus angulosus*, often found in pools or crevices hidden under pieces of shell or gravel. Few large specimens of the false plum anemone *Pseudactinia flagellifera* were also encountered there.

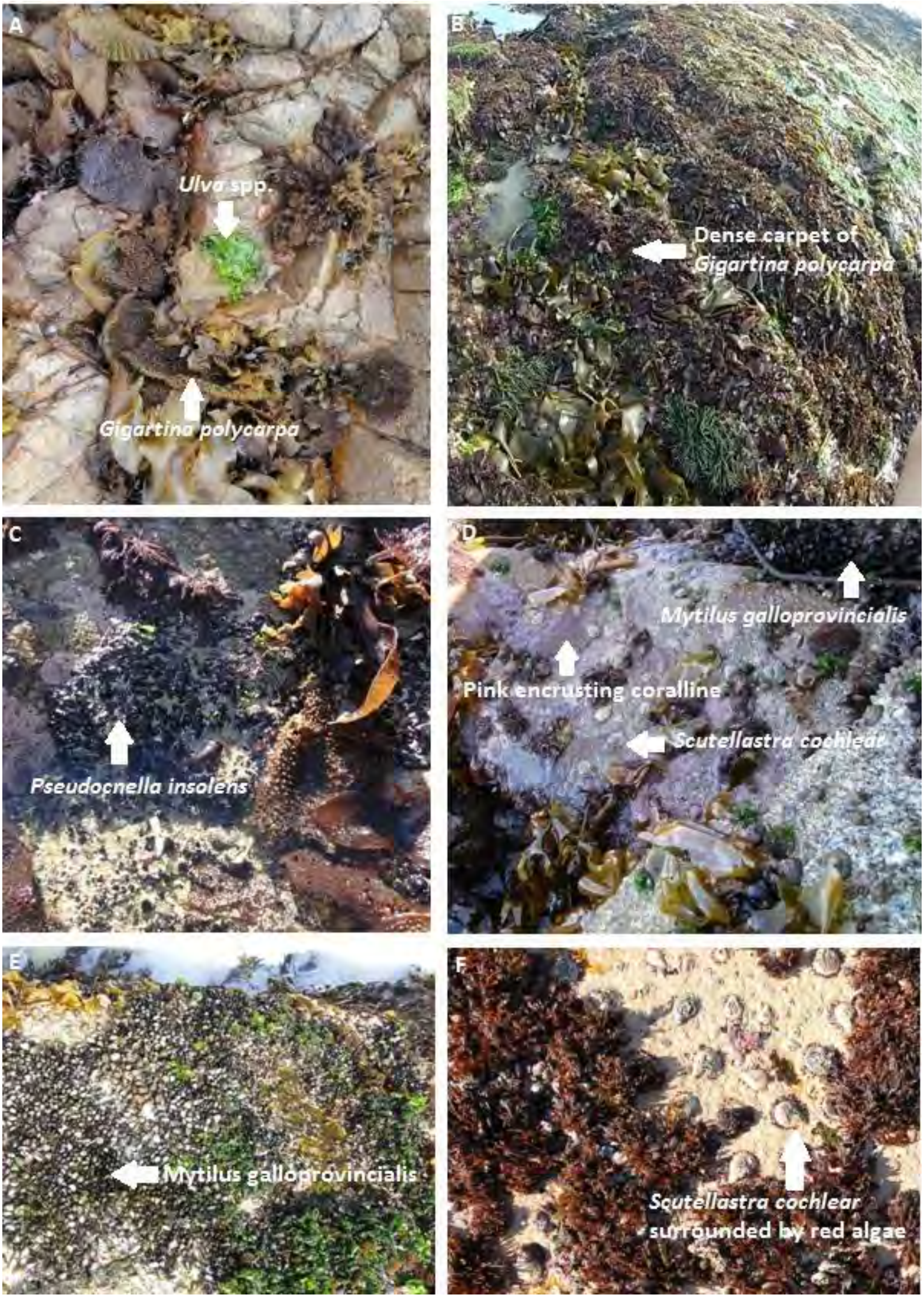


Figure 8.6. **Low shore species in Saldanha Bay. A) Algal cover of *Gigartina polycarpa* and *Ulva* spp. at Dive School; B) dense carpets of *G. polycarpa* at Schaapen Island West; C) dense colonies of *Pseudocnella insolens* embedded in sand at Schaapen Island West; D) encrusting 'pink' corallines, *Mytilus galloprovincialis* and *Scutellastra cochlear* at Iron Ore Jetty; E) *M. galloprovincialis* at Lynch Point; and F) *Scutellastra cochlear* patch with 'gardens' surrounded by encrusting 'pink' coralline at Marcus Island (Photographs: Nina Steffani).**

At the sheltered Schaapen Island sites, the ground cover was dominated by a diverse array of up to 20 different algae species. Most common was a variety of corallines as well as the seaweed *Gigartina polycarpa* (Figure 8.6. B). Other algae included *Pachymenia orbitosa*, *Mazzaella capensis*, *Ulva* spp., and hidden under the algal carpet was a compact layer of sand in which individuals of the red-chested sea cucumber, *Pseudocnella insolens*, burrowed (Figure 8.6. C). Sessile invertebrates were rare but mobile animals included the limpets *Cymbula granatina* and *Siphonaria serrata*, the cushion star *Parvulastra exigua*, the winkle *Oxystele tigrina* and the scavenging whelk *Burnupena* spp.

The low shore of the semi-exposed site Iron Ore Jetty was characterized by patches of *M. galloprovincialis* and algae, in particular encrusting species, as well as *Nothogenia erinacea*, *Plocamium corallorhiza*, and *Ulva* spp. Very common was *Cymbula granatina*, followed by the pear-shaped limpet *Scutellastra cochlear* (Figure 8.6. D). In response to increasing wave action, the low intertidal became progressively dominated by sessile filter feeders, particularly *M. galloprovincialis* (Figure 8.6. E&F). Barnacle presence was largely restricted to secondary growth of *Notomegabalanus algicola* on mussel shells.

Aulacomya atra can be found living deep down in the *Mytilus* bed, taking advantage of the moisture kept in the overlaying dense mussel matrix. In 2011, the indigenous ribbed mussel *Aulacomya atra* was quite prominent at the low shore at Marcus Island and could locally supersede the alien mussel (Anchor Environmental Consultants 2012b) but during the 2013 and 2014 surveys, the ribbed mussel contributed <6% to the cover. As *A. atra* populations cannot be seen without destructive sampling, it is likely that the changes in *A. atra* cover that were recorded between survey years are at least partly due to the overlaying *Mytilus* layers being ripped off from the rocks by waves, exposing the indigenous mussel beneath.

Mobile fauna was characterized by patches of the *Scutellastra cochlear* surrounded by its narrow gardens of fast-growing, fine red algae (e.g. *Gelidium micropterum*, *G. pristiodes*, *Herposiphonia heringii*) that serve as food source and are territorially defended and fertilized by the limpets (Figure 8.6. F). Other limpets included *Cymbula granatina*, *Siphonaria serrata, Scutellastra argenvillei,* and *Helcion pectunculus*. The scavenging whelk *Burnupena* spp. was also common. 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 of wave swept shores, and minor cover of *Sarcothalia stiriata*, and *Ulva* spp.

8.3.2 Spatial variation in community composition

Diversity indices

Changes of the number of species present, biotic cover, evenness and Shannon-Wiener diversity across the eight rocky shores are depicted in Figure 8.7. The sites are sorted from left to right according to increase in wave force and the indices are calculated for the whole shore across all zones. There is a clear increase in biotic cover with rising exposure degree (Figure 8.7A). Similarly, there seems to be an increasing trend in the number of species with increased wave force (Figure 8.7B); however, this is not evident with evenness (Figure 8.7C) and Shannon-Wiener diversity (Figure 8.7D). This indicates that at sheltered sites, few species contribute to the biotic cover.

Abundance of mobile species

The abundances (as opposed to the space they occupy on the rock surface specified as percentage cover) of the seven most common mobile species per site found in 2013 are shown in Figure 8.8. Very few mobile species occurred on the high shore, the most prominent being the typical high shore periwinkle *Oxystele variegata* at the very sheltered sites and the periwinkle *Afrolittorina knysnaensis* at the more exposed sites (Figure 8.8A).

The mid shore had a greater array of common mobile species with *O. variegata* relatively abundant at very sheltered and semi-exposed sites. The whelk *Burnupena* spp. and to a lesser degree the whelk *Nucella dubia,* the periwinkle *Oxystele tigrina* and the limpet *Scutellastra granularis* were also present at a number of mid shore sites. The cushion star *Parvulastra exigua* was typically the most abundant species at the more sheltered sites, while *Afrolittorina knysnaensis and Scutellastra granularis* were abundant at more exposed sites (Figure 8.8B). *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.* 2010). However, at Lynch Point and North Bay the tiny snail reached high abundances in the mid shore (>117 individuals/0.5m^2) living amongst the barnacle *Balanus glandula*. It seems that in the high shore where wave stress is minimal, *A. knysnaensis* is naturally abundant, but in the mid-shore where wave stress is greater the periwinkle normally declines in abundance without shelter (Laird & Griffiths 2008, Griffiths *et al.* 2011). 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 (Laird & Griffiths 2008).

Mobile animals in the low shore of sheltered to semi-exposed sites included *Parvulastra exigua*, the sea cucumber *Pseudocnella insolens* and the sea anemone *Corynactis annulata* (Figure 8.8C). *Burnupena* spp. occurred at all low shores, while the limpet *Scutellastra cochlear* was clearly restricted to wave swept shores where it lives in patches of dense aggregations. The anemone *Bunodactis reynaudi* was more abundant at exposed sites, while *Anthothoe chilensis* was found at both exposed and sheltered sites.

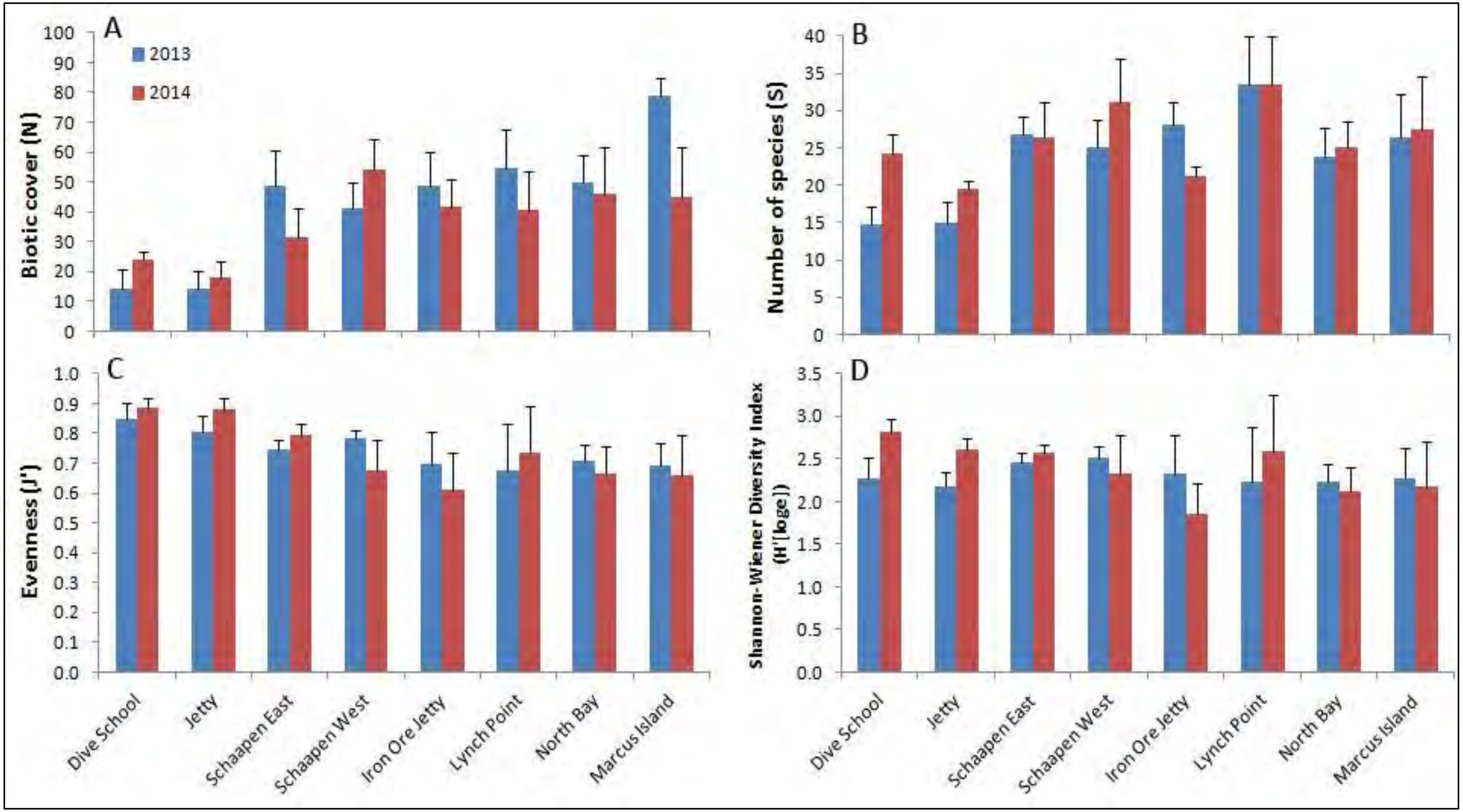


Figure 8.7. **A) Biotic cover (%), B) number of species, C) evenness and D) Shannon-Wiener diversity index at the eight rocky shore sites. Sites are sorted from left to right according to increasing wave exposure. Error bars indicate standard deviation.**

The abundances of the seven most common mobile species per site found in 2014 are illustrated in Figure 8.9. The most prominent high shore specie was again the periwinkle *Afrolittorina knysnaensis* at the more exposed sites and *Oxystele variegata* at the more sheltered sites (Figure 8.9A). *Afrolittorina knysnaensis* and the limpet *Scutellastra granularis* were again abundant in the mid shore at the more exposed sites, while the cushion star *Parvulastra exigua* was yet again the most abundant species at the more sheltered sites (Figure 8.9B). At Lynch Point, North Bay and Marcus Island *A. knysnaensis* reached densities greater than 150 individuals/0.5m^2. The whelk *Burnupena* spp. was also abundant at a number of mid shore sites and the limpet *Siphonaria serrata* was abundant at the Iron Ore Jetty. The graph depicting the low shore in 2014 looked slightly different when compared to that of 2013 due to the appearance of the periwinkle *Gibbula zonata* at Schaapen Island and the dominance of *Oxystele tigrina* at the sheltered sites (Figure 8.9C). *Bunodactis reynaudi* was still abundant at exposed sites, while the sea cucumber *Pseudocnella insolens* was no longer abundant at the sheltered sites.

Functional groups

The distribution of the various functional groups across the shores with regard to exposure is depicted in (Figure 8.10). Very sheltered shores had generally low biotic cover consisting primarily of grazers, corticated algae and encrusting algae, with the exception of Schaapen Island East and West that had high biotic cover and were clearly dominated by algae. With an increase in wave force, the dominance of sessile filter feeders (e.g. barnacles) was evident, but at Marcus Island algae were also abundant.

Many studies have been conducted worldwide focusing on the effect of wave action on the distribution of organisms on rocky shores (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, favoring certain sessile, filter-feeding species and leading to an elevation of overall biomass (McQuaid & Branch 1985, Bustamante & Branch 1996, Bustamante *et al.* 1995, Steffani & Branch 2003a). Although increasing exposure carries an increased risk of dislodgement and physical damage thus limiting the range of susceptible and physically fragile species, Pfaff *et al.* (2011) showed that wave exposure has an overall positive effect on the recruitment of mussels and barnacles on the southern African west coast. In contrast, sheltered shores are typically dominated by algae (McQuaid & Branch 1985) as species richness of most algal groups decrease with increasing exposure. The effect of wave exposure, however, varies with phyla and functional form group as some forms can better withstand hydrodynamic forces than others (Denny & Gaylord 2002, Nishihara & Terada 2010).

Despite adaptations evolved as a result of different wave exposures, hydrodynamic forces can at times cause massive damage to rocky shore communities, fundamentally altering the structure and function of exposed rocky habitats and creating changes that may persist for many years. The magnitude and frequency of physical disturbance is not as severe on protected shores as on exposed shores, thus the structure of protected communities is often more stable than that of exposed assemblages. The rocky shores at Saldanha Bay are separated with regard to wave force and range from very sheltered to exposed.

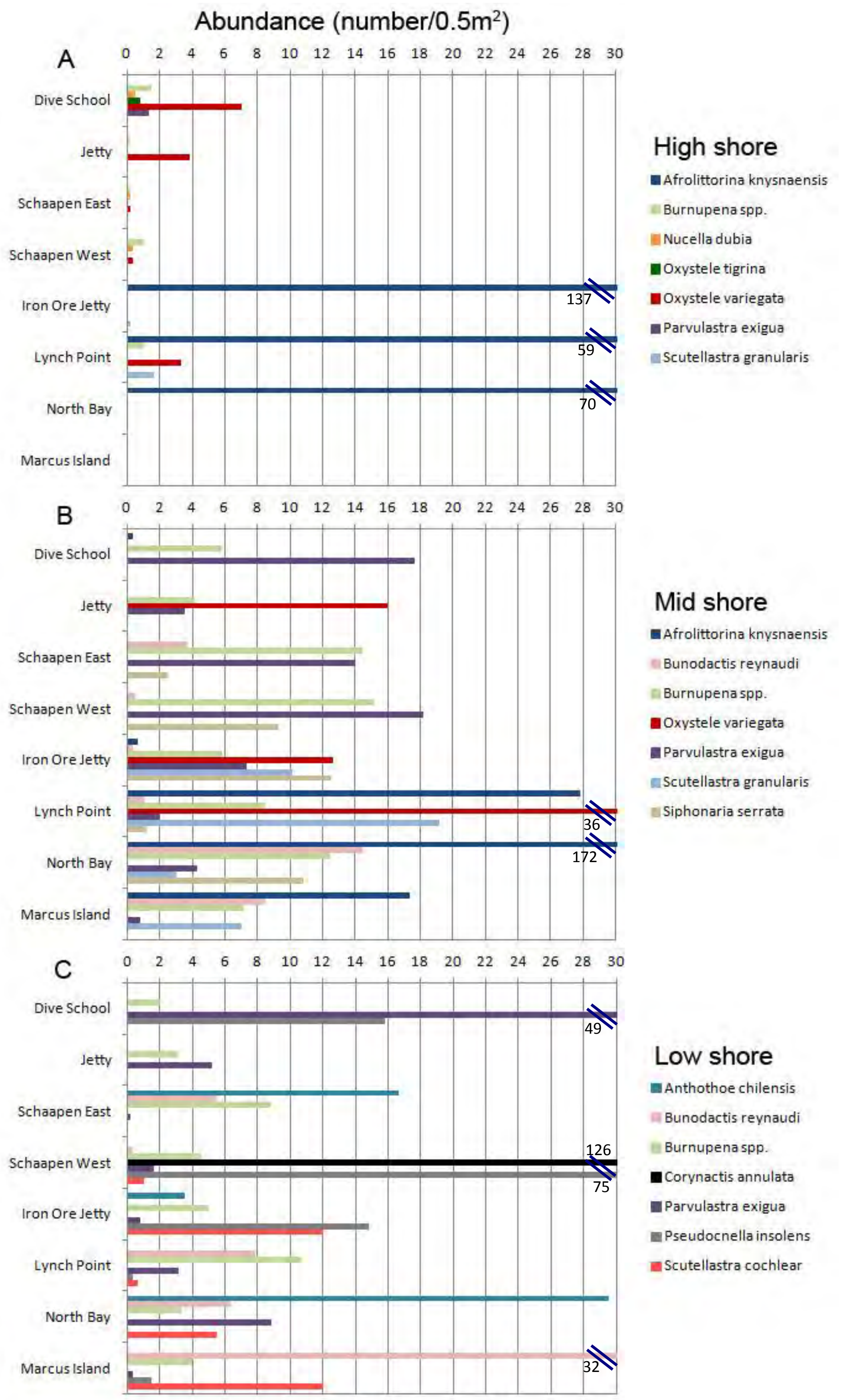


Figure 8.8. **Mean abundance (number/0.5 m^2) of the seven most abundant mobile species at the A) high, B) mid and C) low rocky shores in 2013. Sites are sorted from top to bottom according to increasing wave exposure.**

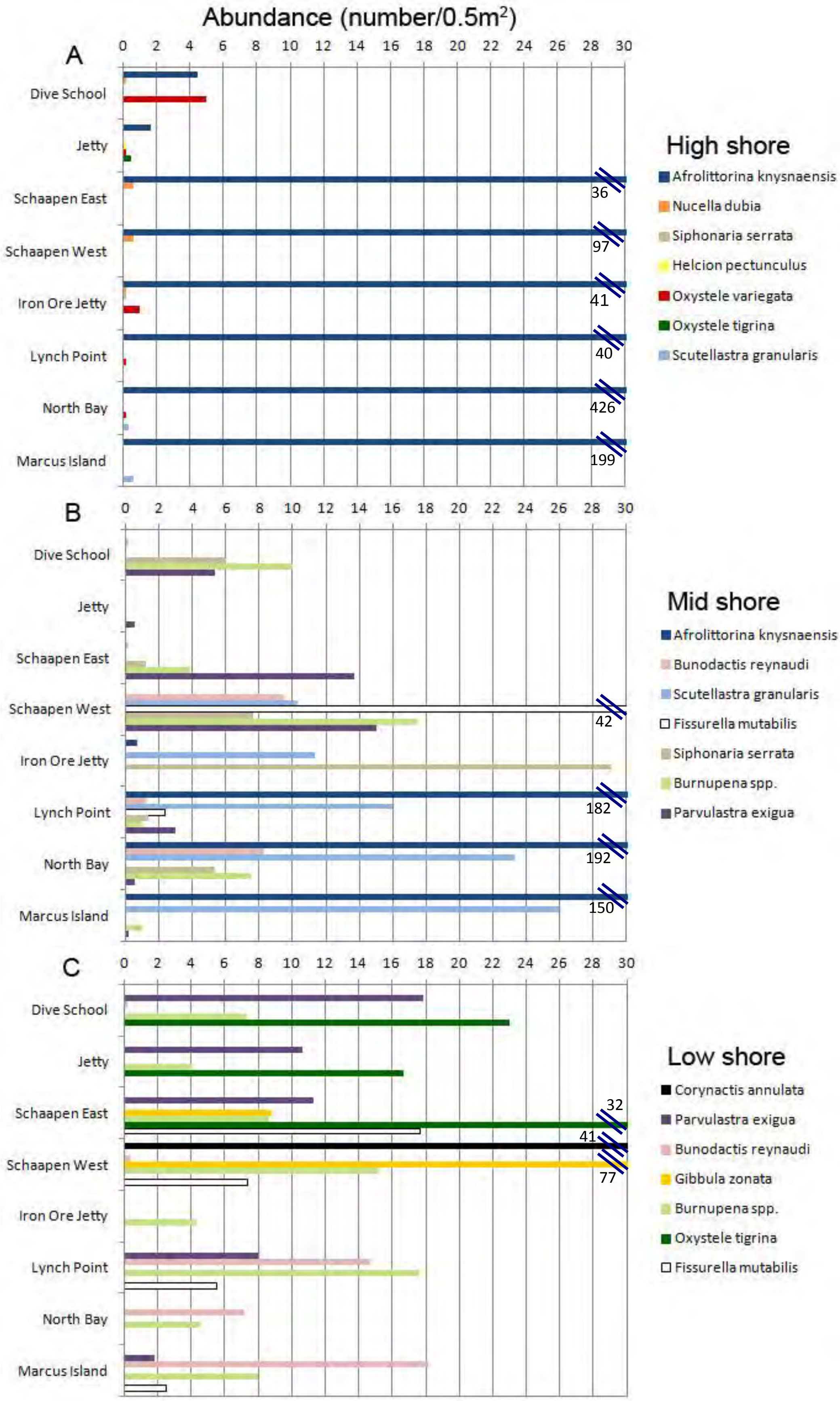


Figure 8.9. **Mean abundance (number/0.5 m²) of the seven most abundant mobile species at the A) high, B) mid and C) low rocky shores in 2014. Sites are sorted from top to bottom according to increasing wave exposure.**

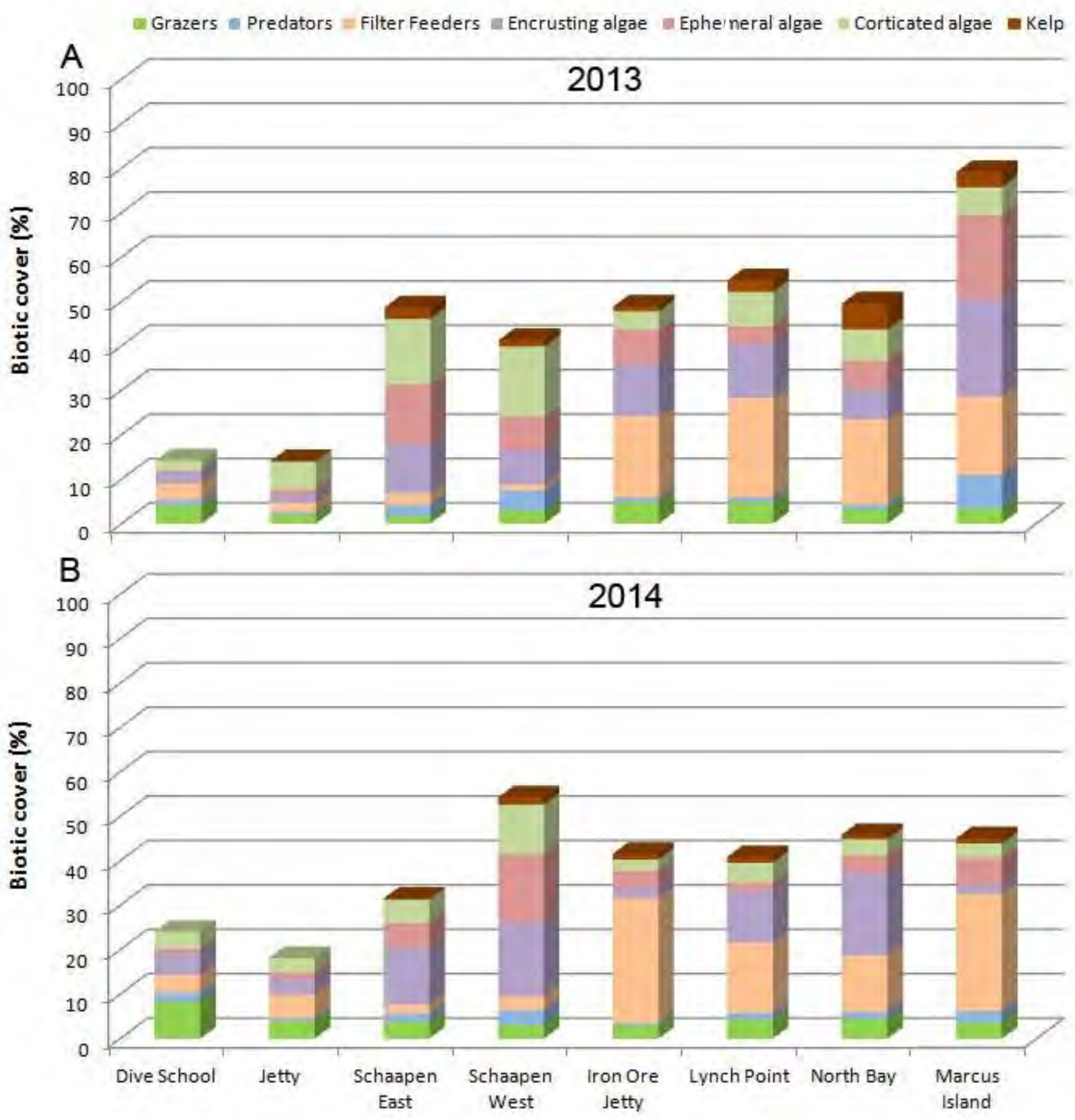


Figure 8.10. **Contribution of the functional groups to the biotic cover (%) across the whole rocky shore at the eight study sites in A) 2013 and B) 2014. Data are sorted from left to right according to increasing wave exposure.**

While wave force is clearly the main factor for differences among the shores, shore topography is also of importance. 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). According to McCoy and Bell (1991), 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). Several studies have shown that many mobile animals exhibit preferential movement from smooth surfaces into habitats with more structural complexity (e.g. crevices) where they are more protected from hydrodynamic forces (McGuinness & Underwood 1986, Kostylev *et al.* 2005, O'Donnell & Denny 2008). This does not apply only to physical complexity, but also microhabitats offered by biota (e.g. the barnacle *Balanus glandula*). Mobile invertebrates can respond to environmental extremes by moving between microhabitats to ameliorate thermal and desiccation stress (Meager *et al.* 2011).

The distribution of sessile species is largely driven by the longer-term processes of settlement, growth and mortality; whereby substratum availability, microtopography and surface smoothness can be limiting factors at local scales (Guarnieri *et al.* 2009). Topographic complexity influences the settlement 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, Archambault & Bourget 1996, Skinner & Coutinho 2005, Guarnieri *et al.* 2009).

Boulder shores also have greater microhabitat diversity compared to more level shores. One of the reasons for this is because the tops of larger boulders stay exposed for a significantly longer period than smaller boulders (or flat platforms), with each boulder essentially having its own shore height zonation. During low tide, the top of the boulder provides the lower section with shade, thus maintaining lower temperatures and higher moisture content (Takada 1999). This arrangement increases the surface area for the attachment of organisms but may reduce water movement, which may cause detritus to accumulate, possibly resulting in low oxygen conditions. Large boulders can considerably reduce the water flow velocity, thus invertebrate biomass is expected to decrease significantly downstream of boulders. Smaller boulders may be unstable and often have a more impoverished community than larger rocks (McGuinness 1987, Guichard & Bourget 1998, Londoño-Cruz & Tokeshi 2007, McClintock *et al.* 2007). All these factors result in boulder fields supporting different species assemblages in comparison to those of flatter shores (Sousa 1979a, McGuinness 1984, McQuaid *et al.* 1985, McGuiness & Underwood 1986, Takada 1999, Cruz-Motta *et al.* 2003, Davidson *et al.* 2004, Hir & Hily 2005).

Shore topography is a likely reason for differences in community structure between the rocky shores on Schaapen Island and the other two sheltered sites, although 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 has slight differences in water quality (e.g temperature) compared to the water in the Bay, which in turn leads to differences in their biological communities (Day 1959, Robinson *et al.* 2007b). For example, Schils *et al.* (2001) report a distinct separation in algal composition between the Bay and the Lagoon as the Lagoon contains a significant number of South Coast species due to its warmer waters. Perlemoen Punt, located less than 1 km from Schaapen Island at the entrance to Langebaan Lagoon, is described as the transition area between the Bay and the Lagoon, but with a marked Lagoon affinity in its overall algal composition. Clear differences in community composition between the Bay and the Lagoon are also described for zooplankton and sandy substrate assemblages (Grindley 1977, Anchor Environmental Consultants 2012b).

8.3.3 Temporal analysis

Temporal analysis of diversity indices

Temporal variation in species number, biotic cover, evenness, and species diversity at the eight rocky shores from 2005 to 2014 are depicted in Figure 8.11 & Figure 8.12. The number of species at each of the shores varied only slightly over the years with few obvious trends of increase or decrease. However, species numbers seem to have increased at Jetty and Schaapen West when compared to the other sites. Biotic cover also showed little temporal variation at the sites Dive School, Jetty, Iron Ore Jetty and Lynch Point, but somewhat greater variation at Schaapen Island East, Schaapen Island West, North Bay and Marcus Island. However, these variations do not follow a consistent trend. Temporal variation in evenness and Shannon-Wiener diversity indices are visible at Jetty, Schaapen Island East, Lynch Point and Marcus Island which show an increasing trend in evenness and diversity, while the opposite is apparent at North Bay. Only further monitoring will show whether these are 'true' trends or just longer period cyclical variation.

Temporal trends in rocky shore community patterns

Temporal trends in rocky shore community patterns are illustrated in the MDS plot (Figure 8.13). Consistent for all years is the grouping according to wave exposure with one cluster at a 40% similarity level containing samples from all years from the very sheltered sites Dive School and Jetty; another cluster containing the two Schaapen Island sites; and a third cluster containing all samples from the more exposed sites Iron Ore Jetty, Lynch Point, North Bay, and Marcus Island. Within the exposed cluster, a separation of Iron Ore Jetty from the other three exposed sites is apparent.

Inter-annual variability within each site is also evident, but this is more pronounced for some of the sites than for others. At Dive School for example, samples from 2013 tend to be more on the right of the plot, while those from 2012 are to the left (Figure 8.13). The greatest within-site variability (or patchiness) occurs at the boulder beach Jetty where the replicates per year often disperse widely. Due to the high stress level of 0.2, the MDS plot needs to be interpreted with caution but the generally good agreement with the pattern observed for single years suggest that the representation is fairly reasonable.

PERMANOVA tests conducted for each site separately confirm significant differences among the years ($p = 0.0001$ for all tests). Pair-wise tests further reveal that for every site-by-year combination tested, inter-annual changes in community composition are significant. For the sake of brevity, only combinations involving subsequent years are shown in Table 8.1.

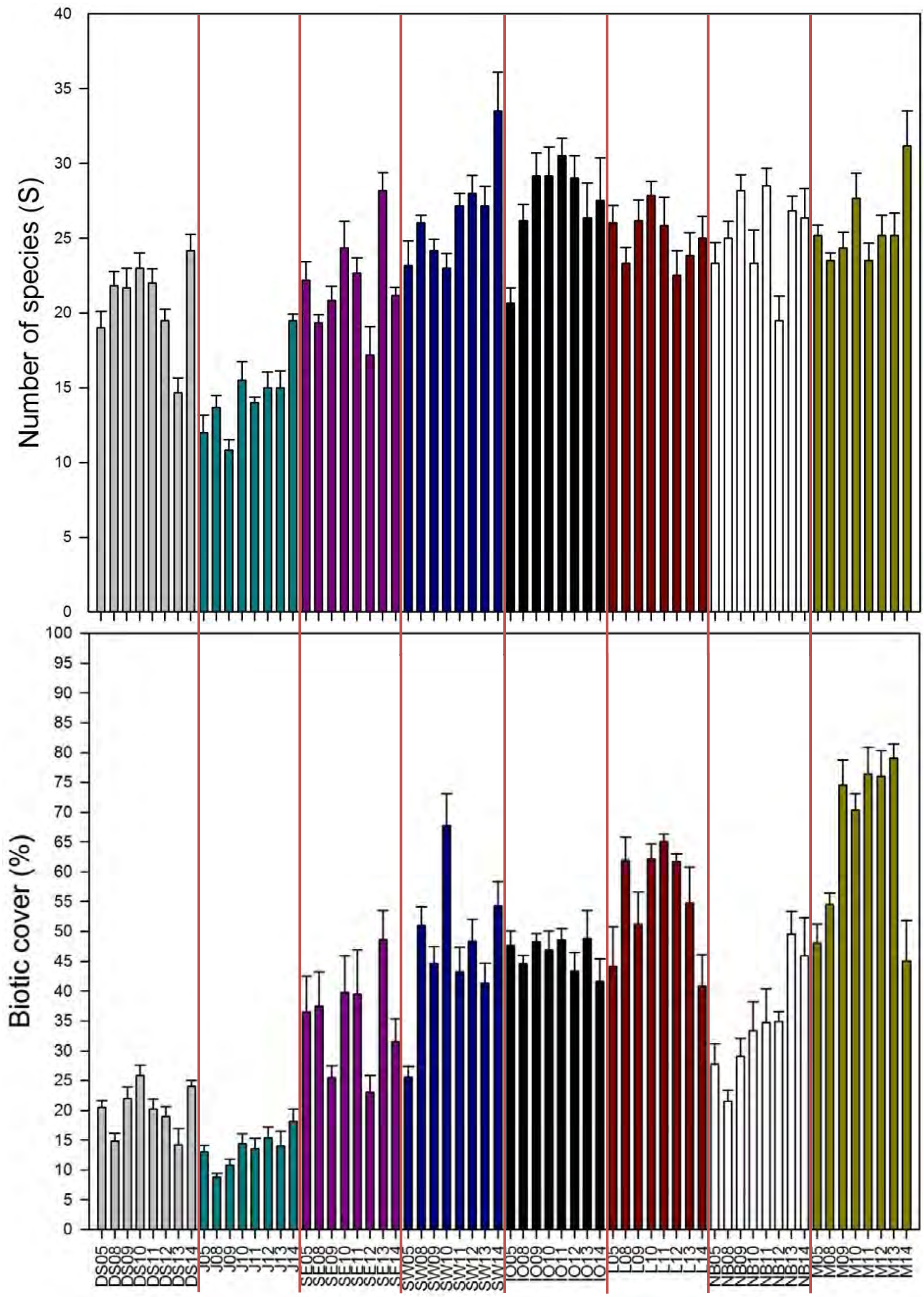


Figure 8.11. Temporal changes of species number and biotic cover (%) at the eight rocky shore sites from 2005 to 2014. Error bars indicate standard error.

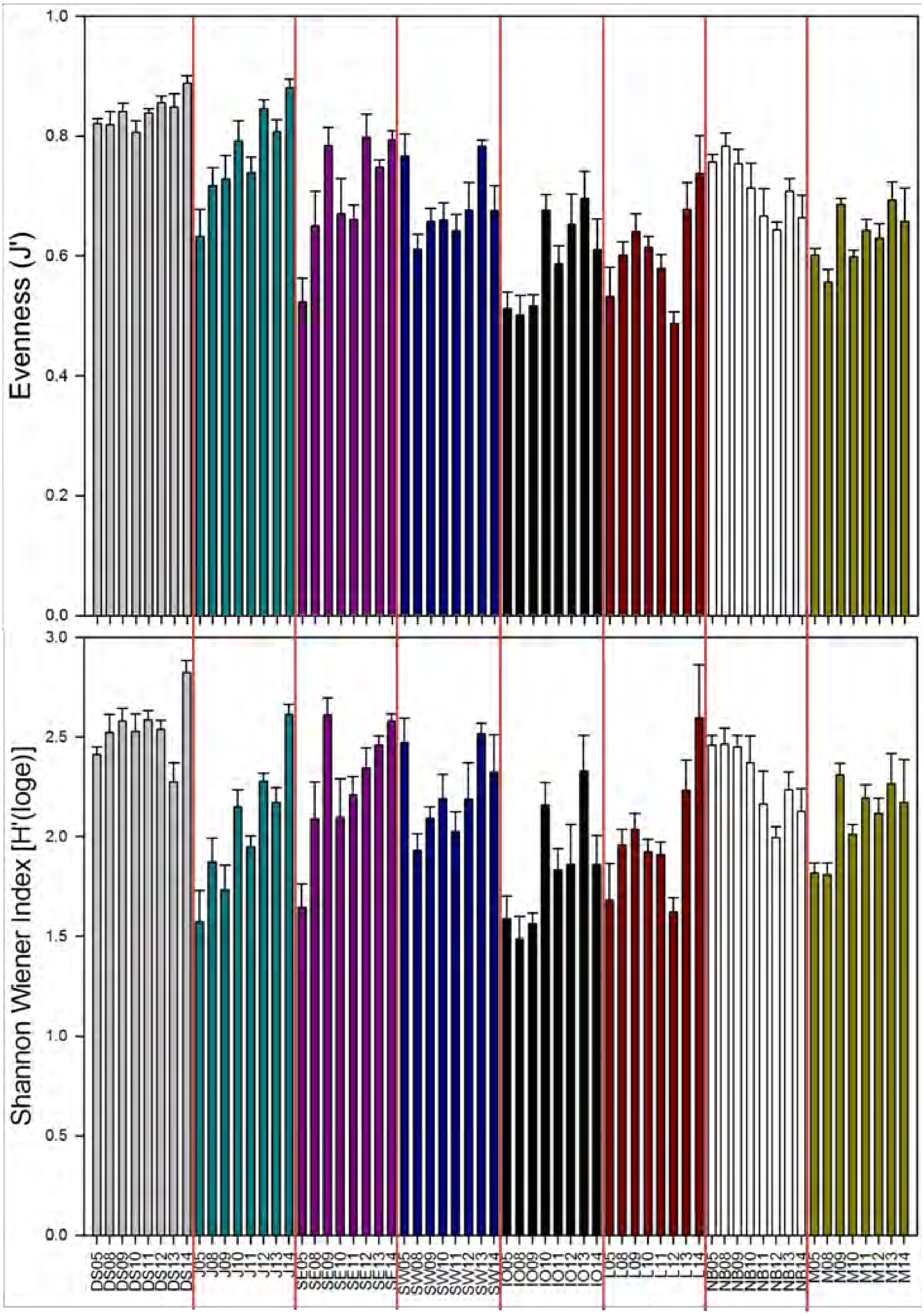


Figure 8.12. Temporal changes of evenness (J') and Shannon-Wiener diversity [H'(log e)] at the eight rocky shore sites from 2005 to 2014. Error bars indicate standard error.

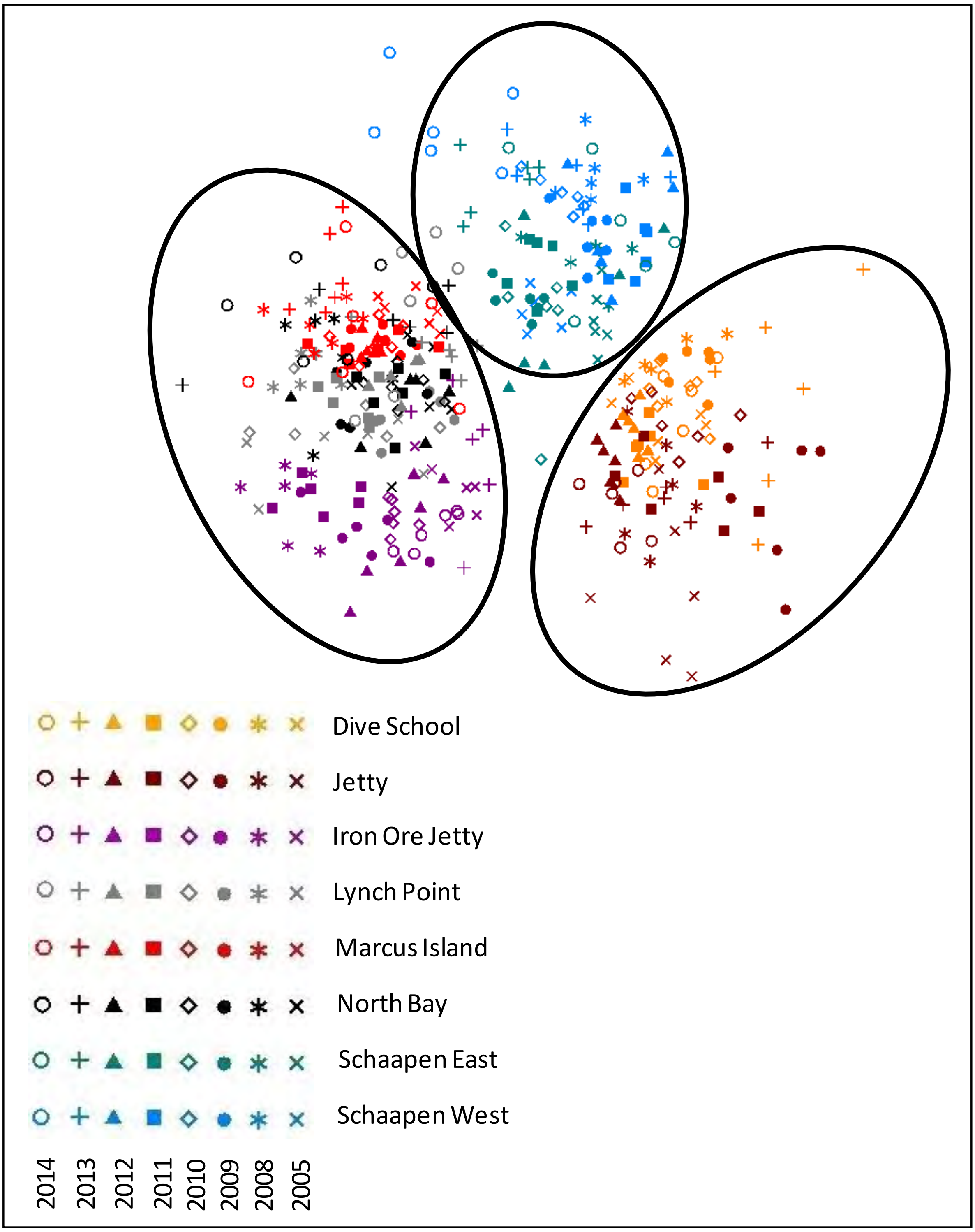


Figure 8.13. Multi-dimensional scaling (MDS) plot of the rocky shore communities at the eight study sites from 2005 to 2014. The circles delineate a 40% similarity level and the plot has with a 2D stress of 0.2.

Table 8.1. PERMANOVA pair-wise testing results following significant main-tests. The number of permutations was 462 for all pair-wise comparisons and percent similarity among the years tested was also reported.

Groups	Pseudo-F	Significance Level	% Similarity
Dive School 2005 vs. 2008	2.7040	0.002	60.8
Dive School 2008 vs. 2009	2.9354	0.002	59.6
Dive School 2009 vs. 2010	1.6863	0.003	69.5
Dive School 2010 vs. 2011	1.9594	0.002	68.2
Dive School 2011 vs. 2012	1.6532	0.002	73.4
Dive School 2012 vs. 2013	2.5404	0.002	52.1
Dive School 2013 vs. 2014	3.1125	0.003	43.3
Jetty 2005 vs. 2008	2.9172	0.002	53.4
Jetty 2008 vs. 2009	3.5556	0.002	47.3
Jetty 2009 vs. 2010	2.2280	0.004	59.4
Jetty 2010 vs. 2011	2.7930	0.002	53.9
Jetty 2011 vs. 2012	2.1239	0.001	65.1
Jetty 2012 vs. 2013	1.7784	0.002	65.5
Jetty 2013 vs. 2014	2.0276	0.002	59.8
Schaapen East 2005 vs. 2008	3.5357	0.002	52.5
Schaapen East 2008 vs. 2009	2.8239	0.004	60.6
Schaapen East 2009 vs. 2010	2.4761	0.002	58.4
Schaapen East 2010 vs. 2011	2.0324	0.003	56.2
Schaapen East 2011 vs. 2012	1.7705	0.004	59.4
Schaapen East 2012 vs. 2013	3.3549	0.002	44.6
Schaapen East 2013 vs. 2014	2.4954	0.003	51.2
Schaapen West 2005 vs. 2008	3.4896	0.003	48.2
Schaapen West 2008 vs. 2009	3.1476	0.003	53.8
Schaapen West 2009 vs. 2010	2.4896	0.003	66.9
Schaapen West 2010 vs. 2011	2.9673	0.002	58.7
Schaapen West 2011 vs. 2012	2.5316	0.003	52.2
Schaapen West 2012 vs. 2013	2.4806	0.001	48.2
Schaapen West 2013 vs. 2014	1.8212	0.003	48.1
Iron Ore Jetty 2005 vs. 2008	4.1406	0.003	40.2
Iron Ore Jetty 2008 vs. 2009	3.8617	0.002	50.2
Iron Ore Jetty 2009 vs. 2010	3.1412	0.003	61.8
Iron Ore Jetty 2010 vs. 2011	3.3210	0.002	67.8
Iron Ore Jetty 2011 vs. 2012	3.0383	0.002	58.2
Iron Ore Jetty 2012 vs. 2013	2.5514	0.003	52.8
Iron Ore Jetty 2013 vs. 2014	2.1566	0.002	57.2
Lynch Point 2005 vs. 2008	2.5450	0.003	54.4
Lynch Point 2008 vs. 2009	2.9096	0.002	55.3
Lynch Point 2009 vs. 2010	2.6087	0.002	57.5
Lynch Point 2010 vs. 2011	1.9788	0.002	65.9
Lynch Point 2011 vs. 2012	2.7796	0.003	68.7
Lynch Point 2012 vs. 2013	3.2757	0.003	54.6
Lynch Point 2013 vs. 2014	1.8556	0.003	55.8
North Bay 2005 vs. 2008	2.2109	0.002	57.1
North Bay 2008 vs. 2009	2.0584	0.003	61.5

Groups	Pseudo-F	Significance Level	% Similarity
North Bay 2009 vs. 2010	1.7195	0.005	67.2
North Bay 2010 vs. 2011	1.9690	0.002	65.0
North Bay 2011 vs. 2012	1.7590	0.002	64.0
North Bay 2012 vs. 2013	2.0370	0.003	52.8
North Bay 2013 vs. 2014	1.8059	0.010	48.9
Marcus Island 2005 vs. 2008	3.6937	0.002	54.7
Marcus Island 2008 vs. 2009	2.7828	0.002	61.2
Marcus Island 2009 vs. 2010	2.8566	0.002	67.2
Marcus Island 2010 vs. 2011	2.3449	0.002	68.7
Marcus Island 2011 vs. 2012	1.4516	0.026	74.5
Marcus Island 2012 vs. 2013	2.5896	0.002	56.5
Marcus Island 2013 vs. 2014	2.1103	0.002	48.1

Species responsible for temporal trends

The species that are primarily responsible for the observed differences in community structure among the years are identified by the SIMPER routine. For brevity, only species contributing >5% to the dissimilarity at any specific site and only comparisons between 2012 and 2013 (Table 8.2) and between 2013 and the current dataset from 2014 (Table 8.3) are presented. At most of the sites only one or two species contributed largely (>5%) to the differences in community structure between 2012 and 2013, except for Dive School and Jetty where four species contributed to each site and for the shores of Schaapen Island and Iron Ore Jetty where no single species contributed >5% (Table 8.2). For the latter sites, the species contributing the most to the dissimilarity is listed.

Algae were common contributors to differences between years as 75% of the species listed in 2013 and 77% in 2014 were algal species (Table 8.2 & Table 8.3). In 2013, one of these species was ephemeral algae, five were corticated algae, three were encrusting algae and one was kelp. In addition, two species of grazers were the only invertebrate fauna listed. A reduction in cover of *Ulva* spp., amongst other taxa, contributed to the difference between the years at Dive School, while an increase in *Ecklonia maxima* cover was partly responsible for changes at Schaapen East, Lynch Point and North Bay. At Jetty, the brown algae *Ralfsia verrucosa* was the main species responsible for the difference between the years having decreased in cover since 2012. Five species of algae and one species of encrusting algae that were not found in 2012 were recorded in 2013 Table 8.2.

The species responsible for the greatest differences in the rocky shore assemblages between 2013 and 2014 included three species of corticated algae, four species of encrusting algae and two species of filter-feeder, the alien barnacles *Balanus glandula* and *Menesiniella regalis*. The presence of diatoms in 2014 contributed to the difference between the years at Dive School and Lynch Point, while a decrease in *Ralfsia verrucosa* cover was partly responsible for changes at Schaapen West and Iron Ore Jetty. At Jetty, the corticated algae *Leathesia marina* was the main species responsible for the difference between the years as it was not present in 2013. Two species of algae that were not found in 2013 were recorded in 2014 (Table 8.2 & Table 8.3).

Diatoms often cover high shore rocks together with other microscopic algae (e.g. spores of macroalgae), but their presence is typically temporary as they are eventually replaced by macroalgae

(Robles 1982, Cubit 1984, Maneveldt *et al.* 2009). This succession is seen in Saldanha Bay with visible increases in the percentage of macroalgal species on the shore at all sites except Dive School. Guano run-off from Schaapen Island is likely to be responsible for enhanced intertidal algal growth in that area (Bosman *et al.* 1986, Bosman & Hockey 1986 & 1988). The contribution of the grazers *Siphonaria serrata* and Parechinus angulosus to the dissimilarity between 2012 and 2013 is most likely a direct result of the increase in algal abundance. In general, average dissimilarities between the years per site are low (Table 8.2 & Table 8.3), indicating that temporal differences in rocky shore communities were small.

Table 8.2. SIMPER results listing the species that contribute >5% to the dissimilarity between 2012 and 2013 at each site. The percentage cover data presented are averages across the six replicates per site and are on the fourth-root transformed scale.

Site	Species	2012 %cover	2013 %cover	% Contribution	Average dissimilarity
Dive School	*Ulva* spp.	0.91	0.20	5.57	47.87
	Siphonaria serrata	0.92	0.13	5.57	
	Parechinus angulosus	1.26	0.57	5.05	
	Codium fragile fragile	0	0.76	5.04	
Jetty	*Ralfsia verrucosa*	1.17	0.45	7.93	34.48
	Ahnfeltiopsis polyclada	0	0.64	6.82	
	Coralline (crustose)	0.95	0.69	6.22	
	Colpomenia sinuosa	0	0.50	5.36	
Schaapen East*	*Ecklonia maxima*	0	1.09	4.47	55.43
Schaapen West*	*Sarcothalia stiriata*	0.28	1.37	4.33	51.82
Iron Ore Jetty*	*Ralfsia verrucosa*	0.72	1.58	4.80	47.16
Lynch Point	*Gigartina polycarpa*	0	1.44	6.30	45.45
	Ecklonia maxima	0	1.22	5.33	
North Bay	*Ecklonia maxima*	0	1.42	7.09	47.25
Marcus Island	*Hildenbrandia lecannellieri*	0	1.89	7.93	43.49

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

Temporal variations in abundance of functional groups

Temporal variations in abundance of functional groups at the eight study sites are illustrated in Figure 8.14 and Figure 8.15. At the two sheltered boulder beaches Dive School and Jetty, filter feeders and ephemeral algae slightly decreased over time, while corticated algae, encrusting algae and grazers increased slightly. At both Schaapen Island sites, the abundance of ephemerals and encrusting algae varied considerably over the years but without a consistent trend. In 2010 and 2011, filter feeders at the Schaapen Island sites had increased in cover to >10% averaged across the whole shore, but declined again from 2012 onwards. Iron Ore Jetty and Lynch Point remained relatively constant over time, with only minor variations in encrusting algae and ephemeral cover. At North Bay, filter feeders increased steadily over time with only a slight drop in cover in 2012. Ephemerals again showed slight temporal fluctuations, with encrusting algae increasing noticeably in 2014. At Marcus Island, ephemeral algae had greatly increased from 2008 to 2009, while at the same time corticated algae, encrusting 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. There was no noteworthy change in functional groups in 2012 but encrusting algae and kelp increased substantially in 2013, decreasing again in 2014. Kelp increased at all but the very sheltered sites in 2013 and was present to a lesser degree in 2014.

Table 8.3. SIMPER results listing the species that contribute >5% to the dissimilarity between 2013 and 2014 at each site. The percentage cover data presented are averages across the six replicates per site and are on the fourth-root transformed scale.

Site	Species	2013 %cover	2014 %cover	% Contribution	Average dissimilarity
Dive School	Diatoms	0	1.22	6.07	56.72
Jetty	*Leathesia marina*	0	0.78	6.37	40.23
	Menesiniella regalis	0.21	0.96	6.08	
	Ralfsia verrucosa	0.45	1.10	5.32	
	Ahnfeltiopsis polyclada	0.64	0	5.07	
	Coralline (crustose)	0.69	1.08	5.02	
Schaapen East*	Red turf	1.20	0	4.99	48.82
Schaapen West*	*Ralfsia verrucosa*	1.02	0.13	3.31	51.91
Iron Ore Jetty*	*Ralfsia verrucosa*	1.58	0.75	4.43	42.76
Lynch Point*	Diatoms	0	0.99	6.92	44.23
North Bay*	*Balanus glandula*	0.82	0.70	3.59	51.13
Marcus Island	*Hildenbrandia lecannellieri*	1.89	0.14	6.72	51.85

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

Overall, none of the sites indicate a temporal change in their rocky shore communities that would suggest a persistent change such as the arrival or loss of a key species. Instead, the intertidal communities show temporal fluctuations that reflect mostly the dominance of ephemerals over one or more years, often with a concomitant decline in filter feeders (e.g. Schaapen West in 2008). Ephemeral algae are usually the first to colonize rock space denuded of biota due to physical (e.g. wave action) or biological (e.g. grazing) disturbance. In the ecological succession that follows, ephemerals are then replaced by longer-lived late successional species (Sousa 1979b, 1984). As low percentages of ephemerals were recorded in 2014, it is unlikely that any disturbance or pollution events have occurred close to the study sites and the small fluctuations of functional groups over the years are likely to be a natural seasonal and inter-annual phenomenon.

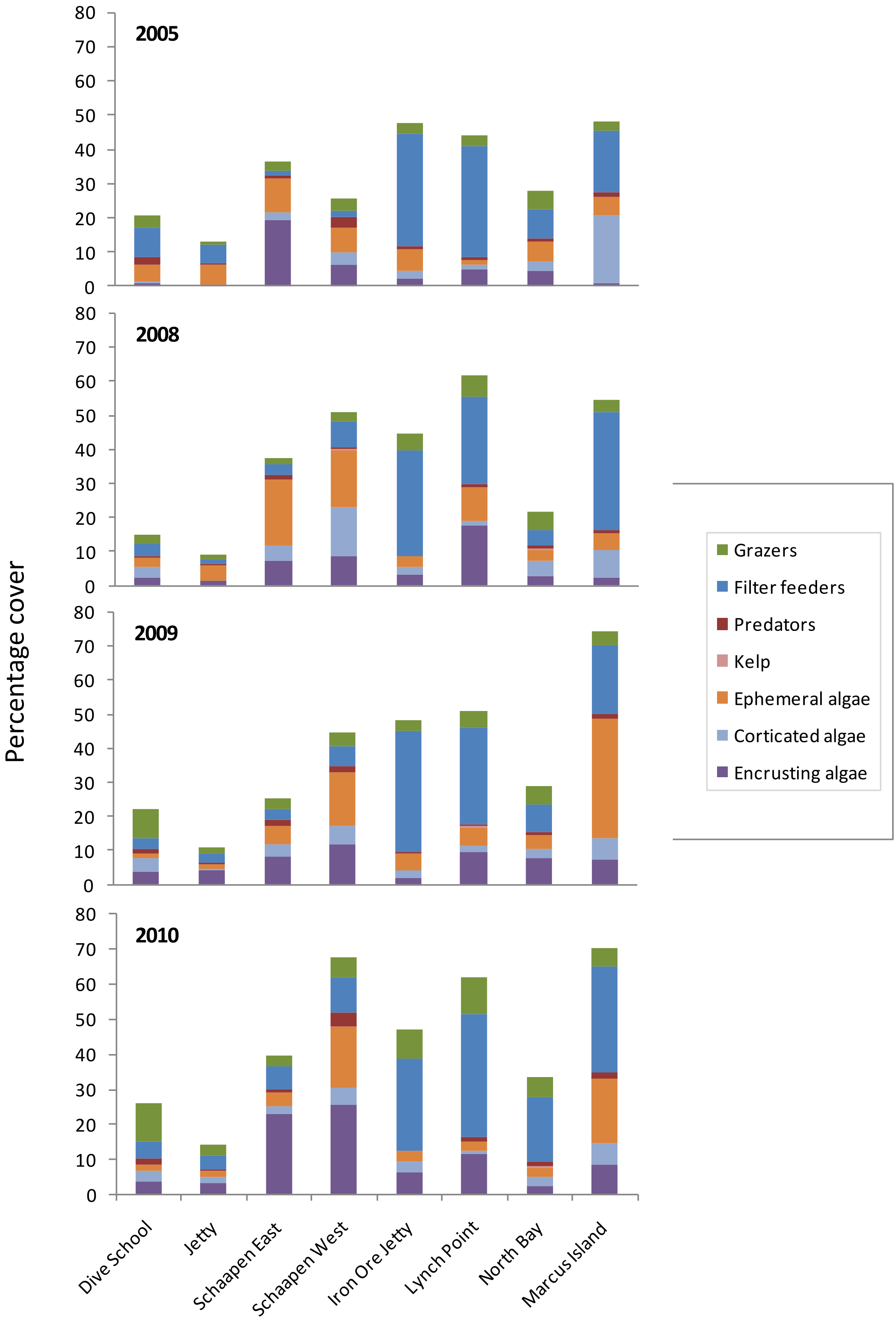


Figure 8.14 **Total percentage cover (averaged across the whole shore) of the various functional groups at the eight study sites from 2005 to 2010.**

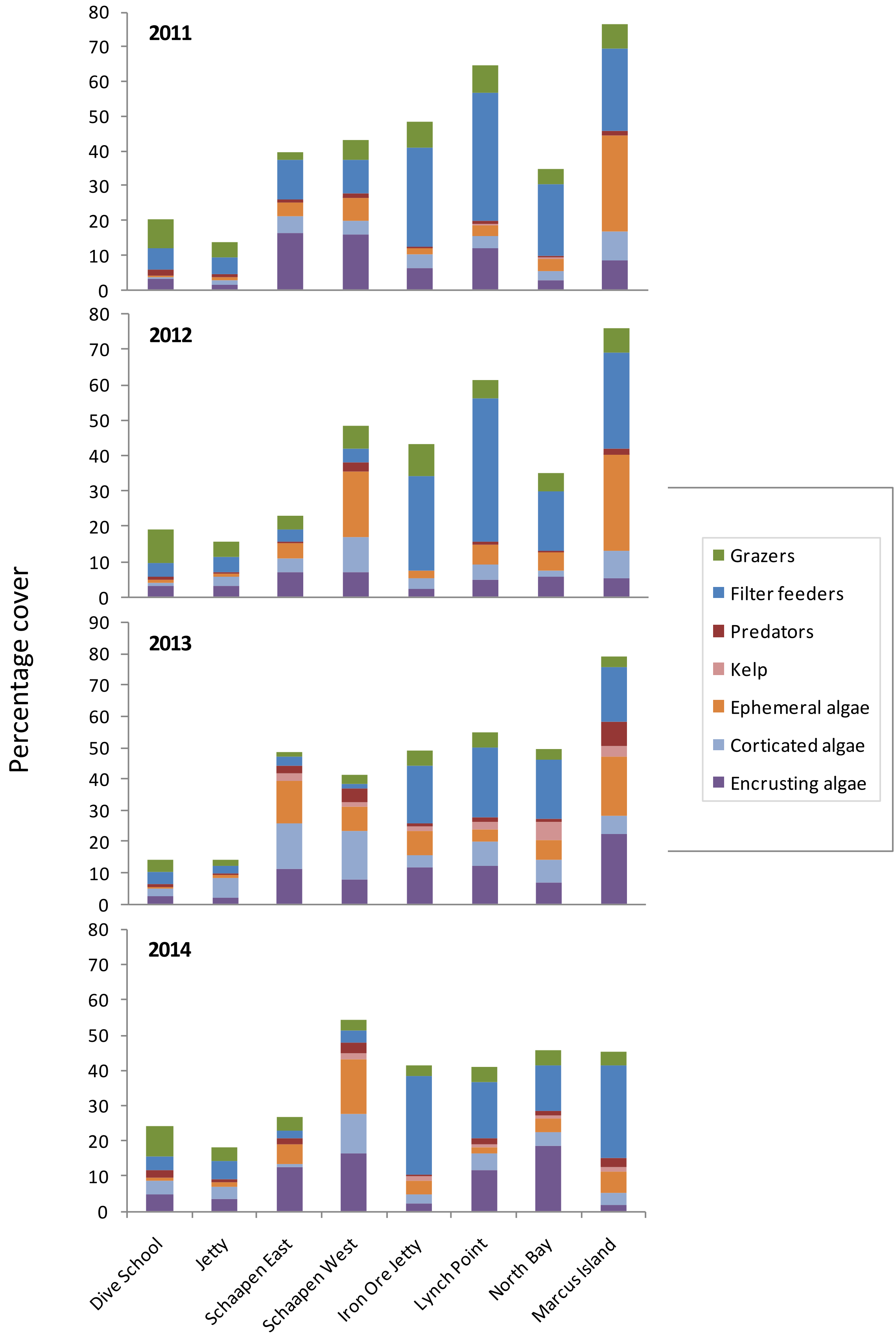


Figure 8.15 **Total percentage cover (averaged across the whole shore) of the various functional groups at the eight study sites from 2011 to 2014**

8.3.4 Summary of findings

A total of 128 taxa were recorded from the eight study sites, most of which had been found in previous survey years. The faunal component was represented by 25 species of filter-feeders, 27 species of grazers, and 23 species of predators and scavengers combined. The algal component comprised 39 corticated (foliose) seaweeds, seven ephemerals, five species of encrusting algae, and two species of kelp. The species recorded in Saldanha Bay 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*. During the present survey, it was confirmed that two additional alien barnacle species were present: *Amphibalanus amphitrite amphitrite* and *Menesiniella regalis*.

Within a site, the vertical emersion gradient of increasing exposure to air resulted in a clear zonation of flora and fauna from low shore to high shore. Differences among the rocky shores, however, were 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, with minor cover of sessile filter feeders and algae. Sheltered shores were dominated by seaweeds and encrusting corallines. With increasing wave exposure filter feeders were clearly the most important group. The two very sheltered boulder beaches in Small Bay separate from the flat Schaapen Island sites. This result may be related to geographic location as Schaapen Island lies in a transitional zone between the Bay and the Lagoon. In addition, nutrient input in the form of seabird guano favours algal growth on Schaapen Island. The steep boulder beach Iron Ore Jetty also separates from the more flattish semi-exposed to exposed sites.

From the temporal variation evident in the rocky shore communities, it appears that there is no directional change in community composition that would indicate a persistent change, such as the arrival or loss of a species. Instead the communities demonstrate temporal fluctuations, reflecting the temporary dominance of short-lived ephemeral species and/or inter-annual 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 were the aliens *M. galloprovincialis* and *B. glandula.* These were the characteristic species at most shores and zones. The latter is most abundant in the mid shore zone of semi-exposed sites, but rarer at exposed sites and low shores. *Mytilus galloprovincialis*, on the other hand, is most abundant at wave-exposed sites and lower down the shore. 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 & 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 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, hound sharks and elf 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 (Næsje *et al.* 2008, Kerwath *et al.* 2009, Tunley *et al.* 2009, Attwood *et al.* 2010, Hedger *et al* 2010, da Silva *et al* 2013). Key findings of these studies include evidence that the Langebaan lagoon Marine Protected Area (MPA) effectively protects white stumpnose, during the summer months that coincides with both peak spawning and peak recreational fishing effort (Kerwath *et al.* 2009). Elf and smooth hound sharks were also shown to derive protection from the MPA with tagged individuals of both species spending the majority of the study period (up to 2 years) within the MPA boundaries, and indeed a high degree of residency within Saldanha Bay as a whole (Hedger *et al* 2010, da Silva *et al* 2013). Tagged elf did show a long term movement out of the lagoon into the Bay and one individual was recaptured in Durban confirming that long distance migration does take place (Hedger *et al* 2010). However, the fact that nearly all fish within the Bay were resident for the one - two years after tagging and the presence of young of the year juveniles in the surf zone suggests that elf within Saldanha Bay exhibit a mixed evolutionary strategy with migratory and resident spawning components (Hedger *et al* 2010). Out of the 24 hound sharks acoustically tagged within Langebaan lagoon, 15 were monitored for more than 12 months and two of these did not leave the MPA at all. Six of these tagged hound sharks left the Saldanha embayment for the open coast, during spring and winter for periods of between two to 156 days, but all returned during the study period. These acoustic telemetry studies have clearly demonstrated that these three priority fishery species all derive protection from the Langebaan MPA.

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) in combination with the protection afforded by the MPA are probably part of the reason that stocks fishery species in Saldanha and Langebaan have to date, been resilient to rapidly increasing recreational fishing pressure (but see paragraph below on stock status). 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 most recent data on the stock status of white stumpnose, the most important angling species within Saldanha-Langebaan, however, shows that the stock is fully exploited or overexploited, suggesting that the Langebaan MPA alone may not be enough to prevent stock collapse with the increases in fishing pressure (Arendse 2011). This author used catch-at-age data from the boat fishery and per-recruit modelling to estimate that spawner biomass at the time (2006-2008) was less than 25% of pristine. The target reference point for optimally exploited stocks is 40-50% of pristine biomass and Arendse (2011) calculated that a 20% reduction in fishing mortality was required to achieve this target. It was recommended by Arendse (2011) that a reduction in bag limit from 10 to 5 fish per person per day, or an increase in size limit to 29 cm Total Length (TL) be implemented.

These management measures were modelled to rebuild spawner biomass to the 40-50% target, but unfortunately have not been implemented to date.

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, and annually over the period 2008-2014 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. In the 2012 report, data on the commercial catch and effort of harders (the principal target of the net fisheries in the Bay) were 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.

This report presents and summarizes the data for the 2013 and 2014 seine-net surveys and investigates trends in the fish communities by comparing this with data from previous seine-net surveys (1986/87, 1994, 2005, 2008-2012) in the Saldanha- Langebaan system.

9.2 Methods

9.2.1 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 over the period 2008-2012, 2-3 hauls have been made at each of 15 sites every April. During the 2013 and 2014 surveys a sixteenth site was added in the lagoon at Rietvlei (Figure 9.1). A new site (Danger Bay) on the open coast to the north of Saldanha Bay was sampled for the first time in 2014. As this site lies outside of the Saldanha Bay- Langebaan lagoon system, data from this site are presented separately and are not included in the summary graphs or statistical comparisons. Large hauls were sub-sampled on site, the size of the sub-sample estimated visually and the remainder of the catch released alive.

Data analysis

Numbers of fish caught were corrected for any sub-sampling that took place in the field 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. The resulting fish 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 in Small Bay, Big Bay and Langebaan lagoon 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. Trends in the abundance of key species that are of importance in local fisheries over time were analysed using a one way ANOVA and post-hoc unequal N HSD tests in STATISTICA 12. Abundance data for all sites throughout the Bay were log (x + 1) transformed to account for heteroscedacity prior to analysis.

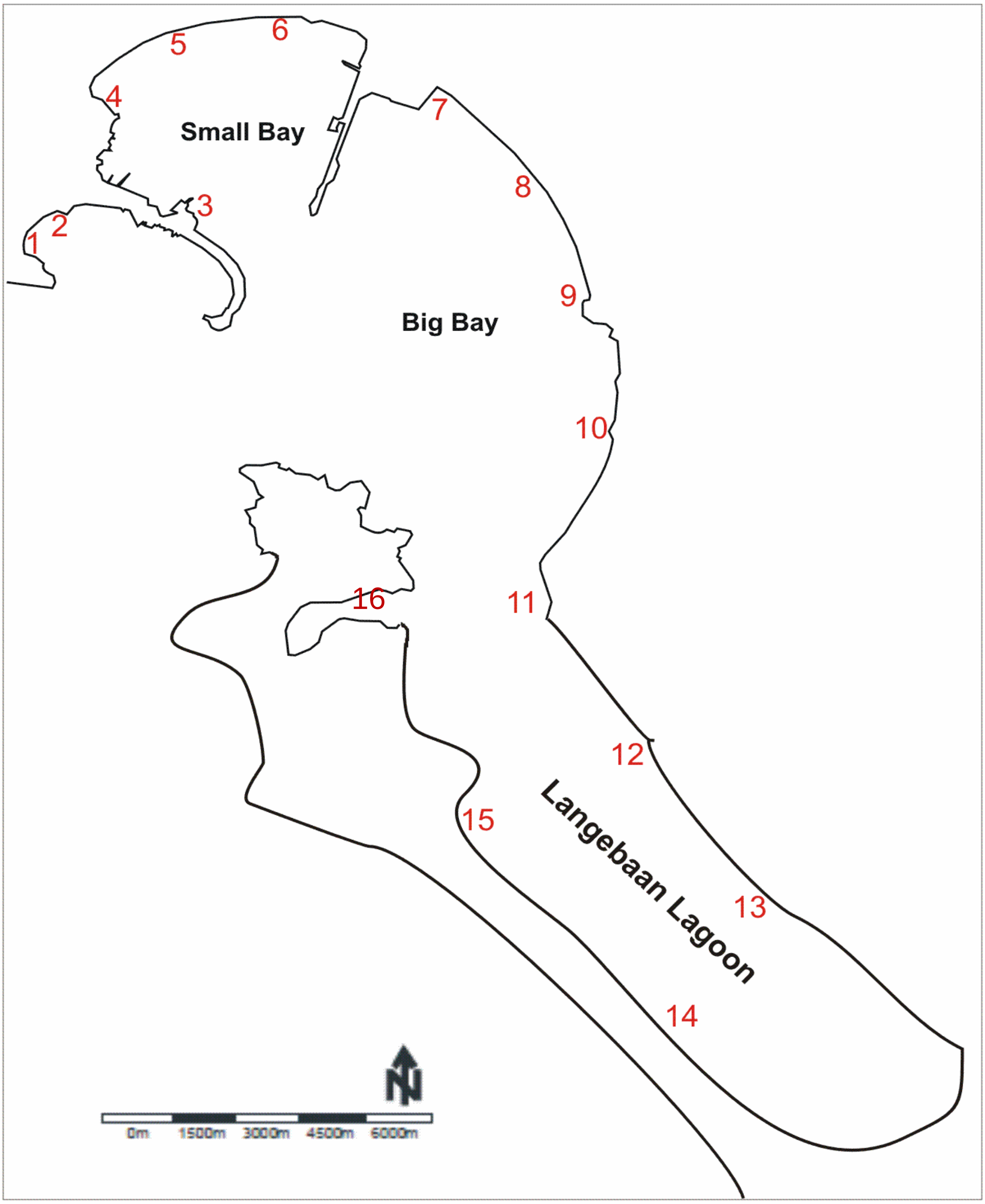


Figure 9.1. **Sampling sites within Saldanha Bay and Langebaan lagoon where seine net hauls were conducted during the 2005 and 2007-2014 annual sampling events. 1: North Bay west, 2: North Bay east, 3:Small craft harbour, 4: Hoedjiesbaai, 5: Caravan site, 6: Blue water Bay, 7: Sea farm dam, 8: Spreeuwalle, 9: Lynch point, 10: Strandloper, 11: Schaapen Island, 12: Klein Oesterwal, 13: Bottelary, 14: Churchaven, 15: Kraalbaai, 16: Rietbaai.**

9.3 Results

9.3.1 Description of inter annual trends in fish species diversity

During the 2013 annual survey, three new species of clinid fish, *Clinus robustus, Clinus venustris* and *Clinus heterodon* were recorded for the first time. These species were found in low numbers (1-6 individuals) in hauls made in Big Bay and Small Bay. Saldanha Bay falls within the natural distribution range of these three Clinids. The total species count in all surveys to date now stands at 47 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), than in Small Bay (32) or the Lagoon (23) (Table 9.1, Table 9.2 & Table 9.3). Species richness is typically highest in Small Bay and has 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). Overall there is no indication of a trend in species richness over time in any of the three parts of the Bay.

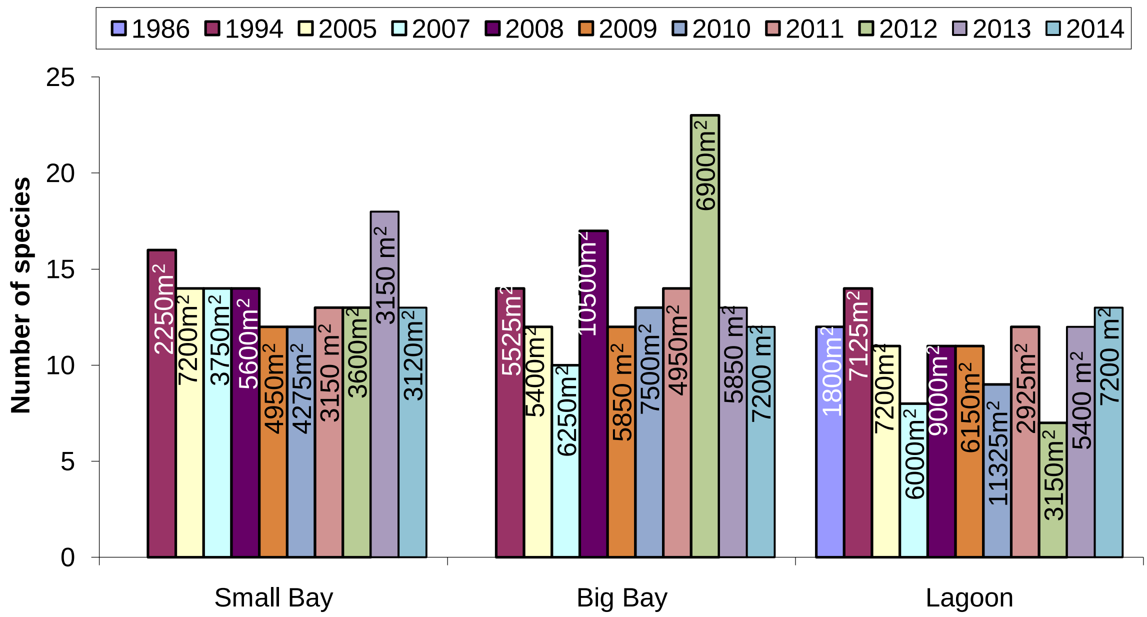


Figure 9.2. Fish species richness during 11 seine-net surveys in Saldanha Bay and Langebaan lagoon conducted over the period 1986-2014. The total area netted in each area and survey is shown. Note: The low species richness for Langebaan lagoon during 2012 is an artefact due to low sampling effort.

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 captured in all of the first six surveys, but not again since 2011. Four of the 33 species recorded in Big Bay occurred in all surveys (gurnard, Cape sole, harders and white stumpnose). Four more species, silversides, False Bay klipvis, elf and sand sharks are only absent in one survey each (2007, 1994, 2009 and 2014 respectively). Similarly, six of the 23 species found in the lagoon occurred in all surveys. 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). Over the past 10 sampling events average species richness has been similar in Small Bay and Big Bay (14 species) and on average slightly lower in the lagoon (11 species) (Figure 9.2).

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

The overall fish abundance (all species combined) shows high inter annual variability in all three areas of the Bay (Figure 9.3). Within the Saldanha-Langebaan system, harders numerically dominated the catches for all surveys and large variation in the catches of these abundant shoaling species is the cause of the observed variability between sampling years. 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. Overall abundance in 2013 remained lower than any of the earlier surveys in both Small Bay and Big Bay, but was higher than average in Langebaan Lagoon. In 2014 the overall abundance compared favourably with earlier surveys, however as stated above this is largely a result of good catches of harders and/or silversides.

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 may be 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. However, there is concerning trend that white stump and blacktail abundance during the last two years are amongst the lowest yet recorded for Small Bay. The estimated density of harders during 2012 and 2013 were well below average, but the second highest catches were recorded in 2014. Within Big Bay too, average fish density observed during the 2013 and 2014 sampling was comparable to earlier surveys, but white stumpnose density was the lowest on record for the last two consecutive years (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 2012-2014 surveys saw a similar situation (with the exception of harders and silverside), and it appears that the unfavourable environmental conditions or anthropogenic impacts 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 and 2012-2013 summers. The situation appears worst in Small Bay where only harders were recorded at densities similar to earlier surveys during 2013 and 2014. In contrast, the estimated abundance of the more common species in Langebaan lagoon during 2013 and 2014 compared favourably with earlier surveys (Figure 9.4). The exception was again white stumpnose and estimated abundance in Langebaan lagoon was also well below the average from all surveys.

Table 9.1. Average abundance of fish species (number.m^{-2}) recorded during annual beach seine-net surveys in Small Bay, Saldanha. Species sampled for the first time in an area are highlighted in bold font.

Year/species	Common name	Apr-94	Oct-05	Apr-07	Apr-08	Apr-09	Apr-10	Apr-11	Apr-12	Apr-13	Apr 14
Argyrozona argyrozona	silverfish								0.0002		
Atherina breviceps	Silverside	1.3084	0.0410	0.9690	1.6505	0.109	0.3397	0.6420	0.1539	0.0644	0.0745
Caffrogobius sp.	goby	0.0160	0.1294	1.0888	0.0162	0.019	0.0039	0.0307	0.0007	0.0011	0.0295
Cancelloxus longior	snake eel								0.0002	0.0008	
Cheilidonichthys capensis	gurnard	0.0022	0.0082	0.0003	0.0004	0.0006	0.0007				
Chorisochismus sp?	suckerfish sp.									0.0006	
Clinus latipennis	False Bay Klipvis					0.0004	0.0006			0.0017	
Clinus sp. larvae	Klipvis larvae				0.0004						
Clinus superciliosus	super klipvis	0.0080	0.0028	0.0090	0.0142	0.0030	0.0017	0.0250	0.0588	0.0003	0.0868
Clinus robustus	robust Klipvis									0.0008	
Clinus venustris	bluntnose klipvis									0.0017	
Clinus heterodon	west coast Klipvis									0.0072	
Dasyatis chrysonota	blue Stingray									0.0011	
Diplodus sargus capensis	black tail	0.0022	0.0178	0.0532	0.4437	0.062	0.0011	0.0007	0.0390	0.0069	0.0014
Etrumeus terres	red eye sardine	0.0009									
Gilchristella aestuaria	estuarine round herring		0.0026								
Gonorhynchus gonorhynchus	beaked sand eel		0.0001		0.0004						
Haploblepherus pictus	dark shy Shark					0.0002		0.0019	0.0011		0.0006
Heteromycteris capensis	Cape sole	0.0049	0.0017	0.0162	0.0022	0.026	0.0108	0.0185	0.0042	0.0039	0.0053
Lithognathus sp	steenbras sp.		0.0079								
Liza richardsonii	harder	0.6951	0.5847	2.1429	0.8742	0.4181	1.1895	38.4739	0.1075	0.2625	3.1544
Mustelus mustelus	smoothhound shark	0.0027		0.0009							
Myliobatis Aquila	eagle ray	0.0013	0.0004	0.0079				0.0004			
Parablennius cornutus	blenny									0.0014	
Pomatomus saltatrix	elf	0.0009		0.0013	0.0003			0.0007			0.0030
Poroderma Africana	striped catshark	0.0009									
Psammogobius knysnaensis	Knysna sand gobi						0.0028		0.0037	0.0011	0.0071
Raja clavata	thornback skate			0.0011							
Rhabdosargus globiceps	white stumpnose	0.0618	0.0079	5.0564	0.4191	0.0562	0.0822	0.0244	0.0640	0.0019	0.0318
Rhinobatos blockii	bluntnose guitar fish	0.0009	0.0013	0.0153	0.0007	0.0010	0.0008	0.0006	0.0012	0.0014	0.0072
Spondyliosoma emarginatum	steentjie	0.0013	0.0092		0.0003			0.0237			0.0002
Syngnathus temminckii	pipe fish	0.0022		0.0037	0.0257	0.0004	0.0035	0.0033	0.0148	0.0069	0.0011
Trachurus trachurus	horse mackerel				0.0094						
Total		**2.11**	**0.81**	**9.37**	**3.46**	**0.70**	**1.64**	**39.25**	**0.31**	**0.37**	**3.40**
Number of species	**32**	**16**	**14**	**14**	**15**	**12**	**12**	**13**	**13**	**18**	**13**
Number of hauls	**103**	**5**	**12**	**6**	**12**	**12**	**12**	**12**	**9**	**12**	**11**
Total area sampled (m^2)	**41 135**	**2250**	**7200**	**3750**	**5600**	**4950**	**4275**	**3150**	**3600**	**3150**	**3210**

Table 9.2. Average abundance of fish species (number.m^{-2}) recorded during annual beach seine-net surveys in Big Bay, Saldanha.

Year/species	Common name	Apr-94	Oct-05	Apr-07	Apr-08	Apr-09	Apr-10	Apr-11	Apr-12	Apr-13	Apr-14
Atherina breviceps	silverside	0.0003	0.0025		0.1257	0.094599	0.02889	0.1679	0.0059	0.0061	0.183
Blennophis sp	blenny sp.		0.0001		0.0001						
Brama brama	angelfish								0.0001		
Caffrogobius sp.	goby				0.0002	0.003086		0.0005	0.0001		0.0001
Callorhinchus capensis	St Joseph	0.0017							0.0002		
Cancelloxus longior	snake eel		0.0001				0.0003	0.0004	0.0008	0.0001	0.0001
Cheilidonichthys capensis	gurnard	0.0021	0.0079	0.0005	0.0054	0.00216	0.0001	0.0063	0.0001	0.0007	0.0014
Cheilidonichthys kumu	bluefin gurnard								0.0002		
Chorisochismus sp?	suckerfish sp.				0.0001						
Clinus latipennis	False Bay klipvis		0.0017	0.0003	0.0007	0.000679	0.0002	0.0002	0.0009	0.0006	0.0032
Clinus sp. larvae	Klipvis larvae				0.0027					0.0002	0.0019
Clinus superciliosus	super klipvis	0.0037			0.0017	0.000556	0.0002		0.0011	0.0012	
Dasyatis chrysonota	blue stingray					0.00037	7.4E-05				
Diplodus sargus capensis	black tail			0.0004	0.0009						
Engraulis japonicus	anchovy						0.0002				
Galeichthyes feliceps	barbell								0.0001		
Gonorhynchus gonorhynchus	beaked sand eel	0.0005								0.0004	
Haploblepherus pictus	dark Shy Shark					0.000185					
Heteromycteris capensis	Cape sole	0.0725	0.0014	0.0897	0.0433	0.014074	0.01067	0.0086	0.0058	0.0043	0.0054
Liza richardsonii	harder	0.3877	0.2098	1.4077	0.1805	0.120123	0.2153	0.9968	0.0951	0.2099	0.3185
Mustelus mustelus	smoothhound shark	0.0013	0.0001						0.0004		
Myliobatis aquila	eagle ray	0.0049		0.0003							
Parablennius cornutus	blenny							0.0002			
Pomatomus saltatrix	elf	0.0005	0.0001	0.0159	0.0430		0.0068	0.0217	0.0101	0.0026	0.0008
Psammogobius knysnaensis	Knysna sand gobi			0.0006				0.0006			
Rhabdosargus globiceps	white stumpnose	0.003	0.0207	0.3358	0.2012	0.050062	0.05096	0.1341	0.0722	0.007	0.0006
Rhabdosargus holubi	Cape stumpnose							0.0007	0.0046		
Rhinobatos blockii	bluntnose guitar fish	0.0066	0.0022	0.0029	0.0019	0.000123	0.0009	0.0009	0.0013	0.0002	
Sardinops sagax	sardine								0.0007		
Sarpa salpa	streepie								0.0002		
Spondyliosoma emarginatum	steentjie	0.0004	0.0004		0.0003				0.0002		
Syngnathus temminckii	pipe fish	0.0002			0.0004	0.000185	0.0002	0.0002	0.0007	0.0002	0.0004
Trachurus trachurus	horse mackerel				0.0001				0.0002		0.0003
Zeus faber	John dory								**0.0002**		
Total		**0.48**	**0.25**	**1.85**	**0.61**	**0.29**	**0.31**	**1.34**	**0.17**	**0.23**	**0.52**
Number of species	**33**	**14**	**12**	**10**	**17**	**12**	**13**	**14**	**23**	**13**	**12**
Number of hauls	**156**	**14**	**12**	**6**	**18**	**18**	**18**	**18**	**16**	**18**	**18**
Total area sampled (m2)	**65 925**	**5525**	**5400**	**6250**	**10500**	**5850**	**7500**	**4950**	**6900**	**5850**	**7200**

Table 9.3. Average abundance of fish species (number.m^{-2}) recorded during annual beach seine-net surveys in Langebaan Lagoon.

Year/species	Common name	1986-87	Apr-94	Oct-05	Apr-07	Apr-08	Apr-09	Apr-10	Apr-11	Apr-12	Apr-13	Apr-14
Atherina breviceps	silverside	1.1916	1.1865	0.0524	0.0786	0.1416	0.0654	0.1206	0.2857	0.2280	3.5085	1.03841
Blennophis sp.	blenny sp.			0.0001								
Caffrogobius sp.	goby	0.0888	0.0608	0.1776	0.3072	0.0626	0.0748	0.0973	0.3764	0.0003	0.2022	0.17628
Cheilidonichthys capensis	gurnard		0.002	0.0038		0.0001					0.0004	0.00030
Clinus latipennis	False Bay klipvis			0.0163		0.0001	0.0002					0.00022
Clinus sp. larvae	Clinid larvae											
Clinus superciliosus	super klipvis	0.0698	0.0063	0.0006			0.0031					0.02802
Clinus heterodon	**west coast Klipvis**										**0.0339**	
Diplodus sargus capensis	black tail	0.0120					0.0003					
Heteromycteris capensis	Cape sole		0.0009	0.0014	0.0027	0.0331	0.0145	0.0148	0.0032	0.0003	0.0024	0.00925
Lichia amia	leervis		0.0002									
Liza richardsonii	harder	0.2452	0.7182	0.3452	3.8468	0.1548	0.3750	9.5032	1.572	0.2239	0.3548	0.3895
Parablennius cornutus	blenny						0.0002					0.0001
Pomatomus saltatrix	elf		0.0001					0.0002	0.0013		0.0024	
Poroderma africana	Striped catshark								0.001			
Psammogobius knysnaensis	Knysna sand gobi	0.0958	0.4916	0.1411	0.6768	0.2237	0.2736	0.1691	0.1176	0.1722	0.2317	0.27579
Rhabdosargus globiceps	white stumpnose	0.0009	0.0055	0.0001	0.2016	0.0354	0.0263	0.2445	0.0959	0.0146	0.0035	0.0006
Rhabdosargus holubi	Cape stumpnose								0.0114			
Rhinobatos blockii	bluntnose guitar fish		0.0176		0.0011	0.0008	0.0065		0.0005	0.0003		0.0002
Sarpa salpa	strepie										0.0204	
Solea bleekeri	blackhand sole		0.0006		0.0004	0.0003		0.0001	0.0003			
Spondyliosoma emarginatum	streepie	0.0001				0.0009		0.0001	0.0006			0.0001
Syngnathus temminckii	pipefish	0.0063	0.0007								0.0015	0.0003
Trachurus trachurus	maasbanker		0.0001								0.0013	
Total		**1.71**	**2.49**	**0.69**	**5.12**	**0.65**	**0.84**	**10.2**	**2.47**	**0.274**	**4.36**	**1.92**
Number of species	**23**	**9**	**14**	**11**	**8**	**11**	**11**	**9**	**12**	**7**	**12**	**13**
Number of hauls	**173**	**30**	**20**	**12**	**9**	**15**	**13**	**15**	**14**	**6**	**18**	**18**
Total area sampled (m2)	**84 675**	**18000**	**7125**	**7200**	**6000**	**9000**	**6150**	**11325**	**2925**	**3150**	**5400**	**7200**

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 2011-2012, as abundance was low throughout the system. The lower than average recruitment 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 (except for harders) at Small Bay sites does, however, appear more severe and sustained (was low since 2009) than that at Big Bay or Langebaan Lagoon and remains a cause for concern. During 2013 and 2014 sampling, the abundance of three out of the five most common species sampled in Small Bay (white stumpnose, silverside and black tail) were amongst the lowest on record, whilst only white stumpnose abundance was substantially lower than the historical average in Big bay and Lagoon catches. This indicates possible a possible decline in juvenile fish habitat quality in Small Bay and flags a concerning trend in the status of the white stumpnose stock throughout the Bay-Lagoon.

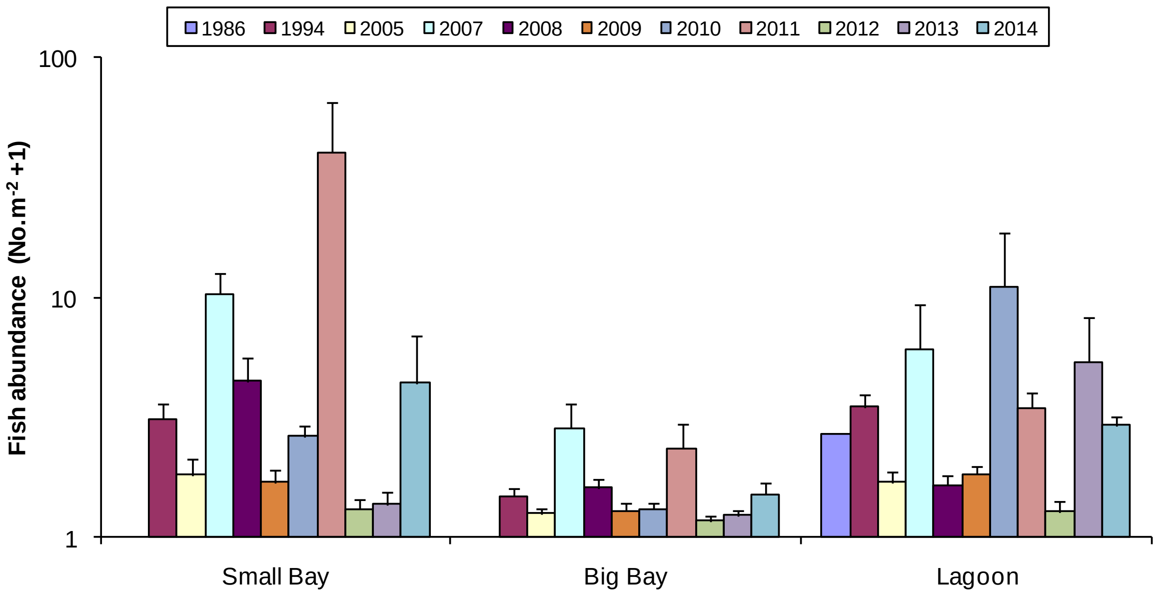


Figure 9.3. **Average fish abundance (all species combined) during nine annual seine-net surveys conducted in Saldanha Bay and Langebaan lagoon. (Error bars show one Standard Error of the mean). The data are transformed (x + 1) and displayed on a logarithmic axis.**

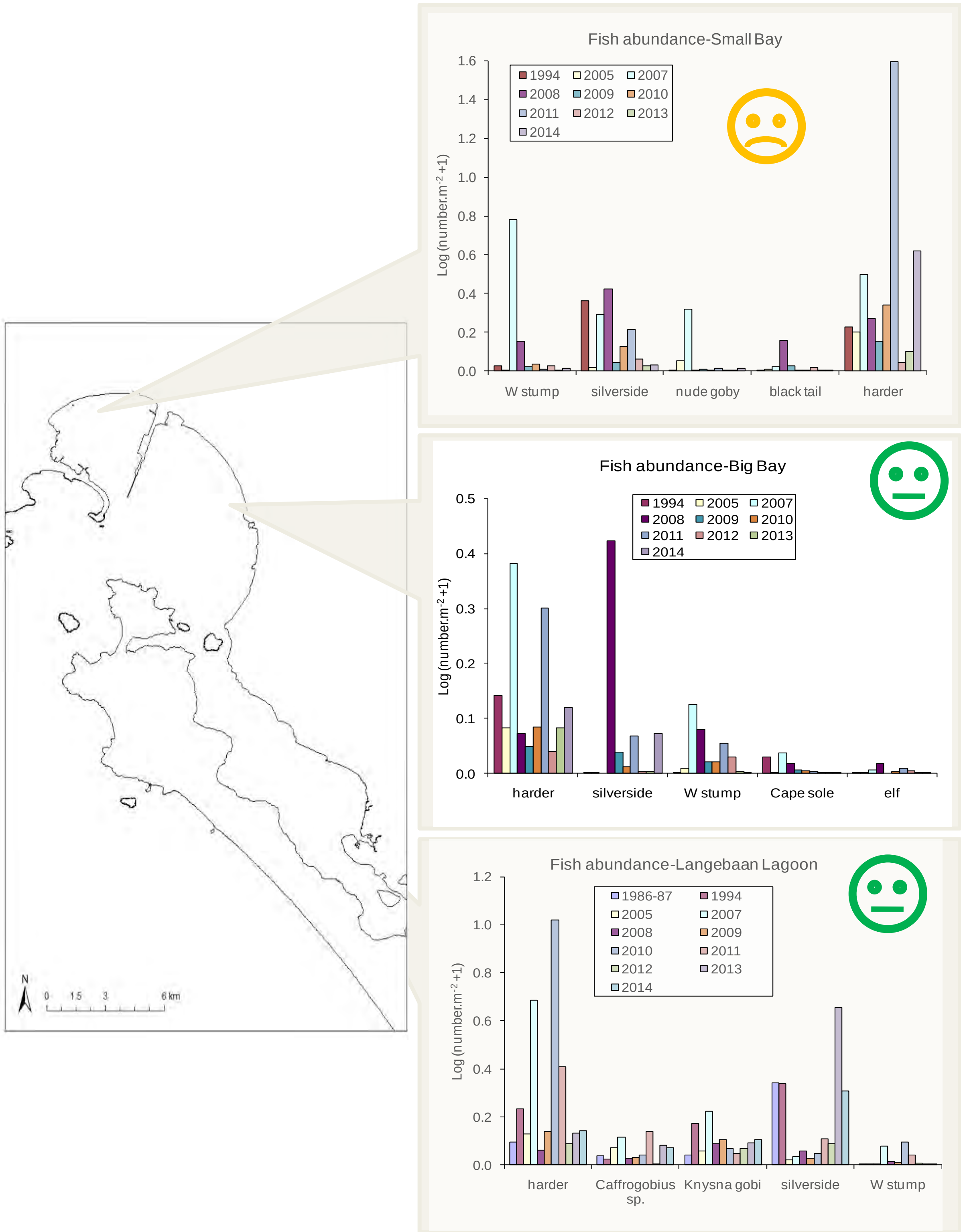


Figure 9.4. **Abundance of the most common fish species recorded in annual seine-net surveys within Saldanha Bay and Langebaan Lagoon (1986/87, 1994, 2005 & 2007-2014).**

9.3.3 Status of fish populations at individual sites sampled in 2013/2014

The average abundance of the four most common species in catches made during all earlier surveys and the most recent 2013 and 2014 surveys at each of the sites sampled is shown in Figure 9.5 , Figure 9.6 and 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). The substantial drops in the average abundance of all species except harders at all Small Bay sites in 2012 have continued with the 2013 and 2014 surveys (Figure 9.5). With the exception of harders, the average abundance of these species at all sites is significantly lower than the average recorded over the previous nine surveys.

At all the Big Bay sites, however, catches of harders and silversides during 2013 and 2014 are similar to or greater than those made in the past. White stump catches at all Big Bay sites are significantly lower than the long-term average (Figure 9.6). 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, 2013 and 2014 surveys 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 these years did adversely affect sampling efficacy, but this is the norm at these sites and good catches were made in the past, despite the presence of weed. Although the average densities of these more common species are highly variable between years, it is clear that the average abundance of most species within Small Bay had decreased substantially (with the exception of harders), but within Big Bay and Langebaan Lagoon, they were of a similar magnitude to the historical average with the exception of white stumpnose (Figure 9.5 , Figure 9.6 & Figure 9.7). Despite the difficulties experienced when sampling some of the Small Bay sites this is a concerning trend, possibly indicating a decrease in habitat quality for juvenile fish within Small Bay. The on-going trend of decreasing abundance of juvenile white stumpnose at all sampled sites is extremely concerning and may indicate recruitment overfishing of this species within Saldanha Bay.

Only three species were caught in the three hauls conducted at Danger Bay during 2014 sampling. Diversity was low compared with catches made at most sites within the Saldanha Bay, therefore, and reflects the less sheltered, cooler and cleaner water found on the more exposed coast. These conditions are less suitable as a nursery area for many fish species in that they do not offer the increased turbidity, temperature and food availability found within the Bay. Indeed two of the three species caught at Danger Bay, False Bay Klipvis (78 individuals) and Sand Sharks (2 individuals) are adults, whilst seven of the 10 harders caught were around 10 cm total length, nearly double the average size harder (6 cm) sampled within Saldanha Bay- Langebaan in 2014.

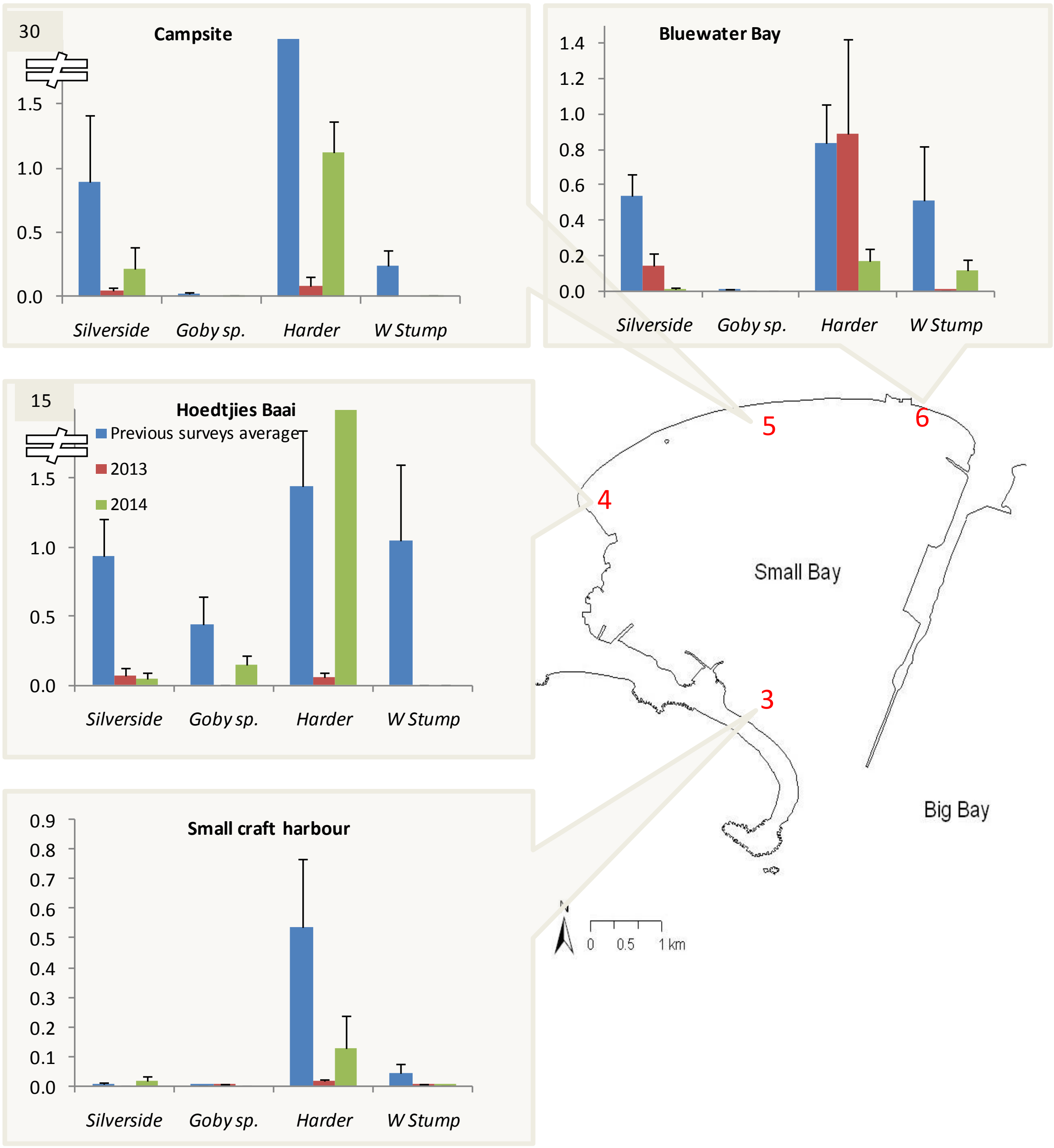


Figure 9.5. **Average abundance (#fish.m-^{2}) of the four most common fish species at each of the sites sampled within Small Bay during the earlier surveys (1994, 2005, 2007-2012) and during the 2013 and 2014 surveys survey. Errors bars show plus 1 Standard error.**

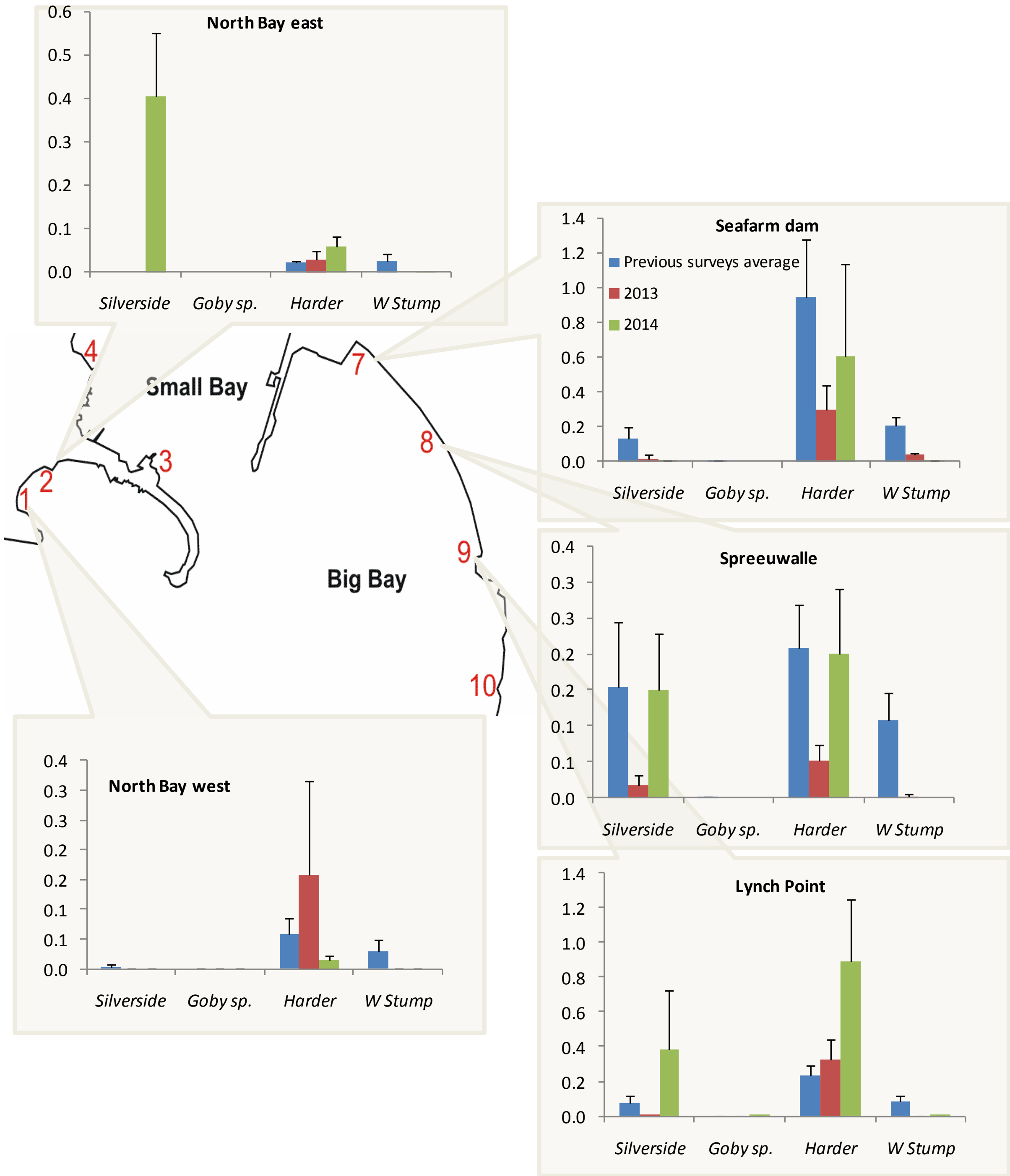


Figure 9.6. **Average abundance (#fish.m-^{2}) of the four most common fish species at each of the sites sampled within Big Bay during the earlier surveys (1994, 2005, 2007-2012) and during the 2013 and 2014 surveys. Errors bars show plus 1 Standard error.**

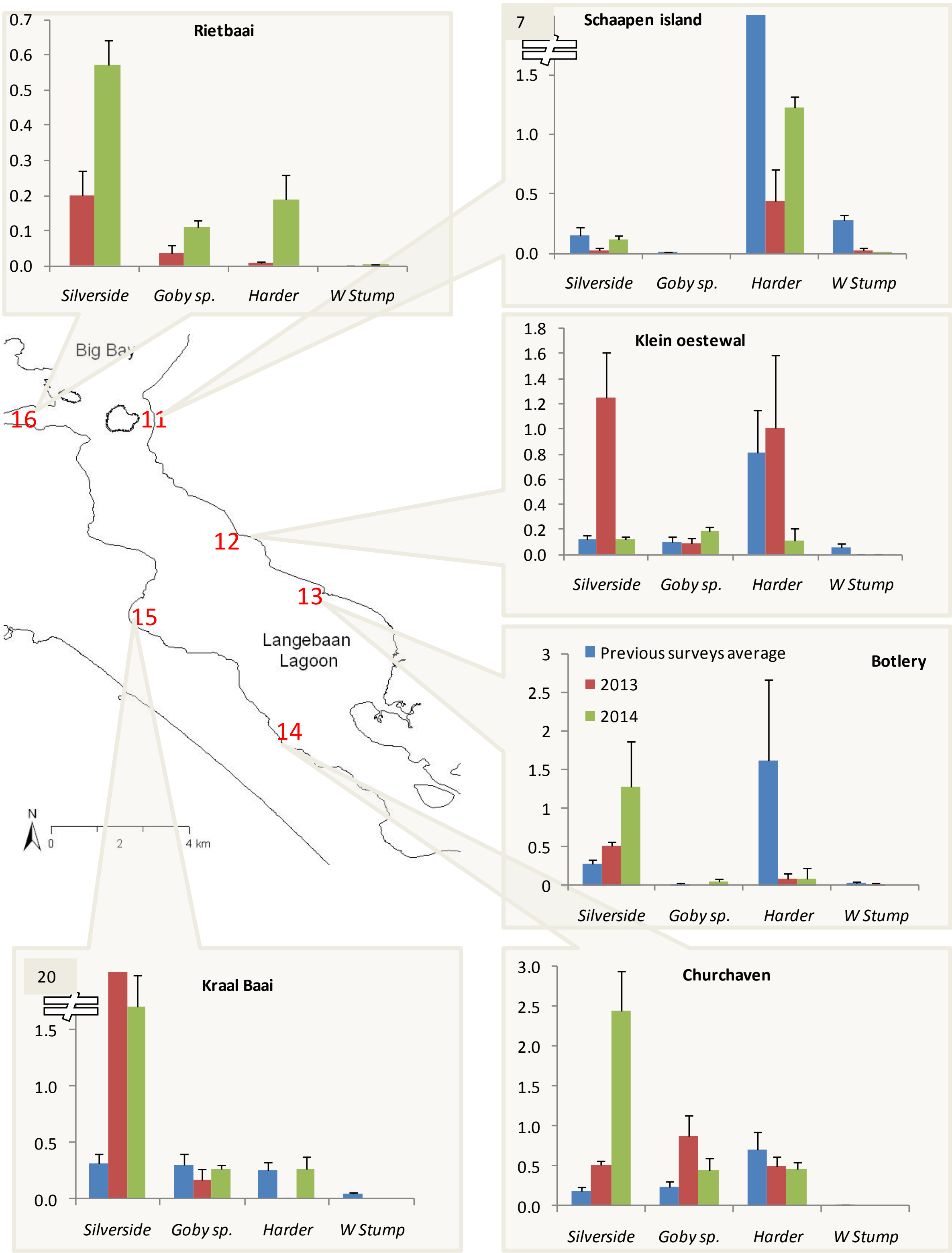


Figure 9.7. **Average abundance (#fish.m-²) of the four most common fish species at sites sampled within Langebaan lagoon during the earlier surveys (1994, 2005, 2007-2012) and during the 2013 & 2014 surveys. Errors bars show plus 1 standard error.**

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 subsequent reports, analysis focused 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.

Small Bay

The MDS plot for Small Bay shows that samples from most years grouped centrally (Figure 9.8). However, there does appear to be a pattern with a disproportionate number of samples collected in recent years (2011, 2013 and 2014) located to the lower left hand side of the MDS plot indicating that they are dissimilar to most of the samples collected in the earlier years. This suggests that there has been some change in the fish community over time (indicated by the arrow in Figure 9.8), although this is not consistent with 2012 samples located mostly within the centre cluster. Outliers around the central cluster in all years are mostly Small Boat harbour sites, reflecting the inter-site rather than temporal variation (this site typically has cooler, cleaner water than other and is a more reflective beach than the other Small Bay sites). In 2013 and 2014 however, Hoedtjies Bay and Campsite samples were also situated to the left or below the center cluster indicating that these were somewhat different from samples collected at these sites in earlier surveys.

A two way PERMANOVA indicated significant differences in the fish community between sample years (Pseudo F = 2.38, P< 0.001) and between sites (Pseudo F = 12.2, P< 0.001) and a significant interaction effect (Pseudo F = 2.9, P< 0.001). 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 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 2014 samples, whilst the 2013 samples were significantly different from the 1994, 2007 and 2008 samples (Table 9.4).

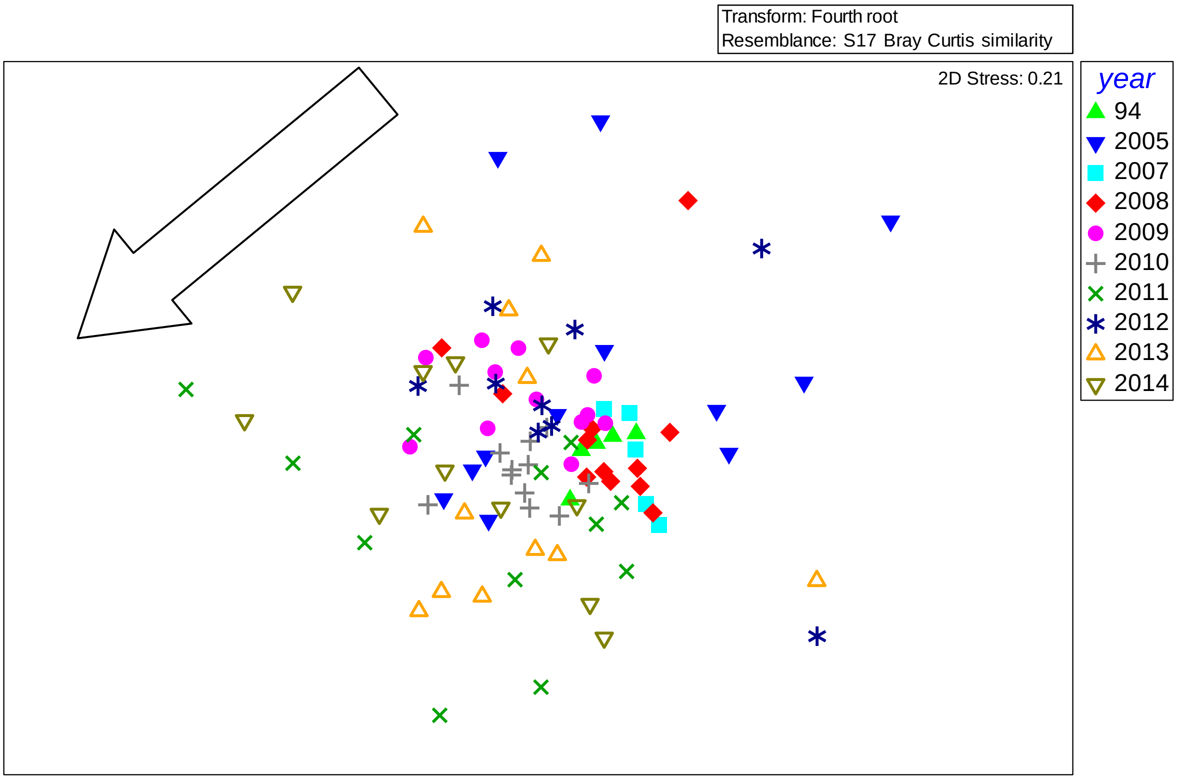


Figure 9.8. Multidimensional scaling plots showing similarities between the fish communities sampled at four sites within Small Bay during 1994, 2005, 2007-2014 sampling events. The block arrow indicates a possible change in fish community over time.

SIMPER analyses identified decreased average abundance of white stumpnose, gobies, black tail and sole in the 2013 and 2014 samples as the dominant causes of dissimilarity between the 2013 and 2014 samples and the 1994 samples. A decrease in abundance of these species was also major contributors to the significant dissimilarity between 2013 and 2007 and 2008 samples. As noted in the 2012 report, none of these species had disappeared from catches in Small Bay during the 2013 and 2014 surveys, but they were on average substantially less abundant than in nearly all of the earlier surveys and this is identified in the SIMPER analysis as a major cause of dissimilarity between these samples and earlier samples. This remains concerning, particular in the case of important fishery species and a univariate analysis for selected fishery species is presented in Section 9.4.

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	2012	2013
1994									
2005	**								
2007	**	NS							
2008	NS	*	NS						
2009	**	NS	NS	*					
2010	NS	*	NS	*	*				
2011	*	NS	*	NS	*	NS			
2012	**	NS	NS	NS	NS	NS	NS		
2013	*	NS	*	*	NS	NS	NS	NS	
2014	**	NS	NS	NS	NS	NS	NS	NS	NS

Big Bay

Within Big Bay, little grouping of sampling years in the MDS plot is evident with the 2008, 2008, 2012 and 2013 outliers representing more exposed sites including North Bay, Plankiesbaai and one Lynch Point 2012 sample (Figure 9.9). With the exception of two North Bay west 2013 samples all the remaining 2013 and 2014 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 = 7.7, P< 0.001), between sampling events (Pseudo F = 2.4, P< 0.01) and a significant interaction effect (Pseudo F = 2.5, P< 0.001). Pairwise testing showed that only the Big Bay fish samples collected during 2014 were significantly different from those collected during 2008, 2010 and 2012, and the 2012 samples were also significantly different from the 2009 and 2013 samples (P<0.05). SIMPER analysis identified the lower abundance of white stumpnose and elf, and higher abundance harders and silversides in the 2013 and 2014 samples as the principal contributors to differences in similarity with the 2008, 2010 and 2012 samples. Big Bay fish samples collected during all other years were statistically similar to those collected during 2013 and 2014, indicating no consistent change in the Big Bay surf zone fish community overall. However, it must be noted that a substantial decrease in white stumpnose abundance in the last two surveys was identified as one of the top contributors to dissimilarity between these two surveys and all other years (even when PERMANOVA did not indicate significant community level differences).

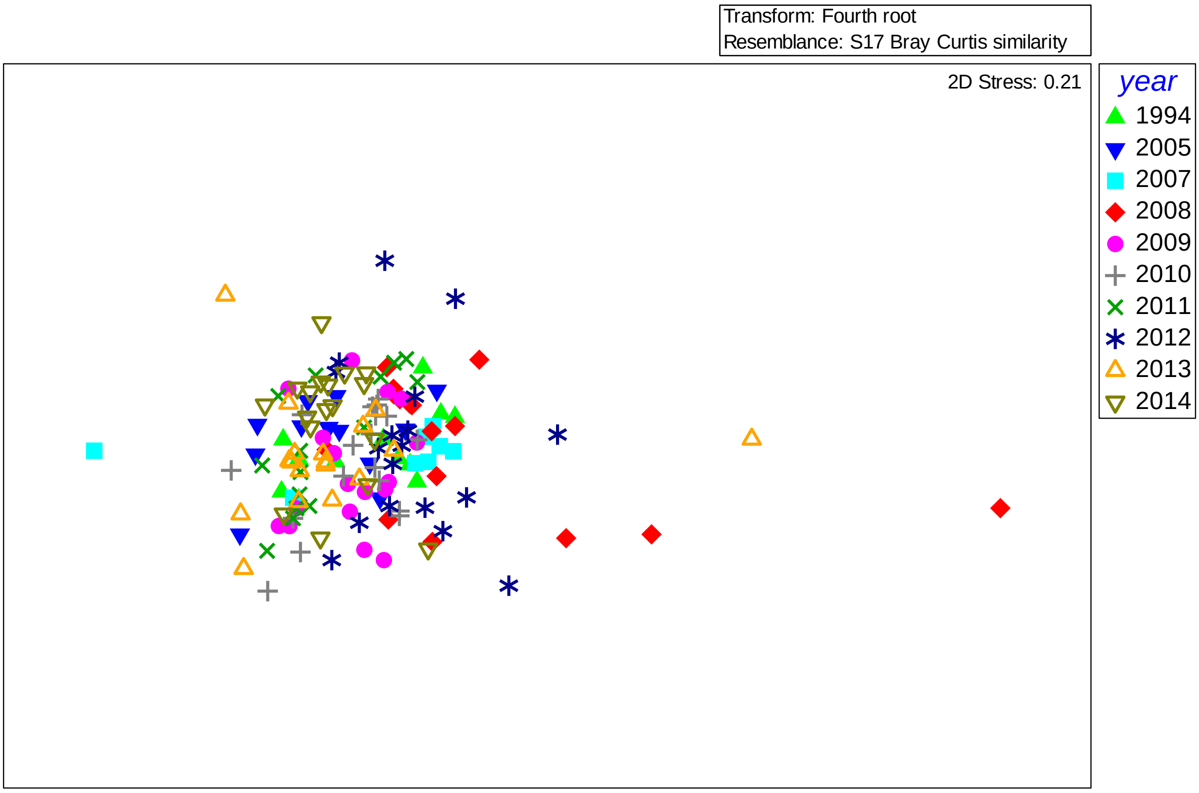


Figure 9.9. **Multidimensional scaling plot showing similarities between the fish communities sampled at seven Big Bay sites during 1994, 2005, 2007-2014 annual sampling events.**

Langebaan Lagoon

An MDS plot of Langebaan Lagoon fish samples shows some evidence of separation between sampling years; with the 2013 outliers on the right hand side of the plot representing Kraalbaai, Klein Oestewal and Rietbaai sites where relatively large catches of silversides or a zero catch of harders were made. The spread of sites on the left of the plot represent exclusively Schaapen Island hauls where depending on the tidal phase at the time of sampling, strong currents influence catches (Figure 9.10). A PERMANOVA test showed significant differences between sites (Pseudo F = 18.2, P< 0.001), between sampling events (Pseudo F = 3.9, P< 0.01) and a significant interaction effect (Pseudo F = 2.85, P< 0.001). Pairwise testing showed that fish catches in all years were different to samples collected in at least one other year (2007) and as many as six other years (2008 & 2011) (Table 9.5). Lagoon fish samples collected during the most recent 2013 and 2014 surveys were significantly different from those collected during 2008, 2009 and 2011 surveys. SIMPER identified greater catches of silversides and in some case harders, and substantially lower catches of white stump, and in most cases also Cape sole, in the 2013 and 2014 surveys as the principal contributing species to the dissimilarity between these two recent surveys and the early 2008-2011 surveys.

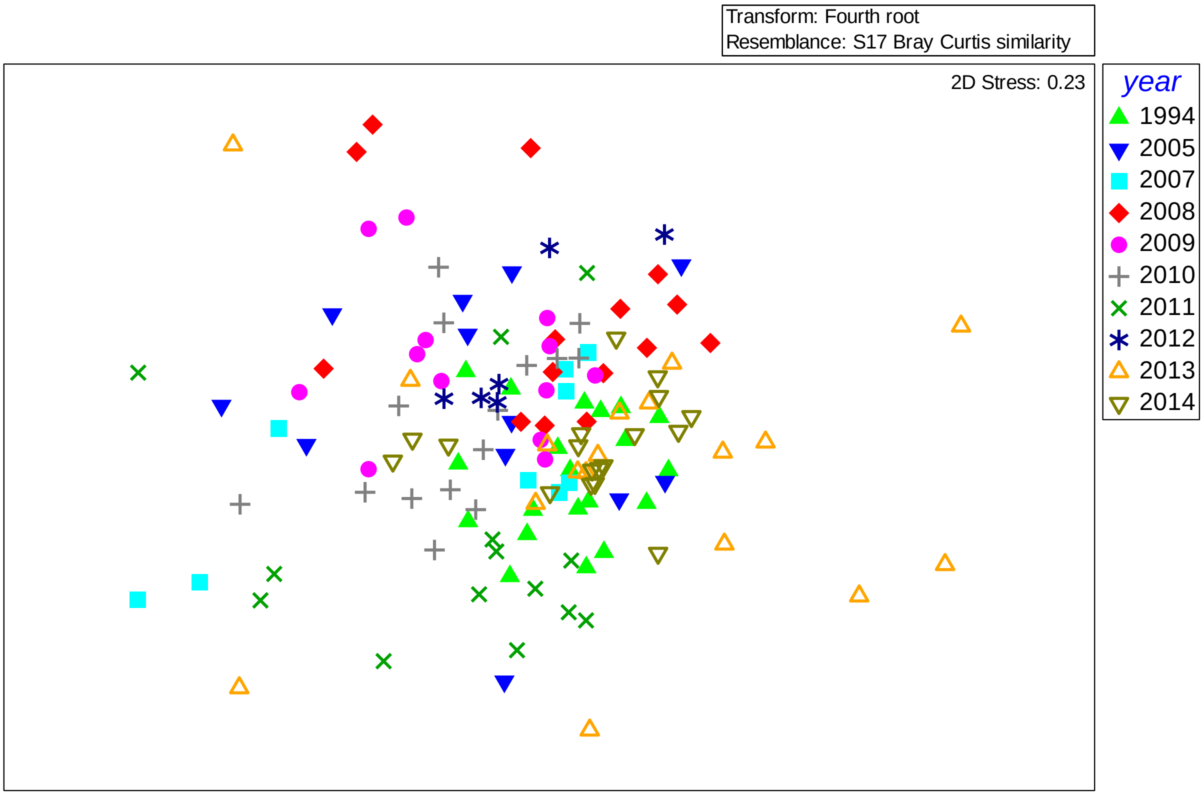


Figure 9.10. **Multidimensional scaling plots showing similarities between the fish communities sampled at six Lagoon sites during 1994, 2005, 2007-2014 sampling events.**

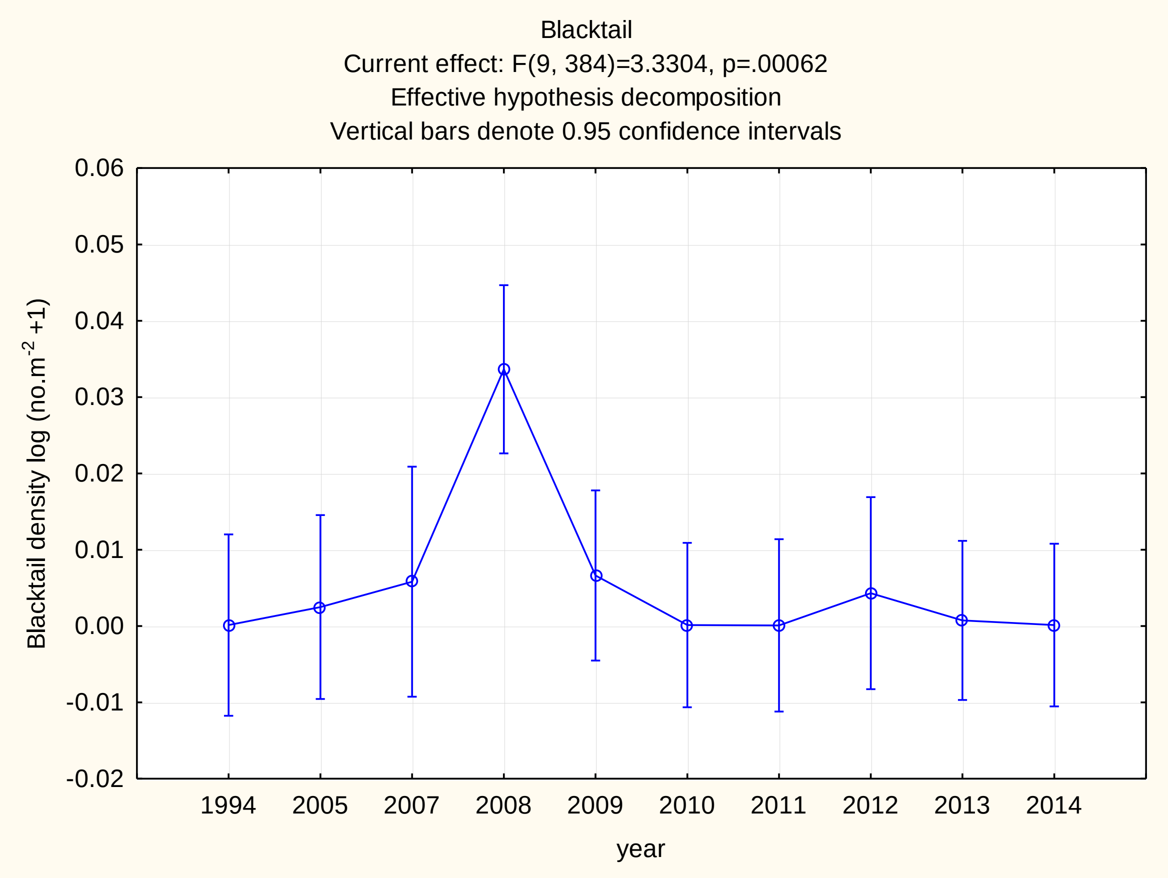
Table 9.5. **Results of the multivariate PERMANOVA pairwise tests between Langebaan fish samples collected in different years. NS: not significant, *: P < 0.05, **: P < 0.01**

	1994	2005	2007	2008	2009	2010	2011	2012	2013
1994									
2005	*								
2007	NS	NS							
2008	NS	NS	*						
2009	NS	NS	NS	*					
2010	*	NS	NS	*	NS				
2011	*	*	NS	**	*	NS			
2012	no test	no test	no test	no test	NS	NS	NS		
2013	NS	NS	NS	**	*	NS	*	NS	
2014	NS	NS	NS	*	*	NS	*	NS	NS

9.4 Univariate analysis of key fishery species trends

The spatially separate analysis of fish survey data by site or embayment (Big Bay, Small Bay and Langebaan Lagoon) is a valid approach for the purposes of ecosystem health monitoring whereby sites or areas of concern need to be identified. The analyses presented above have identified a concerning decrease in abundance most of the dominant species in Small Bay in recent surveys (2009 onwards) and a notable decrease in white stumpnose abundance throughout the system. The inter-annual variation in recruitment of white stumpnose could be due to natural variability in spawning success and survival (poor and good year classes are normal), but given the sustained declines throughout the system, and the findings of Arendse (2011), it appears that recruitment overfishing could be the cause. Recruitment overfishing can be defined as overfishing of the adult population so that the number and size of mature fish (spawning biomass) is reduced to the point that it did not have the reproductive capacity to replenish itself. To further investigate temporal variation in recruitment of species important in the Bay's fisheries (harders, blacktail, elf and white stumpnose) univariate statistical analysis (ANOVA) was used to test for significant differences between survey years. To deal with the observed spatial variability in survey catches and to account for the fact that Saldanha Bay- Langebaan Lagoon is a single system and different sites may be more utilized by juvenile fish in different years depending on prevailing weather and oceanography, abundance data for all sites was combined for this analysis.

These analyses revealed statistically significant inter-annual variation in the abundance of blacktail, harders and white stump, but not in the average density of elf and steentjies (Figure 9.11, Figure 9.12 & Figure 9.13). The density of blacktail juveniles in sampled habitats was significantly higher in 2008 than in all other years except 2007 (Figure 9.11). Inter annual variation in the abundance of harders was greatest, with estimated abundance in 2007, 2010 and 2011 significantly greater than most other sampling events (Figure 9.11). Estimated white stump abundance in 2007 was significantly greater than all other years, whilst the estimated abundance during the two most recent 2013 and 2014 was less than during all other years and significantly less than that recorded during the 2007 and 2008 surveys Recorded steentjie and elf abundance also showed inter-annual variation with relatively high average abundance of steentjie juveniles recorded in 2005 and 2011 and relatively high average abundance of elf juveniles in 2007, 2008, 2011 and 2012. The intra-annual (within year) variability in abundance of these two species, a result of a zero catch at many sites however, means that these differences are not statistically significant.



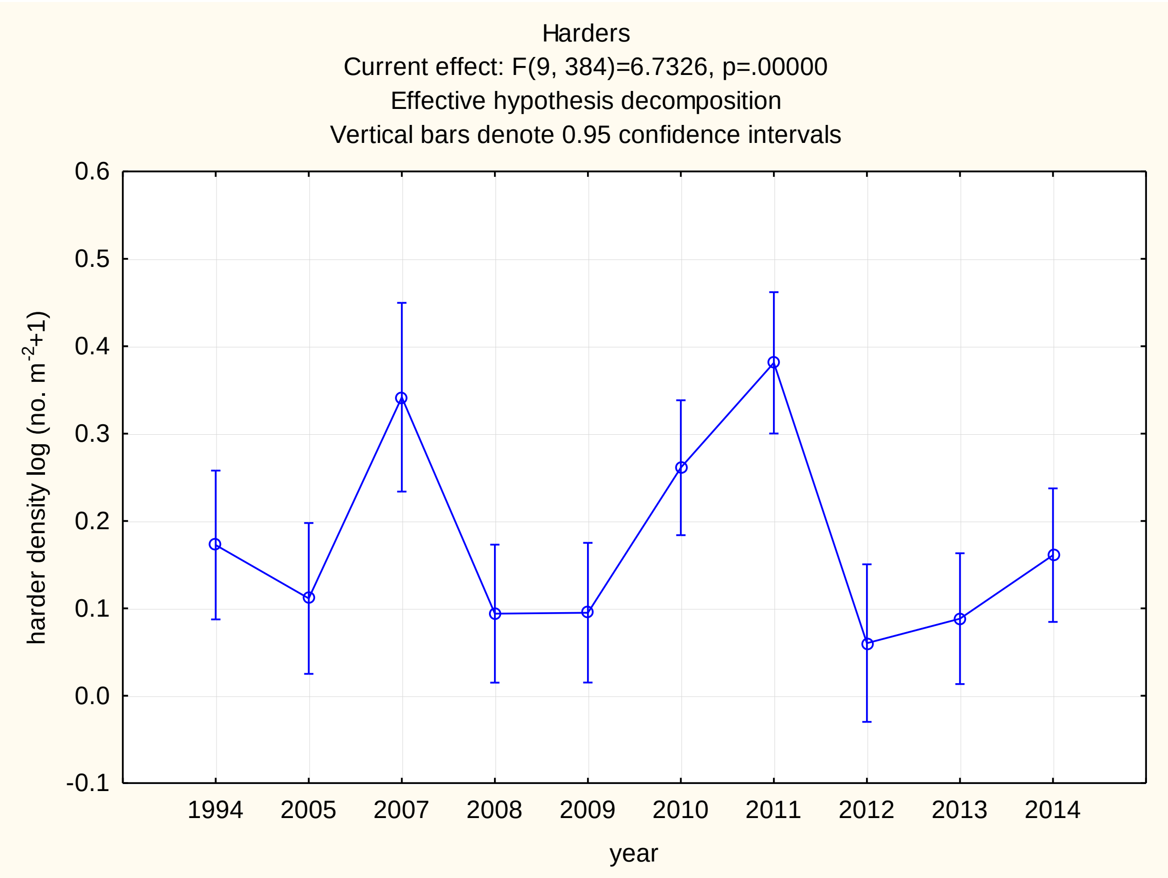


Figure 9.11. ANOVA results comparing the average annual density of blacktail and harders at all sites sampled in all surveys.

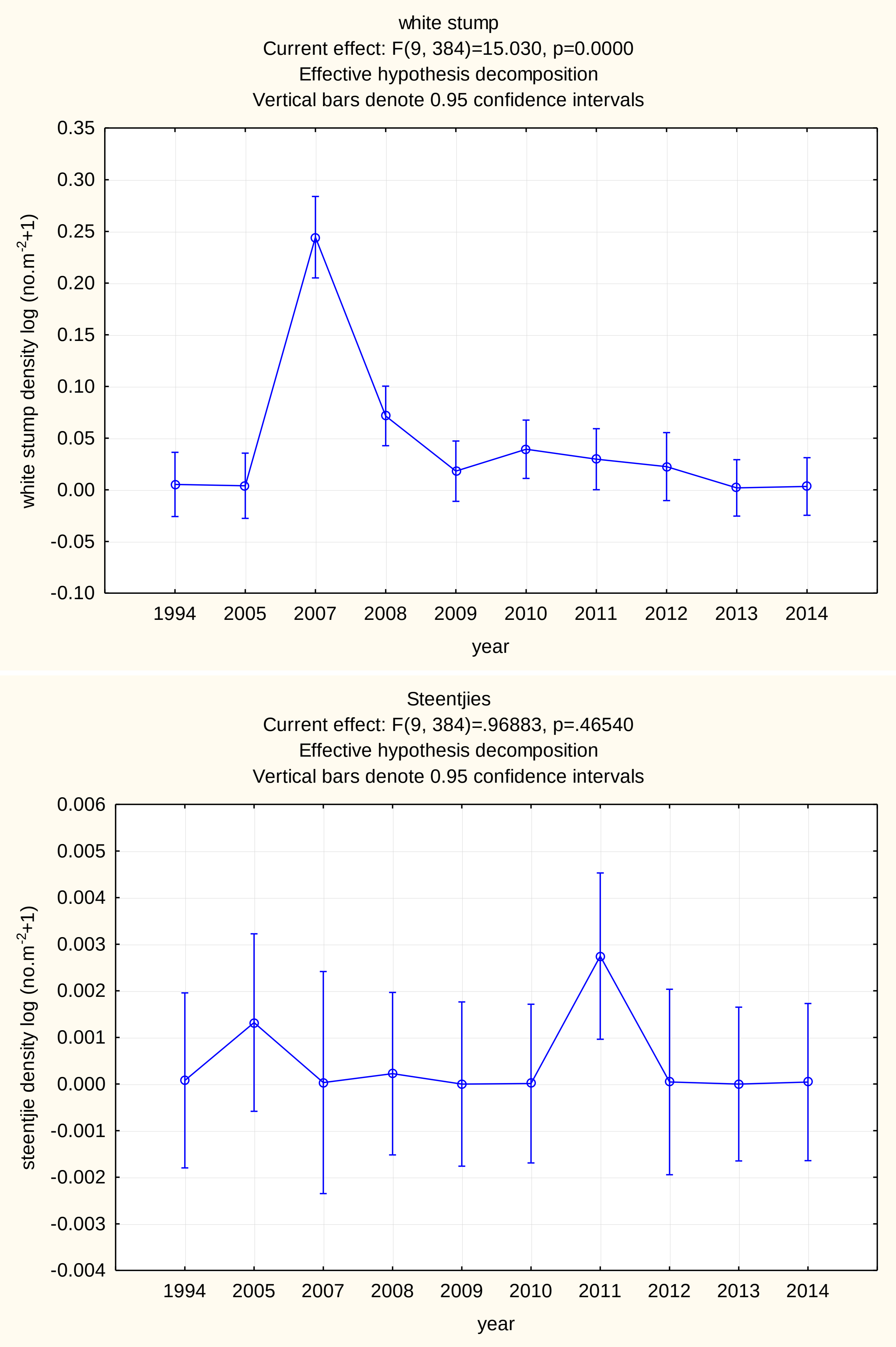


Figure 9.12. ANOVA results comparing the average annual density of white stump and steentjies at all sites sampled in all surveys.

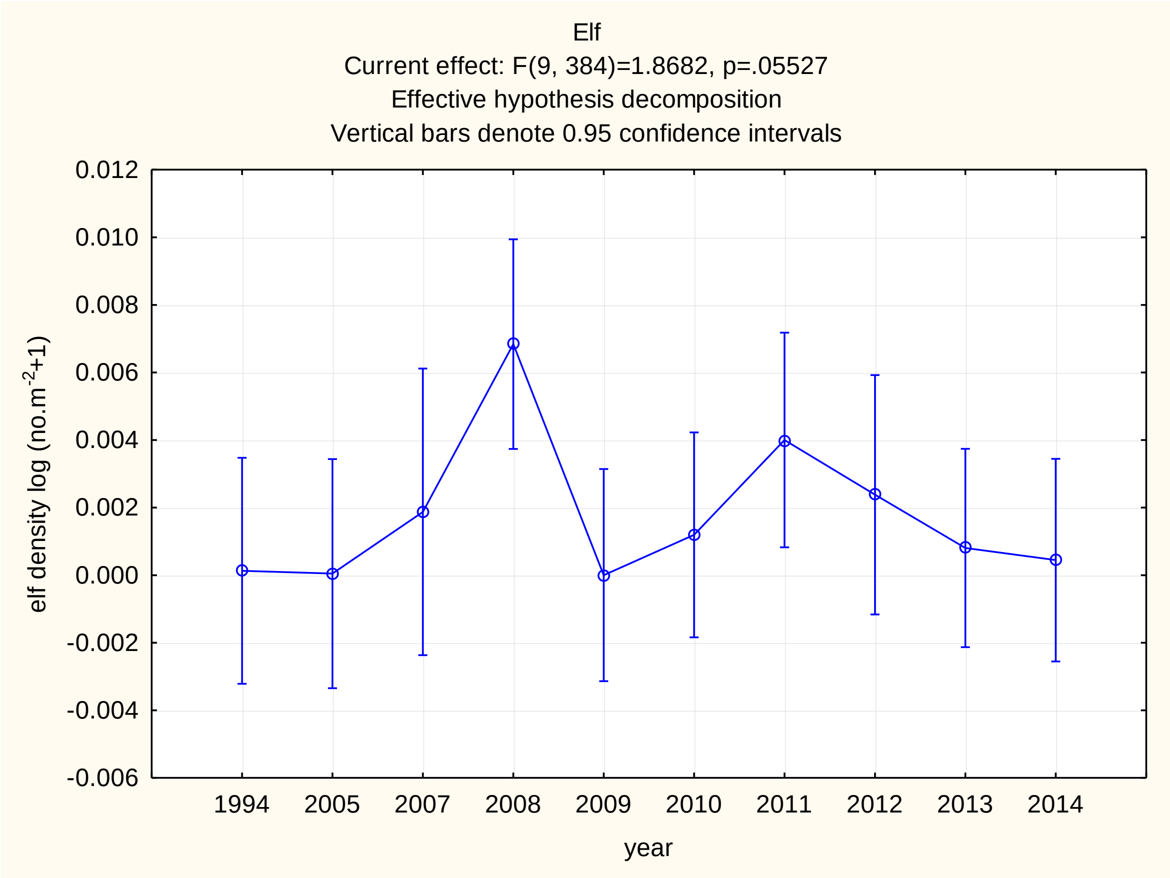


Figure 9.13. **ANOVA results comparing the average annual density of elf at all sites sampled in all surveys.**

9.5 Conclusion

With the exception of white stumpnose, the current status of juvenile fish communities within Big Bay and Langebaan lagoon appears satisfactory, whilst persistent declines in the abundance of common species (except shoaling harders) within Small Bay are occurring. 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 not been detected for the principal species found in Big Bay and Langebaan Lagoon. In fact, fish abundance at sites within or in close proximity to the Langebaan MPA appears to be stable within the observed inter-annual variability. 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 studies by Kerwath *et al.* (2009), Hedger *et al.* (2010) and da Silva *et al.* (2013) demonstrated the benefits of the MPA for white stumpnose, elf and smooth hound sharks; and the protection of harders from net fishing in the MPA undoubtedly benefits this stock in the larger Bay area.

The significant declines in white stumpnose abundance at all sites throughout the system in recent years, however, suggest that the protection afforded by the Langebaan MPA may not be enough to sustain the fishery at the current high effort levels. The low white stumpnose abundance in recent years may simply be a result of natural variability in recruitment strength (possibly at decadal time scales greater than the monitoring record). However, given the findings of Arendse (2011) who found the adult stock to be overexploited using data collected during 2006-08 already, this could indicate that recruitment overfishing is occurring and a precautionary approach is warranted. The annual seine net surveys can act as an early warning system that detects poor recruitment and allows for timeous adjustments in fishing regulations to reduce fishing mortality on weak cohorts and preserve sufficient spawner biomass. The consistent declining trend in juvenile white stump abundance in the nursery surf-zone habitats since 2007, with the two lowest abundance estimates emanating from the last two annual surveys, strongly supports the implementation of the harvest control measures recommended by Arendse (2011); namely a reduction in bag limit from 10 to 5 fish per person per day and an increase in size limit from 25 cm TL to 30 cm TL.

The 2013-2014 sampling events recorded average recruitment of common species such as harders, gobies and silversides within Big Bay and Langebaan Lagoon sites that are comparable with data from earlier surveys. In Small Bay, however, with the exception of harders, estimated abundance of key species was well below average, with the lowest yet recorded blacktail and white stump density and the 2cd and third lowest silverside density to date. This follows the trend observed since 2010/11 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 and Langebaan Lagoon. Multivariate analysis, however, indicated significant differences in the Small Bay fish community sampled during 2013 and 2014 from that sampled in 1994 and the 2013 samples were significantly different from those collected in 2007 and 2008. Decreased average abundance of white stumpnose, gobies, black tail and sole in the 2013 and 2014 samples were identified as the dominant causes of dissimilarity between the 2013 and 2014 samples and the 1994 samples. A decrease in abundance of these species was also major contributors to the significant dissimilarity between 2013 and 2007 and 2008 samples.

In the data set collected to date, the average density of commercially important fish, such as white stumpnose and harders, was much higher at Small Bay sites compared to Big Bay and Lagoon sites. Since 2011, however, estimated densities of these species were similar and low in both Big Bay and Small Bay. 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 0.05 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 industrialized 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 concerning trend in decreasing white stumpnose recruitment throughout the Bay makes it even more critical that the quality of what is demonstrably the most important white stump nursery habitat is maintained.

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 & 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. 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 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), Caspian (25 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 (Pichegru *et al.* 2009, Birdlife International 2011, Crawford *et al* 2011). The Namibian population collapsed in tandem with the collapse of its main prey species, the sardine (*Sardinops sagax*; Ludynia *et al.* 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 & 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 initially grew from 552 breeding pairs in 1987 to a peak of 2 156 breeding pairs in 2001 and then underwent a severe decline to just 314 breeding pairs in 2014 (Figure 10.1). 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.

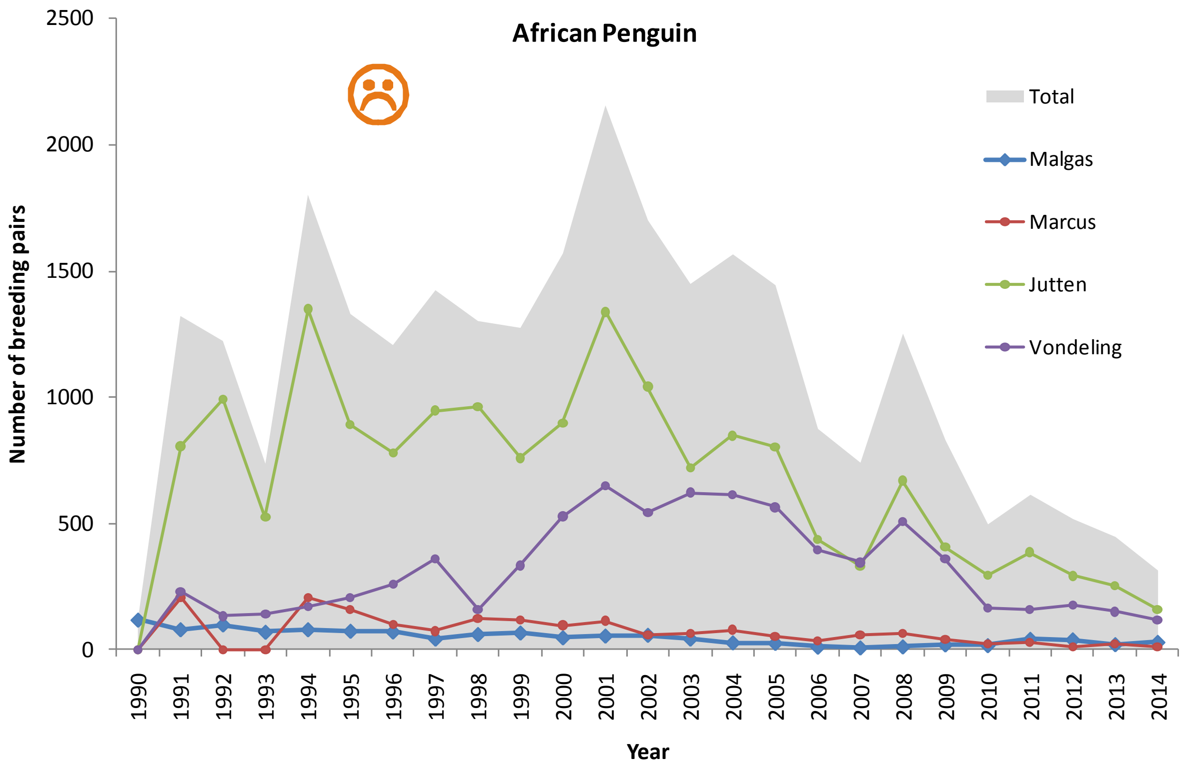


Figure 10.1. Trends in African Penguin populations at Malgas, Marcus, Jutten and Vondeling islands in Saldanha Bay (Data source: Makhado *et al* 2014, Department of Environmental Affairs: Oceans & Coasts).

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, experimental fishing closures at Dassen and Robben Islands have not delivered such positive results, resulting in published rebuttals labelling the findings of Pichegru *et al* (2010) premature.

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 rise in gull numbers associated with the rapidly expanding human settlements in the area during the 1980s, meant that gull predation became problematic. Kelp gull numbers in Saldanha Bay have decreased dramatically in recent years (see below), but the population remains at more than 3 000 pairs and gull predation on penguin eggs probably remains problematic. Research has indicated that the provision of correctly designed artificial nest sites that provide protection both from gull predation and extreme temperatures (half concrete pipes were found to be superior to fibreglass artificial burrows) can be effective in enhancing fledging success (Pichegru 2012). 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. African penguins, 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 (less than half) those at the start of the comprehensive counting period.

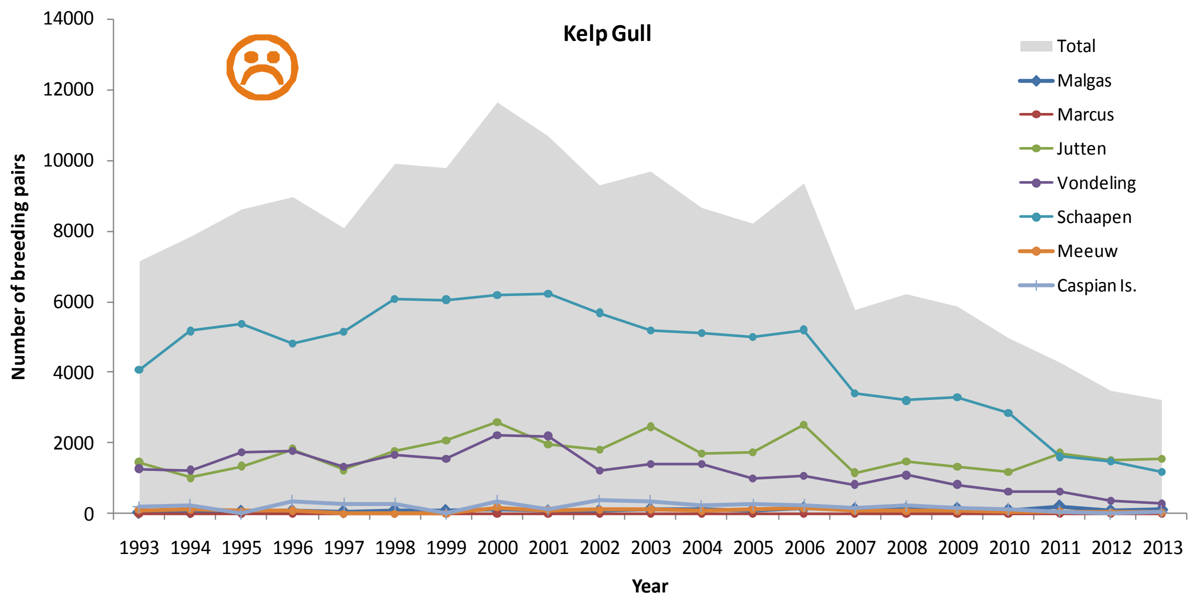


Figure 10.2. Trends in breeding population of Kelp gulls at Malgas, Jutten, Schaapen, Vondeling and Meeuw Islands in Saldanha Bay (Data source: Makhado *et al* 2014, Department of Environmental Affairs: Oceans & Coasts).

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 and again in 2014 when 86 pairs were recorded. They have also been recorded breeding on Meeuw Island in 1996, from 2002 to 2004 and again for the last three years (2012-2014). 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 during the period 2008-2011. The number of pairs breeding on Schaapen Island did, however, recover dramatically with 925 pairs recorded in 2012, but then decreased again to just 20 pairs in 2014 (Figure 10.3). Approximately 200 pairs were counted on both Malgas and Meeuw in 2014 and around 100 pairs on Jutten and Vondeling in 2014. The total number of breeding pairs recorded in 2014 (622) is close to the midpoint of the substantial inter-annual variation observed in the Hartlaub's gull breeding numbers (Figure 10.3).

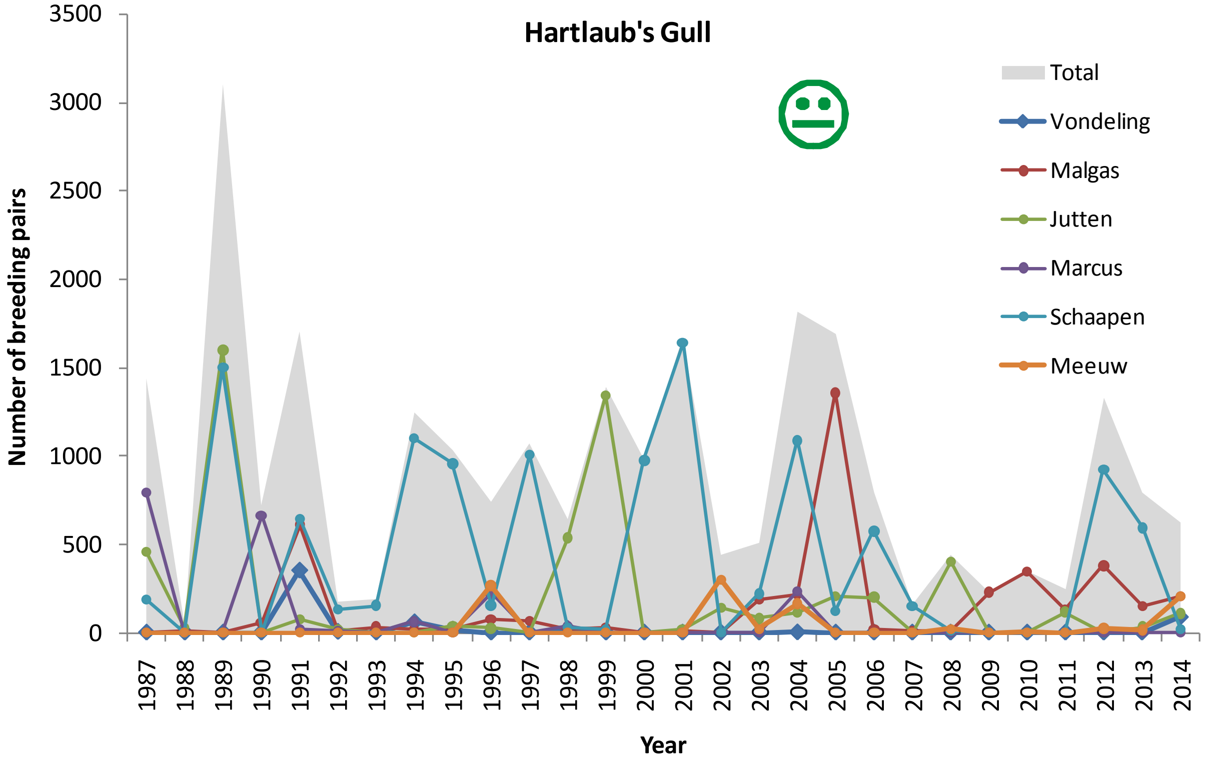


Figure 10.3. Trends in breeding population of Hartlaub's Gulls at Malgas, Marcus, Jutten, Schaapen and Vondeling Islands in Saldanha Bay (Data source: Makhado *et al* 2014, Department of Environmental Affairs: Oceans & Coasts).

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 retuned again in 2012-2014, with 543breeding pairs recorded on Malgas , Juutten and Schaapen Islands in 2014 (Figure 10.4).

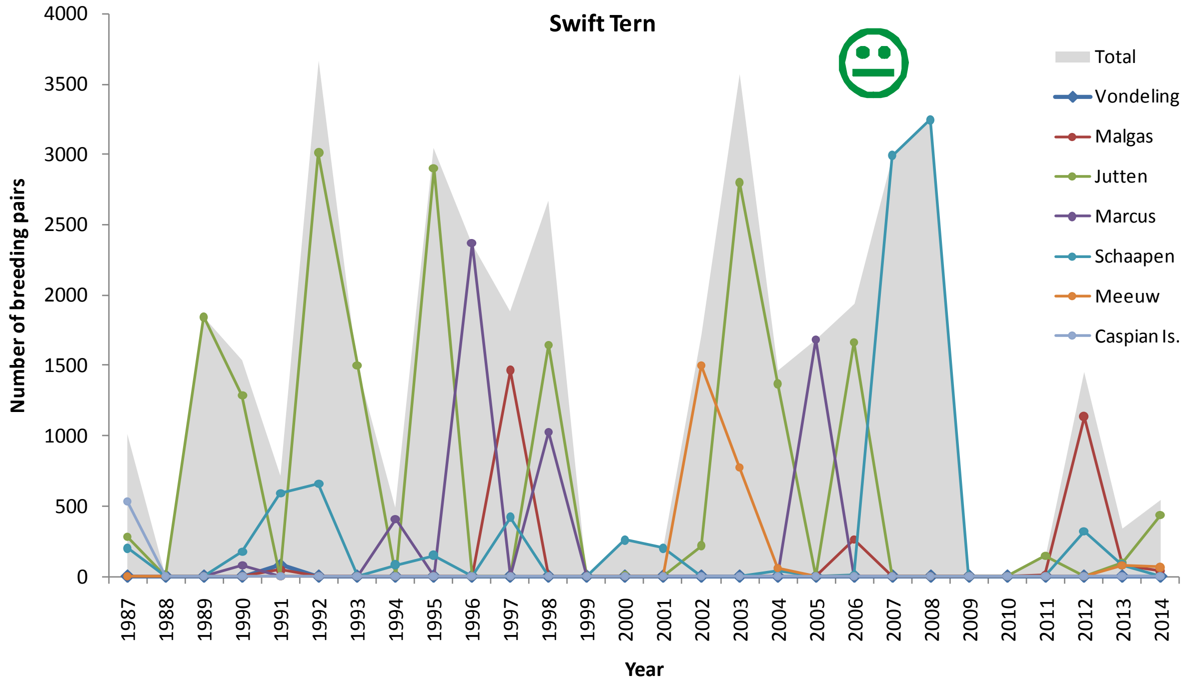


Figure 10.4. Trends in breeding population of Swift Terns at Malgas, Marcus, Jutten and Schaapen islands in Saldanha Bay (Data source: Makhado *et al* 2014, Department of Environmental Affairs: Oceans & Coasts).

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 &

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). The 2012 and 2013 data reveal that the breeding population on Malgas Island has fallen to record low levels. The decline in numbers at Malgas Island contrasts with population figures for Bird Island, off Port Elizabeth, where numbers have increased. The total South African gannet population appears to responded to the population dynamics of small pelagic fish (particularly sardines), with the number of breeding pairs peaking around the turn of the century and the declining to around 100 thousand pairs in 2013 (Data provided by Makhado *et al* 2014). A 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.

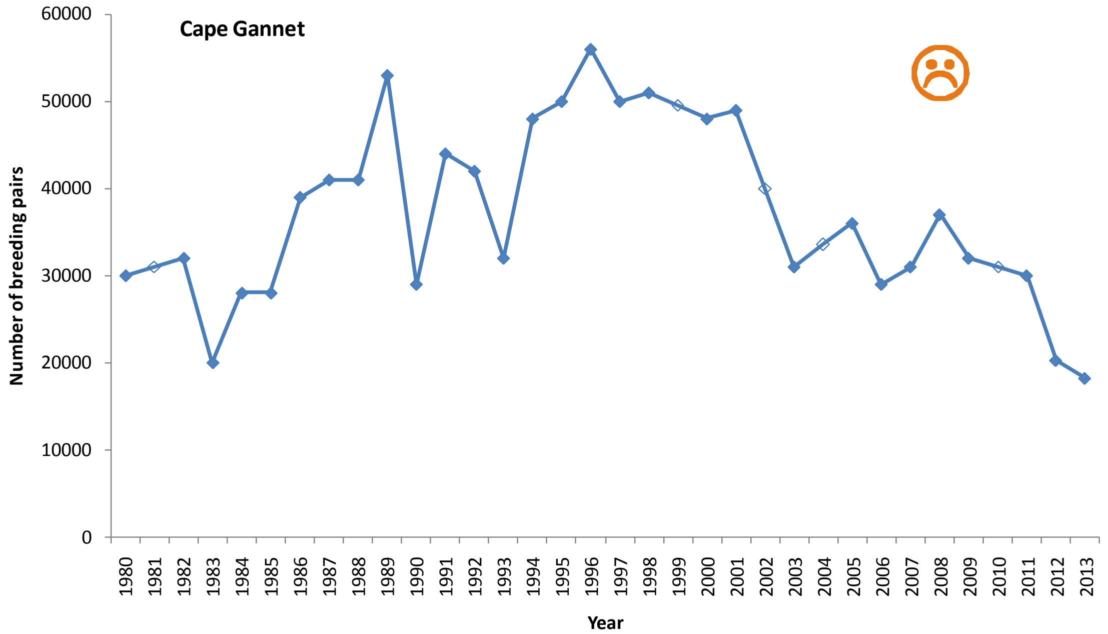


Figure 10.5. Trends in breeding population of Cape Gannets at Malgas Island, Saldanha Bay. Open data points are interpolated (no data). (Data source: Makhado *et al* 2014, Department of Environmental Affairs: Oceans & Coasts).

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 further 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 sagax* 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 substantially on Jutten, Schaapen and Vondeling Islands since 2009. Overall numbers are down 90% since 2009 (down from 13 655 in 2009 to only 1 268 pairs in 2013) and are at the lowest level ever recorded (when counts were conducted on all five islands) (Figure 10.6).

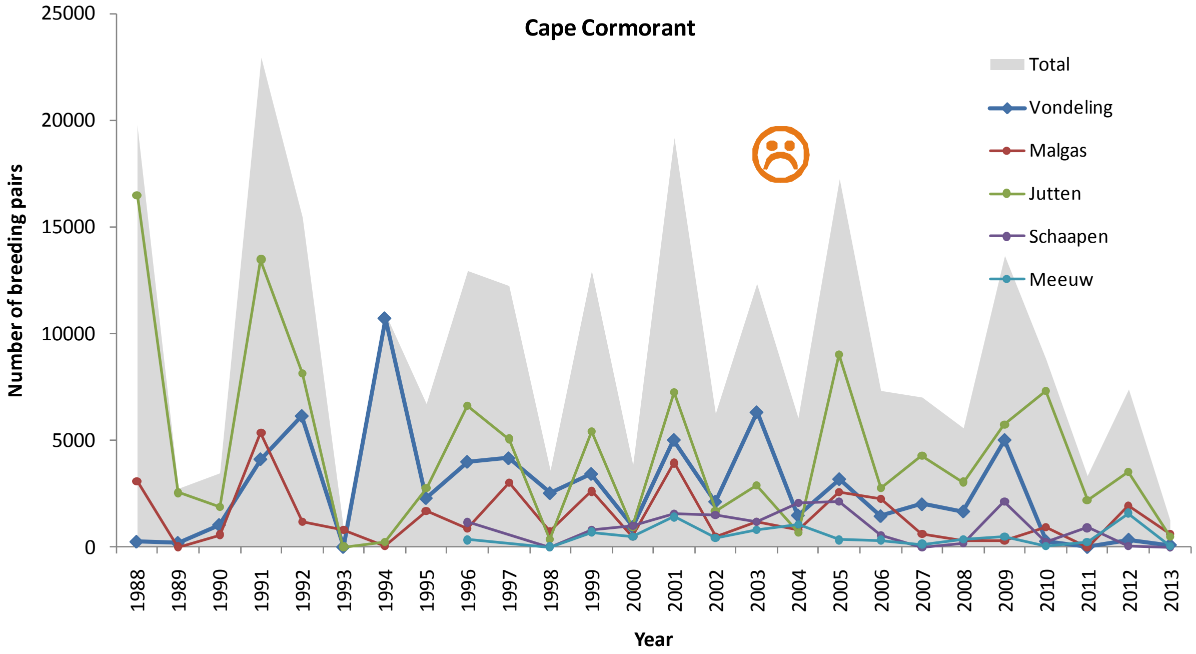


Figure 10.6. Trends in breeding population of Cape Cormorants at Malgas, Jutten, Schaapen, Vondeling and Meeuw islands in Saldanha Bay (Data source: Makhado *et al* 2014, Oceans & Coasts, Department of Environmental Affairs).

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 and increases in illegal fishing, with the national stock rock lobster status now estimated at just 3% of pristine biomass (Cockcroft *et al.* 2008, DAFF 2013). 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. The number of breeding pairs on Jutten, Marcus and Vondeling remained relatively constant at this time, but declined steadily since 2003 on all the islands (except Marcus where the number of breeding pairs remained stable until 2012 when only 2 pairs were recorded). The population in Saldanha Bay has declined drastically approximately by approximately 80% since 1990 (Figure 10.7).

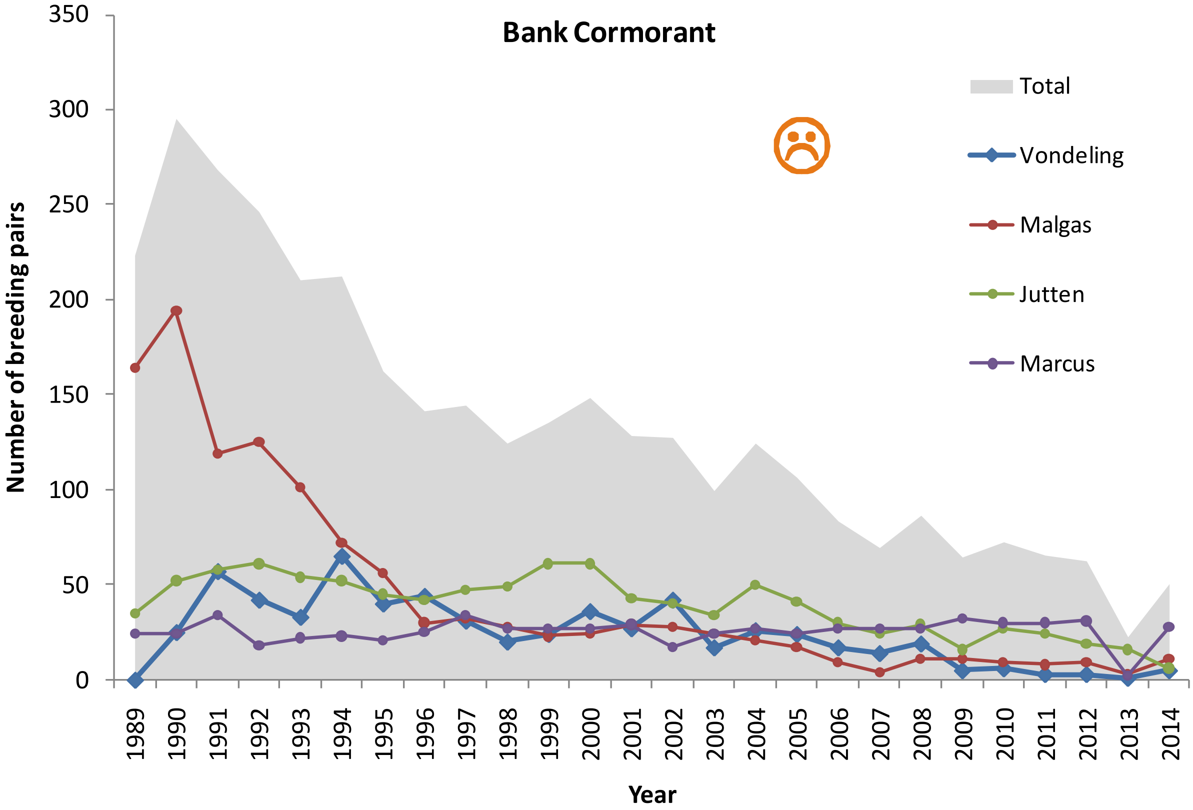


Figure 10.7. Trends in breeding population of Bank Cormorants at Malgas, Marcus, Jutten and Vondeling islands in Saldanha Bay (Data source: Makhado *et al* 2014, Oceans & Coasts, Department of Environmental Affairs).

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 and mugillid fishes e.g. Steentjies, White stumpnose and harders (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. The substantial growth in participation in recreational water sports (particularly kite boarding) over the last decade may have been a contributing factor to the shift in breeding location from Schaapen to Meeuw Island in 2004, but this appears unlikely given that the opposite shift happened ten years previously. Furthermore the total population estimate, although variable, has not shown a decreasing trend, which suggests that recreational water sport activities are not negatively impacting this species.

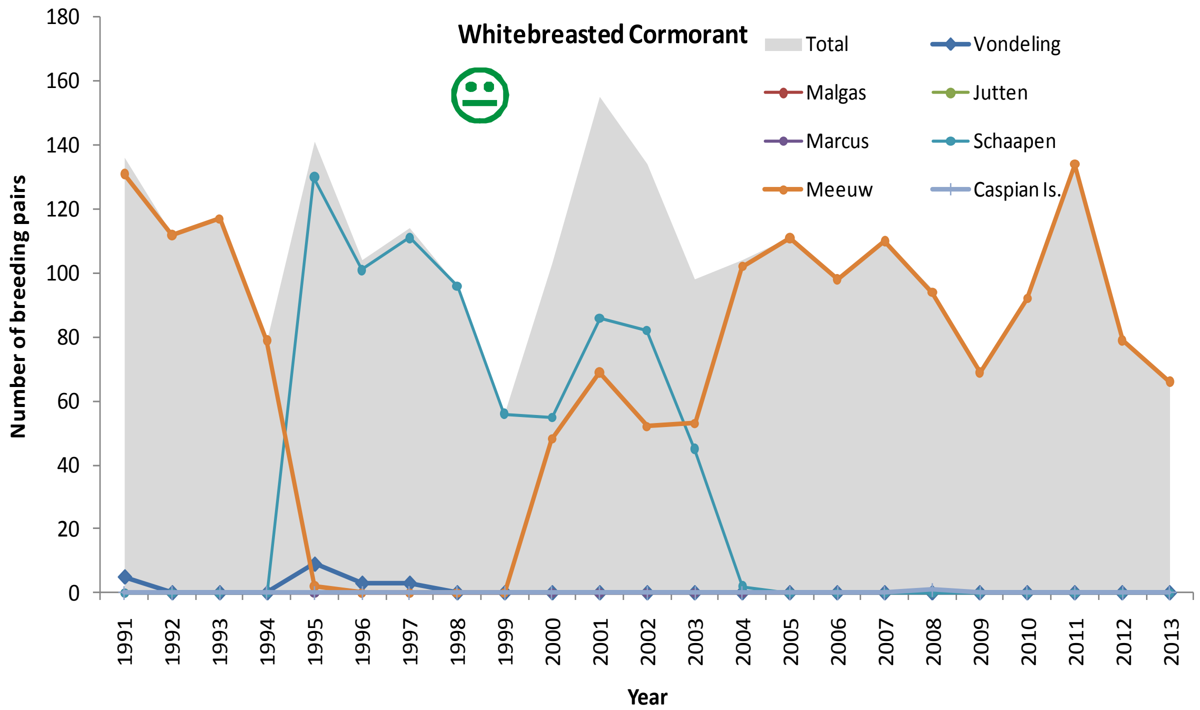


Figure 10.8. Trends in breeding population of White-breasted Cormorants on the islands in Saldanha Bay (Data source: Makhado *et al* 2014, Department of Environmental Affairs: Oceans & Coasts).

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 (Figure 10.9). Since then, numbers have shown considerable interannual variations without much cause for concern (Figure 10.9).

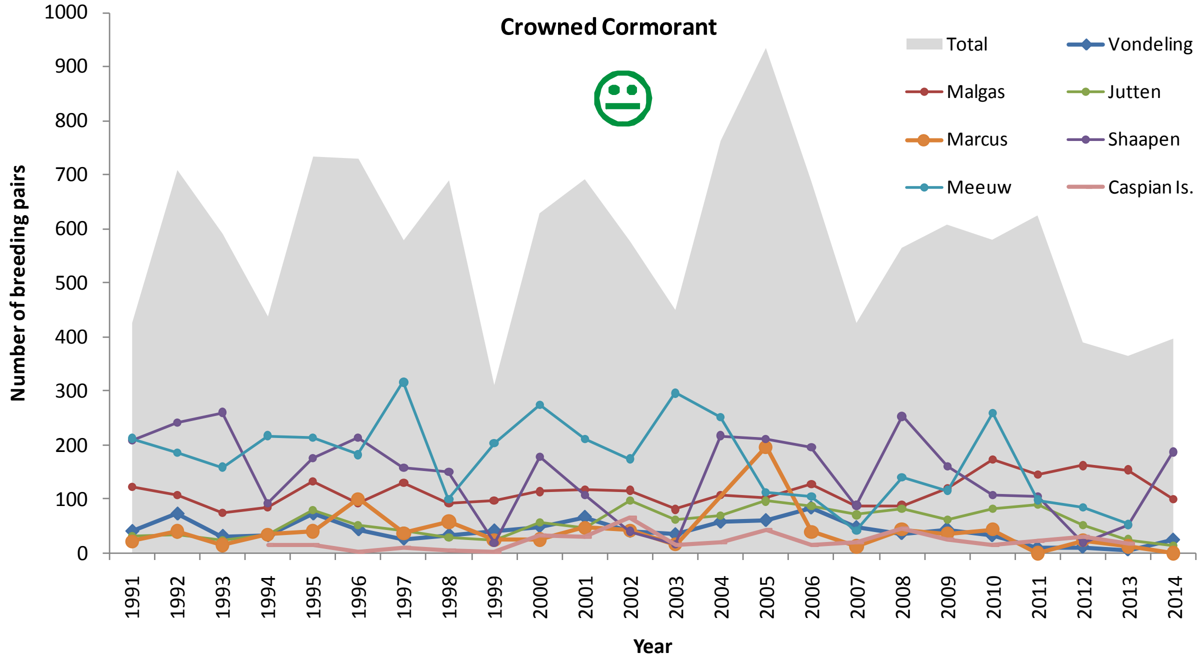


Figure 10.9. Trends in breeding population of Crowned Cormorants on the islands in Saldanha Bay (Data source: Makhado *et al* 2014, Department of Environmental Affairs: Oceans & Coasts).

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 *pers. comm.*). 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. Due to the sad passing of the two champions of the Oystercatcher Conservation Project (Prof. Phil Hockey and Dr Douglas Loewenthal) the regular censuses of oystercatchers in Saldanha Bay have unfortunately stopped. SAN Parks could possibly be encouraged to take on this task as part of their routine ecological monitoring and maintain this valuable long-term data series.

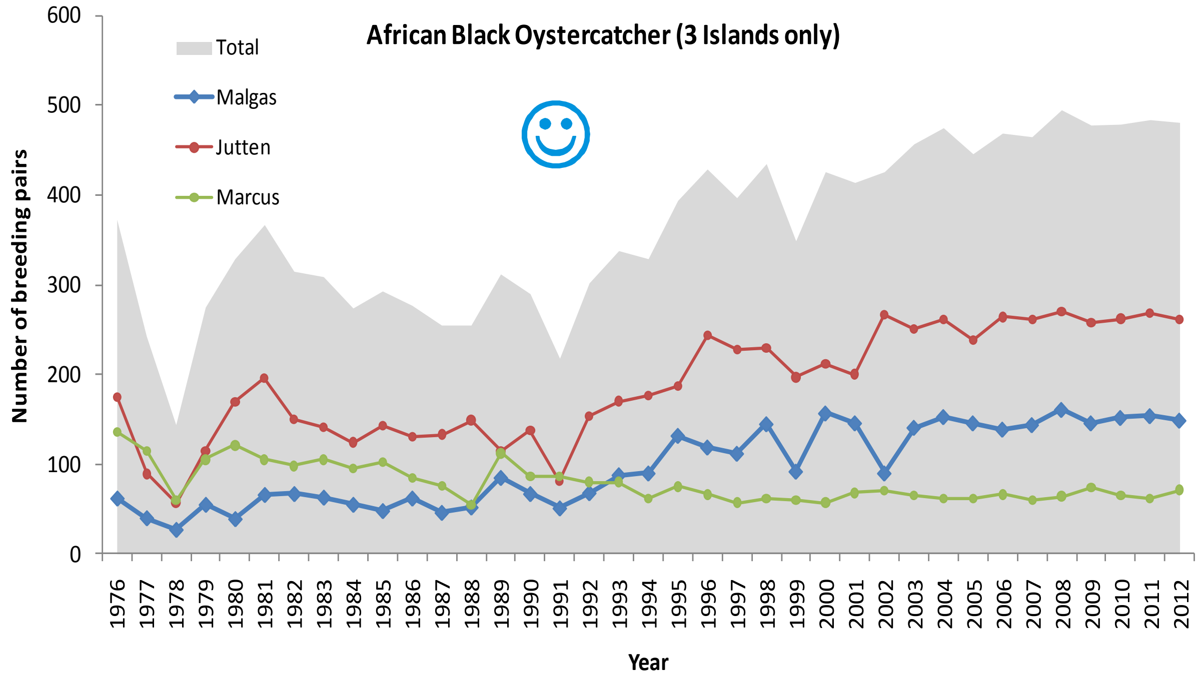


Figure 10.10. Trend in breeding population of African Black Oystercatchers older than 1 year, on Marcus, Malgas and Jutten Islands. (Data source: Douglas Loewenthal, Oystercatcher Conservation Programme).

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	No. of SA resident species	No. of migrant species
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 & Hockey 1993). 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*.

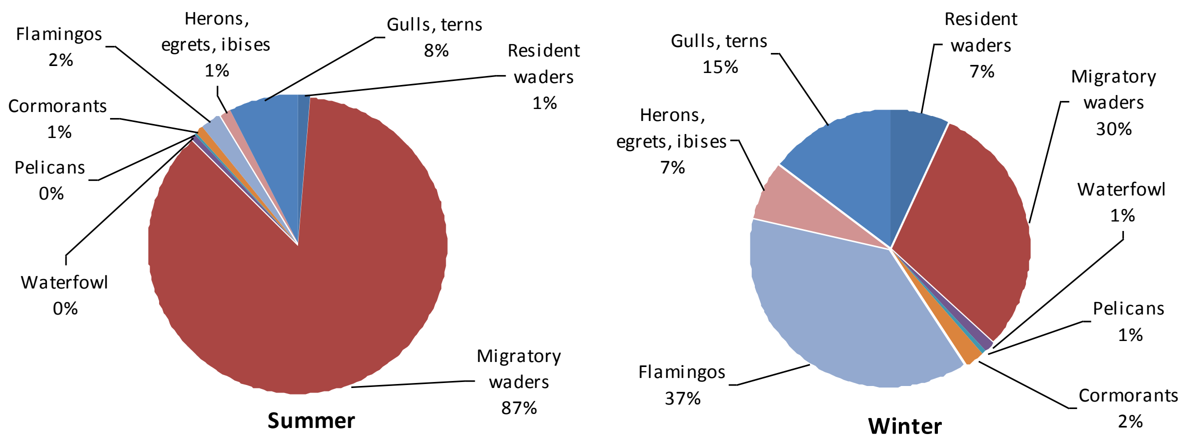


Figure 10.11. Average numerical composition of the birds on Langebaan Lagoon during summer and winter.

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 WCWSG 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 downward trend in the numbers of Palearctic waders at the Lagoon since 1989, with a dramatic further decrease over the period 2008-

2012 (Figure 10.12). This was to some extent related to relatively low numbers of Curlew Sandpiper on the lagoon in during 2011-2012. The 2013 and 2014 data however, show some limited recovery in numbers of Paleartic waders, although the total estimate of 9 120 birds is still 74% down from the pre 1990 average of ~34 000 birds.

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). The downward trend in migrant wader numbers may echo global trends in certain wader populations. Indeed, Ryan (2012) reports on similar declines in migrant waders throughout the Western Cape over the last three decades, irrespective of the protection status of the areas where counts were undertaken. This suggested that factors outside of the Western Cape were at least partially responsible for the observed trends and probably reflected global population declines (Ryan 2012). What is of more concern is that the trend appeared to be echoed by resident waders over the period 1990-2004 (Figure 10.13). In recent years (2005-2012) resident wader numbers appear to have stabilized and as with migrants, some recovery was evident during 2013 and 2014, (although resident wader estimates do still remain at ~50% of the pre 1990 average) (Figure 10.13). Whatever the case, it does suggests that conditions at Langebaan Lagoon were at least partially to blame for the decline in waders numbers (migrant and resident species) during the 1990-2004 period. 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.* 2010 see Chapter 6) and human disturbance, which has been shown to have a dramatic impact on bird numbers in other estuaries (Turpie & Love 2000). The recent increases in estimates of resident (and to a lesser extent migrant) wader populations are encouraging, suggesting that the habitat quality for these birds is improving, or that human disturbance being better managed. Both resident and migrant wader population estimates however, remain substantially down from pre 1990 counts and a cause for concern.

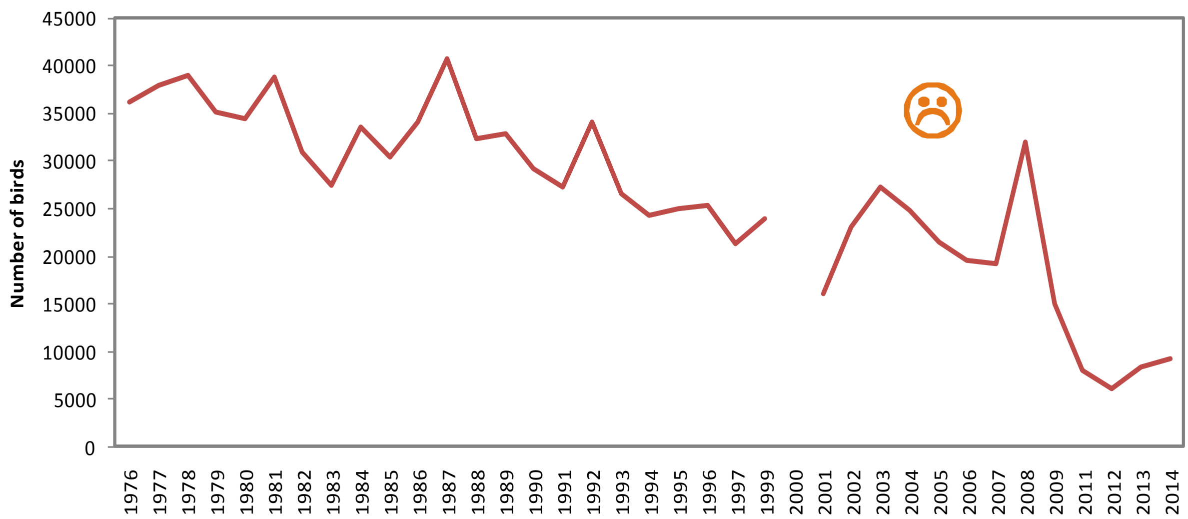


Figure 10.12. Long term trends in the numbers of summer migratory waders on Langebaan Lagoon. (Data source: CWAC data, Animal Demography Unit at the University of Cape Town).

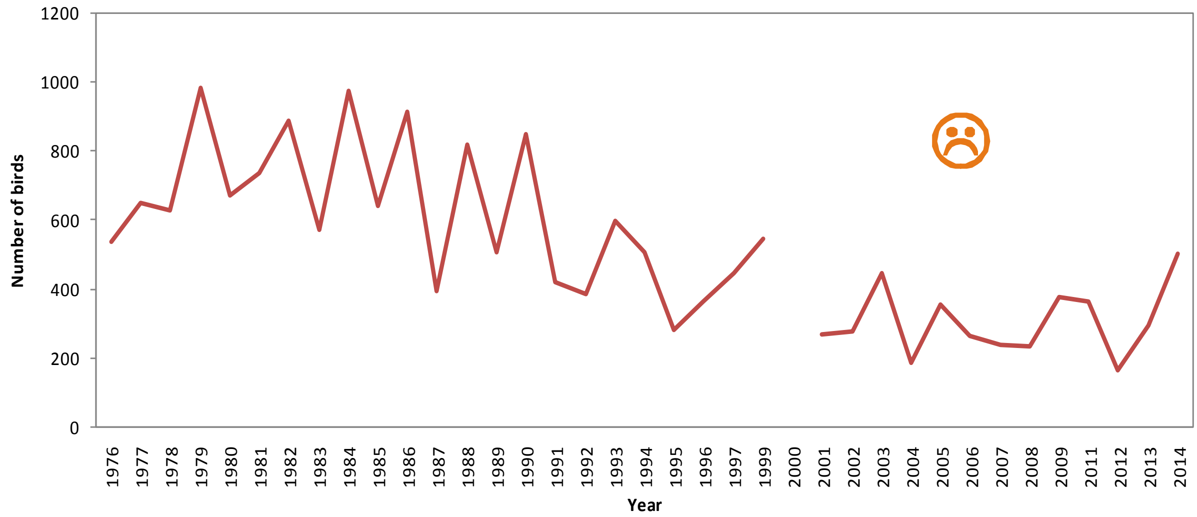


Figure 10.13. Long term trends in the numbers of winter resident waders on Langebaan Lagoon. . (Data source: CWAC data, Animal Demography Unit at the University of Cape Town).

10.4 Overall status of birds in Saldanha Bay and Langebaan Lagoon

Populations of two cormorant species, namely Bank Cormorants and Cape Cormorants, that utilise islands within the Saldanha Bay region for shelter and breeding, have decreased since early to mid-1990. In the past this has been attributed to the construction of the causeway linking Marcus Island to the mainland, and to increased human disturbance. However, given that the populations of several other seabirds that breed on these islands have not decreased over this period, it appears that declines in local availability of their principal prey species, (rock lobster and sardines), as well as egg and chick predation by pelicans and gulls may be the principal drivers. The Cape Gannet population on Malgas Island has also undergone severe 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. Decreasing populations of resident waterbirds in Langebaan Lagoon over the period 1990-2012, a concern in itself, suggested that local conditions may be partly to blame for the decrease in migratory birds over the same period. This long-term trend is most likely due to unfavourable conditions persisting in Langebaan Lagoon as a result of anthropogenic impacts. The most recent (2013 and 2014) waterbird count data do show and encouraging, but limited recovery in resident wader numbers and a slight improvement in migratory waders. This suggests that the Langebaan Lagoon habitat quality for waders has improved and/or human disturbance has lessened in recent years. It remains to be seen if this recent observed recovery in wader populations is sustainable. 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, 92 marine alien species have been recorded from South African waters (Zsilavecz 2007, Mead *et al.* 2011a, Anchor Environmental Consultants 2011, Peters *et al.* 2014). Seventy of these species are thought to occur along the west coast of South Africa, although only 29 have been confirmed from Saldanha Bay and/or Langebaan Lagoon to date (Table 11.1). A small number of these are considered invasive, 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 & Griffiths 2008), and the Pacific South American mussel *Semimytilus algosus* (de Greef *et al.* 2013). An additional 39 species are currently regarded as cryptogenic (of unknown origin and potentially introduced) but very likely introduced to South Africa. Of these, 20 are likely to be found in Saldanha Bay and/or Langebaan Lagoon and six have already been identified from the Bay. Comprehensive genetic analyses are urgently required to determine the definite status of these cryptogenic species (Griffiths *et al.* 2008).

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, 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 trouble 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 Saldanha Bay will be used to confirm the presence of 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). Species occurrence in Saldanha Bay and/or Langebaan Lagoon is listed as either confirmed or likely (not confirmed from Saldanha Bay but inferred from the regional distribution of the species).

Table 11.1. List of introduced and cryptogenic species from Saldanha Bay and Langebaan Lagoon. 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 listed. Data extracted from Mead *et al.* (2011a & b) unless otherwise stated.

Taxon	Occurrence in Saldanha/Langebaan	Introduced/ cryptogenic	Origin	Vector
PROTOCTISTA				
Mirofolliculina limnoriae	Likely	Introduced	Unknown	SB
Zoothamnium sp.	Likely	Cryptogenic	Unknown	SF
DINOFLAGELLATA				
Alexandrium tamarense-complex	Likely	Introduced	N Atlantic/N Pacific	BW
Alexandrium minutum	Likely	Introduced	Europe	BW
Dinophysis acuminata	Likely	Introduced	Europe	BW
PORIFERA				

Taxon	Occurrence in Saldanha/Langebaan	Introduced/ cryptogenic	Origin	Vector
Suberites ficus	Likely	Introduced	Europe	SF
CNIDARIA				
ANTHOZOA				
Sagartia ornata	**Confirmed**	Introduced	Europe	SF/BW
Metridium senile	Likely	Introduced	N Atlantic/N Pacific	SF/OR
HYDROZOA				
Pachycordyle navis	Likely	Introduced	Europe	SF/BW
Coryne eximia	**Confirmed**	Introduced	N Atlantic/N Pacific	SF/BW
Pinauay larynx	Likely	Introduced	North Atlantic	SF/BW
Pinauay ralphi	Likely	Introduced	North Atlantic	SF/BW
Laomedea calceolifera	Likely	Introduced	North Atlantic	SF/BW
Gonothyraea loveni	Likely	Introduced	North Atlantic	SF/BW
Obelia bidentata	Likely	Introduced	Unknown	SF/BW
Obelia dichotoma	Likely	Introduced	Unknown	SF/BW
Obelia geniculata	Likely	Introduced	Unknown	SF/BW
ANNELIDA				
POLYCHAETA				
Boccardia proboscidea	**Confirmed**	Introduced	Eastern Pacific	M
Capitella sp.	Likely	Cryptogenic	Unknown	SF/BW
Polydora hoplura	**Confirmed**	Introduced	Europe	SF/BW
Dodecaceria fewkesi	Likely	Introduced	North American Pacific	SF/BW
Ficopomatus enigmaticus	Likely	Introduced	Australia	SF
Hydroides elegans	Likely	Introduced	Indo-Pacific	SF/BW
Neodexiospira brasiliensis	**Confirmed**	Introduced	Indo-Pacific	SF/BW
Janua pagenstecheri	Likely	Introduced	Europe	SF/BW
Simplicaria pseudomilitaris	Likely	Cryptogenic	Unknown	SF/BW
CRUSTACEA				
CIRRIPEDIA				
Amphibalanus amphitrite amphitrite	**Confirmed** (this report)	Introduced	Unknown	SF/BW
Balanus glandula	**Confirmed**	Introduced	North American Pacific	SF/BW
Menesiniella regalis	**Confirmed** (this report)	Introduced	North American Pacific	SF/BW
ISOPODA				
Dynamene bidentata	Likely	Introduced	Europe	SF/BW
Paracerceis sculpta	Likely	Introduced	Northeast Pacific	SF/BW
Synidotea hirtipes	**Confirmed**	Cryptogenic	Indian Ocean	SF/BW
Synidotea variegata	**Confirmed**	Cryptogenic	Indo-Pacific	SF/BW
Ligia exotica	Likely	Cryptogenic	Unknown	SB
Limnoria quadripunctata	Likely	Introduced	Unknown	SB
Limnoria tripunctata	Likely	Introduced	Unknown	SB
AMPHIPODA				
Chelura terebrans	**Confirmed**	Introduced	Pacific Ocean	SF/SB

Taxon	Occurrence in Saldanha/Langebaan	Introduced/ cryptogenic	Origin	Vector
Ischyrocerus anguipes	Likely	Introduced	North Atlantic	SF/BW
Erichthonius brasiliensis	Likely	Introduced	North Atlantic	SF/BW
Cymadusa filosa	Likely	Cryptogenic	Unknown	BS
Caprella equilibra	Likely	Cryptogenic	Unknown	SF/BW
Caprella penantis	Likely	Cryptogenic	Unknown	SF/BW
Paracaprella pusilla	Likely	Cryptogenic	Unknown	SF/BW
Jassa marmorata	Likely	Introduced	North Atlantic	SF/BW
Jassa slatteryi	**Confirmed**	Introduced	North Pacific	SF/BW
Orchestia gammarella	**Confirmed**	Introduced	Europe	BS
Cerapus tubularis	**Confirmed**	Introduced	North American Atlantic	BS
DECAPODA				
Carcinus maenas	**Confirmed** (G. Branch *pers. comm.*)	Introduced	Europe	SF/BW/OR
Pinnixa occidentalis	**Confirmed** (Anchor 2011)	Introduced	North American Pacific	BW
Xantho incicus	Likely	Introduced	France	M
INSECTA				
Cafius xantholoma	Likely	Introduced	Europe	BS
MOLLUSCA				
GASTROPODA				
Littorina saxatilis	**Confirmed**	Introduced	Europe	BS
Catriona columbiana	Likely	Introduced	North Pacific	SF/BW
Tritonia nilsodhneri	Likely (Zsilavecz 2007)	Introduced	Europe	SF/BW
Kaloplocamus ramosus	Likely (Zsilavecz 2007)	Introduced	Unknown	SF/BW
Thecacera pennigera	Likely	Cryptogenic	Unknown	SF/BW
Anteaeolidiella indica	**Confirmed**	Cryptogenic	Unknown	SF/BW
BIVALVIA				
Mytilus galloprovincialis	**Confirmed**	Introduced	Europe	SF/BW
Ostrea edulis	Likely	Introduced	Europe	M
Crassostera gigas	**Confirmed** (Haupt *et al.* 2010)	Introduced	Japan	M
Semimytilus algosus	**Confirmed** (de Greef *et al.* 2013)	Introduced	South Pacific	SF/BW
Teredo navalis	Likely	Introduced	Europe	SB
Lyrodus pedicellatus	Likely	Introduced	Unknown	SB
Bankia carinata	Likely	Cryptogenic	Unknown	SB
Bankia martensi	Likely	Cryptogenic	Unknown	SB
Dicyathifer manni	Likely	Cryptogenic	Unknown	SB
Teredo somersi	Likely	Cryptogenic	Unknown	SB
BRACHIOPODA				
Discinisca tenuis	**Confirmed** (Peters *et*	Introduced	Namibia	M

Taxon	Occurrence in Saldanha/Langebaan	Introduced/ cryptogenic	Origin	Vector
	al. 2014)			
BRYOZOA				
Watersipora subtorquata	**Confirmed**	Introduced	Caribbean	SF
Bugula neritina	Likely	Introduced	Unknown	SF
Bugula flabellata	Likely	Introduced	Unknown	SF
Conopeum seurati	**Confirmed**	Introduced	Europe	SF
Cryptosula pallasiana	**Confirmed**	Introduced	Europe	SF
CHORDATA				
ASCIDIACEA				
Ascidia sydneiensis	Likely	Introduced	Pacific Ocean	SF
Ascidiella aspersa	Likely	Introduced	Europe	SF
Botryllus schlosseri	Likely	Introduced	Unknown	SF
Ciona intestinalis	**Confirmed** (Picker & Griffiths 2011)	Introduced	Unknown	SF
Clavelina lepadiformis	**Confirmed** (Picker & Griffiths 2011)	Introduced	Europe	SF
Cnemidocarpa humilis	Likely	Introduced	Unknown	SF
Corella eumyota	**Confirmed**	Cryptogenic	Unknown	SF
Diplosoma listerianum	**Confirmed**	Introduced	Europe	SF
Microcosmus squamiger	Likely	Introduced	Australia	SF
Trididemnum cerebriforme	**Confirmed**	Cryptogenic	Unknown	SF
PISCES				
Cyprinus carpio	Likely	Introduced	Central Asia to Europe	I
RHODOPHYTA				
Schimmelmannia elegans	Likely	Introduced	Tristan da Cunha	BW
Antithamnionella ternifolia	Likely	Cryptogenic	Australia	SF/BW
Antithamnionella spirographidis	**Confirmed**	Introduced	North Pacific	SF/BW
CHLOROPHYTA				
Codium fragile fragile	**Confirmed**	Introduced	Japan	SF/BW
VASCULAR PLANTS				
Ammophila arenaria	**Confirmed**	Introduced	Europe	I
Spartina maritima	**Confirmed**	Cryptogenic	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 1979 (Mead *et al.* 2011b) but was only confirmed in 1984 (Grant *et al.* 1984, Grant & 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 the reason for the late detection is due to the fact 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 residual ridge. The preferred habitat of the two species also differs with *Mytilus* occurring higher on the shore and away from sand-inundated sites (Figure 11.1). The alien mussel is commercially cultured in Saldanha Bay and elsewhere, and is widely exploited by recreational and subsistence fishers (Robinson *et al.* 2005 & 2007a).

Figure 11.1 European mussel *Mytilus galloprovincialis*. (Photo: Prof. C.L. Griffiths.)

In Europe, *M. galloprovincialis* is known to form dense subtidal beds directly on sandy bottoms (Ceccherelli & Rossi 1984), while it is typically found on exposed rocky shores in southern Africa. *Mytilus* began establishing dense intertidal beds on the sandy center banks of Langebaan Lagoon in the mid-1990s (Hockey & van Erkom Schurink 1992, Hanekom & Nel 2002, Robinson & Griffiths 2002, Robinson *et al.* 2007a), with biomass peaking at an estimated 8 tonnes in 1998 (Robinson & Griffiths 2002). The population subsequently crashed, decreasing in size by 88% by early 2001 (Hanekom & Nel 2002) and had died off completely by mid-2001, leaving only empty shells and anoxic sand (Robinson *et al.* 2007a). The reason for the die off is still not clear, and impacts on the macrobenthic infauna on the banks was evident for at least six months 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 grew rapidly until 2012, after which densities declined (Figure 11.2). The average percentage of the shore covered by this species across all sites increased from 5.4% in 2005 to 11.1% in 2012, and then decreased again to 6.1% in 2014. *M. galloprovincialis* is still by far the most dominant faunal species on the rocky shore, 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.

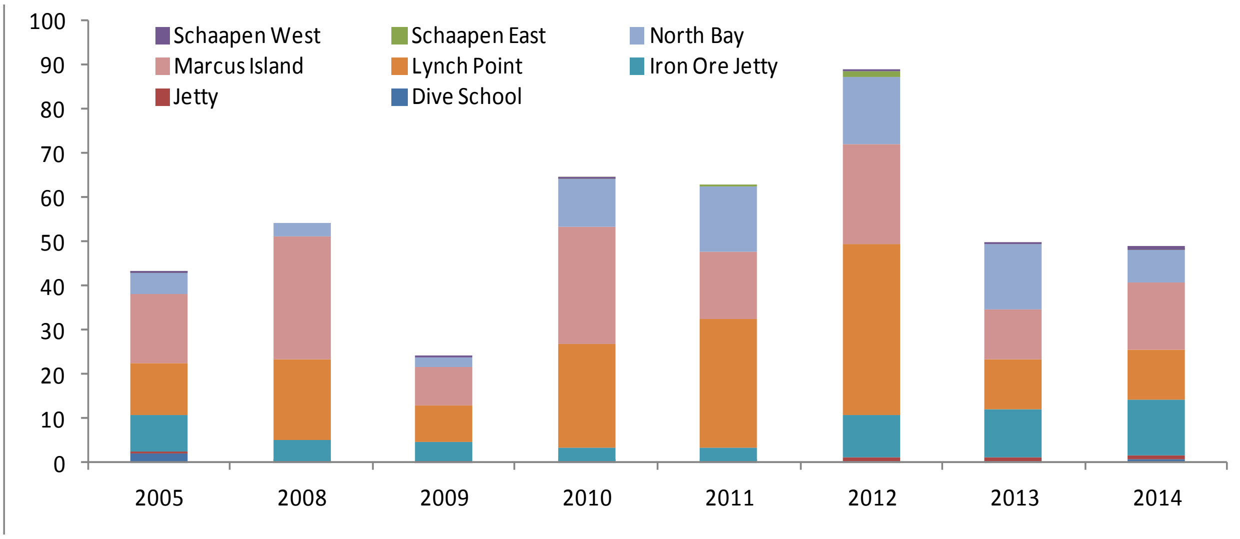


Figure 11.2. Changes in the abundance (% cover) of the Mediterranean mussel Mytilus *galloprovincialis* at eight rocky intertidal sites in Saldanha Bay over the period 2008-2014. Information of the locations of these sampling stations is provided in Chapter 8.

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 & 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 & 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 have 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 at the Small Craft Harbour. Due to a lack of specimens, it is unlikely that there is an extant population in Saldanha Bay at present.

Figure 11.3 European shore crab *Carcinus maenas*. (Photo: Prof. C.L. Griffiths).

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 & 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 & 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 (University of Cape Town, C.L. Griffiths, *pers. comm.*). This species shows a strong preference for wave exposed shores (University of Cape Town, C.L. Griffiths, *pers. comm.*) and thus is unlikely to 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 (Laird & Griffiths 2008, 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 much of the southern west coast (Laird & 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 & Griffiths 2008). *B. glandula* was first correctly identified in the State of the Bay surveys in Saldanha Bay in 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.

Figure 11.4 Acorn barnacle *Balanus glandula* (Photo: Prof. C.L. Griffiths)

Initial records from State of the Bay sampling in 2005 provide evidenced that *Balanus glandula* was already well established in Saldanha Bay by that time. In the next survey undertaken in 2009, it appeared as though populations of this species in the Bay may have expanded, however, it now appears as though the this population is now shrinking again (Figure 11.5). In 2009, this organism accounted for around 7.5% of the biotic cover across all shores, but this has now declined to around 3.4%. Indications from studies conducted elsewhere, and indeed from the State of the Bay surveys, (Anchor Environmental Consultants 2012), 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. Nevertheless, it remains one of the most abundant species on the shore in Saldanha Bay and is still of significant concern.

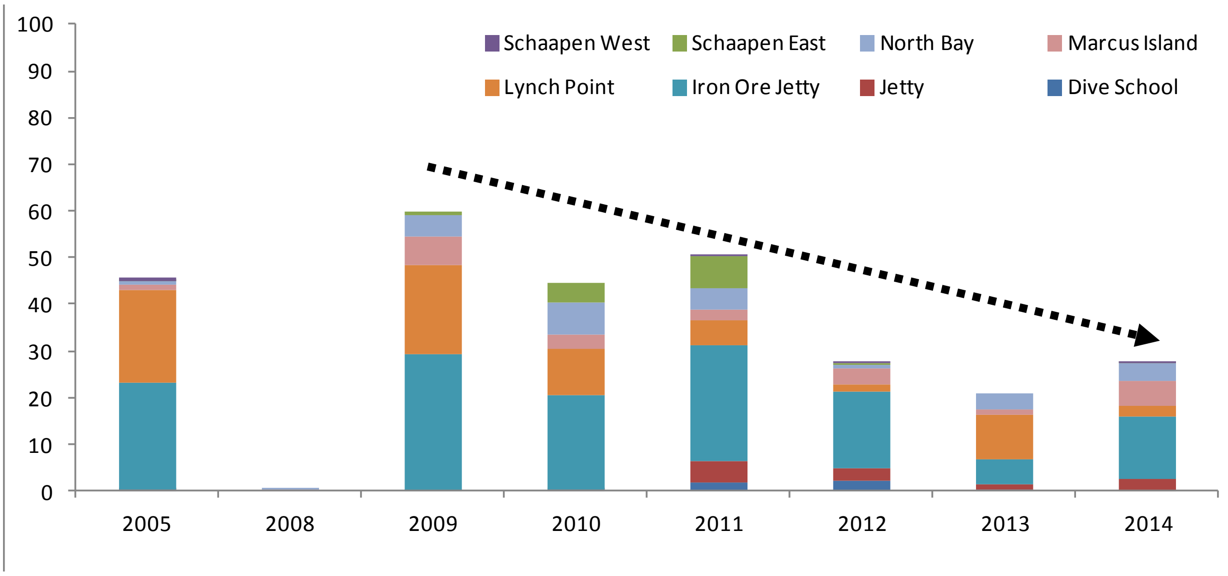


Figure 11.5. Changes in the abundance (% cover) of the acorn barnacle *Balanus glandula* at eight rocky intertidal sites in Saldanha Bay over the period 2008-2014. Information of the locations of these sampling stations is provided in Chapter 8.

11.1.6 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).

Figure 11.6 ***Menesiniella regalis*** **(Pilsbry, 1916) (Photograph: Dr. Nina Steffani)**

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 & Griffiths 2008).

11.1.7 *Amphibalanus amphitrite amphitrite*

This alien barnacle species was recorded from Saldanha Bay in the baseline survey in 2005. Only in 2012 this species was recognised to be *Amphibalanus amphitrite amphitrite*, an alien barnacle which is a prolific fouling species worldwide. This species has longitudinal striations on the exterior shell, which is marked with thick, sparse, purple longitudinal stripes (Figure 11.7). *A. amphitrite amphitrite* is easily confused with another 'purple-pink striped' species which has not yet been identified (Biccard 2012).

Figure 11.7 ***Amphibalanus amphitrite amphitrite*** **(Photo: Prof. C.L. Griffiths)**

11.1.8 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 11.8). It was first recorded clinging on oysters grown in suspended culture in Saldanha Bay in 2008 (Haupt *et al.* 2010). More recently, it has been reported as living freely outside of the oyster culture operation on Schaapen Island (Peters *et al.* 2014). 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 11.8 Disc lamp shell *Discinisca tenuis* (Photo: Prof. C.L. Griffiths)

11.1.9 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 & 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.

11.1.10 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 & 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.

11.1.11 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 (Colan 1990, Picker & Griffiths 2011). 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.

11.1.12 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 & Griffiths 2011).

11.1.13 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 (Figure 11.9). 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 11.9 A typical aggregation of *Ciona intestinalis* (Photo: National Museums Northern Ireland).

11.1.14 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.

11.1.15 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 & Griffiths 2011) (Figure 11.10). 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 11.10 ***Ascidiella aspersa*** **is often found covered in epibionts (Photograph: Arjan Gittenberger).**

11.1.16 Western pea crab *Pinnixa occidentalis*

Figure 11.11 **Western pea-crab** ***Pinnixa occidentalis*** **(Photograph: Anchor Environmental Consultants).**

The Western Pea crab *Pinnixa occidentalis* (Figure 11.11) 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 identified in the collections from the Saldanha Bay State of the Bay surveys in 2010 (Anchor Environmental Consultants 2011), although it was 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 Saldanha 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, the range occupied by this species expanded to eight sites in 2014, with a maximum density of 38.7 individuals m^{-2} in 2010. Since then, the range of sites at which this species has been recorded has varied across areas spanning the deeper parts of Small Bay and Big Bay. The abundance and biomass (number of individuals and grams per square meter) fluctuate over time, with numbers ranging from 6-38 individuals per square meter and biomass from 0.5-3.5 g per square meter (Figure 11.12). This species put in a brief appearance at one site in Langebaan Lagoon in 2009, and was only recorded in Langebaan Lagoon again in 2014 (Figure 11.13). This suggests that the lagoon habitat may not be entirely suited to the species, which favours deeper water (>10 m) in its native range (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 due to a lack of sampling effort.

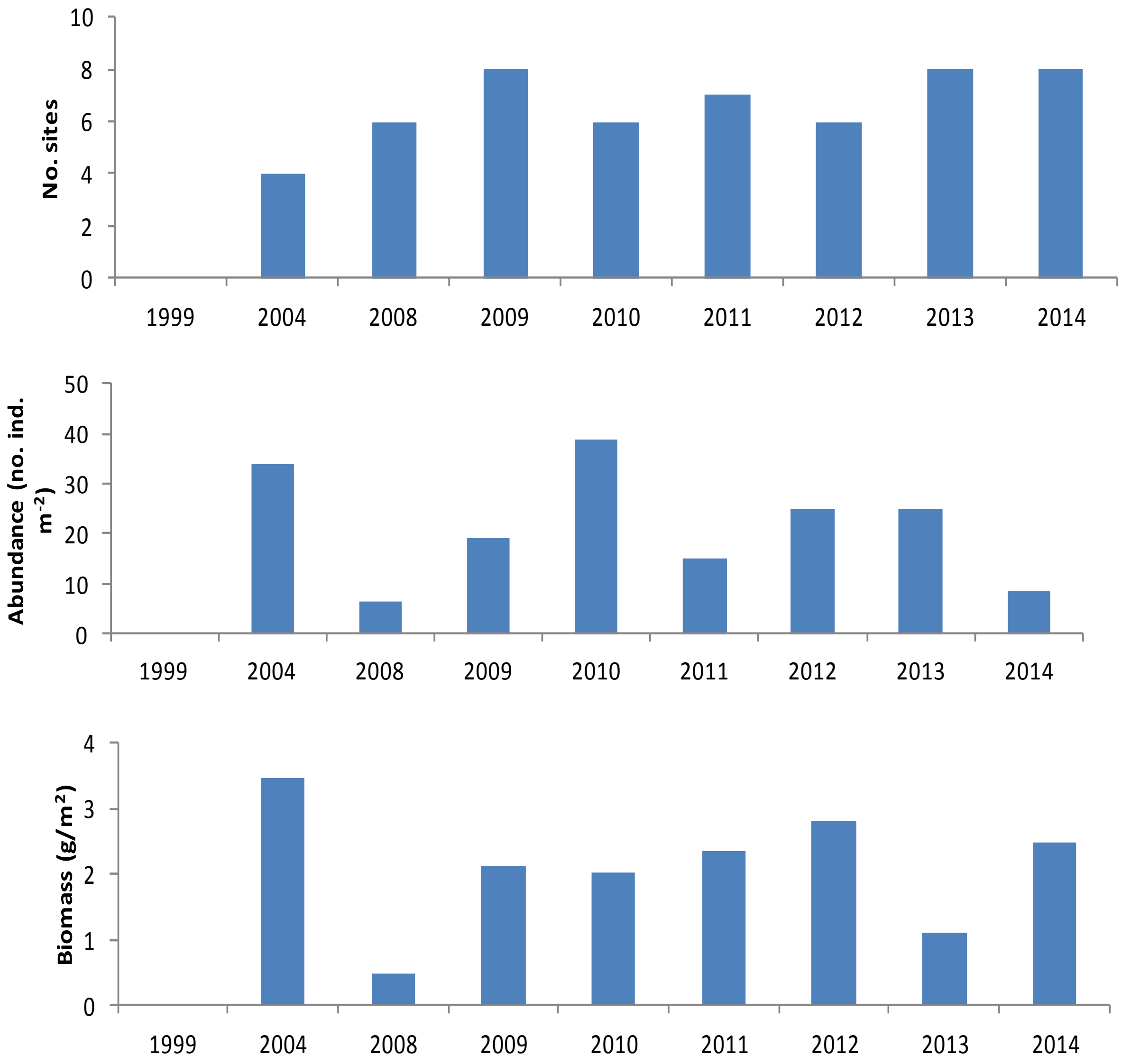


Figure 11.12 **The number of sites (top) at which the Western Pea crab *Pinnixa occidentalis* has been recorded in Saldanha Bay and Langebaan Lagoon in the period 1999-2014, the abundance of the crab (middle) and the biomass (bottom) of the crab over time.**

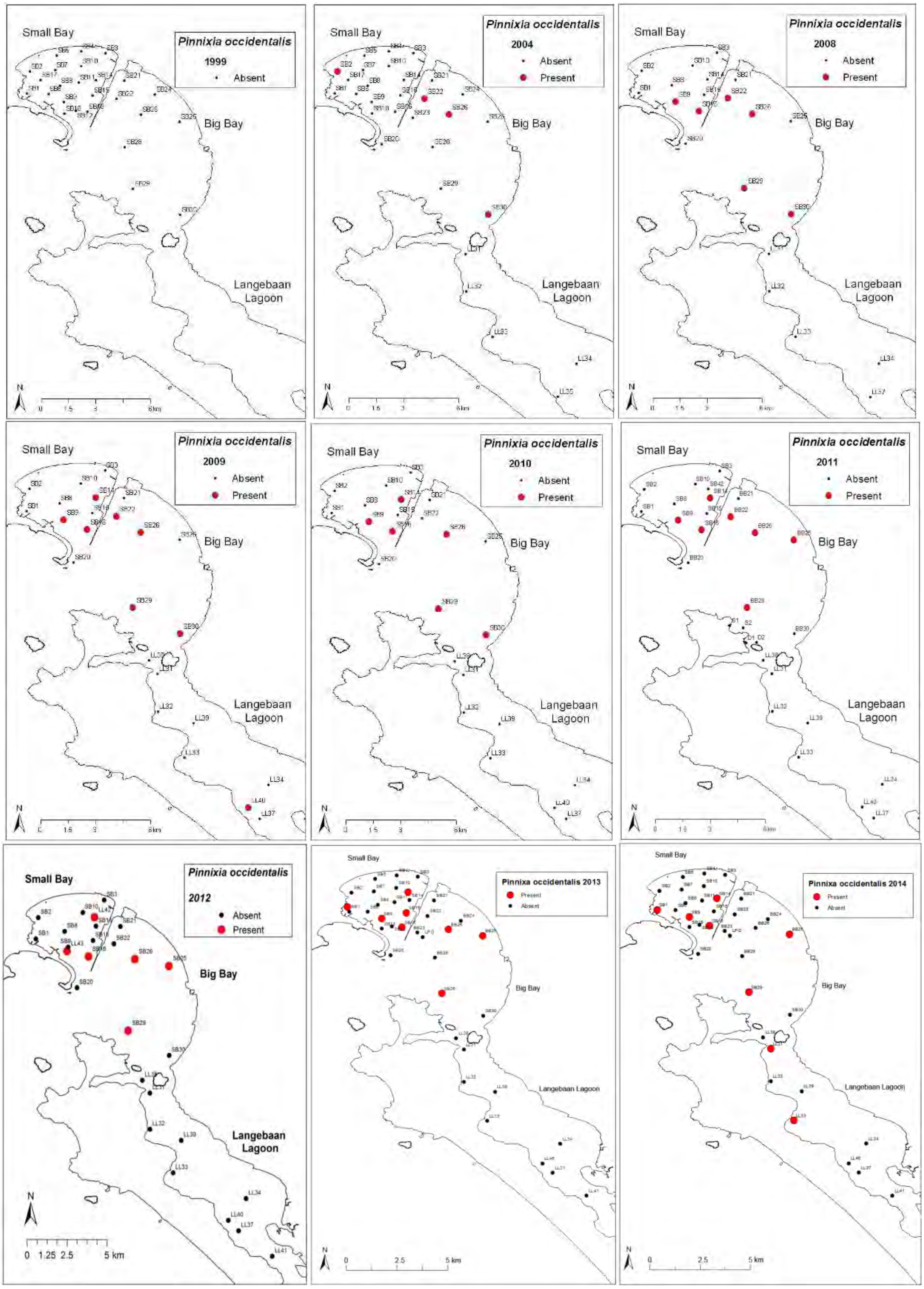


Figure 11.13. Map showing changes in the distribution of the Western Pea crab *Pinnixa occidentalis* in Saldanha Bay and Langebaan Lagoon in the period 1999-2014.

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 and storm water

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 9.24% per annum in Langebaan and nearly 2.66% in Saldanha over the period 2001 to 2011 (Statistics South Africa 2014). Numbers of tourists visiting the area every year have increased by 13% per annum since 2005. This rapid rate in development translates to proportional increase in the amounts of waste and wastewater 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 wastewater 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 wastewater treatments works still operate off an exemption issued under the National Water Act (No. 36 of 1998) in spite of the fact that the ICMA 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 was 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. An Environmental Management Programme (EMPr) to upgrade and maintain mitigation measures for the prevention of erosion was accepted by the Western Cape Department of Environmental Affairs & Development Planning (DEA&DP) and implementation for some of these have been successful to date. Furthermore, coastal management/set-back lines were produced for the West Coast District Municipality (WCDM) is currently in preparation to be published in the *Government Gazette* for public comment. These coastal management/set-back lines will inform planning and development in Saldanha Bay, taking into account short, medium and long-term risks alongside the consideration of the time frame and value of the proposed development.

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 adequately monitored (both volume and water quality) and that the quality of the effluent at the edge of the mixing zone is compliant with existing South African Water Quality Guidelines for the Coast Zone and any other legislative requirements; Implementation of the coastal management/set-back lines around the perimeter of the Bay and Lagoon 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 Wastewater treatment in Saldanha Bay

Effluent from two wastewater treatment works (Saldanha and Langebaan) finds way into the Bay at present. The Saldanha Wastewater Treatment Works (WWTW) operates on an exemption issued by the Department of Water Affairs and Forestry (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. This is an illegal activity in terms of the National Environmental Management: Integrated Coastal Management Act (No. 24 of 2008), which prohibits the discharging of effluent into a Marine Protected Area (MPA). A directive has been issued to the municipality to correct this. There are also 16 sewage pump stations in Saldanha and 27 sewage pump stations in Langebaan many of which are situated very close to the waters' edge. These pump stations have periodically malfunctioned in the past (often due to power failures) with the result that raw untreated sewage directly flowing into the Bay threatening human health and mariculture operations. Since 2012 ten pump stations have been upgraded and remaining upgrades will be completed by the end of this year. Approximately 200 conservancy tanks are mostly situated in Langebaan and are emptied by the municipality on a regular basis and do not pose a direct threat to the Langebaan Lagoon.

Clearly, neither the Saldanha nor the Langebaan WWTW is able to keep up with the ever increasing supply of wastewater generated by the surrounding industry and residential areas, a fact that is evidenced by chronic non-compliance with the applicable wastewater standards (revised General Discharge Limit of the General and Special Standard, *Government Gazette* No. 20526 – 18 October 1999). The NWA allows the disposal of effluent into the municipal system and the responsibility lies with the local municipalities to adequately treat the effluent. There are no national standards to regulate the quality of effluent that is delivered to the municipalities by the industries. Local by-laws are not sufficient to regulate the volume and quality of effluent received by the industry (Eddy, 2003).

Apart from the necessity to upgrade municipal wastewater treatment facilities, local government must first and foremost ensure that the quantity and quality of effluent is controlled at the source to relief the pressure on municipal sewage systems. This can be done by means of stricter by-laws, which regulate the water quality required when industrial wastewater enters the municipal wastewater treatment system. Finally, it is strongly recommended that the local municipality should embark on an educational mission to create awareness among residents to reduce waste disposed down the drain to an absolute minimum.

12.1.4 Fish factories

It appears that at least two out of three operational fish processing plants do not monitor their effluent for compliance purposes, an issue that should be addressed as a matter of urgency. In comparison, Sea Harvest has applied for a Coastal Waters Discharge Permit (CWDP) and operates under a water use license issued in January 2012 and regularly monitors effluent volume and quality. However, it is also evident that this operation is not compliant with the applicable effluent quality standards (*Government Gazette* No. 20526, 8 October 1999). ICMA 69(5)(d) requires that any person who wishes to discharge wastewater into the coastal environment and who has applied for a General Authorization/CWDP must be compliant with any relevant waste standards as specified in the NWA and other legislation dealing with waste, unless the Water Use License/General Authorisation states otherwise. Until all operations have been issued a CWDP, authorities should focus their efforts on ensuring that effluent discharges meet the absolute minimum requirements, i.e. the revised General Discharge Limits as per the General and Special Standards of 1999. 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.

Premier Fishing (previously trading as Southern Seas Fishing) is one of the largest fish processing plants that historically discharged into the Bay but has been out of operation for several years. Operators of the plant but have recently (2013) were granted permission by the authorities to reopen shop. Premier fishing is currently finalizing an application for a CWDP. Although the plant will be required to implement much more strict effluent management protocols than in the past and will have to 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 carefully monitored.

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 180 ha has been allocated to ten mariculture operators within Saldanha Bay. Nine operators hold rights to farm mussels but only six exercise this right. Six operators farm oysters and but also have the right to cultivate abalone, scallops, red bait or seaweed. 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.

Southern Atlantic Sea Farms (Pty) Ltd is the only company that holds a Right to Engage in Marine Aquaculture in terms of Section 18 of the Marine Living Resources Act (No. 18 of 1998) (MLRA). The right is for the production of Atlantic Salmon (*Salmo salar*) for a period of 15 years and commenced on 1 January 2014. No Environmental Authorisation (EA) is required as production falls below the 50 000 kg threshold as per the Environmental Impact Assessment (EIA) Regulations of 2010. Currently the project is in Pilot Phase with two floating cages deployed containing approximately 10 000 Atlantic salmon on-growing trials. The operation is subject to an environmental monitoring programme, biosecurity (Amanzi biosecurity). New Alien and Invasive Species Regulations and Invasive Species Lists were promulgated on 1 August 2014 in terms of the National Environmental Management: Biodiversity Act (No. 10 of 2004) (NEMBA). These regulations and lists specify that any restricted activities related to an alien species legally introduced prior to the promulgation of these regulations and lists are exempted from the requirement of a permit (and therefore a risk assessement). These new regulations raise concerns with regards to the introduction of alien species into new environments. For example, it is of concern that salmon, previously only farmed on land (low risk) can now be introduced into the marine environment (higher/unknown risk) without a permit/risk assessment in terms of NEMBA.

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. 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 liquid petroleum gas terminals, expansion of existing quays), commissioned and/or are under construction 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.

12.1.8 Addressing cumulative effects in Saldanha Bay

Currently, piece meal EIAs are not taking into account cumulative impacts on Saldanha Bay and the Langebaan Lagoon caused by continued and accelerating industrial developments (Saldanha Bay Industrial Development Zone, expansion of iron ore export capacity, aspirations to expand the mariculture sector, expanding liquid petroleum gas import). While many of these developments are ostensibly "land-based", a good number of them rely on ships to bring in or take away their raw material and/or processed products. While the increase in vessel traffic associated with each of these individual developments may be small in each case, they collectively contribute to the ever increasing number of vessels visiting the Bay each year and also to the ever increasing volumes of ballast water that are discharged into the Bay. Similarly, each of the individual developments also contributes to the increases in the volume of wastewater that is produced (and ultimately discharged to the Bay) each year, and also to increases in storm water running off into the Bay.

The challenge of addressing these cumulative impacts in an area such as Saldanha is immense. A number of initiatives have recently been initiated by the SBWQFT in conjunction with the authorities in an effort to address these concerns. Firstly, the DEA&DP: Directorate Land Management is currently drafting a generic EMPr that will need to be adopted as a minimum standard by all future developments requiring EA in terms of the National Environmental Management Act (No. 107 of 1998) (NEMA) EIA Regulations. Secondly, the SBWQFT is currently lobbying the relevant Provincial and National authorities to have Saldanha Bay declared a “Special Management Area” under the ICMA. In terms of section 23 (1) (a) of the Act, the Minister to publish a notice in the *Government Gazette* to declare and area that is wholly or partially within the coastal zone to be a special management area. A special management area may be declared if environmental, cultural or socio-economic conditions require the introduction of measures which are necessary to more effectively conserve, protect or enhance coastal ecosystems and biodiversity in the area of question. The Minister also has the power to prohibit certain activities should these activities be consider contrary to the objectives of the special management area (ICMA Section 23 (4)).

Another initiative that may well contribute to improving the health of Saldanha Bay is a proposal that has been tabled by Frontier Saldanha Utilities (Pty) Ltd for the establishment of a regional marine outfall in Danger Bay. This regional marine outfall will accommodate effluent from three new proposed developments in Sald0naha Bay (a rare earth element separation plant proposed by Frontier Separation (Pty) Ltd, a chlor-alkali production facility proposed by Chlor-Alkali Holdings (Pty) Ltd, and municipal effluent treated by the regional WWTW proposed by the Saldanha Bay Municipality (SBM). The benefits of this project are twofold – firstly effluent from all three plants will be discharged through an open ocean outfall outside of Saldanha Bay (where wave energy and the assimilative capacity of the environment is much higher than in the low energy environment in the Bay) and secondly the outfall has been designed in such a way that it can accommodate effluent from other existing as well as a good number of new proposed developments. The potential thus exists for diverting some of the existing effluent streams that currently find their way into the Bay, outside of the Bay at a fraction of the cost that this may otherwise have required. (Note that the costs of constructing an open ocean or deep water outfall is the most commonly cited reason for needing to discharge effluent directly into the Bay.) Frontier Saldanha Utilities (Pty) Ltd has also joined the Saldanha Bay Water Quality Trust (SBWQT) and have commissioned baseline marine monitoring in Danger Bay even through the intention is only to begin discharging effluent in 2018 at the earliest.

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 SBWQT. 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 Council for Scientific and Industrial Research (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 on-going comparisons with historical data.

So far, Anchor Environmental Consultants deployed temperature loggers in Small Bay near North Buoy in April 2014 but data have yet to be downloaded. No funds are available at this point in time to regularly monitor salinity and dissolved oxygen.

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

There is clear evidence of altered current strengths, circulation patterns and wave energy within Saldanha Bay, which are ascribed to the construction of the ore terminal and causeway. The wave exposure patterns have also been altered as a result of harbour developments in Saldanha Bay, resulting in areas of the Bay becoming more sheltered. 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 (Department of Environmental Affairs Mussel Watch Programme and Mariculture Operators)

The concentrations of metals in the flesh of mussels used to be monitored by the Mussel Watch Programme (DAFF). 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. No new data were received for the 2013/2014 period; however, the programme is due to resume in late 2014. In the interim, Anchor Environmental Consultants collected mussel samples from the same five sites during the field survey in April 2014.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. Data on trace metals concentrations in shellfish from the mariculture farms in the Bay were also obtained from the DAFF (courtesy of the farm operators).

Concentrations of trace metals in marine filter feeders in Saldanha Bay suggest that concentrations of trace metals are high along the shore and are frequently above published guidelines for foodstuffs. Concentrations offshore are much lower and are less of a concern. This may be linked with higher growth rates for farmed mussels, and the fact that the cultured mussels feed on phytoplankton blooms in freshly upwelled, uncontaminated water.

Metal contamination poses a very serious risk to the health of people harvesting mussels from the shore (large qualities of shellfish are harvested and consumed by recreational and subsistence fishers from the shore of the Bay) and high concentrations of trace metals along the shore points to the need for management interventions to address this issue. It is vitally important that this monitoring continues in the future and that data are made available to the public. It is also imperative that this Mussel Watch Program be revamped 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. The microbial monitoring program provides evidence that while some 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 an overall trend of improving compliance for which the relevant authorities should be commended. However, the situation in Small Bay remains a concern, with three sites exceeding the levels for safe mariculture practices, and two sites exceeding the levels for safe recreational activities in 2014. The increasing trend in faecal coliform counts at the Langebaan North site is also cause for concern, and although microbial counts are still within the recreational use guidelines, this is the only site outside of Small Bay that exceeded the mariculture guidelines.

Given the current importance and likely future growth of both the mariculture and tourism industries within Saldanha Bay, it is imperative that sewage treatment and storm water facilities are upgraded to match the rate of development in order to prevent any further degradation of water quality within the Bay. Continued monitoring of bacterial indicators (intestinal *Enterococci* in particular), with regular analysis and interpretation of data is also required and should be undertaken at all sites on a bimonthly basis.

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 (DEA 2012) 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, total organic carbon (TOC) and trace metals

Sediment monitoring in the Bay has revealed that key heavy metal contaminants (Cd, Pb and Cu) are high at a number of sites 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 areas adjacent to the Ore Jetty near the Mussel Farm and the Yacht Club.

Sediment monitoring (particle size, Total organic carbon (TOC) 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 contaminated cultured and wild seafood 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 subsequent monitoring has shown a dramatic increase in total petroleum hydrocarbon (TPH) levels such that the international threshold concentrations were exceeded.. In the latest survey (2014) very high concentrations of hydrocarbons were observed at sites adjacent to the multipurpose quay and the base of the ore jetty. The chemical composition of the hydrocarbons found in sediments at these sites suggests that the contaminant is mostly likely weathered diesel. This suggests that there may have been a pollution incident associated with the shipping activities alongside the jetty or with operational activities on the jetty itself. The monitoring has shown that there is indeed a need for immediate concern as hydrocarbon levels in the sediments have increased and remain above the recommended thresholds. Further investigation and implementation of corrective management action to prevent further contamination is urgently required.

12.4 Aquatic macrophytes in Langebaan Lagoon

Congruent with global patterns, seagrass (*Zostera capensis*) beds have experienced a radical reduction in size with associated fragmentation of large beds. This phenomenon has been attributed to direct and indirect anthropogenic changes such as physical disturbance, pollution, specifically eutrophication and most recently, seagrass biomass was found to be lower in warmer waters (Cloverly Lawrence, University of Cape Town, *pers. comm.* 2014). The dramatic decline in seagrass beds has been shown to have profound negative impacts on species diversity and composition and is very likely to induce change in higher trophic groups within the affected ecosystem. Aerial photographs showing changes of seagrass beds in Langebaan Lagoon over time are only available for the period 1960 to 2007. Recognising the importance of seagrass beds to provide habitat heterogeneity in the lagoon, it is strongly recommended that aerial photographs should continue as soon as possible, such that monitoring of seagrass beds can be continued. This would be especially interesting if combined with future water temperature monitoring in the lagoon to ascertain if temperature fluctuations influence seagrass bed sizes and distribution patterns.

12.5 Benthic macrofauna

Monitoring of benthic macrofaunal communities over the period 1999-2014 have revealed a relatively stable situation in most parts of the Bay and Lagoon with the exception of 2008 when a dramatic shift in benthic community composition occurred at all sites. This shift involved a decrease in the abundance and biomass of filter feeders and an increase in shorter lived opportunistic detritivores. This was attributed to the extensive dredging that took place during 2007-2008. Aside from this Bay-wide phenomenon, localised improvements in health have been detected in the yacht club basin and at Salamander Bay following construction of the boat dock. Notable improvements in the health of benthic communities include the return of the suspension feeding sea-pen *Virgularia schultzei* to Big Bay and Langebaan Lagoon 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. Certain areas of Small Bay that experience reduced water circulation patterns in (e.g. near the Small Craft Harbour and near mussel rafts) which results in the accumulation of fine sediment, organic material and trace metals (aggravated by anthropogenic inputs) still have impoverished macrofauna communities. 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 and ecosystem health as a whole. The regularity (annually) and intensity of benthic macrofauna monitoring should continue at all of the current stations.

12.6 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.

A total of 128 taxa were recorded from the eight study sites, most of which had been found in previous survey years. The faunal component was represented by 25 species of filter-feeders, 27 species of grazers, and 23 species of predators and scavengers combined. The algal component comprised 39 corticated (foliose) seaweeds, seven ephemerals, five species of encrusting algae, and two species of kelp.

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. During the present survey, it was confirmed that two additional alien barnacle species were present: *Amphibalanus amphitrite amphitrite* and *Menesiniella regalis*.

In general, rocky shore communities were relatively stable with only minor changes over the years. However, the establishment of the two new alien species must be monitored closely in continued annual rocky shore surveys.

12.7 Fish

Long-term monitoring of juvenile fish assemblages by means of experimental seine-netting in the surf zone has revealed some concerning trends in recent years.

The significant declines in white stumpnose abundance at all sites throughout the system in recent years suggest that the protection afforded by the Langebaan MPA may not be enough to sustain the fishery at the current high effort levels. The low white stumpnose abundance in recent years may simply be a result of natural variability in recruitment strength (possibly at decadal time scales greater than the monitoring record). However, given the findings of Arendse (2011) who assessed the adult stock to be overexploited using data collected during 2006-08 already, this could indicate that recruitment overfishing is occurring and a precautionary approach is warranted. The annual seine net surveys can act as an early warning system that detects poor recruitment and allows for timeous adjustments in fishing regulations to reduce fishing mortality on weak cohorts and preserve sufficient spawner biomass to sustain catches in future. The consistent declining trend in juvenile white stump abundance in the nursery surf-zone habitats since 2007, with the two lowest abundance estimates emanating from the last two annual surveys, strongly supports the implementation of the harvest control measures recommended by Arendse (2011); namely a reduction in bag limit from 10 to 5 fish per person per day and an increase in size limit from 25 cm TL to 30 cm TL.

In Small Bay, with the exception of harders, estimated abundance of key species was well below average, with the lowest yet recorded blacktail and white stump density, and the 2nd and 3rd lowest silverside density to date. This follows the trend observed since 2010/11 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 and Langebaan Lagoon. 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 0.05 fish.m^{-2} in Langebaan lagoon. Small Bay is often viewed as the more developed or industrialized portion of the Bay and is considered by many as a 'lost cause'. These data provides a strong argument to stamp out such negative thinking and to continue lobbying strongly for enhanced protection of this portion of the Bay. The concerning trend in decreasing white stumpnose recruitment throughout the Bay makes it even more critical that the environmental health of Small Bay, that is demonstrably the most important white stump nursery habitat, is maintained. With the exception of white stump, the current status of fish and fisheries within Big Bay and Langebaan Lagoon appear to be satisfactory.

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 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.

12.8 Birds

An alarming decrease in the abundance of both resident and migrant waders utilising Langebaan Lagoon was evident over the period 2000-2012 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 (Cape cormorants, Bank cormorants, Cape gannets and African Penguins) 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 or rock lobster) outside of the Bay and human disturbance within the Bay. Encouraging increases in the numbers of migrant and resident waders were evident in 2013 and 2014, but populations still remain well below the long term average.

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 on-going monitoring programme, managed by the Avian Demography Unit of the University of Cape Town and Oceans and Coasts (DEA). 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.

12.9 Alien invasive species

At least 70 of 92 recorded introduced species are thought to occur in Saldanha Bay and/or Langebaan Lagoon. Many of these are considered invasive, including the Mediterranean mussel *Mytilus galloprovincialis,* the European green crab *Carcinus maenas* and the recently detected barnacle *Balanus glandula*. An additional 39 species are currently regarded as cryptogenic (of unknown origin) but very likely introduced. Populations of the Western Pea crab *Pinnixa occidentalis,* first detected in the Bay in 2004, seem to have stabilised. This species made a brief incursion into Langebaan Lagoon in 2009 and was absent from this area until this year. 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 *Balanus glandula* are by far the most dominant animal species on rocky shores in the Bay. Populations of *Mytilus* appear to be growing rapidly, while populations of *Balanus* seem to be declining. These two species compete directly with one another for space on the shore, with expanding populations of *Mytilus* displacing those of *Balanus*. *Menesiniella regalis* was again positively identified from Saldanha Bay, while *Amphibalanus amphitrite amphitrite* was identified from the Bay for the first time. 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. Thus, changes in the population of these species in Saldanha Bay should be carefully monitored annually to measure the impacts that they have on the native biota.

12.10 Danger Bay

Initiation of baseline sampling of sediment, benthic macrofauna and fish in Danger Bay in 2014 provided data that this is a more exposed and dynamic environment than Saldanha Bay and does suggest that this site is far more suitable for a regional marine outfall. Discharge of organically and chemically enriched effluent from the proposed regional marine outfall is still expected to have a discernable impact on the physical environment and biological communities within a zone of impact. Ongoing collection of comprehensive baseline data on macrobenthic communities in Danger Bay to capture the natural variability is essential for objective and quantitative assessment of expected impacts. Field observations during the 2014 survey indicate that there is extensive sub tidal reef and associated kelp bed ecosystems in Danger Bay in close proximity to the proposed pipe end locations and adjacent to the sandy substratum habitat that was sampled. Dispersion modeling of effluent from the proposed regional marine outfall is not yet available, but there is a real possibility that the zone of impact may extend to these reefs. We therefore recommend that baseline sampling be expanded to include this sub tidal reef habitat in Danger Bay.

12.11 Summary of environmental monitoring requirements

In summary, the environmental monitoring currently implemented in Saldanha Bay and Langebaan Lagoon (e.g. sediment, benthic macrofauna, birds, rocky intertidal, fish populations) 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, salinity, stormwater quality) 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, Danger Bay and Langebaan Lagoon.

Parameter monitored	Time period	Anthropogenic induced impact	
WATER QUALITY			
Physical aspects (temperature, salinity, dissolved oxygen, nutrients and chlorophyll)	1974-2000, 2010-2011	Dissolved oxygen levels in bottom water in Small Bay are very much lower than they were historically or at least prior to port development. This is attributed to organic loading in the Bay and reduced flushing time. No clear changes are evident with any other physico-chemical parameters.	 
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)	
Microbiological (faecal coliform)	1999-2014	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. Faecal coliform may underestimate actual harmful microbiological concentrations. There is a need to monitor intestinal *Enterococci* instead.	
Trace metal contaminants in water	1997-2008, 2014	Concentrations of cadmium, copper, lead, zinc, iron and manganese in mussel flesh are frequently above the safety guidelines for food stuffs. Any future dredging events should be prevented as far as possible owing to elevated metal concentration in sediments.	
SEDIMENTS			
Particle size (mud/sand/gravel)	1977-2012	The mud fraction in the sediments in the Bay was highly elevated when the State of the Bay surveys commenced in 1999 relative to the period prior to port construction. The situation has improved considerably since this time at most sites, however, levels of mud in the sediment remain highly elevated at some sites (e.g. the near the mariculture rafts and ore terminal).	
Total organic carbon (TOC)	1974-2012	Similar trends as for %mud. Elevated levels of TOC at the Yacht Club basin and near the mariculture rafts (negative impacts) are of particular concern.	
Total organic nitrogen (TON)	1974-2010	Similar trends as for %mud and TOC. Elevated levels of TOC 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	

Parameter monitored	**Time period**	**Anthropogenic induced impact**	
		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, biomass, and diversity	1999-2014	Benthic macrofauna communities in Saldanha Bay and Langebaan Lagoon Bay are highly sensitive to dredging activities and drop dramatically immediately after each major dredging event. Macrofauna communities are currently increasing in abundance and biomass since the last major event in 2009/2010.	 
ROCKY INTERTIDAL AND INTRODUCED SPECIES			
Impact of alien mussel and barnacle introductions	1980-2014	Alien mussel and barnacle have displaced the local mussel and other native species from much of the shore leading to decreased species diversity (negative). Two new alien barnacle species found. The establishment of these species must be closely monitored.	
FISH			
Community composition and abundance	1986-2014	With the exception of white stumpnose, the current status of fish and fisheries within Big Bay and Langebaan Lagoon appear to be satisfactory. Abundance of most species in Small Bay has been declining for several years, though, as is of some concern	
BIRDS			
Population numbers of key species in Saldanha Bay and islands	1977-2014	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	1976-2014	Populations of migrant and resident waders utilising Langebaan Lagoon have decreased dramatically over the last 30 years, attributed to offsite impacts on breeding grounds and local impacts (habitat changes) and disturbance in the lagoon. Modest increases evident for some species in recent years (2013-2014) is encouraging though.	 
DANGER BAY	2014	Currently undisturbed. Ongoing collection of comprehensive baseline data on macrobenthic communities, sediments and fish populations in Danger Bay to capture the natural variability is essential for objective and quantitative assessment of expected impacts.	

13 REFERENCES

Aalbers SA. 2008. Seasonal, diel, and lunar spawning periodicities and associated sound production of white seabass (*Atractoscion nobilis*). *Fishery Bulletin* 106: 143–151.

Abbott R & Bing-Sawyer E. 2002. Assessment of pile driving impacts on the Sacramento blackfish (*Orthodon microlepidotus*). Draft report prepared for Caltrans District 4. San Francisco, CA, Caltrans.

Abbott R, Reyff J & Marty G. 2005. Final Report: Monitoring the Effects of Conventional Pile Driving on Three Species of Fish. Richmond, CA, Manson Construction Company.

Acuña FH, Excoffon & Griffiths CL. 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 JB, Bate GC O'Callaghan M. 1999. Primary producers. In: Allanson BR & Bsird D (ed) *Estuaries of South Africa.* Cambridge: University Press. pp 91-117.

Adams NJ & Navarro RA. 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.

Anchor Environmental Consultants. 2006. State of the Bay 2006: Saldanha Bay and Langebaan Lagoon. Technical Report. Prepared for Saldanha Bay Water Quality Trust. Cape Town, 93 pp. + Appendices.

Anchor Environmental Consultants. 2009. State of the Bay 2008: Saldanha Bay and Langebaan Lagoon. Technical Report. Prepared for Saldanha Bay Water Quality Trust. Cape Town, 174 pp.

Anchor Environmental Consultants. 2010. State of the Bay 2009: Saldanha Bay and Langebaan Lagoon. Technical Report. Prepared for Saldanha Bay Water Quality Trust. Cape Town, 213 pp.

Anchor Environmental Consultants. 2011. State of the Bay 2010: Saldanha Bay and Langebaan Lagoon. Technical Report. Prepared for Saldanha Bay Water Quality Trust. Cape Town, 280 pp.

Anchor Environmental Consultants. 2012a. Re-commissioning of a Fishmeal Processing Plant, Saldanha Bay Marine Specialist Report. Prepared for SRK Consulting (South Africa) (Pty) Ltd. Cape Town, 63 pp.

Anchor Environmental Consultants. 2012b. State of the Bay 2011: Saldanha Bay and Langebaan Lagoon. Technical Report. Prepared for Saldanha Bay Water Quality Trust. Cape Town, 271 pp.

Anchor Environmental Consultants. 2012c. The impact of Fe2O3 on the marine environment in Saldanha Bay. Report prepared for Transnet Port Terminal – Saldanha, October 2012.

Anchor Environmental Consultants. 2013a. Proposed Replacement of Existing Breakwater at the Salamander Bay Special Forces Regiment 4 Boat Park. 2 pp.

Anchor Environmental Consultants. 2013b. State of the Bay 2012: Saldanha Bay and Langebaan Lagoon. Technical Report. Prepared for Saldanha Bay Water Quality Trust. Cape Town, 314 pp.

Anderson MJ, Gorley RN & Clarke KR. 2008. PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods. PRIMER-E: Plymouth, UK, 214 pp.

Angel A, Branch GM, Wanless RM & 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. *Marine Ecology Progress Series* 136: 111-121.

Arendse CJ. 2011. Aspects of the early life history and a per-recruit assessment of white stumpnose *Rhabdosargus globiceps* (Pisces: Sparidae) in Saldanha Bay with recommendations for future research and monitoring. MSc. Thesis, University of Cape Town, 120 pp.

Attwood CG, Næsje TF, Fairhurst L & Kerwath SE. 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 AA, Clarke C, Greyling L, Hillard R, Polglaze J & 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 JR & Lovvorn JR. 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 BH, Schiff K & Washburn L. 2003. Water quality impacts of storm water discharges to Santa Monica Bay. *Marine Environmental Research* 56(1-2): 205-223.

Beckley LE. 1981. Marine benthos near the Saldanha Bay iron-ore loading terminal. *South African Journal of Zoology* 16(4): 269-271.

Bellmann MA & Remmers P. 2013. Noise mitigation systems (NMS) for reducing pile driving noise: Experiences with the “big bubble curtain” relating to noise reduction. *The Journal of Acoustical Society of America* 134(5): 4059.

Biccard A. 2012. Taxonomy, Systematics and Biogeography of South African Cirripedia (Thoracica). MSc. Thesis, University of Cape Town, 172 pp.

Bickerton IB. 1999. Saldanha Bay Water Quality Programme: Benthic Macrofaunal Monitoring. Council for Scientific and Industrial Research (CSIR), Cape Town, 18 pp.

BirdLife International 2011. IUCN Red List for birds. Downloaded from http://www.birdlife.org

Bonvicini Pagliai AM, Cognetti Varriale AM, Crema R, Curini Galletti M & Vandini Zunarelli R. 1985. Environmental impact of extensive dredging in a coastal marine area. *Marine Pollution Bulletin* 16(12): 483-488.

Booth DB & Jackson CR. 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.

Bosman AL, Du Toit JT, Hockey PAR & Branch GM. 1986. A field experiment demonstrating the influence of seabird guano on intertidal primary production. *Estuarine, Coastal and Shelf Science* 23(3): 283-294.

Bosman AL & Hockey PAR. 1986. Seabird guano as a determinant of rocky intertidal community structure. *Marine Ecology Progress Series* 32: 247-257.

Bosman AL & Hockey PAR. 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* 7: 61-68.

Boucher C & Jarman ML. 1977. The vegetation of the Langebaan area, South Africa. *Transaction of the royal Society of South Africa* 42: 241-272.

Boussard A. 1981. The reactions of roach (*Rutilus rutilus*) and rudd (*Scardinius erythrophthalmus*) to noises produced by high speed boating. In: *Proceedings of the 2nd British Freshwater Fisheries Conference.* 188–200 pp.

Branch GM, Griffiths CL, Branch ML & Beckley LE. 2010a. Two Oceans. David Philip Publishers, Cape Town, South Africa.

Branch GM, Odendaal F & Robinson TB. 2008. Long-term monitoring of the arrival, expansion and effects of the alien mussel *Mytilus galloprovincialis* relative to wave action. *Marine Ecology Progress Series* 370: 171-183.

Branch GM, Odendaal F & Robinson TB. 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 GM & Steffani CN. 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.

Bregman AS. 1990. *Auditory Scene Analysis: The Perceptual Organization of Sound*. Cambridge, MA, MIT Press.

Bruun P. 1962. *Sea level Rise as a Cause of Shore Erosion* Journal of Waterways and Harbors Division, 117-130.

Buchman MF. 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 RH & Branch GM. 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 RH, Branch GM & 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 RH, Branch GM, Eekhout S, Robertson B, Zoutendyk P, Schleyer M, Dye A, Hanekom N, Keats D, Jurd M & McQuaid C. 1995. Gradients of intertidal primary productivity around the coast of South Africa and their relationships with consumer biomass. *Oecologia* 102: 189-201.

Carlton JT. 1999. The scale and ecological consequences of biological invasions in the world's oceans. In: Sandlund, OT *et al*. (Ed.), *Invasive Species and Biodiversity Management*. Kluwer Academic Publishing, Netherlands, 195-212 pp.

Carlton JT & Cohen AN. 2003. Episodic global dispersal in shallow water marine organisms: the case history of the European shore crabs *Carcinus maenas* and *Carcinus aestuarii*. *Journal of Biogeography.* 30: 1809-1820.

Carlton JT & Geller JB. 1993. Ecological roulette: the global transport and invasion of non indigenous marine organisms. *Science* 261: 78-82.

Caltrans. 2001. Pile installation demonstration project, fisheries impact assessment. PIDP EA 012081. San Francisco–Oakland Bay Bridge East Span Seismic Safety Project. *Caltrans Contract* 04A0148. San Francisco, CA.

Carr GM & Rickwood CJ. 2008. Water Quality Index for Biodiversity Technical Development Document. Report prepared for Biodiversity Indicators Partnership, World Conservation Monitoring Centre, 219 Huntingdon Road, Cambridge CB3 0DL, United Kingdom. 64 pp.

Carter R & Coles S. 1998. Saldanha Bay General Cargo Quay Construction: Monitoring of suspended sediment distributions generated by dredging in Small Bay. CSIR Report ENVS98100. 26 pp.

Carter RA. 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 VU & Rossi R. 1984. Settlement, growth and production of the mussel *Mytilus galloprovincialis*. *Marine Ecology Progress Series* 16: 173-184.

CEF. 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.

Cempel M & Nikel G. 2006. Nickel: A Review of Its Sources and Environmental Toxicology. *Polish Journal of Environmental Studies* 15(3): 375-382.

Christie ND. 1981. Primary production in Langebaan Lagoon. In: Day JH (ed) *Estuarine Ecology with Particular reference to Southern Africa*. Cape Town: Balkema. pp 101-115.

Christie, ND & Moldan A. 1977. Effects of fish factory effluent on the benthic macrofauna of Saldanha Bay. *Marine Pollution Bulletin* 8: 41-45.

Clark BM. 1997. Variation in surf-zone fish community structure across a wave-exposure gradient. *Estuarine and Coastal Shelf Science* 44(6): 659-674.

Clark RB. 1986. *Marine Pollution*. Claredon Press, Oxford. 215 pp.

Clarke KR & Gorley RN. 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E: Plymouth.

Clarke KR & Warwick RM. 2001. *Change in Marine Communities: An Approach to Statistical Analysis and Interpretation*, 2nd edition. PRIMER-E Ltd, Plymouth.

Cloern JE. 2001. Our evolving conceptual model of the coastal eutrophication problem. *Marine Ecology Progress Series* 210: 223-253.

Cockcroft AC, van Zyl D & 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.

Colan KE. 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. Saldanha, 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. Saldanha, 24 pp.

Cooper J, Brooke RK, Shelton PA & Crawford RJM. 1982. Distribution, population size and conservation of the Cape Cormorant *Phalacrocorax capensis*. *Fisheries Bulletin South Africa* 16: 121-143.

Crawford RJM. 2007. Trends in the numbers of three cormorants *Phalacrocorax* spp. breeding in South Africa's Western Cape Province. In: Kirkman SP. (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 RJM. 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 RJM, Altwegg R, Barham BJ, Barham PJ, Durant JM, Dyer BM, Makhado AB, Pichegru L, Ryan PG, Underhill LG, Upfold L, Visagie J, Waller LJ & Whittington PA. 2011. Collapse of South Africa's penguins in the early 21st century: a consideration of food availability. *African Journal of Marine Science* 33: 139–156.

Crawford RJM, Barham PJ, Underhill LG, Shannon LJ, Coetzee JC, Dyer BM, Mario Leshoro T & 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 RJM, Cockcroft AC, Dyer BM & Upfold L. 2008c. 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 RJM, Dundee BL, Dyer BM, Klages NT, Meyer MA & 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 RJM, Dyer BM & Brooke RK. 1994. Breeding nomadism in southern African seabirds – constraints, causes and conservation. *Ostrich* 65: 231-246.

Crawford RJM, Dyer BM, Kemper J, Simmons RE & Upfold L. 2007. Trends in numbers of Cape Cormorants (*Phalacrocorax capensis*) over a 50 year period, 1956-57 to 2006-07. *Emu* 107:253-261.

Crawford RJM, Nel DC, Williams AJ & Scott A. 1997. Seasonal patterns of abundance of Kelp Gulls *Larus dominicanus* at breeding and non-breeding localities in southern Africa. *Ostrich* 68: 37-41.

Crawford RJM, Sabarros PS, Fairweather T, Underhill LG & Wolfaardt AC. 2008a. 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 RJM & Underhill LG. 2003. Aspects of breeding, molt, measurements and population trend of Hartlaub's gull *Larus hartlaubii* in Western Cape, South Africa. *Waterbirds* 26: 139-149.

Crawford RJM, Underhill LG, Coetzee JC, Fairweather T, Shannon LJ & Wolfaardt AC. 2008b. 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.

Cruz-Motta JJ, Underwood AJ, Chapman MG & Rossi F. 2003. Benthic assemblages in sediments associated with intertidal boulder-fields. *Journal of Experimental Marine Biology and Ecology* 285-286: 383-401.

CSIR. 1996. Environmental Impact Assessment: Proposed changes to oil transfer operations, SFF, Saldanha Bay: Specialist Study (S3(i): Effects of dredging activities on turbidity levels and shoreline stability in Saldanha Bay, prepared by Mocke G, Luger S, Schoonees KS, Smit F & Theron AK. 102pp.

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. 2006. The development of a common set of water and sediment quality guidelines for the coastal zone of BCLME, South Africa. Prepared for Benguela Current Large Marine Ecosystem Programme. CSIR Report No. CSIR/NRE/ECO/2006/0011/C. Stellenbosch, 164 pp.

CSIR. 2012a. 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.

CSIR 2012b. Final 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. Prepared for WorleyParsons (Pty) Ltd. CSIR Report No. GWDS Stel General: 1159, Stellenbosch.

CSIR. 2013a. Environmental Impact Assessment (EIA) for the Proposed Construction, Operation, and Decommissioning of the Marine Outfall Pipeline and Associated Infrastructure for Frontier Saldanha Utilities (Pty) Ltd in the Saldanha Bay Region, Western Cape. Background Information Document. Prepared for Frontier Saldanha Utilities (Pty) Ltd, 8pp.

CSIR 2013b. Environmental Impact Assessment (EIA) for the Proposed Construction, Operation and Decommissioning of the Saldanha Regional Marine Outfall Project for Frontier Saldanha Utilities (Pty) Ltd at Danger Bay in the Saldanha Bay Region. Draft Scoping Report. Prepared for Frontier Saldanha Utilities (Pty) Ltd.

CSIR. 2013c. Final EIA 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 Report No. GWDS 1159 EMS0014, Stellenbosch.

Cubit JD. 1984. Herbivory and the seasonal abundance of algae on a high intertidal rocky shore. *Ecology* 66: 1904-1917.

da Silva C, Kerwath SE, Attwood CG, Thorstad EB, Cowley PD, Økland F, Wilke CG, & TF Næsje. 2013. Quantifying the degree of protection afforded by a no-take marine reserve on an exploited shark. *African Journal of Marine Science*, 35(1): 57-66.

Davidson IC, Crook AC & Barnes DKA. 2004. Quantifying spatial patterns of intertidal biodiversity: is movement important? *Marine Ecology* 25: 15-34.

Day JH. 1959. The biology of Langebaan Lagoon: a study of the effect of shelter from wave action. *Transactions of the Royal Society of South Africa* 35: 475-547.

Day JH. 1974. *A guide to marine life on South African shores*. A.A. Balkema, Cape Town.

Day JH. 1981. The estuarine flora. In: Day JH (ed) *Estuarine Ecology with Particular reference to Southern Africa*. Cape Town: Balkema. pp 77-99.

Denny M & Gaylord B. 2002. The mechanics of wave-swept algae. *Journal of Experimental Biology* 205: 1355-1362.

Denny MW & Gaines S. 2007. Encyclopedia of Tidepools and Rocky Shores. University of California Press, 705 pp.

Department of Agriculture, Forestry and Fisheries (DAFF). 2013. Status of South African Marine Fishery Resources 2012.

Department of Agriculture, Forestry and Fisheries (DAFF). 2014. Aquaculture Yearbook 2013 South Africa.

Department of Environmental Affairs (DEA). 2012. South African Water Quality Guidelines for Coastal Marine Waters. Volume 2: Guidelines for Recreational Use, Cape Town.

Department of Environmental Affairs (DEA) 2014. National Guideline for the Discharge of Effluent from Land-based Sources into the Coastal Environment. Pretoria, South Africa. RP101/2014.

Department of Environmental Affairs & Development Planning (DEA&DP) 2014. Environmental Authorisation: The Proposed Construction of a Liquid Petroleum Gas Handling Facility and Associated Infrastructure on Farm Yzervarkensrug 127/13, Saldanha. EIA Reference Number: E12/2/4/2/F4/16/3001/12.

Department of Water Affairs (DWA) 2013. Support to the Continuation of the Water Reconciliation Strategy for the Western Cape Water Supply System: Status Report October 2013. Prepared by Umvoto Africa (Pty) Ltd in association with WorleyParsons on behalf of the Directorate: National Water Resource Planning, South Africa.

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 - Recreational Use. 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.

de Greef K, Griffiths CL & Zeeman Z. 2013. Deja vu? A second mytilid mussel, *Semimytilus algosus*, invades South Africa's west coast. *African Journal of Marine Science* 35(3): 307-313.

de Ponte Machado M. 2007. Is predation on seabirds a new foraging behaviour for great white pelicans? History, foraging strategies and prey defensive responses. Final report of the BCLME (Benguela Current Large Marine Ecosystem) project on top predators as biological indicators of ecosystem change in the BCLME. Avian Demography Unit, Cape Town. 131-142 pp.

Desideri D, Meli MA, Roselli C & Feduzi L. 2009. A biomonitoring study: 210Po and heavy metals in mussels. *Journal of Radioanalytical and Nuclear Chemistry* 279: 591-600.

Dias MP, Granadeiro JP, Lecog M, Santos CD, Palmeirim JM. 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 (UCT). 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

Eckman JE. 1990. A model of passive settlement by planktonic larvae onto bottoms of differing roughness. *Limnology and Oceanography* 35: 887-901.

Eddy LJ. 2003. *Sewage wastewater management in South Africa*. MSc Thesis. Department of Geography, Environmental Management and Energy Studies (EDTs), University of Witwatersrand.

EPA. 2003. After the storm. US Environmental Protection Agency. EPA 833-B-03-002. http://epa.gov/weatherchannel/storm water.html.

Erasmus T & De Villiers AF. 1982. Ore dust pollution and body temperatures of intertidal animals. *Marine Pollution Bulletin* 13(1): 30-32.

Erftemeijer PLA & Lewis RRR. 2006. Environmental impacts of dredging on seagrasses: A review. *Marine Pollution Bulletin* 52: 1553-1572.

ERM Southern Africa (ERMSA). 2011. Final Scoping Report: Proposed LPG Bulk Importation into Saldanha Bay. Environmental Resources Management Southern Africa (Pty) Ltd, December 2011. ERM Southern Africa Ref: 0110311, DEA&DP Ref: E12/2/4/2-F4/16-3023/11.

ERM Southern Africa (ERMSA). 2010. Saldanha LPG Facility: Environmental Impact Assessment November 2010. Presentation to the Saldanha Bay Water Quality Forum Trust, November 2010.

ERM Southern Africa (ERMSA). 2008a. 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 Southern Africa (Pty) Ltd, April 2008. ERM Southern Africa Ref: 0080265, DEAT Ref: 12/12/20/1143.

Flemming BW. 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 WK, Hayward PJ & Gibbons MJ. 2007. Taxonomy of shallow water Bryozoa from the west coast of South Africa. *African Natural History* 3: 1-58.

Fuggle RF. 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 BS, 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 pp.

Game ET, Grantham HS, Hobday AJ, Pressey RL, Lombard AT, Beckley LE, Gjerde K, Bustamante R, Possingham HP, Richardson AJ. 2009. Pelagic protected areas: The missing dimension in ocean conservation. *Trends in Ecology and 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. Honours Thesis, University of Cape Town, Department of Environmental and Geographical Science.

GIBB. 2013. Port of Saldanha: Proposed Expansion of Existing Iron Ore Terminal Background Information for Public Participation. GIBB (Pty) Ltd. Prepared for Transnet.

Gibbs RJ. 1994. Metals in sediments along the Hudson River Estuary. *Environmental International* 20: 507-516.

Gibson R, Hextall B & Rogers A. 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 JT, Hamer JP, Houvenaghel G, Jelmert A, Lucas I, Masson D, Mccollin T, Olenin S, Persson A, Wallentinus I, Wetsteyn LPMJ & Wittling T. 2002. Life in Ballast tanks. In: *Invasive Aquatic Species of Europe: Distribution, Impacts and Management*. Leppakoski E, Gollasch S, Olenin, S (Eds.), Academic Publishers, Netherlands. 217-231 pp.

Grant WS & Cherry MI. 1985. *Mytilus galloprovincialis* Lmk in southern Africa. *Journal of Experimental Marine Biology and Ecology* 90(2): 179-162.

Grant WS, Cherry MI & Lombard AT. 1984. A cryptic species of *Mytilus* (Mollusca: Bivalvia) on the west coast of South Africa. *South African Journal of Marine Science* 2: 149-162.

Griffiths CL, Hockey PAR, Van Erkom Schurink C & Roux PJL. 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 CL, Robinson TB & Mead A. 2008. The status and distribution of marine alien species in South Africa. In: Rilov G & Crooks J (Eds.). *Marine Bioinvasions: Ecology, Conservation and Management Perspectives*. Springer, Heidelberg. 204: 393-408.

Griffiths CL, Robinson TB & 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 CL, 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.

Griffiths CL, van Sittert L, Best PB, Brown AC, Clark BM, Cook PA, Crawford RJM, David JHM, Davies BR, Griffiths MH, Hutchings K, Jerardino A, Kruger N, Lamberth S, Leslie RW, Melville-Smith R, Tarr R & Van Der Lingen CD. 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 JR. 1977. The zooplankton of Langebaan Lagoon and Saldanha Bay. *Transactions of the Royal Society of South Africa* 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. *Journal of Bioadhesion and Biofilm Research* 25: 593-604.

Guerra-Garcia, JM & Garcia-Gomez CJ. 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.

Hampton SL & Griffiths CL. 2007. Why *Carcinus maenas* cannot get a grip on South Africa's wave-exposed coastline. *African Journal of Marine Science* 29(1): 123-126.

Hanekom N & 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.

Haupt TM, Griffiths CL, Robinson TB & Tonin AFG. 2010. Oysters as vectors of marine aliens, with notes on four introduced species associated with oyster farming in South Africa. *African Zoology* 45(1): 52-62.

He H, Chen F, Li H, Xiang W, Li Y & Jiang Y. 2009. Effect of iron on growth, biochemical composition and paralytic shellfish poisoning toxins production of *Alexandrium tamarense*. *Harmful Algae* 9(1): 98-104.

Heck KL, Hays C & Orth RJ. 2003. A critical evaluation of the nursery role hypothesis for seagrass meadows. *Marine Ecology Progress Series* 253: 123-136.

Hedger RD, Næsje TF, Cowley PD, Thorstad EB, Attwood C, Økland F, Wilke CG & Kerwath S. 2010. Residency and migratory behaviour by adult *Pomatomus saltatrix* in a South African coastal embayment. *Estuarine, Coastal and Shelf Science* 89:12-20.

Hellawell JM. 1986. Biological indicators of freshwater pollution and environmental management. London: Elsevier Applied Science Publishers.

Hemmingra MA & Duarte CM. 2000. *Seagrass Ecology.* Cambridge: University Press.

Herman PMJ, Hemmingra MA, Nienhuis PH, Verschuure JM & Wessel EGJ. 1996. Wax and wane of eelgrass *Zostera marina* and water column silicon levels. *Marine Ecology Progress Series. Oldendorf* 14(1): 303-307.

Hewitt CL, Gollasch S & Minchin D. 2009. The vessel as a vector – biofouling ballast water and sediments. In: *Biological Invasions in Marine Ecosystems*, Rilov G & Crooks JA (Eds.). Springer-Verlag, Berlin. 117-131pp.

Hir ML & Hily C. 2005. Macrofaunal diversity and habitat structure in intertidal boulder fields. *Biodiversity and Conservation* 14: 233-250.

Hockey PAR. 1983. Aspects of the breeding biology of the African Black Oystercatcher. *Ostrich* 54: 26-35.

Hockey PAR, Dean WRJ & Ryan PG (Eds.) 2005. *Roberts Birds of Southern Africa*, 7th edition. Trustees of the John Voelcker Bird Book Fund, Cape Town. 1296 pp.

Hockey PAR & 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.

Hodgkiss IJ & Ho KC. 1997. Are changes in N:P ratios in coastal waters the key to increased red tide blooms? In: *Asia-Pacific Conference on Science and Management of Coastal Environment*. Springer, Netherlands. 141-147 pp.

Howarth R, Chan F, Conley DJ, Garnier J, Doney SC, Marino R & Billen G. 2011. Coupled biogeochemical cycles: Eutrophication and hypoxia in temperate estuaries and coastal marine ecosystems. *Frontiers in Ecology and the Environment* 9(1): 18-26.

Hughes JE, Deegan LA, Wyda JC, Weaver MJ & Wright A. 2002. The effect of eelgrass habitat loss on estuarine fish communities of Southern New England. *Estuaries* 25: 235-249.

Hughes RN. 1979. South African populations of Littorina rudis. *Zoological Journal of the Linnean Society* 65: 119-126.

Hutchings K & Lamberth SJ. 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 & Lamberth, SJ. 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, Porter S, Clark BM & 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.

IUCN. 2009. Marine Menace: Alien invasive species in the marine environment. http://wwwvlizbe/imisdocs/publications/153100pdf

Jackson LF & 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 ML. 1986. Conservation priorities in lowland regions of the fynbos biome. South African national scientific Programme Report No 87. CSIR, Pretoria. 55 pp.

Jensen A & Mogensen B. 2000. Effects, ecology and economy. Environmental aspects of dredging – Guide No. 6. International Association of Dredging Companies (IADC) and Central Dredging Association (CEDA). 119 pp.

Kemper J, Underhill LG, Crawford RJM & Kirkman SP. 2007. Revision of the conservation status of seabirds and seals breeding in the Benguela Ecosystem. In: Kirkman SP (Ed.). Final Report of the Benguela Current Large Marine Ecosystem (BCLME). 325-342 pp.

Källén J, Muller H, Franken ML, Crisp A, Stroh C, Pillay D & Lawrence C. 2012. Seagrass-epifauna relationships in a temperate South African estuary: Interplay between patch-size, within-patch location and algal fouling. *Estuarine, Coastal and Shelf Science* 113: 213-220.

Kensley B & Penrith ML. 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 TF, Attwood CG, Cowley PD, Økland F & Wilke C. 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.

Kikuchi T & Perez JM. 1977. Consumer ecology of seagrass beds. In: McRoy CP, Helferich C (eds) *Seagrass Ecosystems: A Scientific Perspective.* New York: Marcel Dekker pp 147-186.

Kljaković-Gašpić Z, Herceg-Romanić S, Kožul D & Veža J. 2010. Biomonitoring of organochlorine compounds and trace metals along the Eastern Adriatic coast (Croatia) using *Mytilus galloprovincialis*. *Marine Pollution Bulletin* 60(10): 1879-1889.

Knowles R. 1982. Denitrification. *Microbiological Reviews* 46(1): 43-70.

Knudsen FR, Schreck CB, Knapp SM, Enger PS & Sand O. 1997. Infrasound produces flight and avoidance response in Pacific juvenile salmonids. *Journal of Fish Biology* 51: 824–829.

Konings A. 2001. Malawi Cichlids in their Natural Habitat. Cichlid Press.

Kostylev VE, Erlandsson J, Ming MY & Gray AW. 2005. The relative importance of habitat complexity and surface area in assessing biodiversity: fractal application on rocky shores. *Ecology Complex* 2: 272-286.

Kruger N. 2002. Long term changes in the benthic macrofauna of Saldanha Bay. M.Sc. Thesis, University of Cape Town. 1-96 pp.

Kruger N, Branch GM, Griffiths CL & Field JG. 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 MC & Griffiths CL. 2008. Present distribution and abundance of the introduced barnacle *Balanus glandula* Darwin in South Africa. *African Journal of Marine Science* 30(1): 93-100.

La Farré M, Pérez S & Kantiani L. 2008. Fate and toxicity of emerging pollutants, their metabolites and transformation products in the aquatic environment. *Trends in Analytical Chemistry* 27(11): 991-1007.

Laugksch RC & Adams NJ. 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 JR. 1964. The Ecology of Rocky Shores. English Universities Press, London.

Lewis S, Grémillet D, Daunt F, Ryan PG, Crawford RJM & Wanless S. 2006. Using behavioural variables to identify proximate causes of population change in a seabird. *Oecologia* 147: 606-614.

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. *Population Ecology* 49: 275-285.

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

Ludynia K, Roux JP, Jones R, Kemper J & Underhill LG. 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 & Monteiro PMS. 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.

Makhado AB, Crawford RJM & Underhill LG. 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 AB, Dyer BM, Fox R, Geldenhuys D, Pichegru L, Randall RM, Sherley RB, Upfold L, Visagie J, Waller LJ, Whittington PA & Crawford RJM. 2014. Estimates of numbers of twelve seabird species breeding in South Africa. Branch Oceans and Coasts, Department of Environmental Affairs Cape Town, South Africa. 15 pp.

Makhado AB, Meÿer MA, Crawford RJM, Underhill LG, 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.

Manuel RL. 1981. *British Anthozoa*. Academic Press, London. 241 pp.

Marangoni C. 1998. The potential for the introduction of alien phytoplankton by shipping ballast water: Observations in Saldanha Bay. M.Sc. Thesis for the Faculty of Science, University of the Witwatersrand, Johanesburg.

Martin JM & Whitfield M. 1983. The Significance of the River Input of Chemical Elements to the Ocean. In: *Trace Metals in Sea Water*. 265-296 pp.

Mather AA, Stretch DD & Garland G. 2010. A simple empirical model for extreme wave run-up on natural beaches. International conference on Coastal Engineering. Shanghai, China.

McClarty A, Cross J, James GM, Gilbert L. 2006. Design and construction of coastal erosion protection groynes using geocontainers, Langebaan, South Africa. Geosynthetics. In: *Proceedingsof the 8th International Conference on Geosynthetics, Yokohama, Japan, Volume 2*. 765-768 pp.

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.

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 and the physical arrangement of objects in space. Chapman & Hall, New York, 3-27 pp.

McGuinness KA. 1984. Species-area relations of communities on intertidal boulders: testing the null hypothesis. *Journal of Biogeography* 11: 439-456.

McGuinness KA. 1987. Disturbance and organisms on boulders II. Causes of patterns in diversity and abundance. *Oecologia* 71: 420-430.

McGuinness KA & Underwood AJ. 1986. Habitat structure and the nature of communities on intertidal boulders. Journal of Experimental Marine Biology & Ecology 104: 97-123.

McKibben JR & Bass AH. 1998. Behavioral assessment of acoustic parameters relevant to signal recognition and preference in a vocal fish. *Journal of Acoustical Society of America* 104: 3520-3533.

McQuaid CD & Branch GM. 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 CD & Branch GM. 1985. Trophic structure of rocky intertidal communities: response to wave action and implications for energy flow. *Marine Ecology Progress Series* 22: 153-161.

McQuaid CD, Branch GM & Crowe AA. 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 JT, Griffiths CL & Rius M. 2011a. Introduced and cryptogenic marine and estuarine species of South Africa. *Journal of Natural History* 45: 2463-2524.

Mead A, Carlton JT, Griffiths CL & Rius M. 2011b. Revealing the scale of marine bioinvasions in developing regions: a South African re-assessment. *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. *Marine Ecology Progress Series* 428: 1-12.

Membrane Technology. 2013. Transnet uses RO desalination plant from Veolia Water. Membrane Technology News, April 2013 (4): 6-7.

Menge BA & Branch GM. 2001. Rocky Intertidal Communities. In: Burtness MD, Gaines S & Hay ME (Eds.), *Marine Community Ecology*. Sinauer Associates, Sunderland, 221-251 pp.

Menge BA, Daley BA, Wheeler PA, Dahlhoff E, Sanford E & Strub PT. 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.

Monteiro PMS, Anderson RJ & 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 PMS & Brundrit GB. 1990. Interannual chlorophyll variability in South Africa's Saldanha Bay system, 1974-1979. *South African Journal of Marine Science* 9: 281-288.

Monteiro PMS, Mcgibbon S & Henry JL. 1990. A decade of change in Saldanha Bay: natural or anthropogenic? *South African Journal of Science* 86: 454-456.

Monniot C, Monniot F, Griffiths CL & Schleyer M. 2001. South African ascidians. *Annals of the South African Museum* 108: 1-141.

Monteiro PMS & Largier JL. 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 PMS, Pascall A & Brown S. 1999. The Biogeochemical Status of Near-Surface Sediments in Saldanha Bay in 1999. CSIR Report ENV-S-C 99093A.

Monteiro PMS, Warwick PA, Pascall A & Franck M. 2000. Saldanha Bay Water Quality Monitoring Programme. Parts 1 & 2. CSIR.

Næsje TJ, Attwood CG, Kerwath S, Cowley PD, Keulder F & 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.

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 RC, Seiderer LJ & Hitchcock DR. 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 WA. 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.

Nikolaou A, Kostopoulou M, Lofrano G, Meric S, Petsas A & 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 (ORBIS) 2011. www.iobis.org. Accessed 28 July 2011.

O'Donnell MJ & Denny MW. 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 RJ, Carruthers TJB, Dennison WC, Duarte CM, Fourqurean JW, Heck KL, Hughes AR, Kendrick GA, Kenworthy WJ, Olyarnik S, Short FT, Waycott M & Williams SL. 2006. A global crisis for seagrass ecosystems. *BioScience* 56: 987–996.

Orth RJ & Moore KA. 1983. Chesapeake Bay: An unprecedented decline in submerged aquatic vegetation. *Science* 222(4619): 51-53.

OSPAR. 2004. Biodiversity Series: Environmental impacts to marine species and habitats of dredging for navigational purposes. ISBN 1-904426-50-6. 22 pp.

OSPAR. 2010. Quality Status Report 2010: Status and Trend of marine chemical pollution. Accessed at OSPAR.org on 13 June 2012.

Peters K, Griffiths C & Robinson TB. 2014. Patterns and drivers of marine bioinvasions in eight Western Cape harbours, South Africa. *African Journal of Marine Science* 36(1): 49-57.

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. Marine Ecology Progress Series 425: 141-152.

Phillips DJH. 1980. *Quantitative Aquatic Biological Indicators: Their Use to Monitor Trace Metal and Organochlorine Pollution*. London: Applied Science Publishers.

Phillips DJH. 1995. The chemistries and environmental fates of trace metals and organochlorines in aquatic ecosystems. *Marine Pollution Bulletin* 31(4-12): 193-200.

Phillips DJH & Rainbow PS. 1993. *Biomonitoring of Trace Aquatic Contaminants*. Applied Science Publishers, Barking.

Pichegru L. 2012. *Increasing breeding success of an endangered penguin: Artificial nests or culling predatory gulls?* Bird Conservation International, 2013. Cambridge University Press.

Pichegru L, Grémillet D, Ryan PG & Crawford RJM. 2010. Marine no-take zone rapidly benefits endangered penguin. *Biology Letters* 6: 498-501.

Pichegru L, Ryan PG, Le Bohec C, van der Lingen CD, Navarro R, Petersen S, Lewis S, van der Westhuizen J & 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 PG, van der Lingen CD, Coetzee J, Ropert-Coudert Y & Grémillet D. 2007. 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 CL. 2011. *Alien and Invasive Animals: A South African Perspective*. Random House Struik, Cape Town. 240 pp.

Pillay D, Branch GM, Griffiths CL, Williams C & 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.

Pillay D, Branch GM, Dawson J, Henry D. 2011. Contrasting effects of ecosystem engineering by the cordgrass *Spartina maritime* and the sandprawn *Callianassa kraussi* in a marine-dominated lagoon. *Estuarine, Coastal and Shelf Science* 91: 169-176.

Pilsbry HA. 1916. The sessile barnacles (Cirripedia) contained in the collections of the U.S. National Museum; including a Monograph of the American species. *Bulliten of the United States National Mus*eum, 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.

Pitombo FB. 2004. Phylogenetic analysis of the Balanidae (Cirripedia, Balanomorpha). *Zoologica Scripta* 33(3): 261-276.

Poggenpoel CE. 1996. The exploitation of fish during the Holocene in the south-western Cape, South Africa. M. A. Thesis, University of Cape Town: xxii+225p.

Popper AN & Hastings MC. 2009. The effects of anthropogenic sources of sound on fishes. *Journal of Fish Biology* 75: 455-489.

PRDW. 2012. Prestedge Retief Dresner Wijnberg (Pty) Ltd; General Maintenance Quay Upgrade. Report No. 1113/DST/00.

Pullen TA. 2008. Eurotop – overtopping and methods for assessing discharge.

Purser J & Radford AN. 2011. Acoustic noise induces attention shifts and reduces foraging performance in three-spine sticklebacks (*Gasterosteus aculeatus*). *PLoS ONE* 6(2): e17478.

Raffaelli D & Hawkins SJ. 1996. *Intertidal Ecology*. London: Chapman and Hall, 356p.

Rainbow PS. 1995. Biomonitoring of heavy metal availability in the marine environment. *Marine Pollution Bulletin* 31: 183-192.

Rainbow PS. 2002. Trace metal concentrations in aquatic invertebrates: Why and so what? *Environmental Pollution* 120(3): 497-507.

Richardson SD, Plewa MJ, Wagner ED, Schoeny R & DeMarini DM. 2007. Occurrence, genotoxicity and carcinogenicity of regulated and emerging disinfection by-products in drinking water: A review and roadmap for research. *Mutation Research* 636(1-3): 178-242.

Robertson HG. 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. 335-345 pp.

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 TB, Branch GM, Griffiths CL, Govender A & Hockey PAR. 2007b. Changes in South African rocky intertidal invertebrate community structure associated with the invasion of the mussel *Mytilus galloprovincialis*. *Marine Ecology Progress Series* 340: 163-171.

Robinson TB & Griffiths CL. 2002. Invasion of Langebaan Lagoon, South Africa, by *Mytilus galloprovincialis*—effects on natural communities. *African Zoology* 37: 151–158.

Robinson TB, Griffiths CL, Branch GM & Govender A. 2007a. The invasion and subsequent die-off of *Mytilus galloprovincialis* in Langebaan Lagoon, South Africa: effects on natural communities. *Marine Biology* 152: 225-232.

Robinson TB, Griffiths CL & Kruger N. 2004. Distribution and status of marine alien invasive species in and bordering the West Coast National Park. *Koedoe* 47: 79-87.

Robinson TB, Griffiths C, McQuaid C & 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.

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. *Limnology and Oceanography* 44: 950–972.

Ryan PG. 2012. Medium-term changes in coastal bird communities in the Western Cape, South Africa. *Austral Ecology* 38: 251-259.

Saldanha Bay Municipality 2011. *Integrated Development Plan 2006-2011*. Saldanha Bay Municipality, South Africa.

Saldanha Bay Municipality. 2014. Langebaan Stormwater Master Plan: Basic Assessment Report. Saldanha Bay Municipality, Saldanha.

Schils T, Clerck OD, Leliaert F, Bolton JJ & Coppejans E. 2001. The change in macroalgal assemblages through the Saldanha Bay/Langebaan Lagoon ecosystem (South Africa). *Botanica Marina* 44: 295-305.

Schoonees JS, Huizinga P & 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. 87 pp.

Sedlak DL & von Gunten U. 2011. The Chlorine Dilemma. *Science* 331(6013): 42-43.

Shannon LV. 1966. Hydrology of the South and West Coasts of South Africa. Investigational Report, Sea Fisheries Research Institute, South Africa 58: 1-52.

Shannon LV & Stander GH. 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 & Branch GM. 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.

Siebert T & Branch GM. 2006. Ecosystem engineers: Interactions between eelgrass *Zostera capensis* and the sandprawn *Calianassa kraussi* and their indirect effects on the mudprawn *Upogebia africana*. *Journal of Experimental Marine Biology and Ecology*. 338(2): 253-270.

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

Siegfried WR. 1977. Wading Bird Studies at Langebaan Lagoon. Interim Report submitted March 1977.

Simon CA, Thornhill DJ, Oyarzun F & Halanych KM. 2009. Genetic 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 RH. 1977. The algal flora of Saldanha Bay. *Transactions of the Royal Society South Africa* 42: 461-482.

Skinner LF & Coutinho R. 2005. Effect of microhabitat distribution and substrate roughness on barnacle *Tetraclita stalactifera* (Lamarck 1818) settlement. *Brazilian Archives of Biology & Technology* 48: 109-113.

Slabberkorn H, Bouton N, Opzeeland I, Aukje C, ten Cate Carel & Popper N. Article in Press. A noisy spring: The impact of globally rising underwater sound levels on fish. *Trends in Ecology and Evolution* 1243: 9.

Sousa WP. 1979a. Disturbance in marine intertidal boulder fields: the non-equilibrium maintenance of species diversity. *Ecology* 60: 1225-1239.

Sousa WP. 1979b. Experimental investigations of disturbance and ecological succession in a rocky intertidal algal community. *Ecological Monographs* 49: 227-254.

Sousa WP. 1984. Intertidal mosaics: patch size, propagule availability, and spatially variable patterns of succession. *Ecology* 65: 1918-1935.

SRK Consulting 2009. Saldanha Air Quality Permit Basic Assessment: Air Quality Specialist Baseline Study and Impact Assessment. SRK Project Number 399449.

Statistics South Africa 2014. Census 2011. Available at http://www.statssa.gov.za/census 2011/default.asp Accessed 15 August 2014.

Steffani CN & Branch GM. 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 CN & Branch GM. 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 JME, Jackson LF & Busby AJ. 1999. Impact of mussel culture on macrobenthic community structure in Saldanha Bay, South Africa. *Marine Pollution Bulletin* 39: 357-366.

Stenton-Dozey JME, Probyn T & 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 TA & Stephenson A. 1972. Life between tidemarks on rocky shores. Publishers WH Freeman and co., 425 pp.

Summers JK, Wade TL, Engle VW & Malaeb ZA. 1996a. Normalization of metal concentrations in estuarine sediments from the Gulf of Mexico. *Estuaries* 19: 581-594.

Summers RW. 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.

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.

Taylor SR. 1964. Abundance of chemical elements in the continental crust: a new table. *Geochimica et Cosmochimica Acta* 28(8): 1273-1285.

Taylor SR & McLennan SM. 1981. The composition and evolution of the continental crust – Rare earth element evidence from sedimentary rocks. *Royal Society of London Philosophical Transactions Series* A301: 381-398.

Transnet National Ports Authority (TNPA). 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.

Transnet National Ports Authority (TNPA). 2007. Port of Saldanha Oil Spill Contingency Plan. 51 pp.

Tunley KL, Attwood CG, Moloney CL and Fairhurst L. 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.

Turekian KK & Wedepohl KH. 1961. Distribution of the elements in some major units of the earth's crust. *Geological Society of America Bulletin* 72: 175-192.

Turpie JK. 1995. Prioritizing South African estuaries for conservation: A practical example using waterbirds. *Biological Conservation* 74: 175-185.

Turpie JK & Hockey PAR. 1993. Comparative diurnal and nocturnal foraging behaviour and energy intake of premigratory Grey Plovers *Pluvialis squatarola* and Whim-brels *Numenius phaeopus* in South Africa. *Ibis* 135: 156-165.

Turpie JK & Love VC. 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.

Twichell SC, Meyersa PA, Diester-Haassb L. 2002. Significance of high C/N ratios in organic-carbon-rich Neogene sediments under the Benguela Current upwelling system. *Organic Geochemistry* 33: 715-722.

Tyrrell T & Lucas M. 2002. Geochemical evidence of denitrification in the Benguela upwelling system. *Continental Shelf Research* 22: 2497-2511.

Underhill LG. 1987. Waders (Charadrii) and other waterbirds at Langebaan Lagoon, South Africa, 1975-1986. *Ostrich* 58(4): 145-155.

UNEP 2008. Desalination Resource and Guidance Manual for Environmental Impact Assessments. United Nations Environment Programme, Regional Office for West Asia, Manama, and World Health Organisation, Regional Office for the Eastern Mediterranean, Cairo.

van Ballegooyen RC, Mabille E, Brown S, Newman B & Taljaard S. 2012. Transnet Reverse Osmosis desalination plant, Saldanha Bay: Physico-chemical environmental baseline. CSIR Report, CSIR/NRE/ECO/ER/2012/0033/B, 146pp + 19pp App.

van Ballegooyen RC, Steffani N & Pulfrich A. 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 IJ, Ferreira SLA & Zietsman HL. 2005. Growth Potential of towns in the Western Cape. Centre for Geographical Analysis, Stellenbosch University.

van Katwijk MM, Vergeer LHT, Schmitz GHW & Roelofs JGM. 1997. Ammonium toxicity in eelgrass *Zostera marina*. *Marine Ecology Progress Series* 157: 159-173.

Vaquer-Sunyer R & Duarte CM. 2008. Thresholds of hypoxia for marine biodiversity. *Proceedings of the National Academy of Science* 105(40): 15452-15457.

Viljoen R, Silomntu M, Reuther S & Jones S. 2010. Transnet Port Terminal - Bulk Terminal Saldanha: Draft Environmental Management Programme for Air Quality Permit Amendment Application.

Visser D, Goes M & Rosewarne P. 2007. Environmental Impact Assessment: Port Of Saldanha Proposed Reverse Osmosis Water Desalination Plant Groundwater Resources Impact Assessment. SRK Consulting Report.

Voellmy IK, Purser J, Simpson SD & Radford AN. 2014. Increased Noise Levels Have Different Impacts on the Anti-Predator Behaviour of Two Sympatric Fish Species. *PLoS ONE* 9(7): e102946.

Warwick RM. 1993. Environmental impact studies on marine communities: Pragmatical considerations. *Australian Journal of Ecology* 18: 63-80.

Watling RJ. 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 CM, Carruthers TJB, Orth RJ, Dennison WC, Olyarnik S, Calladine A, Fourqurean JW, Heck KL, Hughes AR, Kendrick GA, Kenworthy WJ, Short FT & Williams SL. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *PNAS* 106: 12377-12381.

Weeks SJ, Boyd AJ, Monteiro PMS & Brundrit GB. 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.

Weeks SJ, Monteiro PMS, Nelson G & Cooper RM. 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.

Wesgro. 2012. Saldanha Bay Industrial Development Zone fact sheet. Available at: http://wesgro.co.za/publications/publication-directory. Accessed 22 August 2014.

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

Whittington PA, Randall BM, Wolfaardt AC, Crawford RJM, Klages NTW, Bartlett PA, Chesselet YJ & 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 PA, Randall RM, Wolfaardt AC, Klages NTW, Randall BM, Bartlett PA, Chesselet YJ & Jones R. 2005b. Patterns of immigration to and emigration from breeding colonies by African penguins. *African Journal of Marine Science* 27(1): 205-213.

WHO. 2007. Desalination for Safe Water Supply: guidance for Health and Environmental Aspects Applicable to Desalination. Geneva.

Williams AJ, Steele WK, Cooper J & Crawford RJM. 1990. Distribution, population size and conservation of Hartlaub's Gull *Larus hartlaubii*. *Ostrich* 61: 66-76.

Windom HL. 1988. A Guide to the Interpretation of Metal Concentrations in Estuarine Sediments. Office of Water Policy. Florida Department of Environmental Protection.

Woolsey S & Wilkinson M. 2007. Localized field effects of drainage water from abandoned coal mines on intertidal rocky shore seaweeds at St Monans, Scotland. *Journal of the Marine Biological Association of the United Kingdom* 87(03): 659-665.

WSP Africa Coastal Engineers. 2010. Development of a methodology for defining and adopting coastal development set-back lines. Volume 1. Main report. Report prepared for Department of Environmental Affairs and Developing Planning, Western Cape Government, 81 pp.

Würsig B, Greene CR & Jefferson TA. 2000. Development of an air bubble curtain to reduce underwater noise of percussive piling. *Marine Environmental Research* 49: 79-93.

Zsilavecz G. 2007. *Nudibranchs of the Cape Peninsula and False Bay*. Southern Underwater Research Group Press.

Zullo VA. 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.

Saldanha Bay Water Quality Trust

KUMBA RESOURCES

TRANSNET

SOUTH AFRICAN PORT OPERATIONS
A DIVISION OF TRANSNET LTD.

Black Mountain

MITTAL

SFF

METSEP SALDANHA

SALDANHA BAY OYSTER Co.

SA Lobster Exporters
a division of
FOODCORP

LANGEBAAN COUNTRY ESTATE
GOLF & LEISURE

Sea Harvest

TRONOX

FRONTIER RARE EARTHS
FRONTIER RARE EARTHS LIMITED

CAH
CHLOR-ALKALI HOLDINGS

BLUE BAY AQUAFARM

PPC CEMENT

SALDANHA BAAI BAY

South African NATIONAL PARKS

Duferco

Premier Fishing
The First Choice

A copy of this document can be downloaded from
www.anchorenvironmental.co.za