THE STATE OF

SALDANHA BAY AND LANGEBAAN LAGOON

2017

October 2017

Anchor Environmental Consultants Report No. AEC 1741/1

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Technical Report

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Cover Photo: Anchor Environmental Consultants (Pty) Ltd.

Citation: Clark BM, Massie V, Hutchings K, Brown E, Biccard A, Laird M, Harmer R, Makhosonke A, Wright A & Turpie J. 2017. The State of Saldanha Bay and Langebaan Lagoon 2017, Technical Report. Report No. AEC 1741/1 prepared by Anchor Environmental Consultants (Pty) Ltd for the Saldanha Bay Water Quality Forum Trust, October 2017.

FOREWORD

The residents living in and around Saldanha Bay and Langebaan Lagoon are truly blessed to have such a unique ecological wonder on their doorstep. Visitors to our region continually confirm this view. It has taken millennia of natural processes to provide this phenomenon. The advent of man and his need to develop, almost at all costs, has the potential to destroy this gift within a short time. The question is - how do we balance the need to conserve our natural heritage with the requirement to develop and prosper economically?

There is no simple answer to this very basic question. The conservationists have shouted their 'green' messages from the tree tops whilst the industrialists have simply argued the need to 'provide jobs and grow'. "Never the twain shall meet". We will all have to change our attitudes and work together to find the balance. This is a team effort. The government has taken the first steps in providing legal guidance with the proclamation of the National Environmental Management Act and the Integrated Coastal Management Act. These Acts still have a way to go before they have the required impact to provide the answer to our question.

Saldanha Bay has been identified as an economic development node by national government and the establishment of an Industrial Development Zone is well under way. The Bay hosts a major natural harbour and is actively exporting iron ore, lead, copper and manganese. To date, most environmental impact studies have been localized and the entire Saldanha Bay and Langebaan Lagoon ecological system has not been considered. The Saldanha Bay Water Quality Trust has been instrumental in the establishment of the Integrated Governmental Task Team (IGTT) that has been given the mandate to address this problem and provide environmental guidance for all future development in and around our region and Saldanha Bay. The above-mentioned legislation plus the IGTT Environmental Guidelines will form the cornerstone to a balanced approach in terms of environmental sustainability, social wellbeing and economic growth in the future.

None of the above can take place without scientifically based information on the 'State of the Bay'. The Saldanha Bay Water Quality Trust has been the pioneer in this regard and has conducted a series of all-encompassing scientific tests with minimal resources over the last 18 years. The report is once again a perfect example of the wonderful work that they perform. The report further comes at a critical time in answering our question of balancing conservation and development.

Let us all, National, Provincial and Local Government with the Private Sector and Non-Governmental Organizations, as partners, take hands and make a difference in conserving our Saldanha Bay and Langebaan Lagoon for future generations whilst ensuring responsible development.

Councillor André Kruger

Portfolio Chairperson: Infrastructure and Planning Services
Saldanha Bay Municipality
Chairperson Saldanha Bay Water Quality Trust

Figure i SBWQFT Trustees. From left, Ethel Coetzee, Pierre Nel (SANParks), André Kruger (Saldanha Bay Municipality Councillor), Elmien de Bruyn (Duferco), Christo van Wijk (Metsal), and Frank Hickley (Sea Harvest).

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 Forum Trust (SBWQFT) 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 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 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 SBWQFT as well as those monitored by others (government, private industry, academic establishments and NGOs).

In this 2017 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), groundwater inflows, water quality in the Bay itself (temperature, oxygen, salinity, nutrients, and pH), sediment quality (particle size, trace metal and hydrocarbon contaminants, total organic carbon and nitrogen), and ecological indicators (Chlorophyll a, aquatic macrophytes, benthic macrofauna, fish and birds). Where possible, trends and areas of concern have been identified and recommendations for future monitoring are presented, with a view to further improving the environmental management and monitoring in the area. Key findings for each of the major components of the State of the Bay monitoring programme are summarised below.

Activities and Discharges Affecting the Saldanha Bay and Langebaan Lagoon

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 2.7% per annum in Saldanha and 9.24% in Langebaan over the period 2001 to 2011. Numbers of tourists visiting the Saldanha Bay and Langebaan Lagoon area are constantly rising, especially those visiting the West Coast National Park (WCNP) (Average rate of 18% per annum since 2005). This rapid population and tourism growth translates to corresponding increases in the amounts of infrastructure required to house and accommodate these people, and in the amount of waste and wastewater that is produced which has to be treated and disposed.

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 the small craft harbour, several marinas, mariculture farms and several fish processing factories. Extensive industrial and residential development has also become established on the periphery of the Bay. Anthropogenic pollutants and wastes find their way into the Bay from a range of activities and developments. These port operations, shipping, ballast water discharges and oil spills, export of metal ores, municipal (sewage) and industrial discharges, biological waste associated with mariculture and storm water runoff. Urban and industrial developments encroaching into coastal areas have resulted in the loss of coastal habitats and have affect natural coastal processes, such as sand movement. Development of the port is expected to increase dramatically with the establishment of the Saldanha Bay Industrial Development Zone (SBIDZ), a process that was initiated in 2013.

Metal ores exported from the Port of Saldanha Bay include iron, lead, copper, zinc, and manganese. The Port of Saldanha currently has the capacity to export up to 60 million tonnes of iron ore per year but is in the process of upgrading the infrastructure to support an annual export of 80 million tonnes.

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. With the ongoing drought in the Western Cape, however, industry and local municipalities are coming together to investigate the feasibility of reclaiming potable freshwater from treated sewage in Saldanha Bay. Major infrastructural changes are required for the re-cycling of treated sewage and are associated with significant initial as well as ongoing fiscal investments. Budgetary constraints experienced by local municipalities are significant, and a public-private partnership is likely to be required to ensure successful implementation.

Ballast water discharges are by far the largest 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.

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. Furthermore, fine sediment can drift into the Langebaan Lagoon, changing the sediment composition, which in turn can directly and indirectly affect birds in the lagoon. 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.

Saldanha Bay is a highly productive marine environment and constitutes the only natural sheltered embayment in South Africa (Stenton-Dozey et al. 2001). These favourable conditions have facilitated the establishment of an aquaculture industry in the Bay. A combined 430 ha of sea space are currently available for aquaculture production in Outer Bay, Big Bay and Small Bay. With the support of finances and capacity allocated to the Operation Phakisa Delivery Unit, the Department of Agriculture Forestry and Fisheries is proposing to establish a sea-based Aquaculture Development Zone (ADZ) in Saldanha Bay. The proposed ADZ areas comprise five precincts totalling 1 404 ha of new aquaculture areas in Saldanha Bay. Currently farmed areas will be incorporated into the ADZ, increasing the total mariculture area to 1 872 ha.

Beach erosion in Saldanha Bay, particularly at Langebaan Beach, has been the subject of much controversy in recent years as coastal developments in Langebaan and Saldanha extend right to the water's edge and are at risk from the retreating shoreline. New research has identified dredging operations conducted during the Port construction programme as making a potentially important contribution to this problem. Sediment used to build the causeway to Marcus Island was sourced from the historic ebb tide delta that existed at the mouth of Langebaan (an area where sediment derived from Langebaan Lagoon had been deposited over many thousands of years). Removal of sediment from this area resulted in a reduction in the extent to which incoming waves are refracted and a concomitant increase in the wave energy density along the shoreline by around 50%. This in turn is what has caused the observed erosion of the shoreline. It has been suggested that the most effective way to remedy this situation would be to refill the hole created by the dredging and subsequently nourish the beach with sand from another source.

Each of the aspects summarised above are addressed in more detail in State of the Bay report. The impacts of these various activities and discharges are evaluated against their potential threat to the ecological integrity of Saldanha Bay and Langebaan Lagoon.

Management and Policy Development

Continuously accelerating urban and industrial development is a major cause of fragmentation and loss of ecological integrity of remaining marine and coastal habitats in Saldanha Bay and Langebaan. The challenge of addressing cumulative impacts in an area such as Saldanha is immense. The current and future desired state of the greater Saldanha Bay area is polarised, where industrial development (Saldanha Bay IDZ and associated industrial development) and conservation areas (Ramsar Site, MPAs and National Parks) are immediately adjacent to one another. Furthermore, the Saldanha Bay environment supports conflicting uses including industry, fishery, mariculture, recreation and the natural environment itself. This situation necessitates sustainable development that is steered towards environmentally more resilient locations and away from sensitive areas.

Concerns have been raised that cumulative impacts on the marine environment in Saldanha Bay have not been adequately addressed for many recent development proposals. This applies especially to the cumulative impacts that are anticipated from future development within the Saldanha Bay IDZ and Aquaculture Development Zone (ADZ). Furthermore, the impact on the Saldanha Bay marine environment from projects that are primarily land-based, such as storage facilities for crude oil and liquid petroleum gas, has often been underestimated or even ignored. It has been proposed that a more holistic management strategy is needed to deal with these piece meal Environmental Impact Assessments (EIAs). Various environmental management instruments have been proposed for the Greater Saldanha Bay Area, including (1) a generic Environmental Management Programme (EMPr), (2) an Environmental Management Framework (EMF), (3) a Strategic Environmental Assessment (SEA), and (4) declaration of Saldanha Bay as a Special Management Area. An Intergovernmental Task Team (IGTT) has been established to consider these and other proposals. If these management instruments are indeed implemented, we are confident that measures for the conservation alongside rapid development of the Saldanha Bay area will be addressed more effectively.

Freshwater inflow to Saldanha Bay and Langebaan Lagoon

While Saldanha Bay and Langebaan Lagoon receives little freshwater input via rivers or streams (surface water), groundwater input is significant and plays an important role in sustaining marsh ecosystems around the periphery of the Bay, and especially the Lagoon. There are two main aquifer systems from which groundwater discharges into the Bay – the Langebaan Road Aquifer System and the Elandsfontein Aquifer System. There is little exchange of water between these two aquifer units, each one discharging to the sea through its own paleo-channel. The Langebaan Road Aquifer System discharges into Saldanha Bay (Big Bay) through a northern paleo-channel while the Elandsfontein Aquifer System discharges into Langebaan Lagoon through a southern paleo-channel. Growth of the reeds *Phragmites australis* and *Typha capensis* on the shoreline surrounding Langebaan Lagoon provide clear evidence of the significant influx of groundwater to the Lagoon, because these plants can only survive in water or damp soil, and are only able to tolerate salinity levels up to a maximum of 20–25 ppt (the salinity of the water in the lagoon is generally the same, or occasionally higher, than the 35 ppt of seawater). Increasing pressure on available freshwater water resources in the Saldanha Bay area in recent years has resulted in attention being turned to exploitation of these groundwater resources. The West Coast District Municipality (WCDM) operates a wellfield on the Langebaan Road Aquifer that is licenced to abstract up to 1.46 million m^3 of groundwater per annum. Abstraction of groundwater from this aquifer resulted in a localised depression of water levels in the deeper portion of this aquifer by as much as 10 m in the first few years of operation between 2005 and 2009, and concern has been expressed over how this might be affecting groundwater discharge to Saldanha Bay now, and in the future. A modest (10%) reduction in abstraction rates was effected to address this but it is not clear how effective this has been.

More recently, Elandsfontein Exploration and Mining (Pty) Ltd has started mining phosphate deposits in the area of the Elandsfontein Aquifer System on the eastern side of the R27. Mining is being conducted using an open-pit strip mining method which requires that groundwater levels around the mining pit be lowered to prevent the mine pit from being flooded. Groundwater is being abstracted from a series of boreholes surrounding the mine pit but is reinjected further away, in an effort to ensure that surrounding ecosystems (including the Lagoon) are not affected. Naturally, there is concern that these mitigation measures will not effectively mitigate impacts on the lagoon, so a comprehensive monitoring programme has been initiated to confirm that this is not the case. This includes monitoring of water levels and water quality in a series of boreholes between the mine site and the lagoon edge, and monitoring of salinity levels and macrofauna assemblages in the lagoon itself.

Water Quality

Aspects of water quality (temperature, salinity and dissolved oxygen, nutrients and chlorophyll concentrations) are currently, or have in the past been studied in Saldanha Bay, in an attempt to better understand changes in 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 the 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. Wave exposure has also increased in some areas of Big Bay leading to coastal erosion.

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 SBWQFT in 1999 and has continued since this time with the assistance of the Saldanha Bay Municipality. 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, 16 of the 20 monitoring stations in the Bay are rated as having 'Excellent' water quality, one site (Hoedtjies Bay) is rated as 'Good', two sites are rated as 'Fair' (Caravan Park and Langebaan Yacht Club) whist the Bok River Mouth site is again rated as having "Poor" water quality. The Bok River appears to remain the principal source of microbiological contamination in Small Bay with the impacts spreading to adjacent sites on fairly frequently. Efforts should focus on waste water treatment prior to discharge into the Bok River. Six of the ten monitoring sites within Small Bay did not meet the 80th percentile faecal coliform limits for mariculture in 2016. Faecal coliform counts at all four sites in Big Bay were well within both the 80th percentile limits for mariculture in 2016 and likewise the Langebaan sites all met recreational water quality standards (and have done so for the at least the last decade at most sites).

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 to combat pollution by faecal coliforms in Small Bay (e.g. upgrading of sewage and storm water facilities to keep pace with development and population growth) 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 the Mussel Watch Programme in Saldanha Bay in 2007, but this has now been incorporated into the State of the Bay surveys. Data show that concentrations of trace metals are high along the shore (particularly for lead and cadmium and in 2017, Zinc) are consistently above published regulatory limits for foodstuffs at all monitored sites. Concentrations of trace metals in the cultured mussel in the Bay offshore have in the past been much lower (according to data supplied by operators); although concentrations of lead and cadmium were on occasion above the limit for foodstuff, which is concerning. It is also concerning that the 2016-2017 data obtained from DAFF for mariculture operators did not include any new trace metal results, so we are unable to ascertain if they remain low compared to the samples collected during the 2017 State of the Bay monitoring.

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 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 of 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) 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. Prior to large scale development in the Bay, it was reported that the proportion of mud in the sediments of Saldanha Bay was very low. Reduced water circulation in the Bay and dredging activities have 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. 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) to levels similar to those last seen in 1974. 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 significantly affected in this way are all located in the vicinity of the iron ore terminal the mussel rafts and the Yacht Club Basin.

Levels of total organic carbon (TOC) and total organic nitrogen (TON) remain elevated in the more sheltered and deeper areas of the bay, notably near the Yacht Club Basin and Ore terminal. 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. In the past, accumulation of organic waste, especially in sheltered areas where there is limited water flushing, has led to hypoxia (reduced oxygen) in these areas with negative impacts on benthic communities (e.g. the Saldanha yacht club). Prior to any major development, TOC levels in Saldanha Bay were mostly very low (between 0.2 and 0.5%) throughout the Bay and Lagoon. Data collected in 1989 and 1999 indicated considerably elevated levels of TOC in the vicinity of the iron ore terminal and in Small Bay. Data from subsequent surveys 2000, 2001, 2004 and between 2008 and 2017 suggest that TOC levels have remained high throughout this period, with highest levels being recorded at the Yacht Club Basin and multi-purpose terminal. Levels in TON first recorded in 1999 were low at most sites in the Bay (≤0.2%) except for those in the Yacht Club Basin and near the mussel rafts in Small Bay. Levels were slightly or even considerably elevated at all sites that were monitored again in 2000, 2001 and 2004. Results from the State of the Bay surveys conducted between 2008 and 2017 suggest that levels dropped off slightly at many of the key sites in Small and Big Bay but have remained more or less steady in other parts of the Bay and in the Lagoon.

In areas of the Bay where muddy sediments tend to accumulate, trace metals and other contaminants often 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, manganese 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 2016 and 2017. Key areas of concern regarding trace metal pollution within Small Bay include the Yacht Club Basin where cadmium and copper exceeded recommended thresholds two years in a row and enrichment factors (EF) continue to be high, as well as adjacent to the multi-purpose terminal where levels of cadmium and lead dropped just below internationally accepted guidelines, but still have extremely high enrichment factors for all trace metals measured. Recent increases in the concentration of manganese around the ore terminal are also a little concerning. Regular monitoring of trace metal concentrations is strongly recommended to provide an early warning of any future increases.

Poly-aromatic hydrocarbons (PAH) contamination measured in the sediments of Saldanha Bay since 1999 have been well below ERL values stipulated by NOAA and not considered an environmental risk. Total petroleum hydrocarbon (TPH) levels however, have fluctuated considerably in the vicinity of the ore terminal in recent years. In 2014 TPH Levels were found to be exceptionally high at some sites indicating heavily polluted conditions. The most likely explanation for the high observed 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. While TPH and PAH findings in 2017 remain unchanged from 2016 and present no major concern, it is recommended that TPH monitoring within the vicinity of the ore terminal is continued to identify the occurrence of pollution incidents, like that recorded in 2014.

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 the dune slack rush *Juncus kraussi*; and unvegetated sandflats dominated by the sand prawn, *Callichirus kraussi* and the mudprawn *Upogebia capensis*. The other major vegetation type present in the upper lagoon area, particularly where groundwater inflow occurs, are reed beds dominated by *Phragmites australis.* 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 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. The primary physical factors influencing salt marsh distributions are salinity and water availability. 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. While anthropogenic disturbances and climate change are impacting some macrophyte communities in Langebaan Lagoon (e.g. decreases in discrete salt marsh patches and acute decreases in seagrass beds at some sites) the health and biodiversity of the system is still exceptional. A recent desktop level ecological reserve determination study assessed the health of Langebaan macrophytes and reported a high ranking score of 90.

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 1999-2017 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 impact on and subsequent improvements in health have been detected in the Yacht Club Basin. 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. 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 *Ochetostoma capense*, and several gastropods. Certain areas of Small Bay that experience reduced water circulation patterns in (e.g. base of the iron ore terminal, 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 the ongoing State of the Bay evaluation, baseline conditions relating to rocky intertidal communities in Saldanha Bay was initiated in 2005. Eight rocky shores spanning a wave exposure gradient from very sheltered to exposed, were sampled in Small Bay, Big Bay and Outer Bay. These surveys have been repeated annually from 2008 to 2015, however, due to financial constrains no survey was conducted in 2016 and a two year survey strategy has since been adopted. In the 2017 survey, a total of 114 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 22 species of filter-feeders, 24 species of grazers, and 19 species of predators/scavengers. The algal component comprised 34 corticated (foliose) seaweeds, eight 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. Rocky shore species found included three alien invasive species, the Mediterranean mussel *Mytilus galloprovincialis* and two alien barnacle species, *Balanus glandula* and *Perforatus perforatus*.

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 juvenile fish communities within Big Bay-Langebaan Lagoon appears satisfactory. The encouraging signs of recovery of white stumpnose and blacktail in Small Bay seen in 2016 have unfortunately not continued through to 2017, with a complete absence of blacktail and reduced white stumpnose catches in the most recent survey. The abundance of gobies in Small Bay has also remained low since the 2007 survey. The decline in gobies cannot be attributed to fishery impacts, but may be related to water quality or habitat changes. Fish diversity and overall abundance does not, however, show a declining trend in Small Bay and this suggests that the habitat quality remains good as a juvenile fish nursery. The strong elf recruitment in Big Bay evident in the 2016 and 2017 sampling bodes well for the recreational fishery for this species in coming years, and other species common in Big Bay catches were present in comparable numbers to earlier surveys.

A consistent long-term negative trend, since fish sampling began in 1986-87 has, with the exception of white stumpnose, not been detected for the principal species found in Saldanha 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 pressure to reduce this protection by allowing access to Zone B for commercial gill net permit holders should be resisted. This not only poses a threat to the productivity of the harder stock but also to other fish species that will be caught as bycatch.

The significant declines in juvenile 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. Arendse (2011) found the adult stock to be overexploited using data collected nearly 10 years ago (2006-2008). Evidence from the seine net surveys conducted since then certainly suggests that recruitment overfishing of the white stump stock has occurred. 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 stumpnose abundance in the nursery surf-zone habitats since 2007, and the observed declines in commercial linefish CPUE, 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. This is the fourth time Anchor Environmental are making this recommendation in the State of the Bay Report and these recommendations are now also supported by a comprehensive analysis of fishery dependent and survey data (Parker *et al.* in press.).

At some point fishing mortality will need to be contained, if the Saldanha Bay fisheries are to remain sustainable. We think that point arrived at least four years ago for the Saldanha-Langebaan white stumpnose fishery and recommended that resource users lobby the authorities to implement the recommended harvest control measures. Regional species specific fishery management have been implemented elsewhere in South Africa (e.g. Breede River night fishing ban to protect dusky kob). White stumpnose in Saldanha Bay appear to be an isolated stock and there is good on site management presence in the form of SANParks and DAFF, and we think this approach would work well in Saldanha-Langebaan. We again recommend the reduction of the daily bag limit and an increase in the minimum size limit for white stumpnose caught in the Saldanha Bay-Langebaan system. Although recruitment overfishing appears to have being taking place for several years now, the stock is not extirpated and the situation is reversible. Reductions in fishing mortality can be achieved by effective implementation of more conservative catch limits and have an excellent chance of improving the stock status, catch rates and the size of white stumpnose in the future fishery.

The economic 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. These benefits should be quantified by an economic study of the recreational fisheries. The value of Small Bay as a fish nursery and the economic value of the resultant fisheries could then be quantitatively considered when the environmental impacts of the proposed future industrial developments within Small Bay are assessed. The monitoring record from the annual seine net surveys will prove increasingly valuable in assessing and mitigating the impacts of future developments on the region's ichthyofauna.

Birds

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 deep-water 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.

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 bird species have been recorded within the boundaries of the West Coast National Park. At least 56 non-passerine waterbird species commonly use the area for feeding or breeding; 11 breed on the islands of Malgas, Marcus, Jutten, Schaapen and Vondeling alone. These islands support nationally-important populations of African Penguin, Cape Gannet, Swift Tern, Kelp and Hartlaub's Gull, and four species of marine cormorant, as well as important populations of the endemic African Black Oystercatcher. The lagoon is an important area for migratory waders and terns, as well as for numerous resident waterbird species. Waterbirds are counted annually on all the islands, and bi-annually in Langebaan Lagoon.

With the exception of the cormorants, the populations of the other seabirds that breed on the islands of Saldanha Bay were on an increasing trajectory from the start of monitoring in the 1980s and 90s until around 2000. Factors that probably contributed to this include the reduction and eventual cessation of guano collecting in 1991, banning of egg collecting, increases in the biomass of small pelagic fish particularly sardines over this period, and in the case of the African Black Oystercatcher the increase in mussel biomass as a result of the arrival and spread of the Mediterranean mussel.

On the islands of Saldanha Bay, populations of all of these species then started to decline, particularly, the penguins, gannets and gulls, which have respectively declined to 12%, 39% and 22% of their populations at the turn of the century. Declines in the numbers of seabirds breeding on the Saldanha Bay Islands can be attributed to a number of causes. These include (1) emigration of birds to colonies further south and east along the South African coast in response to changes in the distribution and biomass of small pelagic fish stocks, (2) starvation as a result of a decline in the biomass of sardines nationally, and particularly along the west coast over the last decade, (3) competition for food with the small pelagic fisheries within the foraging range of affected bird species, (4) predation of eggs, young and fledglings by Great White Pelicans, Kelp Gulls and Cape Fur Seals, and (5) collapse of the West Coast Rock Lobster stock upon which Crowned Cormorants feed.

However, because populations are so depressed, conditions at the islands in Saldanha, particularly predation by Cape Fur Seals and Kelp Gulls, have now become the major factors in driving current population decreases for many seabird species. Direct amelioration actions (*Pelican Watch*, problem seal culling) to decrease these impacts at the islands have had mixed results, with the former proving more effective than the latter. Cape Fur Seal and Kelp Gull predation continue to pose a major threat to seabird survival at the Saldanha Bay Island colonies.

Decreasing numbers of migrant waders utilising Langebaan Lagoon reflects a global trend, which can be attributed to loss of breeding habitat and hunting along their migration routes as well as human disturbance and habitat loss on their wintering grounds. In Langebaan Lagoon, drastic population declines in four species, including the Ruddy Turnstone, Red Knot, Grey Plover, and Curlew Sandpiper signified this downward trend in summer migratory bird numbers. Most importantly, Curlew Sandpiper numbers have dropped from a pre-1990 average of just over 20 000 birds to 1 829 birds in 2017. Prior to 1990, this species accounted for almost two thirds of the total summer migratory wader numbers in the lagoon.

The fact that numbers of resident waders may also be declining suggests that unfavourable conditions persisting in Langebaan Lagoon as a result of anthropogenic impacts may be partly to blame. Although wader numbers have not dropped below the lowest numbers as observed in 2011, it remains to be seen if winter resident wader populations remain stable, and if perhaps migratory waders are also stabilising at current levels. 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.

Alien and Invasive Species

Human induced biological invasions have become a major cause for concern worldwide. The life history characteristics of the alien species, the ecological resilience of the affected area, the presence of suitable predators and many other factors determine whether an alien species becomes a successful invader. Biological invasions can negatively impact biodiversity and can result in local or even global extinctions of indigenous species. Furthermore, alien species invasions can have tangible and quantifiable socio-economic impacts. 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.

A recent update on the number of alien marine species present in South Africa lists 89 alien species as being present in this country, of which 53 are considered invasive i.e. population are expanding and are consequently displacing indigenous species. At least 28 alien and 42 invasive species occur along the West Coast of South Africa. Twenty five of these species have been confirmed from Saldanha Bay and/or Langebaan Lagoon, of which all but one are considered invasive. For example, the invasive Mediterranean mussel *Mytilus galloprovincialis*, the European green crab *Carcinus maenas*, the barnacle *Balanus glandula*, and the Pacific South American mussel *Semimytilus algosus*, are commonly found in the study area. Interestingly, the abundance of *B. glandula* and *M. galloprovincialis* on rocky shores in Saldanha Bay has been decreasing in the last few years. This trend may reflect a new ecosystem equilibrium as predator numbers have probably responded to the new food source and now exert more control over the abundance of this invasive species. An additional 41 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.

The presence of three new alien species, including the barnacle *Perforatus perforatus*, the Japanese skeleton shrimp *Caprella mutica*, and the European porcelain crab *Porcellana platycheles,* have been confirmed in Saldanha Bay and Langebaan Lagoon in the last five years.

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. 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. Reclaiming industry-grade or even potable water from effluent will play an important role in improving water quality in Saldanha Bay. 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.

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GLOSSARY

Alien species	Species whose presence in a region is attributable to human actions that enabled them to overcome fundamental biogeographical barriers (i.e. human-mediated extra-range dispersal) (synonyms: Introduced, non-indigenous, non-native, exotic).
Articulated coralline algae	Branching, tree-like plants which are attached to the substratum by crustose or calcified, root-like holdfasts.
Aquaculture	The sea-based or land-based rearing of aquatic animals or the cultivation of aquatic plants for food
Aquifer	Underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt) from which groundwater can be extracted using a water well.
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.
Colony-forming unit	A colony-forming unit (CFU) is a unit used to estimate the number of viable bacteria or fungal cells in a sample.
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.
Cryptogenic	Species of unknown origin.
Ephemeral algae	Opportunistic algae with a short life cycle that are usually the first settlers on a rocky shore.
Extralimital	Species whose native range falls within the political boundaries of a country, but whose presence in another part of the same country is attributable to human transport across fundamental biogeographical

	barriers.
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 behavioural properties.
Grazer	An herbivore that feeds on plants/algae by abrasion from the surface.
Indigenous	Species within the limits of their native range (Synonyms: native).
Intertidal	The shore area between the high- and the low-tide levels.
Invasive	Alien species that have self-replacing populations over several generations and that have spread from their point of introduction.
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.
Native	Species within the limits of their native range (Synonyms: indigenous).
Naturalised	Alien species that have self-replacing populations over several generations outside of captivity or culture, but that have not spread from their point of introduction.
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 animal 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

ADZ	Aquaculture Development Zone
AOU	Apparent Oxygen Utilization
BA	Basic Assessment
BCLME	Benguela Current Large Marine Ecosystem
CBA	Critical Biodiversity Area
COD	Chemical Oxygen Demand
CFU	Colony-Forming Unit
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
DoE	Department of Energy
DWS	Department of Water and Sanitation
EA	Environmental Authorisation
EEM	Elandsfontein Exploration and Mining (Pty) Ltd
EIA	Environmental Impact Assessment
EMF	Environmental Management Framework
EMMP	Environmental Management and Maintenance Plan
EMPr	Environmental Management Programme
FPP	Floating Power Plant
ICMA	National Environmental Management: Integrated Coastal Management Act (No. 24 of 2008)

IDZ	Industrial Development Zone
CNG	Compressed Natural Gas
LNG	Liquefied Natural Gas
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
RWQO	Receiving Water Quality Objectives approach
SBIDZ	Saldanha Bay Industrial Development Zone
SBM	Saldanha Bay Municipality
SBWQFT	Saldanha Bay Water Quality Forum Trust
TNPA	Transnet National Ports Authority
TOC	Total Organic Carbon
TON	Total Organic Nitrogen
TPH	Total Petroleum Hydrocarbon
TSS	Total Suspended Solids
VRF	Vessel Repair Facility
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. Saldanha Bay and Langebaan Lagoon are areas of exceptional beauty, and are considered South African biodiversity "hot spots". 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 Vondeling). As such, Saldanha Bay and Langebaan Lagoon have long been the focus of scientific interest.

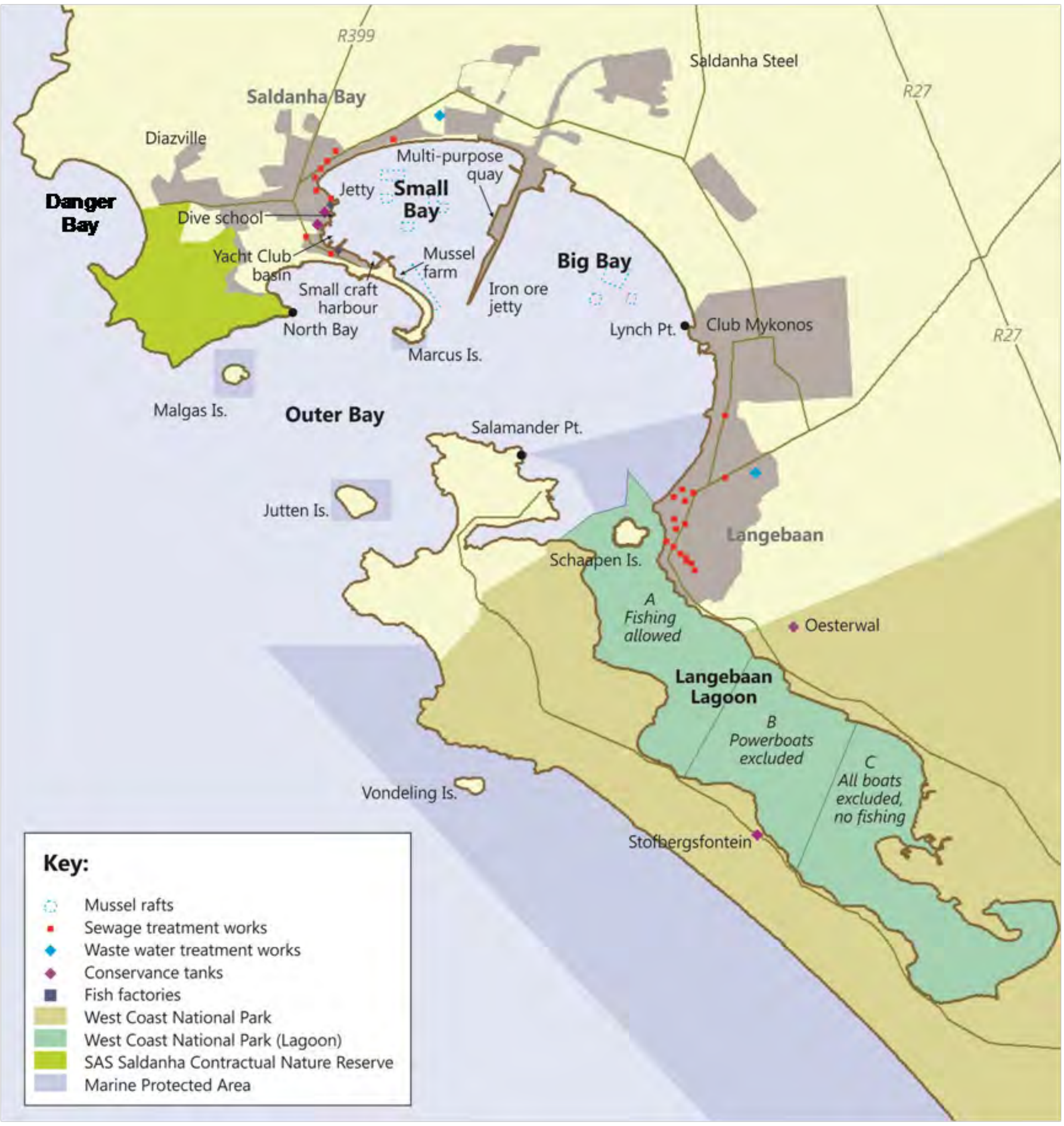

Figure 1.1. Regional map of Saldanha Bay and Langebaan Lagoon and Danger Bay showing development (grey shading) and conservation areas.

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. In spite of these noteworthy successes in environmental monitoring, the history of the area has been tainted with overexploitation and lack of care for the environment, the environment generally being the loser in both instances.

The first State of the Bay report was produced in 2006 by Anchor Environmental Consultants (Pty) Ltd 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 and 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 (2017) report is the 10th in the series and provides an update on the health of all monitored parameters in Saldanha Bay, Langebaan Lagoon and Danger Bay in the time since the last State of the Bay assessment (2016). It includes information on trends in all of the parameters reported on in the previous reports (2006, 2008, 2009, 2010, 2011, 2012, 2013-4, 2015 and 2016).

This edition 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 Saldanha Bay and Langebaan Lagoon 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 outlines the coastal and environmental management measures in the greater Saldanha Bay area developed/implemented to facilitate sustainable development in an area where industrial development (Saldanha Bay IDZ and associate industrial development), residential and conservation areas (Ramsar Site, MPAs and National Parks) are immediately adjacent to one another.

Chapter Five: summarises available information on the importance of groundwater for Saldanha Bay and Langebaan Lagoon and also presents information on the use of groundwater in this region and potential concerns this use poses for the ecology of the Bay.

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

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

Chapter Ten 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 Eleven provides detailed information on the status of key bird species utilising the offshore islands around Saldanha Bay as well as providing an indication of the national importance of the area for birds.

Chapter Twelve 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 Thirteen 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 2017 edition of the State of Saldanha Bay and Langebaan Lagoon 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 SBWQFT 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

Only developments and activities which have experienced changes since the last State of the Bay report (2014) are retained in this chapter. Completed, stagnated or pending developments are briefly summarised in the relevant section and the reader is referred to the previous report of 2016 for more details. Additional and updated sections are listed below:

- New updated information on numbers of visitors to the West Coast National Park;
- Updated information on metal exports from the Saldanha Bay Multipurpose and iron ore terminals;
- New and updated information on new and existing development proposals for Saldanha (the Saldanha Bay Industrial Development Zone, the Sishen-Saldanha Oreline expansion project, the development of liquid petroleum gas facilities in Saldanha Bay, a proposal for the development of a Floating Power Plant in the Bay, development of Liquefied Natural Gas Import Facilities, a proposal for the development of a Combined Cycle Gas Turbine power plant, development of additional crude oil storage infrastructure, development of the Elandsfontein phosphate mine, and the development of additional vessel repair facilities in the Port of Saldanha);
- New and updated information on shipping traffic and ballast water discharges; and
- New and updated information on the volumes and quality of waste water discharged into the Bay from the Saldanha and Langebaan Water Treatment Works, fish processing establishments in Saldanha, and new developments in the mariculture industry in Saldanha.

Chapter 4: Coastal and Environmental Management

- New developments pertaining to how development in the coastal zone surrounding the Bay will be managed and controlled in future, including details on:
  - The Environmental Management Framework (EMF) for the Greater Saldanha Bay Area;
  - The proposed Saldanha Bay Special Management Area; and
  - The adoption of coastal management lines in the West Coast District Municipality

Chapter 5: Groundwater

This is a brand new addition to the State of the Bay report and serves to highlight the importance of groundwater for Saldanha Bay and Langebaan Lagoon. It also presents information on the use of groundwater in this region and the potential concerns that this use poses for the ecology of the Bay.

Chapter 5: 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.

Chapter 6: Sediments

- New updated information on grain size composition and health of benthic sediment in Saldanha Bay (TOC and Nitrogen, Trace metal and hydrocarbon content).

Chapter 8: Benthic macrofauna

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

Chapter 9: 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 10: Fish

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

Chapter 11: Birds

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

Chapter 12: 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.

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.

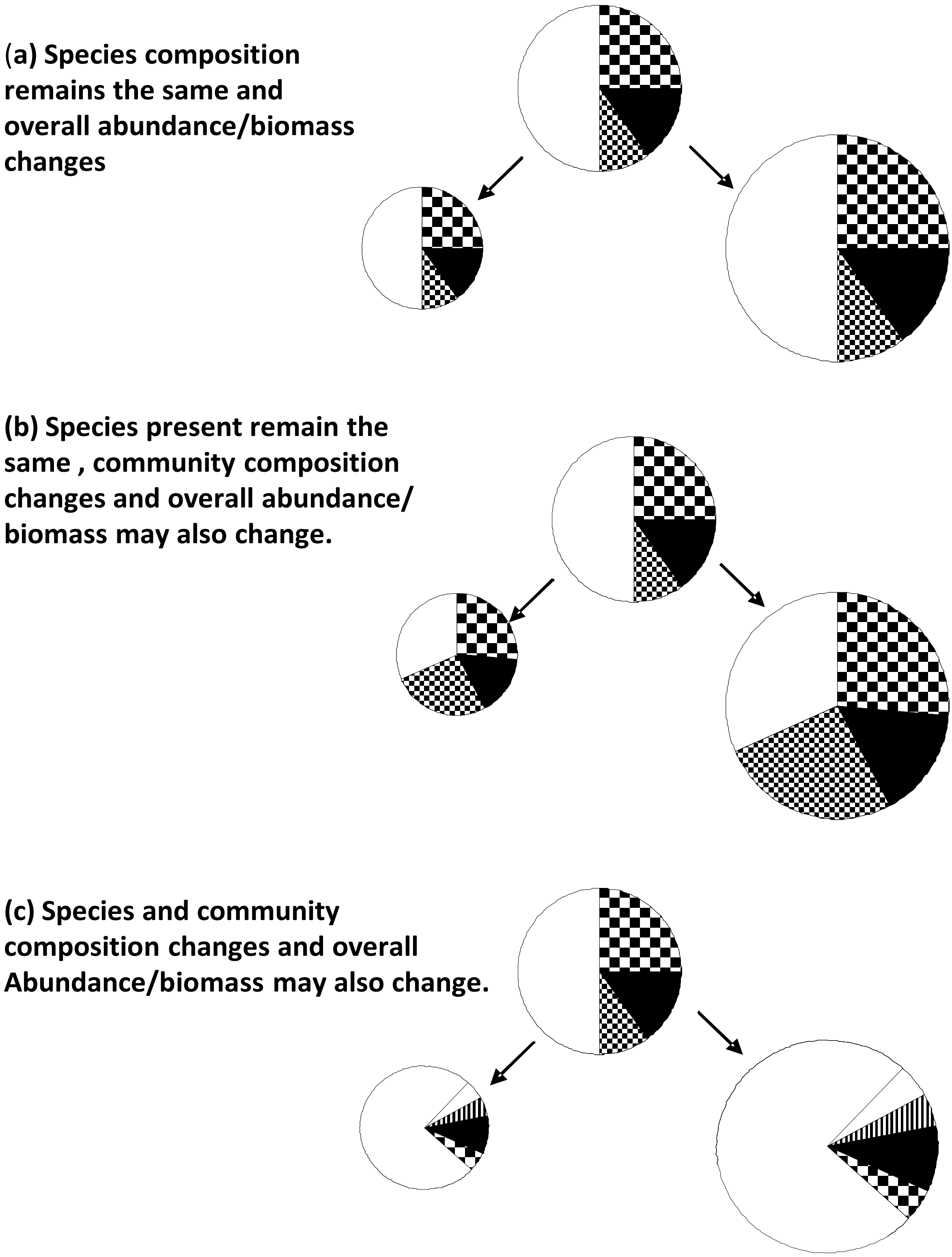

Figure 2.1. **Possible alterations in abundance/biomass and community composition. Overall abundance/biomass is represented by the size of the circles and community composition by the various types of shading. After Hellawell (1986).**

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 1900s with the establishment of a commercial fishing and rock lobster industry in the Bay. By the mid-1900s 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 with a population of more than 40 000 today. 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 1970s. 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 compartments – Small Bay and Big Bay. By the end of the 1970s Saldanha Bay harbour was an international port able to accommodate large ore-carriers.

Port facilities in Saldanha Bay now include the main Transnet iron ore terminal with berths for three ore carriers, an oil jetty, a multi-purpose terminal, and a general maintenance quay, a fishing harbour which is administered by the Department of Environmental Affairs, a Small Craft Harbour which is used by fishing vessels and tugs, three yacht marinas (Saldanha, Mykonos and Yachtport SA), a Naval boat yard at Salamander Bay and numerous slipways for launching and retrieval of smaller craft. Development of the port and fishing industry have served to attract other industry to the area, including oil and gas, ship repair and steel industries, and also resulted in a rapid expansion in urban development in Saldanha and Langebaan. Urban and industrial developments encroaching into coastal areas have caused the loss of coastal habitats and affect natural coastal processes, such as sand movement. Development of the port is expected to increase dramatically with the establishment of the Saldanha Bay Industrial Development Zone (SBIDZ), a process that was initiated in 2013.

Metal ores exported from the Port of Saldanha Bay include iron, lead, copper, zinc, and manganese. The Port of Saldanha currently has the capacity to export up to 60 million tonnes of iron ore per year but is in the process of upgrading the infrastructure to support an annual export of 80 million tonnes.

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. With the ongoing drought in the Western Cape, however, industry and local municipalities are coming together to investigate the feasibility of reclaiming potable freshwater from treated sewage in Saldanha Bay. Major infrastructural changes are required for the re-cycling of treated sewage and are associated with significant initial as well as ongoing fiscal investments. Budgetary constraints experienced by local municipalities are significant, and a public-private partnership is likely to be required to ensure successful implementation.

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.

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. Furthermore, fine sediment can drift into the Langebaan Lagoon, changing the sediment composition, which in turn can directly and indirectly (through their food supply) affect wader birds in the lagoon. 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.

Saldanha Bay is a highly productive marine environment and constitutes the only natural sheltered embayment in South Africa (Stenton-Dozey *et al.* 2001). These favourable conditions have facilitated the establishment of an aquaculture industry in the Bay. A combined 430 ha of sea space are currently available for aquaculture production in Outer Bay, Big Bay and Small Bay. With the support of finances and capacity allocated to the Operation Phakisa Delivery Unit, the Department of Agriculture Forestry and Fisheries is proposing to establish a sea-based Aquaculture Development Zone (ADZ) in Saldanha Bay. The proposed ADZ areas comprise five precincts totalling 1404 ha of new aquaculture areas in Saldanha Bay. Currently farmed areas will be incorporated into the ADZ comprising 1872 ha set aside for mariculture.

Each of the aspects summarised above are addressed in more detail in the various sections of this Chapter. The impacts of these various activities and discharges are evaluated against their potential threat to the ecological integrity of Saldanha Bay and Langebaan Lagoon. In some instances proposed developments (including environmental impacts and proposed mitigation measures) detailed in previous reports have been omitted and the reader is referred to earlier State of Saldanha Bay and Langebaan Lagoon Reports for further information on these development proposals. This only applies to those developments and activities that have not changed significantly in the past year.

Concerns have been raised that cumulative impacts on the marine environment in Saldanha Bay have not been adequately addressed by many of recent development proposals. This applies especially to the cumulative impacts that will arise from future development within the Saldanha Bay IDZ and Aquaculture Development Zone (ADZ). Furthermore, the impact on the Saldanha Bay marine environment from projects that are primarily land-based, such as storage facilities for crude oil and liquid petroleum gas, has generally been underestimated or even ignored. It has been proposed that a more holistic management strategy is needed to deal with the piece meal Environmental Impact Assessments (EIA). Various environmental management instruments have been proposed for the Greater Saldanha Bay Area, including (1) a generic Environmental Management Programme (EMPr), (2) an Environmental Management Framework (EMF), (3) a Strategic Environmental Assessment (SEA), and (4) the declaration of a Special Management Area (Refer to Chapter 4). An Intergovernmental Task Team (IGTT) has been set-up to consider these and other proposals. If these management instruments are indeed implemented, measures for the conservation alongside rapid development of the Saldanha Bay area will be addressed more effectively.

3.2 Urban and industrial development

Saldanha grew from a small fishing village into a town that supports multiple industries largely as a result of the benefits it accrues from being a sheltered Bay on an otherwise exposed coastline. The development of a large scale industrial port in Saldanha Bay commenced with the construction of an iron ore export facility in the 1970s. 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 1975, that linked Marcus Island to the mainland, providing shelter for ore-carriers. 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 3.3.).

In the late 1990s, a multi-purpose terminal (MPT) was completed, which was followed by an offshore fabrication facility. Existing facilities now include an oil import berth, three small craft harbours, a loading quay and a tug quay. Mariculture farms and several fish processing factories also make use of the Bay. Approximately 400 ha of Saldanha Bay was zoned for mariculture operations in 1997, the majority of which farm mussels and oysters. 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. Combined with increasing land-based effluent discharges into the bay, these developments have led to reduced water exchange and increased nutrient loading of water within the Bay.

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. The current layout of the Port of Saldanha is shown in Figure 3.4. Future plans, including short term (2021) and long-term (Beyond 2044) goals for the development of the bay are shown in Figure 3.5 and Figure 3.6.

Future industrial development of Saldanha Bay will be strongly driven by Operation Phakisa, which was launched in July 2014 by the South African Government with the goal of boosting economic growth and creating employment opportunities. Operation Phakisa is an initiative that was highlighted in the National Development Plan (NDP) 2030 to address issues such as poverty, unemployment and inequality in South Africa. "Phakisa" means "hurry up" in Sesotho emphasising the government's urgency to deliver. Operation Phakisa is a cross-sectoral programme, one of which is focused on unlocking the economic potential of South Africa's oceans through innovative programmes. Four critical areas were identified to further explore and unlock the potential of South Africa's oceans:

1. Marine transport and manufacturing
2. Offshore oil and gas exploration
3. Marine aquaculture
4. Marine protection services and ocean governance

In line with this development, Transnet and Transnet National Ports Authority (TNPA) have thus far initiated three developments in the Port of Saldanha Bay related to oil and gas services as well as marine infrastructure repair and fabrication. These developments are described in more detail in the sections below. Furthermore, the established Saldanha Bay aquaculture industry will be expanded through the Saldanha Bay Aquaculture Development Zone (ADZ) under the auspices of Operation Phakisa (Section 3.8).

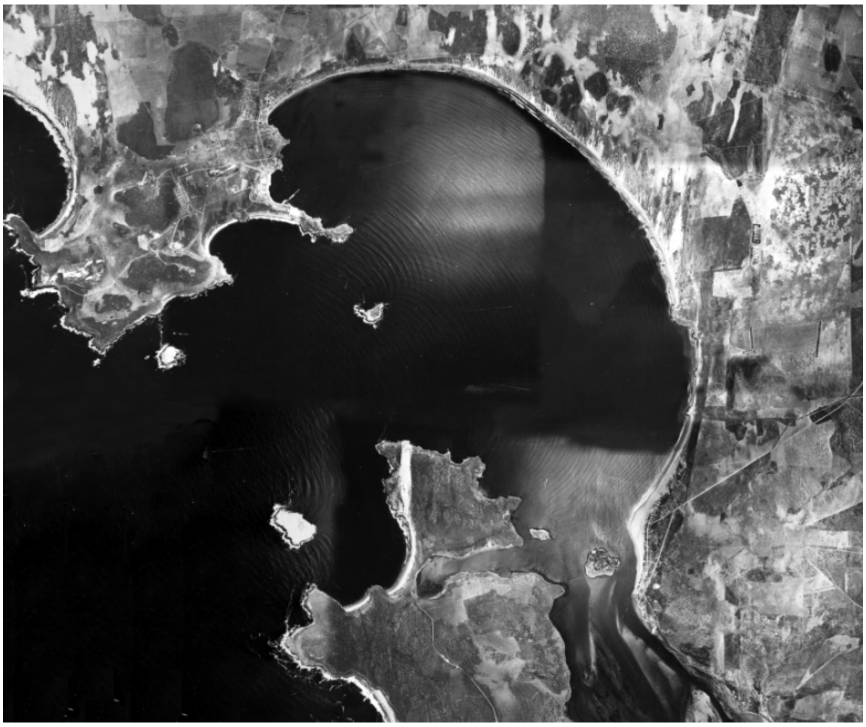

Figure 3.1 Composite aerial photo of Saldanha Bay and Langebaan Lagoon taken in 1960. (Source Department of Surveys and Mapping). Note the absence of the ore terminal and causeway and limited development at Saldanha and Langebaan.

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.

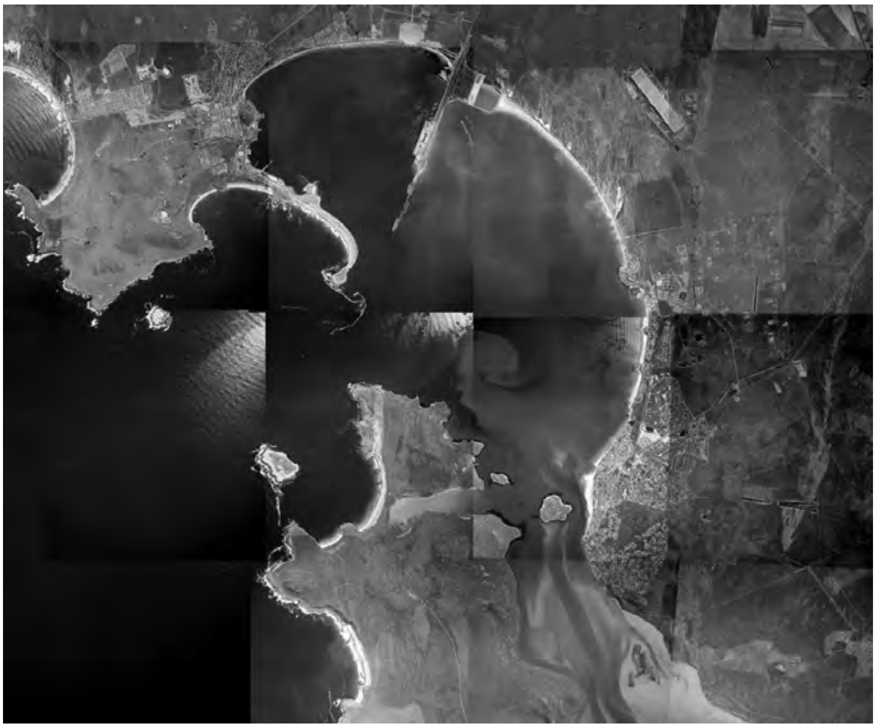

Figure 3.3. Composite aerial photo of Saldanha Bay and Langebaan Lagoon taken in 2007. (Source Department of Surveys and Mapping). Note expansion in residential settlements particularly around the town of Langebaan.

Figure 3.4. Current layout of Transnet Saldanha Bay Port (Source: Transnet National Port Authority 2015, National Port Plans).

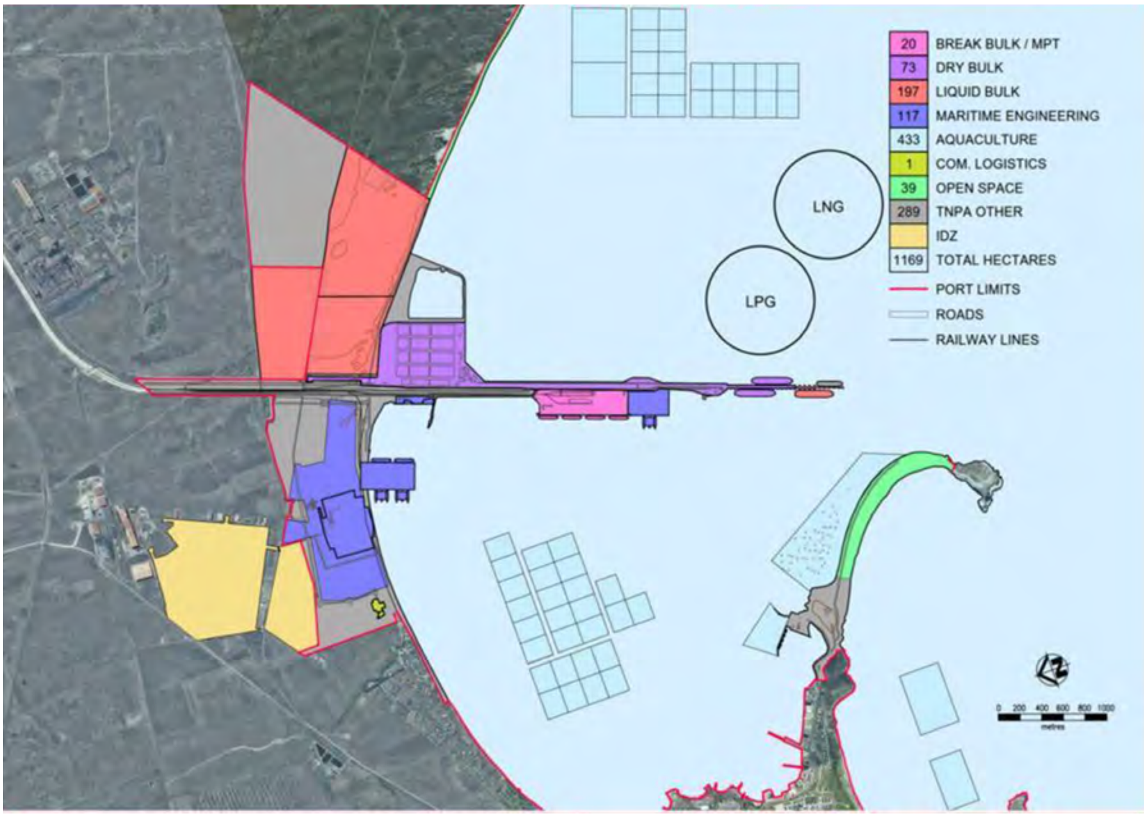

Figure 3.5. Short term layout (2021) of Transnet Saldanha Bay Port (Source: Transnet National Port Authority 2015, National Port Plans 2015).

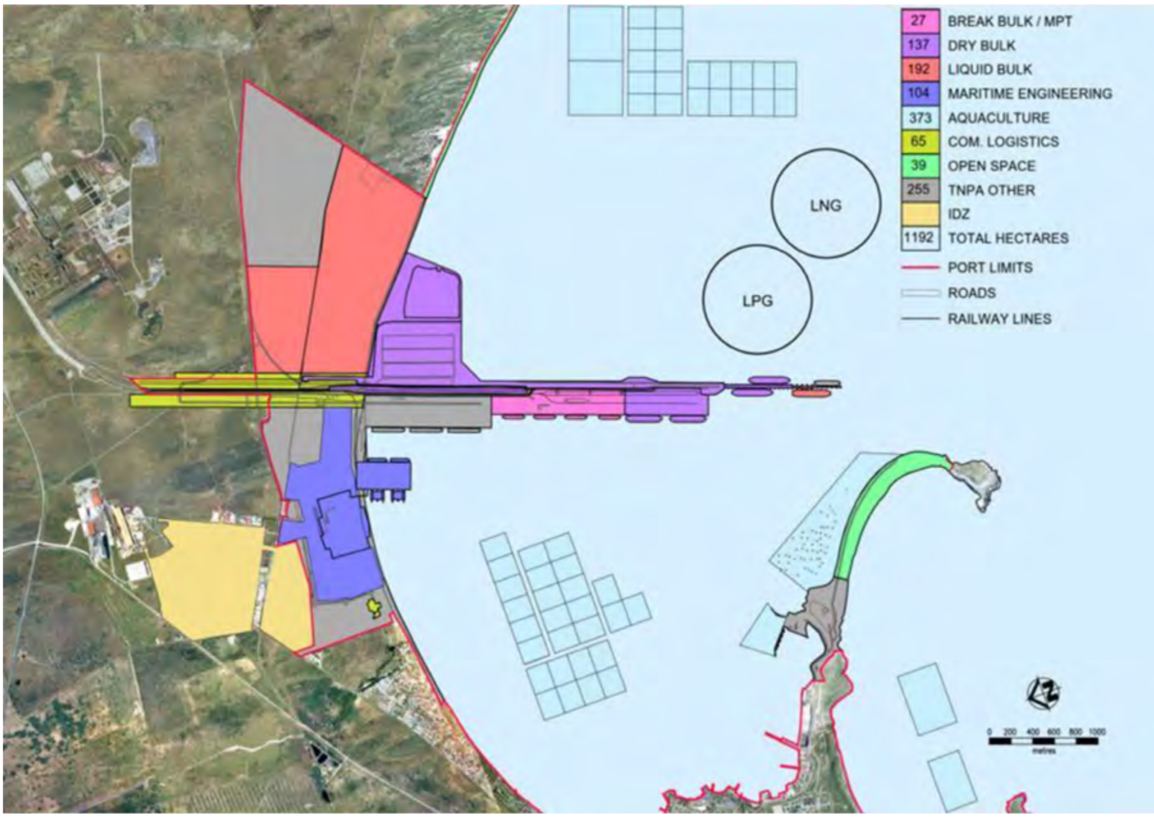

Figure 3.6. Long term layout (2044) of Transnet Saldanha Bay Port (Source: Transnet National Port Authority 2015, National Port Plans 2015).

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% per year 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 also increases the volumes of storm water entering the marine environment, which ultimately can have a detrimental effect on ecosystem health via the input of various contaminants and nutrients (See Section 3.6).

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. Long term data (2005-2017) on numbers of visitors to the West Coast National Park (WCNP) indicate strong seasonal trends in numbers of people visiting the park, peaking in the summer months and during the flower season in August and September (Figure 3.9). Paying day guests (excluding international visitors) and free guests[1] contribute the most to this seasonal pattern, while international guests and overnight guest numbers are relatively constant throughout the year. International and overnight guest numbers are considerably lower than the other visitor categories. Visitor numbers have been increasing at an average rate of 18% per annum since 2005[2], peaking in the 2016-2017 period with a total of just over 337 000 visitors (Figure 3.10). The number of free guests has been increasing steadily over time and now equals the proportion of day guests. The number of international visitors has stayed relatively constant over time while popularity of overnight stays inside the park has decreased substantially since 2005/2006 and reached lowest numbers in 2015/2016 with 2 041 guests (2 529 guests in 2016/2017).

[1] These include Wild Card, school class, military personnel, official visit, staff, residents and 'other' entries.

[2] 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 periods from July 2005 until June 2015.

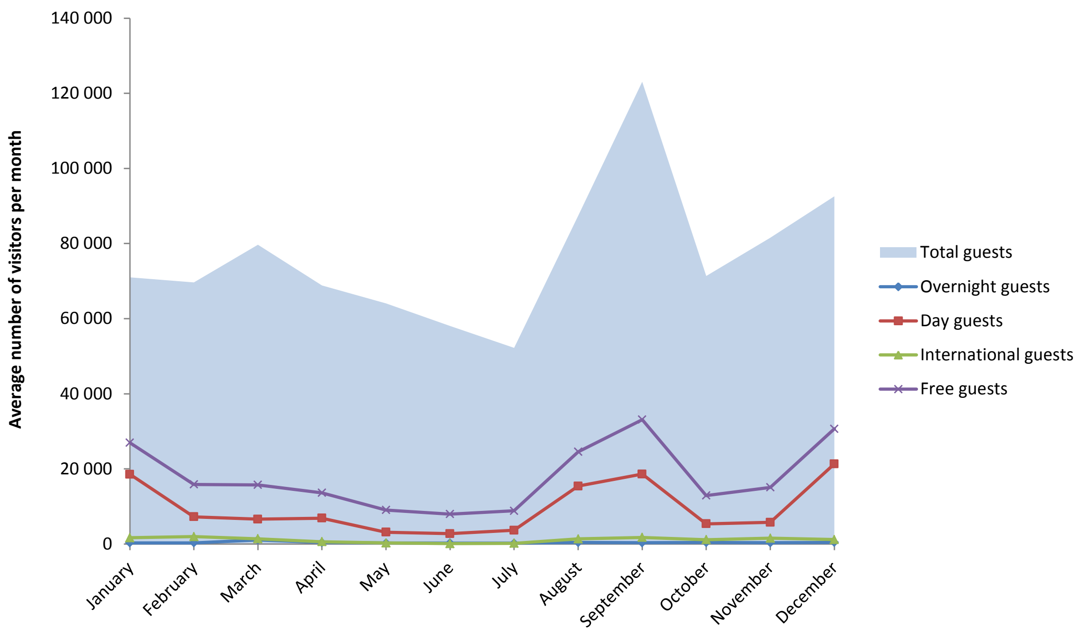

Figure 3.9. **Monthly average numbers of tourists visiting the West Coast National Park between July 2005 and June 2017. Day guests include all South African visitors (adults and children) while Overnight guests refer to those staying in SANPARK accommodation. International guests include all SADC and non-African day visitors (adults and children) while the category 'Other' includes residents, staff, military, school visits, etc. (Source: Pierre Nel, WCNP).**

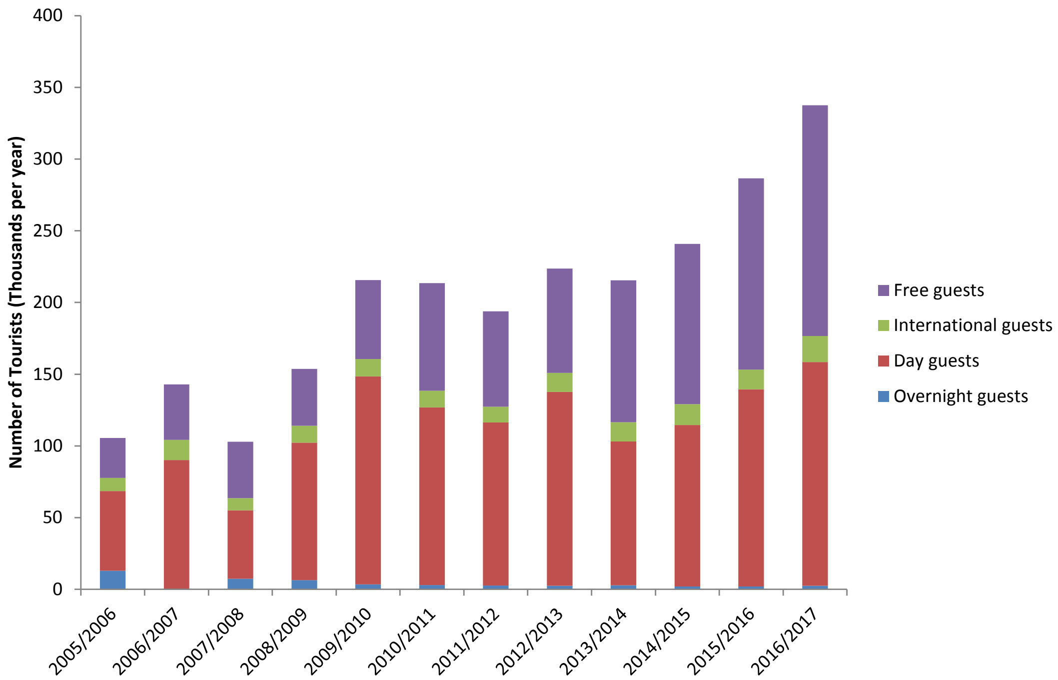

Figure 3.10. **Numbers of tourists visiting the West Coast National Park in a rolling 12 month periods from July 2005 until June 2017. Day guests include all South African visitors (adults and children) while Overnight guests refer to those staying in SANPARK accommodation. International guests include all SADC and non-African day visitors (adults and children) while the category 'Other' includes residents, staff, military, school visits, etc. (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 latest version of the Saldanha Municipality IDP covers the period 2012-2017 IDP. The latest SDF for the Saldanha Bay Municipality (SBM) was produced in 2011 and is available on the municipality website. This document advocates a holistic approach to the development of the municipality, 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. This provided a strong foundation for the establishment of an Industrial Development Zone (IDZ) in October 2013. 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:

(1) 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 –
    a. facilitate the creation of an industrial complex having strategic economic advantage;
    b. provide the location for the establishment of strategic investments;
    c. enable the exploitation of resource-intensive industries;
    d. take advantage of existing industrial capacity, promote integration with local industry and increase value-added production;
    e. create employment and other economic and social benefits in the region in which it is located; and
    f. 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 3.6. Concern has been expressed over the fact that the impacts of the SBIDZ on the marine environment have not been adequate assessed, 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 3.6.3) in Saldanha.

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)

The Saldanha Bay IDZ Licensing Company (LiCo) appointed CCA Environmental (Pty) Ltd to undertake the Scoping and EIA process for the proposed oil and gas offshore service complex (OSC) at the Saldanha Bay IDZ (Portion 2, Figure 3.11). On 16 November 2015 the Department of Environmental Affairs and Development Planning (DEA&DP) granted and issued an Environmental Authorisation (EA) for the project in terms of the National Environmental Management Act (No. 107 of 1998), as amended. This gives the SBIDZ LiCO authorisation to develop an oil and gas offshore service complex within the Saldanha Bay IDZ (SLR 2016). Construction of the project commenced during the first quarter of 2016. The project includes the following components:

- Maintenance and repair of offshore drilling units covering an initial 10 ha, potentially expanding to 14 ha in future;
- A 3 ha small ship repair yard that will service smaller ships 100-150 m in size in four repair bays;
- A regional service base for ports and offshore supply bases for oil and gas activities (16 ha);
- Multi-user fabrication and storage yard for the manufacturing and storage of equipment and associated items for the oil and gas industry. Several operators specialising in different products (25 ha short term, 100 ha long-term);
- Regional oil disaster response base for the storage of major oil spill remediation equipment (1 ha); and
- Communal / support services (unknown area).

Upgrades to the Saldanha Bay WWTW are currently underway and are subject to substantial increases treatment capacity to cater for the proposed activities related to the Saldanha Bay IDZ (Section 3.6.3.3). The total water demand of the entire OSC was calculated as 1 453 kilolitre per day and is characteristic of general office demand as opposed to that of a wet industry. Water will initially be provided by the WCDM bulk water distribution system supplied by the Miswaterstand Water Scheme. Water shortages in the near future are predicted and alternative options are under discussion including water transfer from the Berg River system as well supplies from a proposed regional RO plant situated in Danger Bay (Section 3.6.2). A waste transfer facility on Portion 1 of the Saldanha Bay IDZ is also required, which will be subject to a Waste Management License and associated EIA.

The draft EIR included a description and assessment of environmental impacts on terrestrial ecosystems and biodiversity but failed to address impacts on the marine environment. Comments provided by Interested and Affected Parties resulted in the inclusion of a short marine risk assessment which dealt with the possible impacts of increased vessel traffic as well as stormwater runoff from the proposed OSC. However, it was also clarified that potential impacts that may occur as a result of the construction and operation of marine infrastructure associated with the OSC will be investigated in a separate EIA process undertaken by the TNPA at a later stage.

The direct impact of additional vessels on marine ecology of the Bay (i.e. oil and alien species transfer) was rated to be of low significance due to the very small increase (1-3%) in cargo volume expected over the next 30 years. Furthermore, the risk of alien biota transfer into the port was considered to be low as shallow berth vessel types will not require deballasting within the port and high pressure blasting of vessel hulls to clear hull fouling is not permitted. Large oil spills would also be unlikely as the proposed complex is not associated with oil tankers. The following mitigation measures applicable to the marine environment were listed in the final EIR:

- LiCo should participate in long term water quality monitoring within the Saldanha Bay area as part of the Saldanha Bay Water Quality Forum Trust's State of the Bay monitoring process. Participation could include making data available to the SBWQFT and providing a financial contribution for setting up further monitoring stations within the Port of Saldanha;
- It must be ensured that all operators are aware of and implement existing measures for the management of marine impacts within the Port of Saldanha. These include:
    - Ballast Water Performance Standards as specified in the new Draft Ballast Water Management Bill, 2017.
    - All vessels entering the Port of Saldanha must undergo inspection by a Pollution Control Officer to minimise the risks of pollution in the port
    - Standard Terms and Conditions for Ship Repair Operators which details the Safety, Health and Environmental (SHE) process to be followed for rig/vessel repair within the Port of Saldanha and also includes a Code of Practice for Ship Repair Operators.
    - Onshore stormwater management at the proposed OSC are expected to comply with TNPA's Draft Stormwater Management Plan which requires that all stormwater on-site is collected for infiltration and evaporation in detention ponds of sufficient capacity to retain a 1:50 year rain event.
- An updated Operational EMP must be compiled once it is known which businesses will be established within the OSC. The Operational EMP must address activities as part of all components of the OSC, both onshore and offshore. This Operational EMP should be made available for public review prior to submission to DEA&DP for approval; and
- Sufficient capacity is absolutely necessary in the stormwater planning of the site in order to efficiently manage stormwater in line with TNPA and municipal requirements. No stormwater from onshore facilities is to be discharged to the sea as per TNPA policy (Section 3.6.4.1).

Figure 3.11 **Google Earth image showing the location of the proposed site (red shading) within the Saldanha Industrial Development Zone indicated by the and black outline (Source: Final EIR for the proposed oil and gas offshore service complex at the Saldanha Bay IDZ, CCA Environmental (Pty) Ltd. 2015).**

3.2.2 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. Transnet is currently installing a third iron ore tippler to ensure that 60 million tonnes per annum of iron ore can continue to be exported (GIBB 2013b) (refer to the 2014 State of Saldanha Bay and Langebaan Lagoon report for more information on this project).

Transnet in conjunction with six mining companies (Aquila Steel, Assmang, Kumba Iron Ore, PMG, Tshipi e Ntle and UMK) are now proposing an oreline expansion project. This would increase the capacity of the current Sishen-Saldanha railway and port from 60 to 88 million tonnes per annum by 2017 in order to satisfy the global demand for iron ore (GIBB 2013). 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 three components of this project are currently still in the planning phase (refer to the 2014 State of Saldanha Bay and Langebaan Lagoon report for more information on this project).

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 2017, 282 iron ore ships arrived and departed from the iron ore terminal in the Port of Saldanha, exporting 55.3 million tonnes of iron ore (Section 3.3).

3.2.3 Development of 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.

Sunrise Energy (Pty) Ltd is currently building an LPG import facility in the Saldanha Bay Harbour and was 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. An EIA process in terms of section 24 of the NEMA was initiated by ERM Southern Africa in 2012 and EA was granted on 13 May 2013 by the DEA&DP (refer to AEC 2014 for more information). 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 was recommended that such monitoring be undertaken as part of the Saldanha Bay Water Quality Forum Trust`s monitoring program, and this is currently underway. The bulk earthworks and construction commenced in January 2014, but the installation of infrastructure in the marine environment has not yet begun and was scheduled to start in September 2017 (Sunrise Energy (Pty) Ltd, Janet Barker, *pers. comm.* 2015*)*.

Avedia Energy is in the process of 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 tonnes each (Frans Lesch, ILF Consulting Engineers, Project Manager at Avedia Energy Saldanha LPG plant, *Pers. Comm.* 2015) (refer to AEC 2014 for more information).

3.2.4 Liquefied Natural Gas Import Facilities

The proposed Liquefied Natural Gas (LNG) Import Facilities aim to secure gas supplies to supplement land-based gas power plants, other industrial users and FPPs (ERM 2015b). This project constitutes phase two in national efforts to contribute towards meeting South Africa's electricity requirements. Phase two will allow for the development of medium- to long-term gas power plants outside of the port boundaries (Section 3.2.4) (ERM 2015a and 2015b). ERM provided stakeholders with a Background Information Document in October 2015 of which excerpts and illustrations are provided below (ERM 2015a). The facilities will provide for the importation, storage, regasification and the transmission of natural gas to a distribution hub, and will include both land-based (terrestrial) and marine-based components. Both, floating and landbased regasification technologies are currently considered for this project (Figure 3.12). Floating regasification would consist of the following components:

- A marine import facility consisting of a loading quay, berthing and mooring dolphins, access and services trestle and pipeline;
- A permanently moored Floating Storage and Regasification Unit (FSRU) (marine); and
- A gas pipeline connecting the fuel storage and regasification facility to a common gas distribution hub from which the gas will be distributed to the power plant and domestic users via pipeline.

Land-based regasification technology would consist of the following components:

- A marine import facility consisting of a loading quay, berthing and mooring dolphins, access and services trestle and pipeline;
- A dock at an existing facility in the port or a special purpose docking facility to be constructed for an LNG transport ship;
- A cryogenic gas pipeline connecting the LNG carrier to storage and regasification facilities on land;
- A gas pipeline from the regasification unit to a gas distribution hub which will then distribute the gas further to a power plant and other gas users. Electricity is connected from the power plant to the national grid.

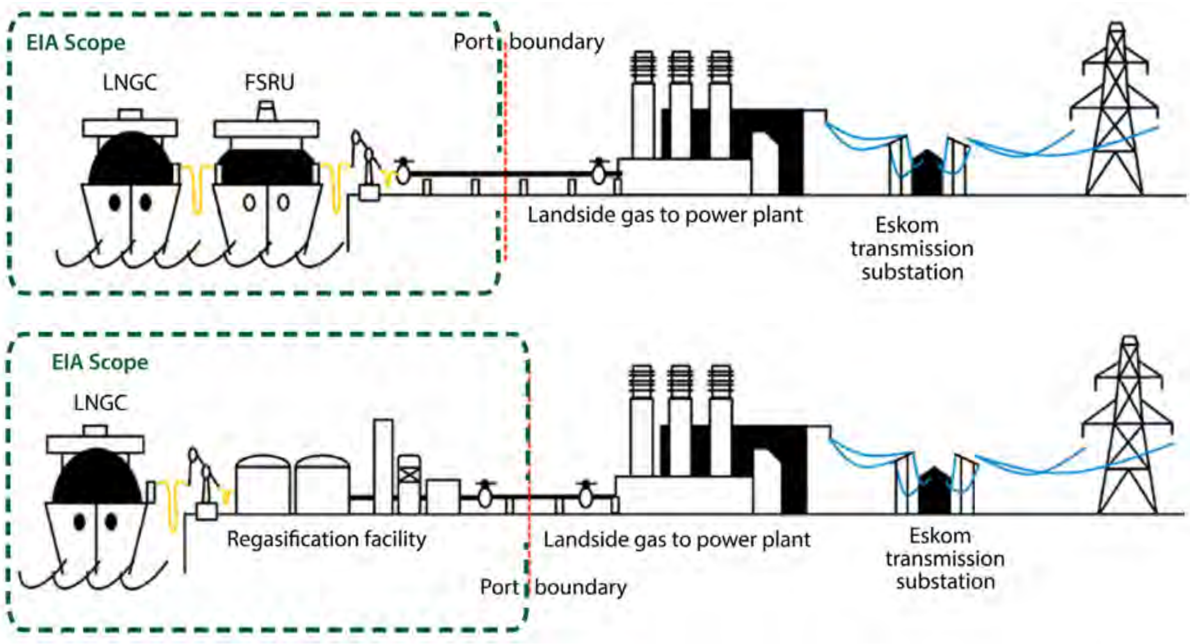

Figure 3.12 An illustration of the floating (top) and land-based (bottom) regasification technology (Source: Background Information Document, ERM 2015a).

3.2.5 Gas fired independent power plant

The International Power Consortium South Africa (Pty) Ltd (”IPCSA”) have proposed the construction of a Combined Cycle Gas Turbine (CCGT) power plant (1507 MW net capacity) as a solution to medium to long-term sustainability of Arcelor Mittal’s Saldanha Steel and surrounding economy (ERM 2015c). The project is primarily a Liquefied Natural Gas (LNG) power supply project to the Saldanha Steel Plant (ERM 2015c). LNG will be supplied by ship to the Port of Saldanha, where it will be re-gasified and then offloaded via a submersible pipeline either from a mooring area located offshore or a berthing location in the Port of Saldanha. ArcelorMittal South Africa obtained Environmental Authorisation (EA) from the National Department of Environmental Affairs (DEA) under the National Environmental Management Act (NEMA) (Act No. 107 of 1998) (as amended) through a Scoping and Environmental Impact Assessment (EIA) process on 24 February 2017.

It is anticipated that this project will connect to the Department of Energy's (DoE's) planned LNG import terminal in the Port of Saldanha (Section 3.2.4). Should this not occur a separate EIA will be undertaken to permit the marine component of the import of LNG.

3.2.6 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, intend 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 construction phase commenced at the beginning of 2015 but It is currently unknown when this project will be completed (refer to the 2014 State of Saldanha Bay and Langebaan Report for more information).

3.2.7 Elandsfontein phosphate mine

The Elandsfontein phosphate deposit is currently the second biggest known resource in South Africa. The deposit is located on the farm Elandsfontein 349, approximately 10 km to the east of Langebaan (Braaf 2014). Two significant aquifers underlie the phosphate deposit namely the Langebaan Road Aquifer System (LRAS) (northern paleo-channel) and the Elandsfontein Aquifer System (EAS) (southern paleo-channel) (Braaf 2014). Consequently, the phosphate deposits underlie the groundwater table (i.e. within the saturated zone) (GEOSS, Julian Conrad, *pers. comm.* 2016).

The dominant application of phosphorus is in fertilisers and the demand in the agricultural sector is growing (Braaf 2014). Kropz, previously known as Elandsfontein Exploration and Mining (Pty) Ltd. (EEM) commissioned Braaf Environmental Practitioners to facilitate the environmental authorisation process for the proposed Elandsfontein Phosphate project. Environmental Authorisation (EA) was granted in February 2015 and a water use license in April 2017 (refer to the 2016 State of Saldanha Bay and Langebaan Lagoon Report for details on the project description, potential impacts on Langebaan Lagoon, and ongoing environmental monitoring).

The commissioning of the mine has been haltered for an extended period due to a long delay in the issuing of the mine’s water use license (Furlong 2017). Phosphate prices have reached a ten-year low, decreasing by almost 30% since the mining company was issued its mining right in January 2015. This, together with technical problems identified during the commissioning phase, has resulted in the temporary suspension of mining activities in Elandsfontein.

3.2.8 TNPA projects under auspices of Operation Phakisa

Due to an increase in offshore activity in South Atlantic and West African waters, and the resulting demand for vessel repair facilities, the National Government and Transnet National Ports Authority (TNPA) proposed the development of new infrastructure at the Port of Saldanha in line with the objectives of Operation Phakisa. The new infrastructure is expected to include the following components:

1. A Vessel Repair Facility (VRF) for ships and oil rigs (Berth 205);
2. A 500 m long jetty at the Mossgas quay; and
3. A floating dry dock for inspection of Offshore Supply Vessels (OSV).

These three projects are described in more detail in Sections 3.2.8.1-3.2.8.3. The potential impacts on the marine environment associated with the VRF and the Mossgas Jetty are also summarised in Section 3.2.8.4. The development of Berth 205 and the Mossgas Jetty will require extensive dredging operations to allow large oil and gas vessels access to new berthing infrastructure. The total dredge area during construction for the long-term development scenarios for the Mossgas Jetty and Berth 205 was estimated by TNPA at approximately 2.6 million m^3. This equates to the second largest dredge event in the history of Small Bay and is comparable to the dredging which commenced in 1996 for the construction of the MPT (refer Section 3.3 for more information about dredging in Saldanha Bay).

3.2.8.1 Vessel Repair Facility (VRF) at Berth 205

At present, Vessel Repair Facilities (VRFs) in Saldanha Bay are limited to minor repairs of fishing vessels, although a few offshore rigs have been repaired at Berths 203, 204 and the MPT. In order to harness opportunities that exist in the vessel repair business, dedicated and purpose built quays with associated bulk services and onshore back of port services are required. The location study identified the site immediately to the south of Berth 204 of the MPT (referred to here as Berth 205) as the preferred location, with the alternative being to the north (ARUP 2014) (Figure 3.13). According to ARUP (2014), the southern location has a number of engineering and logistical advantages over the other sites considered:

- Berth 205 is adjacent to the navigation channel to the MPT and to the dredge channel to the Iron Ore Expansion berth, which will keep dredging to a minimum.
- The location is within the Port security boundary simplifying access.
- In the event of the market failing to materialise, the facility could be incorporated into the MPT or could serve as an additional bulk export facility.

Possible disadvantages are as follows:

- Future expansion would be prevented if the Iron Ore Expansion Project were to proceed, although it would be possible to expand into the MPT.
- Vessels under repair could be impacted by vessels travelling to and from the MPT.
- High airborne dust concentrations at this site may damage vessels unless regularly washed down.

3.2.8.2 Mossgas Jetty

In 2009, a study was undertaken to identify the options and costs for the extension of the Mossgas yard in order to provide a 500 metre long quay to form an offshore vessel repair facility (ZLH 2009). More recently, a pre-feasibility study reported an increasing demand for semi-submersibles, Floating Production Storage Offload Vessels (FPSOs) and jack-up platforms (ARUP 2016). This sparked the proposal of a complimentary offshore supply vessel repair facility adjacent to Mossgas Quay.

The pre-feasibility study considered three possible locations for the jetty (Figure 3.13):

- The eastern side of Mossgas Quay (preferred site)
- The western side of Mossgas Quay (alternative site)
- At the existing Mossgas Quay (not feasible)

The existing Mossgas Quay option was eliminated due to current port operations and existing lease agreements. The western side of the Mossgas Quay was not preferred due to cost limitations and the current location of the marina. As sediment transportation adjacent to Mossgas is predominantly from west to east, more frequent maintenance dredging and a longer groyne would be necessary if the jetty is constructed to the west (ARUP 2016). A jetty positioned to the east is preferable to developers as costs are projected to be lower, while activity will be further away from designated aquaculture areas and the Bluewater Bay residential area (Figure 3.13).

3.2.8.3 Floating dry dock for the inspection of Offshore Supply Vessels

A floating dry dock is essentially a semi-submersible vessel that is able to adjust its ballasting to increase its draft to allow a vessel to manoeuvre into the main dock barrel. The floating dry dock is then de-ballasted to raise the vessel out of the water. The floating dry dock may be manoeuvred into deeper water to service larger vessels, therefore reducing the depth of dredging required at the ship maintenance site.

Figure 3.13 **The iron ore terminal (IOT), the multi-purpose terminal (MPT), the Dry Bulk Terminal (DBT) and the Liquid Bulk Terminal (LBT) separating Big Bay and Small Bay. The preferred (green) and alternative (orange) position of the Berth 205 VRF and the preferred (yellow) and alternative (blue) options for the proposed Mossgas Jetty are indicated (Adapted from: ARUP 2016).**

3.2.8.4 Marine Environmental Impact Assessment

The proposed impact sites are already moderately disturbed by shipping, pollution (including iron ore dust) and maintenance dredging. Despite these existing impacts and pressures, Small Bay should not be regarded solely as an industrial port. This area still provides valuable goods and services to the Saldanha Bay-Langebaan Lagoon system as a whole and is essential for the healthy functioning of the area.

Anchor Environmental Consultants (Pty) Ltd. were appointed by CCA Environmental (Pty) Ltd. (CCA) to conduct a marine environmental screening study for the construction of the VRF at Berth 205 and a 500 m long jetty in the vicinity of the existing Mossgas Quay in the Port of Saldanha (Laird and Clark 2016).

The study found that based on data reviewed from the Saldanha State of the Bay Report (Anchor 2015) and from hydrological and sediment modelling (ZAA 2016), impacts from construction at the 'preferred' and 'alternative' sites are unlikely to differ within a development option (i.e. Mossgas Jetty east no different from Mossgas Jetty west and VRF north no different from VRF south) when viewed from a marine environmental perspective. In contrast, differences in the severity of some impacts are expected between the two projects (i.e. between Mossgas and the VRF at Berth 205).

For example, despite the fact that the proposed construction footprint at the Mossgas Jetty is 150% smaller than that at Berth 205, impacts were rated higher at the Mossgas Jetty due to the ecological importance of the intertidal and shallow subtidal area in the northern part of Small Bay and the relative scarcity of this habitat. Planned annual maintenance dredging at the Mossgas Jetty also elevated significance ratings by increasing the impact duration from short/medium-term to long-term. The shallow intertidal beach area in the northern section of Small Bay is crucially important for fish recruitment. If construction of the Mossgas Jetty is approved, up to 15% of the total nursery area in Small Bay will be lost. Although fish can potentially utilise similar habitat west of the proposed jetty, it is not clear whether this area will be sufficient to sustain increased densities of juvenile fish during a prosperous recruitment year. With the intention of preventing collapse of commercially important fish stocks such as white stumpnose (which are already declining in the Saldanha Bay-Langebaan Lagoon system), it is recommended that no further net loss of shallow intertidal beach habitat in Small Bay should be permitted after the completion of the Mossgas Jetty.

Other impacts that are considered as important include turbidity plumes created by dredging. The effects of increased Total Suspended Solids (TSS) in the water column during dredging can have severe impacts on the marine environment through the mobilisation of fine sediments, contaminants, nutrients and increased turbidity (Refer to Section 3.3 for more information). ZAA reported on the likely severity of an increased concentration of TSS at the dredge sites based on a settling rate of 0.45 mm/s (ZAA 2016). Due to the combination of mud and fine calcrete dust (which creates extensive white plumes when removed) known to be present in Small Bay, previous modelling studies applied settling rates of 0.1 and 0.2 mm/s for very fine (< 2 µm) and fine material respectively (Anderson 2008). The substantially higher settling rate applied for the Berth 205 and Mossgas project is likely to result in an underestimation of the extent of the turbidity plume. Although modelled dredge volume was elevated to anticipated 'worst case scenario' by ZAA, the settling rate may not have been conservative enough considering the presence of the calcrete layer between 3 and 17 m in subsurface marine substrata in the construction footprint (ARUP 2014 and

2016). Although deep sediments are unlikely to contain toxic levels of trace metals, excess fine sediments will intensify the impacts of smothering and increased turbidity. The study by Anchor Environmental therefore recommended that the sediment particle size included in the model is revised to take the estimated dredge volume of calcrete into account. For the construction phase, standard mitigation measures (i.e. real-time monitoring and installation of a silt curtain) for minimising the impact of turbidity plumes were recommended.

3.3 Export of metal ores from the Port of Saldanha

Metal ores exported from the Port of Saldanha Bay include iron, lead, copper, zinc, and manganese. Most of the iron ore is exported from the iron ore terminal (IOT) (Figure 3.14), while more recently a very small proportion has been exported from the *multi-purpose terminal* (MPT) (Figure 3.16). The Port of Saldanha currently has the capacity to export up to 60 million tonnes of iron ore per year but is in the process of upgrading the infrastructure to support an annual export of 80 million tonnes (Section 3.2.2). Iron ore exports have increased steadily from 20.7 to 55.3 million tonnes between 2003 and 2017 (note that annual metal export is calculated based on the fiscal year, i.e. April-March) (Figure 3.14).

Metal exports from the MPT have increased exponentially since 2007 (Figure 3.15). Initially only lead, copper and zinc were exported from the MPT, with lead comprising the largest proportion of the exported material in 2011 (Figure 3.15 and Figure 3.17). The export of combined lead, copper and zinc increased from 74 thousand tonnes in 2007/8 to 183 thousand tonnes in March 2013 and has since fluctuated around 138 thousand tonnes (Figure 3.17). Individual annual export volumes for lead, copper and zinc are only available since 2010/11 (Figure 3.17). Lead exports remained stable between 2010 and 2013 before dropping by nearly a third in 2014. Zinc exports picked up in 2011, roughly equalling lead exports with an average of 57 thousand tonnes per annum (Figure 3.17). Copper is exported in small quantities compared to all other metal ores although exports have steadily increased since 2011, peaking in 2015 at 26.7 thousand tonnes. In 2011, Transnet started the export of iron from the MTP. Up until 2016, iron ore comprised on average 58% of the total exports from the MPT (Figure 3.15).

South Africa accounts for approximately 78% of the world's identified manganese resources, with Ukraine accounting for 10%, in second place. South Africa's manganese production increased from 4.2 million tonnes in 2004 to 13.7 million tonnes in 2016. Most of the locally produced manganese is exported (Chamber of Mines 2017). Manganese exports from the MPT in Saldanha Bay only commenced in 2013 (95 thousand tonnes) but have gained significant momentum in the last three years. Since 2013, manganese export has increased by more than a third each year, totalling just over 3 million tonnes in the 2017 financial year (Figure 3.16), comprising almost 80% of the total metal exported from the MPT (Figure 3.15). In 2016, manganese exports from the Saldanha Bay MPT represented 15% of the total amount exported from South Africa.

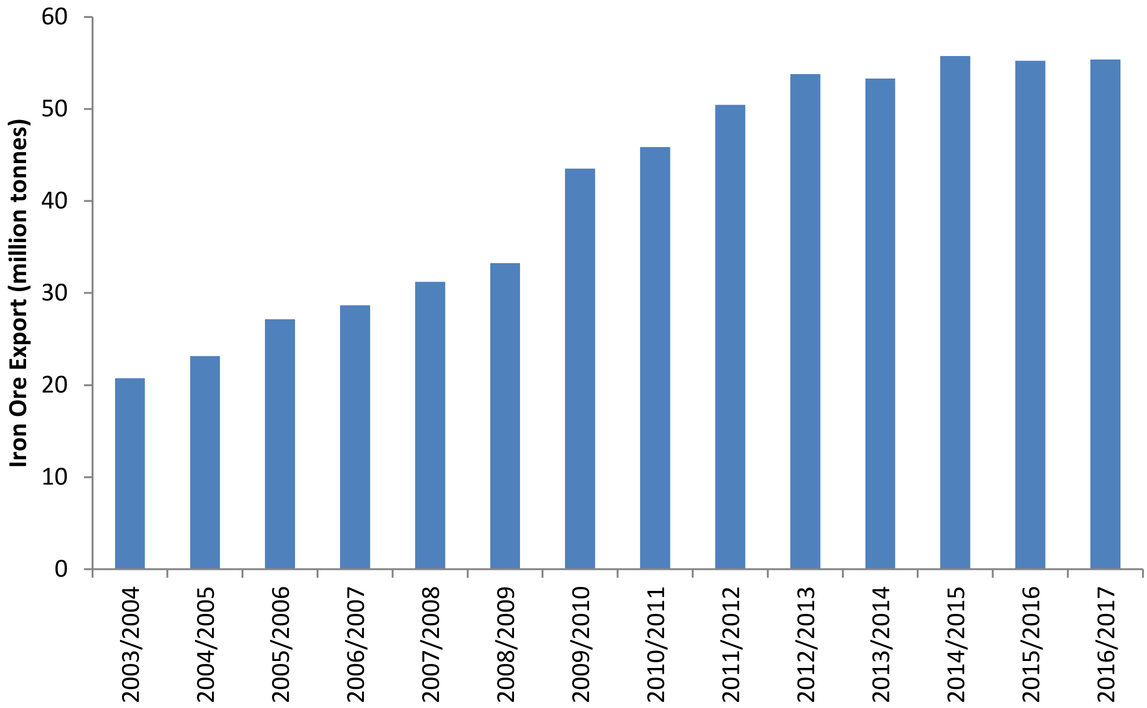

Figure 3.14 **Annual exports of iron ore from the iron ore terminal at the Port of Saldanha between April 2003 and March 2017. (Data provided by Rejean Viljoen, Transnet Port Authority 2017).**

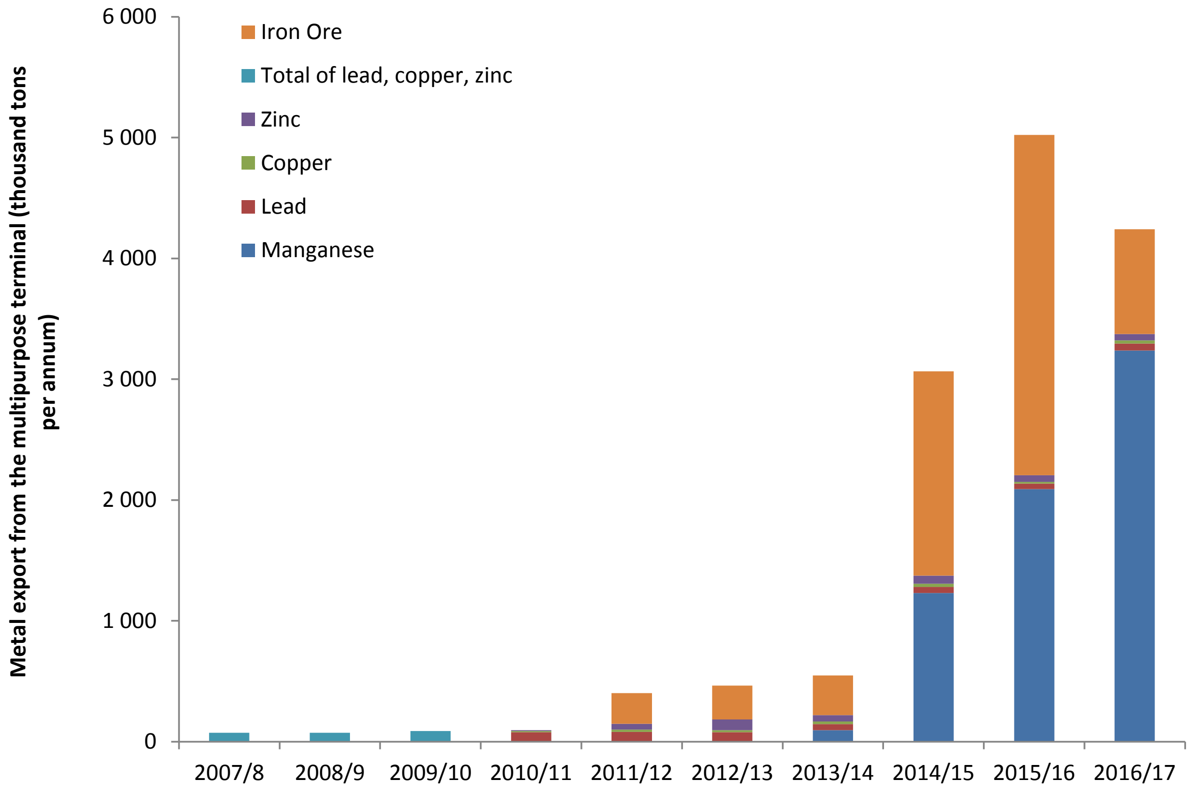

Figure 3.15 **Metal exports from the *multi-purpose terminal* in Saldanha Bay Port from April 2007 – March 2017. (Data provided by Rejean Viljoen, Transnet Port Authority 2017).**

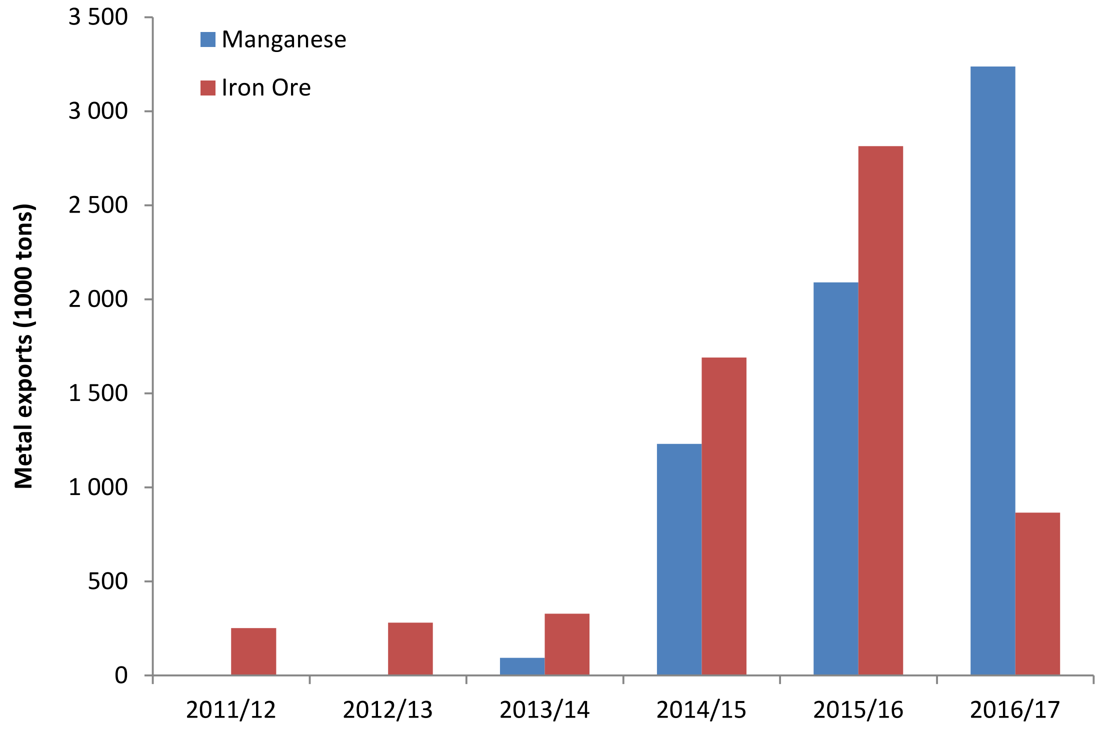

Figure 3.16 **Annual exports (April 2011 – March 2017) of manganese and iron ore from the *multi-purpose terminal* at the Port of Saldanha Bay (Data provided by Rejean Viljoen, Transnet Port Authority 2017).**

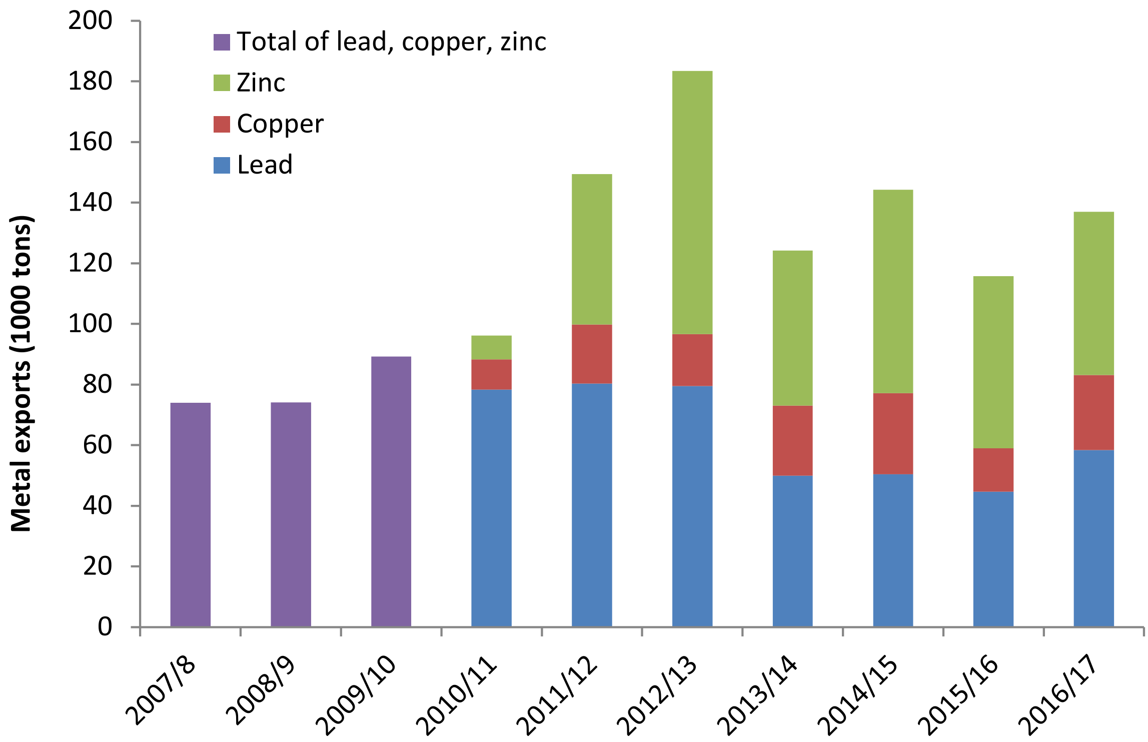

Figure 3.17 **Annual exports (April 2007 – March 2017) of lead, copper and zinc from the *multi-purpose terminal* at the Port of Saldanha Bay. Note that separate data for these commodities was only available for April 2010-March 2017 (Data provided by Rejean Viljoen, Transnet Port Authority 2017).**

3.3.1 Air quality management in Saldanha Bay

Suspended particles in the atmosphere eventually settle and result in pollution of the marine environment of Saldanha Bay and Langebaan Lagoon (direct settlement and stormwater runoff). Chemical processes in the water column facilitate the uptake of metals into the tissue of mariculture organisms destined for human consumption. Effective air quality management in Saldanha Bay is therefore considered an important component of water quality management in the study area.

The West Coast District Municipality acknowledged and accepted its responsibility in terms of Chapter 5 of the National Environmental Management: Air Quality Act, 2004 (Act 39 of 2004) (NEM: AQA) and fulfils the function of licensing authority in the area of jurisdiction of the West Coast District. Since the promulgation of NEM: AQA on 01 April 2010 the majority of atmospheric emission licences were issued within the Saldanha Bay Municipality.

Listing notice GN No. 893 of 22 November 2013 (as amended) published in terms of section 21 of NEM: AQA identifies certain categories of activities requiring an atmospheric emission licence and which must be compliant with minimum emission standards in terms of Part 3 of the Regulations. The storing, processing and handling of minerals is listed as a Category 5 activity and includes the storage of handling of ore and coal not situated on the premises of a mine or works as defined in the Mines Health and Safety Act 29 of 1996 (Subcategory 5.1). Licensing is, however, only required if the location is designed to hold more than 100 000 tonnes.

Transnet currently holds a provisional AEL and it is unknown when a formal license will be issued by the competent authority. Several formal letters of complaint have been submitted by businesses and concerned citizens, of which one was submitted by FerroMarine Africa (Pty) Ltd in July 2015 to the West Coast District Municipality. FerroMarine claims that Transnet's recent public statement to implement dust mitigation measures demonstrates non-compliance to their AEL, as compliance dates for the implementation of those very measures has already passed. FerroMarine also argues that the dust pollution damages important equipment of operational businesses, especially the oil and gas industry. The compliance letter also warns that new businesses have turned away and rig owners docking at repair quays have indicated that they would not return due to dust pollution issues. Current emission control problems are predicted to worsen with the expansion of the iron ore export industry from 60 to 88 million tonnes per annum as proposed by Transnet (Section 3.2.2).

The establishment of a number of small operations not requiring an Atmospheric Emissions License in the Saldanha Bay Municipality resulted in significant cumulative impacts on air quality. Users of the bay and regulating authorities raised concerns, including but not limited to the uncovered transportation of materials through residential areas by rail or road.

To protect the consumer of mariculture organisms and the industry itself, the transportation, storage, handling and exporting of ore (more specifically, manganese ore) were investigated and discussed with role players in July 2016 at the Greater Saldanha Bay (GSB) Intergovernmental Task Team (IGTT). It was concluded that a guideline document be compiled in fulfilment of duty of care obligations specified in NEMA section 28.

The draft guideline document requires that all operators storing and handling ore below the 100 000 tonne threshold should inform authorities of the (i) transport mode (ii) frequency of incoming ore/coal and how much, (iii) average offloading frequency and (iv) storage capacities per month.

The operator should also inform the authorities of increases in handling capacities or relevant infrastructural changes. The guideline further specifies that transportation, loading and offloading, storage and further distribution of ores, coal, concentrates and other dusty materials must be done in such a manner so as to avoid the spread of particulate matter:

- **Transportation:** Material transported by rail or road must be suitably covered to prevent the spread of windblown dust. The use of alternative methods to effectively contain material whilst in transit may be considered, on condition that the transporter provides documentation confirming that the alternative method ensures reliable and equivalent containment of the material to prevent windblown dust. In many instances existing transport corridors i.e. railway lines run through residential developments with the effect that the environment and human health and wellbeing are impacted on. The transportation of material through these corridors must be discouraged and if unavoidable, more stringent conditions such as containerisation should be considered. A suitably designed road vehicle washing facility to effectively remove particulate matter from wheels, wheel arches, mud flaps and undercarriages must be provided on the storage and handling site. Effluent from washing facility must be drained to a sump for re-use or safe disposal;
- **Storage:** Manganese and other potentially hazardous ores, and concentrates must be stored within an enclosed building on a hard, impervious surface graded and drained to a sump from where the effluent will be re-used or safely disposed of;
- **Handling:** Loading and offloading of materials can also be a significant source of dust emissions. Materials can be reclaimed by underfeed conveyor, grab crane or front-end loader with totally enclosed conveyors used to transport dust-forming material. Transfer by pneumatic, dense phase systems may also be used. The loading and offloading of material must as far as practically possible be done inside the enclosed storage facility. In instances where this is not practically possible, material must be offloaded into containers or onto trucks for direct transportation into the enclosed storage facility. The double handling of material must be avoided. The storage of potentially hazardous material (concentrates e.g. manganese and zinc) in open air stockpiles is not allowed. Approved dust suppression methods that result in zero visible emissions must be applied and the area used for this purpose must be provided with a suitably drained, hard and impervious surface such as concrete. Material spillages must be removed immediately and contained for re-use or safe disposal. Emergency spillage incidents must be reported to the relevant authorities in terms of section 30 of the National Environmental Management Act, 1998 (Act 107 of 1998). Excess contaminated water used for dust suppression must be drained to a sump from where it is collected for re-use or safe disposal.

The guideline also requires that dust fallout monitoring be conducted at the storage and handling location, the transport corridor, as well as within residential areas that are in close proximity to the transport corridor. Dust monitoring must be conducted as prescribed in the National Dust Control Regulations No. R. 827 of 1 November 2013 (as amended).

The draft guideline was presented on 5 April 2017 and stakeholders were given until the 18th April 2017 to provide written comment. The WCDM intends promulgate the guideline as a policy document under Section 30 of the WCDM Bylaw. The WCDM will be the competent authority once the guideline has been promulgated as a policy. The adoption and successful implementation of this guideline document will hopefully reduce metal contamination of the Saldanha Bay and Langebaan Lagoon marine environment with a positive impact on the existing and future mariculture sector.

3.4 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 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; and
- 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

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 as listed below (refer to AEC 2014 for more detailed information on the dredging events):

- 1974-1976: 25 million m^3 of sediment was dredged during the establishment of the ore terminal;
- 1996-1997: 2 million m^3 of sediment was removed for the expansion of the multi-purpose terminal;
- 2005-2007: 380 000 m^3 sediment removed from Big Bay for the nourishment of Langebaan Beach
- 2007-2008: 50 000 m^3 of sediment was removed for maintenance of the Mossgas quay and multi-purpose terminal; and

- 2009-2010: 7300 m^3 of sediment was removed to allow for the establishment of a new ore-loading berth.
- 2009-2010: Maintenance dredging (unknown quantity) conducted by the South African National Defence Force (SANDF) at the Salamander Bay boatyard.
- 2015-2016: 25 000 m^3 Expansion of the General Maintenance Quay

The most recent construction-related dredging occurred between July 2015 and October 2016, where a total of 25 000 m^3 of sediment was dredged for the expansion of the General Maintenance Quay.

3.5 Shipping, ballast water discharges, and oil spills

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 ore 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.

3.5.1 Shipping and ballast water

Ships carrying ballast water have 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 out compete 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 International Maritime Organisation (IMO) considers the introduction of harmful aquatic organisms and pathogens to new environments via ships ballast water as one of the four greatest threats to the world's oceans (Awad *et al.* 2003).

To address the above environmental impacts and risks, the International Convention for the Control and Management of Ship's Ballast Water and Sediments of 2004 (BWM Convention) was ratified by 30 states representing 35% of the world merchant shipping tonnage (IMO 2015). The BWM Convention provides for standards and procedures for the management and control of ballast water and sediments carried by ships, which are aimed at preventing the spread of harmful aquatic organisms from one region to another.

Under the BWM Convention all vessels travelling in international waters must manage their ballast water and sediment in accordance with a ship-specific ballast water management plan. It is required that every ship maintains a ballast water record book and holds an international ballast water management certificate. Ballast water management standards and treatment technology are slowly being implemented, but in the interim ships are required to exchange ballast water mid-ocean. Parties to the BWM Convention are given the option to take additional measures to those described above and which are subject to criteria set out in the BWM Convention and to the guidelines that have been developed to facilitate implementation of the Convention.

South Africa ratified to this Convention but it took almost a decade until the Draft Ballast Water Management Bill was published in the *Government Gazette* in April 2013 (Notice 340 of 2013) aimed to implement the BWM Convention. The objectives of the proposed legislation include:

- Minimise or prevent harmful impacts by invasive species on the biological diversity within South African waters;
- Minimise or prevent harmful impacts by invasive species on the environment, human health property or resources of South Africa;
- Provide for cooperative governance in both the management of alien and invasive species introduced by ship's ballast water and the conservation of biological diversity; and
- Meet South Africa's obligations in terms of the Convention.

The bill sets out how ballast water is to be discharged, but specifies that these requirements are not applicable in emergency situations or when ballast water is discharged as a result of a collision. All ships are expected to have a ballast water management plan and to keep an up to date ballast water record book. Vessels constructed after 2009 are required to be designed such that accumulation of sediments is prevented and removal of sediments is facilitated. The bill also contains provisions pertaining to:

- Prototype ballast water treatment technologies
- Sediment management for ships
- Sediment reception facilities
- Duties of officers and crew
- Equivalent compliance
- Port ballast water management plans
- Surveys
- Issuance of certificate
- Report of accidents and defects
- Maintenance requirements
- Offences and penalties

The Department of Transport is the authority responsible for administration of this Act. The Bill was released for public comment in 2017 and it is not known when this bill will be finalised.

A recent update on the number of alien marine species present in South Africa lists 89 alien species as being present in this country, of which 53 are considered invasive i.e. population are expanding and are consequently displacing indigenous species. At least 28 alien and 42 invasive species occur along the West Coast of South Africa. Twenty five of these species have been confirmed from Saldanha Bay and/or Langebaan Lagoon, of which all but one are considered invasive. For example, the invasive 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), are commonly found in the study area. Additionally the presence of the barnacle *Perforatus perforatus*, the Japanese skeleton shrimp *Caprella mutica*, and the European porcelain crab *Porcellana platycheles* have been confirmed in Saldanha Bay and Langebaan Lagoon since 2014. Noteworthy invasive alien species that are present in Saldanha Bay include the Mediterranean mussel *Mytilus galloprovincialis*, the Pacific mussel *Semimytilus algosus*, and the recently detected barnacle *Balanus glandula*. 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 13 of this report.

Other potentially negative effects of ballast water discharges are contaminants that may be transported with the water. Carter (1996) reported 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 Chapter 6).

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 exceedance of these guidelines.

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

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

The total number of ships entering the Port of Saldanha has doubled in the last two decades with 474 ships visiting the port between July 2016 and June 2017 (Figure 3.18). However, the number of vessels entering the port has stabilised since 2011. 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 22.9 million tonnes of ballast water being discharged between July 2016 and June 2017 (Figure 3.19). Overall, iron ore tankers contributed 59% to the observed vessel traffic and 91% to the total water discharged between July 2016 and June 2017 (Figure 3.18 and Figure 3.19).

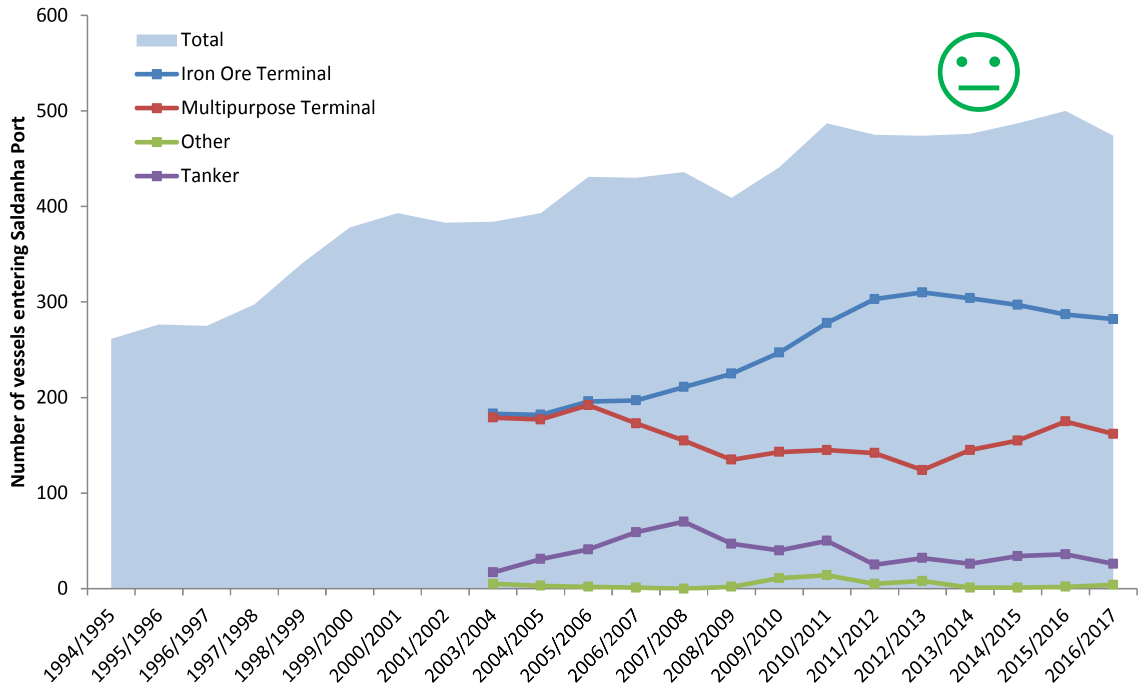

Figure 3.18. **The numbers and types of vessels entering Saldanha Port. The total number of vessels entering Saldanha Port between July 1994 and June 2017 is shown as the blue area. The numbers of vessels docking at the iron ore terminal, the *multi-purpose terminal*, tankers and other vessels are shown in blue, red, green and purple respectively. Data for the different types of vessels is only available from 2003 onward (Sources: Marangoni 1998, Awad *et al.* 2003, Transnet-NPA unpublished data 2003-2017).**

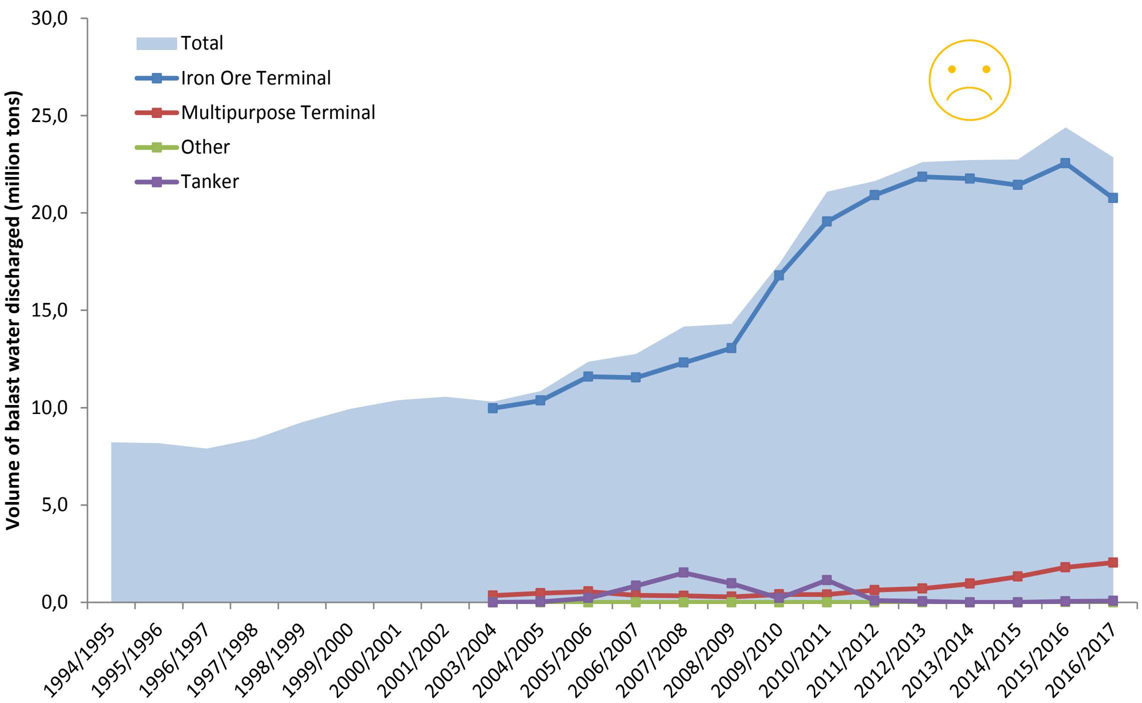

Figure 3.19 **Volumes of ballast water discharged into Saldanha Port. The total amount of ballast water discharged in Saldanha Port between the years 1994 and June 2017 is shown as the blue area. Ballast water discharged by vessels docking at the iron ore terminal, the *multi-purpose terminal*, tankers and other vessels are shown in blue, red, green and purple respectively. Data for the different types of vessels is only available from 2003 onward (Sources: Marangoni 1998, Awad *et al.* 2003, Transnet-NPA unpublished data 2003-2017).**

3.5.2 Oil spills

Also associated with this increase in shipping traffic, is an increase in the incidence and risk of oil spills. In South Africa there have been a total of 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). No comparable oil spills have occurred in Saldanha Bay to date (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 tonnes 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.

Upon 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). The implementation of Floating Power Plants (FPPs) (Section 3.2.5) will increase the risk of oil spills (frequency and magnitude) unless the Environmental Management Programme contains effective mitigation measures and implementation is ensured.

3.5.3 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 aculeatusl*) (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 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).

3.6 Effluent discharges into the Bay

Contemporary coastal water management strategies around the world focus on maintaining or achieving receiving water quality such that the water body remains or becomes fit for other designated uses. Designated uses of the marine environment includes aquaculture, recreational use, industrial use, as well as the protection of biodiversity and ecosystem functioning. This goal oriented management approach arose from the recognition that enforcing end of the pipe effluent limits in the absence of an established context, i.e. not recognising the assimilative capacity and requirements of receiving environments, would reach a point where water bodies would only be marginally fit for their recognised uses. This management approach is referred to as the receiving water quality (RWQ) framework (AEC 2015) and it appears that most countries have adopted this framework and have developed water quality guidelines for a variety of uses, which include target values for a range of contaminants that must be met in the receiving environment. Furthermore, in most countries water quality guidelines are legislated standards and are thus a legal requirement to be met by every user/outfall. Although the importance of managing water quality through the RWQ framework is undisputed, the degree to which this is implemented differs widely between countries.

There are a wide variety of legal instruments that are utilised by countries to maintain and/or achieve water quality guidelines in the receiving environment. These include setting appropriate contaminant limits, the banning or restricting of certain types of discharges in specified areas, prohibiting or restricting discharge of certain substances, as well as providing financial incentives to reduce pollution at the source alongside the implementation of cleaner treatment technology. The only effective method however, that ensures compliance of an effluent with water quality guidelines/standards is to determine site-specific effluent limits which are calculated based on the water quality guidelines/standards of a given water body, the effluent volume and concentration, as well as the site-specific assimilative capacity of the receiving environment. This method is also identified as the water quality based effluent limits (WQBEL) approach (AEC 2015) and recognises 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. The WQBEL approach differs from the Uniform Effluent Standard (UES) 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 (AEC 2015).

3.6.1 Legislative context for pollution control in South Africa

South Africa has adopted the RWQ framework for the management of water quality in both inland (freshwater) and marine water bodies and uses both, the WQBEL and the UES approaches to implement the framework. Receiving water quality guidelines were thus published in 1995 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 (natural environment, recreational use, industrial use and mariculture, Table 3.4.). The 1995 Water Quality Guidelines for Coastal Marine Waters contain narrative statements and guideline values along with relevant background information (e.g. description, source, fate in the environment, occurrence in South African marine waters etc.) for 29 properties (temperature, salinity, dissolved oxygen etc.) and constituents (nutrients, toxic substances, pathogens). These guidelines are now dated and the DEA: O&C is currently in the process of reviewing Volumes 1 (Natural Environment), 3 (Industrial Use) and 4 (Mariculture) of the 1995 Guidelines within the context of contemporary international best practice and to recommend how these Guidelines should be updated.

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 terms of the National Water Act (Act No 36 of 1998), discharging of waste or water containing waste into a "water resource through a sea outfall or other conduit" is listed as a "water use" for which a "licence" is required, unless such use was authorised through a "general authorisation" indicated by a notice published in the *Government Gazette*. The Revised General Authorisation of 2013 (No. 36820 of 2013) exempts users from having to apply for water use licences for the discharge of water containing waste into a water resource provided that the discharge was within certain specified limits and conditions.

With the promulgation of the National Environmental Management: Integrated Coastal Management Act (No. 24 of 2008) (ICMA) (as amended[3]), responsibility for regulating land-derived effluent discharges into coastal waters was transferred to the Department of Environmental Affairs (DEA). In terms of Section 69 of ICMA, no person is permitted to discharge effluent originating from

[3] ICMA was amended by the National Environmental Management: Integrated Coastal Management Amendment Act, 2014 (Act No. 36 of 2014) (ICMAA).

a source on land into coastal waters except in terms of a General Discharge Authorisation (GDA) or a Coastal Waters Discharge Permit (CWDP). Exemptions were issued to proponents who, at the time of promulgation, were discharging effluent into coastal waters 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[4]), and required that they applied for a CWDP within three years of promulgation of the ICMA. In practice though, not all operations that discharge wastewater into the Bay have applied for a CWDPs even though five years has elapsed since the promulgation of the ICMA. New operators wishing to discharge effluent to coastal waters are required to apply for a CWDP before commencing and are also required to comply with the applicable water quality guidelines. 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.

The DEA is currently in the process of developing a permitting system for such effluent discharges and for this purpose, the Assessment Framework for the Management of Effluent from Land Based Sources Discharged to the Marine Environment was recently developed (AEC 2015). This framework recognises that discharges differ in effluent characteristics (volume and quality) and discharge locality (i.e. biophysical conditions, use of the receiving environment), which ultimately determines the risk a particular discharge poses to the receiving environment. It was recommended that the potential scope of a General Discharge Authorisation, the level of assessment during the application process for a CWDP, as well as licensing conditions should be based entirely on the environmental risk posed by a particular effluent. Accordingly, the guidelines provide a framework within which an effluent can be characterised (effluent components and properties) and its potential impacts be assessed within the context of the receiving environment (i.e. sensitive versus robust receiving environments). To date, the fish processing facility owned by Sea Harvest and the Reverse Osmosis Plant of Transnet Port Terminals have been issued with Coastal Waters Discharge Permits (DEA: O&C, *pers. comm.*, 2017).

[4] The latest revision of the General Authorisation was promulgated on 6 September 2013 (Government Gazette No. 36820).

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

	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			N/A
pH	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)			N/A
Suspended solids	Should not be increased by more than 10 % of ambient concentrations			N/A
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)	N/A

	Natural Environment	**Industrial Use**	**Mariculture**	**Recreational Use**
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	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*			
Nitrate				
Reactive phosphate				
Reactive silicate				
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^+)	N/A
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}	

	Natural Environment	Industrial Use	Mariculture	Recreational Use
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 Colony-forming units (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				≤ 500 CFU (90 percentile)

	Natural Environment	Industrial Use	Mariculture	Recreational Use
requirement) (8.5% GI illness risk)				
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. RSA Department 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

Table 3.5. General Limit as specified in the revised general limit for general authorisation (6 September 2013) under the National Water Act (No. 36 of 1998)

Substance/parameter	General limit as specified in the Revision of General Authorisations in terms of Section 39 of the National Water Act (Government Gazette No. 36820, 6 September 2013)
Temperature	-
Faecal Coliforms (per 100 ml)	1000
Electrical Conductivity measured in milliSiemens per meter (mS/m)	70 above intake to a maximum of 150*
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)	6
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)	-

*Electrical conductivity is only applicable to wastewater discharges into freshwater.

3.6.2 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) and the rapidly developing industry in Saldanha Bay requires vast quantities of potable water for their operations. Construction of reverse osmosis desalination plants has been identified as a potential solution to reduce dependency of industry on municipal water supplies.

RO plants can have severe impacts on the receiving marine environment due to the highly saline and negatively buoyant brine water that is discharged by these plants, which often contains biocides that serve to limit marine growth in their intake pipe work. Potential environmental impacts associated with the operation of RO plants are listed below:

- 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.

3.6.2.1 Transnet NPA Desalination Plant

Transnet NPA recently built a RO plant in Saldanha Bay to produce freshwater for dust mitigation during the loading and offloading of iron ore. The RO plant has been operational since obtaining a water use license from the DWA and subsequent performance tests in 2012 (Membrane Technology 2013) (refer to AEC 2014 for more details on the project design and EIA). The RO plant was recently granted a CWDP in terms of ICMA (DEA: O&C, *pers. comm.*, 2017).

A marine baseline monitoring study was conducted by Anchor Environmental Consultants prior to the commissioning of the RO plant to ensure that impacts in the marine environment are such that the beneficial uses of the potentially impacted area are considered (Hutchings and Clark 2011). Monitoring of the physical and chemical characteristics of the receiving environment were also 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).

The monitoring requirements as specified by the Water Use License and the Record of Decision issued by the Department of Environmental Affairs for the RO plant (these are also reflected in the Transnet Specification No. 1243487-SP-0001) were as follows:

(a) Monthly monitoring of temperature, salinity, dissolved oxygen, turbidity, concentrations in the brine basin;
(b) Continuous (hourly) monitoring of temperature, salinity, dissolved oxygen, and turbidity at representative outfall monitoring station and a reference station for at least 1 year; and
(c) Surveys of trace metals and benthic macrofauna to be conducted bi-annually for an unspecified period.

The monitoring of the marine environment in fulfilment of the Environmental Monitoring Programme is currently conducted by the Council for Scientific and Industrial Research (CSIR) (Refer to the 2016 State of Saldanha Bay and Langebaan Lagoon Report for details on the methods and results of the first two surveys conducted in 2014 and 2015).

3.6.2.2 West Coast District Municipality Desalination Plant

The West Coast District Municipality (WCDM) has proposed the construction of an additional RO plant in the Saldanha Bay area, intended as a long-term sustainable alternative water source. The WCDM 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). A feasibility study conducted in 2007 to assess the most viable solution to the water scarcity issue in the WCDM identified the following potential additional water resources:

- 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. 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 (Please refer to the 2013/2014 State of Saldanha Bay and Langebaan Lagoon Report for SOB report more information).

Subsequent costs estimates suggest, however, that the proposed desalination plant and bulk infrastructure will cost R500 million, which is more than double the initial 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 an initial capacity of 8.5 million litres later building up to 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 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.

3.6.3 Sewage and associated wastewaters

3.6.3.1 Environmental impacts

Sewage is by far the most important 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-1950s (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 iron 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. 36820 –6 September 2013) 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).

3.6.3.2 Management of treated effluent in Saldanha Bay

There are two wastewater treatment works (WWTW) that release treated effluent into rivers, which drain into the Saldanha/Langebaan marine environment, namely the Saldanha WWTW and the Langebaan WWTW (Figure 3.21.). 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 3.21.). Problems are encountered when pump stations in Saldanha Bay overflow due to malfunction or power failures and raw sewage is released directly into Saldanha Bay. This is 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 mechanical and electrical equipment upgrades to the pump stations in Saldanha and Langebaan were undertaken in 2012 and implementation of upgrades will continue as and when required. Fifteen million Rand were made available on the 2016-2017 Capital Budget for the implementation of various interventions that prevent overflow of raw sewage and should be completed during 2017 (SBM, Gavin Williams, *pers. comm.* 2016). It is hoped that all these interventions will prevent future spills such as the one experienced in September 2016 (Refer to 2016 State of Saldanha Bay and Langebaan Lagoon Report).

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 the 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. 36820 –6 September 2013) promulgated under the NWA (Table 3.5.).

Figure 3.20 **Emergency generators that have been installed at various pump stations in Saldanha Bay and Langebaan Lagoon (Source: SBM, Gavin Williams, 2016).**

Figure 3.21. **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).**

3.6.3.3 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 placed the plant under considerable stress and resulted 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 control to which extent industries have to treat their effluent before it is directed into municipal wastewater treatment works. However, 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. 36820 –6 September 2013) promulgated under the NWA (Table 3.5.). The upgrades to double the capacity of the Saldanha Bay WWTW for treating effluent from the IDZ is funded and managed by the Saldanha Bay IDZ. Constructions started in June 2016 and are projected to finish in October 2016 (SBM, Gavin Williams, *pers. comm.* 2016). The project also includes the installation of by-pass lines which will allow for the cleaning of the existing maturation ponds on site (SBM, Gavin Williams, *pers. comm.* 2016). The Saldanha Bay WWTW treats raw sewage by means of activated sludge with mechanical aeration and drying beds. Thirty six million Rand were spent on upgrades to this plant in the last year,including (SBM, Gavin Williams, *pers. comm.* 2015):

- Minor alterations to the motor control centre building;
- Installation of new pipe work;
- Construction of new reinforced concrete reactor;
- Construction of division chambers;
- Repair and enlargement of chlorine contact channel;
- Construction of new sludge thickener;
- Refurbishment of existing sludge beds and connecting pipe work;
- Associated site works and temporary works;

- Installation of new drum-type screen and screening press;
- Refurbishment of existing degritter equipment and installation of new degritter;
- Refurbishment of surface aerators in existing reactor and installation of new aerators, mixers and pumps in new reactor;
- Upgrade of chlorination equipment; and
- Installation of rotating bridge in sludge thickener.

Recognising the impact of the effluent discharges into the Bok River, the Saldanha Bay Municipality recently commissioned CCA Environmental (Pty) Ltd to compile a Maintenance Management Plan (MMP) for proposed maintenance activities (corrective measures) within the Bok River, downstream of the Saldanha WWTW. The objective of the MMP is to permit the SBM and/or its Agent to undertake future maintenance activities in accessible areas along the river and associated banks to ensure that:

- The river channel does not become blocked with sediment, debris or nuisance vegetation growth;
- No erosion of the river channel occurs at the point of discharge from the WWTW;
- The indigenous vegetation within the river channel and riparian zone is properly established and any disturbed areas remain clear of invasive alien plants; and
- Weeds, alien invasive and/or undesirable species do not become dominant within aquatic habitat.

The proposed maintenance works would trigger Listing Notice 1, Activity 19 (Government Notice [GN] No. R983 of 4 December 2014, as amended) of the Environmental Impact Assessment (EIA) Regulations 2014 (as amended). This activity refers to the infilling, depositing, excavating, etc., of more than 10 m^3 of any material into or from a watercourse. However, where such activities are undertaken in accordance with a Maintenance Management Plan (MMP) agreed to by the relevant competent authority, environmental authorisation for this listed activity would not be required. The MMP still needs to be approved by the Western Cape Department of Environmental Affairs and Development Planning.

Figure 3.22 The pictures show the new aerator basin, digester and mechanical equipment at the Saldanha Waste Water Treatment Works (Source: SBM, Gavin Williams, 2016).

The SBM has submitted an application for a new water use licence, as daily discharge volumes of the current and upgraded plant exceed the limits prescribed by the general authorisation (Saldanha Bay Municipality, *pers. comm.* 2015). Before 2008, the average daily volume discharged never exceeded the average daily limit of 2625 m^3, but volumes of effluent released have been increasing steadily over time (Figure 3.23.). Between the years 2008-2012, the Saldanha WWTW was non-compliant only during the winter months. Since January 2013 however, the average daily limit was exceeded 72% of the time, reaching unprecedented levels of 3452 m^3 effluent in August 2014. It is important to note though that the WWTW plant capacity was upgraded to 5000 m^3 some time ago, which means that the effluent quality is not compromised despite regular exceedance of the legal limit.

Concentrations of faecal coliforms in the effluent from the WWTW exceeded the allowable limit of 1000 org/100 ml on 33 occasions since 2003 (20% of the time) (Figure 3.24). 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 January 2013, allowable limits for faecal coliforms in the effluent were exceeded on 16 occasions, frequently reaching the maximum detectable limit (the maximum detectable limit = 2419 org/100ml, which is multiplied by a safety factor of three = 7257 org/100ml). Notwithstanding long-term trends, some improvement is evident for the period July 2016-June 2017. The legal limit was only exceeded twice and compliant measurements were generally very low (<1 org/100ml = minimum detection limit) (Figure 3.24). It remains to be seen whether the upgrades to the WWTW will indeed result in long-term water quality improvements.

Allowable limits for total suspended solids (TSS) of 25 mg/l have been exceeded 17% of the time since April 2003 (Figure 3.34). While compliance clearly improved between 2008 and 2014, the allowable limit has been exceeded 52% of the time since December 2014. Overall, some improvement is evident for the period July 2016-June 2017, except for readings in November and December 2016, where TSS levels reached 85 and 53 mg/L respectively. Major improvements are required to prevent exceedance of the legal limit.

Chemical oxygen demand (COD) in filtered effluent exceeded the allowable limit of 75 mg/l 18% of the time since April 2003 (Figure 3.26). 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 coincided with the high faecal coliform counts in the effluent over the same period. Overall, compliance has improved substantially since the beginning of 2009 and the allowable limit was only exceeded on ten occasions at a much lower magnitude than in 2008. It is, however, important to note that COD levels were increasing steadily between 2011 and December 2016, but have dropped to lower levels in 2017.

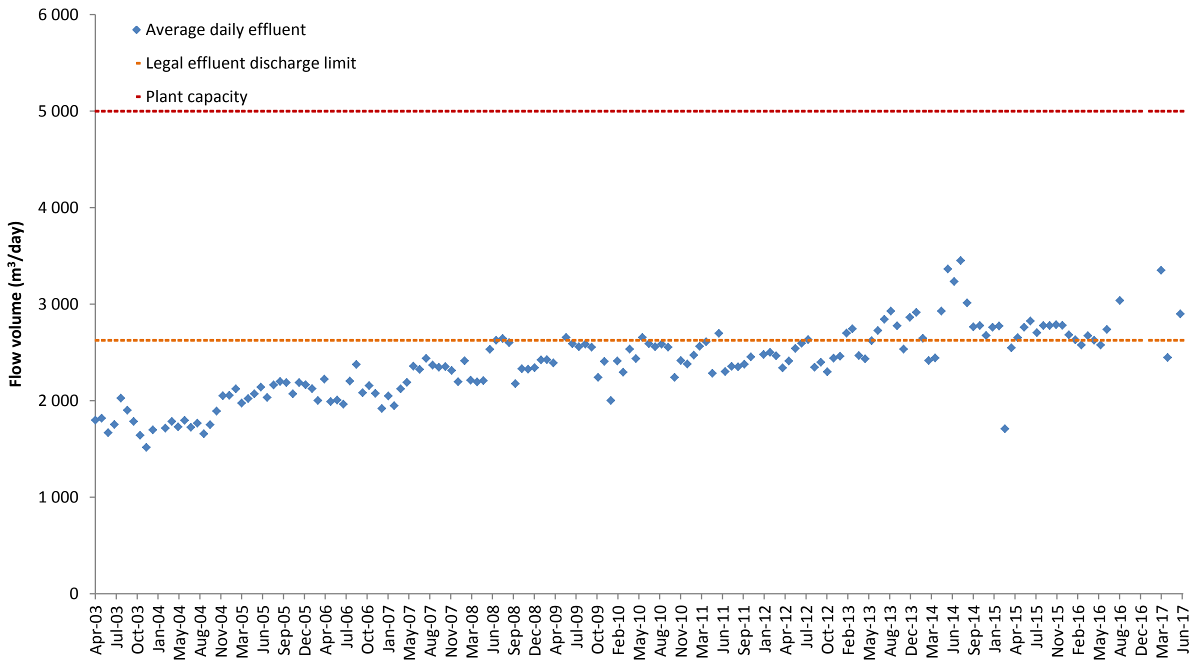

Figure 3.23. Trend in average daily effluent (m^3/month) released from the Saldanha Wastewater Treatment Works, April 2003-June 2017. Allowable discharge limits in terms of the exemption issued by DWS under the National Water Act (No. 36 of 1998) are represented by the dashed orange line and the design capacity of the plant by the red line (Source: Saldanha Bay Municipality).

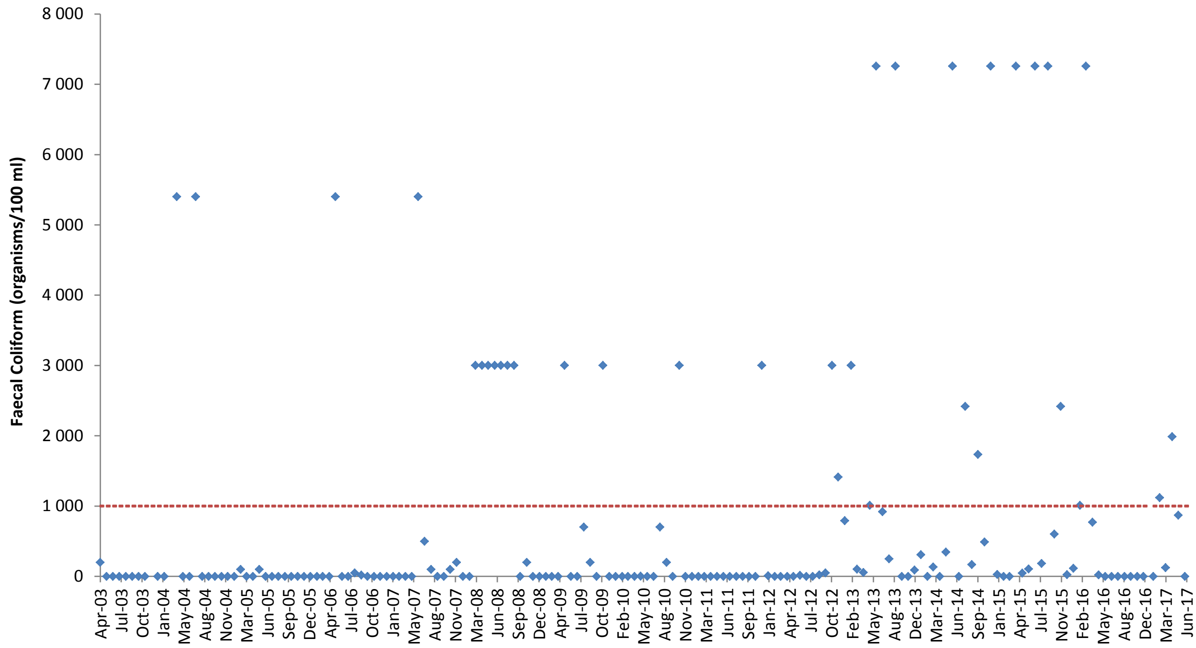

Figure 3.24 **Monthly trend in Faecal Coliforms (org/100ml) in effluent released from the Saldanha Wastewater Treatment Works, April 2003-June 20117. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line (Source: Saldanha Bay Municipality).**

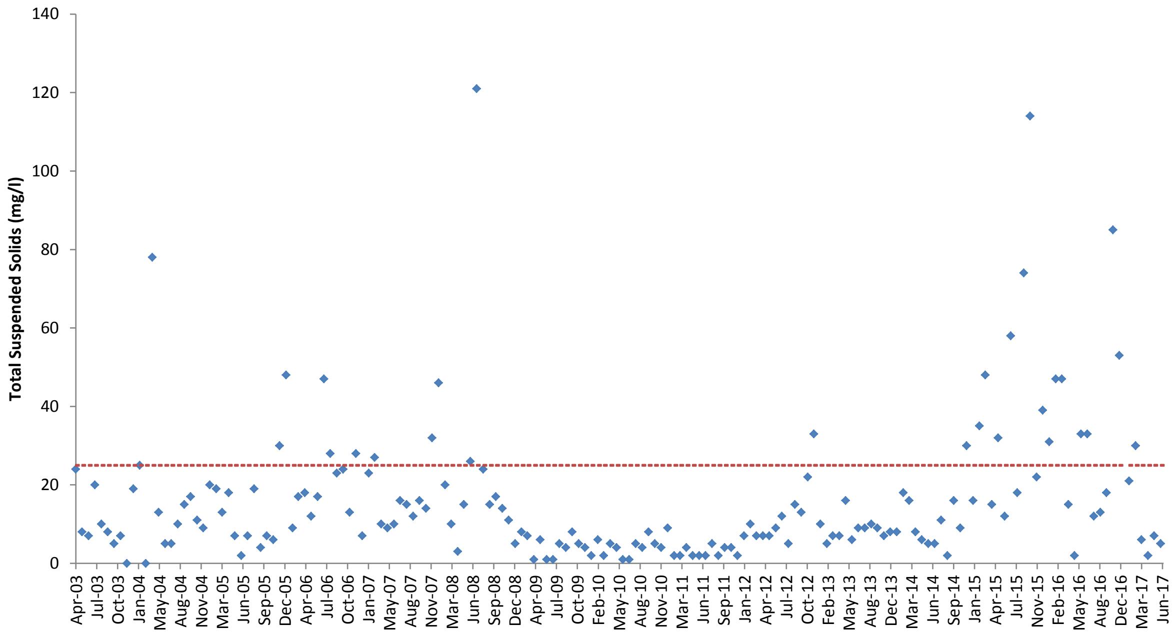

Figure 3.25 **Monthly trend in total suspended solids (mg/l) in effluent released from the Saldanha Wastewater Treatment Works, April 2003 – June 2017. Allowable limits as specified in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line (Source: Saldanha Bay Municipality).**

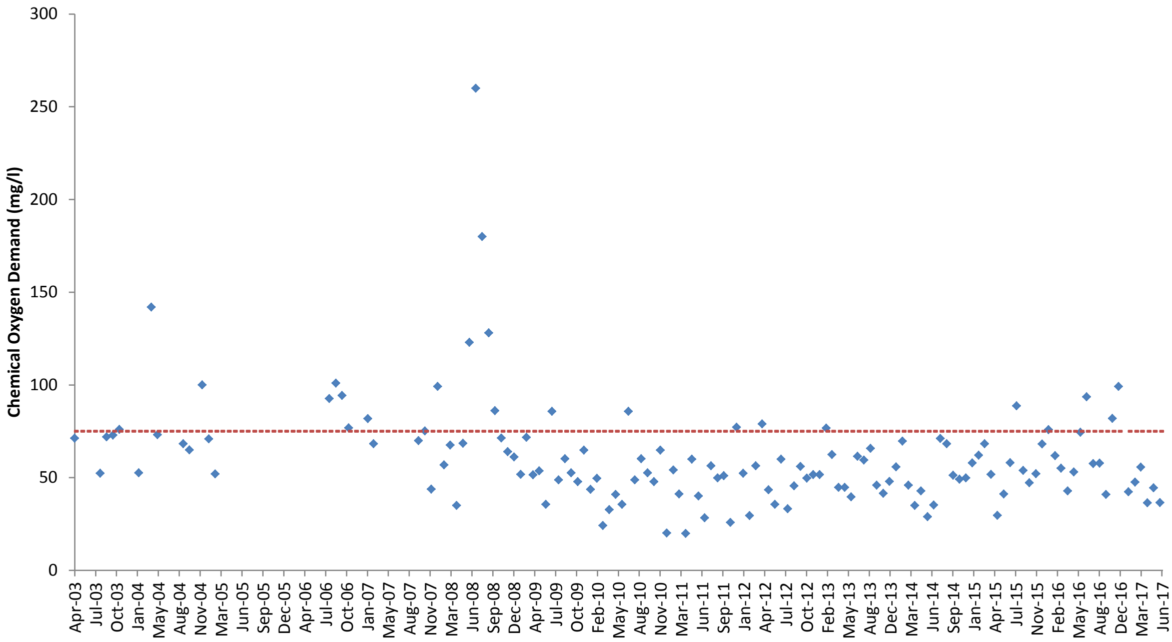

Figure 3.26 **Monthly trends in chemical oxygen demand (mg/l filtered) in effluent released from the Saldanha Wastewater Treatment Works, April 2003-June 2017. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line (Source: Saldanha Bay Municipality).**

Levels of Ammonia-Nitrogen (mg/l as N) are of great concern in the effluent discharged by the Saldanha WWTW as readings exceed the allowable limit of 6 mg/l, 80% of the time (Figure 3.27.). Towards the end of 2016 Ammonia-Nitrogen levels were extremely high, reaching 63 and 58 mg/l in November and December respectively, which represent the highest concentrations recorded to date. The performance of the newly constructed plant was poor during these months with both aeration basins not operating reliably. However, these problems were attended to and ammonia-nitrogen levels were significantly reduced from January 2017 onward (100% compliance).

The Nitrate-Nitrogen limit of 15 mg/l was exceeded 17% of time since 2003. Nitrate-Nitrogen levels have been fluctuating over time, reaching levels exceeding the legal limit in 2005, 2009/2010, 2013, and 2016/2017 (Figure 3.28). It is possible that generally higher Nitrate-Nitrogen levels in 2017 can be attributed to more effective treatment of effluent in the new aeration basins, where more Ammonia-Nitrogen is converted into Nitrate-Nitrogen by means of bacterial treatment processes.

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. Orthophosphate levels have dropped since February 2013 and the allowable limit of 10 mg/l was only exceeded on two occasions, most recently in November 2016 when the new, upgraded plant was being commissioned and effluent quality was generally poor (Figure 3.29). However, concentrations have remained well below the legal limit since then.

Permissible chlorine levels of 0.25 mg/l have been exceeded 61% of the time (Figure 3.30) since 2003. 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. maximum detection limit of 2419 multiplied by a factor of three). In January 2008, chlorine levels were measured at 12 mg/l, although this data point was removed from the graph such that the pattern could be demonstrated more clearly. Chlorine levels are very high and very frequently exceed the legal limit. It does not appear that the upgrades to the plant have measurably improved chlorine levels in the final effluent.

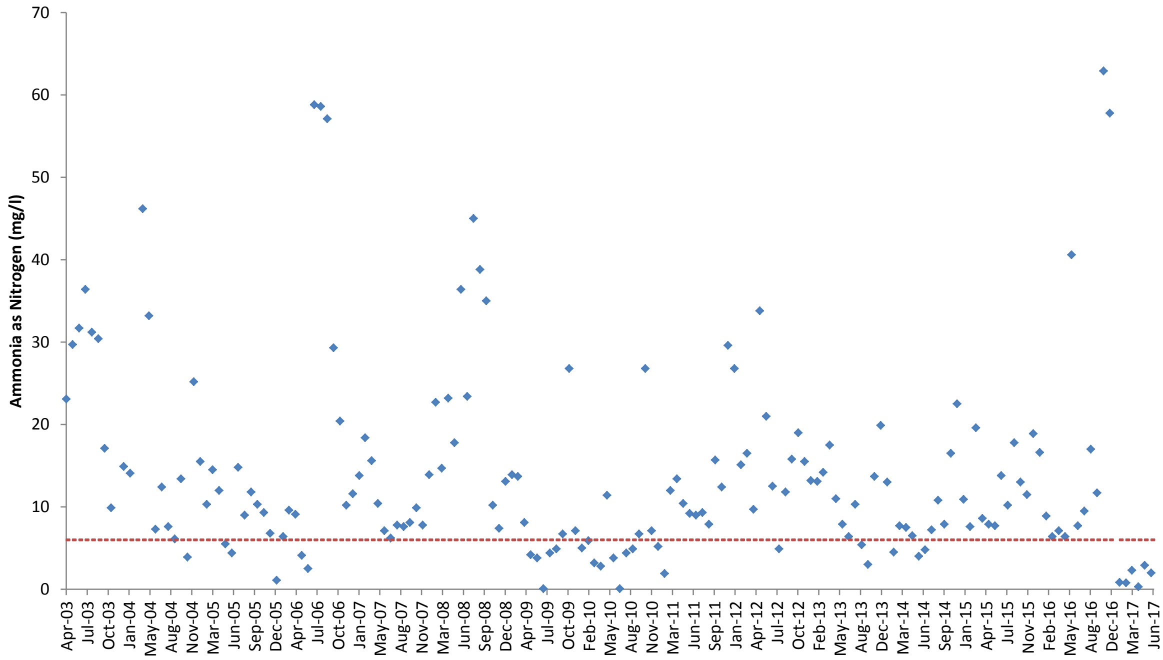

Figure 3.27. Monthly trends in Ammonia Nitrogen (mg/l as N) in effluent released from the Saldanha Wastewater Treatment Works April 2003-June 2017. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line (Source: Saldanha Bay Municipality).

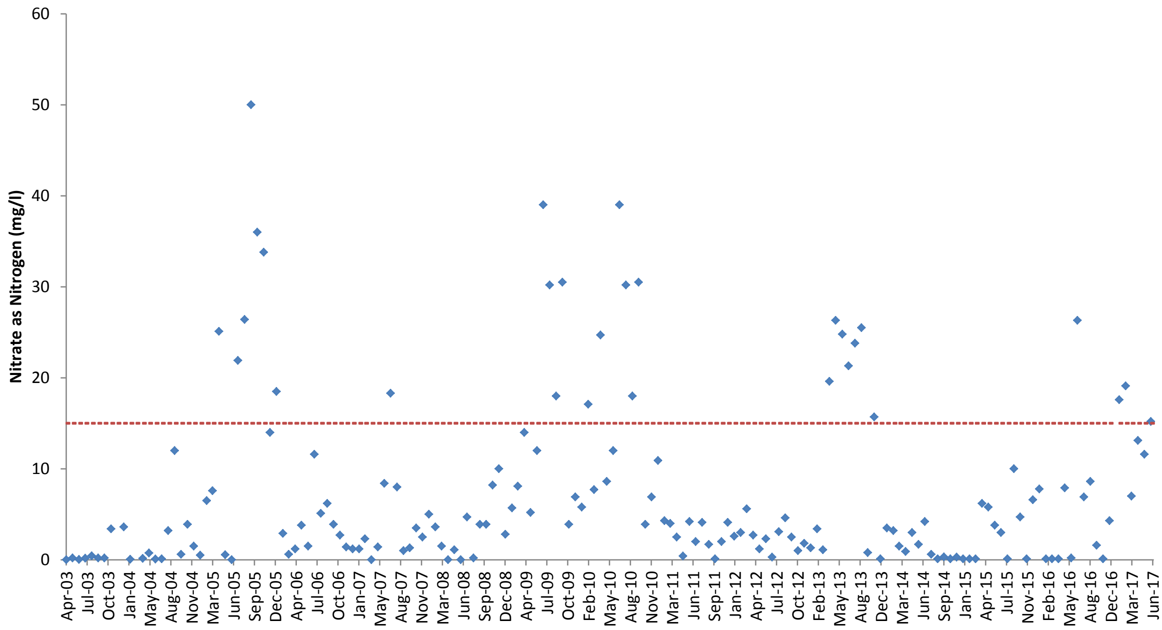

Figure 3.28 **Monthly trends in Nitrate Nitrogen (mg/l as N) in effluent released from the Saldanha Wastewater Treatment Works April 2003-June 2017. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line (Source: Saldanha Bay Municipality).**

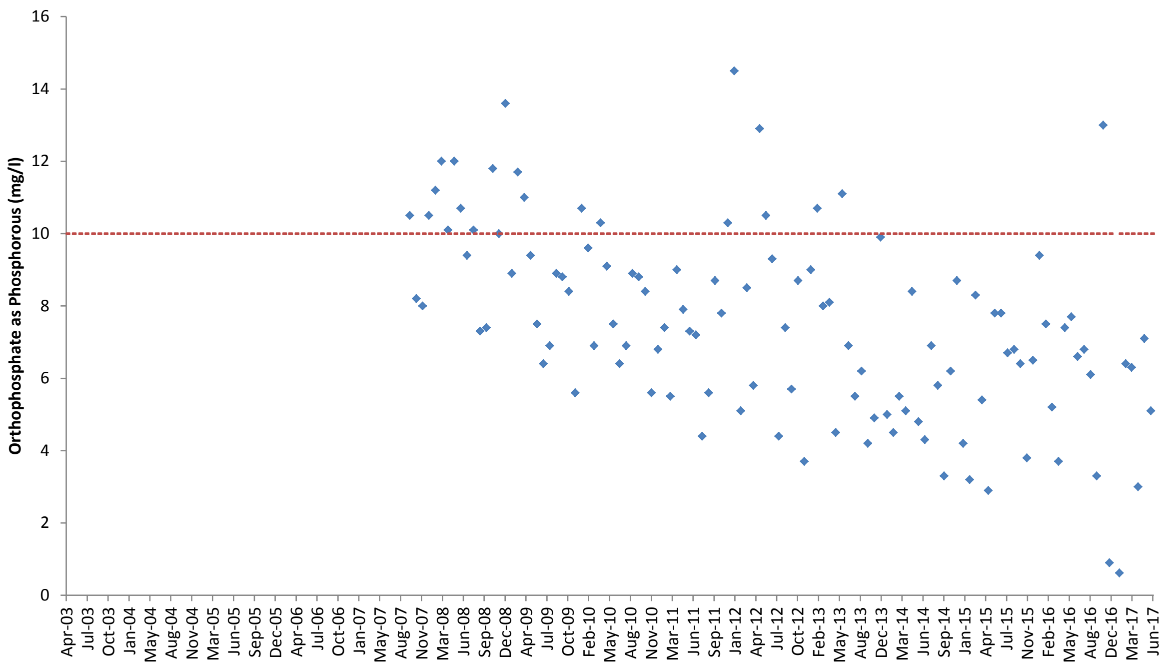

Figure 3.29 **Monthly trends in Orthophosphate (mg/l as P) in effluent released from the Saldanha Wastewater Treatment Works April 2003-June 2017. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line (Source: Saldanha Bay Municipality).**

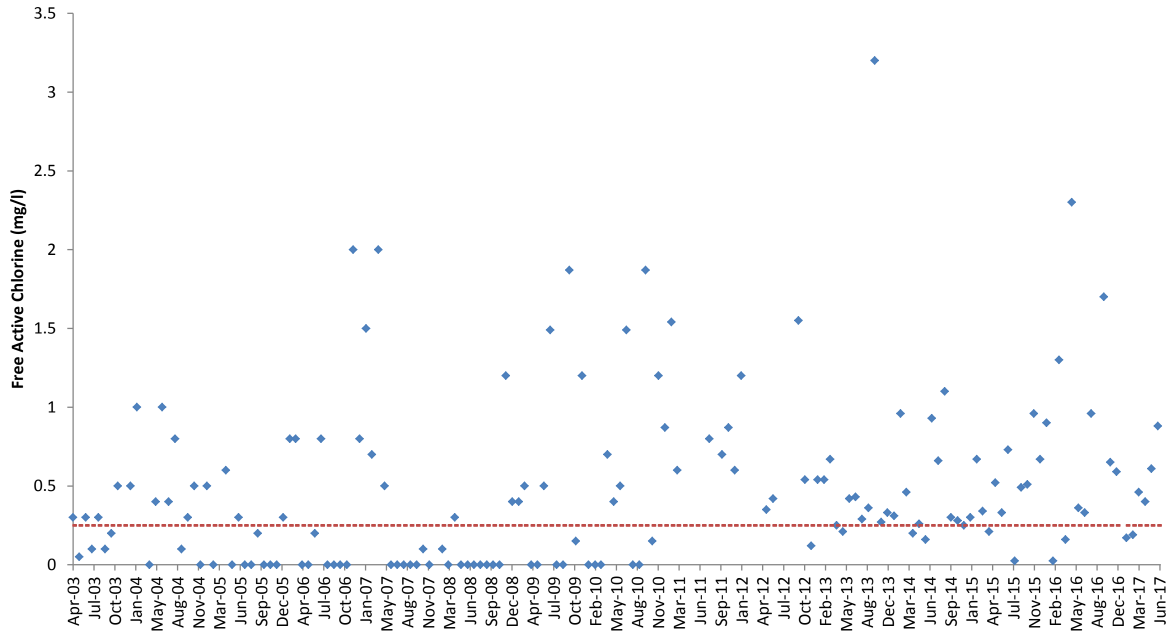

Figure 3.30 **Monthly trends in Free Active Chlorine (mg/l) in effluent released from the Saldanha Wastewater Treatment Works April 2003-June 2017. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line. An outlier of 12 mg/l measured for January 2008 was removed to show the trend more clearly (Source: Saldanha Bay Municipality).**

3.6.3.4 Langebaan Wastewater Treatment Works

Until recently the Langebaan WWTW did not discharge any effluent into the water course 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. 36820 –6 September 2013) 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 was predicted to be finalised by the end of 2014 (SBM, Gavin Williams, *pers. comm.* 2014). However, more recently, the SBM was asked to resubmit their application for a water use license, as the discharge volumes now exceed the requirements of a General Authorisation (SBM, *pers. comm.*2015). No decision has been made by the Department of Water and Sanitation to date (SBM, *pers. comm.*2017)

The Langebaan WWTW treats sewage by means of activated sludge with BNR and drying ponds. Trends of water quality parameters in the effluent released into the Langebaan Lagoon MPA between 2009 and 2015 are shown in Figure 3.31. -Figure 3.35 and Figure 3.36 - Figure 3.39. Various upgrades are required to improve the overall performance of the treatment plant (SBM, Gavin Williams, *pers. comm.* 2016). Construction of a new reactor basin, installation of new aeration equipment and new sludge drying beds will be completed by the end of this financial year. The next phase will include a new clarifier, inlet works and additional drying beds. Future upgrades will include new infrastructure to increase the capacity of the plant to 5 ML (SBM, Gavin Williams, *pers. comm.* 2016 and 2017). The SBM currently conducting a comprehensive study regarding the re-use of treated effluent from the Langebaan WWTW and other WWTW (Refer to Section 3.6.3.6 for more details on this topic).

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 has been exceeded 86% of the time since 2009 (Figure 3.31.). 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. Overall, effluent volumes peak over the December holidays when plant capacity is often reached and in some instances exceeded (e.g. December 2016, average daily effluent volumes were 2840 m^3 with a maximum daily flow of 5545 m^3) (Figure 3.31.). It follows that the magnitude of non-compliance for the 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 24 occasions since June 2009 (25% of the time) (Figure 3.33). The WWTW struggled to remain compliant between 2013 and end of 2015, frequently reaching the maximum detectable limit (the maximum detectable limit = 2419 org/100ml, which is multiplied by a safety factor of three = 7257 org/100ml). Compliance has improved dramatically since then with the legal limit only being exceeded in April 2017.

TSS values exceeded the allowable limit of 25 mg/l on 15 occasions since 2009 (15% of the time) (Figure 3.34). Overall, TSS levels were highest at the beginning of 2015, frequently exceeding the allowable limit and reaching a maximum of 198 mg/l in March 2015. Although TSS level decreased temporarily, non-compliance has become more frequent once again, exceeding the legal limit four times since July (Figure 3.34). 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 31% of the time since June 2009, reaching an all-time maximum of 130 mg/l in January 2015 (Figure 3.35). Compliance has generally improved since 2015, although recent data (July 2016 to June 2017) demonstrates that the legal limit was exceeded four times (Figure 3.35).

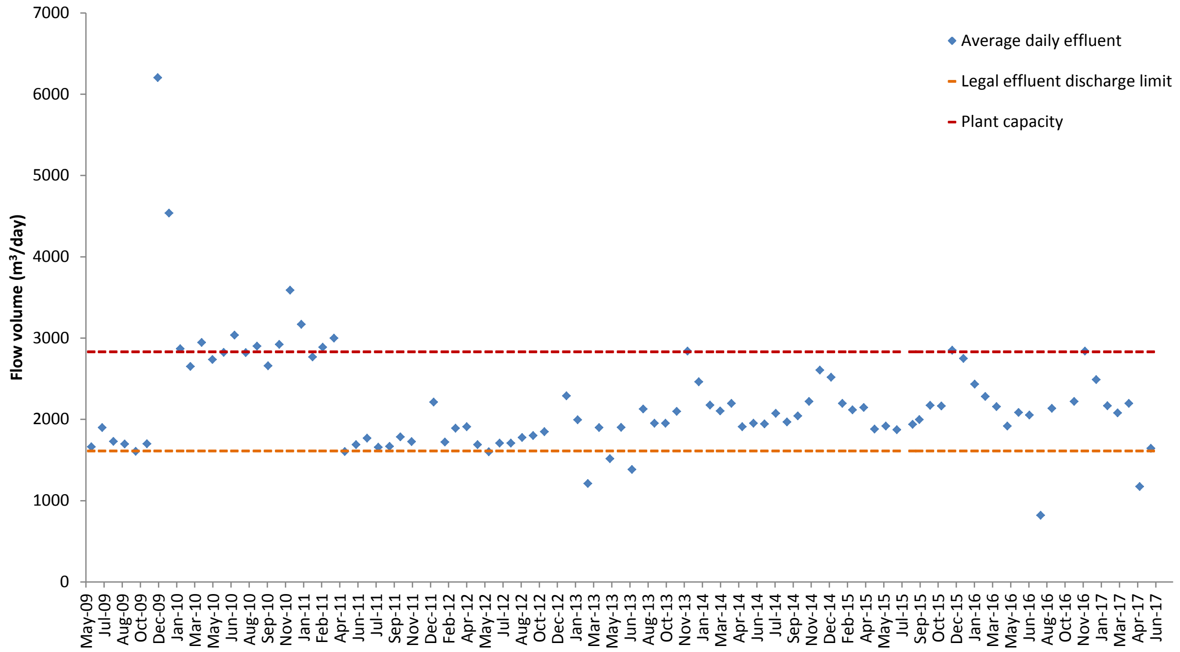

Figure 3.31. Trends in average daily effluent volume (m^3/month) released from the Langebaan Wastewater Treatment Works, June 2009 - June 2017. Allowable discharge limits in terms of the exemption issued by DWAF under the National Water Act (No. 36 of 1998) are represented by the dashed orange line and the design capacity of the plant by the red line (Source: Saldanha Bay Municipality).

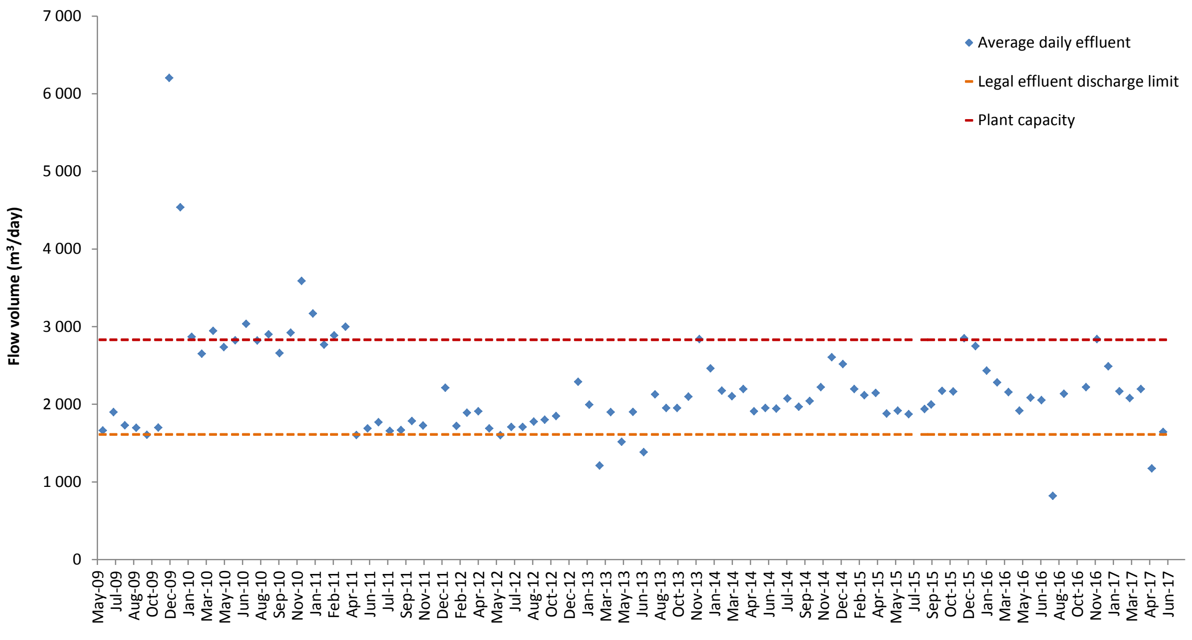

Figure 3.32. Trends in maximum daily effluent volume (m^3/month) released from the Langebaan Wastewater Treatment Works, June 2009 - June 2017. Allowable discharge limits in terms of the exemption issued by DWAF under the National Water Act (No. 36 of 1998) are represented by the dashed orange line and the design capacity of the plant by the red line (Source: Saldanha Bay Municipality).

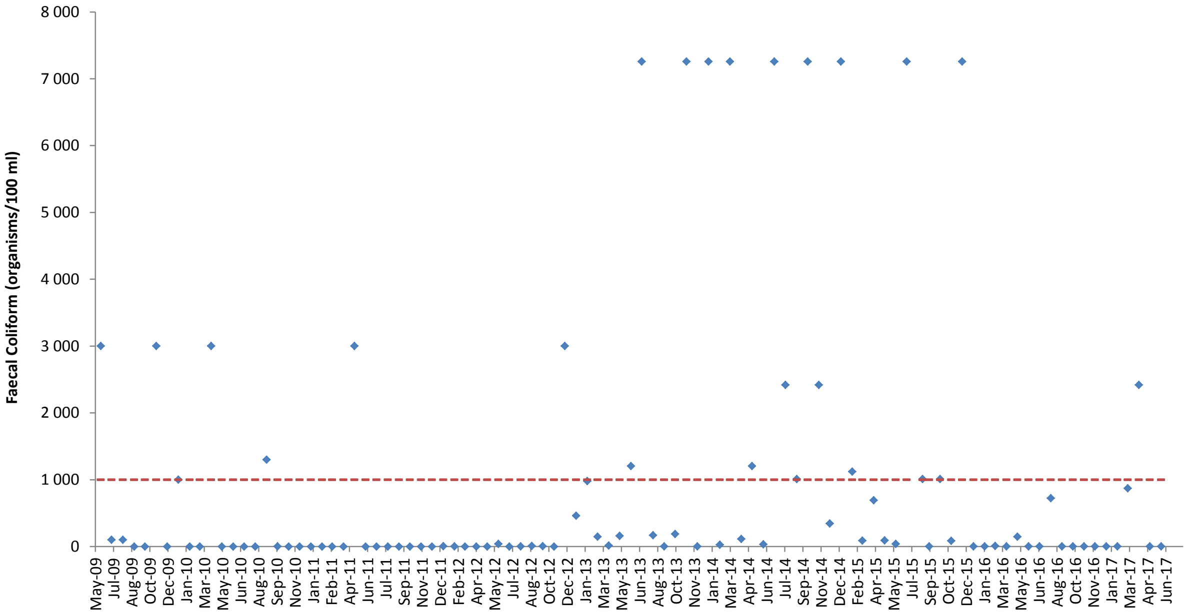

Figure 3.33 **Monthly trends in Faecal Coliforms (org/100ml) in effluent released from the Langebaan Wastewater Treatment Works, June 2009 - June 2017. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line (Source: Saldanha Bay Municipality).**

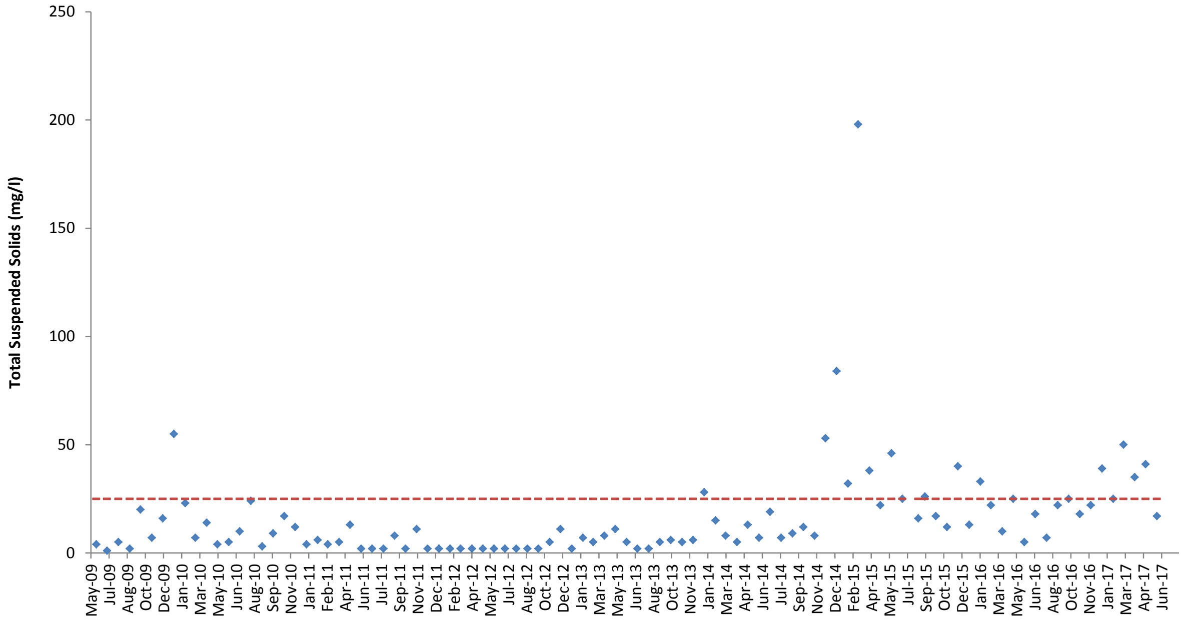

Figure 3.34 **Monthly trends in total suspended solids (mg/l) in effluent released from the Langebaan Wastewater Treatment Works, June 2009 - June 2017. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line (Source: Saldanha Bay Municipality).**

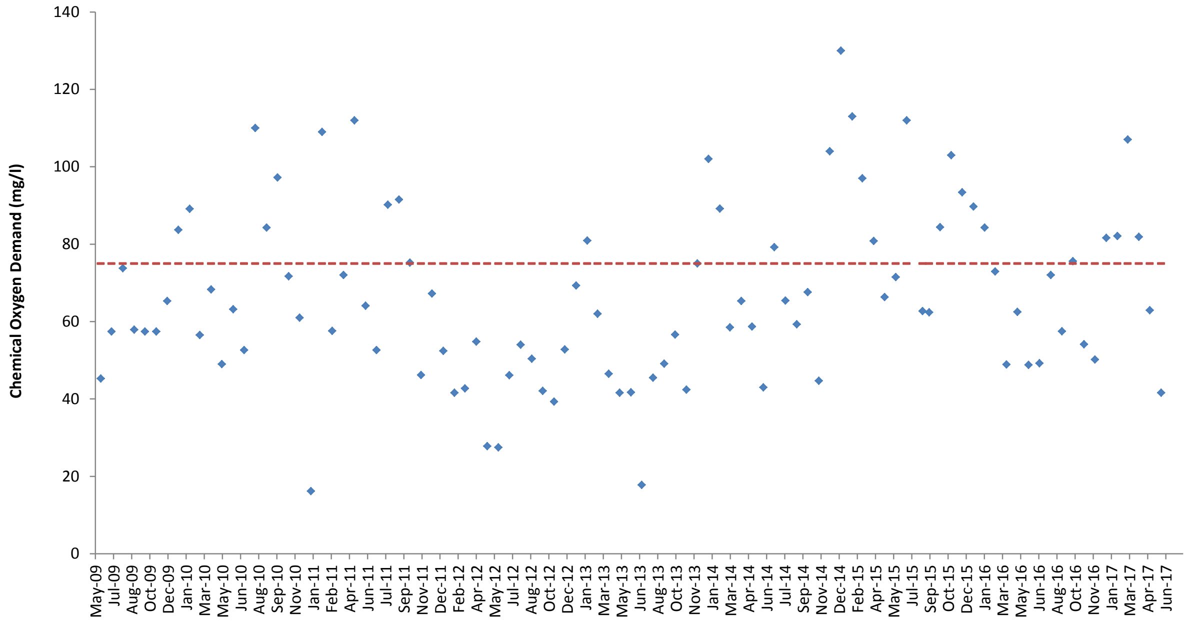

Figure 3.35 Monthly trends in chemical oxygen demand (mg/l filtered) in effluent released from the Langebaan Wastewater Treatment Works, June 2009 - June 2017. Allowable limits as specified in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line (Source: Saldanha Bay Municipality).

The Langebaan WWTW has not been compliant with the Ammonia Nitrogen limit of 6 mg/l since January 2013 (Figure 3.36.). Although this limit is very conservative considering that the water quality guidelines for the coastal environment specify a target of the same value (DAFF 1995), it is unlikely that the very high average concentrations of 54 mg/l are sufficiently diluted in the marine environment. Ammonia is a biocide and discharges of such poor quality into Langebaan Lagoon are unacceptable.

Nitrate Nitrogen levels have only exceeded allowable limits once since June 2009 (Figure 3.37). 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 in January 2014 (19.3 mg/l as N, note that this data point has been removed from Figure 1.39 for easier data analysis), 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 3.38). 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. Between July 2016 and June 2017 the legal limit was exceeded once in April 2017 with 14.5 mg/l. Effluent quality was generally very poor in that month (see ammonia, *E. coli* and COD readings).

Free active chlorine concentrations have been fluctuating over time, showing an increasing trend since September 2015. The Langebaan WWTW has not been complied with the legal limit of 0.25 mg/l since August 2016 (Figure 3.39). As observed at the Saldanha WWTW, free active chlorine levels above the allowable limit are always detected immediately after a rise in faecal coliforms.

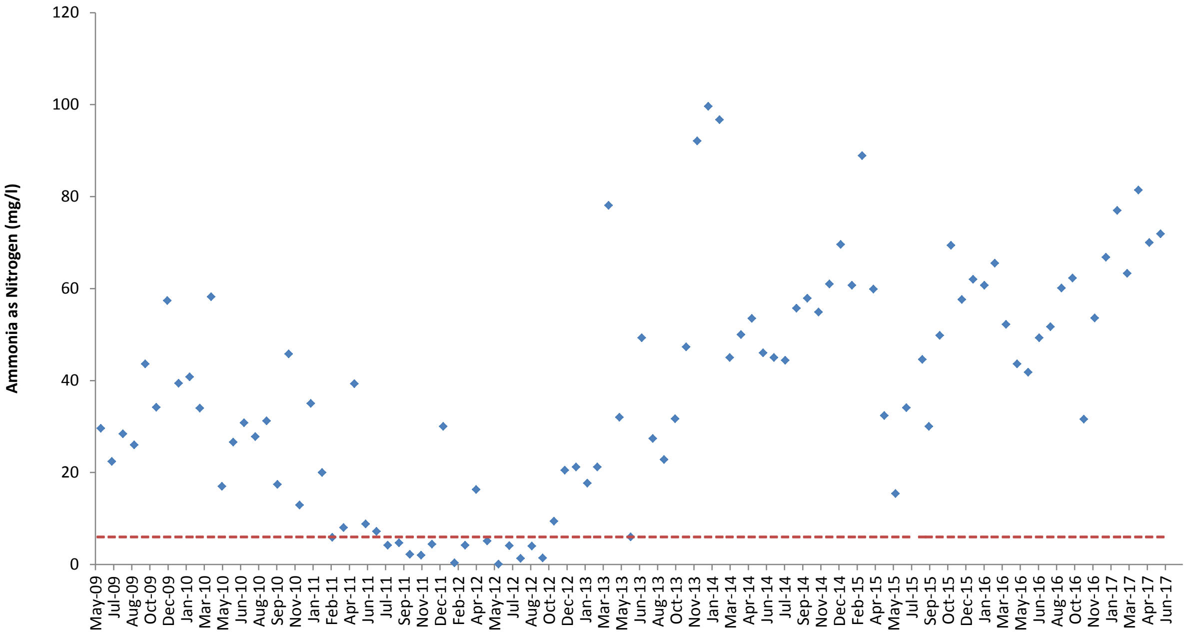

Figure 3.36. Monthly trends in Ammonia Nitrogen (mg/l as N) in effluent released from the Langebaan Wastewater Treatment Works June 2009 - June 2017. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line (Source: Saldanha Bay Municipality).

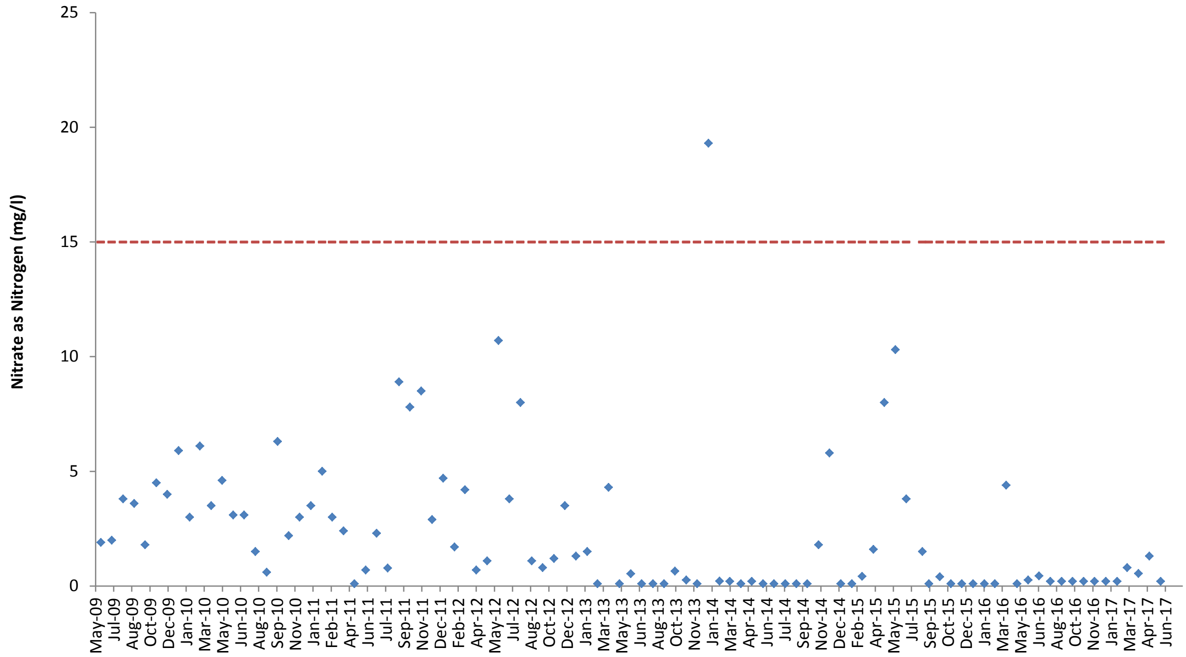

Figure 3.37 Monthly trends in Nitrate Nitrogen (mg/l as N) in effluent released from the Langebaan Wastewater Treatment Works June 2009 - June 2017. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line (Source: Saldanha Bay Municipality).

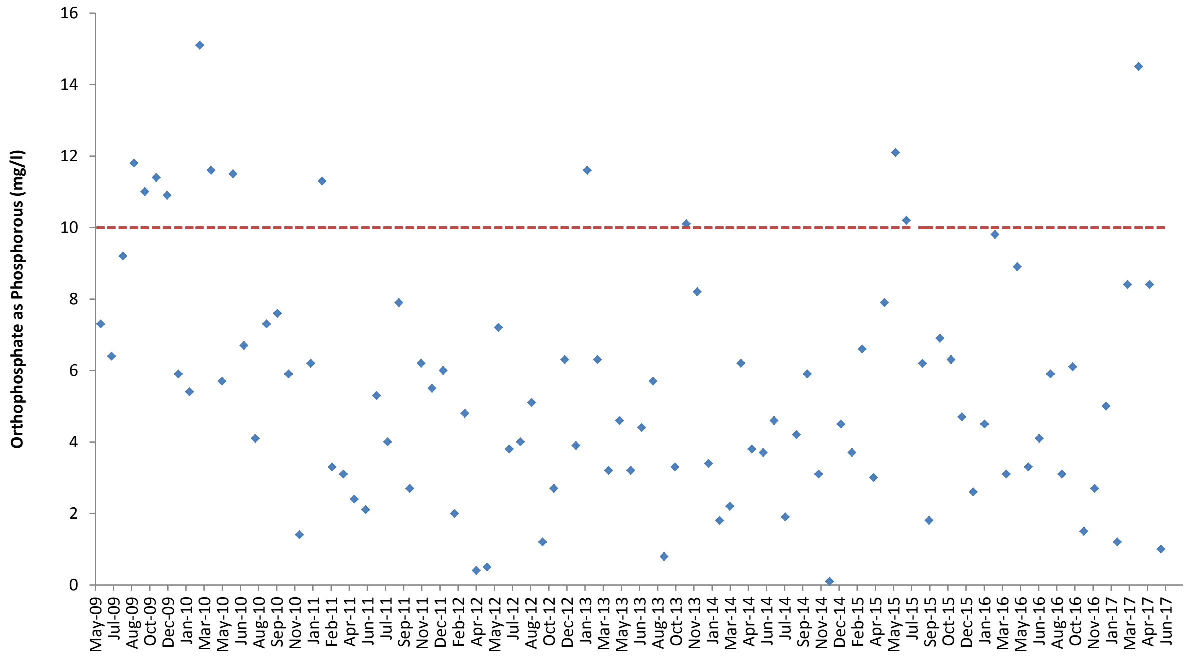

Figure 3.38 **Monthly trends in Orthophosphate (mg/l as P) in effluent released from the Langebaan Wastewater Treatment Works June 2009 - June 2017. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line (Source: Saldanha Bay Municipality).**

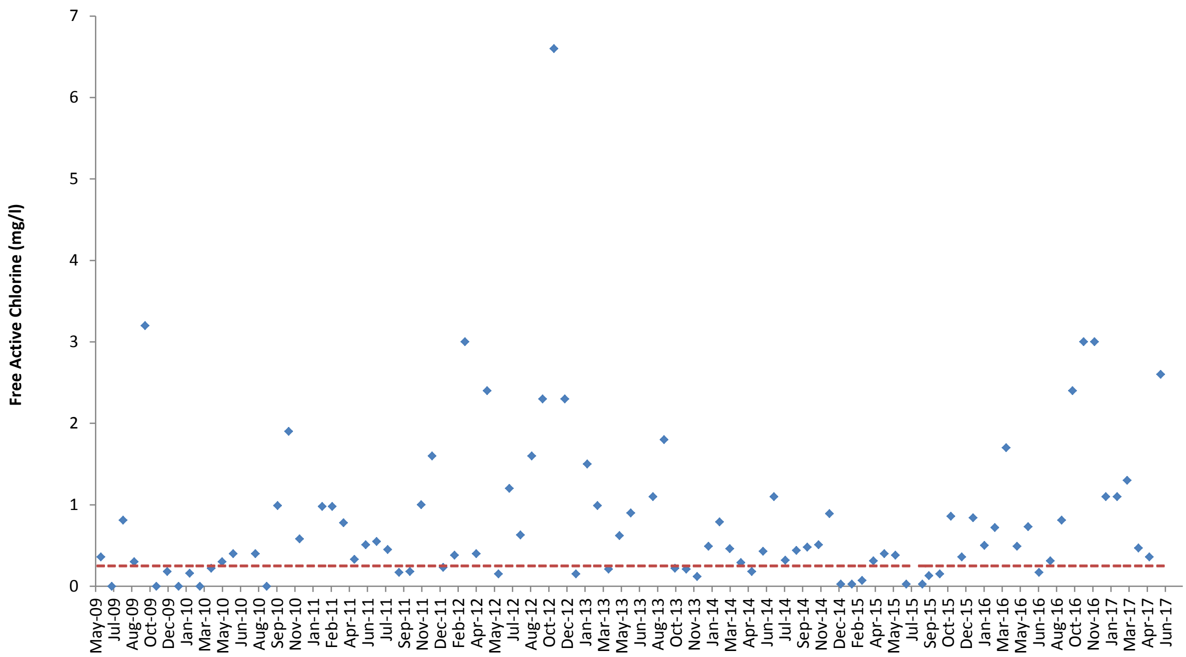

Figure 3.39 **Monthly trends in Free Active Chlorine (mg/l) in effluent released from the Langebaan Wastewater Treatment Works June 2009 - June 2017. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line (Source: Saldanha Bay Municipality).**

3.6.3.5 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. 36820, 6 September 2013) (Table 3.5.). The data shows that both the Saldanha and Langebaan WWTW are receiving greater volumes of effluent for treatment than permitted. However it should be noted that plant capacities for both WWTWs are nearly double that of the legal limits and that plant capacity is rarely exceeded. Excessive ammonia nitrogen concentrations found in the effluent from the Langebaan WWTWs are of great concern and need to be addressed as soon as possible. In the last year (July 2016-June 2017), however, upgrades to the Saldanha Bay WWTW appear to have reduced ammonia-nitrogen to concentrations consistently below the legal limit. Continued monitoring will reveal whether this improvement can be maintained going forward. Short-term impacts on effluent quality were evident during the construction phase of the upgrades to the Saldanha Bay WWTW. Similar impacts are expected at the Langebaan WWTW while construction is ongoing. Effluent quality should be monitored closely to detect short-term negative impacts during the construction phase and long-term positive impacts after implementation of the upgrades.

Table 3.6 Summary of effluent water quantity and quality discharged into Saldanha Bay and Langebaan Lagoon by the Saldanha and Langebaan Wastewater Treatment Works (Source: Saldanha Bay Municipality). Compliance is evaluated for 2016/2017 in terms of the current water use license conditions.

Parameter	Saldanha Bay WWTW		Langebaan WWTW	
	Trend	Compliance (2016/2017)	Trend	Compliance (2016/2017)
Flow volume	Increasing	No, although plant capacity is not exceeded.	Stable	No, although volumes mostly below plant capacity
E. coli	Decreasing	Mostly	Decreasing	No
Total suspended solids	Decreasing	Yes, since January 2017	Increasing	No
Chemical oxygen demand	Stable	Yes, since January 2017	Stable	No
Ammonia Nitrogen	Decreasing	Yes, since January 2017	Stable	No
Nitrate as Nitrogen	Increasing	Mostly	Stable	Yes
Orthophosphate	Decreasing	Yes	Stable	Mostly
Free active chlorine	Stable	No	Increasing	No

3.6.3.6 Re-thinking wastewater: treated sewage as a freshwater resource

As the global climate pattern termed El Niño Southern Oscillation[5] weakens, most of the country has been able to recover from the worst drought since 1904. The Western Cape, however, continues to struggle meeting water demands in the province. Water shortages will be a reality for many years to come, as several years of above-average rainfall conditions are required to fill the dams to pre-drought levels. Additionally, long-term climate models predict that global warming will result in drier conditions in the Western Cape and it is very well possible that water shortages must be understood as the 'new normal'. Not only climate patterns must be considered in this scenario, but also the growing demand by industry, especially in the Saldanha Bay Municipality. This critical situation is bringing industry and local municipalities together to investigate the feasibility of reclaiming potable freshwater from treated sewage. Major infrastructural changes are required for the re-cycling of treated sewage and are associated with significant initial as well as ongoing fiscal investments. Local municipalities experience significant budgetary constraints, and a public-private partnership is likely to be required to ensure successful implementation.

This concept has been proven successful in Durban, where the water recycling project commissioned in May 2001 has shown exceptional results, demonstrating the economic potential of wastewater (Bhagwan, 2012). The city of Durban in the Ethekweni municipality was faced with the challenge of sewage capacity constraints and the high cost of constructing a new outflow or marine outfall pipeline. A Public Private Partnership with Veola Water Services (VWS) facilitated the construction of a secondary wastewater treatment plant and a water recycling plant, aimed at treating effluent to a level acceptable to an industrial recipient (Bhagwan, 2012). Using re-cycled wastewater for industrial processes freed up significant amounts of potable water for consumption by the domestic sector. Additionally, advanced treatment of re-cycled water also contributed towards seven percent of the potable water demand of Durban city (Bhagwan, 2012). At the same time, the reclamation project reduced the city's total treated wastewater discharge by 10% and reduced the partially treated load on the marine environment by up to 24% (Bhagwan, 2012).

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[5] El Niño is the warm phase of the El Niño Southern Oscillation (commonly called ENSO) and is associated with a band of warm ocean water that develops in the central and east-central equatorial Pacific (between approximately the International Date Line and 120°W), including off the Pacific coast of South America. El Niño Southern Oscillation refers to the cycle of warm and cold temperatures, as measured by sea surface temperature, SST, of the tropical central and eastern Pacific Ocean. El Niño is accompanied by high air pressure in the western Pacific and low air pressure in the eastern Pacific. The cool phase of ENSO is called "La Niña" with SST in the eastern Pacific below average and air pressures high in the eastern and low in western Pacific. The ENSO cycle, both El Niño and La Niña, cause global changes of both temperatures and rainfall.

Veola Water Services has proposed water reclamation projects in the Saldanha Bay Municipality using treated effluent from the Vredenburg and Saldanha WWTWs (Veola Water Services 2017). Industry in Saldanha Bay are also proposing to invest in wastewater reclamation infrastructure if the SBM is willing to make treated effluent from the wastewater treatment plant available at no cost for the next twenty years. It is projected that this would reduce municipal water demand by 23%. Such an agreement between the municipality and industry would constitute an important step towards improving water quality in Saldanha Bay.

3.6.4 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).

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 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. 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**

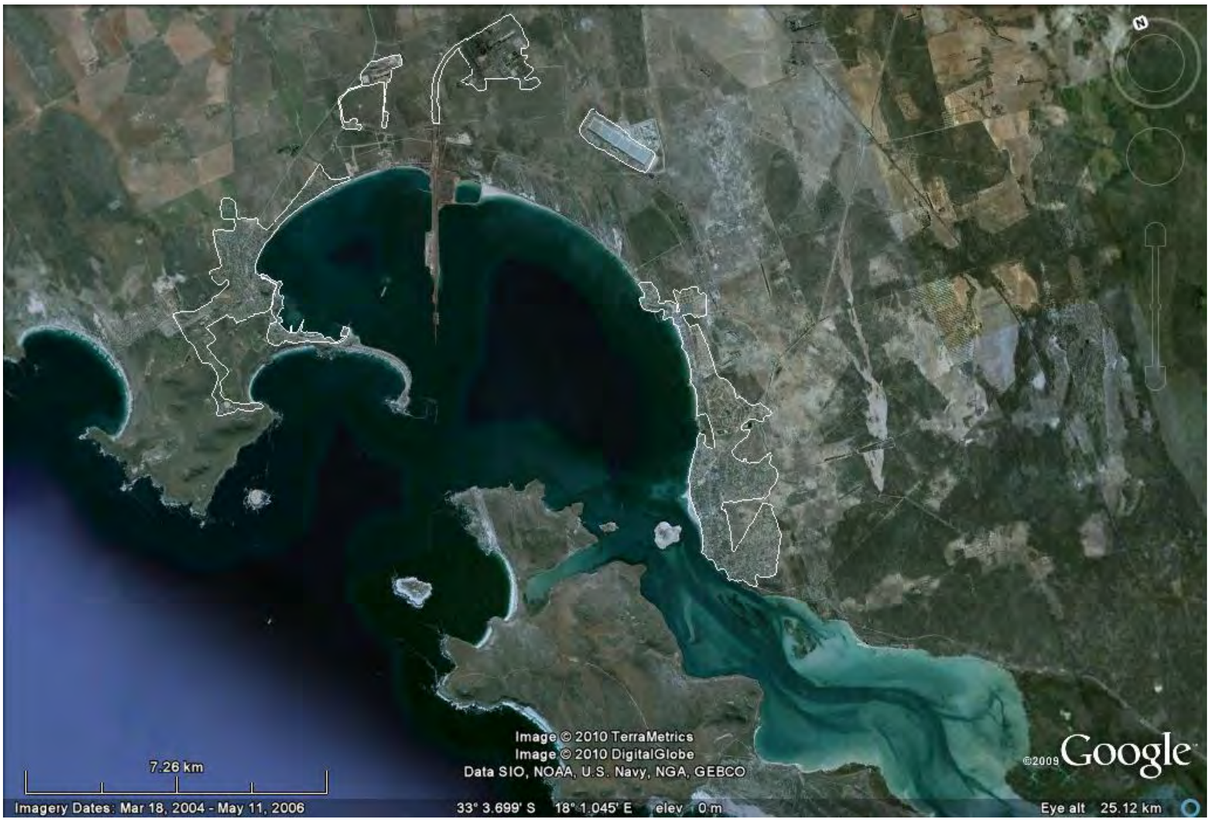


Figure 3.40. Spatial extent of residential and industrial areas surrounding Saldanha Bay and Langebaan Lagoon from which storm water runoff is likely to enter the sea (areas outlined in white). Note that runoff from the Port of Saldanha and ore terminal have been excluded as this is now reportedly all diverted to storm water evaporation ponds.

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 3.40.). All residential and industrial storm water outlets drain into the sea.

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 3.40. and Table 3.8.). 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 3.8. 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

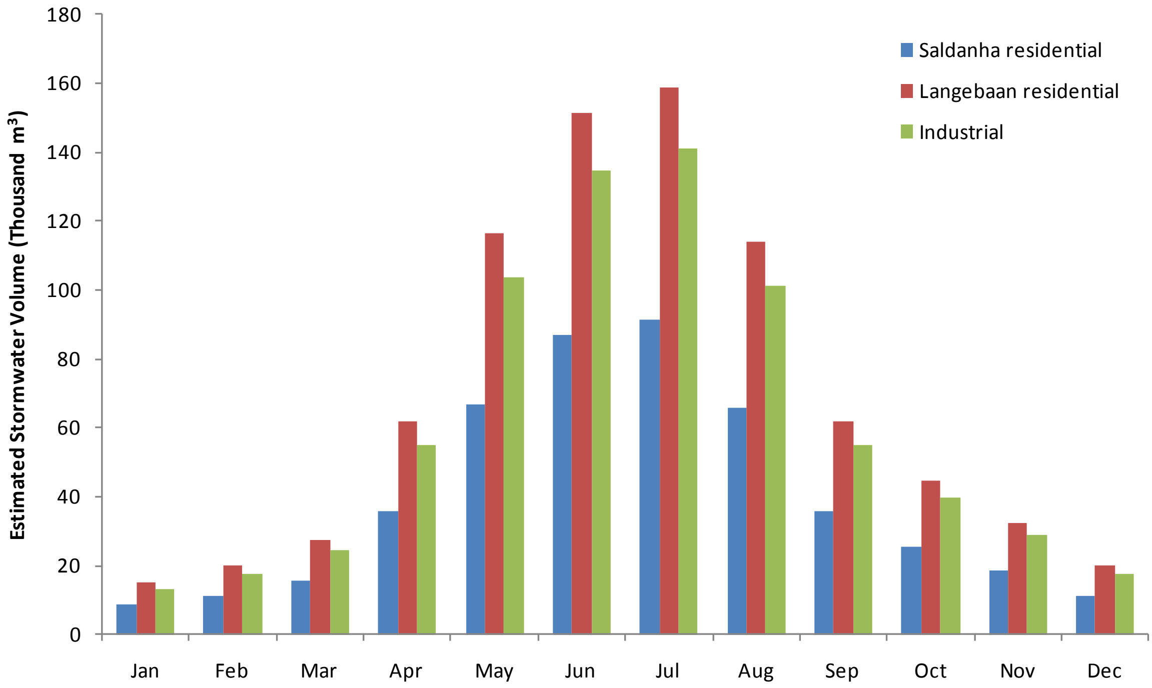


Figure 3.41. Monthly estimated storm water volume (m^3) for Saldanha and Langebaan residential areas and industrial area. Note that runoff from the Port of Saldanha and ore terminal have been excluded as this is now reportedly all diverted to storm water evaporation ponds.

3.6.4.1 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 Saldanha Bay Municipality (SBM) intends to upgrade the existing stormwater infrastructure in the operational and non-operational areas within the boundaries of the Port of Saldanha. These upgrades include:

- Development of three new storm water retention ponds;
- Expansion and reshaping of existing storm water retention ponds;
- Development of a waste water treatment facility,
- Upgrade of the storm water management infrastructure as well as maintenance of existing ones; and
- Associated activities.

These upgrades require Environmental Authorisation from the Western Cape Department of Environmental Affairs and Development Planning and the SBM has commissioned NSOVO Environmental Consulting to conduct the Basic Assessment Process (NSOVO Environmental Consulting 2017).

Despite the efforts by the iron ore industry to reduce dust emission (refer to Section 3.3.1) and to divert and store stormwater in evaporation ponds, Saldanha Bay experiences frequent and considerable pollution, especially when the terminals are washed down with hosepipes (Figure

3.42). 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 state affects organism by either smothering or through physical damage, thereby reducing the survival fitness of the affected organism. For example, high concentration of iron dust is known to inhibit photosynthesis in primary producers (Woolsey & Wilkinson 2007) and reduce fitness of intertidal organisms by changing the rate of heat absorption and reflective properties of their 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 also increase 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).

Figure 3.42 Pollution of Saldanha Bay by particulate iron carried by stormwater runoff (Source: Jaco Kotze, September 2014, Langebaan Rate Payers Association)

3.6.4.2 Stormwater management in Langebaan

Concerns and complaints have been publicly 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 of these concerns, a Stormwater Management Master Plan was drafted and is amended as new issues arise (living document) (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 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.

3.6.5 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 3.43. 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 to 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. No CWDP has been issued (Source: DEA: OC) and it is unknown whether this organisation is compliant with the revised General Discharge Limit.

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 and no CWDP has been issued (Source: DEA: OC). 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.

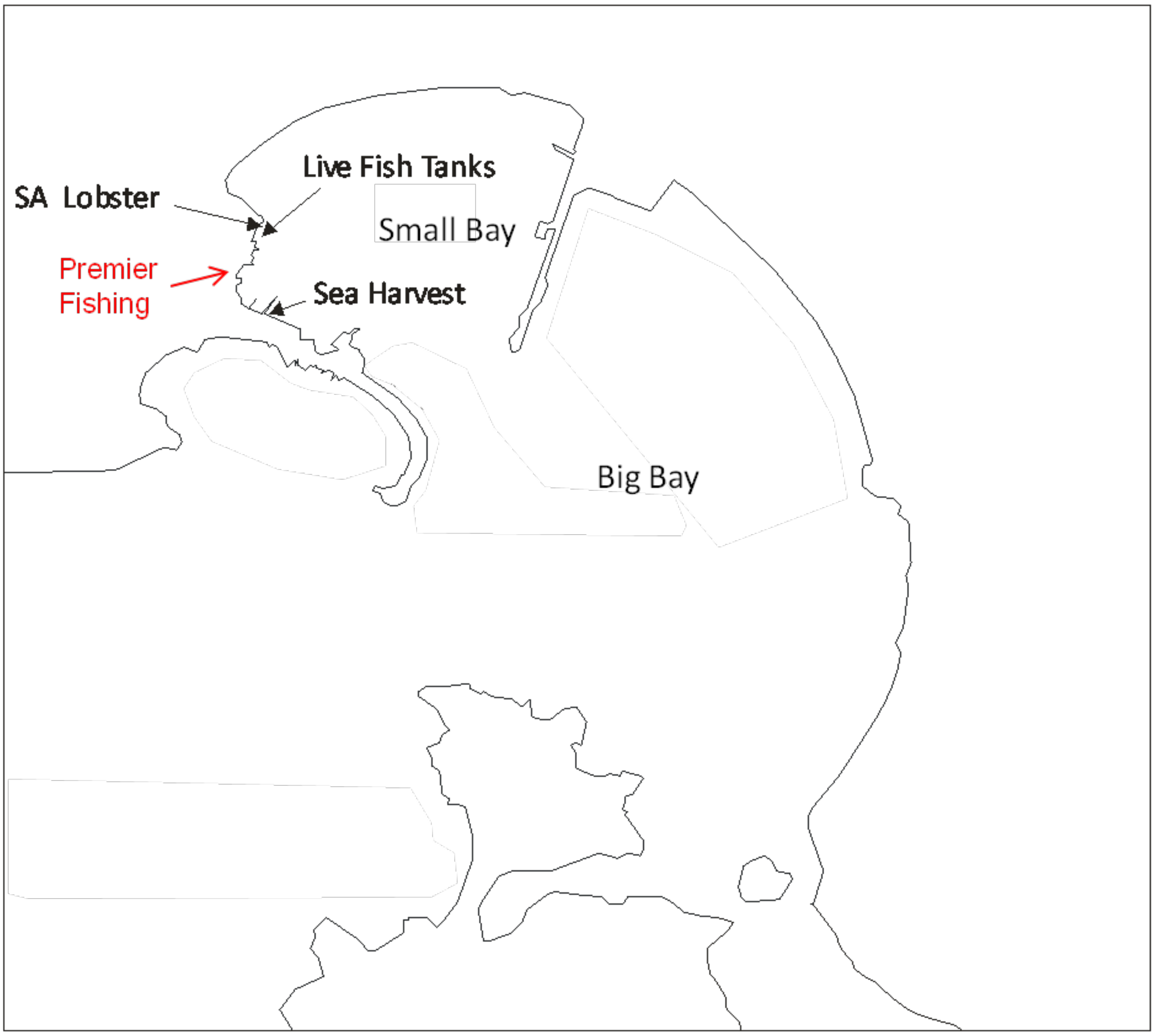


Figure 3.43. **Location of seawater intakes and discharges for current and proposed seafood processing factories in Saldanha Bay. Current factories are indicated in black while the proposed Premier Fishing Fish Processing Plant is indicated in red.**

3.6.5.1 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 processes mostly hake (*Merlucius paradoxus* and *M. capensis*) into a variety of primary fish products including fillets, cutlets, steaks and loins.

Sea Harvest discharges large volumes of brackish effluent from the fish processing (FFP) plant into the sea. This includes seawater that has been used as wash-water as well as freshwater effluent originating from the fish processing. The effluent contains suspended solids, fat, oil and grease, ammonia nitrogen, protein, and phosphate.

In 2014, the plant was upgraded to ensure continuous operation and better solids handling capabilities (Sea Harvest, Site Engineer Nico Van Houwelingen, *pers. comm.* 2014) (Refer to AEC 2014 and 2015 for a description of the facility prior to 2014). The two effluent streams are directed through a modular mesh conveyor (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 modular conveyor is then transported off-site for disposal. The water containing solids <20 mm is then pumped into the contrashear screen for further screening. The filtered water passes through a flow meter before being discharged into the sea via the discharge line going down to the seabed below the jetty.

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; and
- The contrashear screen 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 to ensure quick reaction to deviations that occur mostly due to issues inside the processing area. Currently, residual hygiene chemicals in the effluent are not removed or measured. The quaternary ammonia compound based sanitizer previously used for disinfection was replaced with Peracetic acid-based sanitizer in May 2016. Peracetic acid degradation products are non-toxic and can easily dissolve in water (by-products are water, oxygen and carbon dioxide) (Lenntech 2017). The replacement of some components of the effluent discharge system seems to have contributed towards improving effluent quality in 2016 (see below).

With the promulgation of the Integrated Coastal Management Act (Act 24 of 2008) (ICMA) in 2008, Sea Harvest Fish Processing Plant was given 36 months to submit an application for a Coastal Waters Discharge Permit (CWDP) to the DEA. However, Sea Harvest was issued a new Water Use License on January 2012, which stipulated that an application for a CWDP should be submitted to the DEA:O&C within 6 months. This application was submitted on 12 July 2012 (note that this application was submitted prior to the expiry date (November 2014) of the valid water use license). Until the CWDP was issued in 2017, effluent quality at the pipe end was compared to the General Discharge Limits of the General and Special Standard (most recent amendment constitutes Government Notice No. 36820 –6 September 2013) promulgated under the NWA. The General Discharge Limit can be considered as the minimum requirement for compliance with the ICMA.

Sea Harvest was issued a CWDP on 26 June 2017. This permit authorises the disposal of industrial effluent into the Saldanha Bay harbour through an existing marine outfall. This CWDP authorises Sea Harvest to dispose a maximum quantity of 420 480 m^3 per annum at a maximum daily discharge volume of 1152 m^3. Unfortunately, the Saldanha Bay Municipal Water Treatment Works does not have the capacity to process the effluent volume and type generated by this operation and therefore the effluent is disposed directly into the sea. End of pipe effluent quantity and quality compliance and monitoring requirements (i.e. prior to discharge) of the CWDP are summarised in Table 3.9. Additionally, the CWDP stipulates that an independent external auditor should conduct sampling of the effluent bi-annually to verify the results obtained (measured at the end of pipe). Importantly, the permit requires that dispersion modelling must be conducted within 12 months of the date of issue (by 3 April 2018) to establish effluent plume behaviour (size and shape).

Due to the potential environmental impacts of the effluent on the receiving marine environment, the CWDP stipulates the need to monitor the receiving environment as shown in Figure 3.44. The receiving environment must be monitored every two years and includes water quality, sediment quality and benthic macrofauna (Table 3.9). Levels must not exceed the limits as specified in the South African Water Quality Guidelines for Coastal Marine Waters (Volume 1): Natural Environment published by the Department of Water Affairs and Forestry in 1995 or any amended version thereof. This list of parameters should, however, be expanded to include salinity and ammonia nitrogen (marked with an asterisk in the table) to complement the effluent composition and permit requirements stipulated for the pipe end. A detailed monitoring programme must be submitted to the Department for approval within 12 months of the date of issue, which should take the above-mentioned shortcoming into consideration.

Figure 3.44 **Sediment and benthic macrofauna (red markers labelled SH1-7), and water quality monitoring sites (blue markers labelled WQ1-6) for the Sea Harvest effluent outfall.**

Table 3.9 Sea Harvest effluent quantity and quality (i.e. at the pipe end prior to discharge), as well as environmental (i.e. receiving environment) monitoring requirements stipulated by the Coastal Waters Discharge Permit issued by the Department of Environmental Affairs on 26 June 2017. Note that target values of the environmental monitoring components marked with an asterisk should be added to monitoring and reporting requirements to complement the effluent composition and permit requirements stipulated for the pipe end.

Parameter	End of pipe effluent monitoring		Receiving environment monitoring	
	Limit	Monitoring frequency	Target value as specified in the South African Water Quality Guidelines for Coastal Marine Waters (Volume 1): Natural Environment (1995)	Frequency
Effluent volume	1152 m^3	Continuous	N/A	N/A
Temperature	38 °C	Weekly	± 1°C of ambient	Every two years
pH	5.5-9.5	Weekly	7.3-8.2	Every two years
Salinity	37 PSU	Weekly	33-36 PSU*	Every two years
Oil and Grease	10 mg/L	Weekly	No target value specified	N/A
Total Suspended Solids	230 mg/L	Monthly	Not to be increased by more than 10% of ambient concentration	Every two years
Chemical Oxygen Demand	150 mg/L	Monthly	No target value specified	N/A
Dissolved oxygen	N/A	N/A	>8 mg/L. Depression below the target value should only occur as a result of natural processes	Every two years
Ammonia Nitrogen	100 mg/L	Monthly	<6 mg/L*	Every two years
Sediment quality	N/A	N/A	Sediment quality guidelines	Every two years
Benthic macrofauna	N/A	N/A	Healthy macrofauna community	Every two years

Effluent is discharged seven days a week with the exception of weekends extended by a public holiday on Monday and/or Friday. Effluent is also released on public holidays that fall on a Tuesday, Wednesday or Thursday in the early morning hours and after 8pm for sanitation purposes. No effluent volume monitoring data is available between January 2008 and 14 July 2013. Prior to 2015 effluent meter readings were not taken on public holidays and weekends. Although meter readings are now supposed to be taken daily, the flow metre has been malfunctioning more frequently and even fewer measurements have therefore been taken in recent years (Table 3.10). Sea Harvest had 1 619 operational days since 15 July 2013 and readings were only taken 34% of the time.

In the last year (July 2016-June 2017) effluent meter readings were only recorded 20% of the time due to a broken meter (Table 3.10). Consequently, on most days effluent volume discharge remains unmonitored and a solution is required to ensure compliance with the CWDP conditions. However, the recorded data is considered reliable and indicates that Sea Harvest has been compliant with permissible daily effluent limits since July 2013 (only 1% exceedance, 0% exceedance since July 2016) (Table 3.10)[6]. This is a significant improvement to the time period between 2004 and 2007 where Sea Harvest was only compliant 39% of the time.

Table 3.10 Effluent volume monitoring efforts by Sea Harvest for various periods. Note that no data is available for January 2008 – 14 July 2013 and this time period has been omitted from the calculations.

	January 2004 – December 2007	Since 15 July 2013	July 2016-June 2017
Number of operational days	1436	1619	359
Number of readings	704	548	71
Readings taken relative to number of operational days (%)	49	34	20
Number of days where effluent volume was recorded[A]	571	481	68
Legal daily effluent volume limit (m^3)	2000	3546	3546
Available effluent volume data (count)	571	481	68
Effluent volume data available relative to operational days (%)	40	30	19
Exceedance of legal effluent volume limit (count)	225	3	0
Exceedance of legal effluent volume limit relative to number of operational days (%)	**39**	**1**	**0**

[6] Effluent volume is calculated by subtracting the previous day’s reading. The first reading after a gap (public holiday or weekend) can not be used to calculate an effluent volume for the day as the volume represents several days of effluent discharge. These data gaps do not occur in a reliable pattern throughout the dataset and are therefore not conducive for automated data processing. Average values for these gaps could therefore not be calculated. Compliance with the maximum daily discharge limit of 1152 m^3 was therefore only calculated using a subset of effluent volumes calculated from reliable effluent volume readings.

Average effluent discharged per day was 3 285 m^3 in 2003/4, increased to 7 312 m^3 in 2006/7 and has dropped to 529 m^3 in 2016/17. Annual effluent discharge was estimated from the average daily effluent volume[7] and compared to the prescribed annual effluent limit of 758 847 m^3 (Figure 3.45). Estimated total annual fish processing effluent volumes discharged into Small Bay between July 2003 and June 2017 by Sea Harvest is shown in Figure 3.45. No data is available for the period April 2007 to December 2012. Overall, measurements show that 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.*). It can be concluded with reasonable confidence that the annual effluent volume has not exceeded the prescribed limit since 2013. Furthermore, the 2016/2017 data shows that Sea Harvest is likely to meet the new annual limit of 420 480 m^3 as specified in the CWDP conditions.

[7] Average daily effluent volume was calculated by dividing the measured annual volume by the number of measurements taken.

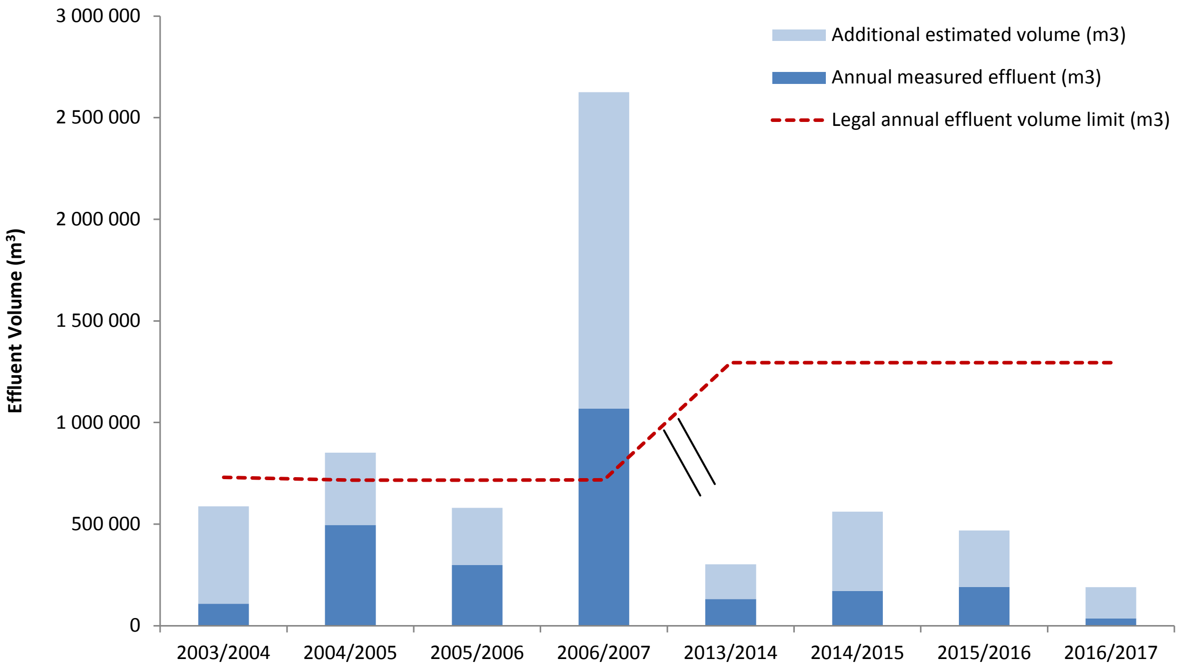


Figure 3.45 Estimated Fresh fish processing effluent volume discharged into Small Bay per year by Sea Harvest from July 2004 - June 2016. Data was not available for the period May 2007 – August 2013. The legal annual effluent limit of is indicated as the red dashed line. Additional estimated volume was calculated by multiplying the average daily discharge volume (per year) by 365 days. Note that from July 2017 onward the legal annual effluent volume limit will change to 420 000 m^3 as per Coastal Waters Discharge Permit issued in June 2017 (Source: Frank Hickley, Risk Control Manager at Sea Harvest fish Processing Plant).

Initially, the CWDP conditions were incorrect, listing mostly irrelevant water quality parameters. The final corrected CWDP was then granted in June 2017. No end of pipe effluent quality monitoring data is available for the period between April and June 2017. Although the revised CWDP conditions will only be applicable post June 2017, the CWDP limits have been included to provide context (Figure 3.46-Figure 3.50).

TSS concentrations have been extremely high and compliance with the revised General Discharge Limit of 25 mg/l was only achieved in October 2013 (14 mg/l) (Figure 3.46). Trends in TSS since 2010 suggest that concentrations fluctuate over time and it appears that peak concentrations are decreasing in magnitude (Figure 3.46). The CWDP issued on 26 June 2017 specifies a legal limit of 230 mg/L. With current effluent management strategies, Sea Harvest will be likely to meet the limit going forward.

Sea Harvest was required to comply with the revised General Discharge Limit for ammonia nitrogen of 6 mg/l until the CWDP was issued on 26 June 2017. This limit was very conservative considering that the water quality guidelines for the coastal environment specify a target of the same value (DAFF 1995). This limit was therefore exceeded 95% of the time. Notwithstanding, ammonia levels have been unacceptably high in the past, reaching a maximum of 474 mg/l in September 2012. Overall, ammonia nitrogen has been decreasing since then. Results for the period December 2015 to March 2017 look particularly promising (note that no data could be obtained for January and February 2016), which could be due to a change in sanitising protocols. The CWDP issued on 26 June

2017 specifies a legal limit of 100 mg/L, which has been exceeded only once since December 2015. It is anticipated that Sea Harvest will be compliant with the new legal limit for ammonia nitrogen.

Fish processing involves the use of freshwater and sea water and salinity (ppt) is therefore lower than what is expected in the receiving environment (Figure 3.48). It is, however, evident that salinity has increased since January 2015 (see the 2015 State of Saldanha Bay and Langebaan Lagoon for conductivity (mS/m) trends prior to January 2015), approaching levels expected in the receiving environment. This is likely due to the increasing use of seawater for fish processing. The limit specified in the CWDP is 37 ppt, which Sea Harvest will meet comfortably.

Sea Harvest has been measuring COD since November 2015. COD is extremely high (average 972 ±328 mg/l) and suggests that a large amount of oxygen is required to breakdown the organic waste in the effluent. Sea Harvest has not been able to meet the requirements of the General Authorisation (<75 mg/l) and is unlikely to meet the requirements of the new CWDP (<200 mg/L) under current effluent treatment methods (Figure 3.49). Improving COD to acceptable levels will reduce risks of anoxic conditions developing in the receiving marine environment, especially in Small Bay which is considered a sheltered environment with limited mixing capacity

Oil and grease were monitored monthly between March and December 2015 (Figure 3.50). Values exceeded the General Authorisation limit of 2.5 mg/l at all times, with a very high average of 27±25 mg/l, reaching a maximum of 91 mg/l in September 2015. The CWDP requires that Sea Harvest's effluent contains less than 10 mg/L of oil and grease and effluent monitoring will therefore be reinstated going forward. It is unlikely, however, that Sea Harvest will meet this limit unless major improvements to effluent treatment technology are implemented.

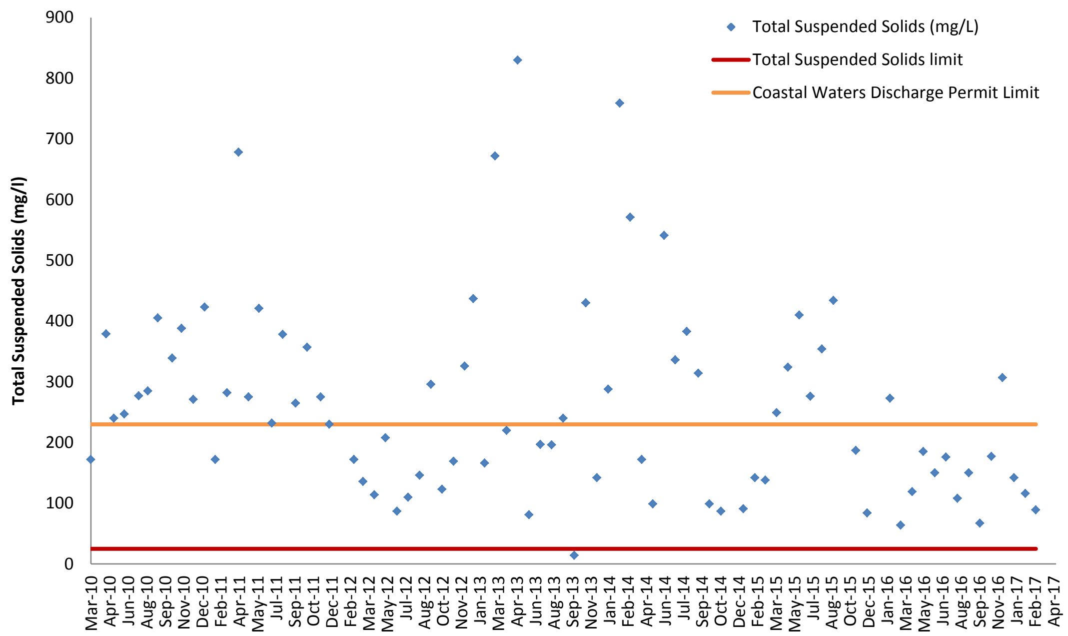


Figure 3.46 **Monthly trends in total suspended solids (TSS) (mg/l) in the effluent discharged from the Sea Harvest fresh fish processing (FFP) plant into Small Bay in the period March 2010 to April 2017 (concentration measured at the end of pipe). No data is available from April 2017 onward. The red line indicates the limit prescribed by the General Discharge Limit of the revised General and Special Standard (25 mg/l) (Government Notice No.36820 –6 September 2013). Note that Sea Harvest was granted a Coastal Waters Discharge Permit on 26 June 2017, which prescribes a limit of 230 mg/L (depicted as the orange line). (Source: Frank Hickley, Risk Control Manager at Sea Harvest fish Processing Plant).**

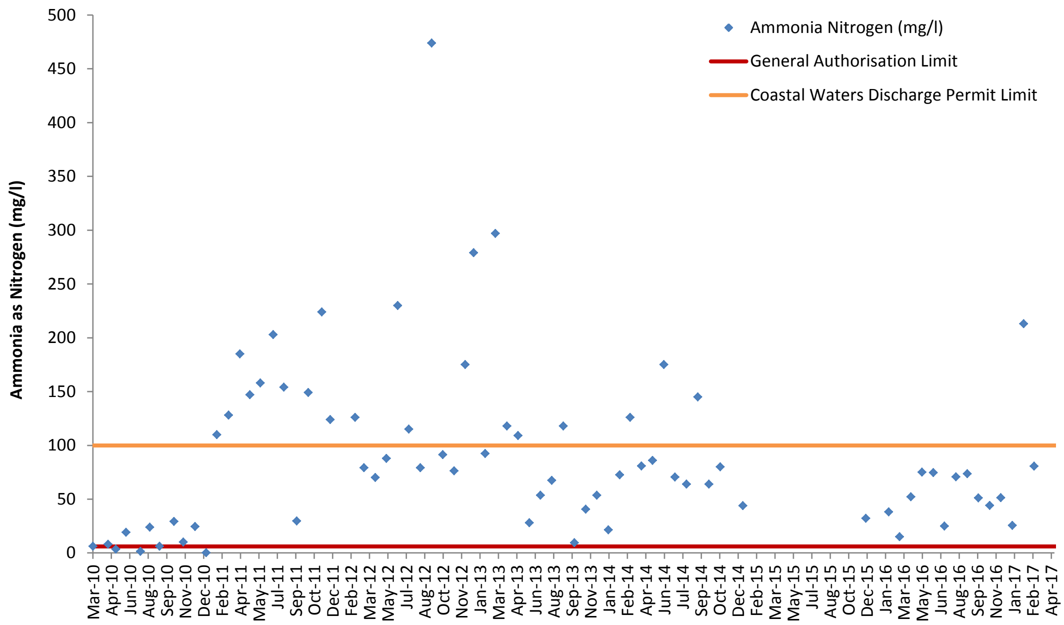


Figure 3.47 **Monthly trends in ammonia nitrogen (mg/l) in the effluent discharged from the Sea Harvest fresh fish processing (FFP) plant into Small Bay in the period March 2010 to April 2017 (concentration measured at the end of pipe). No data is available from April 2017 onward. The red line indicates the limit prescribed by the General Discharge Limit of the revised General and Special Standard (6 mg/l) (Government Notice No.36820 –6 September 2013). Note that Sea Harvest was granted a Coastal Waters Discharge Permit on 26 June 2017, which prescribes a limit of 100 mg/L (depicted as the orange line). No data is available from February – November 2015 and from April 2017 onward. (Source: Frank Hickley, Risk Control Manager at Sea Harvest fish Processing Plant).**

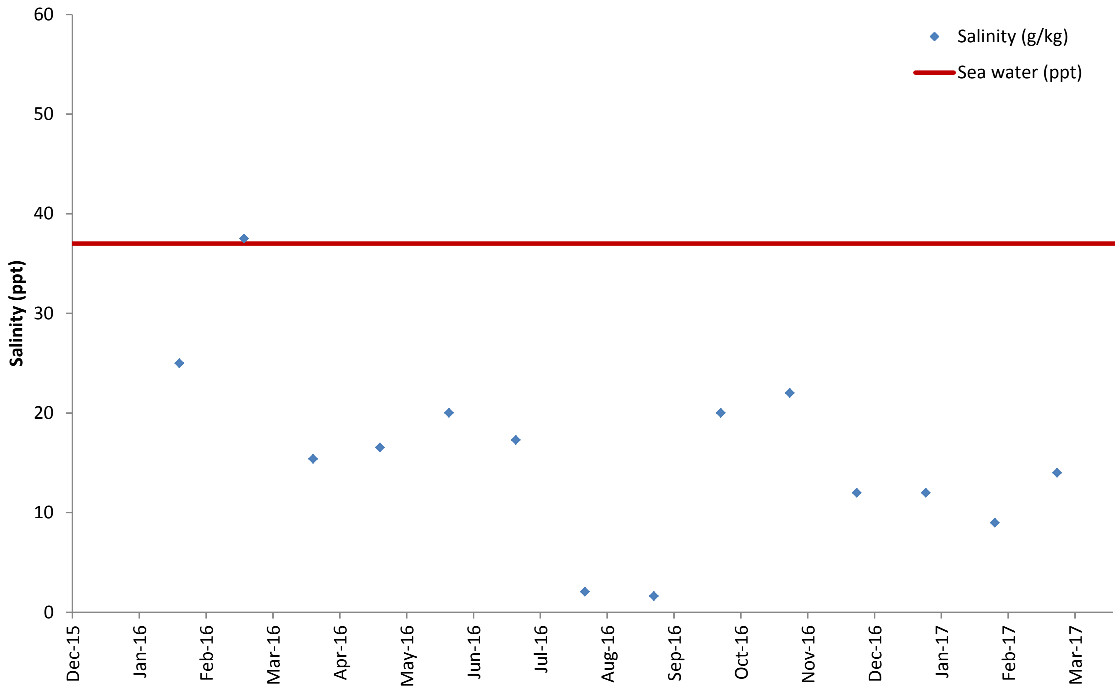


Figure 3.48 **Monthly salinity (ppt) trends in the effluent discharged from the Sea Harvest fresh fish processing (FFP) plant into Small Bay in the period January 2015 to June 2017 (concentration measured at the end of pipe). The red line indicates the salinity of typical seawater. No data is available from April 2017 onward. (Source: Frank Hickley, Risk Control Manager at Sea Harvest fish Processing Plant).**

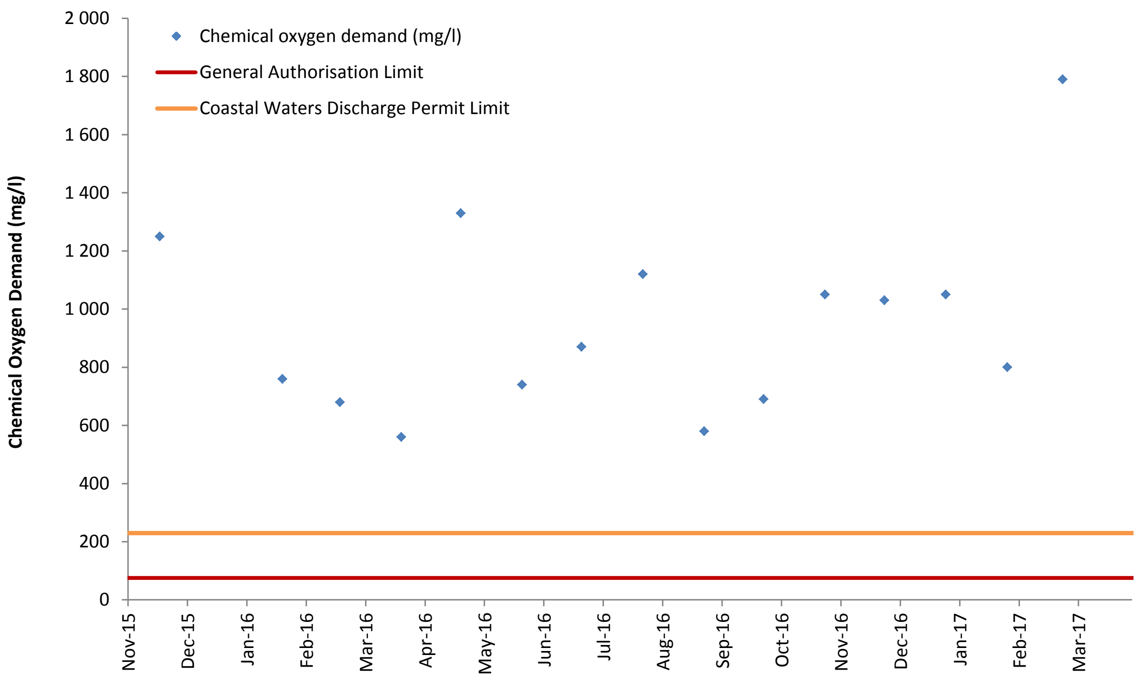


Figure 3.49 **Monthly chemical oxygen demand (COD) trends in the effluent discharged from the Sea Harvest fresh fish processing (FFP) plant into Small Bay in the period November 2015 to June 2017 (concentration measured at the end of pipe). The red line indicates the limit prescribed by the General Discharge Limit of the revised General and Special Standard (75 mg/l) (Government Notice No.36820 –6 September 2013). Note that Sea Harvest was granted a Coastal Waters Discharge Permit on 26 June 2017, which prescribes a limit of 100 mg/L (depicted as orange line). No data is available from April 2017 onward. (Source: Frank Hickley, Risk Control Manager at Sea Harvest fish Processing Plant).**

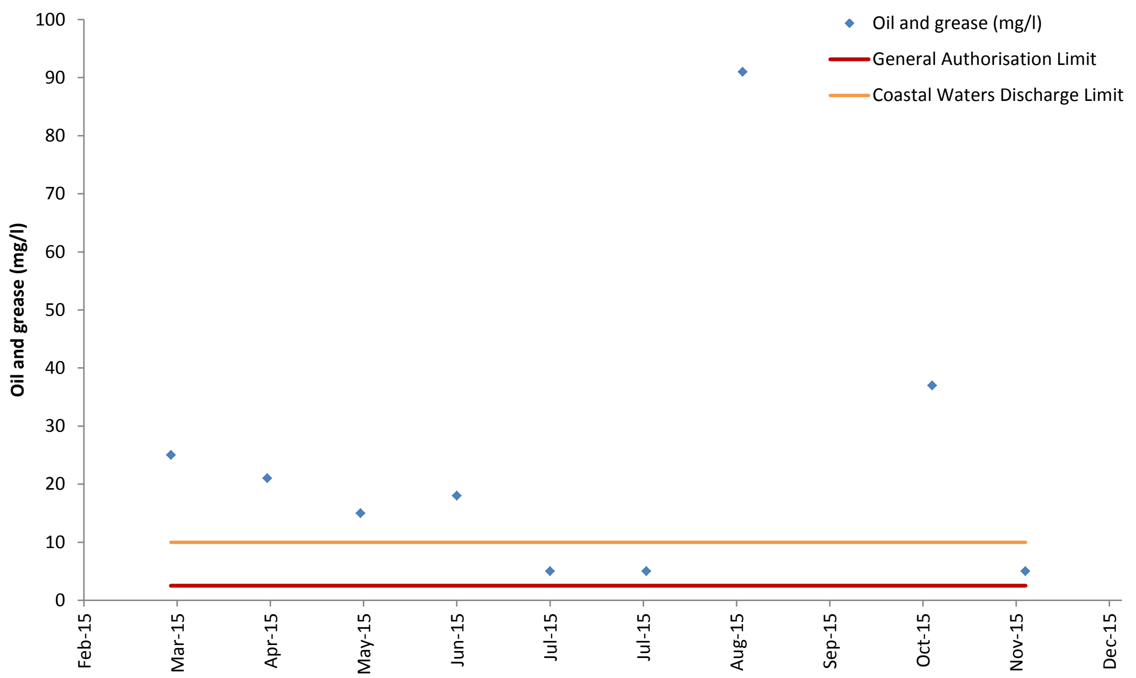


Figure 3.50 **Monthly trends of oil and grease (mg/L) in the effluent discharged from the Sea Harvest fresh fish processing (FFP) plant into Small Bay in the period March to December 2015 (concentration measured at the end of pipe). The red line indicates the limit prescribed by the General Discharge Limit of the revised General and Special Standard (2.5 mg/l) (Government Notice No.36820 –6 September 2013). Note that Sea Harvest was granted a Coastal Waters Discharge Permit on 26 June 2017, which prescribes a limit of 10 mg/L (depicted as orange line). No data is available from November 2015 onward. (Source: Frank Hickley, Risk Control Manager at Sea Harvest fish Processing Plant).**

In conclusion, Sea Harvest is committed to meeting effluent quality thresholds and environmental monitoring requirements as stipulated in the CWDP. 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. Data since 2010 shows that Sea Harvest fish Processing Plant has been non-compliant in terms of the revised General Discharge Limit for TSS, ammonia nitrogen, COD and oil and grease. Some improvements can be observed for TSS and ammonia nitrogen in the effluent however further drastic improvements are required to meet the new CWDP effluent quality requirements for chemical oxygen demand as well as oil and grease at the end of pipe. With the ongoing drought in the Western Cape, Sea Harvest is investigating the feasibility of reclaiming freshwater from pre-treated effluent by means of a reverse osmosis plant (Frank Hickley, Sea Harvest *pers. comm*., 2017). This would improve water quality dramatically with regards to most water quality parameters discussed in this report. However, brine discharge has other significant impacts on the marine environment, which would have to be assessed within the context of the receiving environment.

3.6.5.2 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. EA was granted in June 2013 and the Atmospheric Emission Licence was also approved in April 2014, but has been appealed. An application for a CWDP in terms of ICMA has been 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 is subjected to another round of public participation. No Coastal Waters Discharge Permit has since been issued and construction/operation has not commenced (Department of Environmental Affairs, Branch Oceans and Coast 2017).

3.7 Fisheries

There is a long history of fishing within the Bay and Lagoon, with commercial exploitation beginning in the 1600s (Thompson 1913). Presently, there is a traditional net fishery that targets mullet (or harders), while white stumpnose, white steenbras, silver kob, elf, steentjie, yellowtail and smooth hound shark support large shore angling, as well as recreational and commercial boat line-fisheries. These fisheries contribute significantly to the tourism appeal and regional economy of Saldanha Bay and Langebaan.

The two most important species in the fisheries in Saldanha Langebaan are white stumpnose that are caught by commercial and recreational line fishers, and harders that are commercially harvested by approximately 16 gill net permit holders. The total annual catch of white stumpnose by commercial (31% of total) and recreational line fishers (boat: 56% and shore 13%) was estimated at 125.3 tonnes for the 2006-2008 period (Parker et al. 2017). Assuming a selling price of R40/kg, the landed catch value of the commercial sector's catch of 39 tonnes is approximately R 1.6 million; the value of the recreational fisheries in the region has not yet been quantified, but undoubtedly exceeds the landed catch value of the commercial fisheries. Commercial white stumpnose catch-per-unit-effort has declined considerably in the last 15 years, whilst recruitment has also crashed (Figure 3.51). This Saldanha - Langebaan white stumpnose stock is clearly under threat and more stringent catch control measures are required.

The commercial gill net fishery in Saldanha Langebaan reports an average of approximately 20 tonnes per year with a landed catch value of around R 200 000 (DAFF, unpublished data). This stock also appears to be under pressure with a notable decline in the average size of harders landed in both Saldanha and Langebaan between 1999 and 2012 (See Chapter 11 for more information). The observed shift towards a smaller size class of harders in catches does suggest that growth overfishing is occurring and further increases in fishing pressure will probably lead to declines in overall yield (catch in terms of mass) from the fishery. There has been considerable pressure to open the restricted Zone B within the Langebaan MPA to all commercial gill net fishers resident in

Saldanha and Langebaan. Permitting increased fishing effort within Zone B would drive further declines in average harder size which has a disproportionate negative impact on the reproductive output of the stock, as large female fish spawn exponentially more eggs as the grow. This would negatively impact the productivity of the harder stock in the Saldanha-Langebaan system and may lead to further long-term declines in the overall fishery catch (See Chapter 11 for more information on the impacts of fisheries on fish populations).

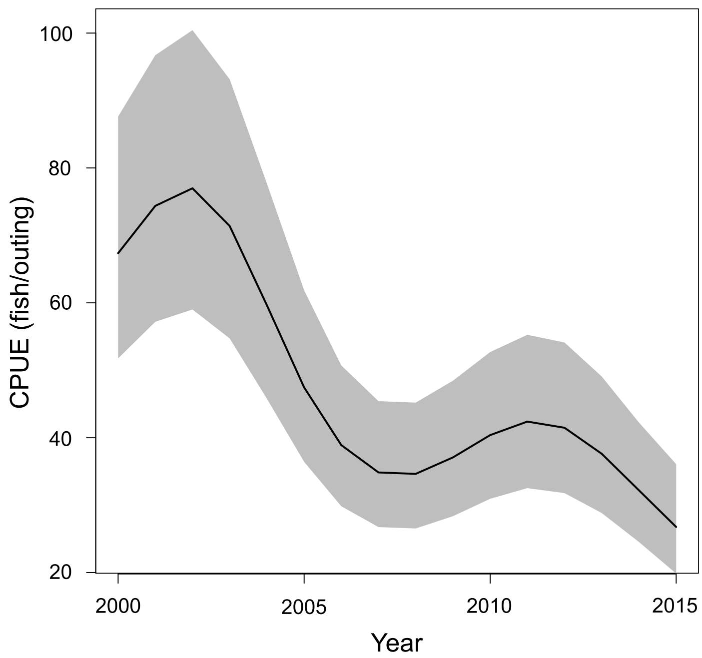


Figure 3.51 **Annual Catch Per Unit Effort (CPUE) estimates (±95% Confidence Interval) of white stumpnose derived from commercial boat catches logged in the National Marine Linefish System (NMLS) database (Source: Parker et al. 2017).**

3.8 Marine aquaculture

The Department of Agriculture, Forestry and Fisheries (DAFF) is currently driving accelerated development of the aquaculture sector in South Africa with the aim to create jobs for marginalised coastal communities, and contribute towards food security and national income. The development of the aquacultures sector is considered a sustainable strategy to contribute to job creation and the local economy, and was therefore identified as a key priority of Operation Phakisa (Section 3.2).

Saldanha Bay is a highly productive marine environment and constitutes the only natural sheltered embayment in South Africa (Stenton-Dozey *et al.* 2001). These favourable conditions have facilitated the establishment of an aquaculture industry in the Bay. A combined 430 ha of sea space are currently available for aquaculture production in Outer Bay, Big Bay and Small Bay (Figure 3.52), of which 316.5 ha have been leased to 14 individual mariculture operators (Table 3.11 and Figure 3.52.). Just over seventy percent of these concession areas are actively farmed for mussels, oysters and finfish, mostly in Small Bay (Table 3.11).

Table 3.11. Details of marine aquaculture rights issued in Saldanha Bay (BB and SB refer to Big Bay and Small Bay respectively) (Sources: Aquaculture Rights Register Department of Agriculture Forestry and Fisheries February 2017, Transnet Property Geo-Spatial data).

	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	x						52.1 ha (SB)	2002-2016
Blue Sapphire Pearls CC	x	x	x			x		10 ha (SB)	2010-2024
Imbaza Mussels (Pty) Ltd (previously trading as Masiza Mussel Farm (Pty) Ltd)	x	x		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			5 ha (SB) 10 ha (BB)	2010-2024
West Coast Oyster Growers CC	x	x						10 ha (BB) 15 ha (SB)	2010-2024
West Coast Seaweeds (Pty) Ltd	x	x						10 ha (SB)	2010-2024
African Olive Trading 232 (Pty) Ltd	x							30 ha (SB) Port of Saldanha	2013-2028
Aqua Foods SA (Pty) Ltd	x	x						Port of Saldanha 10 ha (BB) 10 ha SB	2014-2030
Southern Atlantic Sea Farms (Pty) Ltd.							x	Port of Saldanha 15 hectares (Outer Bay - North)	2014-2029
Salmar Trading (Pty) Ltd.		x						10 ha (BB) 5 ha (SB)	2016-2031
Molapong Aquaculture (Pty) Ltd.							x	1 ha (Outer Bay - south) 4.1 ha (BB)	2016-2032
Chapman’s Aquaculture (Pty) Ltd	X							North Bay	2016-2031
Requa Enterprises	X							15 ha (BB)	2016-2031

Figure 3.52. Mariculture concession areas in Saldanha Bay 2017 (430 ha). The total area leased to the aquaculture sector currently comprises 316.5 ha. Note that Transnet is not at liberty to disclose the names of their tenants to third parties. (Source: Transnet Property, Geo-Spatial: Western Region, Burton Siljeur).

3.8.1 Saldanha Bay Aquaculture Development Zone

With the support of finances and capacity allocated to the Operation Phakisa Delivery Unit, DAFF proposes to establish a sea-based Aquaculture Development Zone (ADZ) in Saldanha Bay. The aim is to (a) encourage investor and consumer confidence (b) create incentives for industry development (c) provide marine aquaculture services, (d) manage the risks associated with aquaculture; and to provide skills development and employment for coastal communities.

The proposed ADZ project triggers activities listed in terms of Listing Notice 1 of the EIA Regulations, 2014, requiring a Basic Assessment. SRK Consulting (Pty) Ltd. (SRK) was appointed as the independent consultant to develop a framework for the Saldanha Bay ADZ and undertake the Basic Assessment. The Basic Assessment Report was made available for public comment for an extended public commenting period from 8 February to 31 March 2017. The BAR was updated in response to the approximately 60 submissions and 1600 petitions received on the BAR. The Final BAR was subjected to a second round of public comment in May and June and is currently being prepared for submission to the competent authority (Western Cape Department of Environmental Affairs and Development Planning). A decision is expected to be issued towards the end of this year.

(Note that the following paragraphs have been extracted from the Executive Summary that accompanied the Final BAR compiled by SRK Consulting). Potentially suitable areas for aquaculture were identified based on oceanographic conditions such as depth, waves and swell. Aspects such as nutrients and dissolved oxygen in any one area were not taken into account in the selection of areas, but will have to be considered by prospective farmers in relation to individual operations.

3.8.1.1 Project description

The potential ADZ areas comprise five precincts, totalling 1404 ha of new aquaculture areas in Saldanha Bay (Figure 3.53) for a total ADZ comprising 1872 ha (Currently farmed areas will be incorporated into the ADZ):

- Small Bay: no additional aquaculture areas are proposed. It is thought that Small Bay has reached its carrying capacity due to the fact that poor flushing of the artificially confined bay coincides with increasing volumes of land-based effluent discharges;
- Big Bay: north of Mykonos entrance channel;
- Big Bay South: south of Mykonos entrance channel – two alternative layouts are proposed for this area;
- Outer Bay North: north of Port entrance channel, near Malgas Island; and
- Outer Bay South: south of Port entrance channel, near Jutten Island.

The following species are considered for the ADZ:

- Currently cultivated bivalve species:
  - Pacific oyster (*Crassostrea gigas*)
  - Mediterranean mussel (*Mytilus galloprovincialis*)
  - Black mussel (*Choromytilus meridionalis*)
- Indigenous shellfish species not currently cultivated:
  - Abalone *(Halioatis midae*)
  - South African scallop (*Pecten sulcicostatus*)
- Indigenous finfish species:
  - White stumpnose (*Rhabdosargus globiceps*)
  - Silver kob (*Argyrosomus inodorus*)
  - Yellow tail (*Seriola lalandi*)
- Alien finfish species:
  - Atlantic salmon (*Salmo salar*)
  - Coho salmon (*Oncorhynchus kisutch*)
  - King/Chinook salmon (*Oncorhynchus tshawytscha*)
  - Rainbow trout (*Oncorhynchus mykiss*)
  - Brown trout (*Salmo trutta*)
- Seaweed:
  - *Gracilaria gracilaris*

The following production methods are considered most viable for farming in the ADZ:

- Longlines for bivalve culture (and abalone barrels);
- Rafts for bivalve culture (and abalone barrels); and
- Cages for finfish production.

The ADZ bivalve production volumes assessed in the BA were determined based on estimated ecological carrying capacity for bivalves and through discussion with industry and proposals submitted to DAFF for fish farming. Based on estimates, the full ADZ could support total annual graded aquaculture bivalve production of up to 15 203 t, more than a six-fold increase over current graded production of ~2 000 tonnes per annum.

The ADZ finfish production volumes were determined based on the area available for finfish farming, with an assumed average farming density of 40tonnesof fish per ha based on current proposals by the industry. Additionally, the estimated generation of nutrients from waste as Nitrate (N) as a proportion of overall estimated N in Saldanha Bay was taken into account. As a precautionary measure, DAFF has accepted that finfish production be initially capped so that estimated N produced by finfish farming does not exceed 15% of the estimated N load in the Bay. This equates to a finfish production limit of ~5 150 tonnes per annum.

Research on cultivating seaweed commercially in southern Africa is limited, and realizing the potential of this resource will require cooperation between research agencies and industry. In the Saldanha ADZ, potentially suitable areas for *Gracilaria* production are likely located in Small Bay and Big Bay in areas shallower than 6 m.

No land-based facilities that require EA are included in this assessment, and obtaining authorisation will be the responsibility of individual operators/farmers. Sea-based activities associated with the ADZ include:

- Servicing and maintenance of aquaculture structures;
- Harvesting of cultivated species;
- Initial processing of bivalves, including de-clumping and grading, typically on a raft or support vessel; and
- Vessel trips between the shore and aquaculture areas, e.g. to service structures or harvest species.

3.8.1.2 Stakeholder engagement

Stakeholder engagement is a key component of the BA process and is undertaken in accordance with Chapter 6 of the EIA Regulations, 2014. Concerns raised during the stakeholder engagement process during the BA process related to the following aspects:

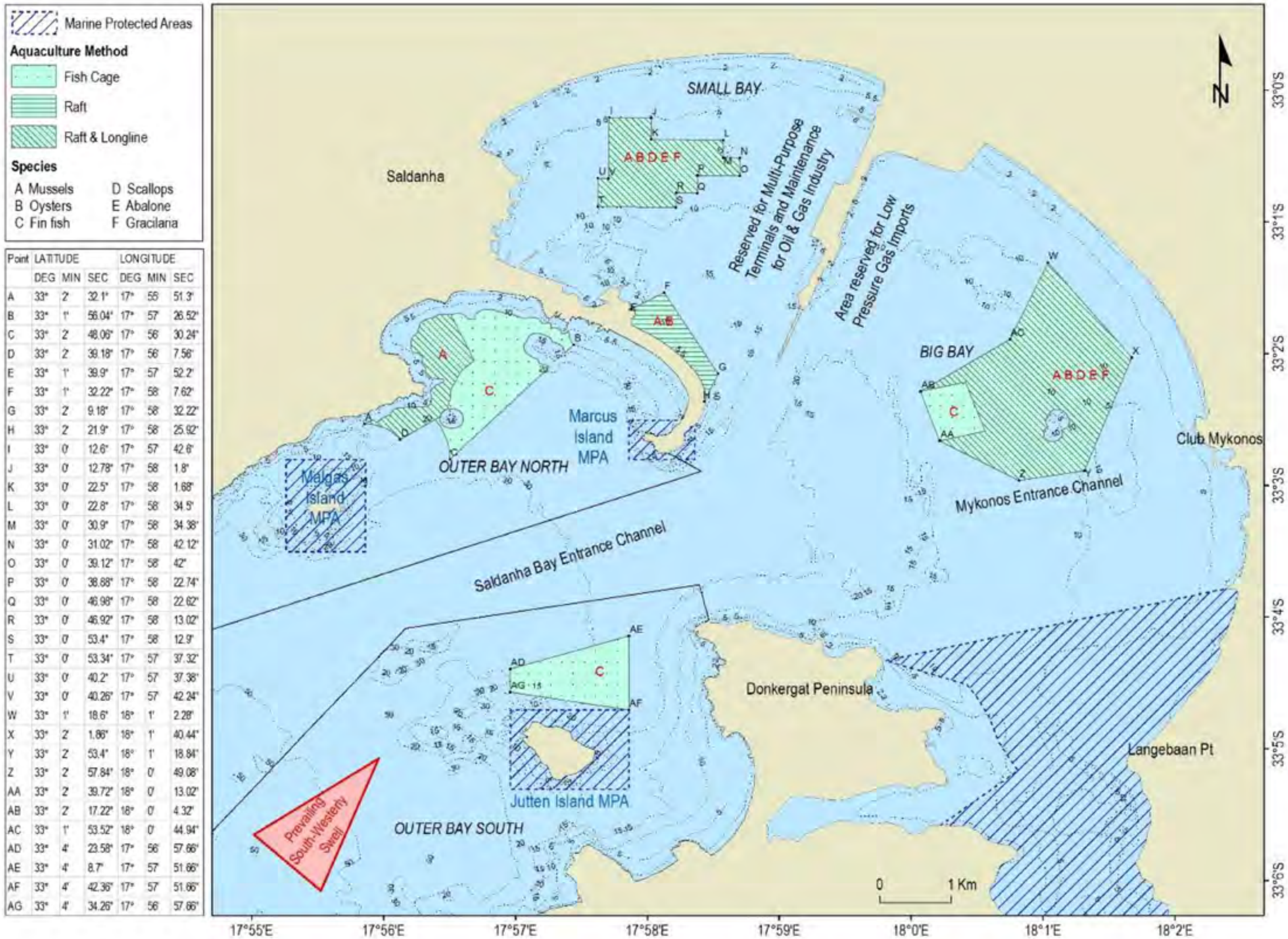
- The extent of the ADZ relative to Saldanha Bay;
- Potential impacts on water sports due to spatial overlap and associated impacts on tourism and businesses;
- Potential visual impacts and associated impacts on tourism and property values;
- Creation and loss of jobs as a result of the ADZ;
- Potential impacts on water quality;
- Management and monitoring of the ADZ;
- Potential impacts of fish farming, including introduction of aliens and diseases;
- The need for modelling of potential impacts; and
- Lack of alternative sites.

3.8.1.3 Potential environmental impacts

The SBWQFT provided comment on the proposed development, specifically raising issues with regards to potential impacts on the marine ecology of Saldanha Bay and Langebaan Lagoon.

The Saldanha Bay Water Quality Trust Forum (SBWQTF) has several concerns about the proposed siting and scale of development of the ADZ within Saldanha Bay. Saldanha bay is an area with diverse users including recreational water sports enthusiasts, recreational and commercial fishing, existing mariculture operations and large industrial scale shipping; it also adjoins unique and internationally important Lagoon and Island habitats that are included in Marine Protected Areas (MPAs). Three of the proposed ADZ areas abut directly onto MPAs that serve to protected vulnerable species and habitats. The annual state of the Bay monitoring has provided scientific evidence that the ecology of the Bay and Lagoon are negatively impacted by existing activities and developments. Mariculture development of the proposed scale would have devastating impacts on the already stressed ecosystem and further threaten many endangered bird (e.g. waders, gannets, bank and crowned cormorants, African penguins) and overexploited fish species (e.g. white stumpnose, white steenbras). Most of the SBWQT's concerns relate to the proposed area of **finfish farming**, an activity that has had severe environmental impacts globally and is unlikely to be effectively mitigated at the scale of proposed development. The following are the main points of concern as included in the SBWQTF's submitted comment on the EIA report:

- The marine specialist report for the ADZ EIA identified buffers of 1000 m from existing MPAS for finfish cage culture, which would exclude Big Bay south, and large portions of both the Outer bay sites. The final BAR presents a substantially reduced footprint with a buffer greater than 1000 m for the Langebaan Lagoon MPA. Although the areas in the outer bay were also reduced, the buffer areas around the island MPAs are less than 1000 m.
- Finfish cage farming requires at least 5 m below the bottom of the nets to allow for sufficient dispersal of wastes (uneaten food, fish faeces, fouling organisms) below cages. Nutrient enrichment and resulting eutrophication of sediments under fish cages is regarded as a serious issue in some areas. Nearshore marine environments with low flushing rates and or sediments susceptible to organic loading should be avoided when selecting sites for finfish cages. Big bay is such an environment, and furthermore the depth within the identified ADZ areas in Big Bay is shallower than 15 m. Commercial scale fish cages are typically 15 m deep, hence nowhere within Big Bay is suitable for commercial scale fin fish cages. The FAO (2015) actually recommends that cages should be no deeper than one-third of the site's depth and at least 15 meters should be left between the net base and the sea bed (at low tide). This is substantially more than the 5 m recommended in the BAR. Furthermore current velocities within Big Bay typically do not exceed 10 $cm.s^{-1}$ for much of the time, considered the minimum necessary to adequately disperse wastes below cages (FAO 2015).
- The estimation of shellfish carrying capacity is entirely based on the potential surplus production in the bay and a rough estimate of the ecological carrying capacity (~10 % of PCC). This may be appropriate or even considered a precautionary approach in areas with deeper water and higher flushing rates than Saldanha Bay, but does not adequately cater for the sensitivity of the Saldanha Bay Langebaan lagoon system (where there is tidal water exchange with a nutrient poor shallow lagoon).
- The fish carrying capacity was similarly assessed using a rough (not validated) estimate that an addition of 15% of the naturally occurring nitrogen load is acceptable. There is no evidence to indicate that this is the case and possibly more critically, the natural nitrogen load comes in as dissolved nitrate, whilst fish waste is excreted as ammonia that is toxic to marine life and behaves completely differently to dissolved nitrate.
- The anticipated future production figures for shellfish are provided as graded and ungraded (total) but for finfish only production figures are given. This is a serious omission as the total biomass of fish in the cages incorporates all the growing out stages, not just the final production tonnage.
- The SBWQTF also expressed concerned that the impact assessment for the transmission of diseases from cultured stock to wild populations that was rated as VERY LOW with mitigation was incorrect. The recommended mitigation to use only prescribed veterinary chemicals will help reduce the impacts but internationally these measures have proved only partially effective in mitigating the very serious issue of disease transmission from cultured finfish to wild stocks.



Point	LATITUDE			LONGITUDE		
	DEG	MIN	SEC	DEG	MIN	SEC
A	33°	2'	32.1"	17°	55	51.3"
B	33°	1'	56.04"	17°	57	26.52"
C	33°	2'	48.06"	17°	56	30.24"
D	33°	2'	39.18"	17°	56	7.56"
E	33°	1'	39.9"	17°	57	52.2"
F	33°	1'	32.22"	17°	58	7.62"
G	33°	2'	9.18"	17°	58	32.22"
H	33°	2'	21.9"	17°	58	25.92"
I	33°	0'	12.6"	17°	57	42.6"
J	33°	0'	12.78"	17°	58	1.8"
K	33°	0'	22.5"	17°	58	1.68"
L	33°	0'	22.8"	17°	58	34.5"
M	33°	0'	30.9"	17°	58	34.38"
N	33°	0'	31.02"	17°	58	42.12"
O	33°	0'	39.12"	17°	58	42"
P	33°	0'	38.88"	17°	58	22.74"
Q	33°	0'	46.98"	17°	58	22.62"
R	33°	0'	46.92"	17°	58	13.02"
S	33°	0'	53.4"	17°	58	12.9"
T	33°	0'	53.34"	17°	57	37.32"
U	33°	0'	40.2"	17°	57	37.38"
V	33°	0'	40.26"	17°	57	42.24"
W	33°	1'	18.6"	18°	1'	2.28"
X	33°	2'	1.86"	18°	1'	40.44"
Y	33°	2'	53.4"	18°	1'	18.84"
Z	33°	2'	57.84"	18°	0'	49.08"
AA	33°	2'	39.72"	18°	0'	13.02"
AB	33°	2'	17.22"	18°	0'	4.32"
AC	33°	1'	53.52"	18°	0'	44.94"
AD	33°	4'	23.58"	17°	56	57.66"
AE	33°	4'	8.7"	17°	57	51.66"
AF	33°	4'	42.36"	17°	57	51.66"
AG	33°	4'	34.26"	17°	56	57.66"

Figure 3.53 Proposed Saldanha Bay Aquaculture Development Zone areas, species and production methods post-mitigation (recommended) (Source: SRK Consulting 2017.

3.8.2 Aquaculture sub-sectors

Most established operators hold rights to farm mussels (*Mytilus galloprovincialis* and *Choromytilus meridionalis*) and the pacific oyster *Crassostrea gigas*, while fin fish rights (*Salmo salar* and *Oncorhynchus mykiss*) have only been issued to two farms since 2014 (Table 3.11). Abalone, scallops, red bait and seaweed are currently not cultured on any of these farms, although some of the farms have the right to do so (Refer to the 2014 and 2015 State of Saldanha Bay and Langebaan Lagoon Reports for details on individual farms). At the time of writing, most of the farming occurs in Small Bay and only oysters are cultured in Big Bay by the Saldanha Bay Oyster Company and West Coast Oyster Growers.

It has been recommended that species that have been cultivated successfully in Saldanha Bay should remain the key species farmed in the proposed Saldanha Bay ADZ. It has been proposed that new shellfish or finfish species will be exclusively indigenous to South Africa, as they do not require comprehensive risk assessments and are likely to have a lower impact on the marine ecology of Saldanha Bay and Langebaan Lagoon. New species include Abalone (*Haliotis midae*), South African scallop (*Pecten sulcicostatus*), white stumpnose (*Rhabdosargus globiceps*), kabeljou (*Argyrosomus inodorus*) and yellow tail (*Seriola lalandi*). A preliminary conceptual spatial plan was developed as part of the project definition phase, which shows where each species would be farmed and which farming method would be suitable (Figure 3.53).

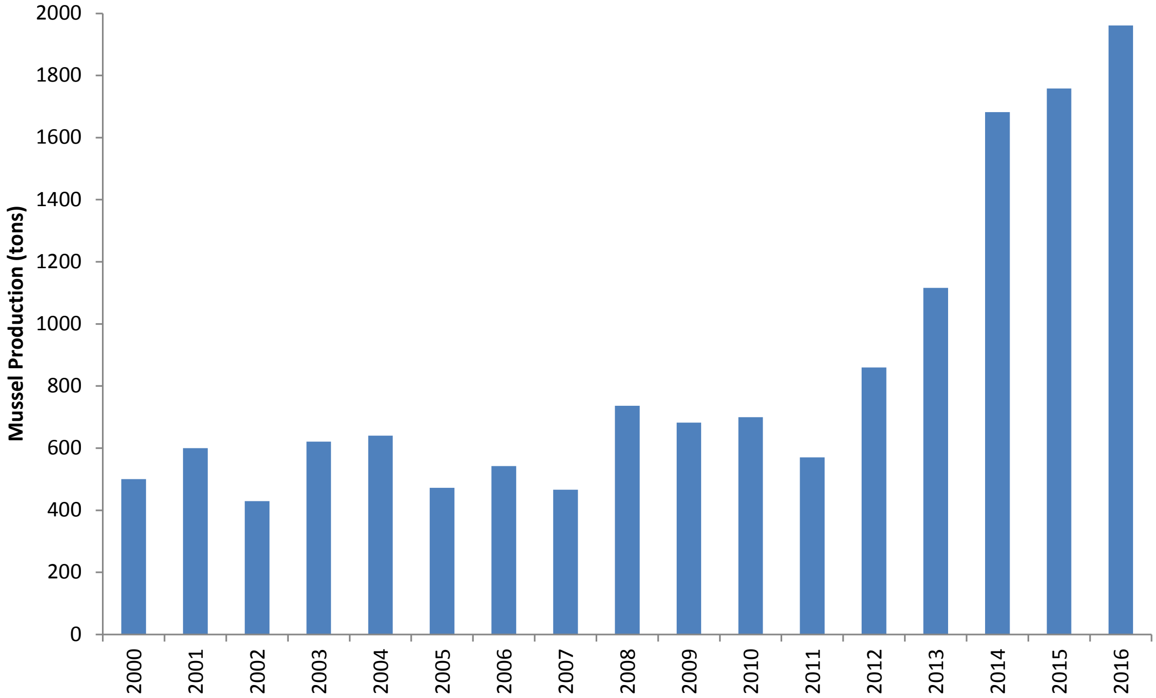
3.8.2.1 Shellfish marine aquaculture

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 of a boat. Overall mussel productivity has been increasing exponentially since 2007, peaking in 2015 at 1758 tonnes (Figure 3.54.). Mussel production has doubled since 2012, which can be attributed to the establishment of a new mussel farm and the conversion of an oyster farm to a mussel farm (DAFF 2015). In 2013 the mussel sub-sector (based in Saldanha Bay) contributed 37% to the total mariculture production and is currently the second highest contributor to the overall mariculture productivity for the country (DAFF 2015).

A study conducted between 1997 and 1998 found that the culture of mussels in Saldanha Bay created organic enrichment and anoxia in sediments under mussel rafts (Stenton-Dozey *et al.* 2001). The ratios of carbon to nitrogen indicated that the source of the contamination was mainly faeces, decaying mussels and fouling species. In addition, it was found that the biomass of macrofauna was reduced under the rafts and the community structure and composition had been altered (Stenton-Dozey *et al.* 2001).

Ongoing environmental impact monitoring surveys undertaken in Saldanha Bay by the Department of Agriculture, Forestry and Fisheries (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.

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.



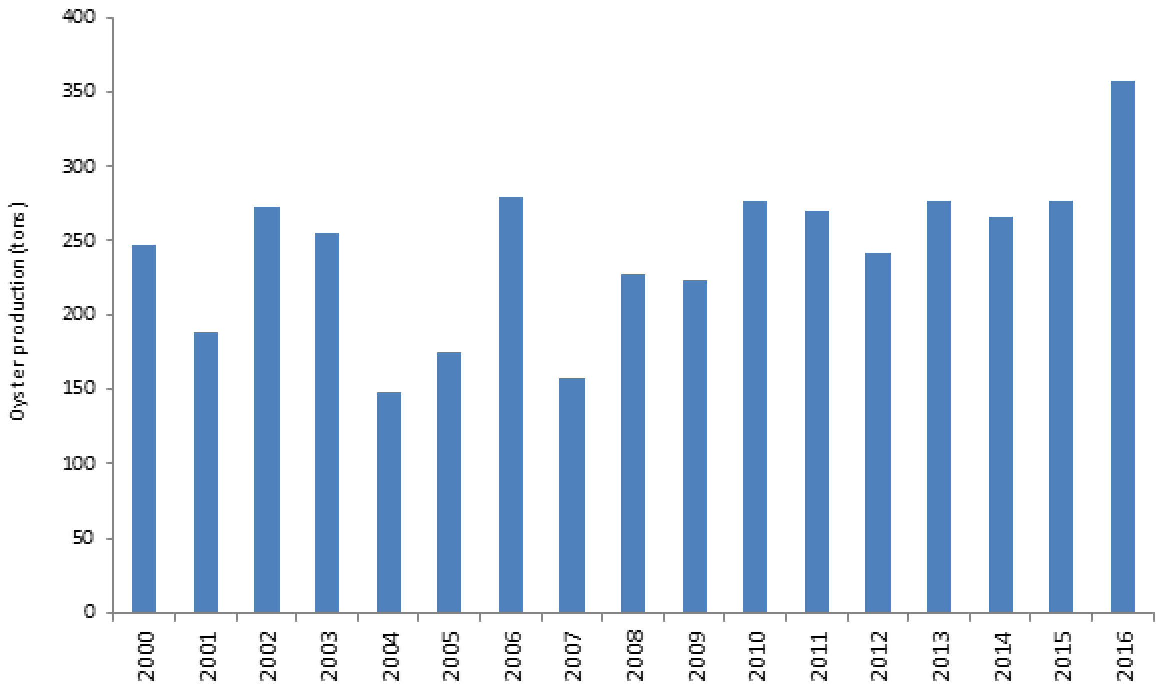


Figure 3.54. Annual mussel (top) and oyster (bottom) production (tonnes) in Saldanha Bay between 2000 and 2016 (source: Department of Agriculture, Forestry and Fisheries 2016).

3.8.2.2 Finfish cage farming

Marine cage culture of Atlantic salmon was piloted in Gansbaai several years ago, however, this reportedly failed when the heavily fouled cages 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). The identification of marine aquaculture sites is a complex process that must take into consideration a number of factors. These include physical (e.g. sea surface temperatures, currents), biophysical (e.g. harmful algal blooms, optimal culture temperatures), infrastructural (e.g. road access, airports), and existing resource-use issues (e.g. urbanisation, parks and recreational areas) (FAO 2015).

Saldanha Bay is protected when compared to the exposed west coast of South Africa and has been identified as one of very few areas where finfish cages can be installed successfully (Ecosense CC 2017). Offshore finfish cage culture is currently being pioneered in Saldanha Bay and is largely focused on the farming of salmonid species, including Atlantic salmon (*Salmo salar*) and rainbow trout (*Onchorhynchus mykiss*). Both species are non-native to South Africa, however, *O. mykiss* is farmed in many parts of the country in land-based systems.

Southern Atlantic Sea Farms attempted to pioneer Atlantic salmon in Saldanha Bay. During the pilot phase of this project, however, it was found that Small Bay is not suitable for Atlantic salmon due to the susceptibility of this species to amoebic gill disease, which combined with frequent low dissolved oxygen events led to high mortality rates. The project was therefore terminated in 2015 (Southern Atlantic Seafarms, Director Gregory Stubbs, *pers. comm.,* 2015).

Molapong Aquaculture (Pty) Ltd (Molapong) has experimentally been farming 50 tonnes of finfish per annum in Saldanha Bay during the last year. The experimental phase has been successful and Molapong appointed Ecosense CC to conduct a Basic Assessment process to obtain Environmental Authorisation the phased installation of sea cages on 28 ha for the production of finfish, mussels and sea weed in Saldanha Bay up to 2000 tonnes per year. The final Basic Assessment Report has been completed for submission to the Competent Authority. The following project phases have been proposed:

- Phase 1 (Experimental) – The current level of finfish project (50 tonnes/annum – duration 12 -14 months).
- Phase 2 – early commercial phase finfish project (100 t/annum 12 -14 months). Establish seaweed lines. Establishment of mussel settlement lines.
- Phase 3 – 500 t/annum finfish project (12/14 months). Seeding mussel production lines.
- Phase 4 – 1200 t/annum finfish project (12-14 months. Harvesting mussels and possibly reducing numbers.
- Phase 5 – 2000 t/annum finfish project (12-14 months). Harvesting mussels and possibly reducing numbers.

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 (Refer to AEC 2016 for more detail on amoebic gill disease (AGD) caused by *Paramoeba*

perurans can cause high mortality, poor fish welfare and reduced growth if not treated early in the eruption phase);
- 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; and
- 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 behaviours and food webs may be altered. Farmers tend to kill problem predators or use acoustic deterrents; and
- User conflict due to exclusion from mariculture zones for security reasons.

Some of the above-listed impacts can be mitigated by implementing an Environmental Management Programme (as required in the EIA regulations R982 of 2014, as amended). 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. However, some impacts are difficult to mitigate effectively. For example, although chemical treatment of cultured stock to control disease and parasite outbreaks is possible (unlike wild stocks), build-up of antibiotic and chemical resistance is becoming increasingly problematic (Staniford 2002). Furthermore, disinfectants, antifoulants and therapeutic chemicals (medicines) are typically used in sea cage fish culture. These chemicals are often directly toxic to non-target organisms and may remain active in the environment for extended periods (Kerry *et al.* 1995, Costello *et al.* 2001). The tendency for bioaccumulation of many chemicals used in used in fish cage culture is not well researched and even with the implementation of mitigation measures, the impacts are still likely to be considerable. Seals, sharks and predatory sea birds are abundant in the Saldanha Bay area and interactions with finfish sea cages are highly likely. Due to the extensive foraging range of most large marine predators, however, interactions cannot be completely mitigated by site selection. The most effective and common response by farmers is to install top and curtain anti-predator nets (Wuersig & Gailey 2002).

Untreated wastes resulting mainly from uneaten food and faeces of fish in sea cages are discharged directly into the sea and are not an insignificant source of nutrients (Brooks et al. 2002, Staniford 2002). Studies have documented increased dissolved nutrients and particular components (POC and PON) both below, and in plumes downstream, of fish cages (Pitta et al. 2005). These wastes impact both on the benthic environment and on the water column. Sediments and benthic invertebrate communities under fish farms usually show chemical, physical and biological changes attributable to nutrient loading. Elevations in carbon, ammonia and hydrogen sulphide concentrations are frequently observed (Carroll et al. 2003, Heggoey et al. 2005). Nutrient enrichment and resulting eutrophication of sediments under fish cages is regarded as a serious issue in some areas (Staniford

2002). The extent of contamination of the sediments under fish cages is obviously highly site and project specific. Nearshore marine environments with low flushing rates and or sediments susceptible to organic loading should be avoided when selecting sites for finfish cages. Cages should also be situated in water of sufficient depth to allow flushing and reduce the build-up of wastes directly below cages. The main concern is that farming finfish at the proposed scale could produce enough organic waste to cause eutrophication in Langebaan Lagoon with severe impacts on the marine ecosystem.

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 are exempted from the requirement of a permit and risk assessment (NEMBA Section 65(1)). These new regulations raise concerns with regards to the introduction of alien species into new environments, as demonstrated in the case of pioneering sea-based finfish cage farming practices. Salmon and trout, 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.

3.9 Shoreline erosion in Saldanha Bay

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.

A recent report by Flemming (2016) has identified dredging operations conducted during the Port construction programme as being the source of problem (i.e. erosion of Langebaan Beach, Figure 3.55). Flemming (2016) highlights the fact that much of the sediment used to build the causeway to Marcus Island was dredged from the historic ebb tide delta that existed at the mouth of Langebaan (an area where sediment derived from Langebaan Lagoon had been deposited over many thousands of years) (Figure 3.56, Figure 3.57). Removal of sediment from this area reduced the extent to which incoming waves were refracted and increased in the wave energy density along the shoreline by around 50% (Figure 3.58). This in turn resulted in the observed erosion of the shoreline. Flemming (2016) has suggested that the most effective way to remedy this situation would be to refill the hole created by the dredging and subsequently nourish the beach with sand from another source.

Figure 3.55. Position of the orginal shoreline at Langebaan Beach in 1975 (Source: Flemming 2016).

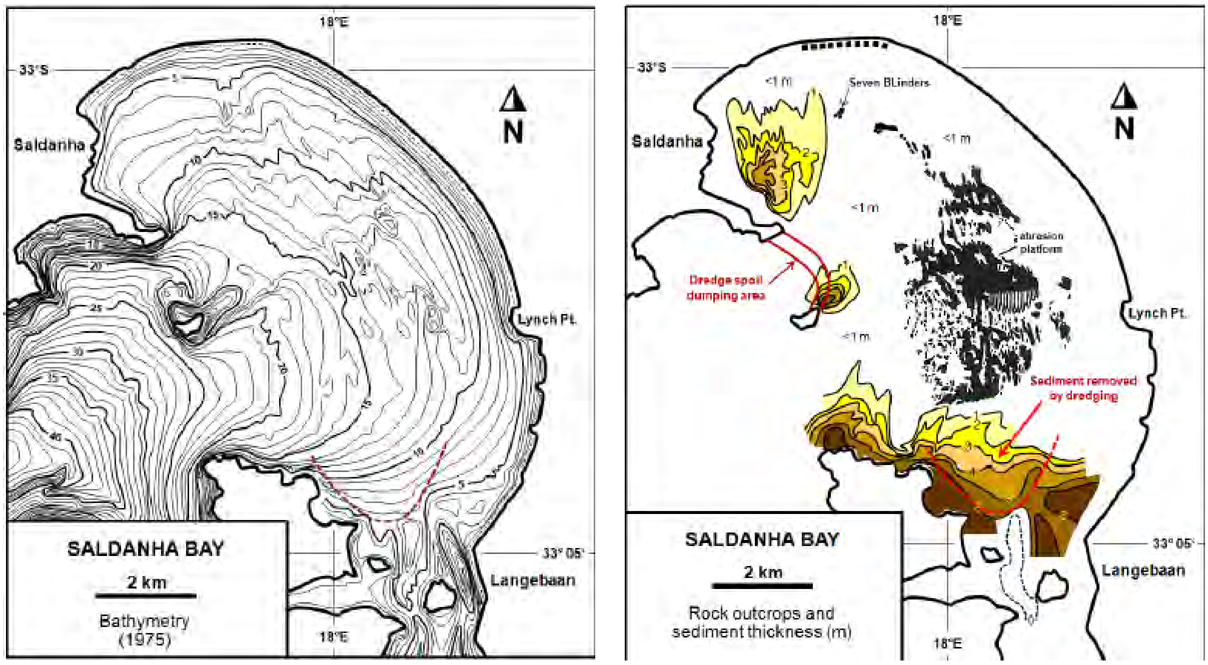


Figure 3.56. Ebb tide delta at the entrance to Langebaan Lagoon where sediment was dredged for construction of the causeway between Marcus Island and the mainland in the late 1970s. Source: Flemming (2016).

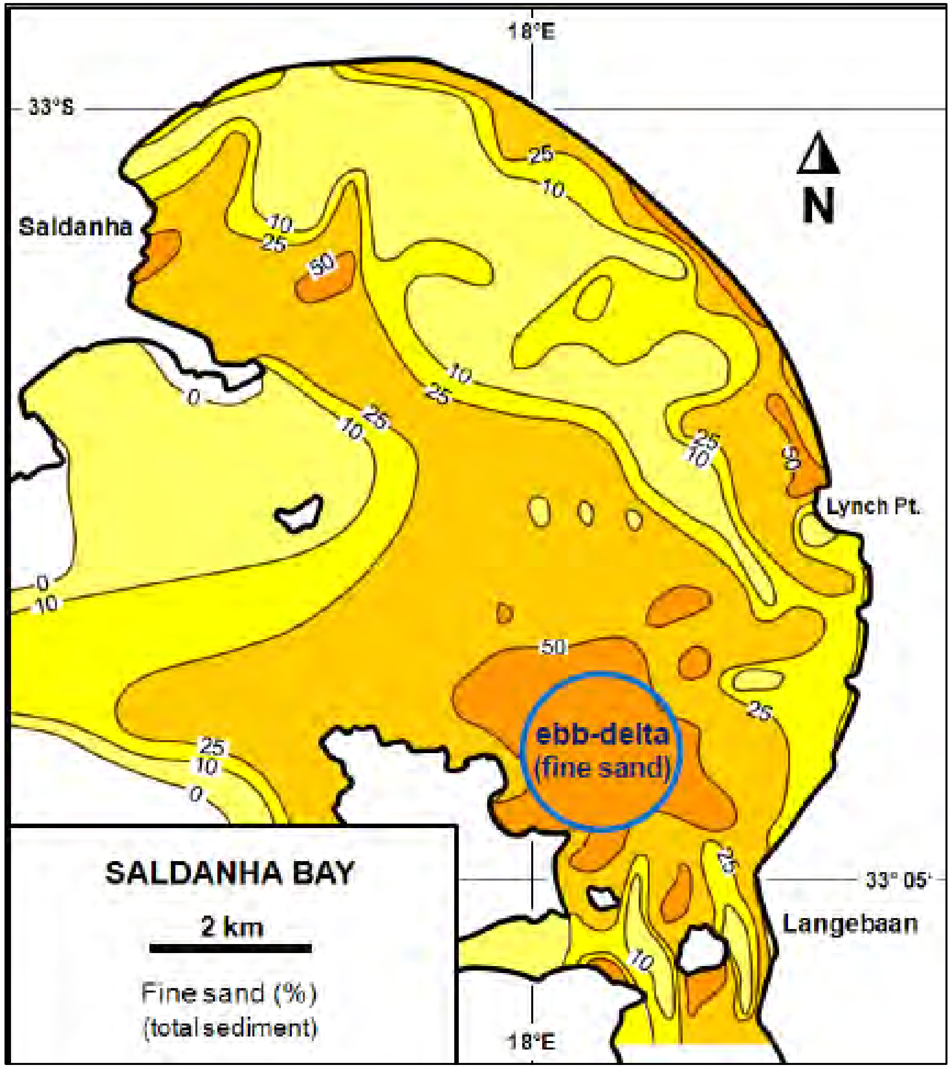


Figure 3.57. Ebb tide delta at the entrance to Langebaan Lagoon where sediment was dredged for construction of the causeway between Marcus Island and the mainland in the late 1970s. Source: Flemming (2016).

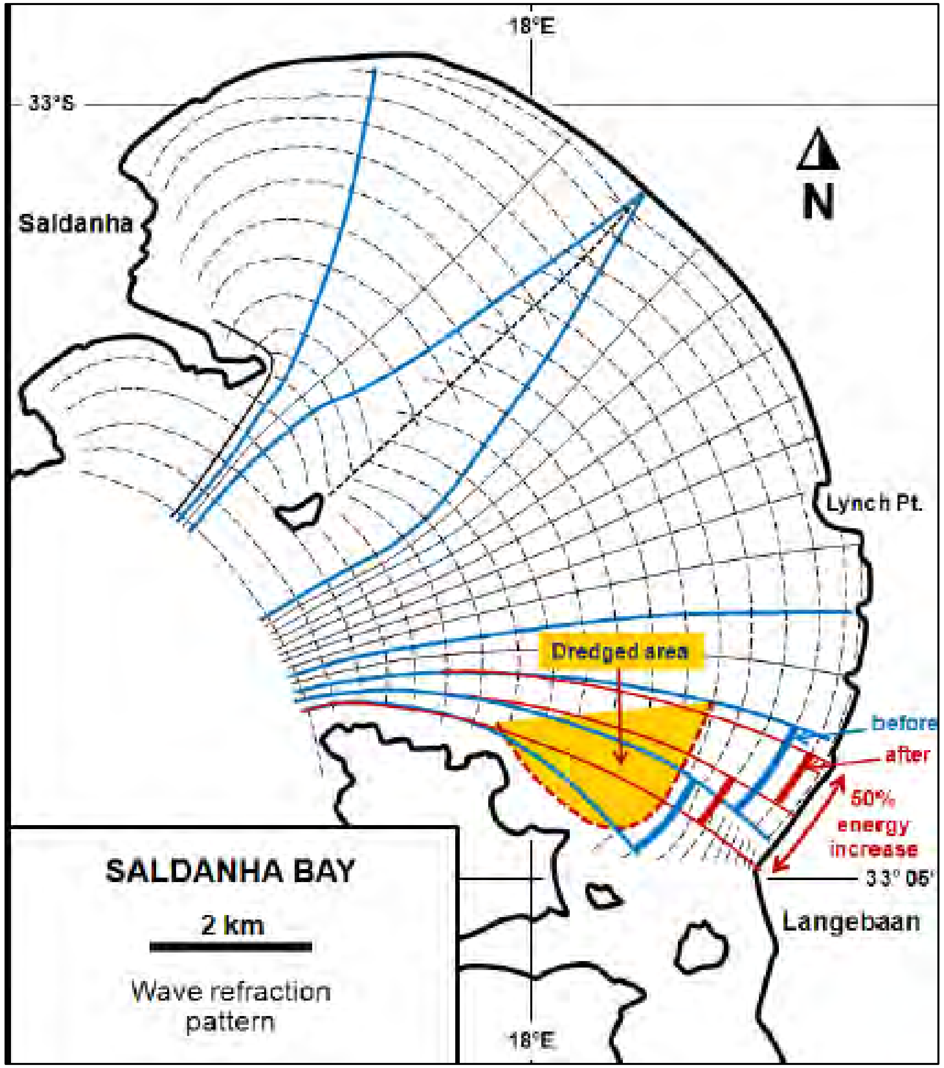


Figure 3.58. Changes in wave refraction patterns and a consequent increase in wave energy density at the shoreline at Langebaan Beach - a result of sediment removal during the construction of the causeway linking Marcus Island with the mainland. Source: Flemming (2016).

3.9.1 Current status of Langebaan beach erosion management measures

Further 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 reached between the Saldanha Bay Municipality (SBM) and Department of Environmental Affairs & Development Planning (DEA&DP) that such works could be undertaken in terms of an EMMP. The EMMP 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 and none of the recommended monitoring has been implemented to date (SBM, Environmental Officer, Nazema Duarte 2015, *pers. comm.*).

Upgrading, maintenance or managed retreat is also needed at 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 in the EMMP 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 walking in the dunes. Unfortunately, neither dune rehabilitation nor the redirecting of stormwater was implemented due to the lack of funds. No awareness was created about the impacts of dumping of coals in the dunes (SBM, Environmental Officer, Nazema Duarte 2014, *pers. comm.*). This is despite the low financial cost associated with, for example, distributing flyers, emails or small signboards. Two different engineering solutions were proposed in the EMMP to stop further shoreline retreat in this area, both of which 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 environmental authorisation and would be financially infeasible and the nature of such mitigation strategies would not desirable within a National Park. It was therefore decided that managed retreat was the only feasible option for the Leentjiesklip Caravan Park. Unit 4A, which was identified as the highest risk area, was recently given notice regarding the termination of the lease agreement and tenants were asked to vacate the property. Other units in this area on municipal property have also been notified that managed retreat may be enforced in the near future should coastal erosion continue advancing at the current rate (SBM, Environmental Officer, Nazema Duarte, *pers. comm.* 2015).

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 considered urgent because of a sewer line that 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 been completed but the contractor is still involved in the ongoing beach clean-up as construction material washes ashore (SBM, Environmental Officer, Nazema Duarte, *pers. comm.* 2015).

Figure 3.59. Groynes and rock revetment at Langebaan North beach. Source: Google Earth.

4 COASTAL AND ENVIRONMENTAL MANAGEMENT

Continuously accelerating urban and industrial development poses a significant threat in the form of fragmentation and loss of ecological integrity of remaining marine and coastal habitats in Saldanha Bay and Langebaan. 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 and stormwater that is produced (and ultimately discharged to the Bay) each year. The challenge of addressing these cumulative impacts in an area such as Saldanha is immense.

The current and future desired state of the greater Saldanha Bay area is polarised, where industrial development (Saldanha Bay IDZ and associated industrial development) and conservation areas (Ramsar Site, MPAs and National Parks) are immediately adjacent to one another. Furthermore, the Saldanha Bay environment is home to a range conflicting uses including industry, fishery, mariculture, recreation and the natural environment itself. This situation necessitates sustainable development that is steered towards environmentally more resilient locations and away from sensitive areas (Thérivel *et al.*, 1994).

A task team has been set up by the Department of Environmental Affairs and Development Planning (DEADP) with the objective to conduct a Strategic Environmental Assessment (SEA) in the Saldanha Bay Area (DEADP 2016). An SEA is an effective environmental management instrument, which aims to ensure that environmental and other sustainability aspects are considered effectively in policy, plan and programme making within an area such as Saldanha Bay. The development of an SEA will involve formulating a desired environmental state for the Greater Saldanha Bay Area. Limiting environmental attributes will need to be identified and evaluated to set thresholds beyond which the realisation of the desired environmental state would be compromised. Any proposed development would then be evaluated against the SEA to ascertain whether the activities are congruent with the desired environmental state. An SEA could indeed facilitate management towards achieving a desired state in the Saldanha Bay area.

DEADP has also compiled an Environmental Management Programme (EMPr) Key in collaboration with the National Department of Environmental Affairs (Directorates Oceans and Coast and Environmental Impact Assessment), the Saldanha Bay Municipality and the Saldanha Bay Water Quality Forum Trust (DEADP 2016). The EMPr Key contains mitigation measures and other interventions appropriate for a range of developments and associated impacts on the coastal and marine environment of Saldanha Bay. This document was implemented this year and allows government officials involved in the environmental authorisation process to compare the EMPr submitted by the applicant against a definite set of criteria applicable to the environmental challenges faced in the Greater Saldanha Bay Area.

Finally, an initiative for the establishment of a Special Management Area in Saldanha Bay is gathering momentum and has the potential to improve environmental management in Saldanha Bay and Langebaan Lagoon. A Special Management Area under the ICMA may be declared in terms of section 23 (1) (a) of the Act, 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 may declare any area that is wholly or partially within the coastal zone to be a special management area and has the power to prohibit certain activities should these activities be considered contrary to the objectives of the special management area (ICMA Section 23 (4)).

Other initiatives that also have an important role to play in this respect include the implementation of coastal management lines and the preparation of an Environmental Management Framework for Saldanha have been described in previous editions of the State of the Bay Report (AEC 2014, 2015).

5 GROUNDWATER

5.1 Introduction

Langebaan Lagoon, a unique 'estuary', which forms a part of the greater Berg Water Management Area (WMA), is not fed primarily by surface water runoff, but rather by groundwater. Classification of the 16 km long Langebaan Lagoon that adjoins Saldanha Bay on the West Coast about 100 km north of Cape Town, has been debated for some time. Langebaan Lagoon has many of the characteristics of an estuary, including calm coastal waters that are protected from marine wave action and a biota that includes many species typically found in estuaries. However, the system lacks a conventional estuarine salinity gradient due to the absence of any inflowing river, although there is groundwater that feeds into certain sections of the lagoon. At 3-4 km wide, with channels up to 5 m deep, Langebaan is much larger and deeper than conventional coastal lagoons which are usually small and shallow. Whitfield (2005) suggested that the term "coastal embayment" type of estuary be used to describe Langebaan owing to the fact that it does receive freshwater inflow from land drainage (aquifer input), and also has typical estuarine biota. This would place it in a class of its own; separate from "estuarine bays", all of which are fed by rivers.

The area directly surrounding Langebaan Lagoon is mainly under natural vegetation, waterbodies or wetlands, some of which falls within the West Coast National Park. Outside of the National Park, cultivated land makes up the next most common land use, followed by urban development in the Saldanha region (Figure 5.1).

Ground water and its potential to serve as a natural resource is growing in importance in the Saldanha area, an arid region with low average annual rainfall, which is facing growing pressure from industrial development and residential growth. South African water legislation considers groundwater as a national resource to be managed in a sustainable manner. The Water Services Act and National Water Act (DWAF, 1997, DWAF, 1998) provide the framework for delivery of water services while also providing a combination of legal obligations, rights, responsibilities and constraints for the sustainable development and management of water resources in South Africa (Pietersen 2006). Ground water resides under the earth's surface in soil pore spaces and in the fractures and fissures of rock formations. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called the water table. Groundwater is recharged from, and eventually flows to the surface naturally; natural discharge often occurs at springs and seeps, and can form oases or wetlands. Groundwater is often withdrawn for agricultural, municipal, and industrial use by constructing and operating extraction wells or bore holes. Groundwater is often cheaper, more convenient and less vulnerable to pollution than surface water. Therefore, it is commonly used for public water supplies. Polluted groundwater is less visible, but more difficult to clean up, than pollution in rivers and lakes. Groundwater pollution most often results from improper disposal of wastes on land. Major sources include industrial and household chemicals and garbage landfills, excessive fertilizers and pesticides used in agriculture, industrial waste lagoons, tailings and process wastewater from mines, industrial fracking, oil field brine pits, leaking underground oil storage tanks and pipelines, sewage sludge and septic systems. In addition to pollution, over extraction can severely alter or irreparably deplete an aquifer to such an extent that it reaches an unsustainable level.

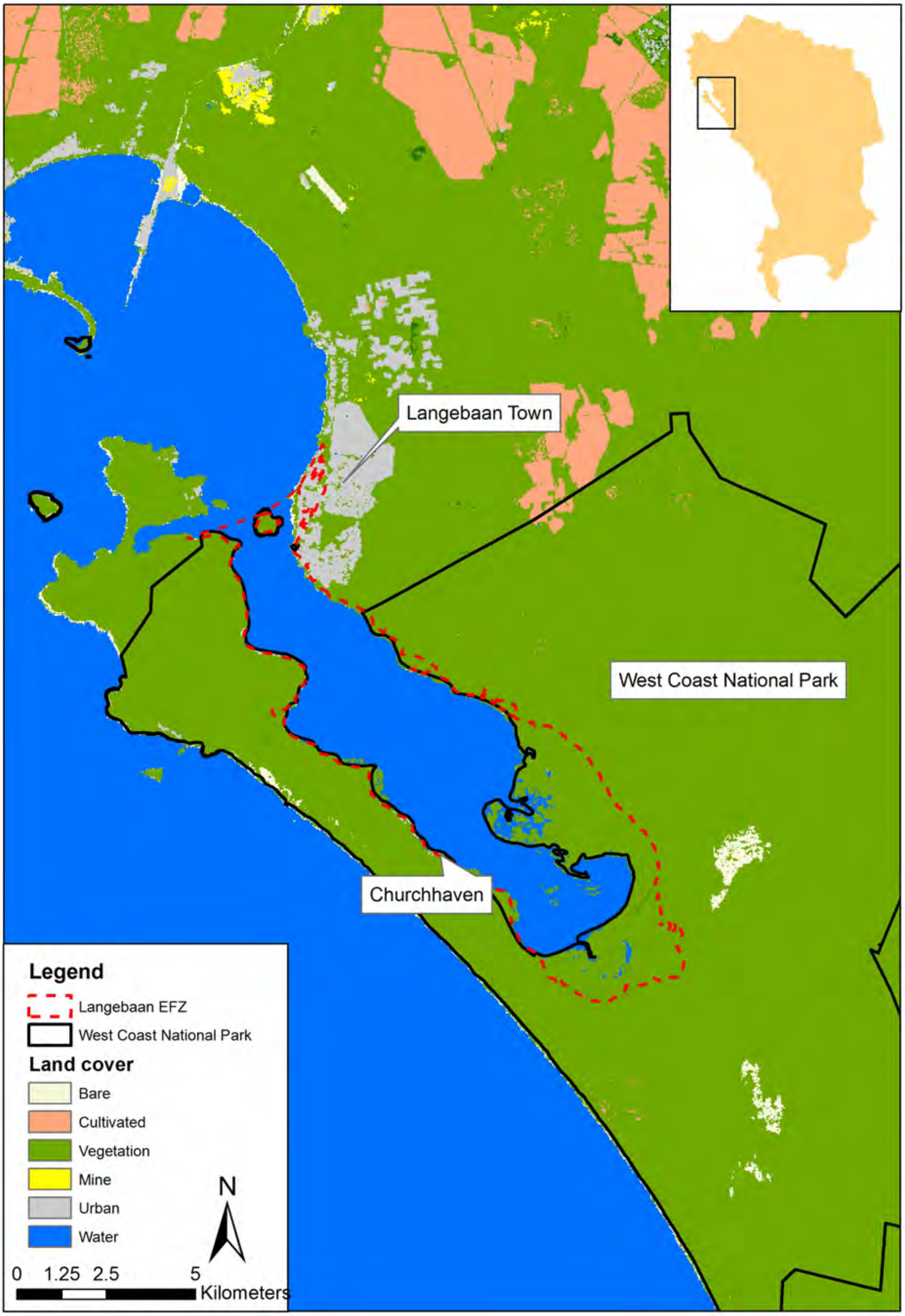


Figure 5.1 Basic landuse map surrounding Langebaan Lagoon.

The West Coast District Municipality (WCDM) operates a wellfield on the Langebaan Road Aquifer that is licenced to abstract up to 1.46 million m^3 of groundwater per annum. Abstraction of groundwater from this aquifer resulted in a localised depression of water levels in the deeper portion of this aquifer by as much as 10 m in the first few years of operation between 2005 and 2009, and concern has been expressed over how this might be affecting groundwater discharge to Saldanha Bay now, and in the future. A modest (10%) reduction in abstraction rates was effected to address this but it is not clear how effective this has been. Groundwater extraction from the Elandsfontein Aquifer System (EAS), which is in close proximity to the Langebaan Road Aquifer System (LRAS), by Elandsfontein Exploration and Mining (Pty) Ltd (EEM), now known as Kropz, and subsequent wastewater from the mining process has also been of concern in the Langebaan and greater Saldanha region.

It is well known that there is a phosphate deposit situated in Elandsfontein (on Farm Elandsfontein 349, situated between the town of Hopefield and the Langebaan Lagoon area) and that the EEM intends to mine this area using an open-pit strip mining method sustaining a production rate of 1.5 million tonnes per annum over the next 20 years. Raw process water will be primarily supplied from within the pit. Additional water will be abstracted from the aquifer discharge pumping streams (Braaf 2014). For strip mining to take place, the water table is lowered by extracting groundwater from the underlying aquifer via a series of boreholes upstream of the mining site which prevents the mine pit from being flooded. Concern has been expressed over potential impacts that the proposed phosphate mine at Elandsfontein may have on groundwater quality and flows to Langebaan Lagoon. As such, a detailed description of the hydrogeology in this area, the relationship of Langebaan lagoon to ground water, as well as the current data on historic ground water monitoring and a current monitoring regime put in place by consensus between EEM, Geohydological and Spatial Solutions International (Pty) Ltd (GEOSS), SBWQT, and AEC follows in order to track any significant change to this important natural resource. It should be noted, however, that the EEM/Kropz operations are currently suspended due to a delay in the issuing of the mine's wateruse license as well as other complications (Furlong 2017).

5.2 Detailed geology, aquifer description and climatic setting

A geohyrdological assessment was performed by GEOSS as a part of the scoping report for the phosphate mining permit application at Elandsfontein and a summary of the information in this report has been included here to facilitate an understanding of the local topography on the farm Elandsfontein No. 349 (Magisterial District of Malmesbury). The geology of the area consists of basement Cape Granite and Malmesbury Group rocks that underlie the sediments of the Sandveld Group. In the farm area it is assumed that the Malmesbury Group is bedrock and closer towards the coast the bedrock is granite (GEOSS Draft Report 2014).

There are two main aquifer systems from which groundwater discharges into Saldanha Bay – the Langebaan Road Aquifer System (LRAS) and the Elandsfontein Aquifer System (EAS). There is little exchange of water between these two aquifer units, each one discharging to the sea through its own paleo-channel. The LRAS discharges into Saldanha Bay (Big Bay) through the northern paleo-channel while the EAS discharges into Langebaan Lagoon through the southern paleo-channel. The EAS (Weaver & Wright 1994, Valiela *et al.* 1990, Burnett *et al.* 2001), which comprises of a Lower Aquifer

Unit (LAU) that lies on a basement rock formation and an Upper Aquifer Unit (UAU) located in variably consolidated sands and calcretes which are separated by an impermeable layer of clay, known as an aquitard (DWAF 2008, Figure 5.2). These aquifer systems are defined by palaeo-channels that have been filled with gravels of the Elandsfontein Formation and represent preferred groundwater flow paths. A steep hydraulic gradient exists where the Elandsfontein aquifer intersects with the lagoon, and coupled with presence of the clay beneath the lagoon, forces groundwater to flow towards the surface at the lagoon edge (Figure 5.3) resulting in significant groundwater outflow to the lagoon.

Field data from the GEOSS study suggests that water quality in the LAU is good (conductivity less than 80 mS/m) and water levels in the Elandsfontein area are mostly between 10 and 20 m below ground level (GEOSS Draft Report 2014). Generally water quality in the Lower Aquifer Unit is better than that of the Upper Aquifer Unit but field chemistry measurements suggest that all the groundwater is of a good quality (GEOSS Draft Report 2014). Due to the largely unconsolidated nature of a number of formations the aquifer has a high vulnerability to contamination. The aquifer is classified as a "Special Aquifer Region" and a "high" to "strictly non-degradation" level of groundwater protection is required.

The area of interest and surrounding greater Saldanha region is a Mediterranean climate where rainfall primarily occurs during winter months (May through August). Annual rainfall for the region has been measured at less than 280 mm per year (DWAF 2008). At the Langebaan Road rainfall station (approx. 25 km north of Geelbek), 185-IR, the average rainfall calculated over a 34 year period (from 1973 until 2007) is 268 mm, the minimum rainfall for this period was 159.7 mm in 2000 and the maximum 420 mm in 2007. This weather station is no longer recording, so the next nearest station, Koperfontein (near Hopefield and approximately 26 km east of Geelbek), is being used for rain data. The long term annual average (1999-2013, with exception of a 5 month period from November 2004 to March 2005) is 324 mm/a.

The maintainable aquifer yield is defined as the pumping rate that can be sustained indefinitely without mining an aquifer *continually.* Discharge from wells upsets the dynamic equilibrium by producing a loss from aquifer storage; and under pumping at the maintainable aquifer yield, over time a new state of dynamic equilibrium is approached when there is no further loss from storage. The maintainable aquifer yield therefore is a rate that can be maintained by reduced discharge and or induced recharge in a new dynamic equilibrium of the aquifer, such that the aquifer storage doesn't deplete. It does not *directly* depend on the pre-abstraction recharge rates. The length of time required for the new state of dynamic equilibrium to be reached, where there is no further loss from storage has been referred to as the aquifer Response Time. If sustainable groundwater use is defined as groundwater use that is socially, environmentally (ecologically), and economically acceptable, then long-term abstraction of the maintainable aquifer yields does *not necessarily* reflect sustainable groundwater use. A critical step from quantification of a maintainable aquifer yield to quantification of sustainable groundwater use is to determine the volume contribution from each source under the new dynamic equilibrium, and the equivalent piezometric head distribution, and then take a socio-economic-environmental decision as to whether this is acceptable. If it is acceptable, then the long-term abstraction of the maintainable aquifer yield can be considered sustainable groundwater use, and the maintainable aquifer yield reflects a sustainable aquifer yield.

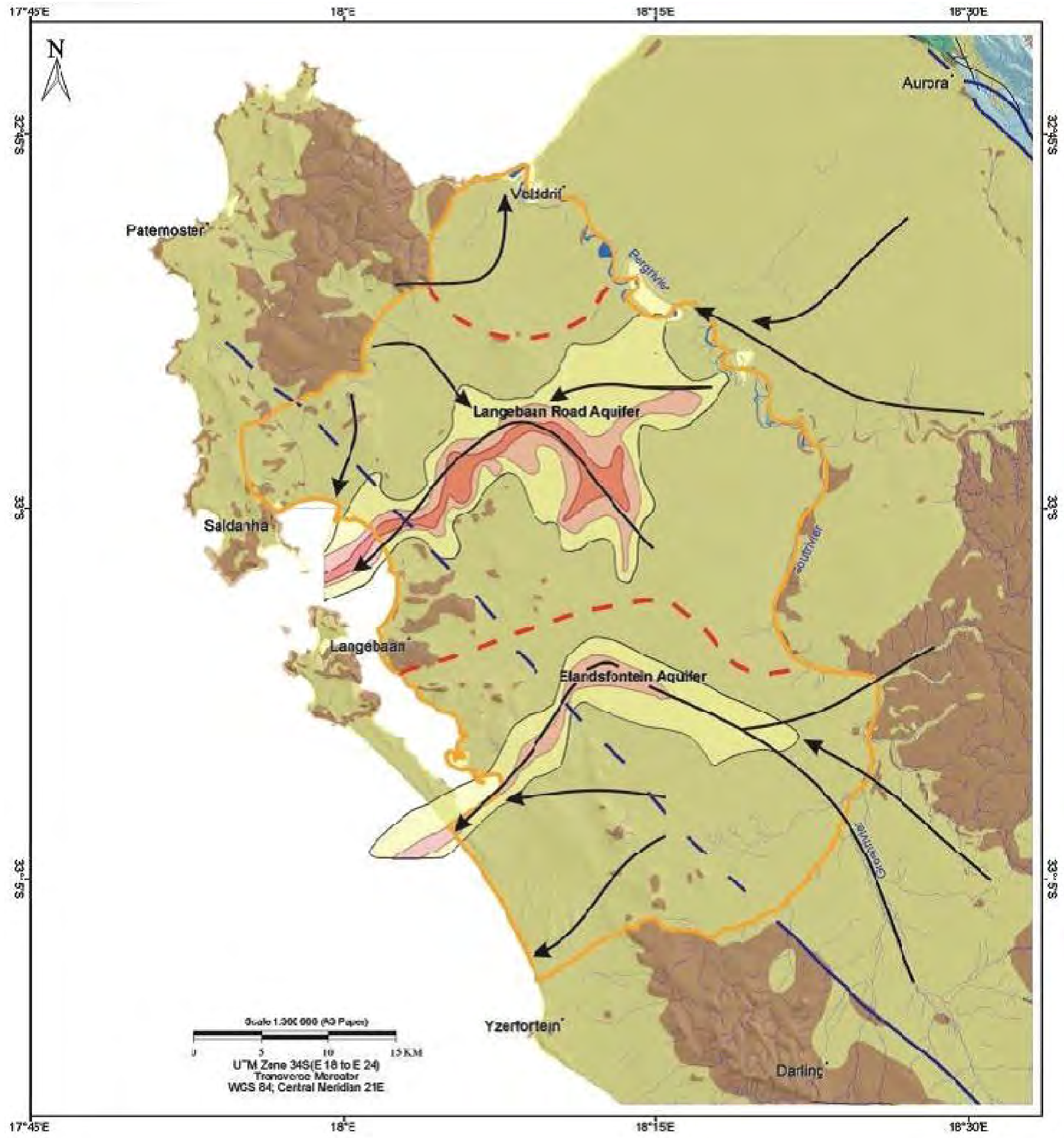


Figure 5.2 **Paleo-channels through which the Langebaan Road and Elandsfontein Aquifers discharge (Redrawn from DWAF 2008).**

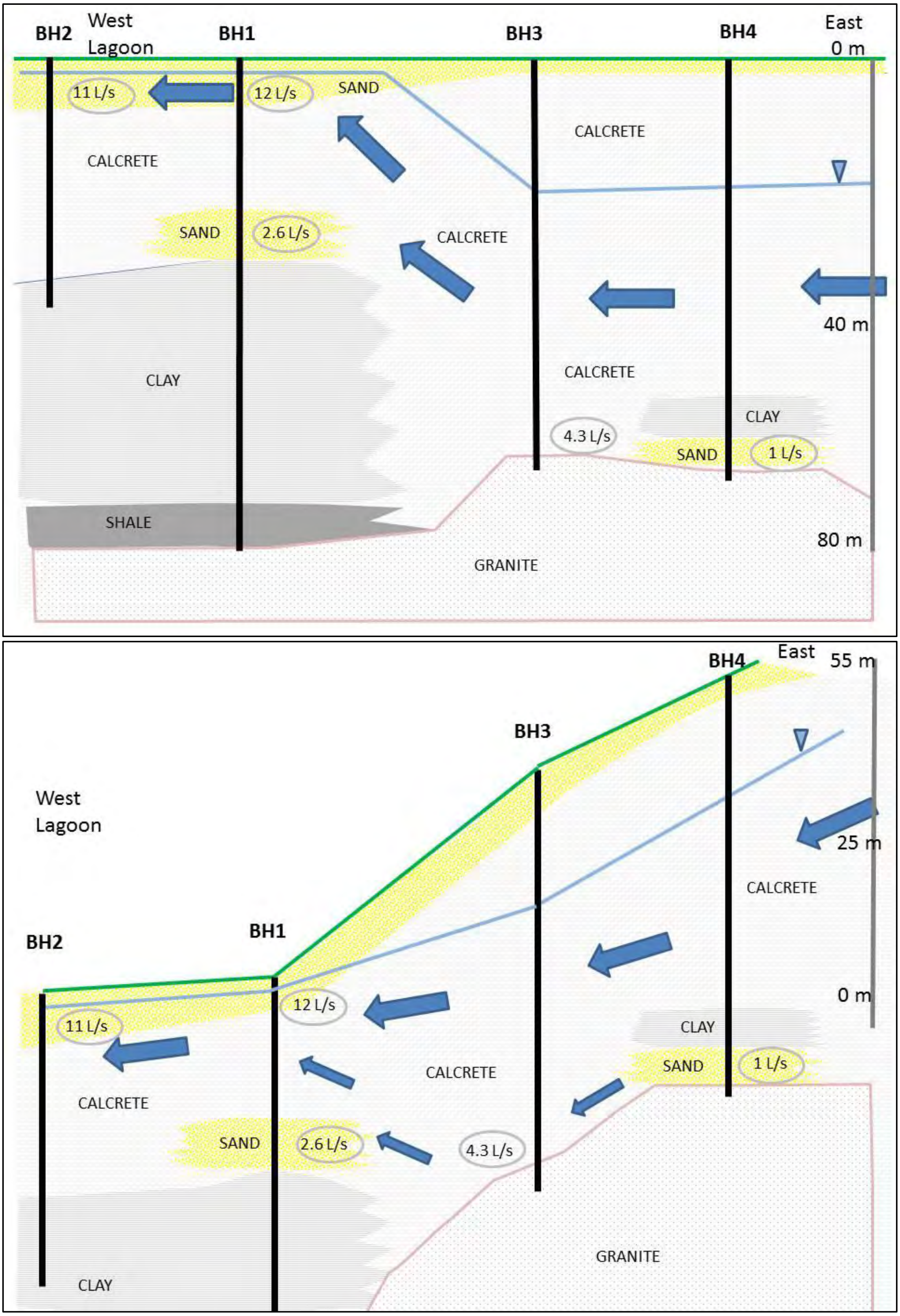


Figure 5.3 **Geological cross-section of the Geelbek borehole (mbgl), showing ground at surface level (top) and corrected for elevation (bottom) (GEOSS 2014).**

5.3 Current Status

While high conservation status has been afforded to Langebaan Lagoon, it is not fed by overland streams or rivers due to the porous nature of the sediments and the arid conditions. Groundwater plays a very significant role in sustaining the marsh ecosystem surrounding the head of the lagoon (Valiela et al., 1990; Burnett et al., 2001). Diagnostic plants, such as *Phragmites australis* and *Juncus kraussi,* indicate significant contributions of groundwater (Adams & Bates, 1999). Information from David Le Maitre (CSIR, *pers. comm.,* 2010) indicates that reeds found in and around the lagoon are not tolerant of sea-water salinity levels for more than a few weeks, yet have existed there for decades, despite the anticipated evaporative increase in salinity expected in the southern part of the lagoon and the low rainfall which is insufficient to maintain the reed beds. Thus, the Langebaan Lagoon, despite not having river inflow, is thought of as an estuary surrounded by a thriving wetland at the head as there is significant subsurface inflow.

Boreholes drilled around the edge of the lagoon as well as geophysical surveys have shown a significant inland hydraulic freshwater head intruding into the lagoon (Saayman et al. 2004). The borehole drilling information is detailed in a report prepared by the CSIR (Weaver et al. 1998). The authors collated borehole information, yield tests and borehole construction information to be able to determine the flow rates per geological formation. These results can be viewed in Appendix H in the GEOSS Draft Report 2014. Notably, the flow rates are high within the calcrete zone, whereas, typically calcrete are a low yielding geological formation. Also of relevance are the very high flow rates of the shallow sands in close proximity to the lagoon edge. Figure 5.4 shows the distribution of the CSIR borehole sites relative to Langebaan Lagoon and Elandsfontein.

The south-west corner of the proposed pit at Elandsfontein is 10 km away from BoreHole 1 at Geelbek. To try and understand the groundwater flow dynamics at Geelbek, a schematic of the geological cross-section was drawn, initially just with borehole details as metres below ground level (i.e. keeping the ground surface level) (Weaver *et al.* 1998). The cross-section is shown in Figure 5.3**.** Notice the high groundwater flow rates within the different portions of the cross-section and the presence of clay beneath the lagoon.

Of greater relevance, however, is to assess the geological cross-section that is corrected for elevation differences. Figure 5.3 shows the cross-section according to the elevation of the boreholes. There are a number of factors that result in the groundwater outflow in the Geelbek area. These are:

- The steep hydraulic gradient towards the lagoon from inland;
- The high flow rate (hydraulic conductivity of the calcrete) – permitting the flow of groundwater;
- The very high groundwater flow rate of the shallow sands in close proximity to the lagoon; and
- The presence of the clay beneath the lagoon, which will force the deeper groundwater flow upwards towards the lagoon.

Concern does exist that any groundwater abstraction and recharge may affect this flow of fresh groundwater into the lagoon, especially when viewing the bedrock topography of the Elandsfontein aquifer (Figure 5.5). Woodford and Fortuin (2003) assessed the groundwater recharge of the area and found that high recharge occurred to the east of the lagoon (Riefontein area). In addition, Woodford and Fortuin (2003) assessed the groundwater flow directions of the area and found that the flow into the lagoon is directly from the east of Geelbek (and not from the north-east where the Elandsfontein site is located). Another issue is whether the groundwater flow into Geelbek is from the Upper Aquifer Unit or Lower Aquifer Unit. From the geological section Figure 5.3, it's evident that the groundwater flow occurs in the Upper Aquifer Unit. In addition, Figure 5.6 shows a geological cross-section of the area (DWAF 2008). This cross-section also confirms the groundwater flow into the Geelbek area is from the Upper Aquifer System according to the GEOSS report.

Figure 5.4 **CSIR bore holes in relation to Langebaan Lagoon and Elandsfontein (depicted by white polygon).**

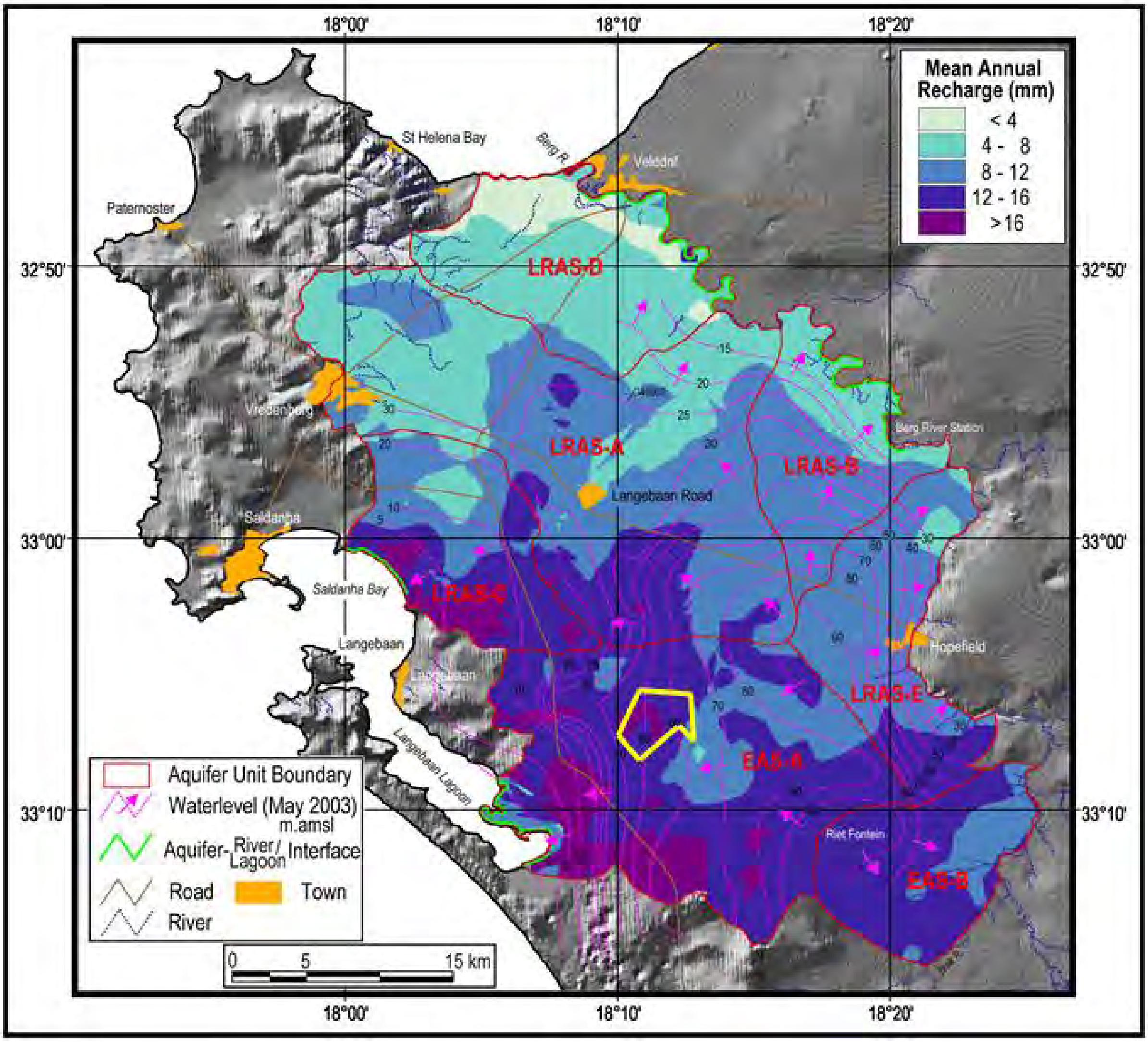


Figure 5.5 **Groundwater recharge map indicating Rietfontein and the groundwater flow direction towards Geelbek (Woodford & Fortuin, 2003).**

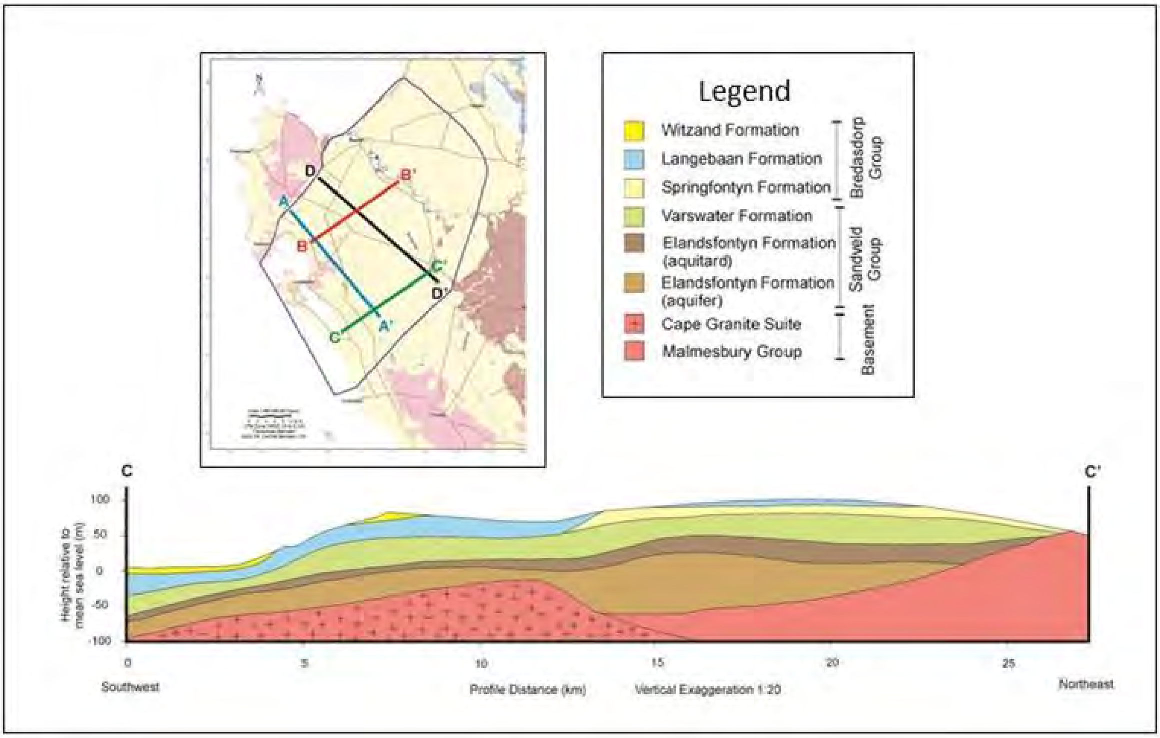


Figure 5.6 **Geological cross-section (C-C') beneath the Geelbek area (DWAF 2008)**

5.4 Results of groundwater modelling and monitoring

Seyler *et al.* (2016) have attempted to estimate groundwater flow to Langebaan Lagoon using a 3D groundwater flow model SPRING, developed by delta h Ingenieurgesellschaft mbH, Germany (König 2011). They modelled a dynamic equilibrium base case prior to abstraction being initiated by the West Coast District Municipality (WCDM) from the Langebaan Road Aquifer System and the Langebaan Road wellfields, in November 1999, and a series of steady state scenarios (n = 5) designed to replicate future states of dynamic equilibrium under a range of specified abstraction regimes at the WCDM wellfield (Table 5.1). The volume of water abstracted from the aquifer increased from around 4.94 million m^3/a under the base case scenario to a combined 18.53 million m^3/a under Scenario 5 (Table 5.1). Impacts of these increases in abstraction on the depth of the water table for the UAU and LAU near the lagoon edge and outflow rates to the lagoon from each of these aquifer systems are presented in Table 5.3 and Table 5.2, respectively. Net outflow to the lagoon from the UAU and LAU barely changes under the various scenarios, dropping from around 5.7 Mm^3/a under the base case to around 5.5 Mm^3/a under Scenario 5. For water level, water, the model predicts no change in the level of the UAU between the base case and the most extreme abstraction scenario modelled, and a very modest change in the water level for the LAU: <0.1 m at the waters' edge, increasing to 0.1-0.5 m, 500 m from the water's edge for Scenario 5. Thus, while the base case scenario incorporates abstraction of some 4.94 Mm^3/a from the Langebaan Road wellfields it is likely that this corresponds closely with the reference condition.

To characterise the actual flow of the upper aquifer, two boreholes were drilled to within the phosphate member and pumping tests were completed by GEOSS. The yield of the boreholes was approximately 2.5 ℓ/s and 0.8 ℓ/s respectively. During the pumping tests, five exploration boreholes were monitored and they showed no response to the abstraction. When the proposed mine reaches it full size, approximately 23 ℓ/s will have to be removed from the mine on all four sides of the pit.

Table 5.1 Historic and future groundwater abstraction scenarios for the West Coast District Municipality (WCDM) and the Langebaan Road wellfields. (Source: Seyler et al. 2016.)

Scenario	WCDM wellfield abstraction (million m3/a)	Dispersed abstraction (million m3/a)
Base case	0	4.94
Scenario 1	1.35	6.53
Scenario 2	3.5	6.53
Scenario 3	5.5	6.53
Scenario 4	7	6.53
Scenario 5	12	6.53

Table 5.2 Modelled change in water level in the UAU and LAU in the vicinity of Langebaan Lagoon under different abstraction scenarios (Source Seyler et al. 2016).

	Base case	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Drawdown at Langebaan Lagoon LAU (m)	n/a	<0.1	<0.1	<0.1, increasing to 0.1-0.5 ~680m from water	<0.1, increasing to 0.1-0.5 ~500m from water	<0.1, increasing to 0.1-0.5 500m from water
Drawdown at Langebaan Lagoon UAU (m)	n/a	<0.1	<0.1	<0.1	<0.1	<0.1

Table 5.3 Modelled groundwater flow results for base case and future scenarios. See 1.1 for details on scenarios (Source Seyler et al. 2016).

Aquifer Flux	Base case	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	million m^3/a	million m^3/a	% Change	million m^3/a	% Change	million m^3/a	% Change	million m^3/a	% Change	million m^3/a	% Change
Langebaan Lagoon UAU net	-0.6	-0.6	0%	-0.6	-1%	-0.6	-1%	-0.6	-1%	-0.6	-2%
Langebaan Lagoon LAU net	-5.1	-5.1	-1%	-5	-2%	-5	-3%	-5	-3%	-4.9	-4%
Langebaan Lagoon net	-5.7	-5.7	-1	-5.6	-3	-5.6	-4	-5.6	-4	-5.5	-6%

During the pumping tests extensive soil moisture monitoring took place and it was found that the soil moisture was not impacted by the groundwater abstraction (GEOSS Draft Report 2014). EEM planned to abstract the groundwater and then recharge it, via lateral drains, down-gradient of the proposed pit. The abstraction and recharge will take place in a closed system, ensuring the groundwater does not come into contact with the atmosphere thereby minimizing any alteration to the groundwater chemistry (GEOSS Draft Report 2014). The most suitable site still needs to be determined by GEOSS and EEM. It has been suggested that the proposed mining operation does go deeper than the base of the Muishond Fontein Pelletal Phosphorite Member. The Lower Aquifer Unit, which is the higher yielding aquifer, must remain intact. The geohydrological project steering committee have recommended the establishment of a permanent groundwater monitoring network for both the Upper and Lower Aquifer Systems (GEOSS Draft Report 2014). A preliminary design has been completed of the monitoring boreholes for both the upper and lower aquifer. Groundwater level loggers be installed at all GEOSS monitoring sites and it has been suggested that the boreholes be designed so that accurate groundwater sampling can be carried out.

Groundwater recharge in the area is between 16 and 24 mm/a (in the order of 7 % of MAP) and although recharge possibly occurs further east this still gives an indication of the need to manage and conserve the groundwater resource appropriately. From the DWAF 1:500 000 hydrogeological map series the exploration area plots in an intergranular aquifer with a groundwater yield of 0.1 - 0.5 ℓ/s and is near an area with a mapped yield of 0.5 – 2.0 ℓ/s. Further tests will be required to confirm the accuracy of the DWA mapping. The DWA (DWAF, 2008) modelling of the Langebaan and Elandsfontein aquifers which shows the major groundwater flow passes through the farm/exploration area (Figure 5.2) (GEOSS Draft Report 2014).

WDCM and DWS have provided the most current data on the LRAS water level and abstraction rates from two municipal boreholes (GIN0189 and GIN0190, Figure 5.7) where it is clear that while natural recharge to the system does occur, the overall temporal trend is a decrease in the water level over time. It is critical that all stakeholders get a deep understanding and consensus between groups on the long term sustainable amounts of water abstraction rates (volume over time) as a collective. The delineation and existence of separate aquifer systems is useful so that we know abstraction from one area won't be impacting on another area, but clear and concise consensus between the various groups involved on numbers of present and proposed abstraction rates and natural and unnatural recharge rates is extremely critical in order for this natural resource to be monitored and managed appropriately and legally.

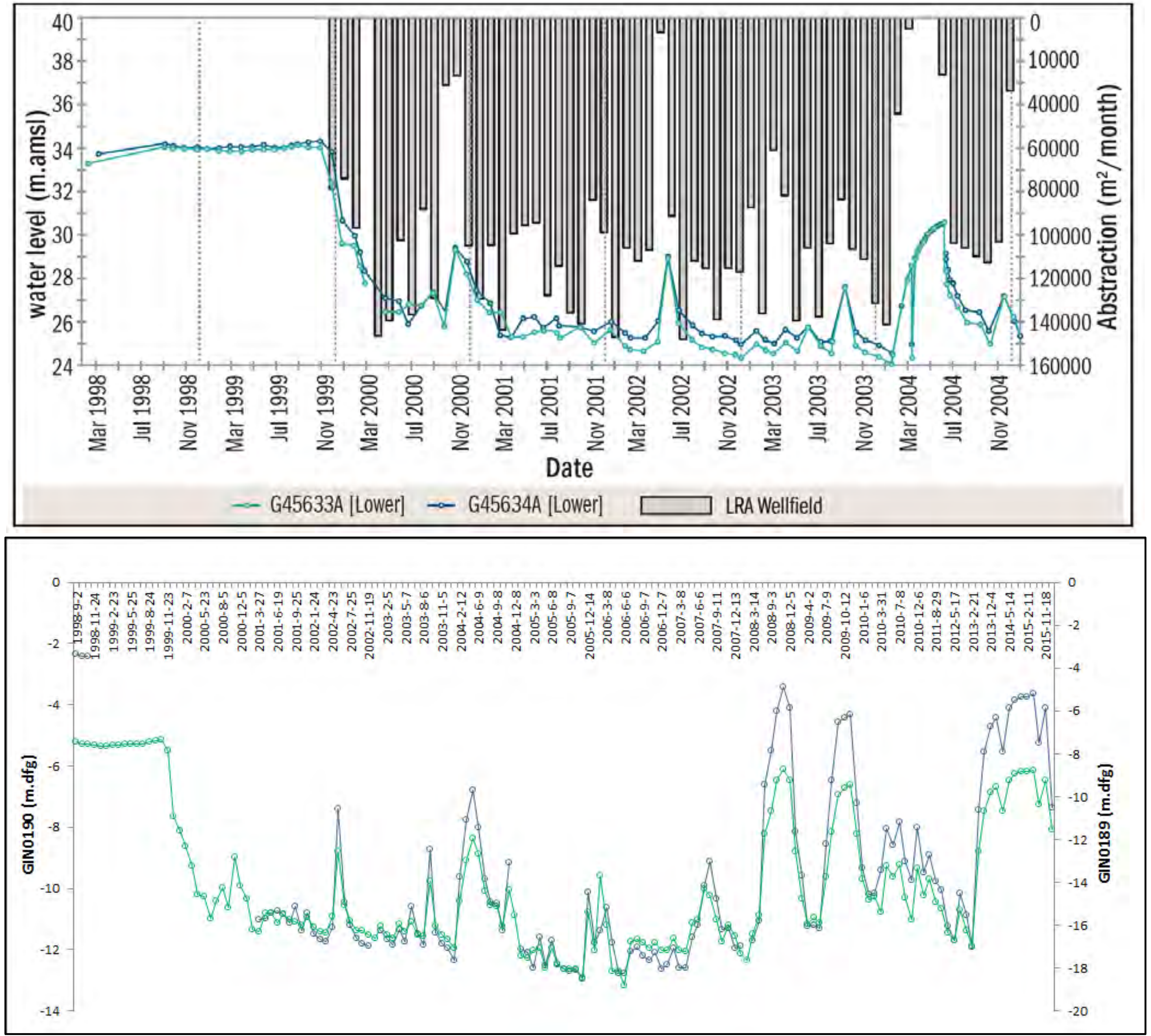


Figure 5.7 **Monthly abstraction and water level in the Upper and Lower Aquifers in the vicinity of the Langebaan Road Wellfield (up to Jan 2016) (Redrawn from SRK 2005).**

In addition to GEOSS and WDCM ground water level monitoring, the SBWQFT has established an independent water quality monitoring regime in Langebaan Lagoon. For the past year, water quality (salinity/conductivity), macro benthos and coverage by macrophyte communities in the Geelbek area of Langebaan Lagoon have been monitored. Data on macrobenthos and vegetation monitoring are included in their respective chapters in this report. Salinity has been monitored by a temperature/salinity logger that is able to take measurements at frequent intervals (roughly every 10 minutes) at a site near the head of Langebaan Lagoon. This first year of monitoring is considered to be the baseline condition that can be referred to once mining has commenced.

Upon retrieval in December 2016 of the first three months data from the moored CTD, a significant drift in salinity was apparent (Figure 5.8). It was suspected that the depth of the water where the mooring was placed was too shallow. The length of the subsurface mooring line may also have allowed the instrument to be exposed to air at times, thus introducing air bubbles into the sensor head and causing it to read and record inaccurately. In Figure 5.8 the fluctuation in the depth of the instrument coinciding with tidal change, as well as the unrealistic decrease in salinity values overtime pointed to the need to change the positioning of the instrument. The mooring was thus shifted to the deepest part of the channel, the mooring line extended, as well as weights added above and below the CTD in order to keep the instrument upright and submerged at all times, regardless of tidal height. A 'check-in' retrieval and data download after one week indicated that the instrument was recording accurately at that time (Figure 1.10).

As expected in this area in summertime, conditions are predominantly hypersaline (Christie 1981, Krug 1999). Historically, salinity at the head of the Lagoon has been recorded as increasing steadily from October to January, up to a maximum of 38.04 PSU due to evaporation (Christie, 1981). Salinities reaching an excess of 43.00 PSU have been recorded in the salt marsh areas here and are correlated to water temperature and solar radiation (Christie 1981). In general the variation in salinity coincides with the tides whereby it decreases with an increase in tidal height and increases at lower tides (Figure 5.9). This effect is compounded by higher temperatures during the day, thus pushing salinity values to their maximum. Temperature has a diurnal pattern whereby it decreases at night and rises again during the day (Figure 5.9). Additionally, the depth of the instrument remains near to constant providing assurance in CTD positioning in the water column (Figure 5.9).

Another retrieval and re-deployment took place in April where again a significant drift as well as erroneous noise was apparent in the data. Following further investigation, it was discovered that the instrument was faulty and was subsequently recalled by the manufacturer. Additional problems were encountered with the new instrument at which stage the manufacturer replaced it again. Once a new instrument was acquired and redeployed results were recorded from 30 June to July 20, 2017. Upon retrieval on 25 August it was discovered that the instrument had been stolen and the data from 20 July to 25 August was lost. A third new instrument was deployed on 31 August and will be downloaded on 20 October 2017.

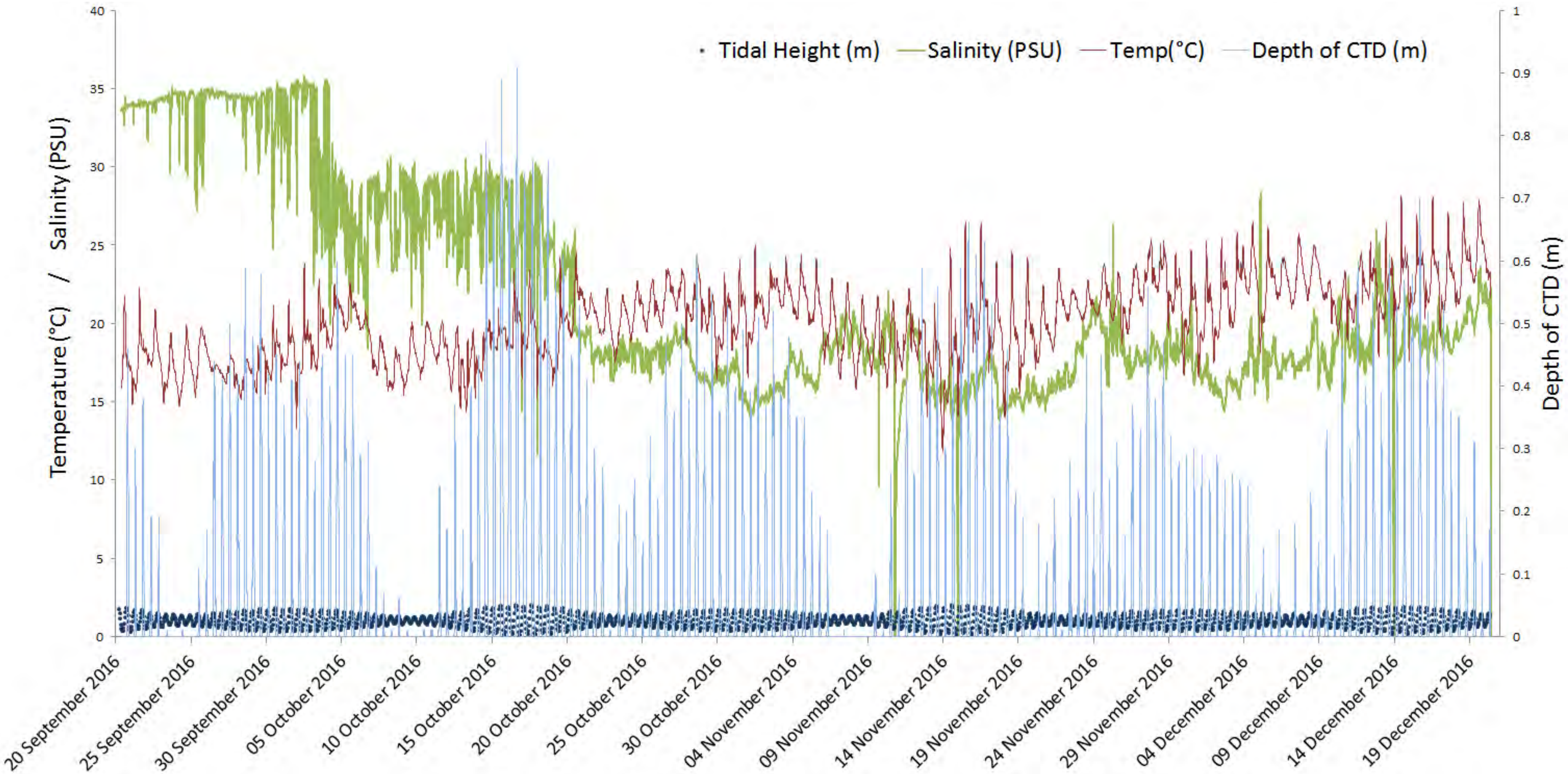


Figure 5.8 **Salinity (green), temperature (red) and instrument depth (light blue) in ten minute intervals over a three month period from September through December. Tidal data (dark blue points) are in hourly intervals over the same time period (tidal data provided by hydrographer, SA Navy).**

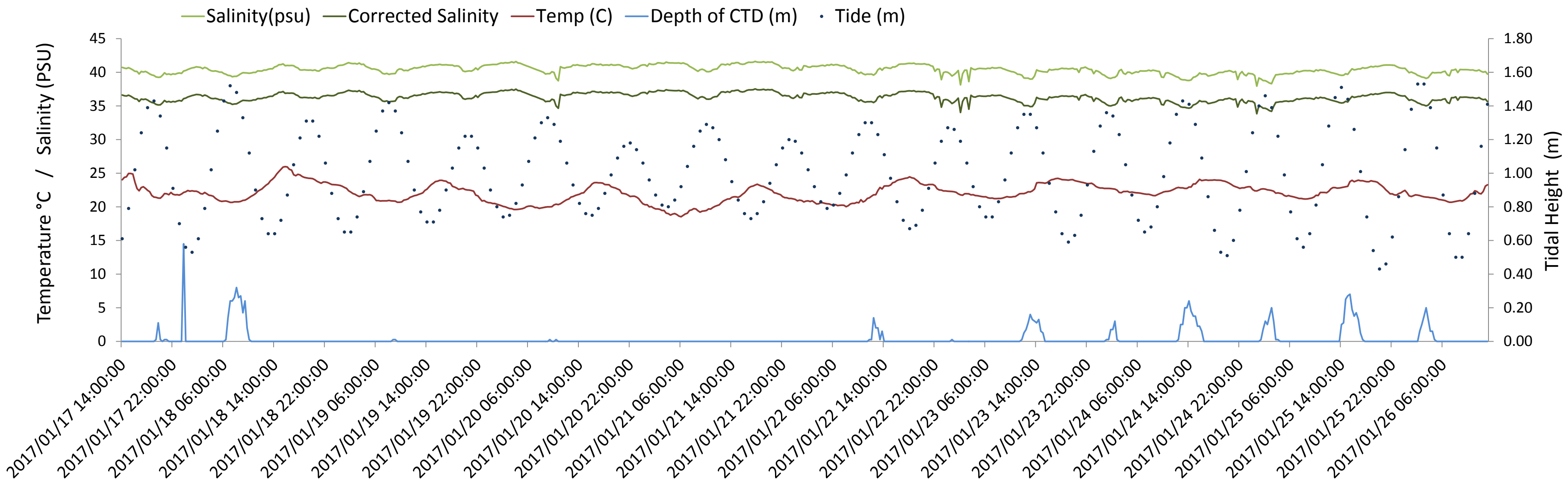


Figure 5.9 **Salinity (green), temperature (red) and instrument depth (light blue) in twenty minute intervals over a nine day period in January 2017. Tidal data (dark blue points) are in hourly intervals over the same time period (tidal data provided by hydrographer, SA Navy). Grey shaded blocks indicate day-night cycle.**

6 WATER QUALITY

6.1 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). A trial deployment of a conductivity temperature and depth (CTD) instrument in this vicinity in April 2017 also provided six weeks of recent data in this area. A thermistor string comprising five underwater temperature meters (UTMs), used for continuous monitoring of water temperature in the Bay, was deployed at North Buoy in Small Bay in April 2014 by Anchor Environmental on behalf of the SBWQFT. The intention was to maintain this array in situ for as long as possible but unfortunately the thermistor string had disappeared (lost or stolen) when we sought to retrieve it to download the accumulated data in 2016. The thermistor string has since been replaced but unfortunately the data for 2015-2016 has been lost. 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.

6.2 Circulation and current patterns

Circulation patterns and current strengths in Saldanha Bay prior to development (1974-75) were investigated using various different 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 6.1). 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 terminal (Figure 6.1).

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.

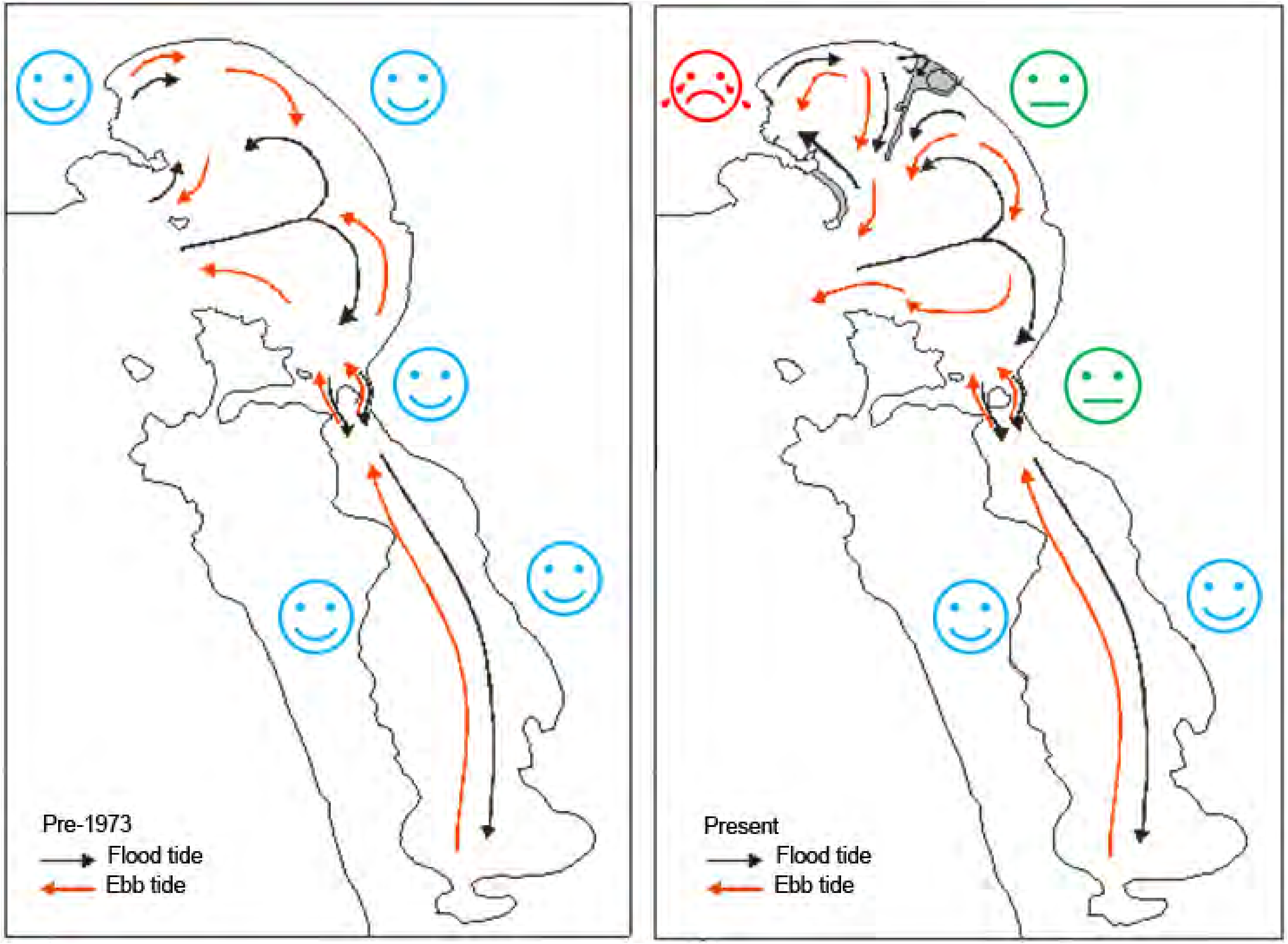


Figure 6.1 **Schematic representation of the surface currents and circulation of Saldanha Bay prior to the harbour development (Pre-1973) and after construction of the causeway and iron ore terminal (Present) (Adapted from: Shannon & Stander 1977 and Weeks et al. 1991a).**

6.3 Wave action

Construction of the iron ore terminal 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 6.2). 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 6.3). 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).

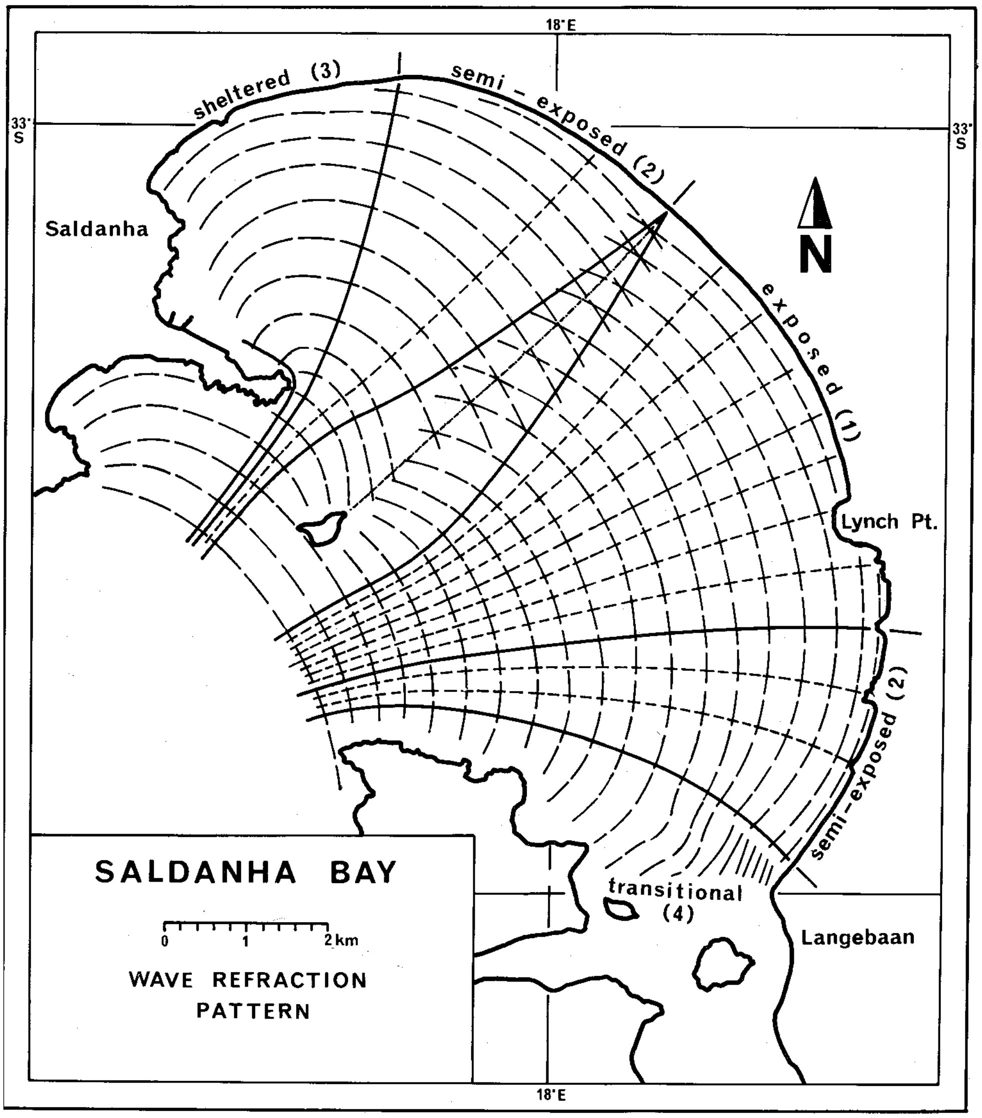


Figure 6.2 **Predicted wave field in Saldanha Bay showing wave height and direction prior to harbour development (Source: Flemming 1977).**

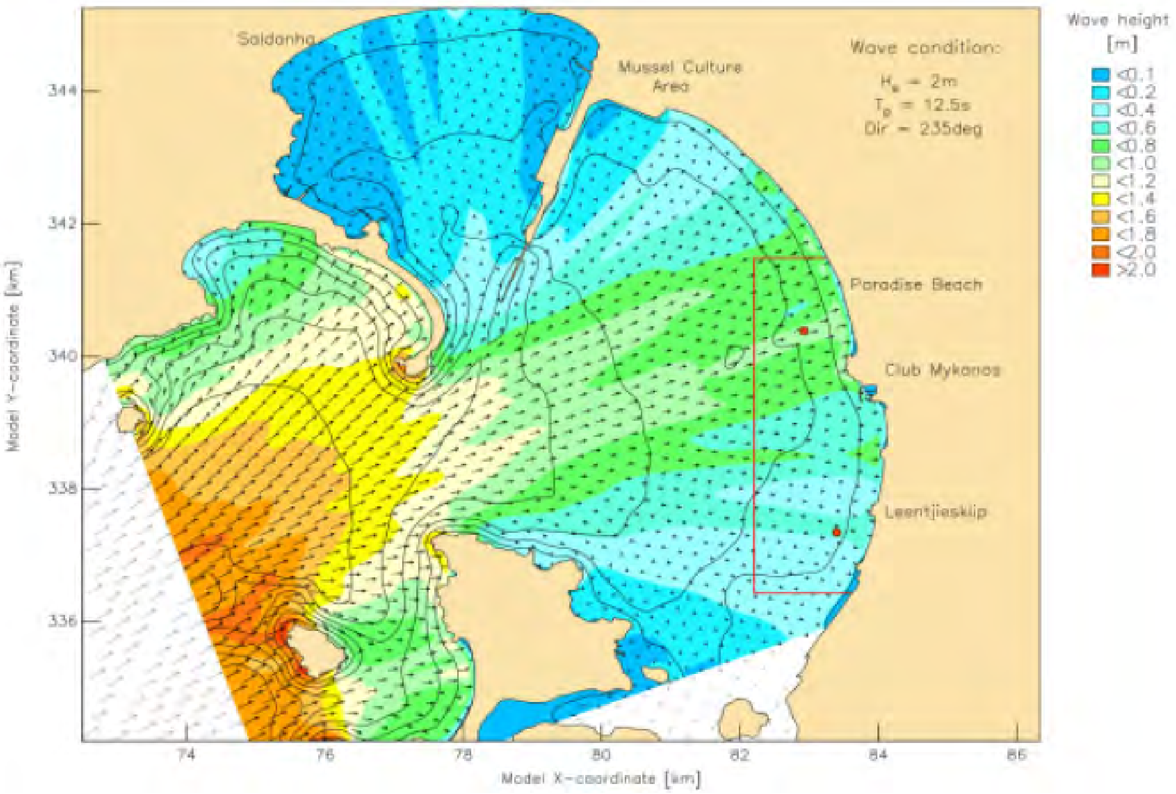


Figure 6.3 **Predicted wave field in Saldanha Bay showing wave height and direction after the construction of the causeway and the iron-ore Terminal (Source: WSP Africa Coastal Engineers, 2010).**

6.4 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 16.0-18.5°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 6.4. 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 6.4). 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 6.4). 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 6.4).

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 6.8), 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 6.4) 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.

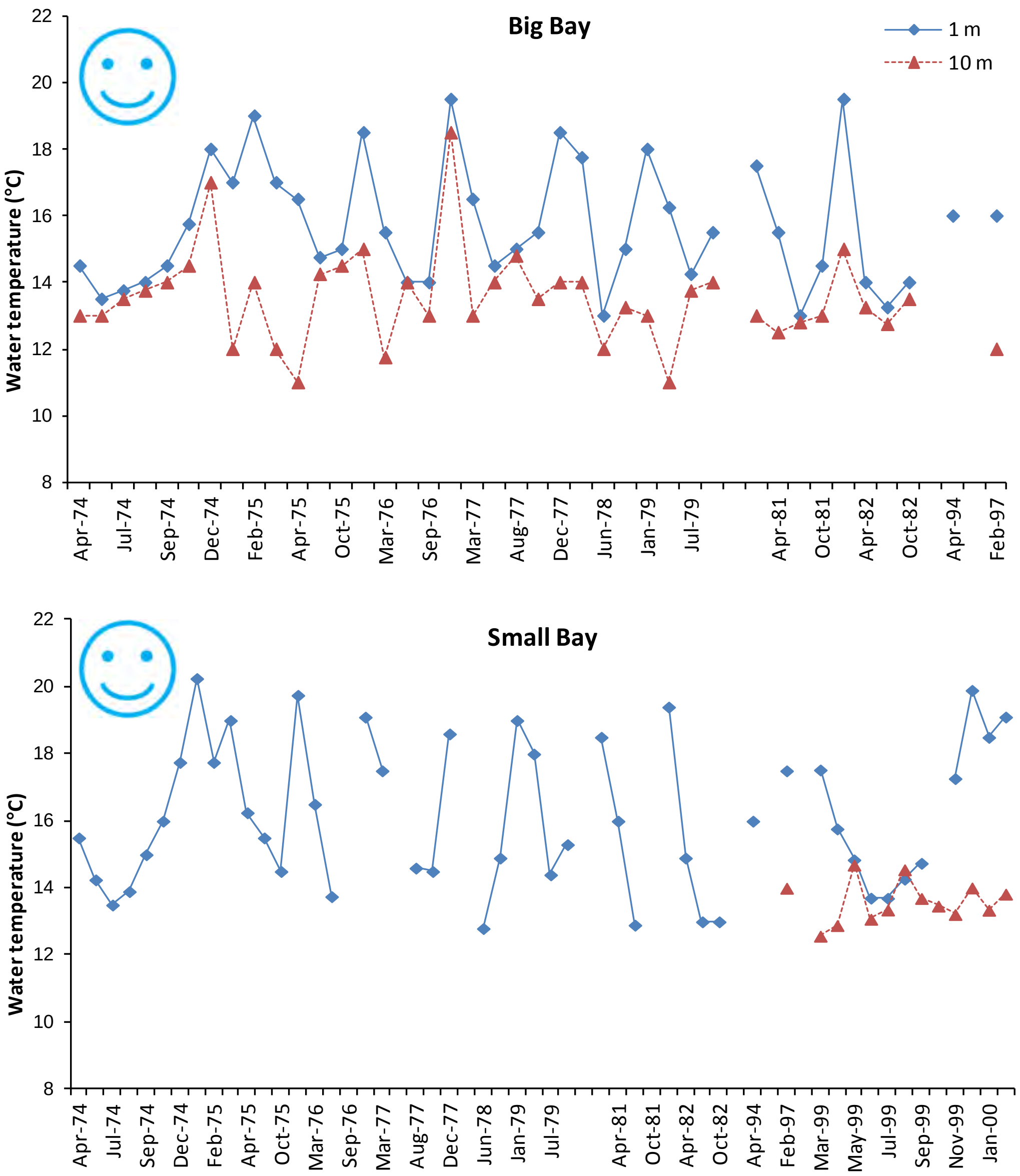


Figure 6.4 **Water temperature time series at the surface and at 10m depth for Big Bay and Small Bay, Saldanha Bay (Data: Monteiro *et al.* 1990, Monteiro & Brundrit 1990. Monteiro *et al.* 2000 and Shannon & Stander 1977).**

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 6.4. 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 6.4). 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 6.1 and indicated on Figure 6.5. 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.

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 as remote from the discharge as is the Big Bay site.

Table 6.1 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	1 875	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

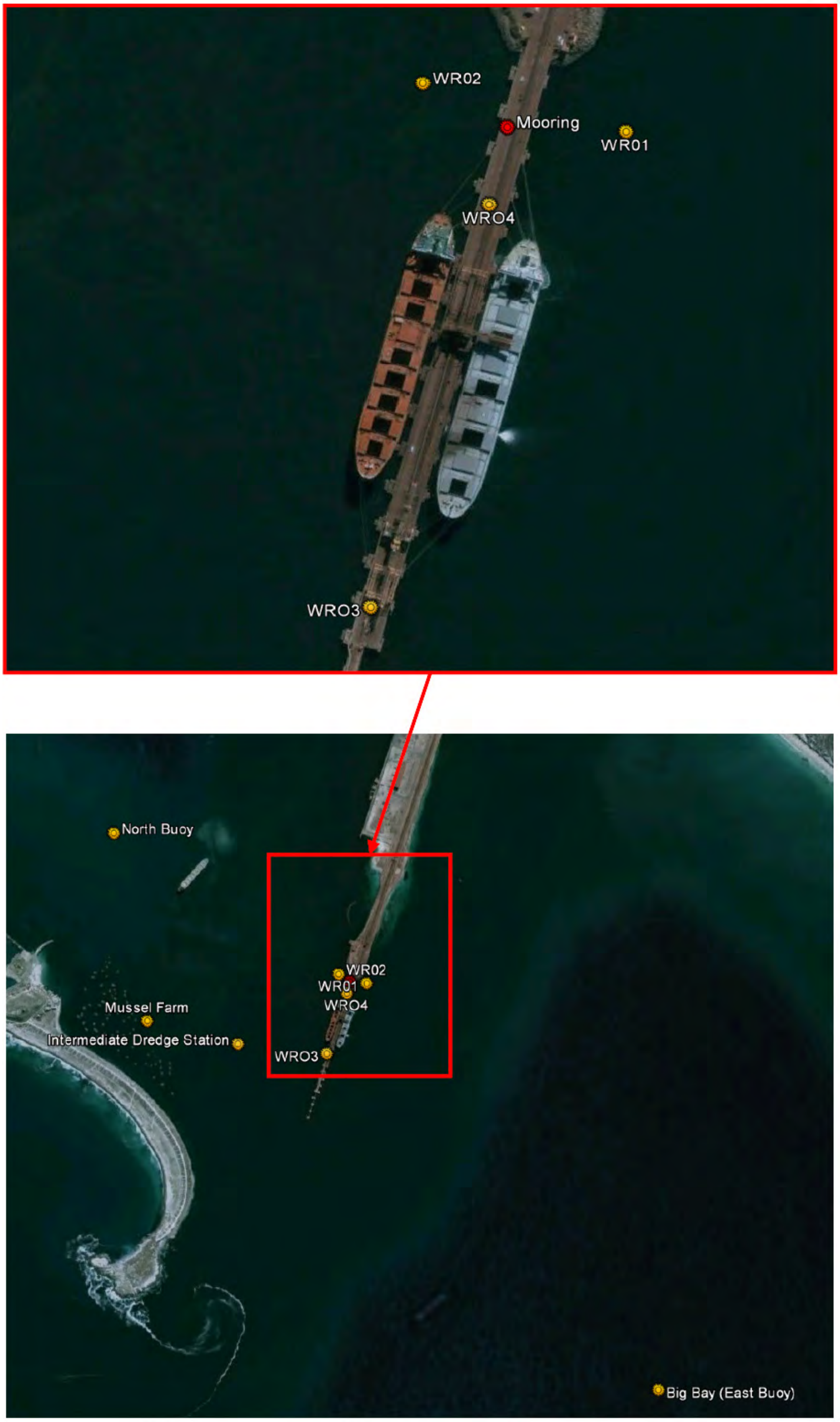


Figure 6.5 **Water quality monitoring stations adopted for the RO plant baseline survey undertaken by the Council for Scientific and Industrial Research (Source: van Ballegooyen *et al.* 2012).**

Examples of the temperature data from the water column profiling exercises undertaken at North Buoy are shown in Figure 6.6. 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 enters the Bay.

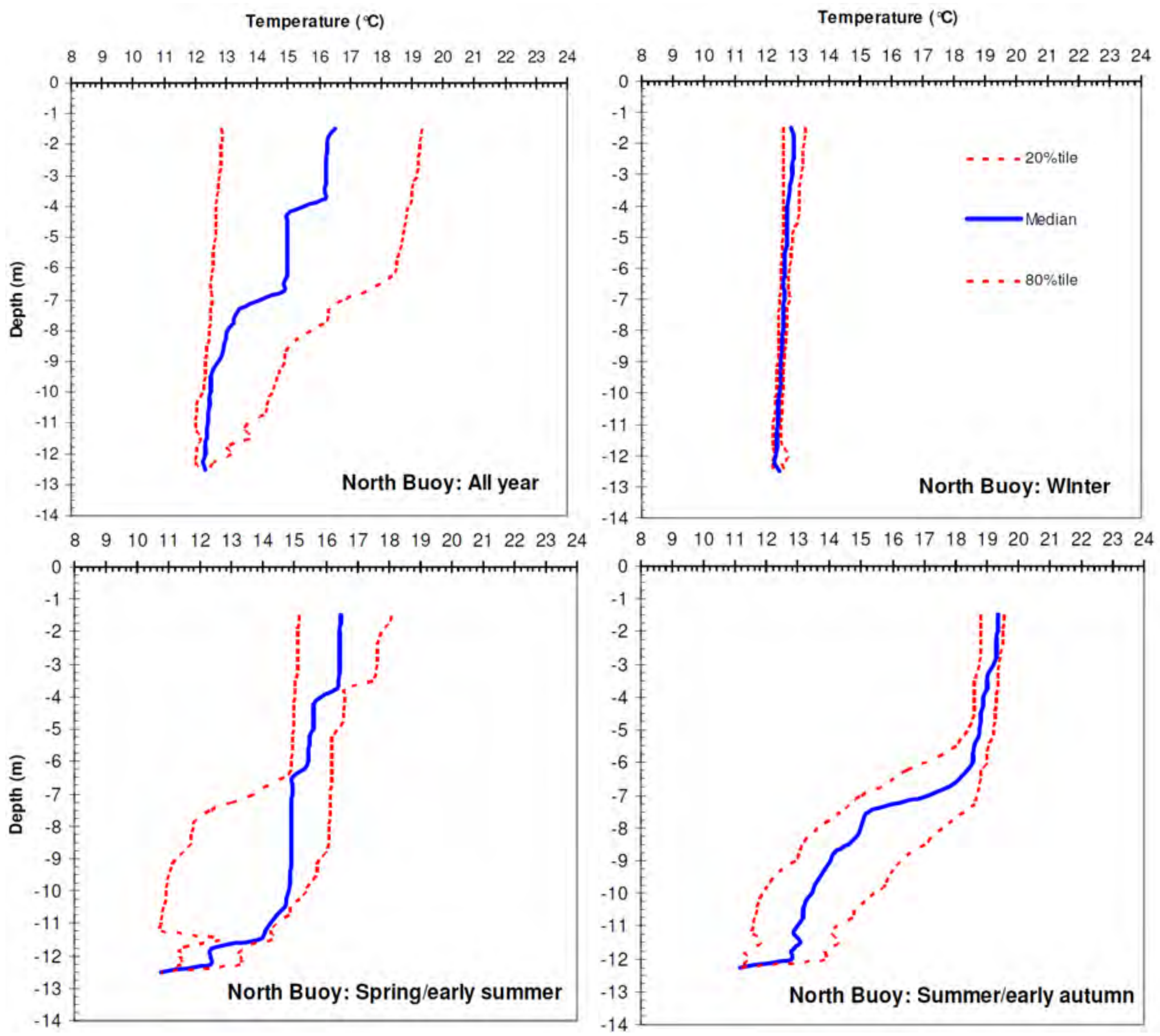


Figure 6.6 **Seawater temperature median profiles at North Buoy for all seasons (winter, spring/early, summer and summer/early autumn). The 20 and 80 percentile limits of the profiles are indicated by the dotted red lines (Source: van Ballegooyen *et al.* 2012).**

With a view to continuing the long term temperature data set at North Buoy, five Vemco mini-loggers, programmed to record temperature every six minutes were deployed at 2.0 m, 4.5 m, 7.0 m, 9.5 m and 12.0 m depth on the 12 April 2014. These thermistors were retrieved and serviced on the 22 April 2015. Unfortunately the thermistor string was missing when we attempted to retrieve it in March 2016 (lost or stolen) which means that data accumulated between April 2015 and March 2016 was lost. The thermistor string was replaced in March 2016 and successfully retrieved and redeployed in April 2017. Data for the two periods (2014/2015 and 2016/2017) are shown in Figure 6.7.

The data from 2014/2015 and 2016/2017 show a similar pattern to historical data, with high variability and water column stratification evident from September to May (i.e. from spring through to autumn) and a well-mixed, isothermal water column in the winter months (Figure 6.7). Variation in bottom water temperature is greater than in the surface waters and appears to happen over synoptic time scales as noted by van Ballegooyen *et al. (*2012). Relaxation of upwelling and the down mixing of warmer surface waters, or the intrusion of warm oceanic waters that results in warming of the bottom water is most frequently observed in Spring-early summer and late Summer-early autumn. It is interesting to note that the duration of the winter isothermal water column period during 2016 (June and July) was noticeably shorter than that seen during the winter of 2014 (when the water column remained mixed until late August). During the summer months of 2016/17 the stratification of the water column also appeared more persistent with a mixed water column evident on fewer occasions than during the 2014/15 summer. This more persistent stratification indicates more steady southerly winds and fewer upwelling relaxation events during the latter monitoring period. This inter annual variation is not unusual and may be linked with *El Nino- La Nina* climatic cycles. The monthly average bottom (12-14°C) or surface (13-20°C) water temperatures are similar to those recorded in earlier monitoring (since 1974) (Figure 6.4). Establishment of continuous, high temporal resolution water temperature monitoring will, however, prove valuable in analysing long term trends. This is an economically viable way of detecting changes in the frequency of anomalous conditions such as the intrusion of warm oceanic water events etc. which would have significant impacts on ecosystem productivity and health.

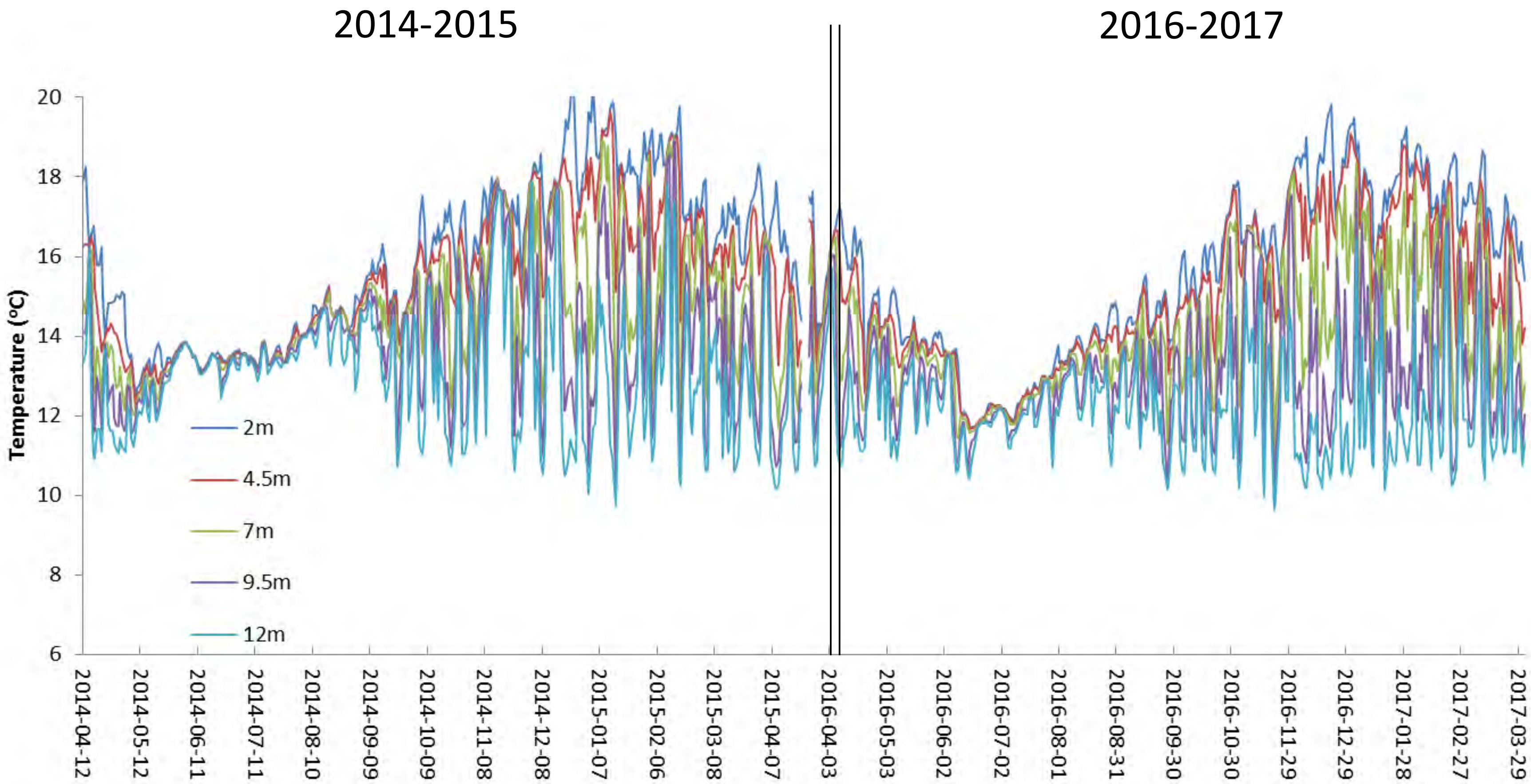


Figure 6.7 **North buoy temperature time series for the period 12 April 2014 - 22 April 2015 and the 23 March 2016-1 April 2017. The average daily temperature is shown (temperature was recorded every six minutes and the daily average is shown).**

6.5 Salinity

Salinities of the inshore waters along the west coast typically vary between 34.6-34.9 practical salinity units (PSU) (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 6.8). 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 6.8. 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 6.8). 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 6.9). 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 6.10 (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).

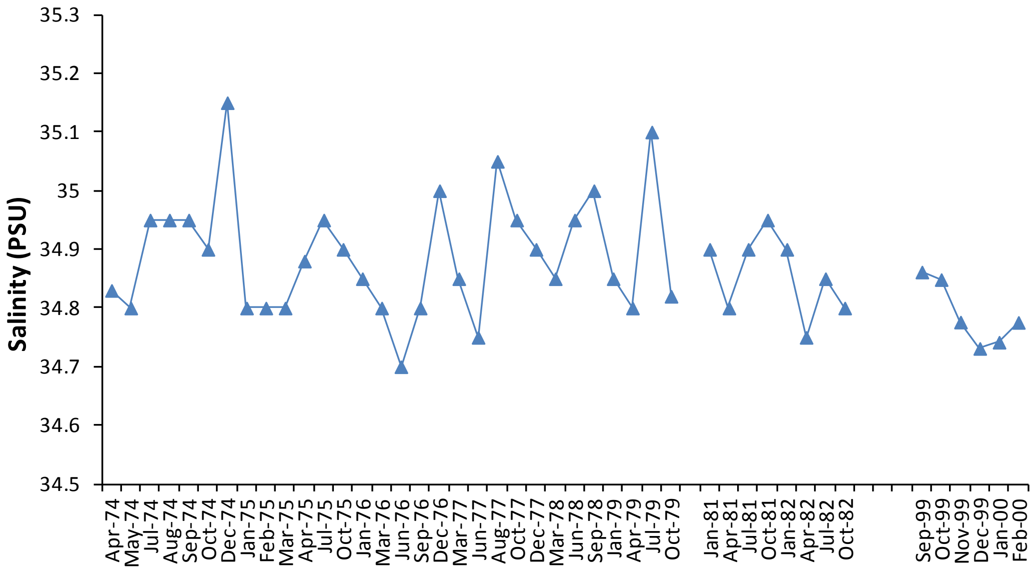


Figure 6.8 **Time series of salinity records for Saldanha Bay (data sources: Shannon & Stander 1977, Monteiro & Brundrit 1990, Monteiro et al. 1990 and Monteiro et al. 2000).**

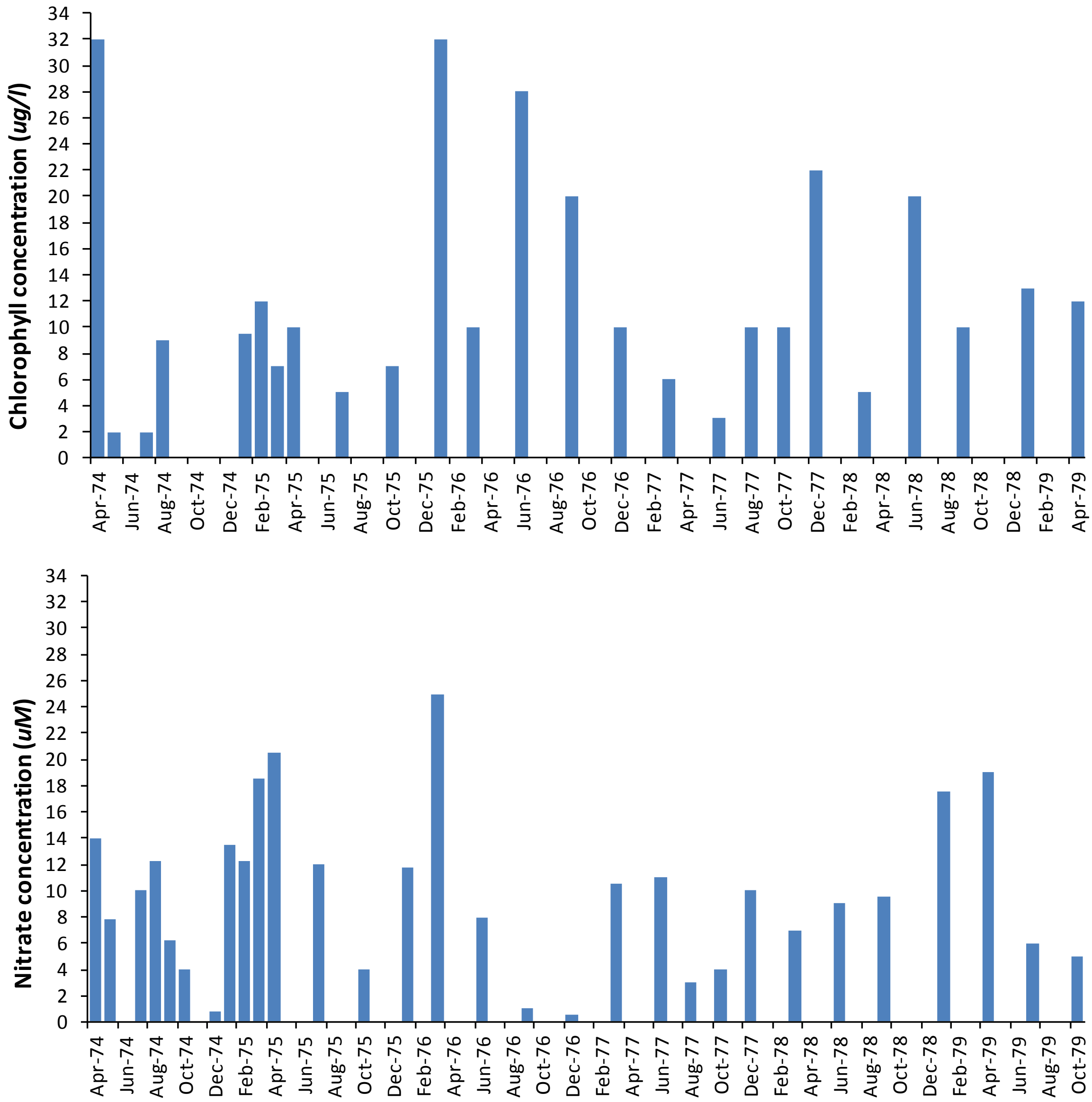


Figure 6.9 **Time series of chlorophyll and nitrate concentration measurements for Saldanha Bay (Data source: Monteiro & Brundrit, 1990).**

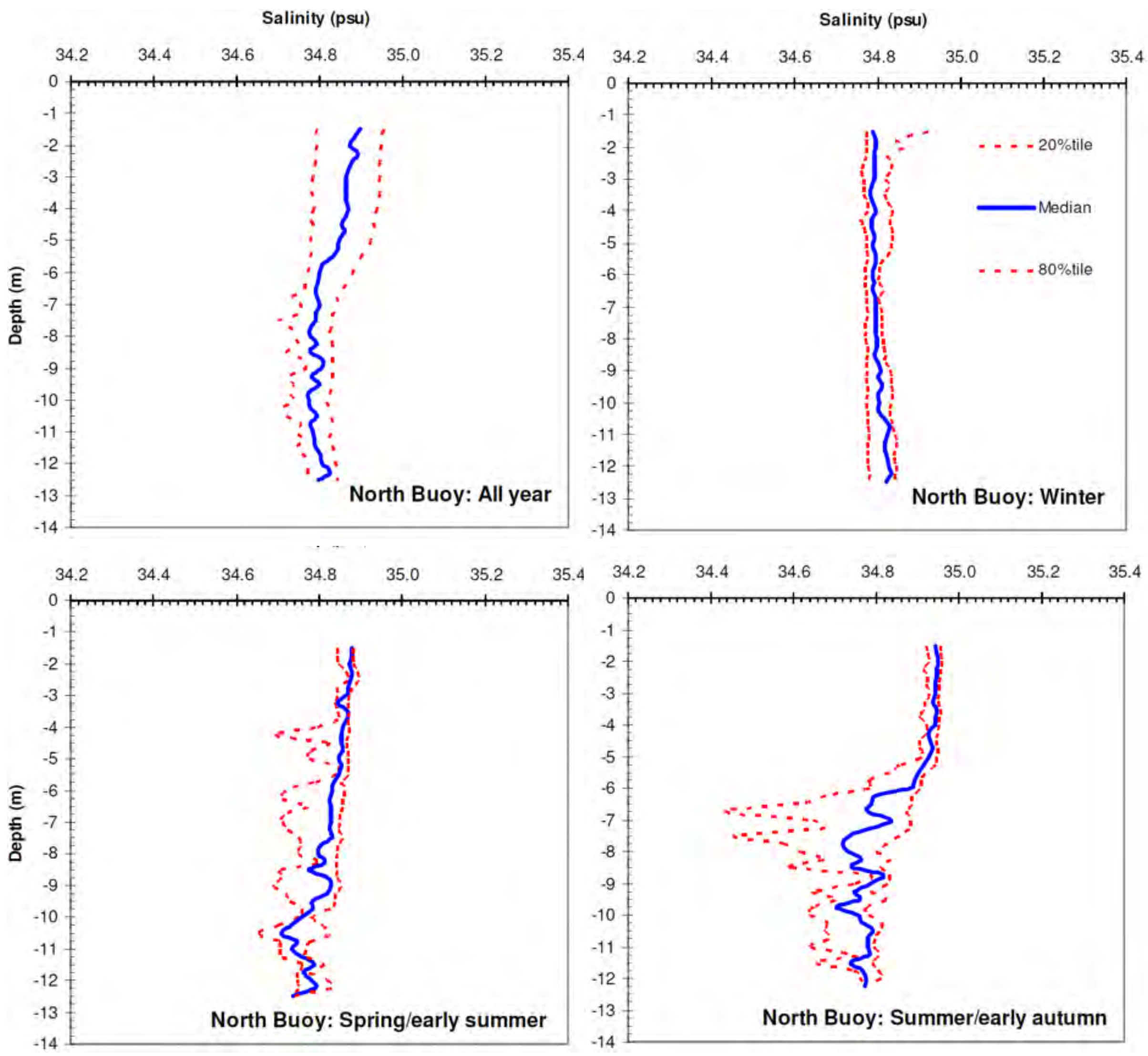


Figure 6.10 **Salinity median profiles at North Buoy in Small Bay for all seasons (winter, spring/early, summer and summer/early autumn). The 20 and 80 percentile limits of the profiles are indicated by the dotted red lines (Source: van Ballegooyen *et al.* 2012).**

6.6 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 (highlighted red in Figure 6.11). 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 6.9.

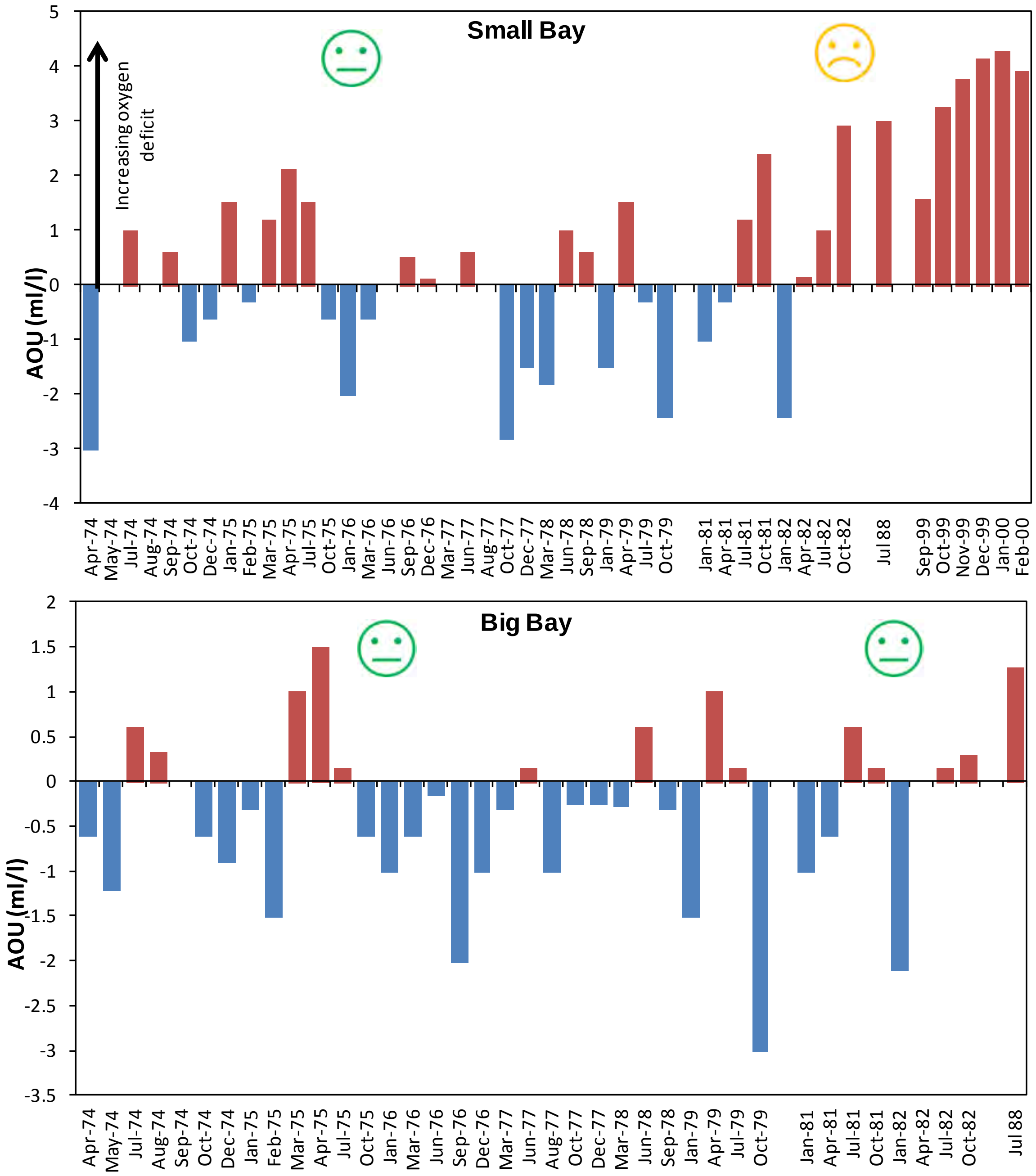


Figure 6.11 Apparent oxygen utilization time series for Small Bay and Big Bay in Saldanha Bay. Positive values in red indicate an oxygen deficit (Data sources: Monteiro *et al.* 1990 and 2000).

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 6.11). 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 6.11). 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 oxygen data from the water column profiling exercises undertaken by the CSIR at North Buoy in 2010/2011 are shown in Figure 6.12 (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 m, and 5.13 ± 1.80 mg/l at -20m for period April 1974 to October 1975.

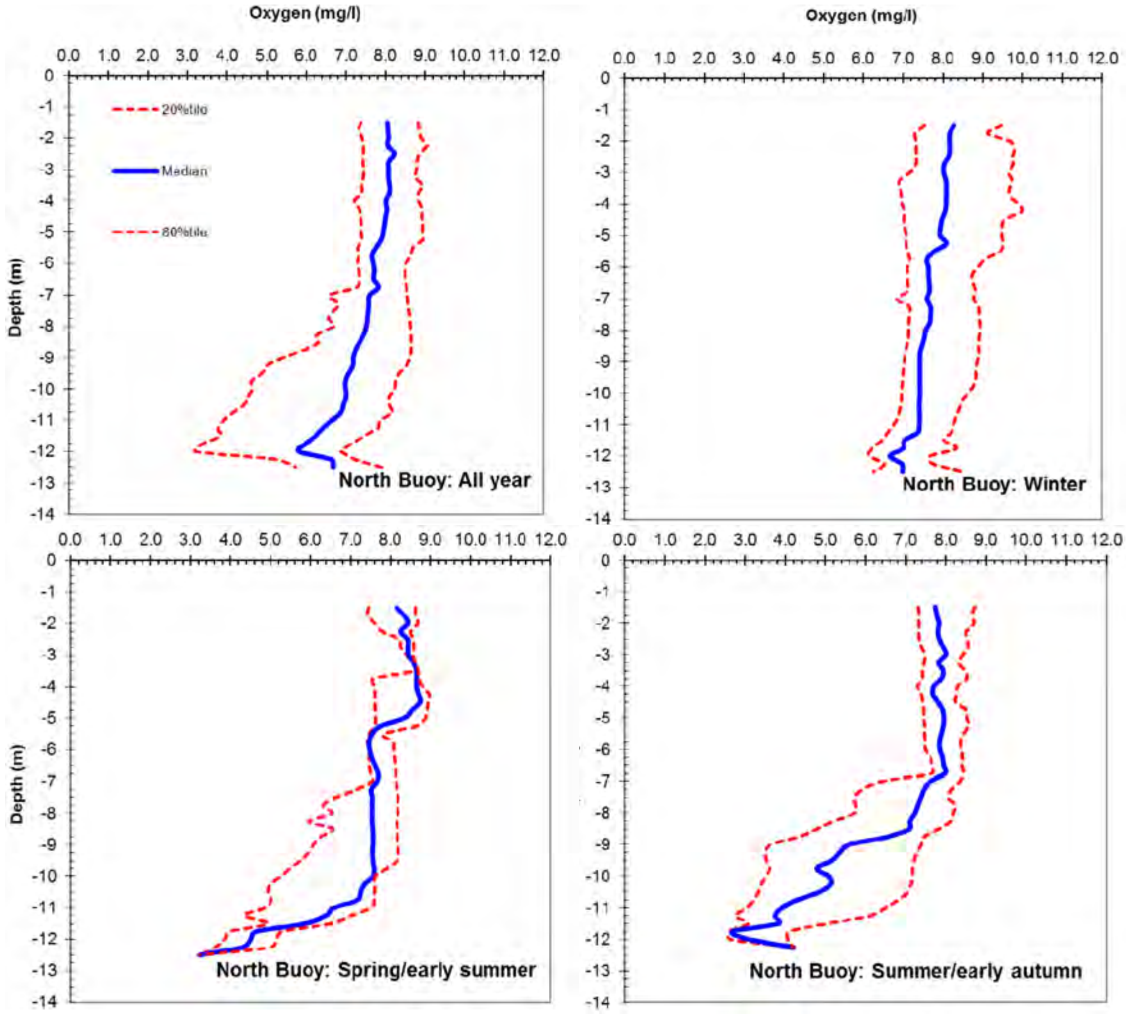


Figure 6.12 **Dissolved oxygen concentration median profiles at North Buoy for all seasons (winter, spring/early, summer and summer/early autumn). The 20 and 80 percentile limits of the profiles are indicated by the dotted red lines (Source: van Ballegooyen *et al.* 2012).**

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 (Figure 6.13). 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 advects 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. Coupled with vertical mixing, this 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; and
- 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.

The CTD deployment during April-May 2017 in 22m water depth on the Big Bay side of the RO Plant discharge was very close to the mooring deployed by the CSIR in 2010-11. The instrument recorded depth, temperature, pH salinity and dissolved oxygen at 20 minute intervals (Figure 6.14). The data show the same synoptic scale variability in temperature and dissolved oxygen as reported by van Ballegooyen *et al.* (2012) with a positive correlation between dissolved oxygen and temperature reflecting alternate stratification and water column mixing associated with upwelling and relaxation phases over 3-10 day periods. During this late autumn deployment, dissolved oxygen levels were noticeably lower than those recorded by the CSIR mooring that was deployed shallower water (18 m vs 23 m) and during the spring-early summer period. The very low dissolved oxygen values recorded for a short period in early May (1-2 $mg.l^{-1}$) are below the level that is tolerable for many invertebrates and most fish. This low oxygen event was associated with an influx of cold water from the adjacent coast where low oxygen water is known to occur during autumn. Salinity remained constant with a narrow range for most of the deployment period except for two sharp drops to just below 33.5 ppt (these are probably anomalous readings due to instrument error). No salinity spikes were detected in the data series indicating that discharges of brine from the RO plant were not detected at the mooring site during the deployment. (Note that it is not known if the RO Plant was operational during this period).

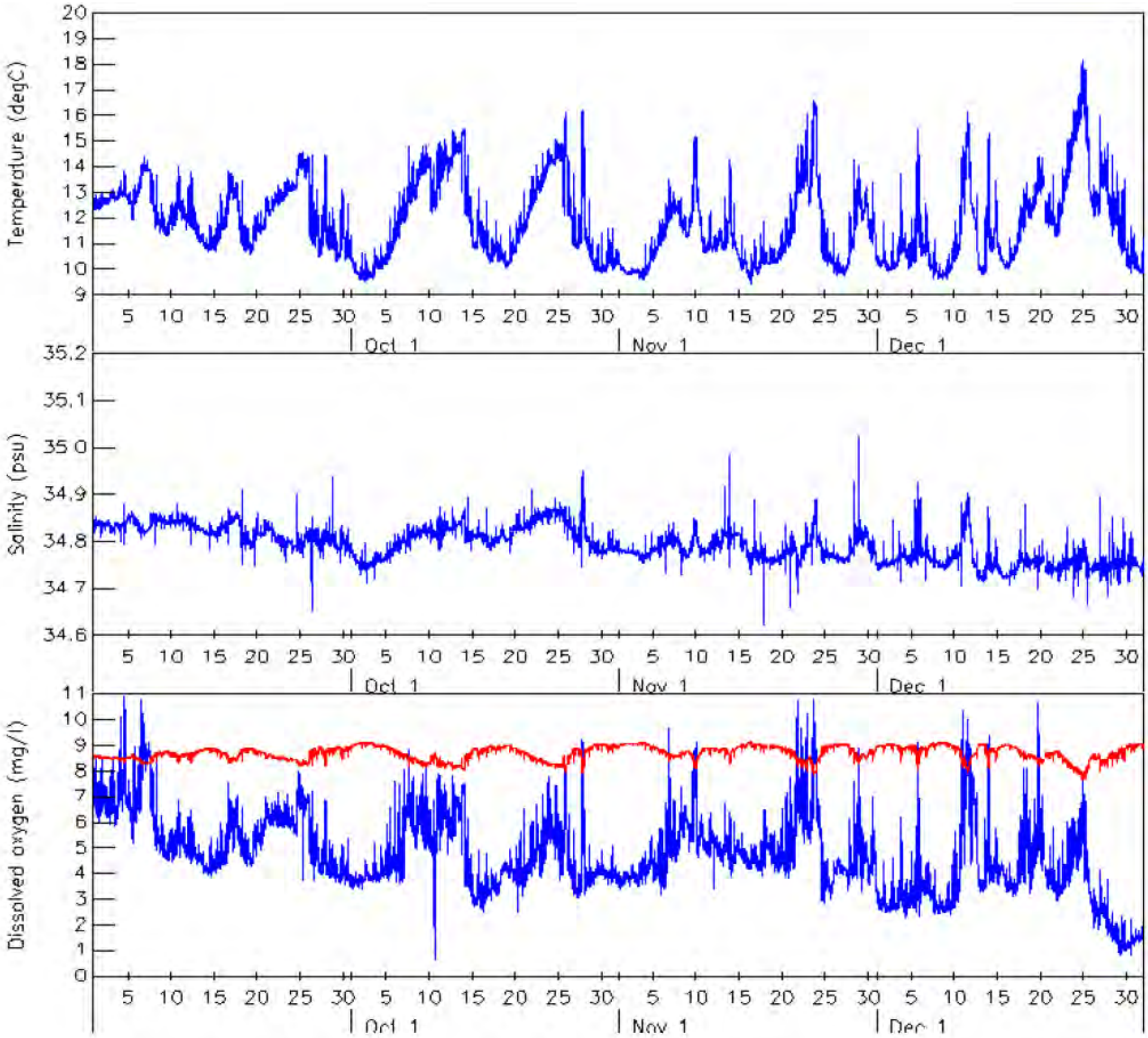


Figure 6.13. Time series of water temperature, salinity and dissolved oxygen concentration from the mooring site (33° 01.679'S: 17° 59.143'E) for spring/early summer (Source: van Ballegooyen *et al.* 2012).

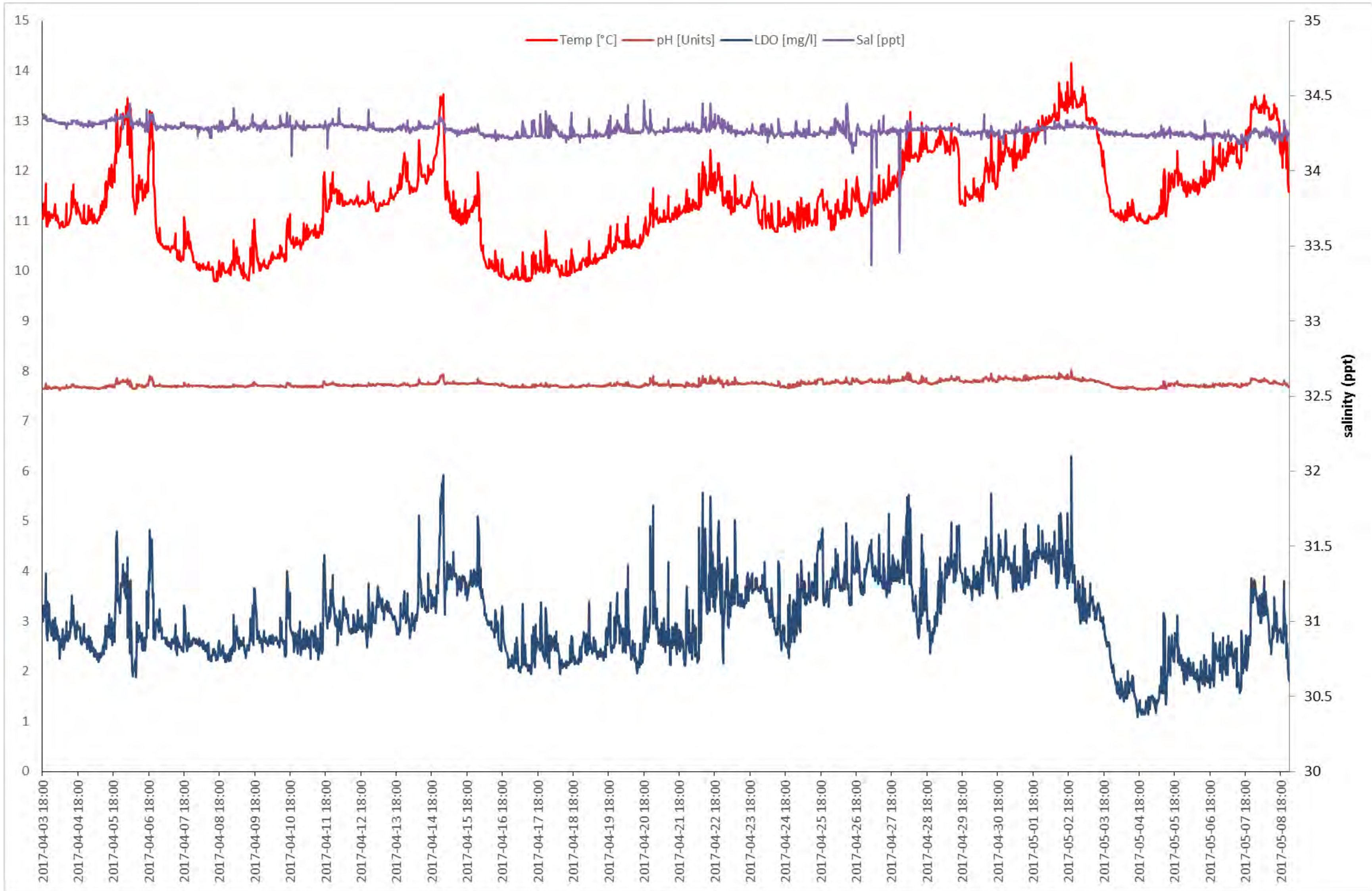


Figure 6.14. Temperature, salinity (sal), pH and dissolved oxygen (DO) recorded by the CTD deployed in 23 m water depth adjacent to the RO plant discharge at the base of the iron ore terminal.

6.7 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 2010/2011 (van Ballegooyen *et al.* 2012). Turbidity data for the North Buoy site in Small Bay are shown here (Figure 6.16). 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-iron ore terminal). 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 6.15 Turbidity generated under high wind conditions (top) and by propeller wash (bottom) in Saldanha Bay (Source: van Ballegooyen *et al.* 2012).

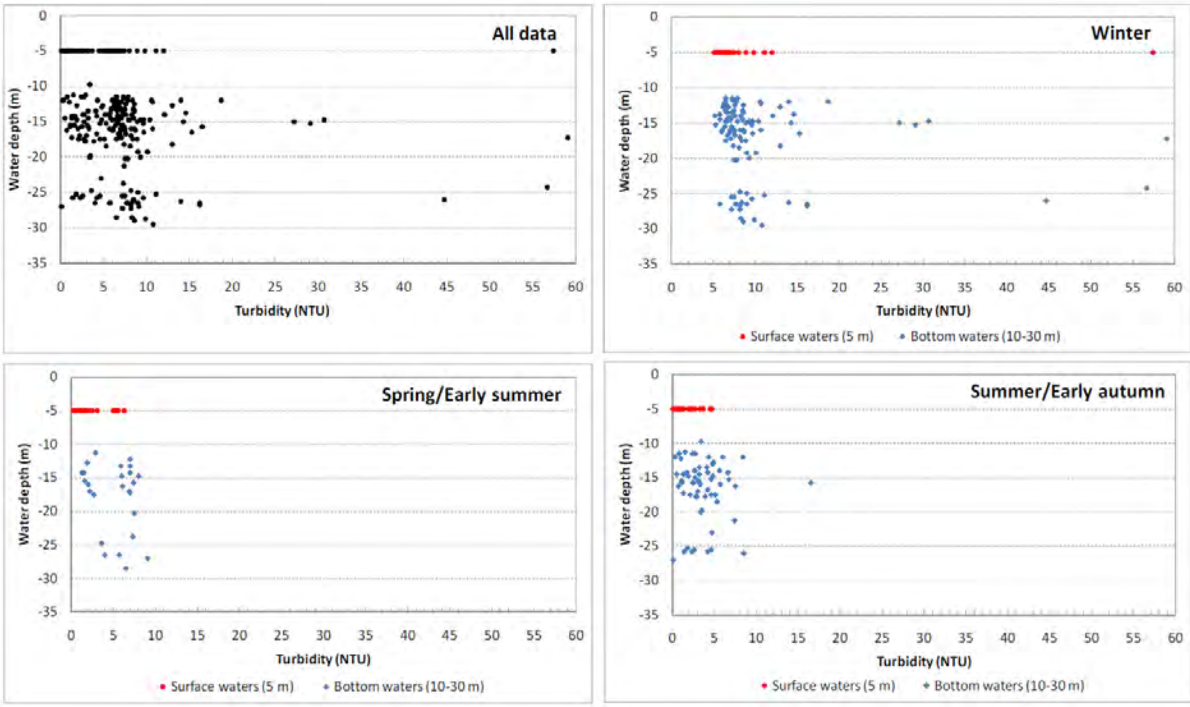


Figure 6.16 Turbidity (NTU) plotted as a function of depth and season (red –surface; blue – bottom) (Source: van Ballegooyen *et al.* 2012).

6.8 Bromide

Measurements of bromide concentrations were collected at their water column profiling stations sampled for the RO plant baseline 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.

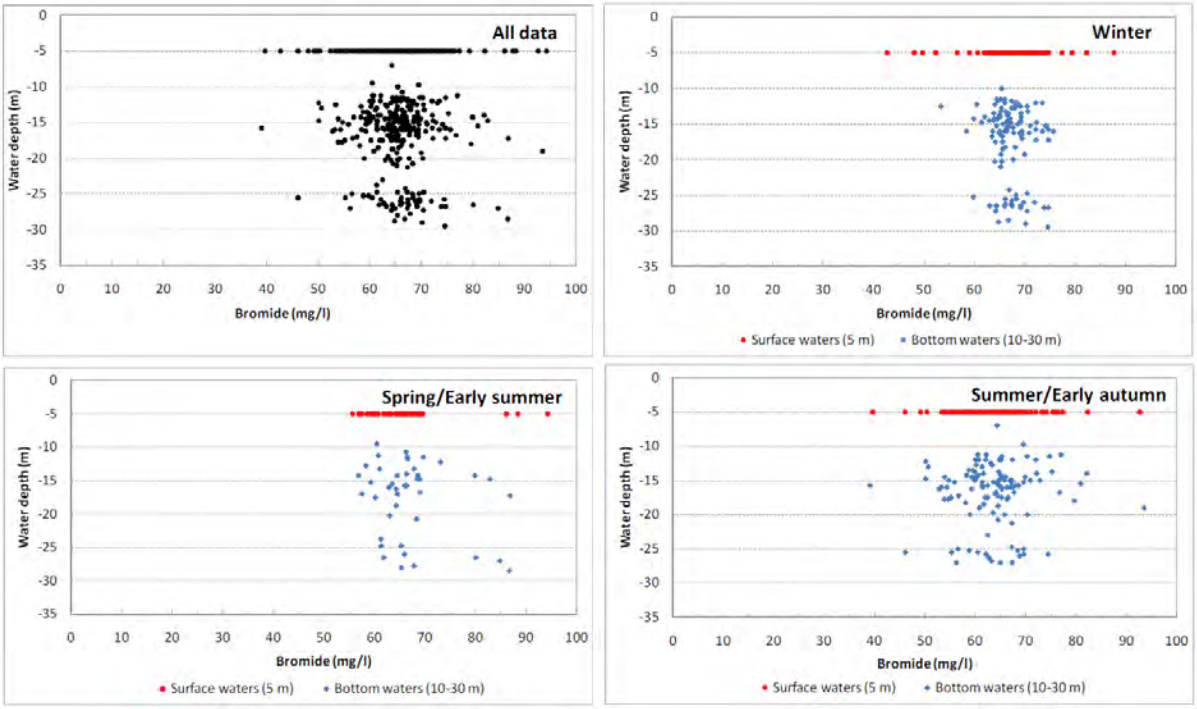


Figure 6.17 **Bromide concentrations as measured at all stations in winter, spring/early summer and summer/early autumn (Source: van Ballegooyen *et al.* 2012).**

6.9 Microbial indicators

Untreated sewage or storm water runoff may introduce disease-causing micro-organisms (usually as a result of faecal pollution) 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 revised guidelines for recreational use (DEA 2012) and the existing (DWAF 1995) guidelines for mariculture use.

6.9.1 Water quality guidelines

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 were to be trialled in South Africa over a period of a 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 6.18). 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.

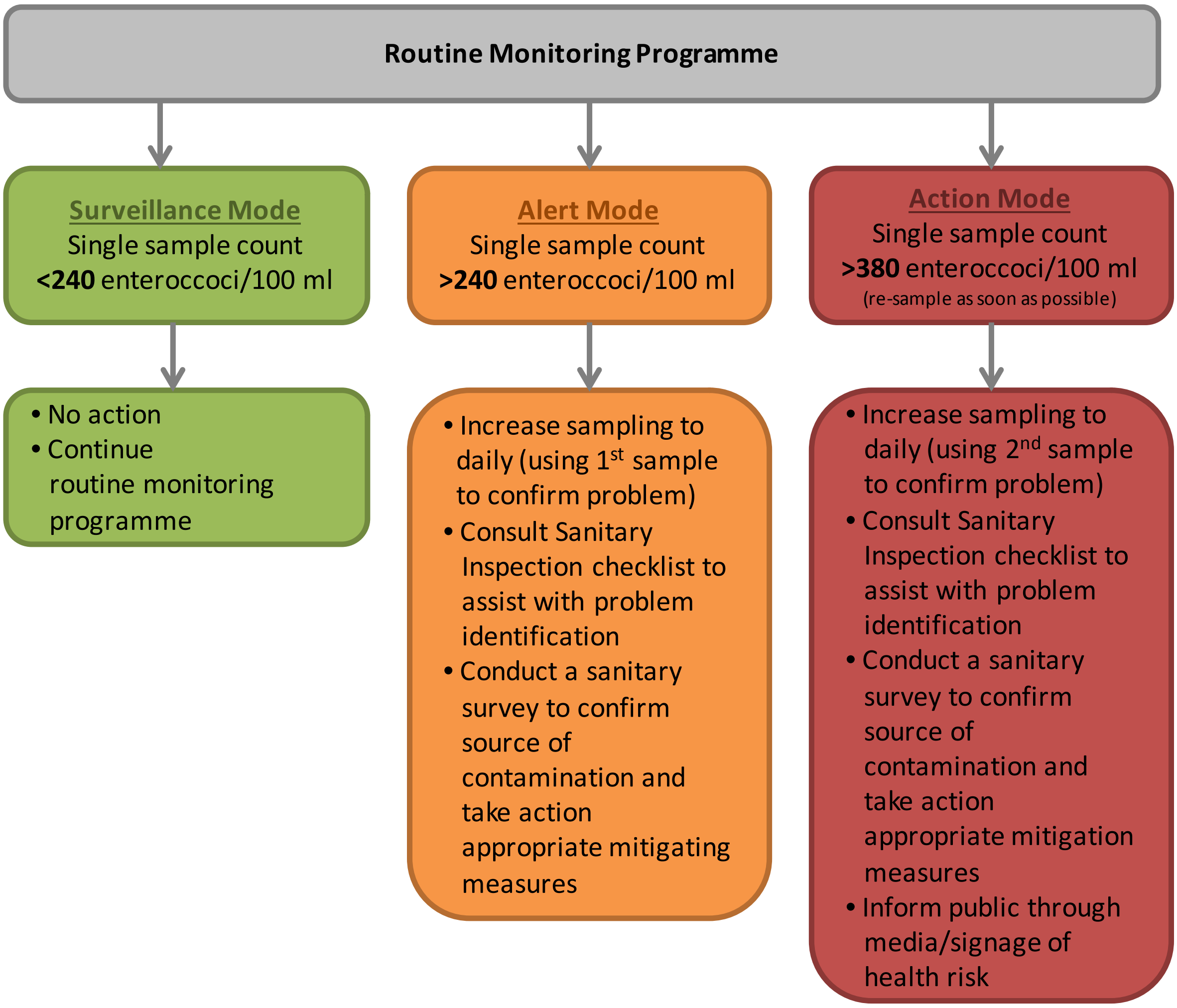


Figure 6.18 **An illustration of the proposed routine monitoring programme to be trialled in South Africa. Source: South African Water Quality Guidelines for Coastal Marine Waters (DEA 2012).**

The Hazen non-parametric statistical method is recommended for dealing with the microbiological data as these data do not typically 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/or *E. coli*, for recreational water use are indicated below (Table 6.2). 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 6.2 **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)

The *Guidelines for Inland and Coastal Waters: Volume 4 Mariculture* (DWAF 1995) provides target levels for faecal coliforms in water bodies used for mariculture as these filter feeding organisms such as shellfish can accumulate pathogenic organisms in their bodies and thereby infect people that consume them (Table 6.3).

Table 6.3 **Maximum acceptable count of faecal coliforms (per 100 ml sample) for mariculture according to the DWAF 1995 guidelines (DWAF 1995).**

Purpose/Use	Guideline value
Mariculture	20 faecal coliforms in 80% of samples 60 faecal coliforms in 95% of samples

6.9.2 Microbial monitoring in Saldanha Bay and Langebaan Lagoon

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 (the 1995 guidelines of 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).

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 December 2016 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. Data presented covers a complete calendar year to account for seasonal differences, thus 2017 data will be included in the 2018 report. Compliance with mariculture guidelines were assessed using faecal coliform counts and the DWAF 1995 guidelines, whilst recreational use compliance was assessed using *E. coli* count data and the DEA 2012 guidelines.

6.9.3 Water quality for recreational use

Recreational water quality rankings for all sampled sites throughout Saldanha Bay and Langebaan Lagoon are shown in Table 6.4, whilst Figure 6.19 and Figure 6.20 graphically depict these data for Langebaan Lagoon. Data from the microbial monitoring programme suggest that nearshore coastal waters in Saldanha Bay have improved considerably for recreational use since 2005 (Table 6.4). Based on the 2016 *E. coli* data, 16 of the 20 sampled stations were categorized as having excellent water quality. Hoedtjies Bay Beach (Site 7), Mykonos (Site 13) Langebaan North (Site 15) and Langebaan Main Beach (Site 16) were ranked as having 'Good' or "Excellent" water quality, all improvements from their 2015 ratings. Water quality dropped from "excellent" to "Fair" at the Caravan site in Small Bay (Site 8) and the Langebaan Yacht club (Site 17), whilst the most severe decline in water quality was documented at the Bok River Mouth (Site 9) that dropped from an "Excellent" rating in 2015 to a "Poor" ratings in 2016. Mykonos Harbour (Site 13) and Langebaan - Main Beach both showed an improvement in 2016, up from "Fair" to "Excellent". Inadequate treatment of sewage is the probable cause of the decline in water quality at the Bok River and Caravan beach sites, and this as well as other contributing sources, should immediately be dealt with. Ongoing efforts to maintain the good water quality at the popular swimming and water sport sites must be continued.

Table 6.4 Sampling site compliance for recreational use 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 90^{th} and 95^{th} percentile results grouped together to give an overall rating per annum. 'ND' indicates that no data were collected in that year and 'Ex.' indicates excellent water quality.

	Site	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Small Bay	1. Beach at Mussel Rafts	Fair	Fair	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.
	2. Small Craft Harbour	Ex.	Fair	Good	Ex.	Ex.	Ex.	Good	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Good	Ex.	Ex.	Ex.	Ex.
	3. Sea Harvest - Small Quay	Fair	Fair	Ex.	Ex.	Fair	Ex.	Fair	Ex.	Ex.	Ex.	Good	Ex.	Fair	Ex.	Ex.	Ex.	Ex.	Ex.
	4. Saldanha Yacht Club	Poor	Poor	Poor	Fair	Poor	Poor	Poor	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.
	5. Pepper Bay - Big Quay	Poor	Fair	Poor	Fair	Fair	Fair	Fair	Poor	Ex.	Ex.	Fair	Ex.	Ex.	Good	Ex.	Ex.	Ex.	Ex.
	6. Pepper Bay - Small Quay	Poor	Fair	Fair	Good	Ex.	Good	Ex.	Ex.	Good	Ex.	Good	Good	Ex.	Good	Fair	Fair	Ex.	Ex.
	7. Hoedjies Bay Hotel - Beach	Fair	Fair	Poor	Fair	Good	Poor	Poor	Good	Fair	Ex.	Fair	Fair	Poor	Poor	Fair	Good	Fair	Good
	8. Beach at Caravan Park	Fair	Fair	Fair	Poor	Ex.	Fair	Poor	Ex.	Good	Poor	Fair	Fair	Fair	Poor	Good	Fair	Ex.	Fair
	9. Bok River Mouth - Beach	Poor	Fair	Poor	Poor	Poor	Poor	Poor	Ex.	Fair	Poor	Poor	Good	Ex.	Poor	Fair	Good	Ex.	Poor
	10. General Cargo Quay - TNPA	Ex.	Fair	Ex.	Ex.	Ex.	Ex.	Good	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.
Big Bay	11. Seafarm - TNPA	Ex.	Fair	Ex.	Ex.	ND	ND	Ex.	Ex.	Ex.	ND	Ex.	ND	ND	Ex.	Ex.	Ex.	Ex.	Ex.
	12. Mykonos - Paradise Beach	Ex.	Fair	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.
	13. Mykonos - Harbour	Fair	Fair	Ex.	Ex.	Fair	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Fair	Ex.	Ex.	Good	Fair	Ex.
	14. Leentjiesklip	ND	ND	Good	Fair	Good	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Fair	Ex.	Good	Ex.	Ex.
Langebaan Lagoon	15. Langebaan North - Leentjiesklip	Ex.	Fair	Good	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Poor	Good	Ex.	Good	Ex.
	16. Langebaan - Main Beach	ND	ND	Fair	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Good	Ex.	Ex.	Ex.	Ex.	Ex.	Fair	Ex.
	17. Langebaan Yacht Club	ND	ND	ND	ND	ND	Poor	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Good	Ex.	Ex.	Fair
	18. Tooth Rock	ND	ND	ND	ND	ND	Fair	Ex.	Ex.	Ex.	Ex.	Fair	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.
	19. Kraalbaai North	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	Ex.	Ex.	Ex.	Ex.	Ex.
	20. Kraalbaai South	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	Ex.	Ex.	Ex.	Ex.	Ex.

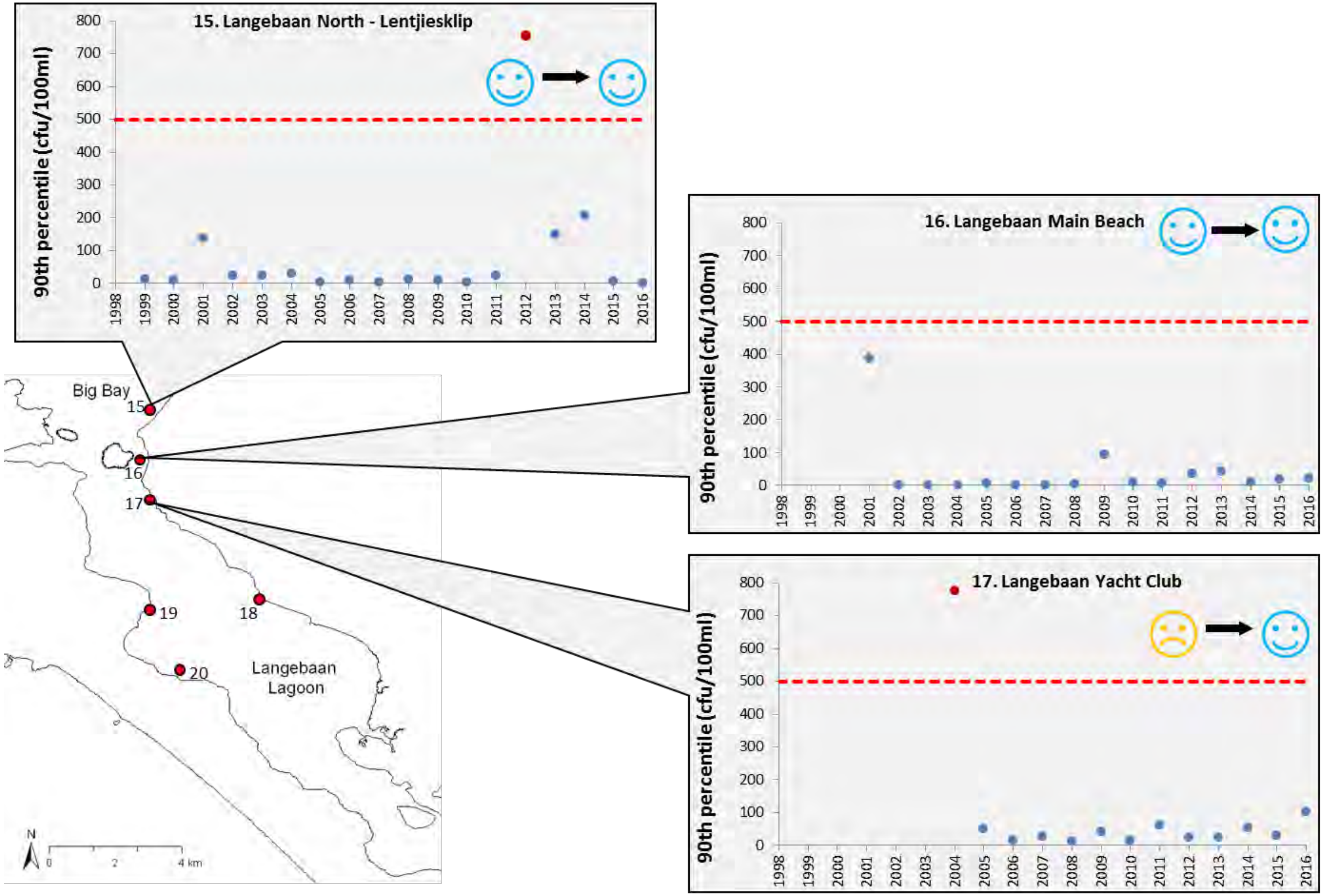


Figure 6.19 Hazen method 90th percentile values of *E.coli* counts at three of the 6 sampling stations within Langebaan Lagoon (Feb 1999 - Dec 2016). The red line indicates the Hazen method <u>90th percentile contact recreation limit of *E.coli* counts</u> (500 colony-forming units/100 ml) above which water quality is ranked as 'Poor/Unacceptable'. Red data points indicate 90th percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The smiley faces correspond to changes in *E.coli* counts over time.

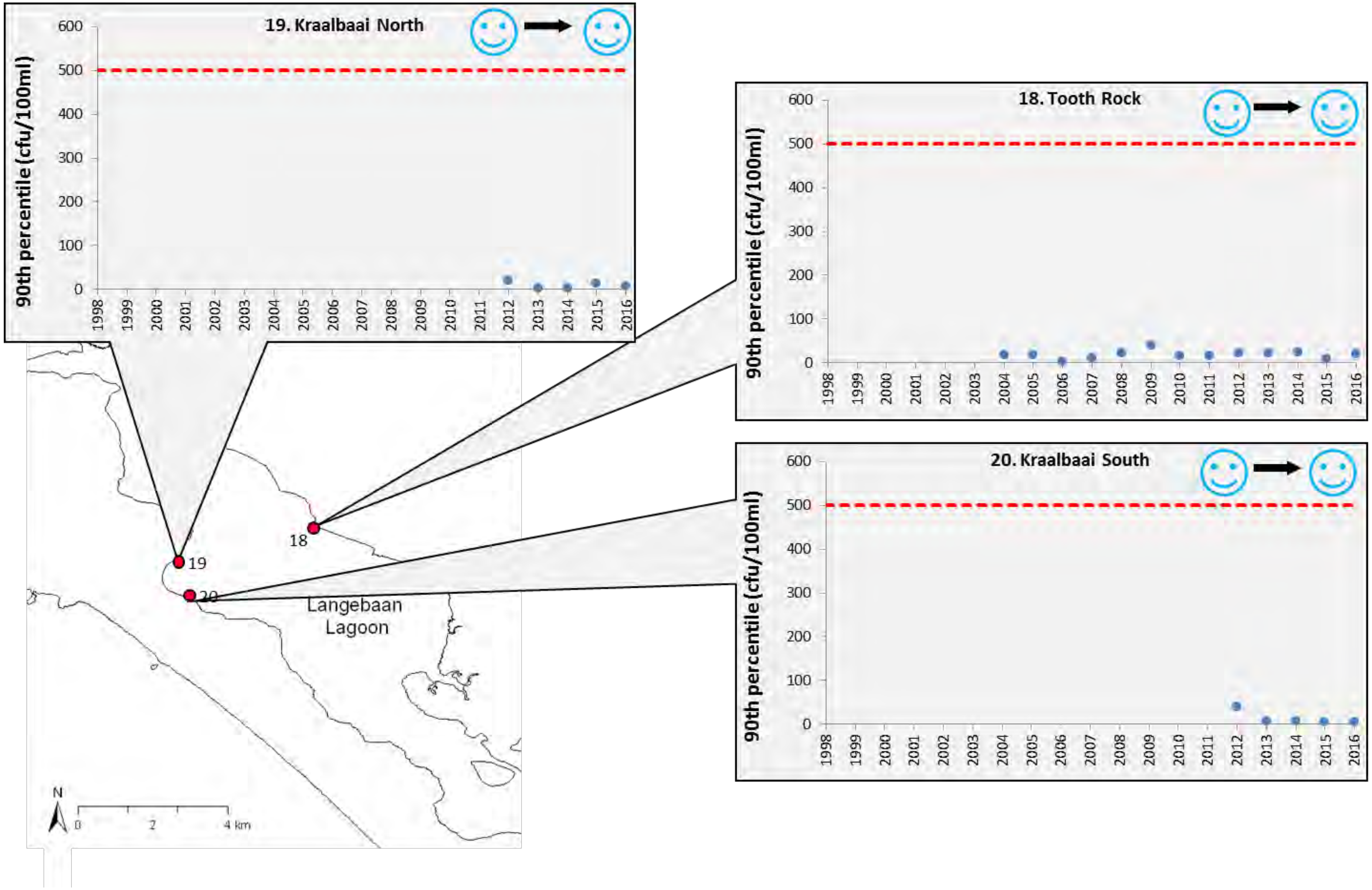


Figure 6.20 Hazen method 90th percentile values of *E.coli* counts at three of the 6 sampling stations within Langebaan Lagoon (Feb 1999 - Dec 2015). The red line indicates the Hazen method <u>90th percentile contact recreation limit of *E.coli* counts</u> (500 colony-forming units/100 ml) above which water quality is ranked as 'Poor/Unacceptable'. Red data points indicate 90th percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The smiley faces correspond to changes in *E.coli* counts over time.

6.9.4 Water quality for mariculture

Guideline limits for mariculture are much stricter than the recreational guideline limits and levels of compliance for mariculture remain much lower than for recreational use. At the start of the monitoring in 1999, nine out of the 10 sites in Small Bay (Sites 1-9) were not compliant in respect of the 80th percentile mariculture guideline limits for faecal coliforms (Figure 6.21, Figure 6.22 and Figure 6.23). There has been some improvement over time particularly at sites near the entrance to the Bay (beach at Mussel Rafts, Small Craft harbour and Saldanha Bay Yacht Club) as well as in the vicinity of the General Cargo Quay (Site 10) that have all met the required standards in 2017 and for a sustained period prior to this (at least the preceding decade). The remaining six sites within Small Bay however, continue to exceed the mariculture guidelines. These data indicate that there remains a serious issue of water quality with respect to mariculture operations within Small Bay. The areas of particular concern are Hoedjies Bay, Caravan Park Beach and the Bok River Mouth which have not shown any improvement towards meeting guidelines over the last 16 years, and continue to exceed the guidelines by a substantial margin (Figure 6.22 and Figure 6.23).

As samples are collected in shallow coastal waters close to sources of contamination (storm water drains etc.), concentrations of microbiological contaminants in the samples are likely to be higher than those near the offshore mariculture rafts. Nevertheless, the exceedance of mariculture water quality guidelines in near-shore waters remains a concern, particularly in light of the proposed additional mariculture development in the area. Land-based mariculture facilities that may become established in the IDZ will need to extract water from Small Bay. The prevailing poor water quality near-shore will force sea water abstraction further offshore at an increased cost.

At the other sites within Small Bay, water quality has either remained well within the guideline limits (e.g. beach at Mussel Rafts, Small Craft harbour, General Cargo Quay) or a sustained improvement in levels of compliance with the guidelines for mariculture has occurred since the earlier 1999-2005 period (Figure 6.21, Figure 6.22). The most noticeable improvement has been at the Small Quay-Sea Harvest, the Saldanha Bay Yacht Club and the two Pepper Bay sites (Figure 6.21 and Figure 6.22). Faecal coliform counts remain above guideline levels at three of these four sites, but they have come down considerably and do not exceed the guidelines by such a large margin as they once did (Figure 6.21 and Figure 6.22).

Faecal coliform counts at all four sites sampled within Big Bay in 2016 were well within both the 80th percentile limits for mariculture (Figure 6.24). There has been no discernible trend over time at these four sites with the exception of a dramatic decrease in faecal coliform counts after the first three (2001-2003) sampling events at Leentjiesklip. The water quality in Big Bay has met mariculture guidelines nearly every year since 2004, with the exception of the Mykonos Harbour site when levels were marginally exceeded only in 2009 and 2011.

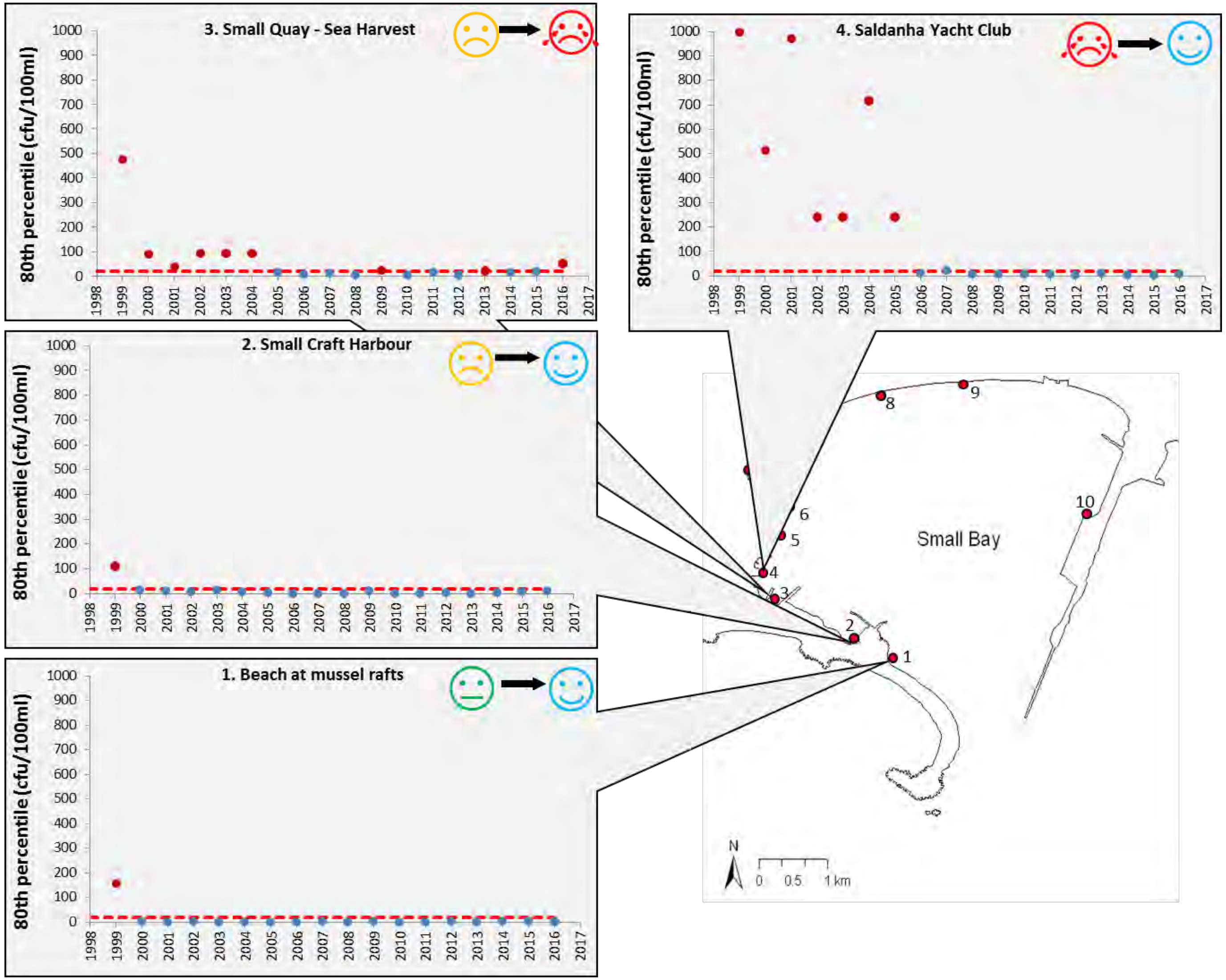


Figure 6.21 80th percentile values of faecal coliform counts at four of the 10 sampling stations within Small Bay (Feb 1999 - Dec 2016). The red line indicates the <u>80th percentile mariculture limit of faecal coliforms</u> (20 colony-forming units/100 ml). Red data points indicate 80th percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The smiley faces correspond to changes in faecal coliform counts over time.

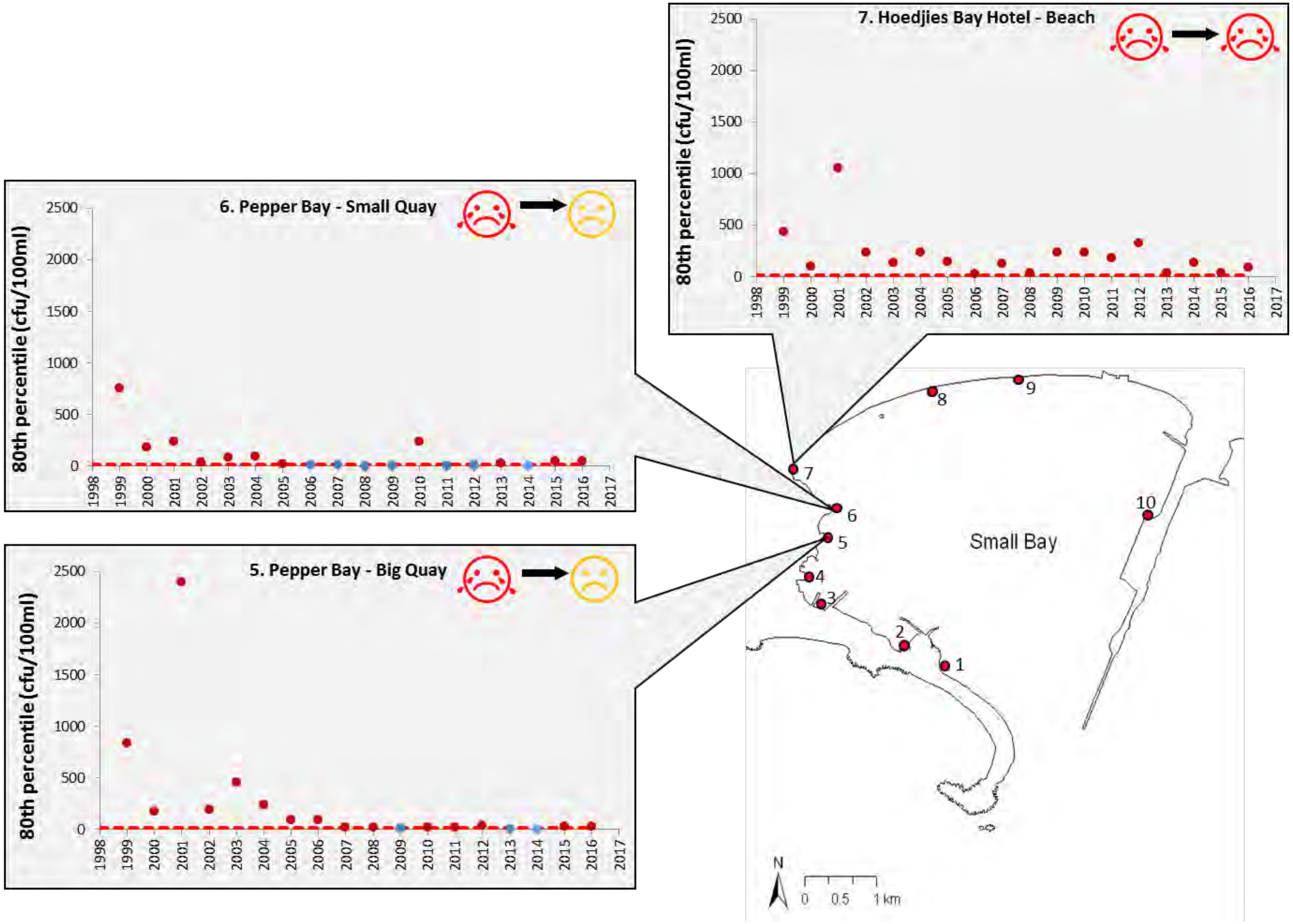


Figure 6.22 80th percentile values of faecal coliform counts at three of the 10 sampling stations within Small Bay (Feb 1999 - Dec 2016). The red line indicates the <u>80th percentile mariculture limit of faecal coliforms</u> (20 colony-forming units/100 ml). Red data points indicate 80th percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The smiley faces correspond to changes in faecal coliform counts over time.

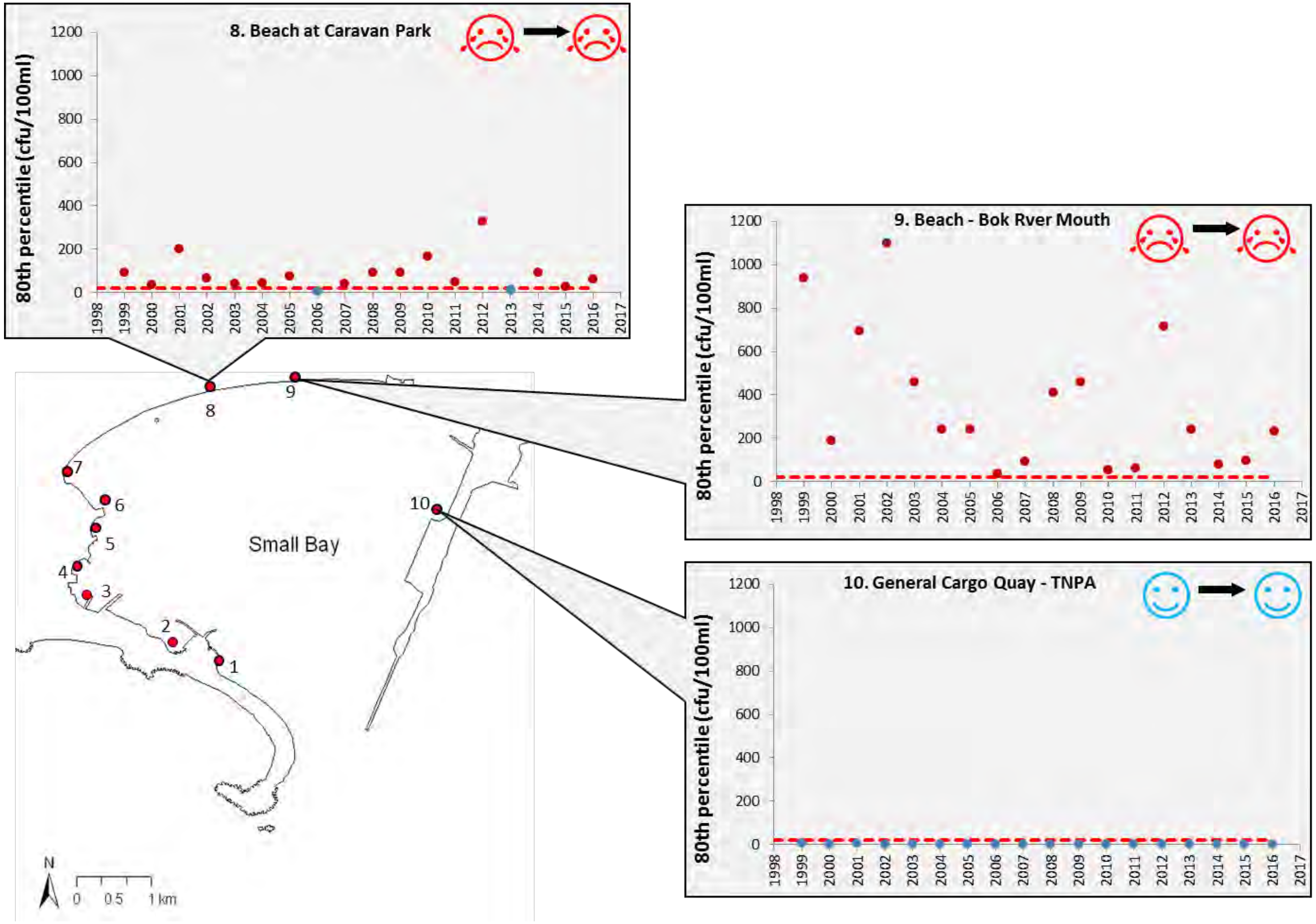


Figure 6.23 80th percentile values of Faecal coliform counts at three of the 10 sampling stations within Small Bay (Feb 1999 – Dec 2016). The red line indicates the 80th percentile mariculture limit of faecal coliforms (20 colony-forming units/100 ml). Red data points indicate 80th percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The smiley faces correspond to changes in faecal coliform counts over time.

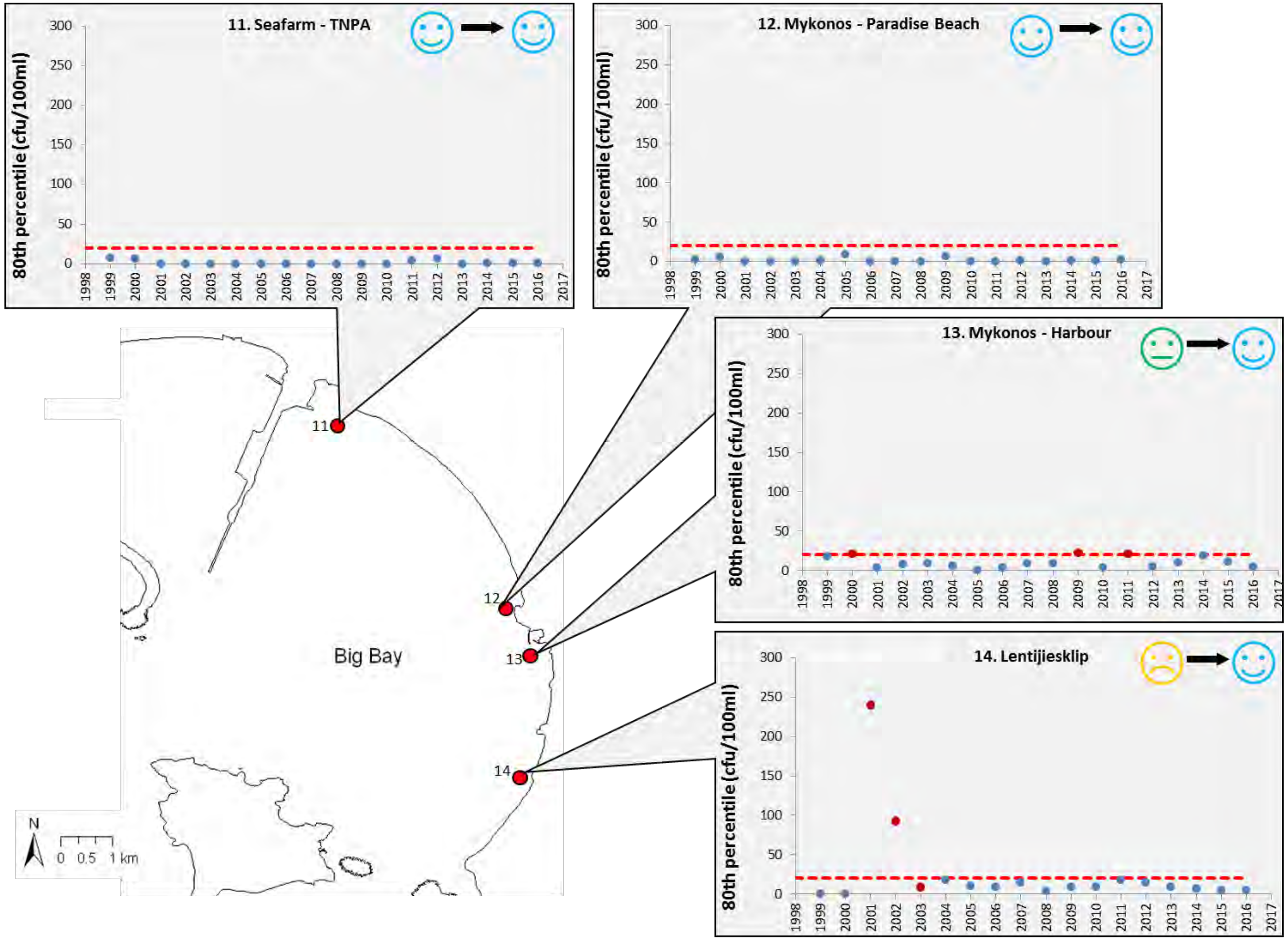


Figure 6.24 80th percentile values of Faecal coliform counts at the four sampling stations within Big Bay (Feb 1999 - Dec 2016). The red line indicates the 80th percentile mariculture limit of faecal coliforms (20 colony-forming units/100 ml). Red data points indicate 80th percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The smiley faces correspond to changes in faecal coliform counts over time.

6.10 Trace metal contaminants in the water column

It is common practise globally in countries like Canada, Australia, New Zealand and South Africa to monitor the long-term effects of pollution in water bodies by analysing levels in the tissues of 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 an early warning of poor water quality and dramatic changes in contaminant levels in the water column.

Trace/heavy metals are often regarded as pollutants of aquatic ecosystems. However, they are naturally occurring elements, some of which (e.g. copper and 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).

6.10.1 Mussel Watch Programme

In 1985 the Marine and Coastal Management (MCM) branch of the Department of Environmental Affairs (DEA) initiated the Mussel Watch Programme whereby brown mussels *Perna perna* or Mediterranean mussels *Mytilus galloprovincialis* were collected every six months 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 have been received since 2007 despite the fact that the programme was due to resume in late 2014. In the interim, Anchor Environmental Consultants continued the programme by collecting mussel samples from the same five sites annually during the field surveys from 2014 to 2017. The mussel samples were analysed for the metals lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), iron (Fe), manganese (Mn) and mercury (Hg) in 2017.

Data from the Mussel Watch Programme and from the annual State of the Bay field trips are represented in Figure 6.26 to Figure 6.31 below. The maximum legal limits prescribed for each contaminant in shellfish for human consumption in South Africa (as stipulated by the Regulation R.500 of 2004 published under the Foodstuffs, Cosmetics and Disinfectants Act, Act 54 of 1972) are listed in Table 6.5 and indicated in red text on each series of graphs. Where limits have not been specified in national legislation, those adopted by other countries have been used (Table 6.5).

Table 6.5 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.

Mercury concentrations within mussel tissues were measured for the first time in 2016 and again in 2017. Mercury exceeded safe limits at the Fish Factory and at Saldanha Bay North in 2016 and Portnet in 2017 (Figure 6.25). The source of contamination at these sites is currently unknown.

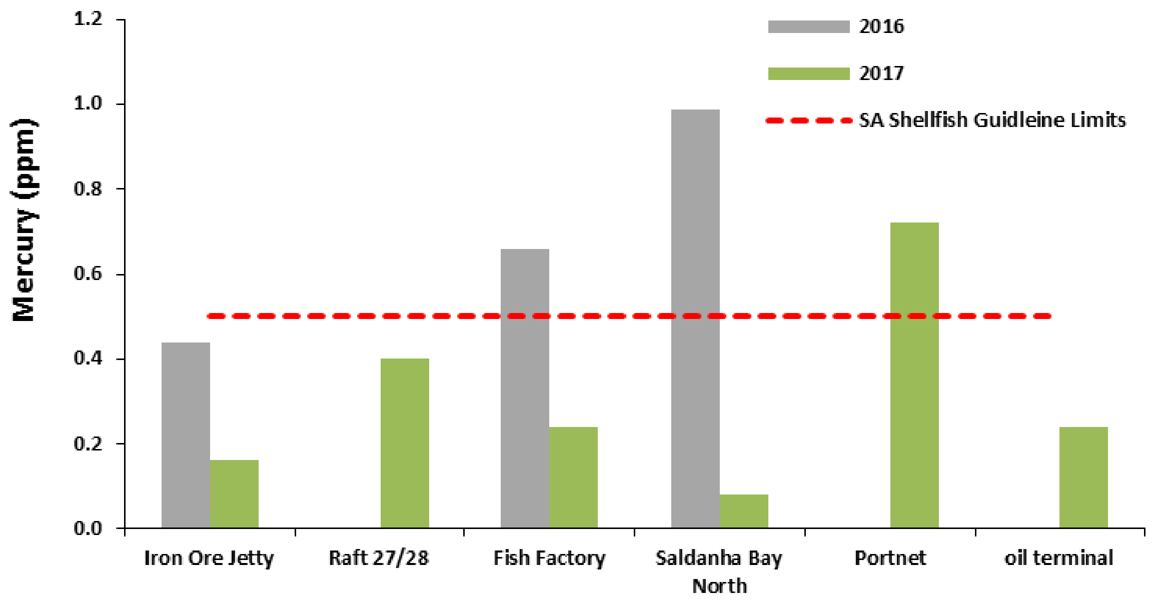


Figure 6.25 **Mercury concentrations in mussels collected from five sites in Saldanha Bay by Anchor in 2016 and 2017. The recommended maximum limit for mercury in seafood (0.5 ppm) is shown as a dotted red line.**

Data showed that concentrations of lead in mussels at the Portnet site were consistently above the regulatory limit for foodstuffs, with values averaging 111 ppm over the whole data series (Figure 6.26). Values spiked to very high levels at this site in May 1999 (252 ppm) and October 2001 (714 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 limit of 0.5 ppm, lead concentrations were found to be extremely high. Although concentrations dropped to an average of 1.3 ppm over all the sites in 2014, they increased to around 7 ppm in 2015 and 2016 but then dropped again to an average of 4 in 2017. While the situation is greatly improved from 2007, especially at the Portnet site, the average level of lead in mussels at this site is still over eight times the value deemed as being safe for human consumption and over 16 times the limit at the mussel rafts. This is extremely concerning considering that mussels on the rafts are produced for human consumption.

Concentrations of cadmium frequently exceeded the regulatory limit of 3 ppm at all sites (Figure 6.27). Levels of cadmium in mussels from Saldanha Bay fluctuated less than those of lead and ranged between 1-10 ppm, but occasionally exceeded this level with a maximum reading of 49 ppm in April 2007 at the Mussel Rafts. The concentration of cadmium in mussels tissue collected at all sites in 2017 averaged 4.9 ppm and was found to be 4.5 ppm at the mussel rafts, which is high relative to the safe limit of 3 ppm.

Zinc concentrations in mussel tissue collected in 2017 were higher than the 150 ppm regulatory limit listed by the Canadian Authorities (Table 6.5) at all five of the sampled sites (Figure 6.28). In contrast with lead, cadmium and zinc, concentrations of copper remained well below the specified level of 70 ppm at all sites over the entire sampling period. The maximum value recorded for copper was 9.7 ppm at Saldanha Bay North. No regulatory limits exist for manganese, which reached a maximum of 5.5 ppm in 2017 at Portnet down from the concentration of 11.3 ppm recorded at this site in 2015 (Figure 6.30). Despite the increase of manganese export volume from 95 000 tonnes in 2014 to just over 3 million tonnes in 2017 (see Chapter 3) manganese concentrations in mussel tissue had decreased at most sites in 2017 (see Chapter 5).

In 2017 iron concentrations in mussel tissue had increased from 2016 values at two sites and decreased at three sites (Figure 6.31). Iron concentrations were highest at the Portnet site and lowest at the Ore jetty. As there are no official limits outlined 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. Iron poisoning may be associated with the ingestion of more than 10-20 mg/kg of human body weight (http://www.webmd.com/a-to-z-guides/iron-poisoning) but no cases of acute toxicity from regular foodstuffs (excluding supplements) have ever been recorded. As Iron ore is processed in Saldanha Bay on a large scale and iron ore residue is apparent on all structures in the vicinity of the Saldanha Steel processing plant, 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.

The high level of trace metals in nearshore bivalves in Small Bay remains a human health concern, especially due to the high concentrations of lead and cadmium. Signs warning of the health risks of consuming coastal mussels in this area and discouraging their collection should be posted in areas where these bivalves are easily accessible (e.g. Hoedjiesbaai).

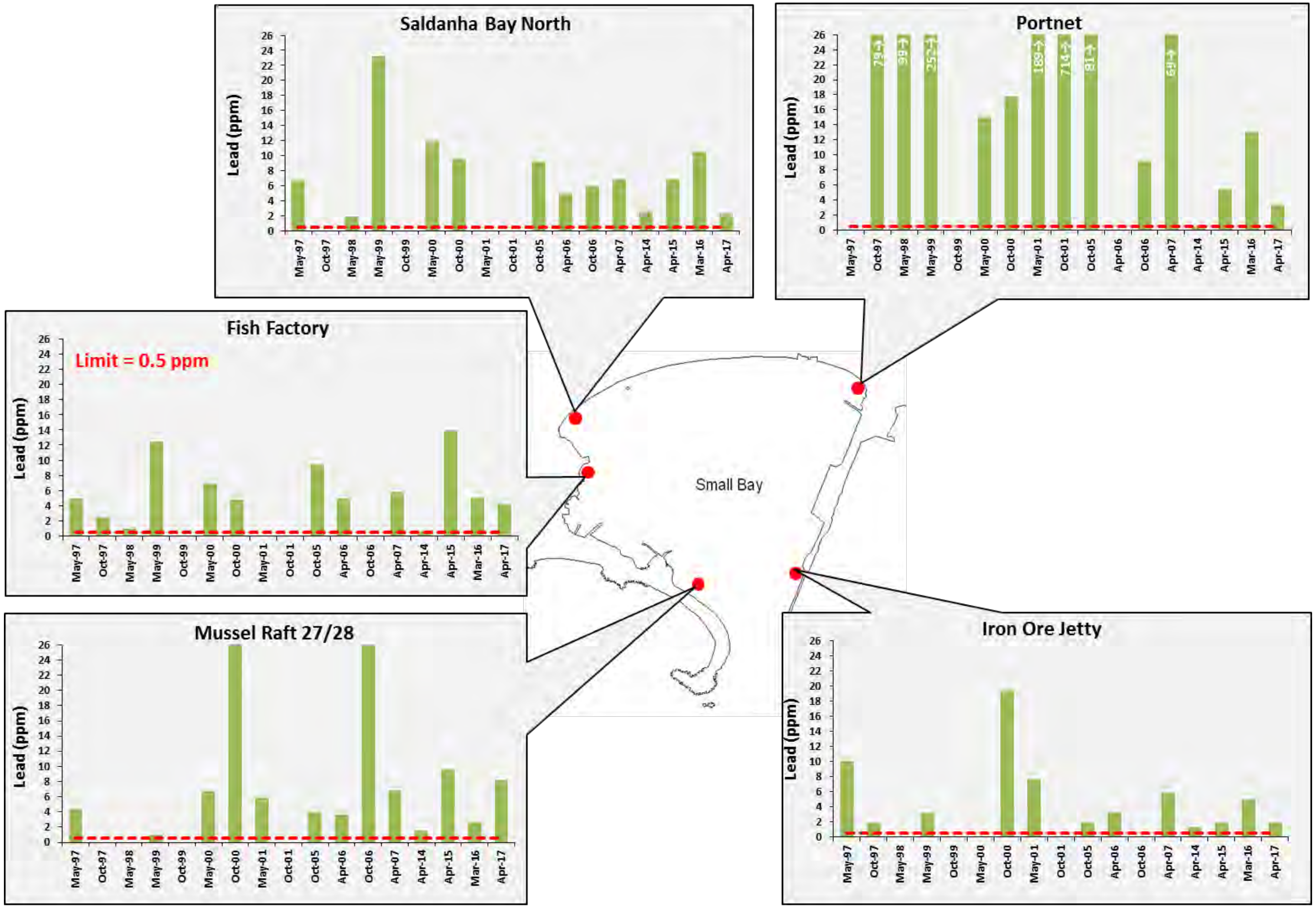


Figure 6.26 **Lead concentrations in mussels collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (Source: G. Kiviets, Department of Environmental Affairs) and by Anchor from 2014 to 2017. The recommended maximum limit for lead in seafood (0.5 ppm) is shown as a dotted red line. Values exceeding 26 ppm are indicated by text on the data bars.**

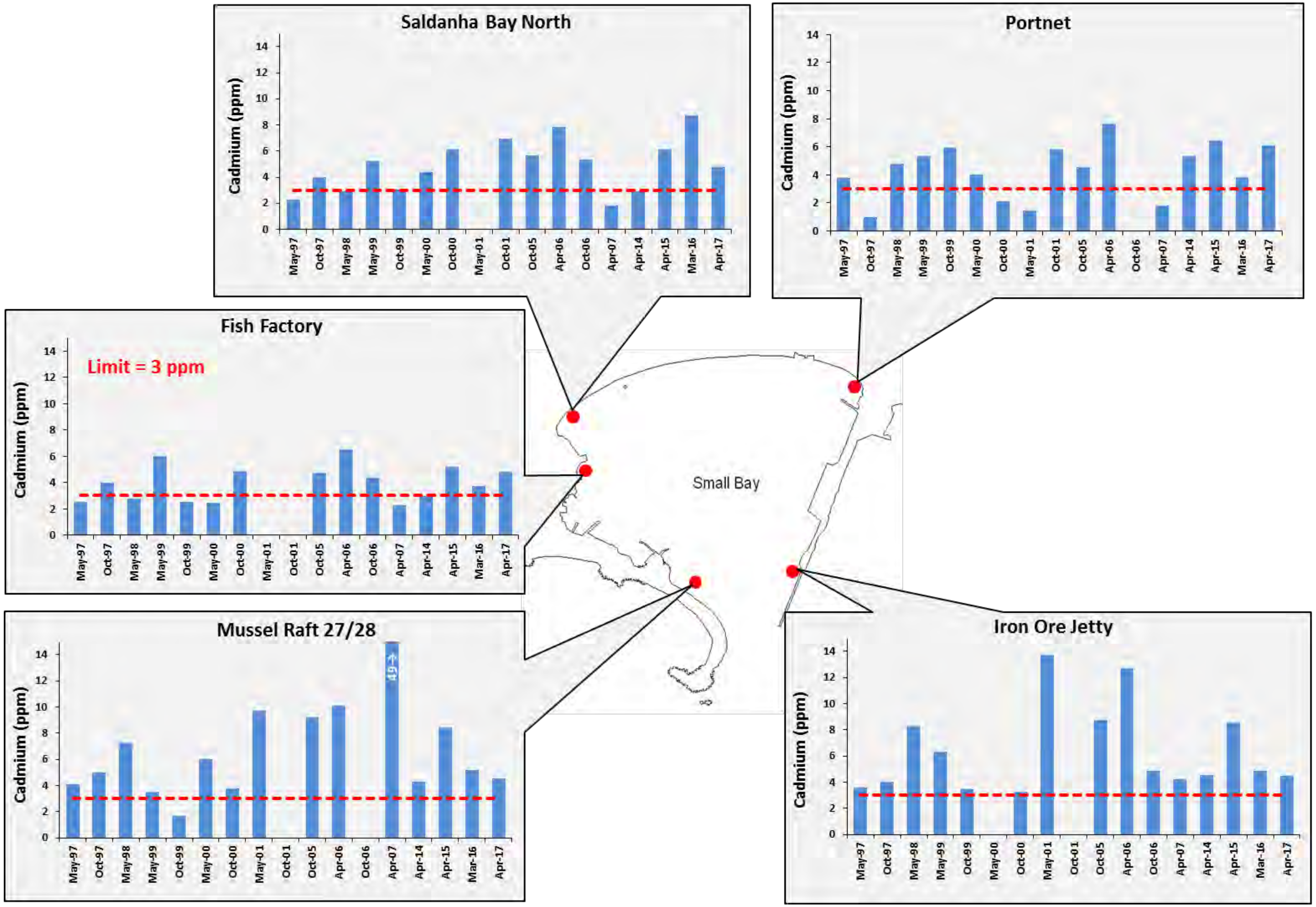


Figure 6.27 **Cadmium concentrations in mussels collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (Source: G. Kiviets, DEA) and by Anchor from 2014 to 2017. The recommended maximum limit for cadmium in seafood (3 ppm) is shown as a dotted red line. Values exceeding 14 ppm are indicated by text on the data bars.**

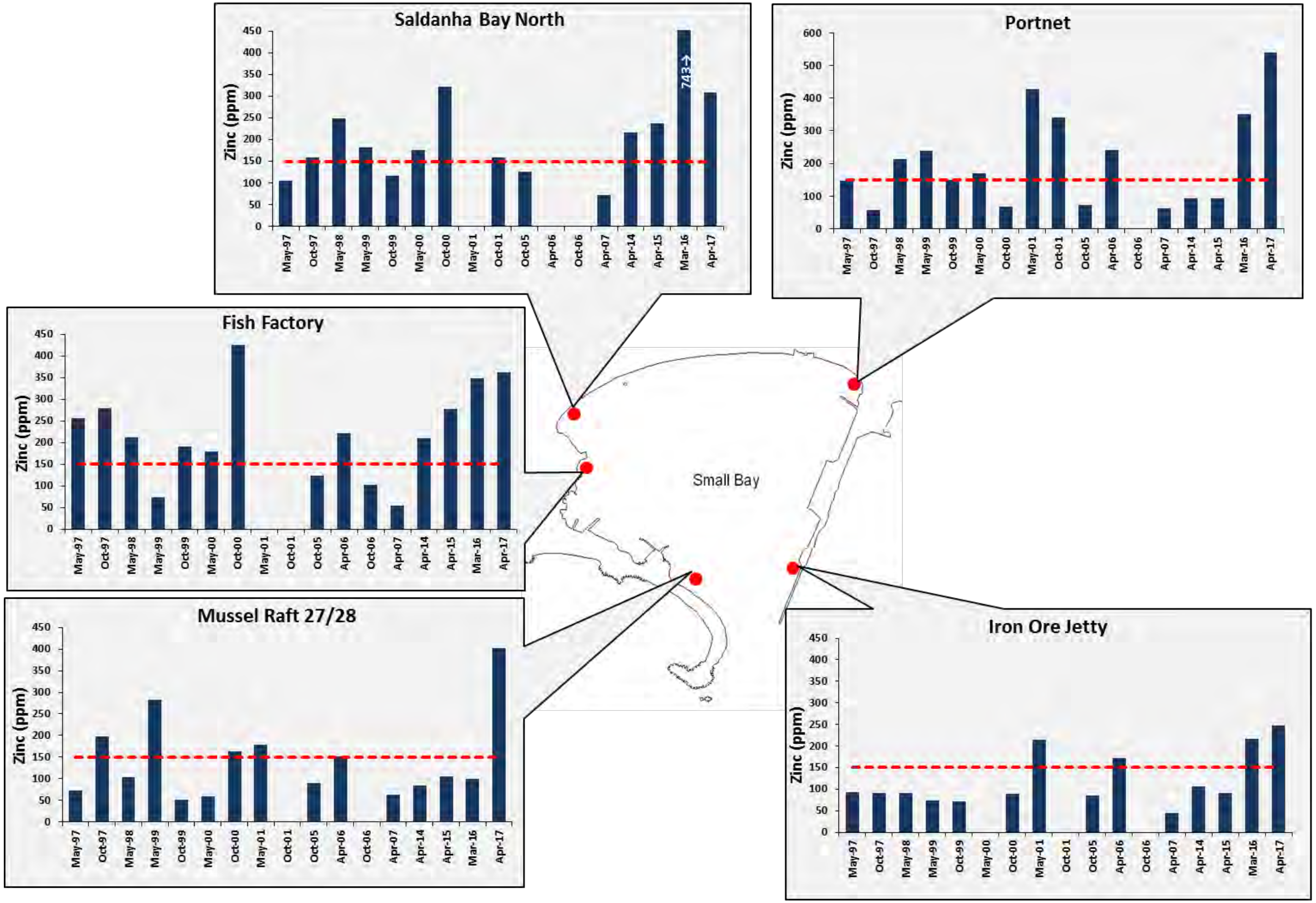


Figure 6.28 Zinc concentrations in mussels collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (source: G. Kiviets, Department of Environmental Affairs) and by Anchor from 2014 to 2017. The recommended maximum limit for zinc in seafood (150 ppm) is shown as a dotted red line. Values exceeding 450 ppm are indicated by text on the data bars.

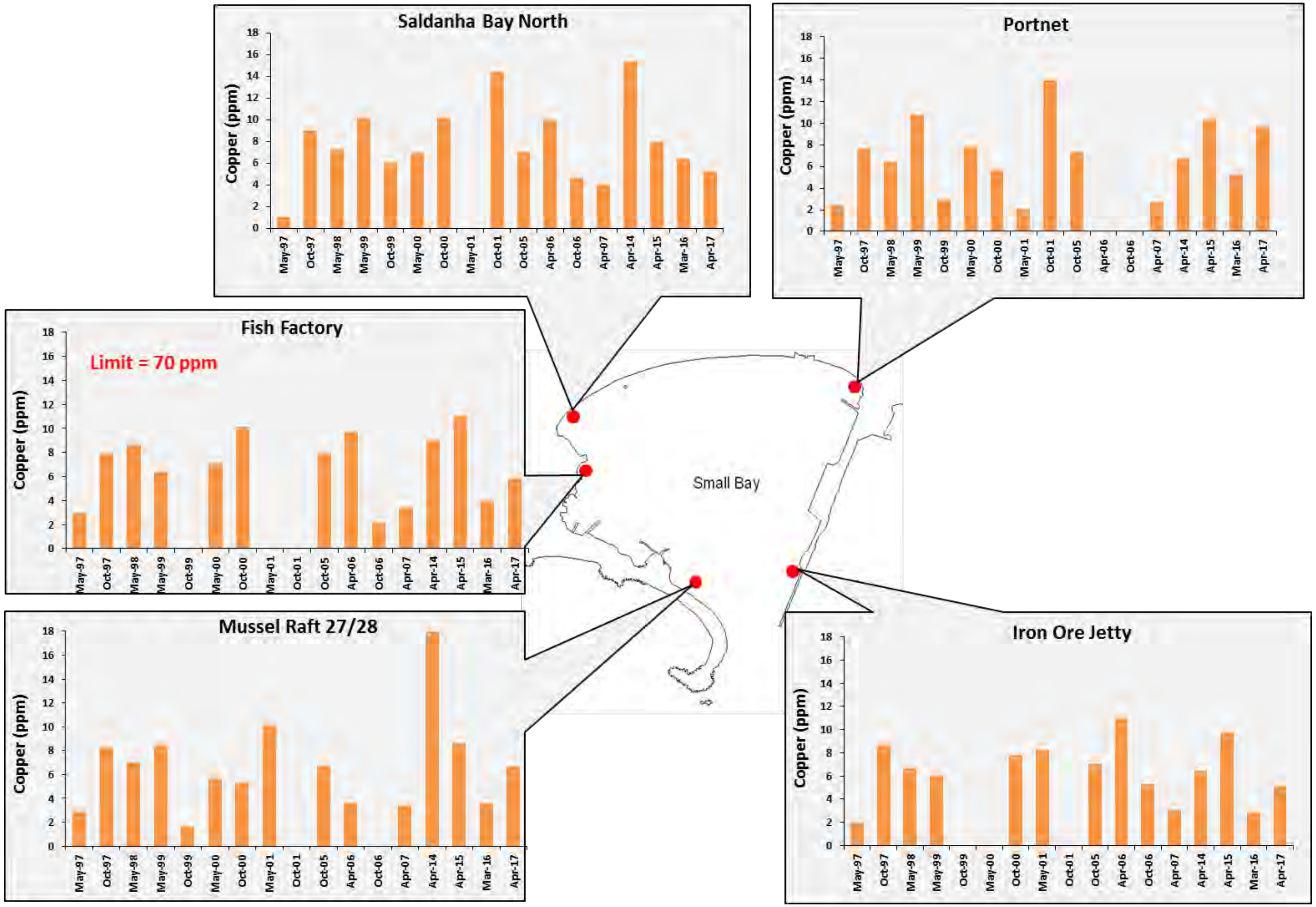


Figure 6.29 Copper concentrations in mussels collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (Source: G. Kiviets, Department of Environmental Affairs) and by Anchor from 2014 to 2017. The recommended maximum limit for copper in seafood is 70 ppm.

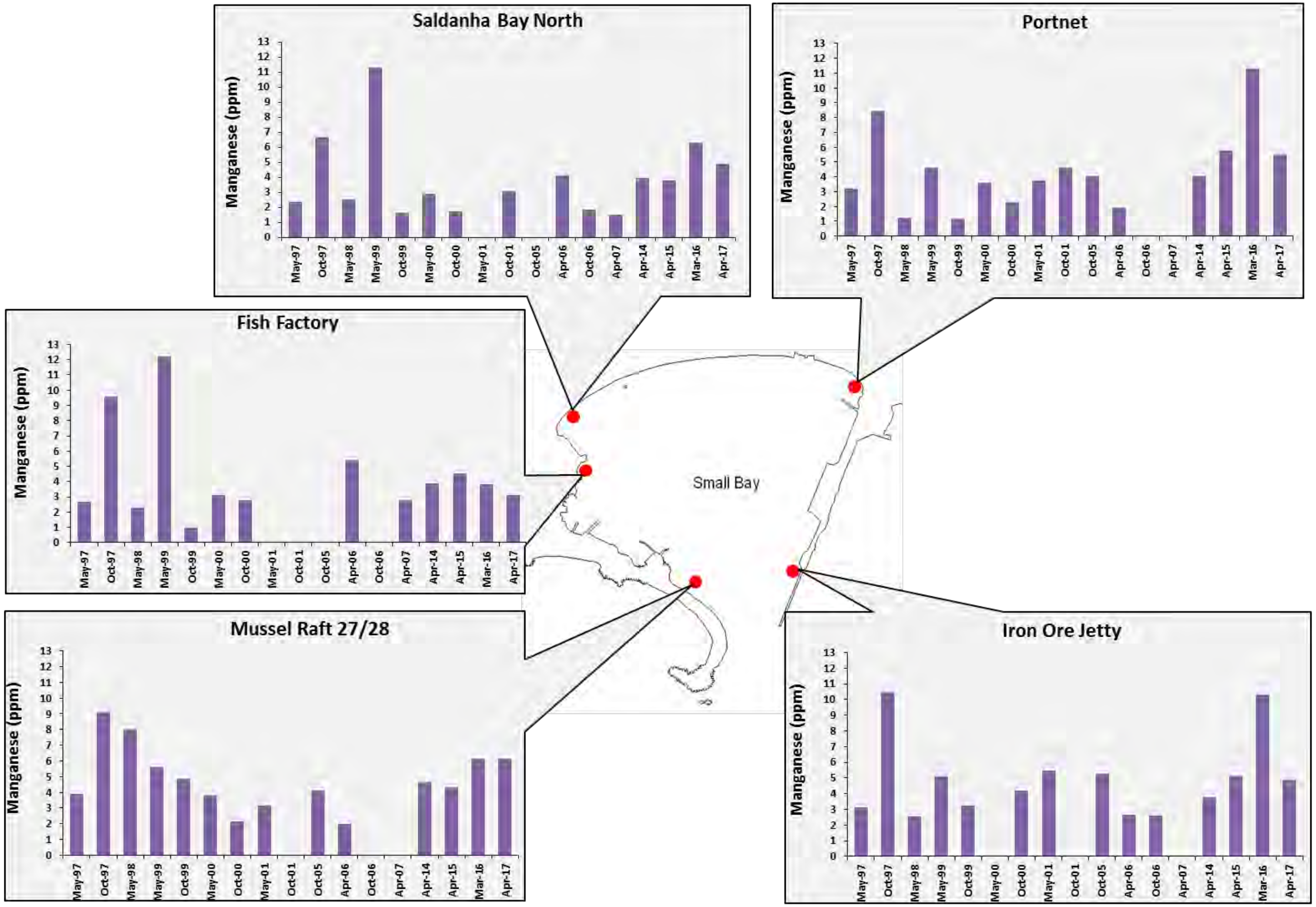


Figure 6.30 Manganese concentrations in mussels collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (Source: G. Kiviets, Department of Environmental Affairs) and by Anchor from 2014 to 2017. No limits are specified for manganese.

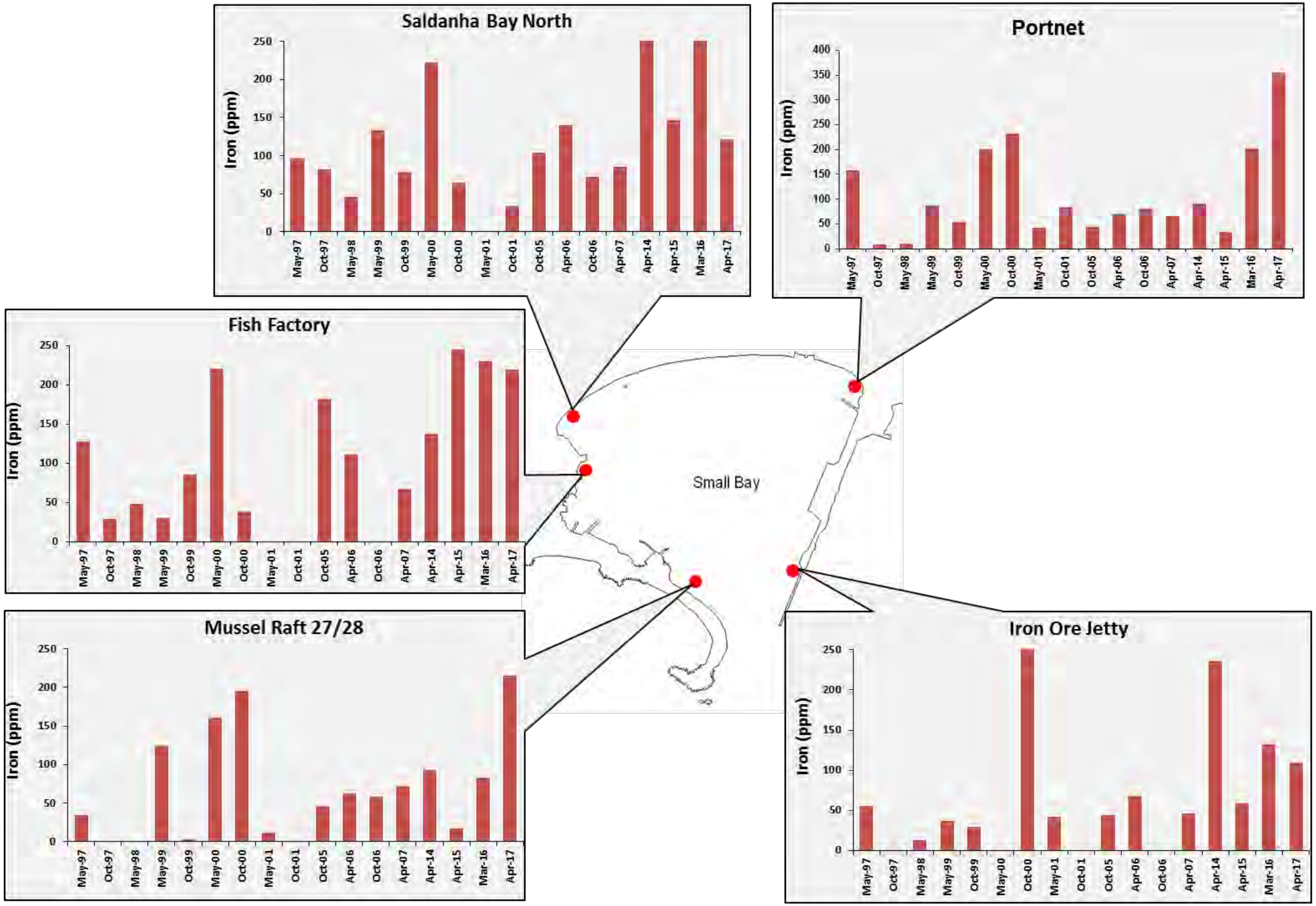


Figure 6.31 Iron concentrations in mussels collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (Source: G. Kiviets, Department of Environmental Affairs) and by Anchor from 2014 to 2017. No limits are specified for iron.

6.10.2 Mariculture bivalve monitoring

Rights holders engaged in bivalve culture of mussels and oysters in South Africa are required to report annually on concentrations in harvested organisms. Data is reported for up to four trace metal indicators (lead, cadmium, mercury and arsenic) in mussels and oysters for eight aquaculture farms in Saldanha Bay. In 2017 no new trace metal data was obtained for the period June 2016 – June 2017 (Refer to AEC 2016 for a discussion on results up until June 2016).

6.11 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, increased residence time, increased water temperature, decreased salinity and decreased 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 chronic problems with faecal coliform pollution were present in the early parts of the record; conditions have improved considerably since this time. Currently, 16 of the 20 monitoring stations in the Bay are rated as having 'Excellent' water quality, one site (Hoeddjies Bay) is rated as 'Good', while two are rated as 'Fair' and one (Bok River Mouth) is rated as "Poor". It is a concerning that faecal coliform levels along the north shore of Small Bay, between Hoedjiesbaai Beach and the Bok River mouth are still elevated on occasion and water authorities are advised to remain vigilant. Faecal coliform counts at all four sites in Big Bay were well within both the 80th percentile limits for mariculture in 2015. 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 harmful microbes, (for which *E. coli* and faecal coliforms are indicators), 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 data collected as part of the State of the Bay Monitoring Programme 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 and cadmium) or frequently (zinc) above published guidelines for foodstuffs. In comparison, data collected by mariculture operators in Saldanha Bay clearly show that concentrations offshore are lower; although concentrations of lead and cadmium frequently rise above the limit for foodstuff which is concerning. 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 serious risk to the health of people harvesting mussels from the shore.

7 SEDIMENTS

7.1 Sediment particle size composition

The particle size composition of the sediments occurring in Saldanha Bay and Langebaan Lagoon are strongly influenced by wave energy and circulation patterns in the Bay. Coarser or heavier sand and gravel particles are typically 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 areas where sediments were previously much coarser. 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 changes to the natural patterns of wave action and current circulation prevailing in the Bay. 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 contaminant loading that may occur in Saldanha 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.

Contaminants such as metals and organic toxic pollutants are predominantly associated with fine sediment particles (mud and silt). This is because fine grained particles have a relatively larger surface area for pollutants to adsorb and bind to. 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 retention (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 is therefore of particular interest and are summarised in this section.

The earliest detailed study on the sediments of Saldanha Bay and Langebaan Lagoon was conducted by Flemming (1977a, b) based on a large number of samples (n = ~500) collected from the Bay and Lagoon in 1974, prior to large scale development of the area. He found that sediments in Saldanha Bay were comprised mostly of fine (0.125-0.25 mm) or very fine sand (0.063-0.125 mm). Significant amount of medium and coarse sand were also present but coarse (0.5-1.0 mm) and very coarse sand (1-2 mm) was rare, as was mud (<0.063 mm) (Figure 7.2).

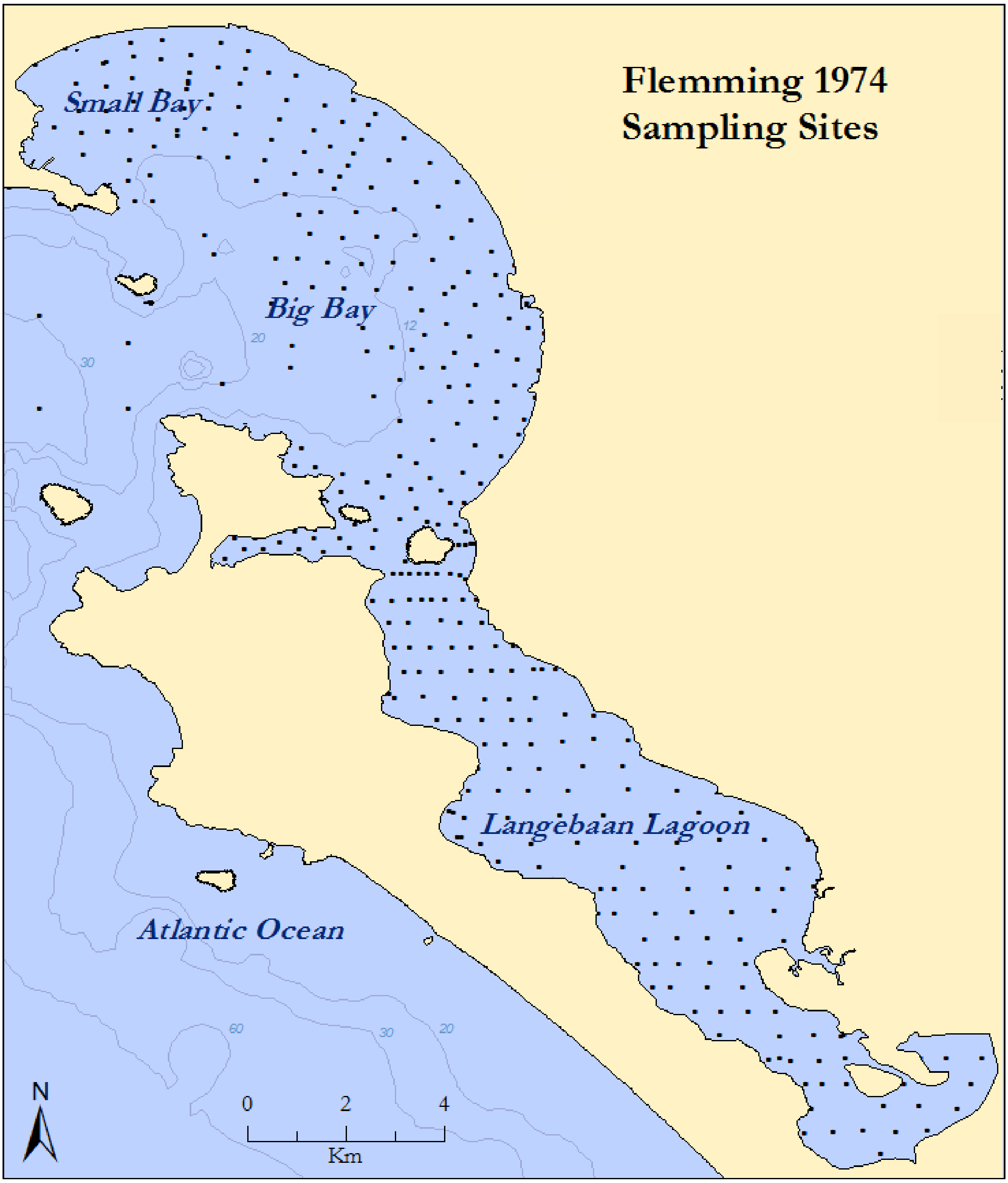


Figure 7.1 Stations sampled by Flemming (1977b) in Saldanha Bay and Langebaan Lagoon in 1974.

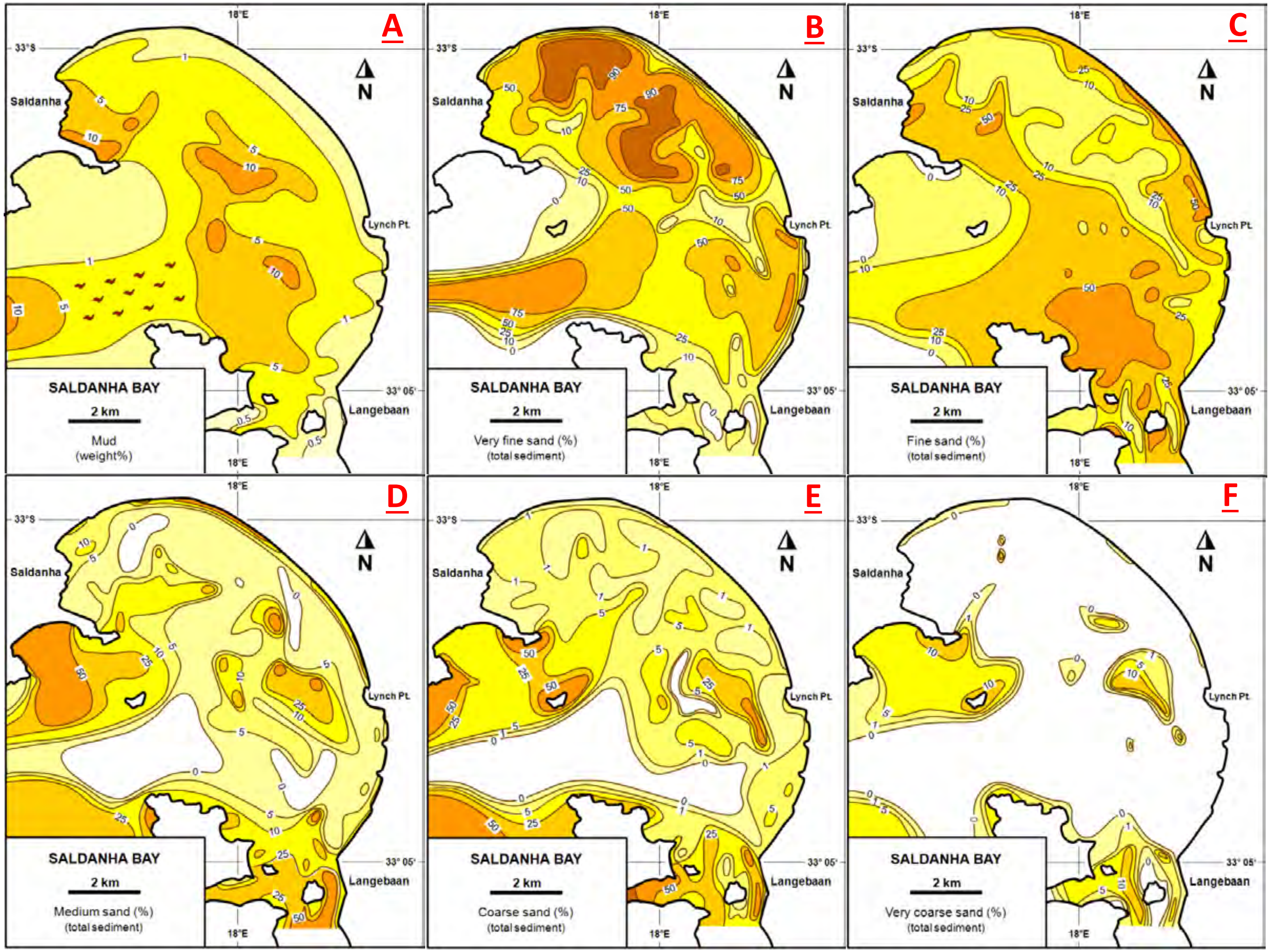


Figure 7.2 Distribution of different sediment types (% of total) in Saldanha Bay in 1975: (A) mud (<0.063 mm), (B) very fine sand (0.063-0.125 mm), (C) fine sand (0.125-0.25 mm), (D) medium sand (0.25-0.5 mm), (E) coarse sand (0.5-1.0 mm), (F) very coarse sand (1-2 mm). Source: Flemming (2015).

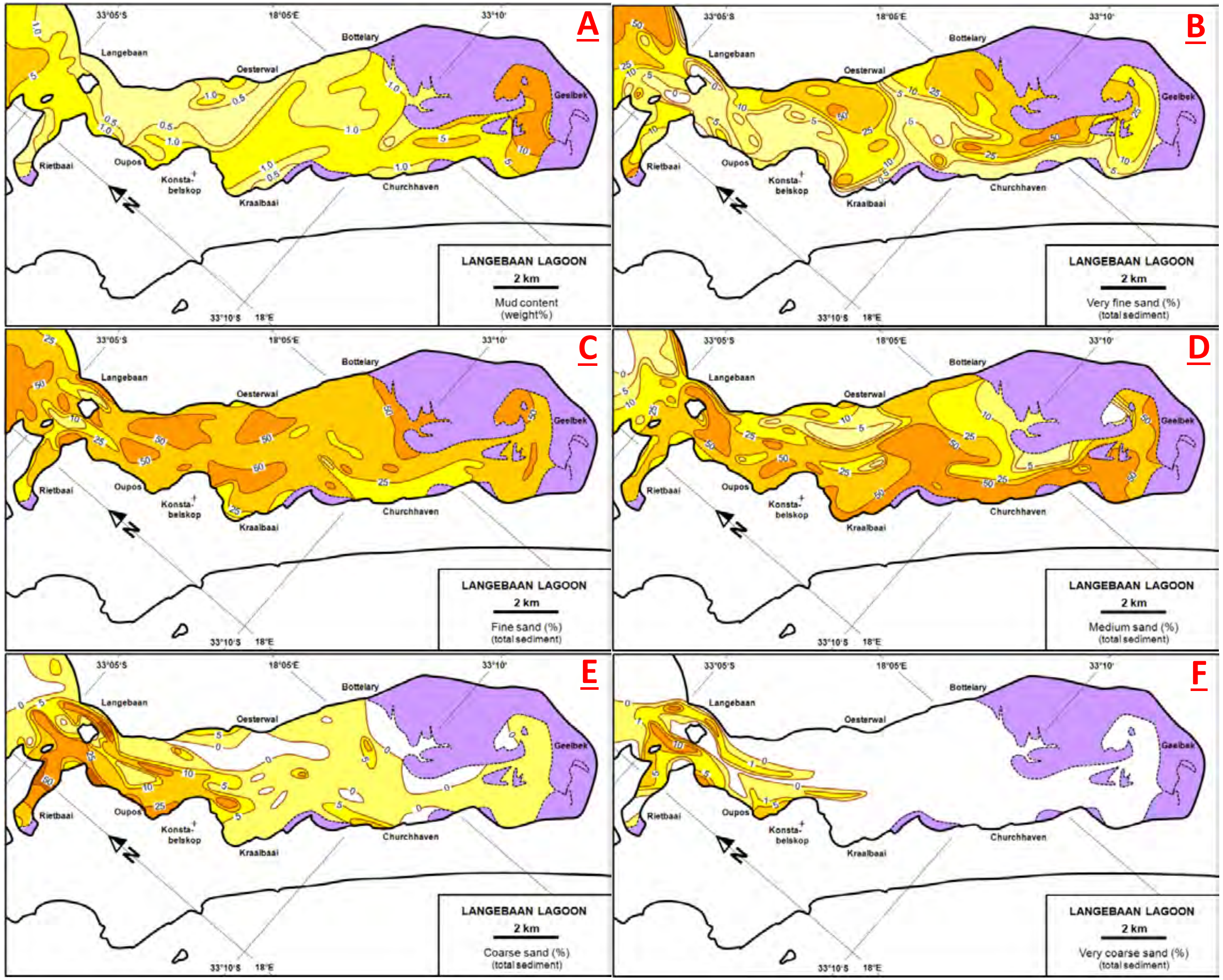


Figure 7.3 Distribution of different sediment types (% of total) in Langebaan Lagoon in 1975: (A) mud (<0.063 mm), (B), very fine sand (0.063-0.125 mm), (C) fine sand (0.125-0.25 mm), (D) medium sand (0.25-0.5 mm), (E) coarse sand (0.5-1.0 mm), (F) very coarse sand (1-2 mm). Source: Flemming (2015).

Sediments in Langebaan Lagoon were comprised mostly of medium, fine and very fine sand, with significant amounts of coarse and very coarse sand near the entrance of the lagoon, but again very low levels of mud (Figure 7.3).

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 terminal 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. Sampling was only conducted at a limited number of stations in 1989 and 1990 but results suggested 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 (Figure 7.7).

Sampling of sediment in Saldanha Bay as part of the State of the Bay monitoring programme commenced in 1999 (nearly a decade later) and was followed by two further sampling events in 2000 and 2001. However, immediately preceding this (in 1997/98) an extensive area adjacent to the ore terminal was dredged, resulting in a massive disturbance to the sediments of the Bay. Data from the 1999 study, where sampling was conducted in Small and Big Bay (Figure 7.4, Figure 7.7) suggested that there had been a substantial increase in the proportion of mud in sediments in the Bay, specifically at the multi-purpose terminal, Channel end of the ore terminal, the Yacht Club Basin and the Mussel Farm area. Two sites least affected by the dredging event were the North Channel site in Small Bay and the site adjacent to the iron ore terminal 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 fine sediments appear to be removed to some extent by the scouring action of oceanic waves in this area. Subsequent studies conducted in 2000 and 2001, which were restricted to Small Bay only, 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 (Figure 7.7).

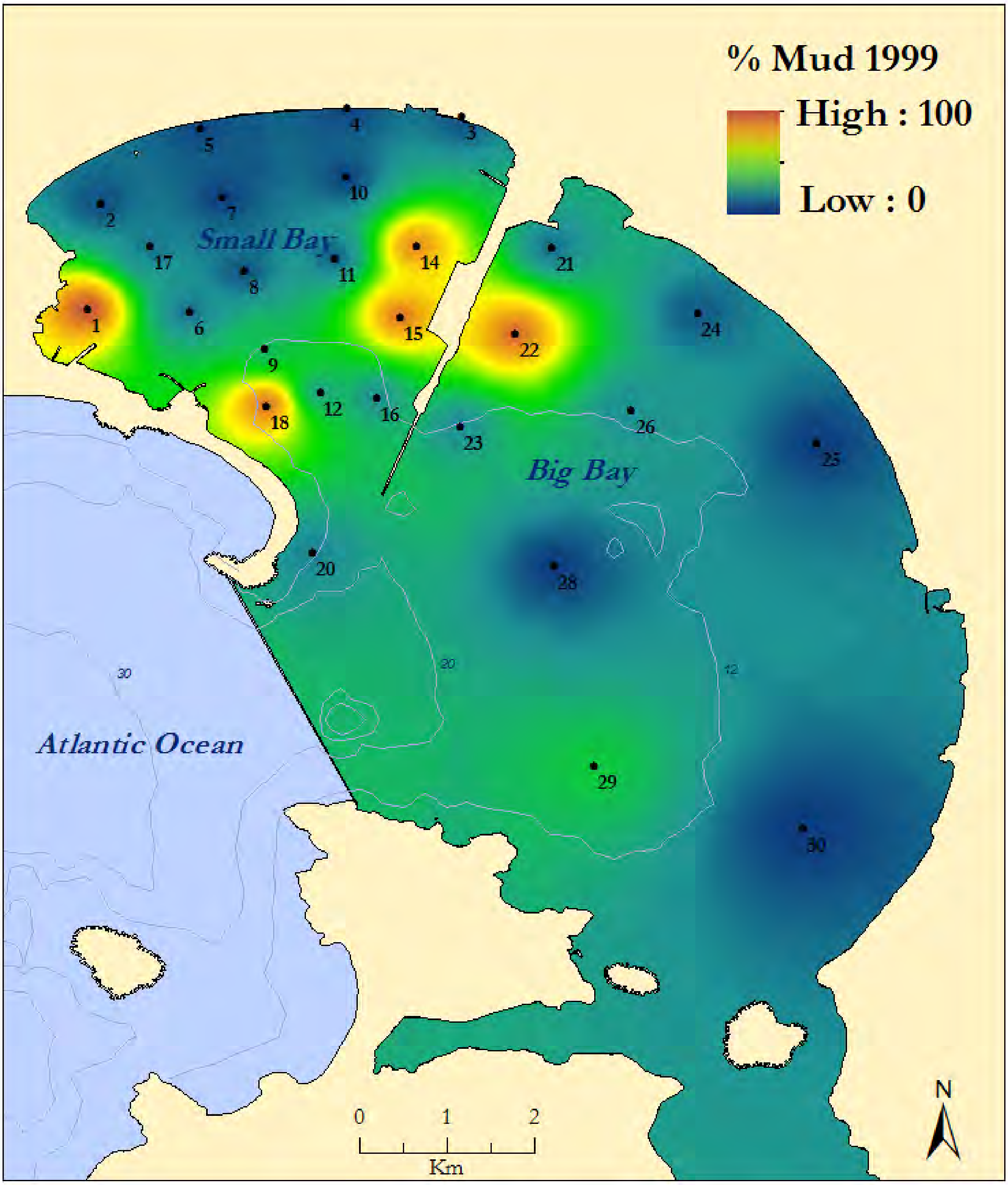


Figure 7.4 Variations in mud percentage in Saldanha Bay in 1999 (Source: CSIR 1999a).

Sampling as part of the State of the Bay programme was conducted again in 2004, and encompassed the whole of the Bay and Lagoon for the first time since 1974. Data collected as part of this sampling event indicated an almost complete recovery of sediments over the 1999 situation, to a situation where sand (as opposed to mud) made up the bulk of the sediment at most of the six sites assessed in this study (Figure 7.7). The only site where a substantial mud component remained was at the multi-purpose terminal. The shipping channel adjacent to the terminal 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 next survey, conducted in 2008, revealed that there had been an increase in the percentage of mud at most sites in Small and Big Bay, most notably in the Yacht Club Basin and at the multi-purpose terminal (Figure 7.7). This was probably due to the maintenance dredging that took place at the Mossgas and multi-purpose terminals at the end of 2007/beginning of 2008. The Yacht Club basin and the Small Bay side of the multi-purpose terminal 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 terminal was severely compromised, with benthic organisms being virtually absent from the former.

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 SANDF Boat park. The former programme seems to have had a minimal impact on 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 2016[8]. 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. This is certainly a positive development as it suggests that sediments in the Bay may be reverting back to a more natural condition where sediments were comprised of mostly sand with a very small mud fraction.

The paucity of data on variations in sediment grain size composition in Langebaan Lagoon do not allow for such a detailed comparison as for the Bay. Available data do suggest, however, that sediments in Langebaan Lagoon have changed little over time and continue to be dominated by

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[8] Data for six key sites surrounding the iron ore terminal and in Small Bay are shown on Figure 1.7. The reader is referred to individual State of the Bay reports for each year for more detail on this.

medium to fine grained sands with a very small percentage of mud. It is important to note though that the absence of any data between 1974 and 2004 does not allow us to assess what happened during the period between 1999-2001 when levels of mud in sediments in the Bay rose to such critically high levels and may mask a corresponding spike in mud levels in the Lagoon as well.

Sediment samples were collected from a total of 31 sites in Saldanha Bay and Langebaan Lagoon in 2017 as part of the annual State of the Bay sampling programme (Figure 7.5). This included 10 sites in Small Bay, 9 in Big Bay, and 12 in Langebaan Lagoon. Samples collected comprised predominantly sand (particle size ranging between 63 µm and 2000 µm). Sites located in Small Bay had on average the highest proportion of mud (5.64%), followed by Big Bay (2.94%) (Table 7.1). An overall increase in mud percentage in both Small and Big Bay sites are evident compared to 2016 results. No gravel (particles exceeding 2000 µm) was found across all samples sites (Figure 7.7, Figure 7.6).

Mud is the most important particle size component to monitor given that fine grained particles provide a larger surface area to which contaminants bind. The sites beneath the mussel farm, and in the shipping channels adjacent to the iron ore terminal, are the deepest and are expected to yield sediments with a higher mud fraction than elsewhere in the Bay. Long term sampling confirms these expectations, with the highest proportion of mud recorded in sediments in the vicinity of the iron ore terminal, multi-purpose terminal, the mussel farms and the Yacht Club Basin. 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.

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 which peaked around 2000, and has been followed in more recent times by a reduction in the mud fraction to levels similar to those last seen in 1974. This pattern is very clearly evident in a comparison between the proportions of mud present in sediments in the Bay in 1974, 1999 and 2017 (Figure 7.8).

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.

Table 7.1. **Particle size composition and percentage total organic carbon (TOC) and total organic nitrogen (TON) in surface sediments collected from Small Bay, Big Bay and Langebaan Lagoon in 2017 (Particle size analysed by Scientific Services and TOC and TON analysed by the Council for Scientific and Industrial Research).**

	Sample	Depth (m)	Sand (%)	Mud (%)	TOC (%)	TON (%)	C:N
Small Bay	SB1	9.00	85.19	14.81	4.03	0.56	8.39
	SB2	7.00	98.88	1.12	0.61	0.07	10.02
	SB3	6.80	97.48	2.52	0.48	0.07	8.27
	SB5	5.90	99.26	0.74	0.23	0.03	7.77
	SB8	10.50	98.30	1.70	0.37	0.07	6.43
	SB9	15.30	91.20	8.80	0.76	0.13	6.75
	SB10	7.70	99.23	0.77	0.35	0.04	9.86
	SB14	16.00	91.53	8.47	2.99	0.48	7.25
	SB15	17.00	87.52	12.48	2.68	0.34	9.33
	SB16	17.50	95.03	4.97	4.81	0.20	28.17
	Average	**11.27**	**94.36**	**5.64**	**1.73**	**0.20**	**10.22**
Big Bay	BB20	21.00	99.15	0.85	1.10	0.08	15.95
	BB21	10.00	96.48	3.52	0.34	0.05	7.81
	BB22	12.60	94.06	5.94	0.51	0.10	5.79
	LPG	17.30	96.25	3.75	0.22	0.04	6.55
	BB24	13.20	95.59	4.41	0.37	0.08	5.51
	BB25	11.00	99.36	0.64	0.27	0.05	5.95
	BB26	16.30	94.27	5.73	0.58	0.11	6.11
	BB29	15.50	98.63	1.37	1.77	0.23	8.98
	BB30	4.50	99.79	0.21	0.10	0.02	6.43
	Average	**13.49**	**97.06**	**2.94**	**0.58**	**0.08**	**7.68**
Langebaan Lagoon	LL31	5.60	99.84	0.16	0.30	0.02	14.16
	LL32	4.00	99.94	0.06	0.15	0.03	6.62
	LL33	3.10	99.66	0.34	0.15	0.03	5.51
	LL34	5.30	99.02	0.98	0.28	0.03	9.43
	LL37	2.00	99.18	0.82	0.32	0.03	10.88
	LL38	6.60	98.98	1.02	0.61	0.13	5.51
	LL39	3.50	99.98	0.02	0.07	0.02	3.64
	LL40	3.20	99.81	0.19	0.11	0.03	4.63
	LL41	3.40	99.56	0.44	0.35	0.07	5.63
	Average	**4.08**	**99.55**	**0.45**	**0.13**	**0.02**	**2.77**

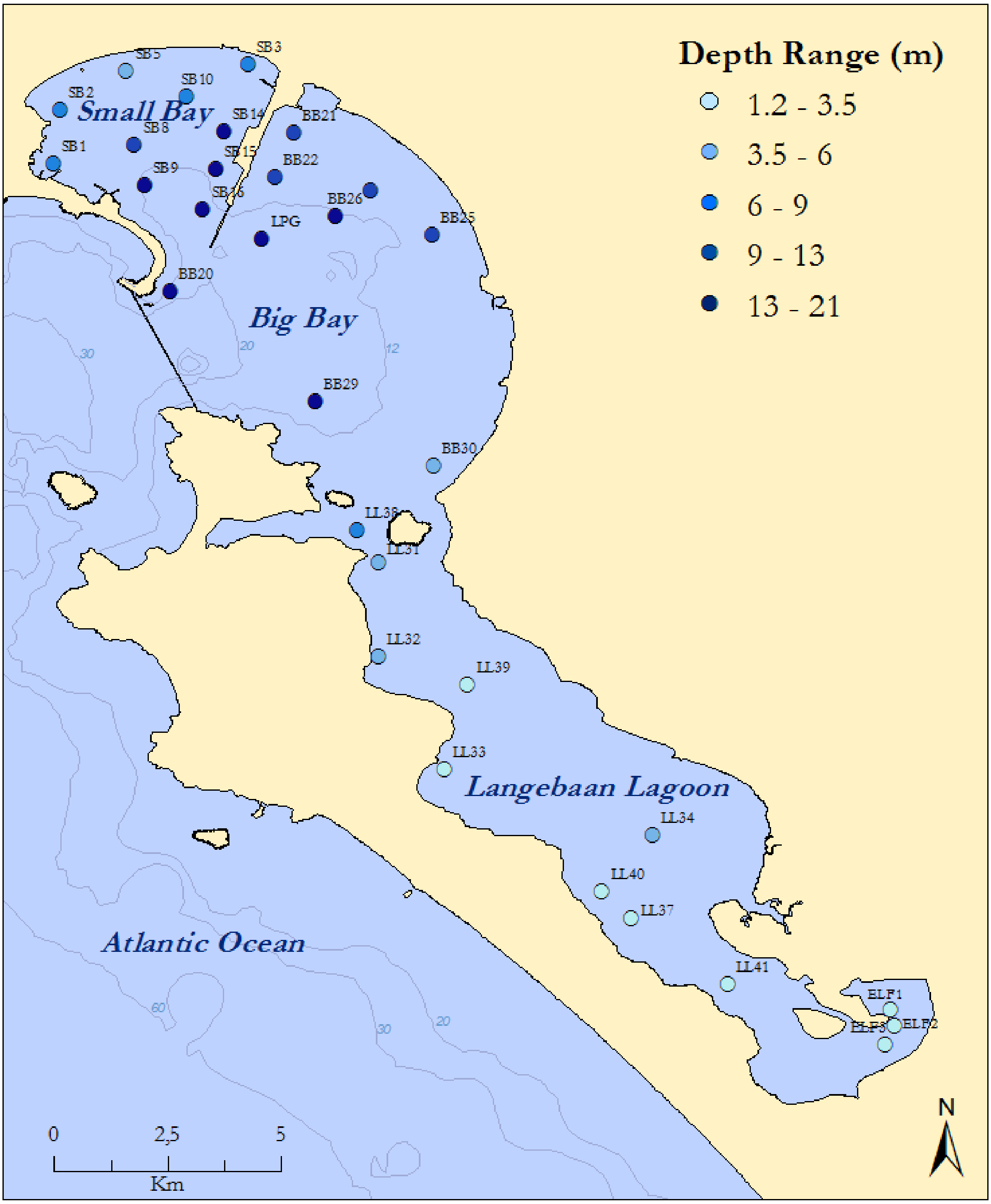


Figure 7.5 **Sediment sampling sites and respective depth ranges (m) in Saldanha Bay and Langebaan Lagoon for 2017.**

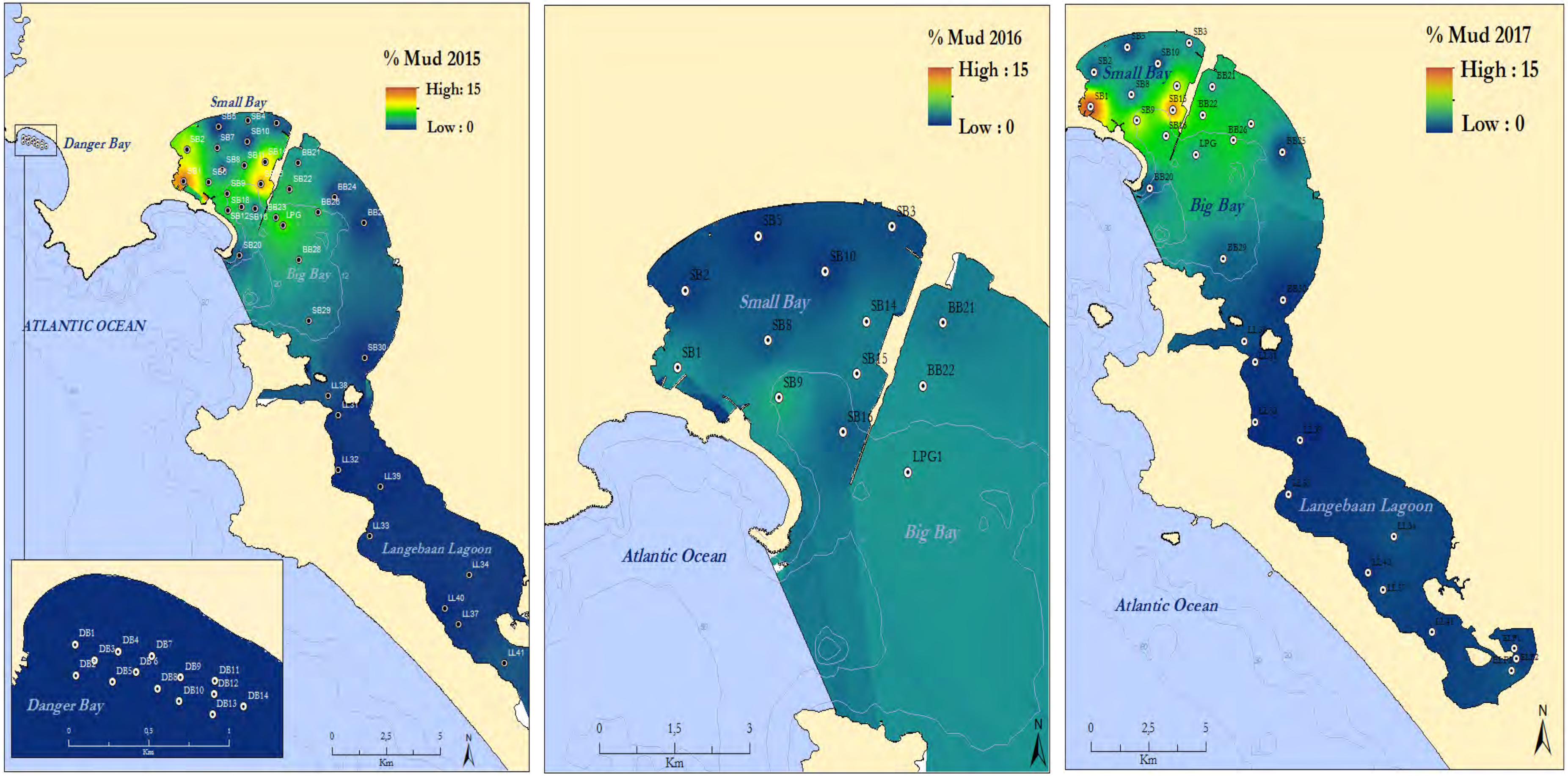


Figure 7.6 Variation in the percentage mud in sediments in Saldanha Bay, Danger Bay and Langebaan Lagoon as indicated by the 2015 (left), 2016 (centre) and 2017 (right) survey results.

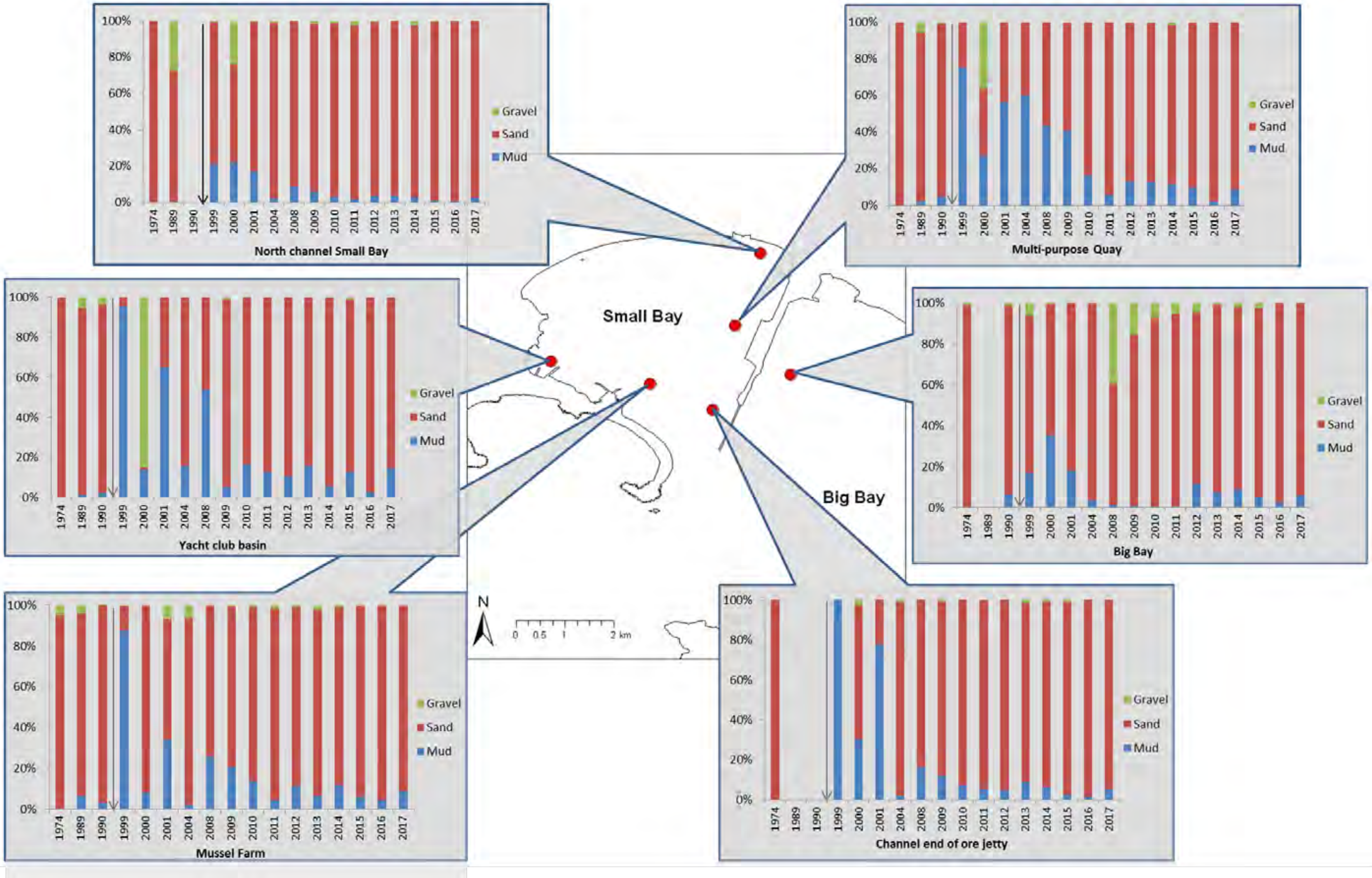


Figure 7.7 Particle size composition (percentage gravel, sand and mud) of sediments at six localities in the small bay area of Saldanha Bay between 1974 and 2017. Data sources: 1974: Flemming (1977b), 1899-1990: Jackson & McGibbon (1991), 1999-2017: SBWQFT.

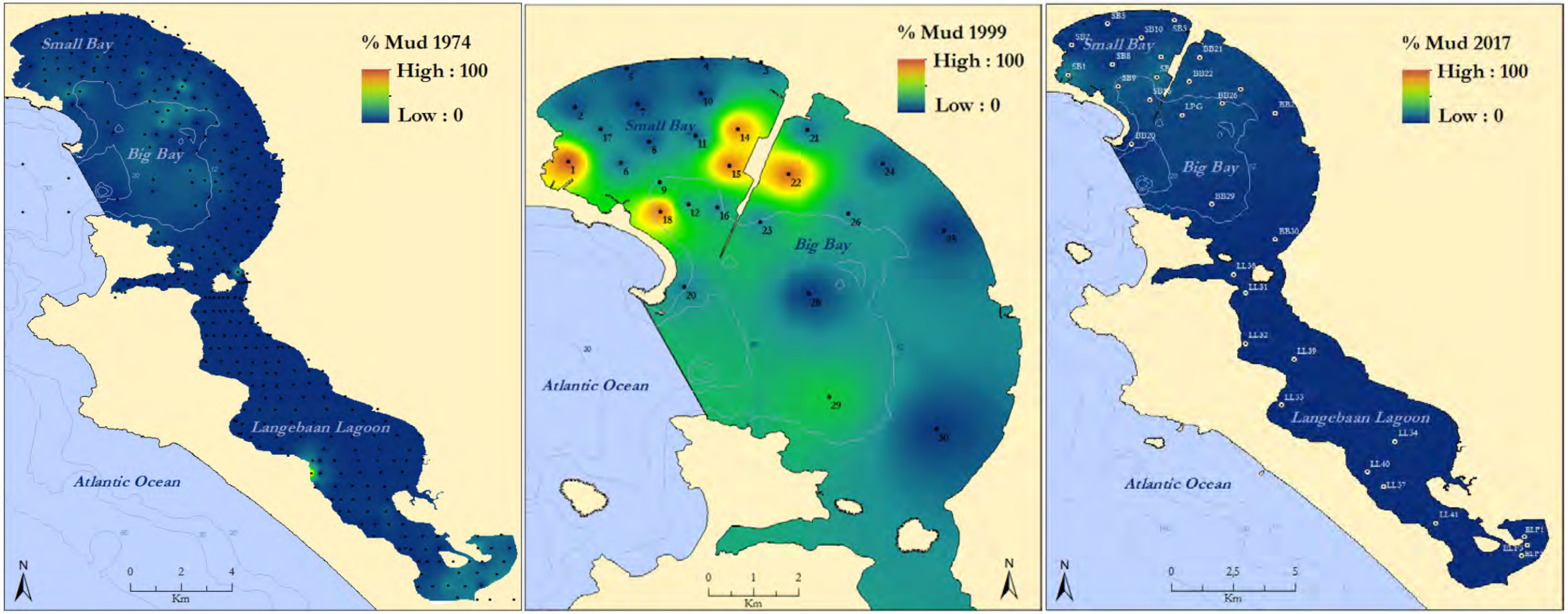


Figure 7.8 Change in the percentage mud in sediments in Saldanha Bay, and Langebaan Lagoon between 1974 (left), 1999 (centre) and 2017 (right) survey results.

7.2 Total organic carbon (TOC) and nitrogen (TON)

Total organic carbon (TOC) and total organic nitrogen (TON) accumulates in the same areas as mud as most organic particulate matter is of a similar particle size range and density to that of mud particles (size <60 µm) and settle 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 the 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 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 typically 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.

Historical data on organic carbon levels in sediments in Saldanha Bay are available from 1974 (Flemming 1977), 1989 and 1990 (Jackson & McGibbon 1991), 1999, 2000 and 2001 (CSIR 1999a, 2000, 2001) and from 2004 and 2008-2017 from the State of the Bay sampling programme. According to data from Flemming (1977), TOC levels in Saldanha Bay were mostly very low (between 0.2 and 0.5%) throughout the Bay and Lagoon prior to any major development (Figure 7.9 and Figure 7.10).

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 key monitoring sites in the vicinity of the iron ore terminal and in Small Bay, had considerably elevated levels of TOC with the greatest increase occurring in the vicinity of the Mussel Farm (Figure 7.13). By the time the next surveys had been undertaken in 1999 (CSIR 1999a, Figure 7.11, Figure 7.13) levels of TOC had increased still further at some sites (e.g. Yacht Club Basin but had decreased at others). Results from 2000 and 2001, which were restricted to Small Bay, showed a similar pattern (Figure 7.13). Data from subsequent surveys undertaken in 2004, and between 2008 and 2017 are presented in the individual State of the Bay reports and are summarised in Figure 7.13, while data on the spatial distribution of TOC from the most recent survey (2017) is shown in Figure 7.14. These data suggest that TOC levels have remained high throughout this period, with highest levels being recorded at the Yacht Club Basin (SB1) and multi-purpose terminal (SB14).

Figure 7.9 Levels of organic carbon in sediments Saldanha Bay in 1974. Source: Flemming (2015).

Figure 7.10 Levels of organic carbon in sediments in Langebaan Lagoon in 1974. Source: Flemming (2015).

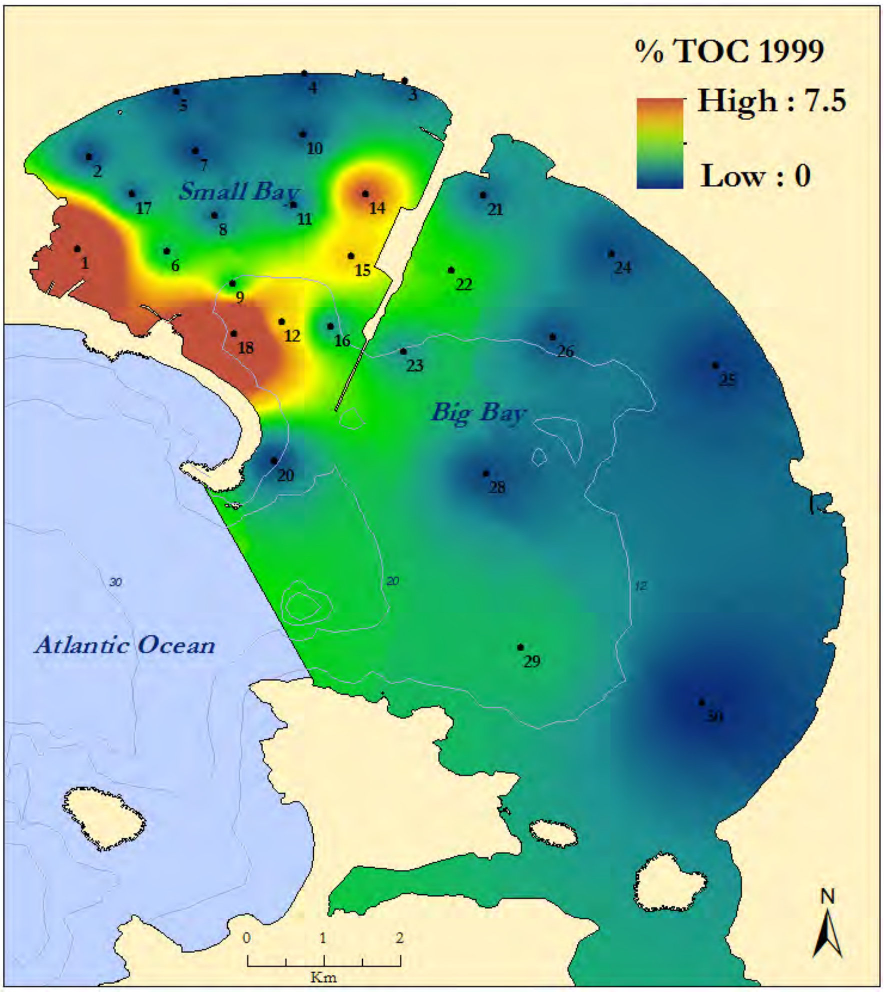


Figure 7.11. Levels of organic carbon in sediments Saldanha Bay in 1999. Source: CSIR (1999a).

Levels of Total Organic Nitrogen (TON) in sediments in the Bay were first recorded in 1999 by the CSIR (CSIR 1999a) at the behest of the SBWQFT. Levels of TON in sediments were assessed again in 2000 and 2001 (CSIR 2000, 2001) again at the behest of the SBWQFT, and the more regularly from 2004 onwards as part of the State of the Bay monitoring programme. TON levels in 1999 were low at most sites that were sampled in the Bay (≤0.2%) except for those in the Yacht Club Basin and near the mussel rafts in Small Bay (Figure 7.12). Levels were slightly or even considerably elevated at all sites that were monitored again in 2000 and 2001 (Figure 7.16). Sampling conducted in 2004 spanned a large number of sites in Small Bay, Big Bay and Langebaan Lagoon and results indicated that levels remained elevated at sites near the Yacht Club Basin, Mussel Raft and iron ore terminal in Small Bay, near the iron ore terminal and in the deeper depositional areas in Big Bay, but were low elsewhere, especially in the Lagoon (Figure 7.16, see also the 2004 State of the Bay report). Results from the State of the Bay surveys conducted between 2008 and 2017 suggest that levels have dropped off slightly at many of the key sites in Small and Big Bay but have remained more or less steady in other parts of the Bay and in the Lagoon (Figure 7.16). Spatial variation in the amount of TON recorded in the sediments in Saldanha Bay and Langebaan Lagoon in 2017 are presented in Figure 7.15. Concentrations were generally highest in Small Bay at the Yacht Club Basin and along the iron ore terminal. This pattern mirrors the distribution of muddy sediments in the bay. The only clear change in TON in 2017 relative to 2016 were slight increased levels at the end of the iron ore terminal (SB16) near the entrance of Big Bay. Levels of TON at these sites remain low relative to levels recorded in 1999 and this is certainly encouraging.

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. Elevated levels of TON in Small Bay are 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.

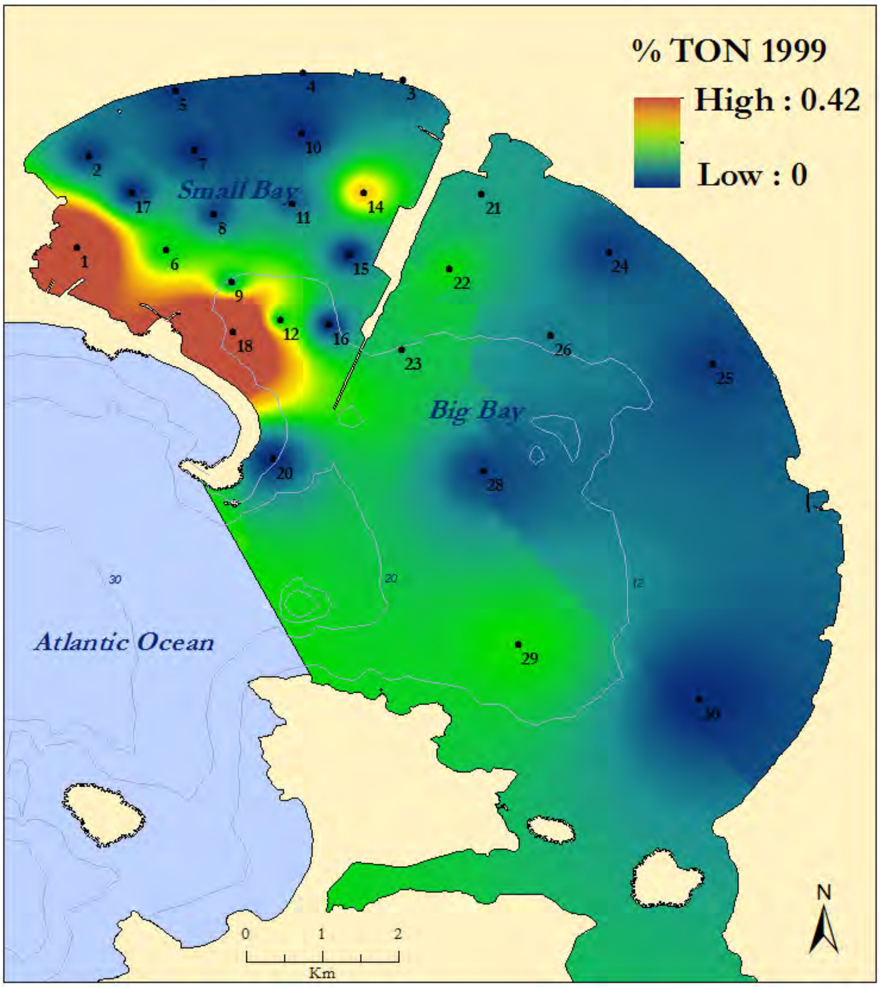


Figure 7.12. Levels of organic nitrogen in sediments Saldanha Bay in 1999. Source: CSIR (1999a).

The ratio between TOC and TON in marine sediments is also important and provides an indication of the source of the organic matter present in sediment. The C:N ratio results from 2015-2017 were somewhat variable. In 2015, four sites within Langebaan Lagoon 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 majority of sites in 2016 were within the expected range of marine production, only one site (SB1 –Yacht Club Basin) was above the expected range for marine sediments (Figure 7.17). There were some exceptions in Small Bay in 2016, with below expected C:N ratios recorded in the vicinity of the Bok River, which is known to be enriched with processed sewage (Figure 6.6). The results of 2017 indicated sites located along the iron ore terminal and at the entrance to Big Bay were above the expected range, however, this is likely not associated with terrestrial inputs and rather nitrogen depletion in the area.

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 deeper 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 2015 and 2017, 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 Basin and Bok River sites) is probably more informative than a temporal analysis.

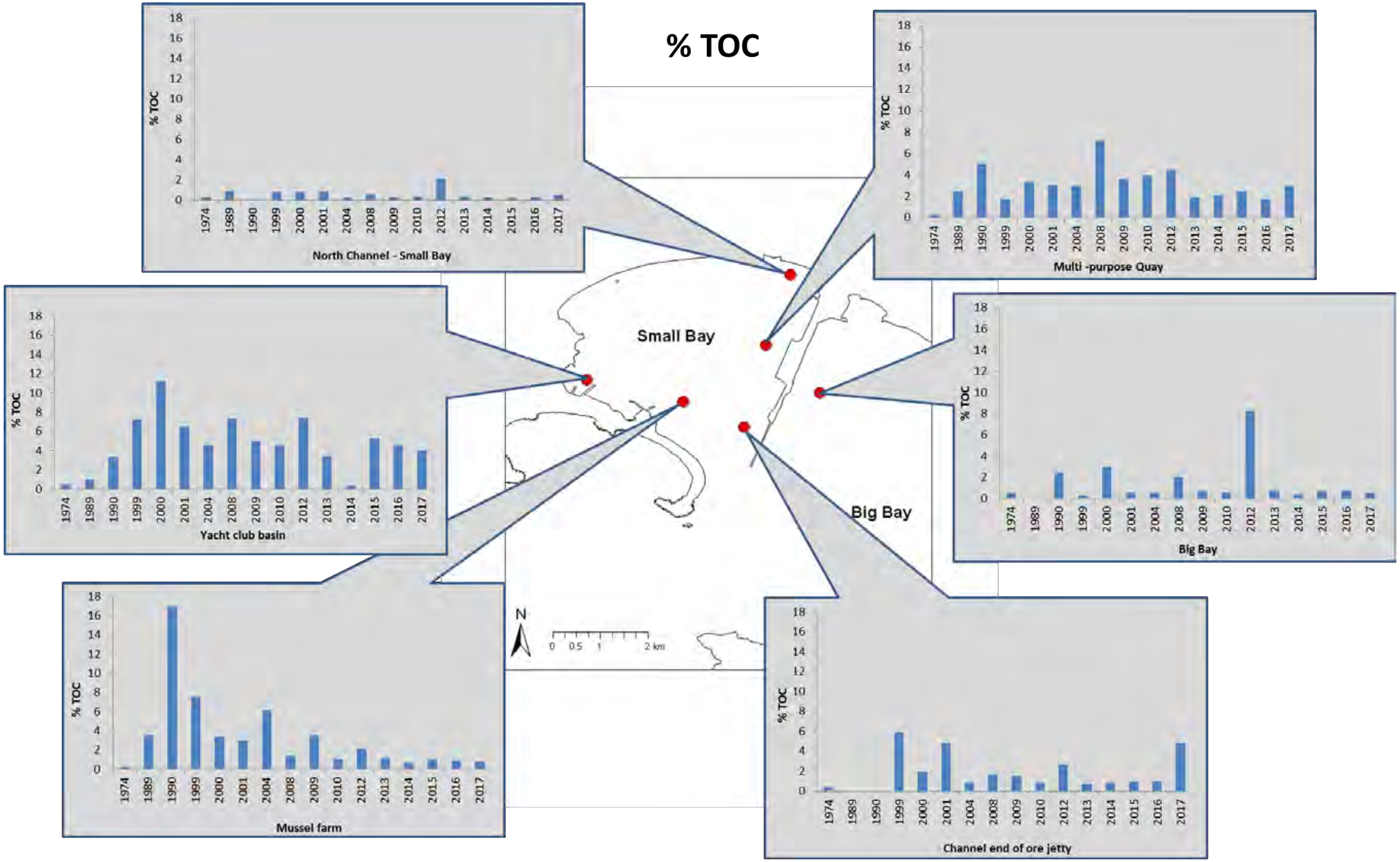


Figure 7.13 **Total organic carbon percentage occurring in sediments of Saldanha Bay at six locations between 1974 and 2017. Data sources: 1974: Flemming (1977b), 1899-1990: Jackson & McGibbon (1991), 1999-2017: SBWQFT**

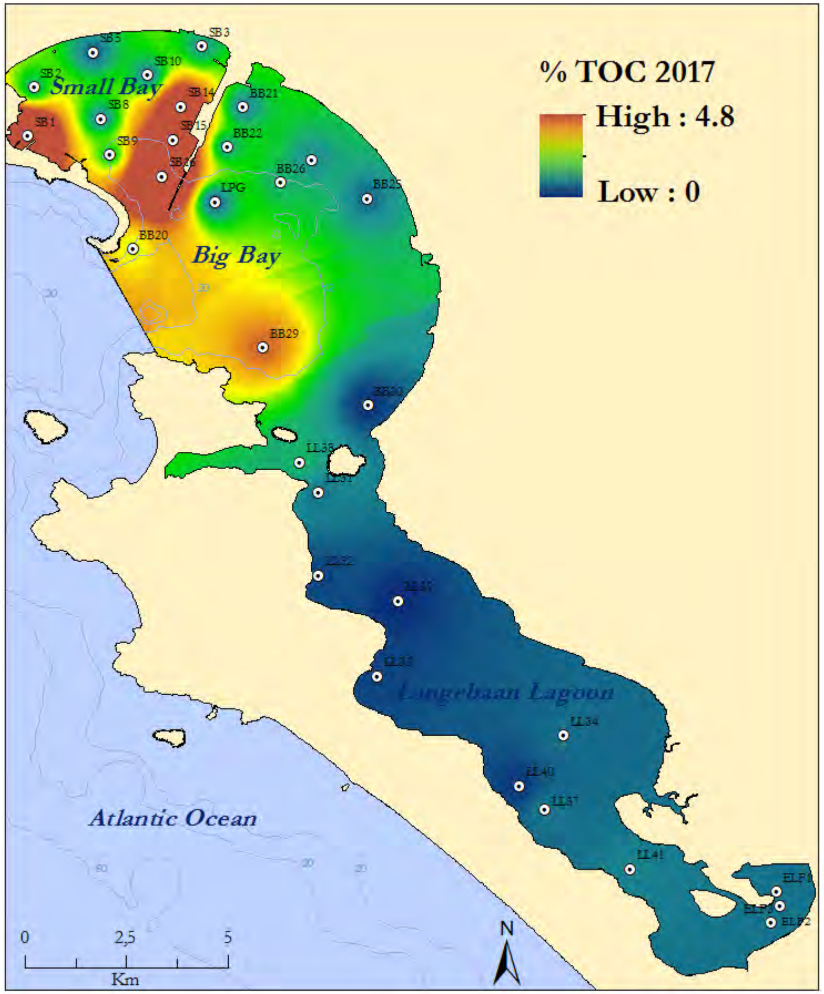


Figure 7.14 Total organic carbon in Saldanha Bay as indicated by the 2017 survey results.

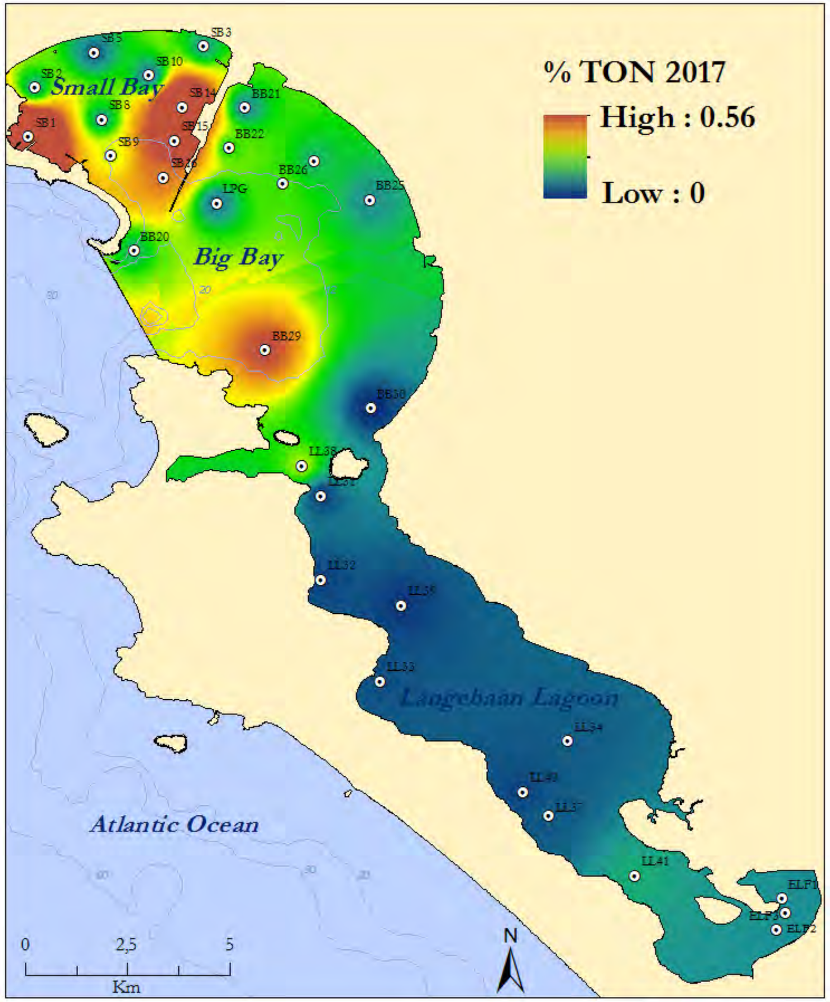


Figure 7.15 Total organic nitrogen in Saldanha Bay as indicated by the 2017 survey results.

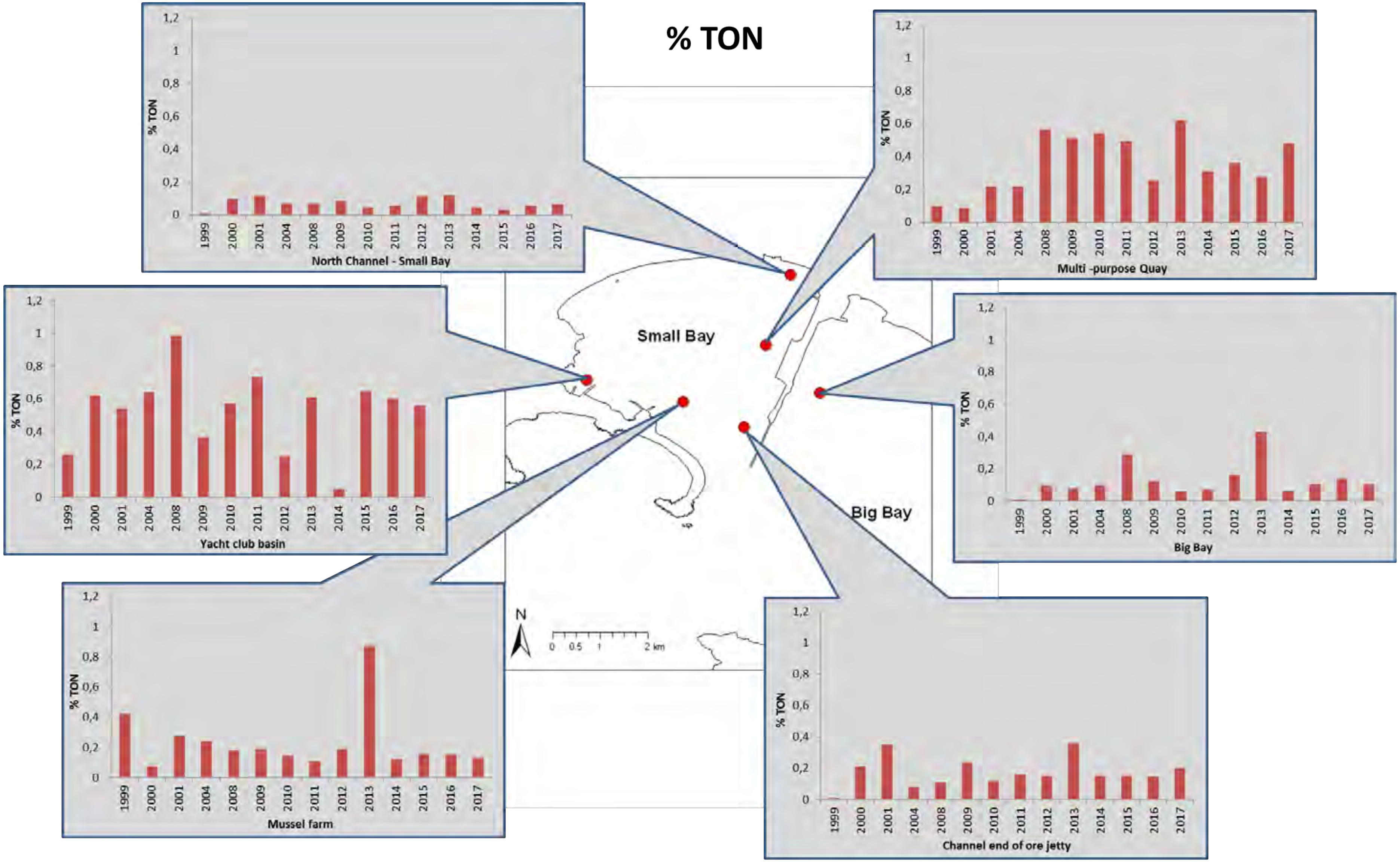


Figure 7.16 Total organic nitrogen percentage occurring in sediments of Saldanha Bay at six locations between 1999 and 2017.

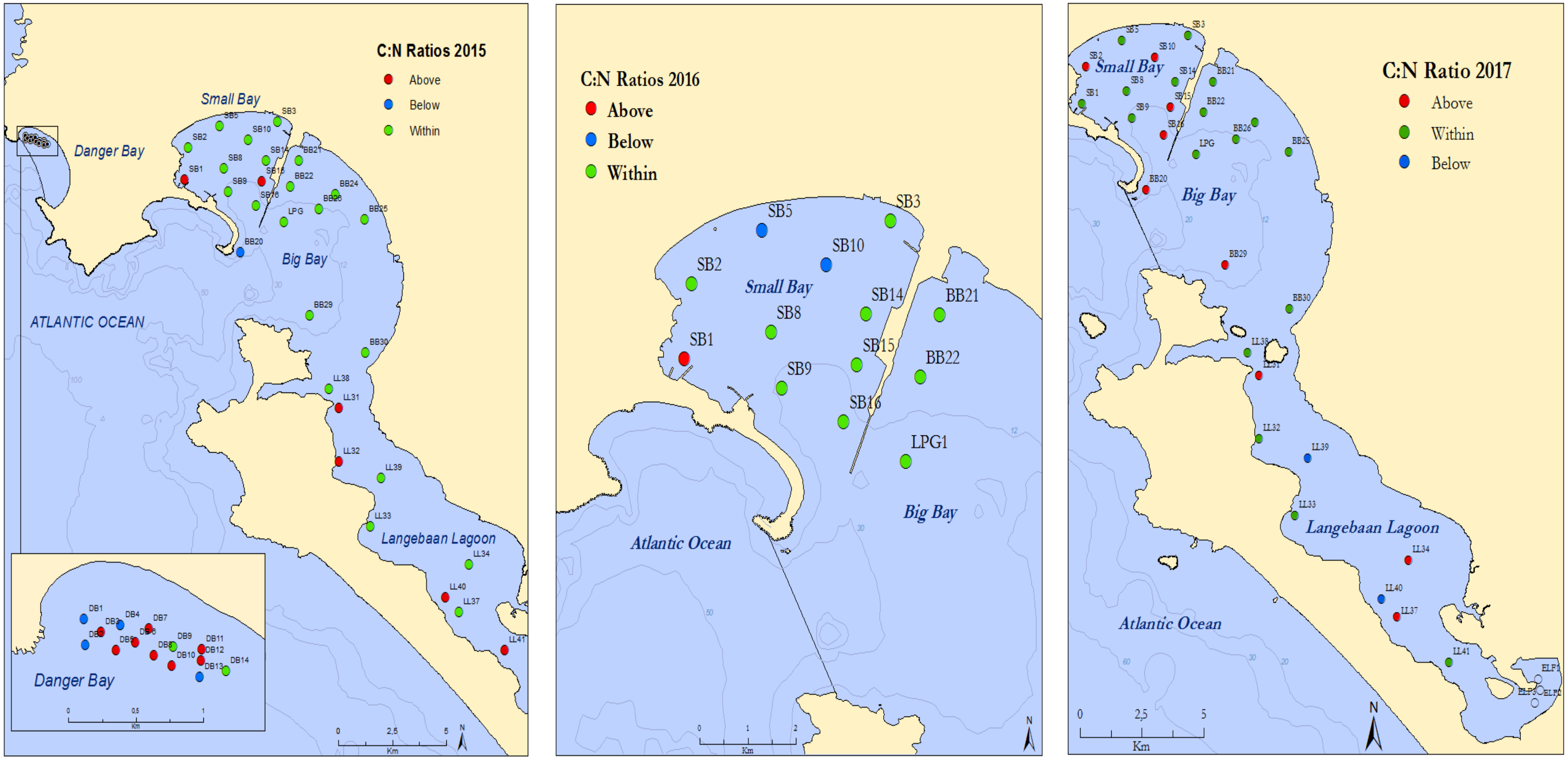


Figure 7.17 C:N ratios at different sites surveyed in Saldanha Bay and Langebaan Lagoon in 2015, 2016 & 2017 (red = exceeds the range expected for marine production, green = within the range expected for marine production and blue = below range expected for marine production).

7.3 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) program 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 7.2). The BCLME guidelines cover a broad concentration range and still need to be refined to meet the specific requirements of each country within the BCLME region (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) have published a series of sediment screening values, which cover a broad spectrum of concentrations from toxic to non-toxic levels as shown in Table 7.2

The Effects Range Low (ERL) represents the concentration at which toxicity may begin to be observed in sensitive species. The ERL is calculated as lower 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 7.2 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	
	Special care	Prohibited	ERL	ERM
Cd	1.5 – 10	> 10	1.2	9.6
Cu	50 – 500	>500	34.0	270.0
Pb	100 – 500	> 500	46.7	218.0
Ni	50 – 500	> 500	20.9	51.6
Zn	150 – 750	> 750	150.0	410.0
1(CSIR 2006), 2 (Long et al. 1995, Buchman 1999)				

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 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 terminal (Small Bay) and 3 km south of the multi-purpose terminal (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 2017 indicates that with a few exceptions, metal concentrations had continued to decrease in Saldanha Bay and have decreased from the exceptionally high concentrations recorded in 1999 and 2000.

Sediments were analysed for concentrations of aluminium (Al), iron (Fe), cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb), and manganese (Mn). 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. Trace metal concentrations recorded in the sediments of Saldanha Bay are shown in Table 7.3 and Figure 7.18 to Figure 7.21.

Table 7.3 Concentrations (mg/kg) of metals in sediments collected from Saldanha Bay in 2017. Values that exceed sediment quality guidelines are highlighted in red font. ND indicates no data.

	Sample	Al	Fe	Cd	Cu	Ni	Pb	Mn
***ERL Guideline (mg/kg)**		-	-	**1.2**	**34**	**20.9**	**46.7**	-
Small Bay	SB1	8870	10679	**2,32**	**35,42**	11,51	17,71	41,09
	SB2	1811	3983	0,13	2,66	4,43	3,83	15,37
	SB3	1261	2427	ND	1,20	2,85	7,21	11,21
	SB5	874	2937	ND	1,15	3,96	1,85	11,95
	SB8	1415	3100	ND	1,08	3,86	3,28	14,30
	SB9	2781	4639	0,15	2,46	5,24	4,15	18,13
	SB10	1158	3296	ND	0,87	3,98	4,40	12,76
	SB14	4391	6140	0,62	11,09	6,65	30,04	26,43
	SB15	5525	7191	0,64	9,22	7,71	22,65	31,86
	SB16	2326	3474	0,16	2,87	5,14	3,11	16,18
Big Bay	BB20	1081	2234	0,09	0,49	3,57	0,82	9,67
	BB21	1536	2488	ND	ND	3,06	1,47	9,42
	BB22	2667	4414	0,14	1,50	4,69	3,18	16,63
	LPG	1705	2763	0,06	0,85	3,87	2,31	11,14
	BB24	2390	3408	0,35	1,04	4,43	3,23	14,17
	BB25	1010	1952	ND	0,30	3,32	0,24	8,93
	BB26	3020	4362	0,21	1,29	5,64	2,76	17,97
	BB29	1758	3087	ND	0,60	4,75	1,05	13,07
	BB30	700	2038	ND	0,07	2,95	ND	8,88
Langebaan Lagoon	LL31	1641	3830	ND	0,58	3,92	1,41	16,37
	LL32	1286	4800	ND	0,53	3,72	1,94	15,04
	LL33	1006	3211	ND	0,72	3,90	0,91	12,63
	LL34	1788	3133	ND	0,44	4,07	0,86	12,70
	LL37	1065	2880	ND	0,74	3,78	0,51	11,72
	LL38	3483	7255	0,14	2,28	6,76	2,95	33,30
	LL39	758	3126	ND	0,27	3,22	0,15	15,67
	LL40	552	2983	ND	0,36	3,43	0,20	21,70
	LL41	755	2040	ND	ND	3,30	0,20	7,80

In 2017, cadmium and copper concentrations were highest, and exceeded ERL guidelines, in the vicinity of the Yacht Club Basin (Table 7.3; Figure 7.18 and Figure 7.19). All other metal concentrations were slightly elevated in the vicinity of the Yacht Club Basin and iron ore terminal, but did not exceed ERL guideline levels (Figure 7.20). Although lead levels also did not exceed ERL guidelines, concentrations were considerably higher at the Yacht Club Basin and adjacent to the multi-purpose terminal (Figure 7.21). 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 influences, for example a high concentration of mud or organic carbon.

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. Due to the known anthropogenic input of iron from the iron ore quay and industrial activity in Saldanha Bay, metal concentrations were normalized against (divided by) aluminium and not iron.

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 7.4). Unfortunately historic enrichment factors could not be calculated for Ni and Mn as no data was available for these elements in 1980. Enrichment factors equal to (or less than) 1 indicate no elevation relative to pre-development conditions, while enrichment factors greater than 1 indicate a degree of metal enrichment within the sediments over time. The extent of contamination for Cd, Cu, Ni and Pb is discussed below using both metal concentrations and the metal enrichment factors.

7.3.1 Spatial variation in trace metals levels in Saldanha Bay

7.3.1.1 Cadmium

Sediments from sites located alongside the iron ore terminal and in the vicinity of the yacht club within Small Bay displayed elevated cadmium concentrations (Figure 7.18; Table 7.3). Cadmium is a trace metal used in electroplating, in pigment for paints, in dyes and in photographical process. The likely sources of cadmium to the marine environment are in emissions from industrial combustion processes, from metallurgical industries, from road transport and waste streams (OSPAR 2010). A likely point source for cadmium contamination in the marine environment is that of storm water drains. Cadmium is toxic and liable to bioaccumulation, and is thus a concern for both the marine environment and human consumption (OSPAR 2010). Given the spatial pattern it is unlikely that the contamination of cadmium in the Bay is a result of storm water drainage, but rather that the cadmium contamination is resulting from shipping and boating. The area where this is particularly concerning is site SB1 (near the Yacht Club Basin) as the level of contamination at this site frequently exceeds the ERL limits. Furthermore the enrichment values for this site since 1980 are high, indicating significant contamination of these areas with cadmium since 1980 (Table 7.4).

7.3.1.2 Copper

Copper concentrations were highest along the iron ore terminal and near the Saldanha Bay Yacht Club within Small Bay (Figure 7.19; Table 7.3). This suggests that there may be a source of copper pollution affecting the Small Bay region. Copper is used as a biocide in antifouling products as it is very effective for killing marine organisms that attach themselves to the surfaces of boats and ships. Anti-fouling paints release copper into the sea and can make a significant contribution to copper concentrations in the marine environment (Clark 1986). The areas with elevated normalized copper 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 copper 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 copper. The copper concentration at the Yacht Club Basin in Saldanha Bay exceeded the ERL guideline, the normalized value indicates the pollution source was anthropogenic and the enrichment factor was also alarmingly high in 2017 (Table 7.4).

7.3.1.3 Nickel

Nickel values measured in 2017 were elevated at the yacht club and alongside the iron ore terminal within Small Bay (Figure 7.20 & Table 7.3). Nickel is introduced to the environment by both natural and anthropogenic means. Natural means of contamination include windblown 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.

7.3.1.4 Lead

Elevated lead concentrations were recorded in Small Bay, particularly in the vicinity of the multi-purpose terminal and the yacht club (Figure 7.21 & Table 7.3). Lead pollution is a worldwide problem and is generally associated with mining, smelting and the industrial use of lead (OSPAR 2010). Lead is a persistent compound which is toxic to aquatic organism and mammals, and thus the contamination is of concern for the marine environment and human consumption (OSPAR 2010). The area adjacent to the multi-purpose terminal had the highest lead values indicating that this area is subject to high levels of lead pollution. The enrichment factor for the site nearest to the multi-purpose terminal was very high (47.9), however, the concentration of lead was below recommended ERL toxicity limits (Table 7.4). Normalized metal/aluminium ratios revealed that lead contamination was high at numerous sites in Small Bay (Table 7.5). Areas of concern corresponded with sites where high metal concentrations and metal enrichment were indicated.

7.3.1.5 Manganese

Manganese concentrations were highest near the Yacht Club Basin and along the iron ore terminal within Small Bay (Figure 1.13 & Table 1.3). This suggests that there may be a source of manganese pollution affecting these areas of the Small Bay region. Manganese is naturally ubiquitous in the marine environment, however, can become potentially harmful through its tendency to accumulate in certain organisms, such as shellfish. The concentration of manganese recorded is possibly associated with the recent start of manganese exports (Section 3.3).

Table 7.4 **Enrichment factors for Cadmium, Copper and Lead in sediments collected from Saldanha Bay in 2017 relative to sediments from 1980.**

	Sample	Cd	Cu	Pb
	1980 average	**0,075**	**0,41**	**0,8**
Small Bay	SB1	30,9	86,4	22,1
	SB2	1,8	6,5	4,8
	SB3	ND	2,9	9,0
	SB5	ND	2,8	2,3
	SB8	ND	2,6	4,1
	SB9	1,9	6,0	5,2
	SB10	ND	2,1	5,5
	SB14	8,3	27,0	37,6
	SB15	8,5	22,5	28,3
	SB16	2,1	7,0	3,9
Big Bay	BB20	1,2	1,2	1,0
	BB21	ND	ND	1,8
	BB22	1,9	3,7	4,0
	LPG	0,8	2,1	2,9
	BB24	4,7	2,5	4,0
	BB25	ND	0,7	0,3
	BB26	2,8	3,1	3,5
	BB29	ND	1,5	1,3
	BB30	ND	0,2	ND

Table 7.5 **Normalized values for Cadmium, Copper, Nickel, Lead and Manganese in sediments collected from Saldanha Bay and Langebaan Lagoon in 2017.**

	Sample	Cd:Al	Cu:Al	Ni:Al	Pb:Al	Mn: Al
Small Bay	SB1	2,62	39,93	12,98	19,97	107,96
	SB2	0,73	14,69	24,46	21,19	67,37
	SB3	ND	9,52	22,63	57,22	50,51
	SB5	ND	13,18	45,29	21,26	20,83
	SB8	ND	7,63	27,31	23,24	40,70
	SB9	0,52	8,84	18,85	14,94	42,53
	SB10	ND	7,51	34,35	38,05	32,10
	SB14	1,42	25,25	15,15	68,42	90,60
	SB15	1,16	16,69	13,95	40,99	63,75
	SB16	0,68	12,34	22,11	13,40	45,16
Big Bay	BB20	0,82	4,55	33,04	7,62	31,53
	BB21	ND	ND	19,92	9,59	34,81
	BB22	0,54	5,63	17,58	11,95	39,53
	LPG	0,35	4,98	22,72	13,56	41,49
	BB24	1,46	4,36	18,52	13,53	46,46
	BB25	ND	2,99	32,86	2,42	23,52
	BB26	0,69	4,27	18,68	9,17	33,66
	BB29	ND	3,41	27,00	5,99	24,28
	BB30	ND	1,01	42,12	ND	14,27
Langebaan Lagoon	LL31	ND	3,55	23,90	8,60	22,97
	LL32	ND	4,14	28,92	15,11	30,49
	LL33	ND	7,20	38,82	9,10	16,38
	LL34	ND	2,46	22,78	4,83	22,31
	LL37	ND	6,99	35,53	4,87	17,03
	LL38	0,40	6,53	19,41	8,47	31,35
	LL39	ND	3,59	42,45	2,02	26,62
	LL40	ND	6,52	62,11	3,77	10,30
	LL41	ND	ND	43,67	2,68	14,03

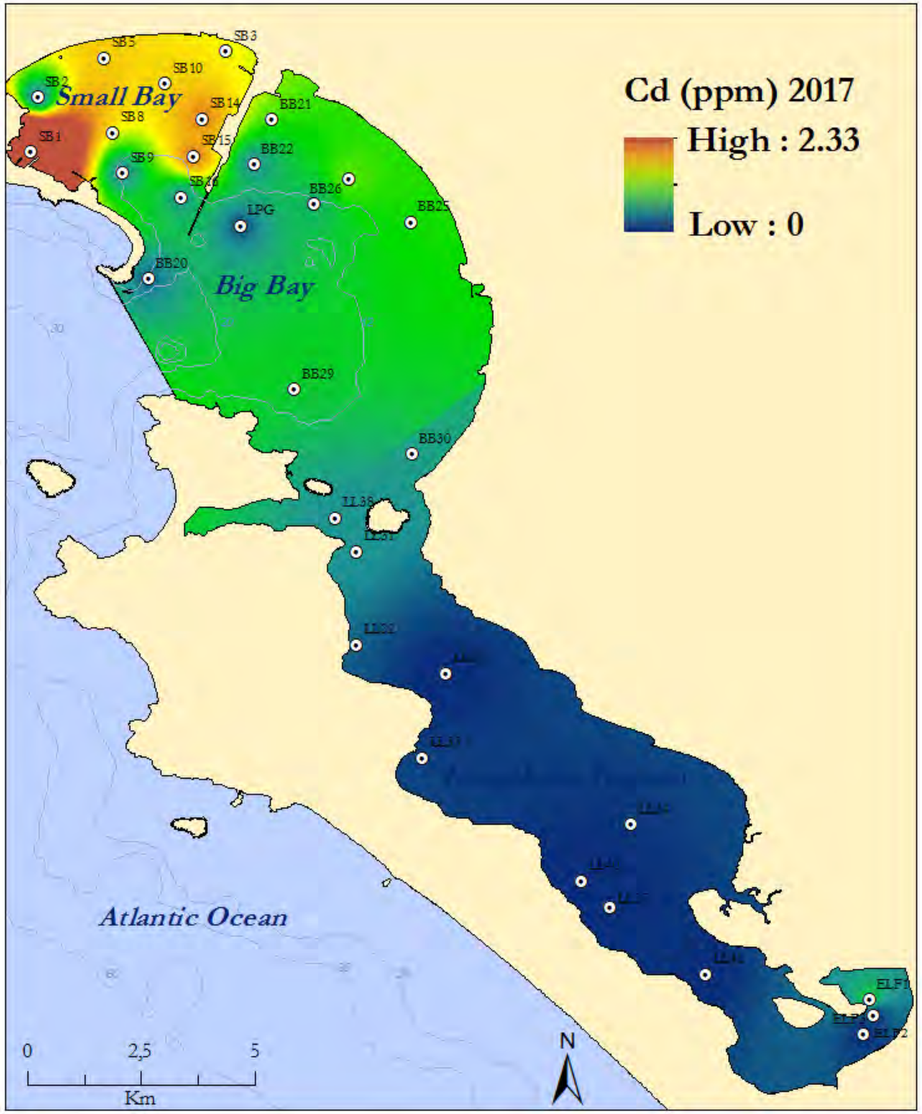


Figure 7.18 Spatial interpolation of cadmium values based on values measured in sediments in Saldanha Bay in 2017.

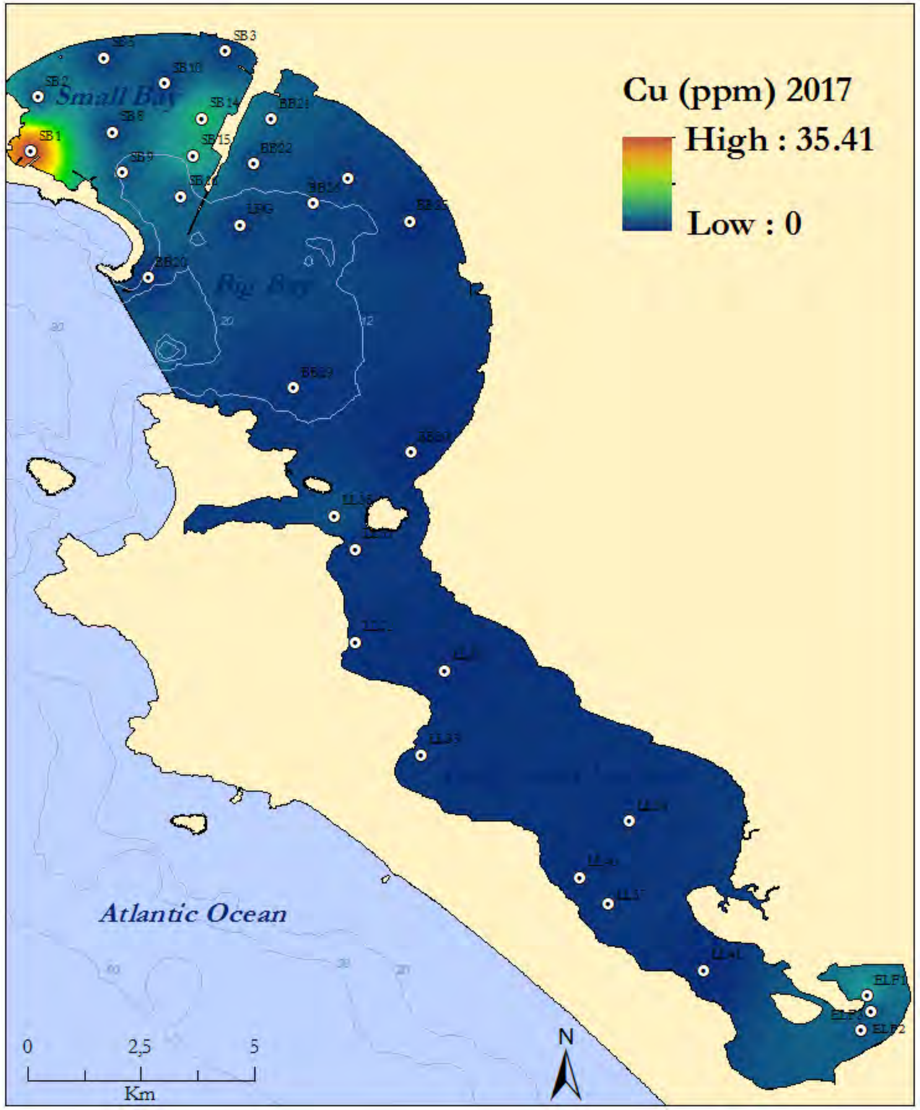


Figure 7.19 Spatial interpolation of copper values based on values measured in sediments in Saldanha Bay in 2017.

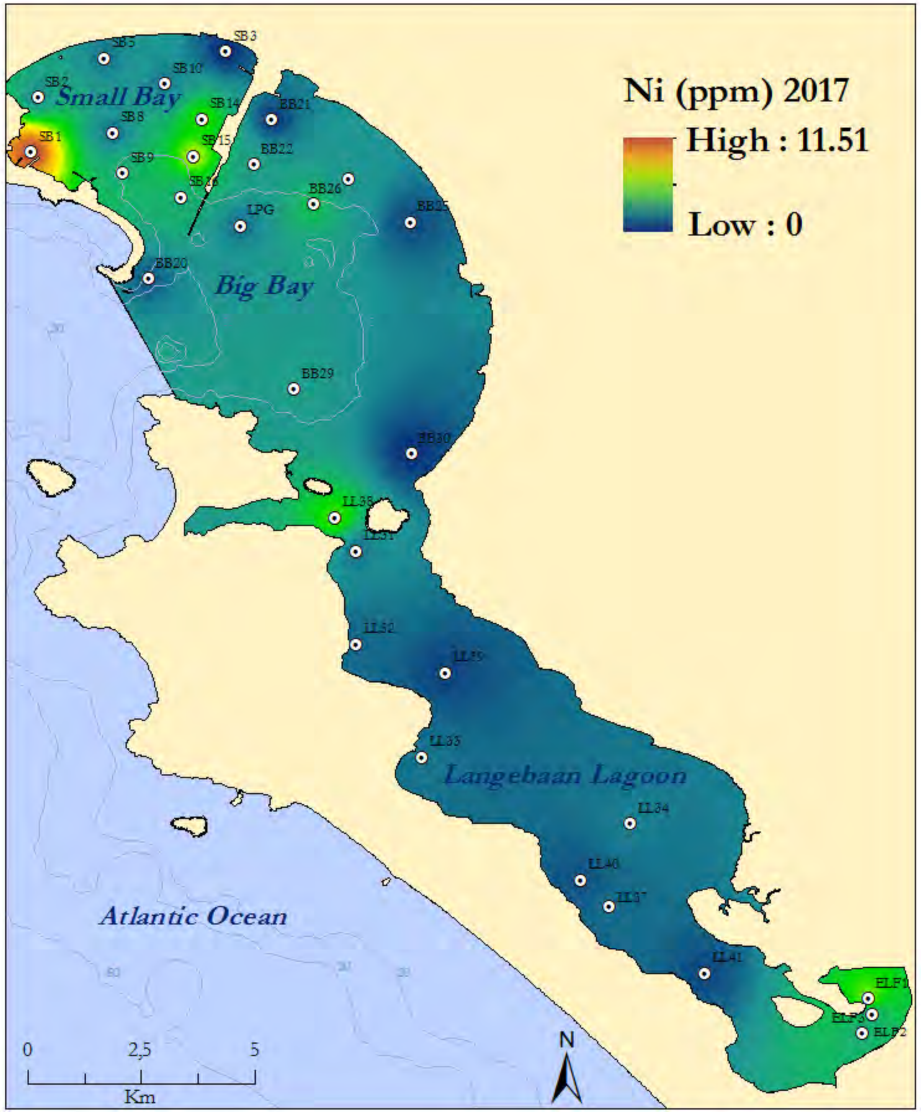


Figure 7.20 Spatial interpolation of nickel values based on values measured in sediments in Saldanha Bay in 2017.

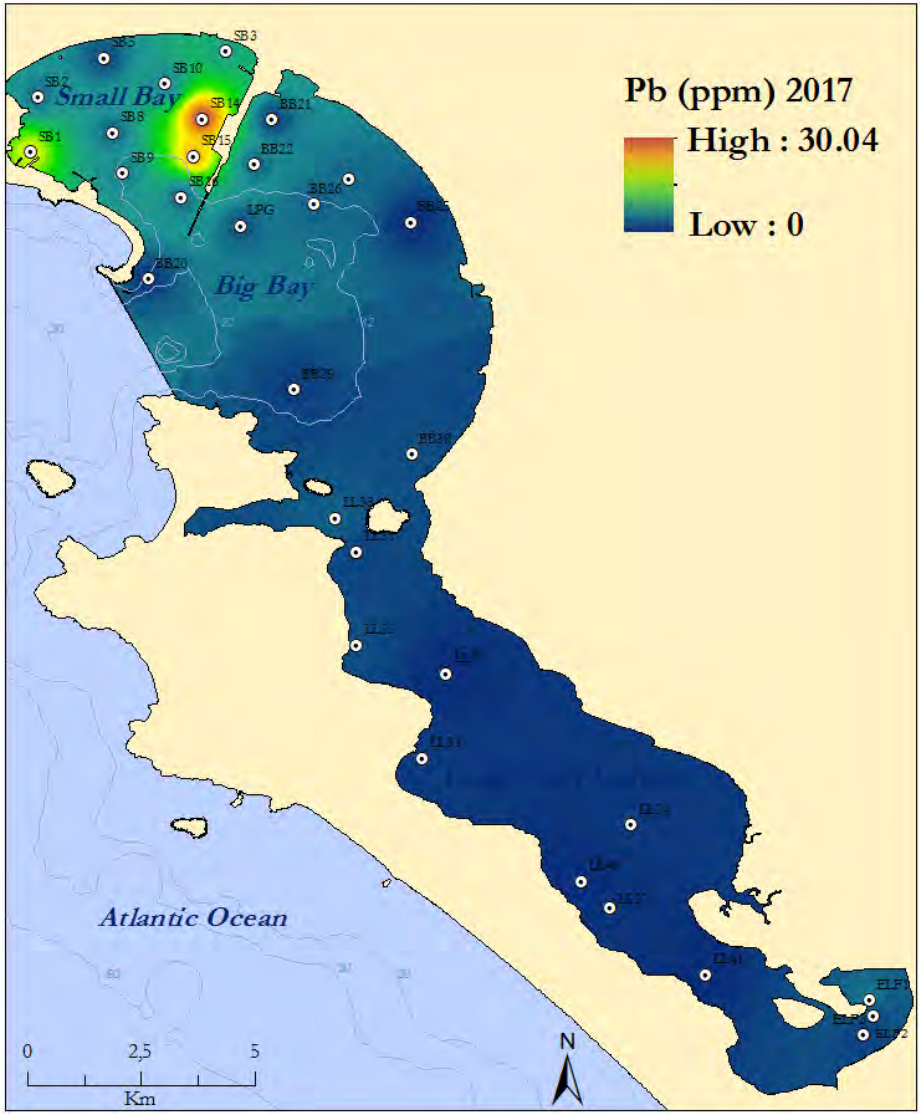


Figure 7.21 Spatial interpolation of lead values based on values measured in sediments in Saldanha Bay in 2017.

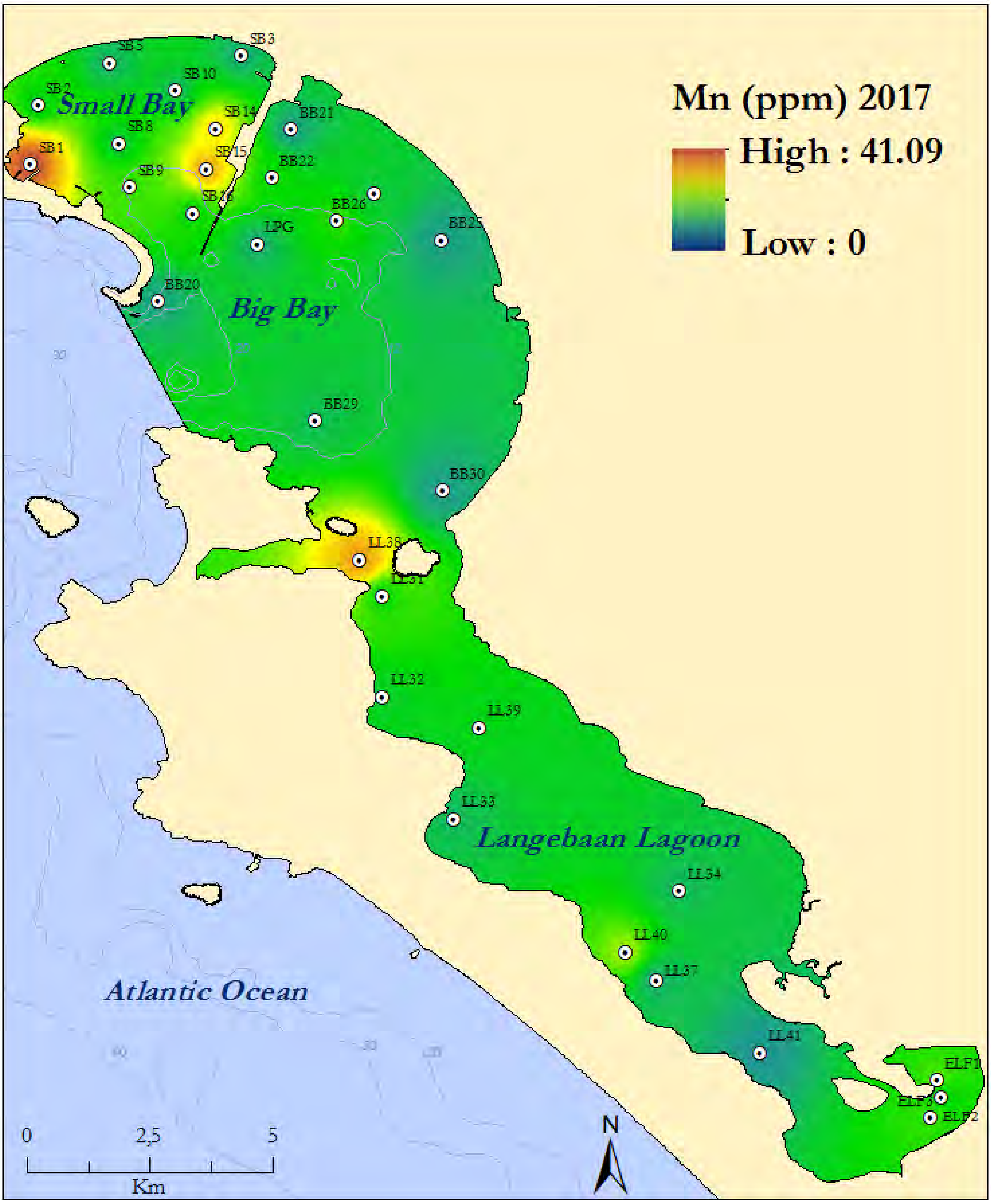


Figure 7.22 Spatial interpolation of manganese values based on values measured in sediments in Saldanha Bay in 2017.

7.3.2 Temporal variation in trace metal levels in Saldanha Bay

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

7.3.2.1 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 iron ore terminal exceeded the ERL toxicity threshold of 1.2 mg/kg established by NOAA (Figure 7.23). 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 at the Yacht Club Basin and Muilti-purpose Quay. At the time of the 2014 survey, cadmium concentrations had decreased to below the ERL toxicity threshold within the Yacht Club Basin but since 2015 to levels have remained high. Concentrations at the multi-purpose terminal have shown a steady decrease since 2014. Cadmium concentrations at all other sites have remained low in recent years.

7.3.2.2 Copper

The total concentration of copper in the sediments has remained well below the ERL threshold consistently since 1980, with the exception of the Yacht Club Basin which has exceeded the ERL in most years (Figure 7.24). Apart from the low levels recorded in 2014, copper concentrations at the Yacht Club Basin have remained high over the past seven years.

7.3.2.3 Nickel

The concentration of nickel was the highest at the Yacht Club Basin and the Mussel Farm in 1999 where it exceeded the ERL threshold (Figure 7.25). 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 and remained relatively constant to present date.

7.3.2.4 Lead

The concentration of lead peaked and exceeded the ERL threshold at the Yacht Club Basin and Mussel farm site in 1999 (Figure 7.26). The concentration of lead at these sites has not exceeded the ERL level since this time. Lead concentrations in sediments adjacent to the multi-purpose terminal have frequently exceeded the ERL threshold over the last 15 years. This result suggests that industrial and shipping activities taking place at the multi-purpose terminal continue to contaminate the adjacent marine environment with lead.

7.3.2.5 Manganese

The temporal variation in manganese concentrations in sediments around the ore terminal in Saldanha Bay is shown in Figure 7.27. Manganese concentrations at sites located along the ore terminal within Small Bay have fluctuated over recent years. High concentrations of manganese were recorded at the Small Bay sites in 2014 but have gradually decreased over the last three years. The two sites located along the ore terminal within Big Bay have also shown decreases from 2015 to 2017.

7.3.2.6 Iron

The temporal variation in the concentration of iron in sediments around the ore terminal in Saldanha Bay is shown in Figure 7.28. The concentration of iron increased between 1999 and 2004 at sites SB14 and SB15 which are in closest proximity to and on the downwind side (of the predominant southerly winds) of the multi-purpose terminal. 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 terminal 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 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, and surfacing of roads and improved housekeeping (road sweeper, conveyor 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 tonnes per month during 2007-2008 to around 6.5 million tonnes 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 2017. However, the concentration of iron at SB15 has fluctuated dramatically since 2012, but has shown an overall decrease in the last six years. This does suggest that the improved dust control methods implemented since 2007 have been successful in reducing the input to the marine environment. On-going monitoring of sediment iron concentration will reveal whether the decrease recorded across these sites will continue with the anticipated higher volumes of ore handling or if concentrations will continue to fluctuate.

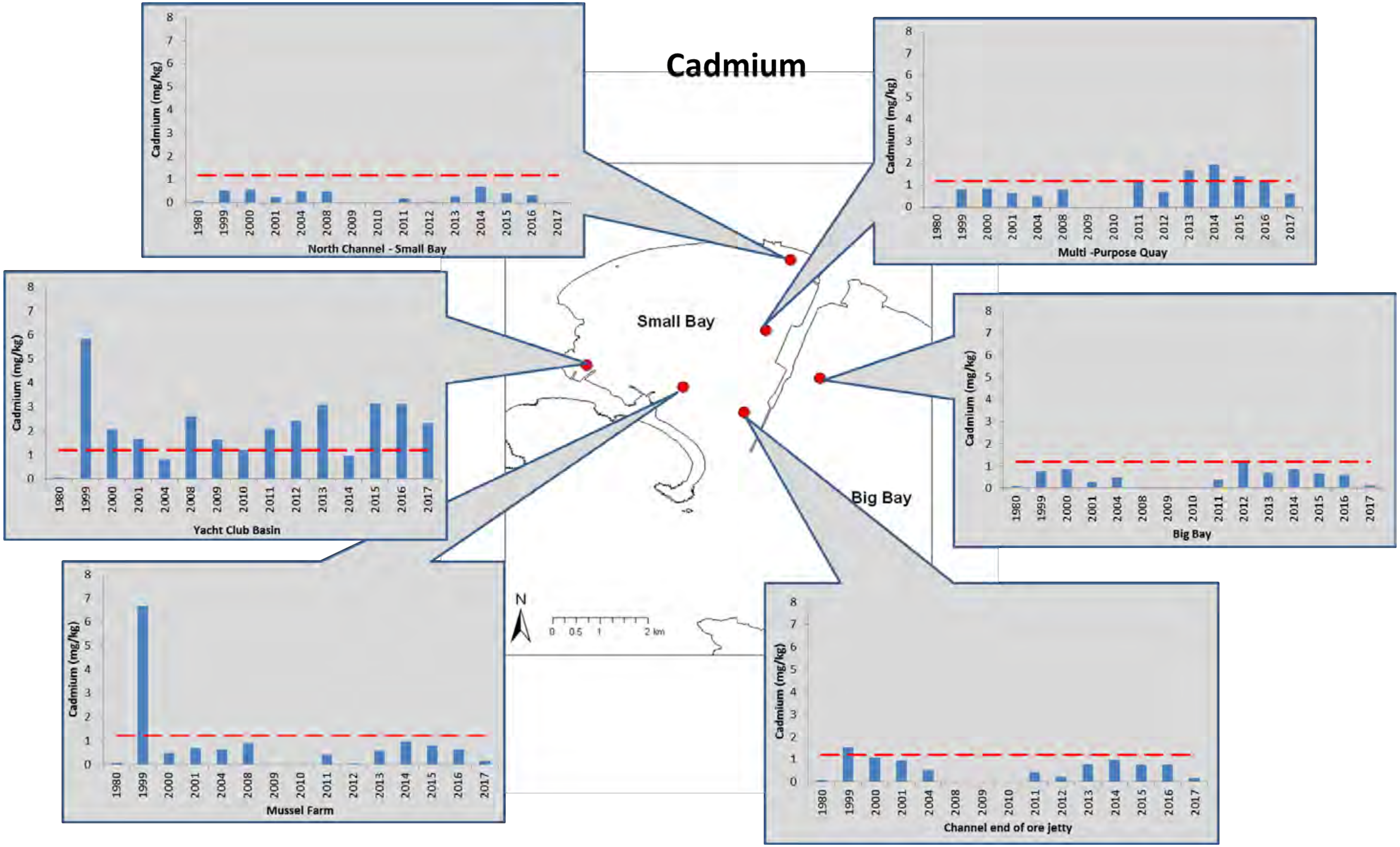


Figure 7.23 **Concentrations of Cadmium (Cd) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2017. Dotted lines indicate Effects Range Low values for sediments.**

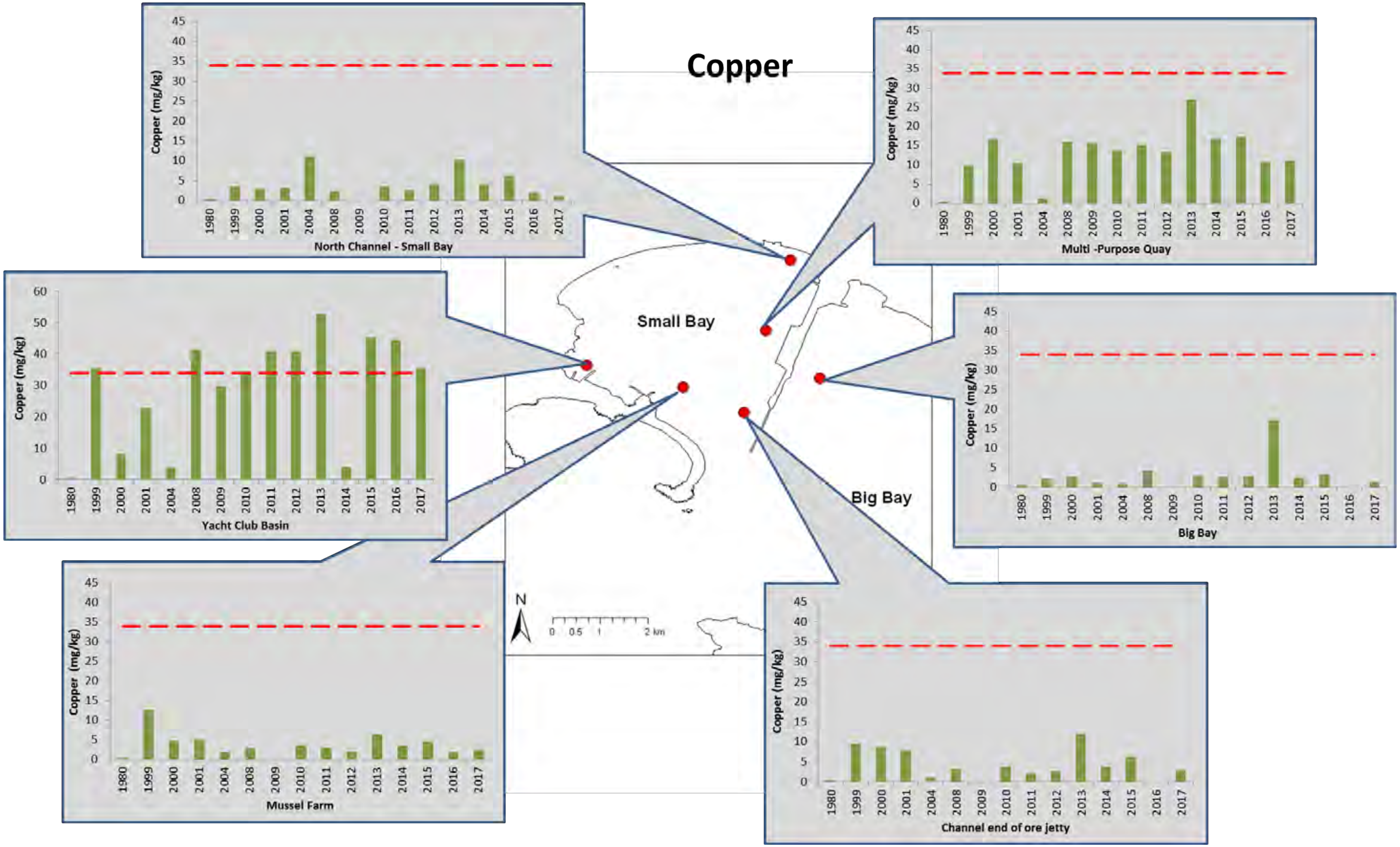


Figure 7.24 Concentrations of Copper (Cu) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2017. Dotted lines indicate Effects Range Low values for sediments.

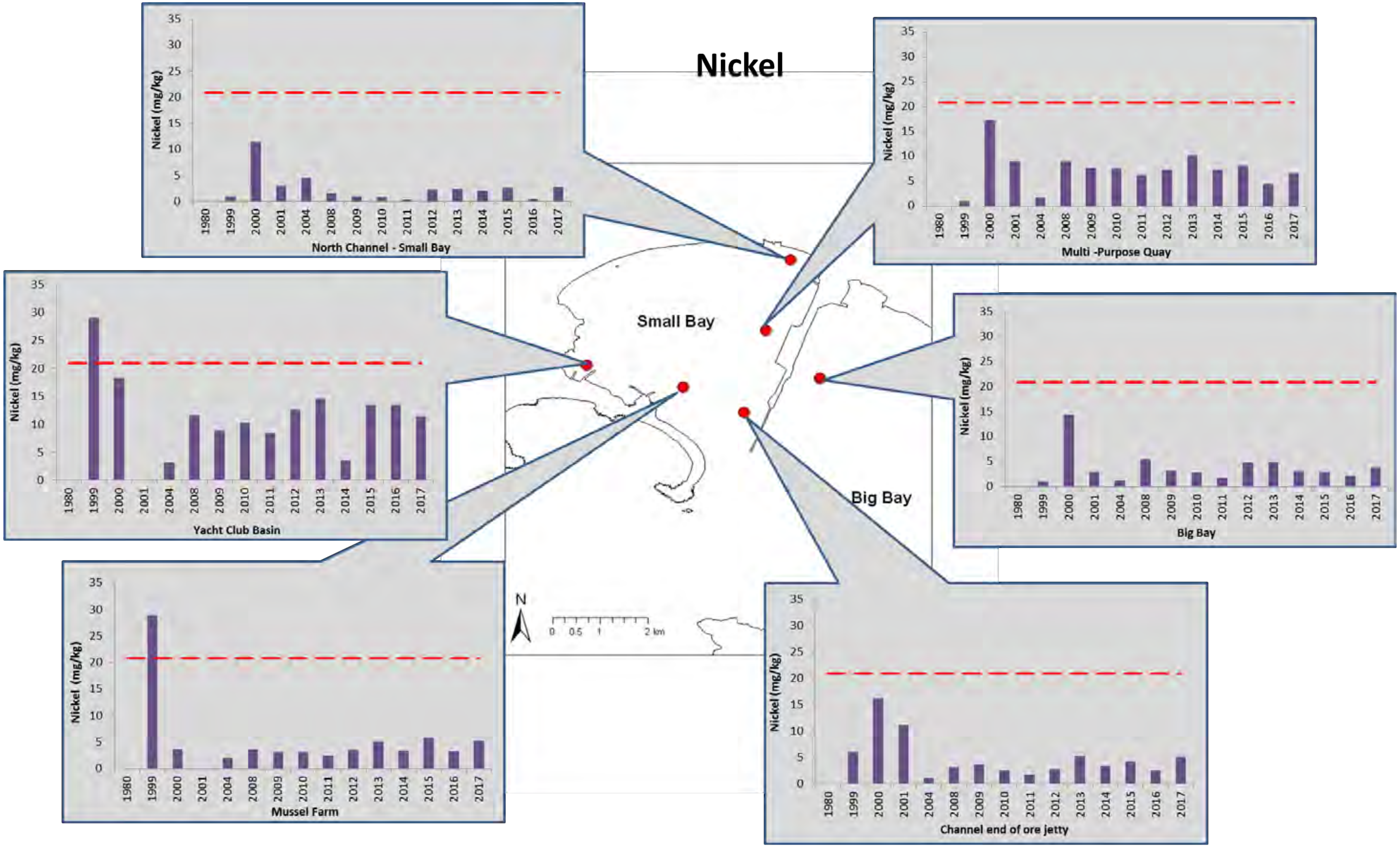


Figure 7.25 Concentrations of Nickel (Ni) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2017. Dotted lines indicate Effects Range Low values for sediments.

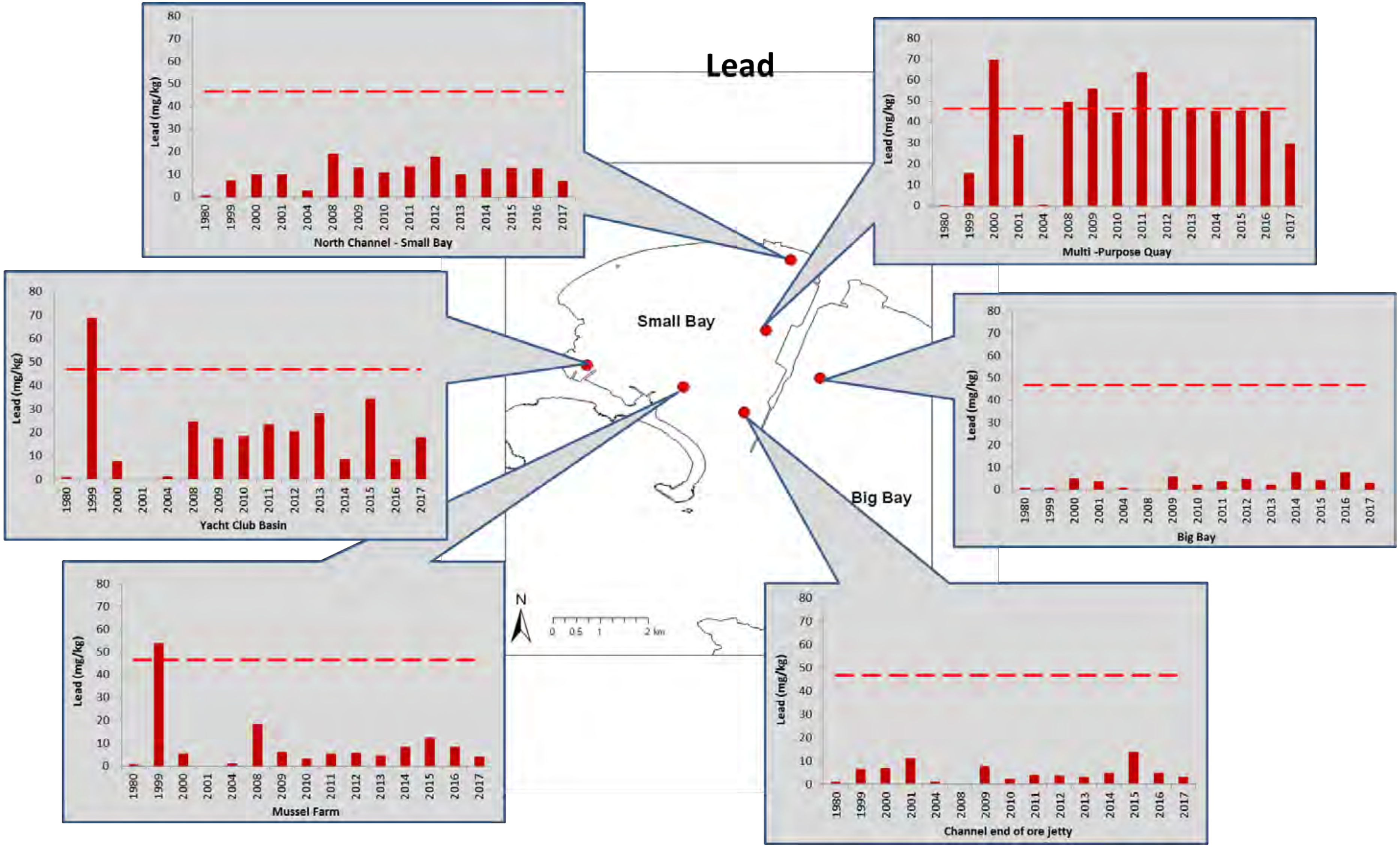


Figure 7.26 Concentrations of Lead (Pb) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2017. Dotted lines indicate Effects Range Low values for sediments.

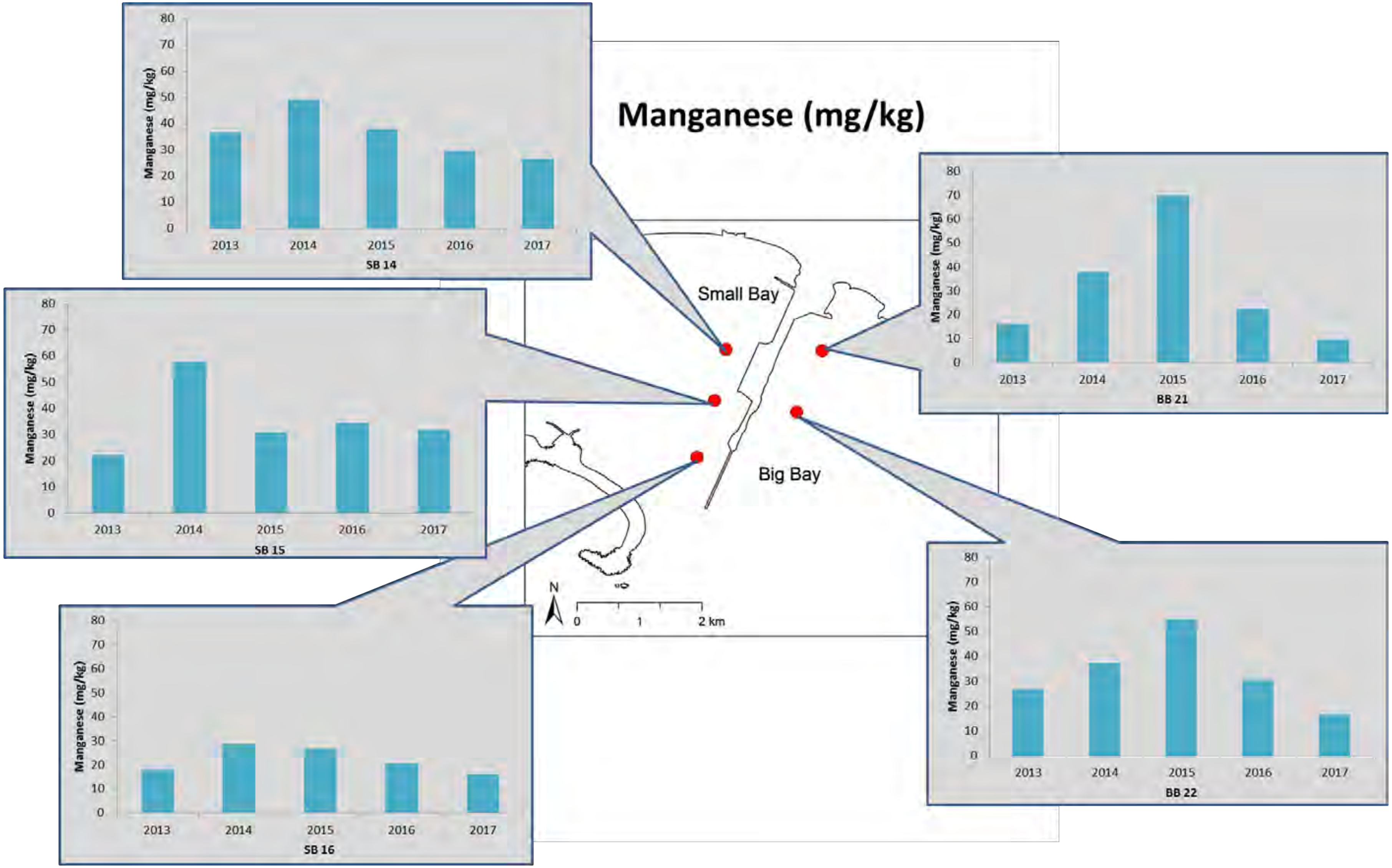


Figure 7.27 Concentration of manganese (Mn) in mg/kg recorded at five sites in Saldanha Bay between 2013 and 2017

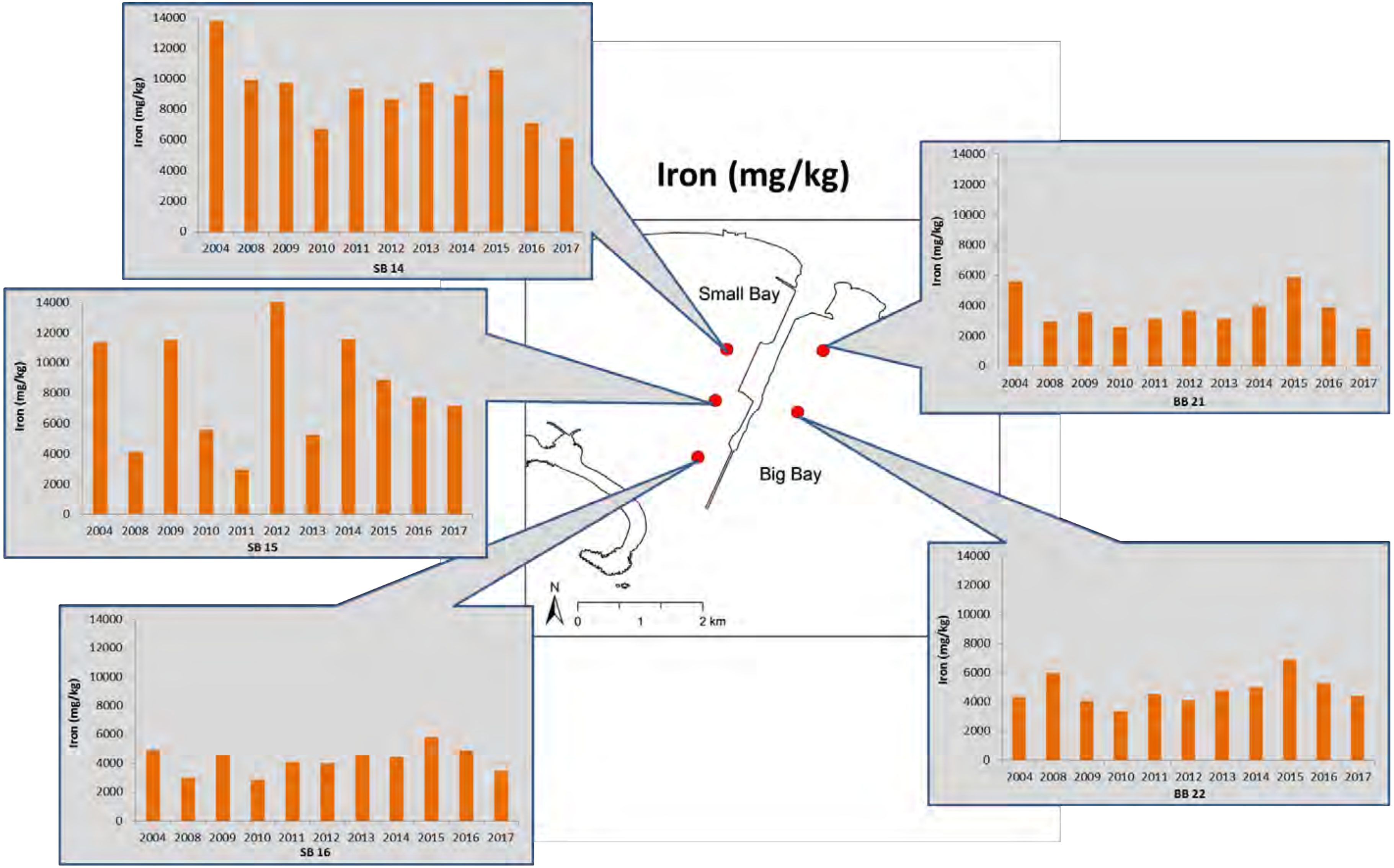


Figure 7.28 Concentrations of Iron (Fe) in mg/kg recorded at five sites in Saldanha Bay between 2004 and 2017.

7.4 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 (combustion of fuels) and 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 detectable 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 PAH contamination in April 2010. PAH concentrations at all five sites were well below ERL values stipulated by NOAA. From 2011 to 2014 PAH levels were not tested due to the continual low levels, however, analysis of total petroleum hydrocarbon (TPH) concentrations was continued.

Table 7.6 Total petroleum hydrocarbons (mg/kg) in sediment samples collected over the period 2011-2017 from five stations in Saldanha Bay. Values in red indicate exceptionally high total petroleum hydrocarbon levels. ND indicates no data available.

	2011	2012	2013	2014	2015	2016	2017
SB14	<20	34	130	19	<38	<38	<38
SB15	<20	35	ND	53	<38	<38	<38
SB16	<20	24	28	14 649	<38	<38	<38
BB21	<20	20	32	20	<38	<38	<38
BB22	<20	17	27	<0.2	<38	<38	<38

PAH levels have been well below the guideline limits and despite there being no guideline limits to determine the toxicological significance of TPH contamination there have been considerable fluctuations in contamination levels since 2011. TPH levels recorded in 2011 were below the detection limit of 20 mg/kg while slight increases were recorded at all sites in 2012 and 2013 (Table 6.6). TPH levels at site SB14 decreased from 130 mg/kg to 19 mg/kg in 2014, however, there was the extreme increase at site SB16 from 28 mg/kg to 14 649 mg/kg. The most likely explanation for the high TPH levels recorded 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 root of this contamination. Since 2015 TPH concentrations have been below the detection limit of 38mg/kg and remain at this level at all five sites to present date.

Sediment samples collected in 2017 had low PAH levels across all sites (Table 7.7). While the TPH and PAH finding present no major concern, it is recommended that TPH monitoring within the vicinity of the ore terminal is continued annually so as to identify the frequency of occurrence of pollution incidents, like that recorded in 2014, and assess the ecological implications to the Bay.

Table 7.7 Sediment Quality guidelines and Poly-aromatic hydrocarbons concentrations measured in sediment samples collected from Saldanha Bay in April 2017.

Hydrocarbon (mg/kg)	ERL*	ERM**	SB14	SB15	SB16	BB21	SB22
Acenaphthene	**0.016**	**0.5**	<0.002	<0.002	<0.002	<0.002	<0.002
Acenaphthylene	**0.044**	**0.64**	<0.002	<0.002	<0.002	<0.002	<0.002
Anthracene	**0.0853**	**1.1**	<0.002	<0.002	<0.002	<0.002	<0.002
Benzo(a) anthracene	**0.261**	**1.6**	<0.002	<0.002	<0.002	<0.002	<0.002
Benzo(a) pyrene	**0.43**	**1.6**	<0.002	<0.002	<0.002	<0.002	<0.002
Benzo(b+k) flouranthene	-	-	<0.002	<0.002	<0.002	<0.002	<0.002
Benzo(g.h.i) perylene	-	-	<0.02	<0.02	<0.02	<0.02	<0.02
Crysene	**0.384**	**2.8**	<0.002	<0.002	<0.002	<0.002	<0.002
Dibenzo(a.h) anthracene	**0.0634**	**0.26**	<0.1	<0.1	<0.1	<0.1	<0.1
Flouranthene	**0.6**	**5.1**	<0.002	0.007	<0.002	<0.002	0.003
Flourene	**0.019**	**0.54**	<0.002	<0.002	<0.002	<0.002	<0.002
Indeno(1.2.3-c.d) pyrene	-	-	<0.02	<0.02	<0.02	<0.02	<0.02
Naphthalene	**0.16**	**2.1**	<0.002	<0.002	<0.002	<0.002	<0.002
Phenanthrene	**0.24**	**1.5**	<0.002	0.008	<0.002	<0.002	0.003
Pyrene	**0.665**	**2.6**	<0.002	0.005	<0.002	<0.002	<0.002
Total PAH	**4**	**44.7**	-	-	-	-	-

*Effects Range Low guideline stipulated by NOAA below which toxic effects rarely occur in sensitive marine species.

**Effects Range Median guideline stipulated by NOAA above which toxic effects frequently occur in sensitive marine species.

8 AQUATIC MACROPHYTES IN LANGEBAAN LAGOON

8.1 Community composition and distribution

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 the dune slack rush *Juncus kraussi*, and unvegetated sandflats dominated by the sand prawn, *Callianassa krausii* and the mudprawn *Upogebia capensis* (Siebert & Branch 2005). The other major vegetation type present in the upper lagoon area, particularly where groundwater inflow occurs, are reed beds dominated by *Phragmites australis.* The most recent, detailed vegetation map of the area surrounding Langebaan Lagoon dates to 2013 (Figure 8.2) (van der Lindern 2013). In this map, eelgrass *Zostera capensis* falls within the submerged macrophyte category.

Salt marsh communities are generally comprised of herbs, shrubs and grasses within areas that are tidally inundated (Nybakken 2001). Within traditional salt marshes, plant communities occur along distinct zones following a tidal gradient and elevation pattern (Hughes and Paramor 2004; Perry and Atkinson 2009). Salt marsh species occur in a hostile environment, and as few species are able to cope in such environments, species diversity is low. Salt marshes tend to be associated with euhaline (30 to 35 ppt) conditions that many salt marsh species are able to cope with, however, growth rates tend to decrease as salinity increases and germination occurs only when the surrounding water salinity decreases (Smart and Barko 1980, Price et al. 1988).

The primary abiotic factors influencing salt marsh distributions are salinity and water availability (Pan et al. 1998). Salt marshes growing in areas with high water availability (high rainfall and intertidal zones) are influenced by sediment salinity more than by water availability in terms of zonation patterns (Krüger and Peinemann 1996). Sediment moisture limits the growth of xerohalophytes (those that occur in drier soils, Zedler *et al.* 1986), which in turn is dependent on the depth of the water table (Bornman *et al.* 2008). Salt marsh communities often show a distinct zonation pattern along tidal inundation and salinity gradients, whereby different plant species and different vegetation colours are seen (Adams and Ngesi 2002). Salt marshes are often separated into three zones, subtidal, intertidal and supratidal (Figure 8.2). Zonation is influenced by biotic interactions and by spatial and temporal gradients in physical variable such as salinity and soil moisture (Noe and Zedler 2001; Rogel et al. 2001). Subtidal and intertidal zones are generally structure by stress tolerances, especially by high salt gradients, while the supratidal zone may be characterised by competition (Emery et al. 2001).

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. These habitats 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 was 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 8.1. Seagrass (black) and saltmarsh (green) near Bottelary in Langebaan Lagoon. Source: Google Earth.

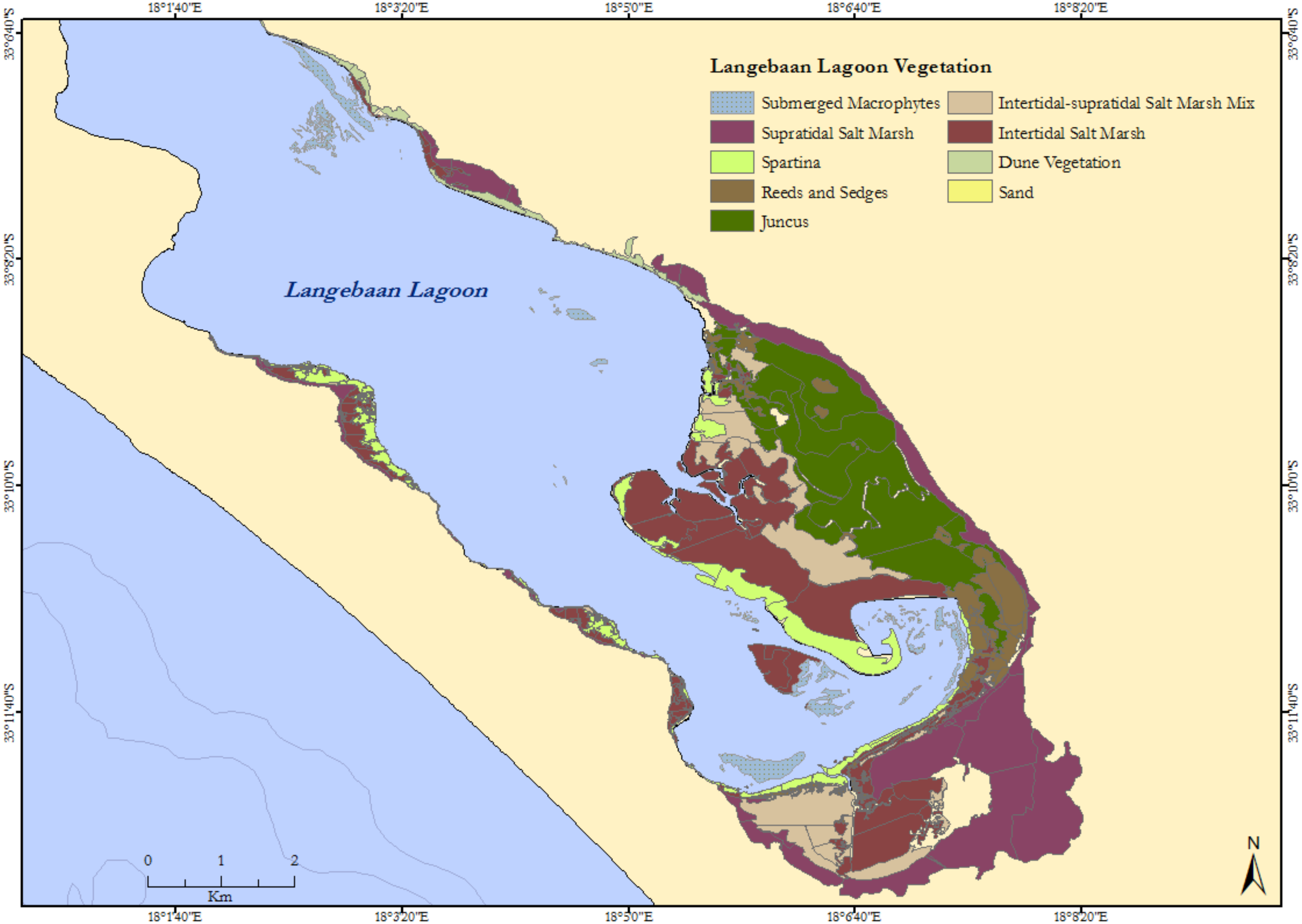


Figure 8.2. **Vegetation and habitat structure at Langebaan Lagoon (Source: Shapefiles provided by van der Linden 2013).**

8.2 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 in water quality through nutrient enrichment or eutrophication, alterations to food webs caused by the overexploitation of predatory fish, modified sediment dynamics associated with coastal and harbour development and direct physical damage through bait collection (Waycott *et al.* 2009, 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 was more homogenous 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 8.3.). 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 substantial fluctuations in the abundance 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 8.3.). 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 these 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*, 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. Species that burrowed predominantly in unvegetated sand, such as amphipods *Urothoe grimaldi* and the polychaetes *Scoloplos johnstonei* and *Orbinia angrapequensis* increased in density over that same period. Pillay *et al.* (2010) was also able to show that the abundance of at least one species of wading bird, the 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 and in the last decade, kite surfing, has become very popular (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 favour higher seagrass biomass than warmer more exposed areas. This finding could partly explain the distribution patterns in the lagoon as determined from 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 a 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 seagrass bed decline (Whitfield *et al.* 1989, Orth *et al.* 2006). To date, however, despite more than a decade of monitoring, changes in fish and bird communities (with the exception of the Terek Sandpiper) in Langebaan that can be attributed to sea grass loss have not been detected. This may be due to several reasons; certainly the timing of sea grass loss predated the State of the Bay monitoring that started in 2005 and any significant changes in the community compositions of fish and birds had already occured. The relatively modest scale of seagrass loss throughout the lagoon may also explain the undetected impacts on higher trophic level species, despite Pillay *et al.* (2010) recording a reduction to nearly 25 ha, Van Der Linden (2014) mapped the area of submerged macrophytes (*Zostra*) at 85.8 ha indicating that substantial *Zostra* habitat remains in the Lagoon (Adams 2016). Alternatively, more severe impacts on fish and bird populations (e.g. fishing and hunting) may be masking the effect of sea grass loss on higher trophic level species. This does not imply that the loss of sea grass beds in Langebaan is not concerning, as site specific changes in associated macrofauna and at least one wader species were clearly documented by Pillay *et al.* (2010). Also important to note, is the fact that the Terek Sandpiper is a summer migratory bird and its decline is occurring globally (see Chapter 12). However, continued loss of sea grasses could cause a "tipping point" beyond which major ecosystem changes would occur throughout the lagoon.

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. Additionally, several studies have highlighted the potential for climate driven changes in water temperature and pH to alter seagrass physiology and possibly their distribution and abundance (Duarte 2002, Mead et al. 2013). However, information on the temperature and pH tolerance of South African seagrasses is currently lacking and warrants investigation. 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.

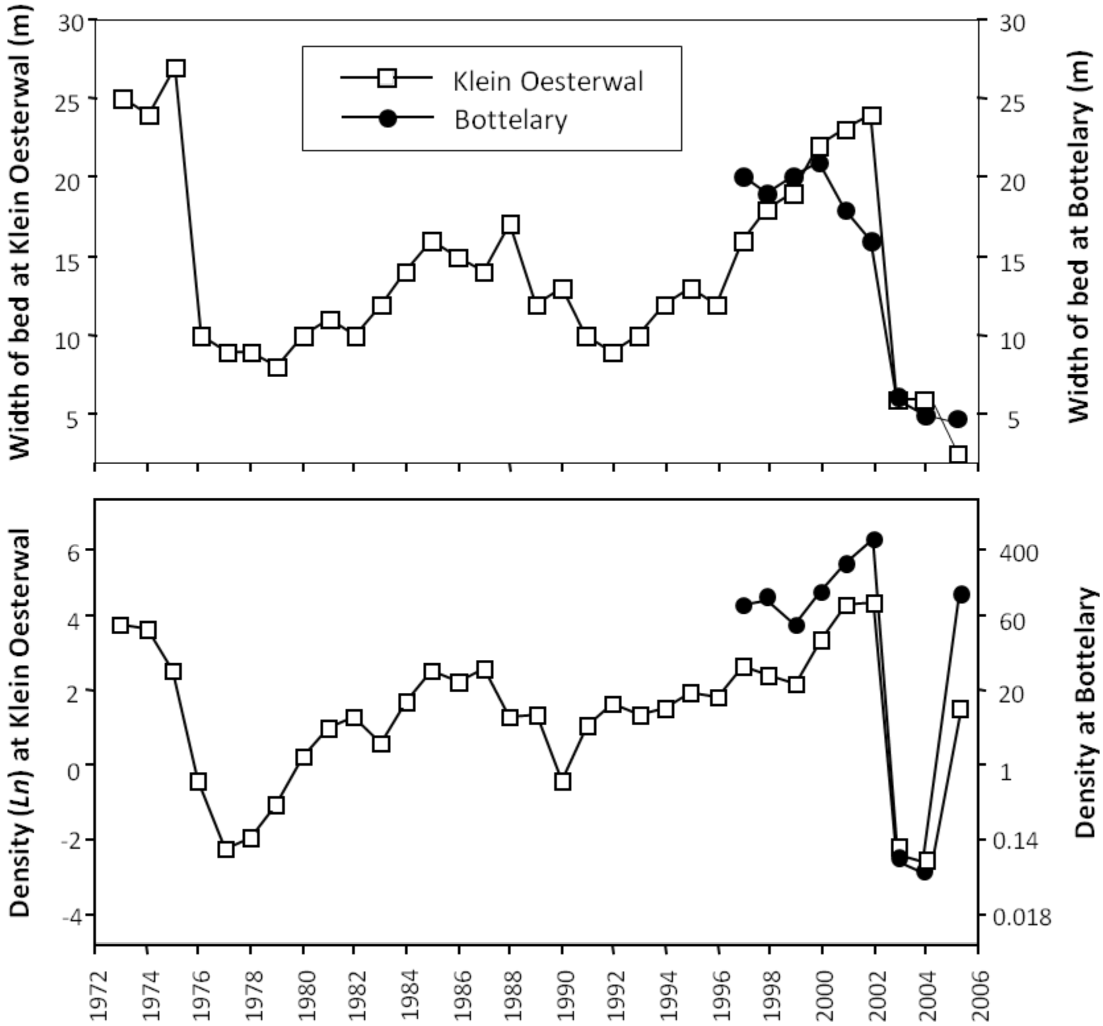


Figure 8.3. Width of the *Zostera* beds and density of *Siphonia* at Klein Oesterwal and Bottelary in Langebaan Lagoon, 1972-2006.

8.3 Long term changes in saltmarshes in Langebaan Lagoon

Saltmarshes in Langebaan are 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 8.4.). 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 in 2000. 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).

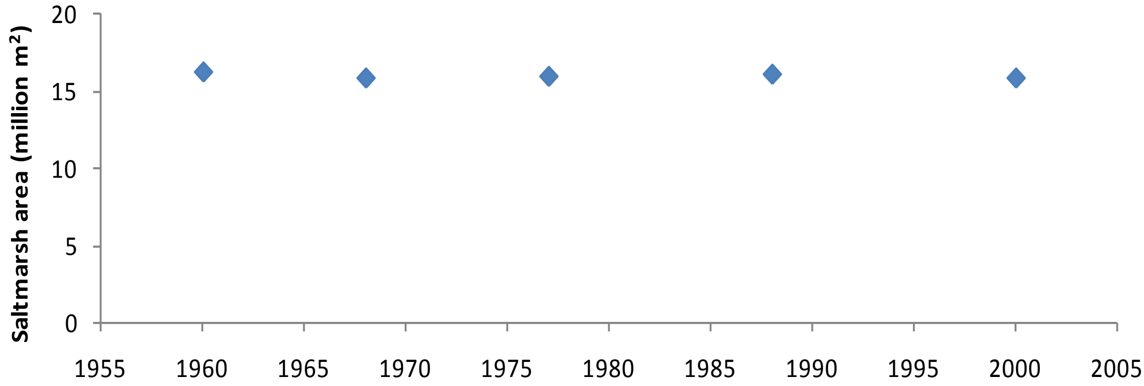


Figure 8.4. Change in saltmarsh area over time in Langebaan Lagoon. (Data from Gerricke 2008).

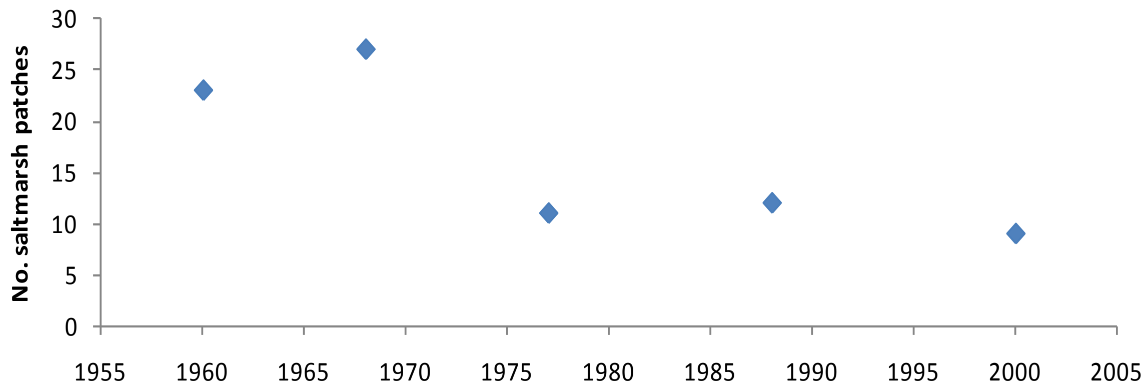


Figure 8.5. Change in the number of discrete saltmarsh patches over time in Langebaan Lagoon. (Data from Gerricke 2008).

Recently, concern has been voiced about potential impacts that the Elandsfontein Exploration and Mining (Pty) Ltd (EMM) phosphate mine at Elandsfontein may have on groundwater quality and flows to Langebaan Lagoon.

Due to the porous nature of the surrounding sediments and the arid conditions, Langebaan lagoon is not fed by overland streams or rivers and it has been suggested that groundwater plays a significant role in sustaining the marsh ecosystems at the head of the lagoon (Valiela et al. 1990; Burnett et al. 2001). Diagnostic plants indicate significant contributions of groundwater (Adams and Bate 1999). For example, reeds (*Phragmites australis* and *Typha capensis*) occur at discrete points on the shoreline surrounding Langebaan lagoon (Figure 8.2.) These plants can only survive in water or at least damp soil and are only able to tolerate salinity levels up to a maximum of 20-25 ppt (Adams and Bate 1999, Nondoda 2012). The salinity of the water in the lagoon is generally the same (or occasionally higher) than that of seawater – i.e. 35 ppt, and these species' are only found at sites where freshwater is seeping into the lagoon (i.e. the main groundwater input sites in the south east of the lagoon along the shoreline at Geelbek). The fauna and flora in the Lagoon are mostly marine and estuarine in nature, and while some are euryhaline and are able to tolerate salinity (salt) levels anywhere between fresh water (i.e. 0 parts per thousand) and normal seawater (35 parts per thousand), most species are not tolerant of salinities in excess 35ppt.

Reducing freshwater inflow into Langebaan Lagoon that may result from the mining activities could result in the development of more extreme hypersaline conditions in the upper lagoon, killing flora and fauna sensitive to salinities in excess of normal seawater. To mitigate impacts on groundwater flow, it was suggested that the extracted water is injected back into the aquifer system via boreholes downstream of the mining site. This mining method is predicted to use only a small proportion of the extracted water for mining and processing and thus have little to no impact on the marsh habitat at Geelbek (Conrad 2014).

While it has been established from a groundwater assessment undertaken by Conrad (2014) that the proposed mining operations are highly unlikely to have any impact on the groundwater quality and flow, EMM have opted to take a precautionary approach and carefully monitor any potential impacts on Langebaan Lagoon in association with the Saldanha Bay Water Quality Forum Trust (SBWQFT). The State of the Bay monitoring activities undertaken by the SBWQFT have thus been expanded to incorporate monitoring of various biological and physico-chemical variables to establish an appropriate baseline against which any potential future changes in the Lagoon can be benchmarked. This includes monitoring of salinity and biota (benthic macrofauna) at the top of the lagoon (for more detail and results see Chapter 5 and Chapter 9).

In closing, while anthropogenic disturbances and climate change are impacting some macrophyte communities in Langebaan Lagoon (e.g. decreases in discrete salt marsh patches and acute decreases in seagrass beds at some sites) the health and biodiversity of the system is still exceptional. A recent desktop level ecological reserve determination study assessed the health of Langebaan macrophytes and reported a high ranking (score 90, DWS 2017). As long as good management informed by scientifically sound monitoring programmes continue to be implemented, the lagoon will continue to provide great pleasure and value for all of its users and inhabitants.

9 BENTHIC MACROFAUNA

9.1 Background

It is important to monitor biological components of the ecosystem in addition to physico-chemical and eco-toxicological variables, as biological indicators provide a direct measure of the state of the ecosystem in space and time. 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 changes in community composition and abundance, 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 from 1999 to 2017 (with the addition of new sites at Elandsfontein), are considered in this report.

9.2 Historic data on benthic macrofauna communities in Saldanha Bay

The oldest records of benthic macrofauna species occurring in Saldanha Bay date back to the 1940s, 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 2008-2016 do, however, provide benthic macrofauna data from Saldanha Bay and Langebaan Lagoon that are comparable with those collected in 2017. 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, balloth 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 has been 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 1999-2016 studies also differed (refer to previous versions of this report), however, the broad distribution of sites throughout the sampling area ensures that the data collected are representative of the study areas concerned and as such, can be compared with one another.

9.3 Approach and methods used in monitoring benthic macrofauna in 2017

9.3.1 Sampling

Due to constraints in the 2016 survey budget, macrofauna samples were collected from only a select number of sites in Small Bay, where there is greatest cause for concern with regards to the health of the environment. This year, however, monitoring of benthic macrofauna has returned to its former spatial extent with samples collected from 31 sites throughout the entire system (ten in Small Bay, nine in Big Bay, nine in Langebaan Lagoon and three at Elandsfontein). The localities and water depth ranges of the 2017 sampling sites are illustrated in Chapter 5.

Concern has been raised over potential impacts that the proposed phosphate mine at Elandsfontein may have on groundwater quality and flows to Langebaan Lagoon (Chapter 5). The State of the Bay monitoring activities have therefore been expanded to include monitoring of benthic macrofauna at three sites at the head of the lagoon where groundwater input is most prominent to establish an appropriate baseline against which any potential future changes in the Lagoon can be benchmarked. Results from this baseline monitoring programme, now in its second year, are presented in this chapter.

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, totalling a sampling surface area of 0.08 m^2. Five hand-cores were collected each of the Elandsfontein sites and were retained as separate replicate samples. 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 2008-2016 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.

9.3.2 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 2017 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 Bay.

9.3.2.1 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.

9.3.2.2 Diversity indices

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

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

$$H' = - \Sigma ipi(\log pi)$$ [9]

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.

9.4 Benthic macrofauna 2017 survey results

9.4.1 Species diversity

Variations in species diversity (represented by the Shannon Weiner Index, H') are presented in Figure 9.1. Diversity was highest at sites LL 34, BB 29 and BB 24 in Langebaan Lagoon and Big Bay and was lowest at the Elandsfontein sites near the head of the Lagoon. Temperature data collected at the Elandsfontein monitoring sites indicate high daily ranges in temperature with a minimum of 17°C and a maximum of 28°C recorded on 14 December 2016 (Chapter 6). The upper end of the lagoon also experiences high rates of evaporation and at time groundwater input leading to substantial variation in salinity. Indeed, it has been found that salinity values frequently exceed 37 psu at the head of the lagoon (Krug 1999). The natural fluctuations in temperature and salinity in the upper lagoon arguably represent a harsher environment for benthic macrofauna than other areas of

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

the lagoon and only species tolerant of these conditions are likely to persist at the Elandsfontein. This is a plausible explanation for the low diversity observed at these sites.

Of the sites within Saldanha Bay, those around the iron ore terminal (SB 15, SB 14), in the yacht basin (SB 1) and at the Liquid Petroleum Gas (LPG) site in Big Bay also displayed low levels of diversity. This is corresponds with results from earlier surveys and is most likely attributable to the high levels of anthropogenic disturbance (mainly dredging) and the presence of elevated levels of contaminants (trace metals, organic material, etc.) in the fine sediment (mud) collected at these sites. It is well known that high levels of disturbance associated with pollution can allow a small number of 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.

9.4.2 Community structure

Ordination plots prepared from the 2017 macrofauna abundance data, are presented in Figure 9.2. These data show a very similar pattern as for the diversity data, with the Langebaan Lagoon and Elandsfontein sites 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. Upon closer inspection, sites within Small Bay itself also show some spatial grouping of their own with sites in the northern reaches of the bay (SB 2, SB 3, SB 5, and SB 10) forming a separate cluster from those further south. This observation is 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 at Elandsfontein and in Langebaan Lagoon but are largely absent from the Big Bay sites and the southern Small Bay sites in proximity the iron ore terminal. It should be noted that differences in community structure are also partly explained by the physical and environmental parameters present at each site (i.e. freshwater ingress, tidal currents, sediment granulometry and depth) each of which are known to influence the community structure of the benthic macrofauna.

The “hardier” filter feeders such as *Upogebia capensis* are, 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 than Small Bay. Similarly, the sea pen *Virgularia schultzei,* widely regarded *as a “*sensitive species*”* was found only in Big Bay.

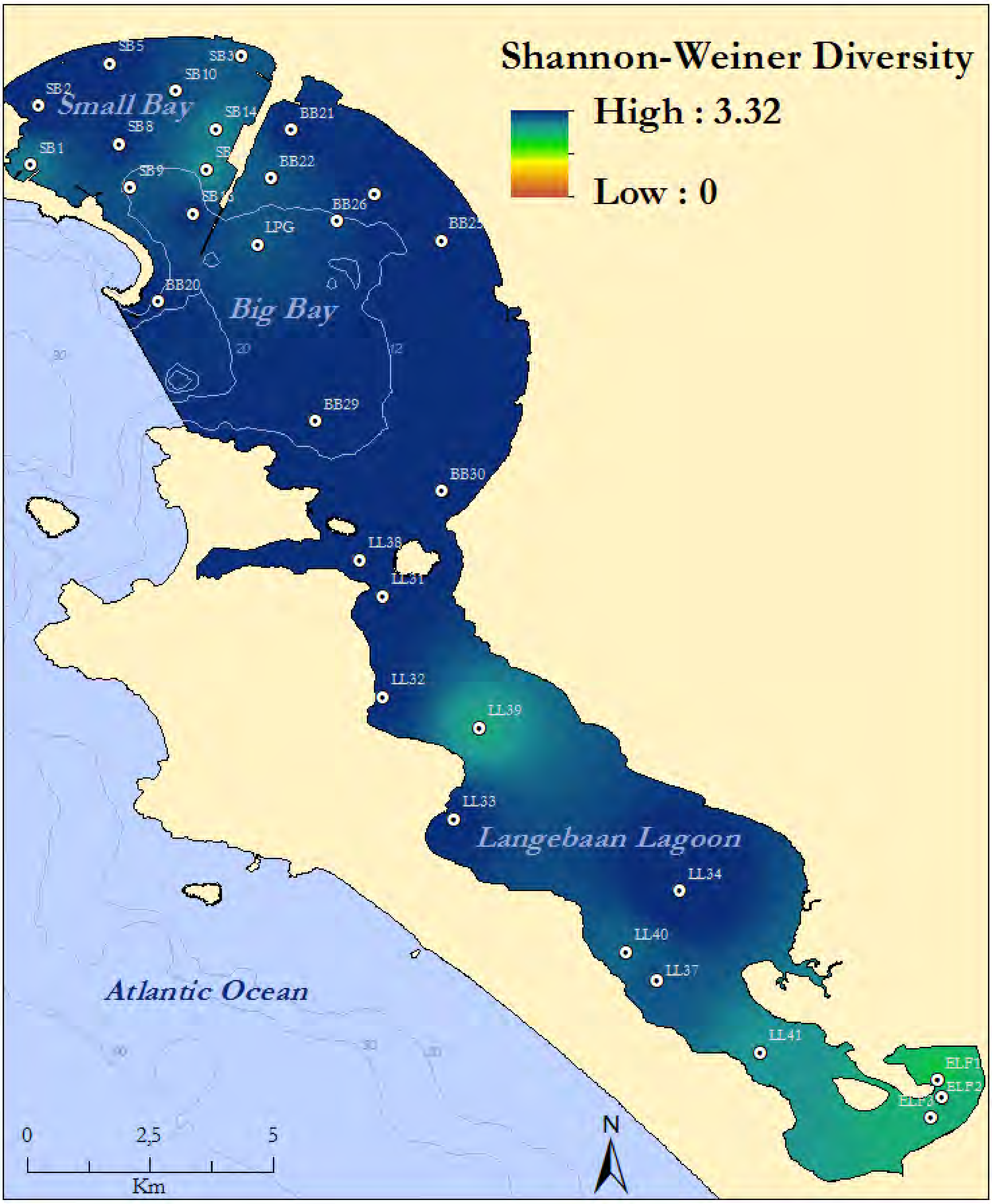


Figure 9.1 **Variation in the diversity of the benthic macrofauna in Saldanha Bay and Langebaan Lagoon as indicated by the 2017 survey results (H' = 0 indicates low diversity, H' = 3.32 indicates high diversity).**

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 the lagoon samples.

The community structure of benthic macrofauna at Elandsfontein was dominated by small crustaceans (mostly amphipods), and polychaetes. The presence of unique species such as the sandflat crab, *Danielella edwardsii* and the abundance of the sand prawn, *Callichirus kraussi,* and small sand-dwelling amphipod, *Urothoe grimaldii*, were the main causes of dissimilarity in community structure between Elandsfontein and the Saldanha Bay and Langebaan Lagoon samples.

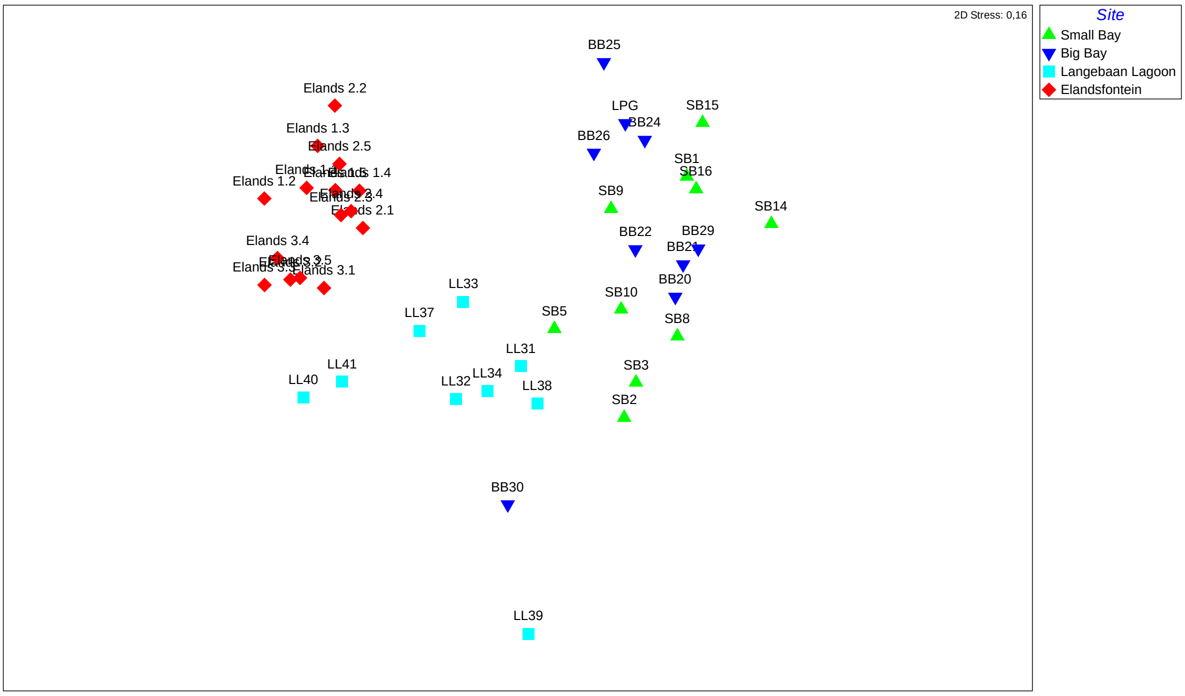


Figure 9.2 **Ordination plots showing similarity amongst sample sites based on benthic macrofauna abundance in 2017. Symbols on the ordination plots are as follows: Small Bay (SB), Big Bay (BB), Langebaan Lagoon (LL) and Elandsfontein (Elands).**

Species composition can sometimes be more easily understood at higher taxonomic or functional group (essentially feeding mode) levels. Macrofaunal abundance and biomass results for each of the areas sampled in Small Bay, Big Bay, Langebaan Lagoon and Elandsfontein are shown in Figure 9.3. 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 (bristle worms), and a relatively greater abundance of these worms were found in Langebaan Lagoon and at Elandsfontein than in Small Bay and Big Bay Figure 9.3. 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 9.3. Detritivores were numerically the most abundant group on the mudflats at Elandsfontein and in Langebaan Lagoon Figure 9.3. These differences are attributable to physical habitat differences between the benthic environments found in the different areas which in turn are linked to past and present anthropogenic activities e.g. port construction, dredging, organic pollution.

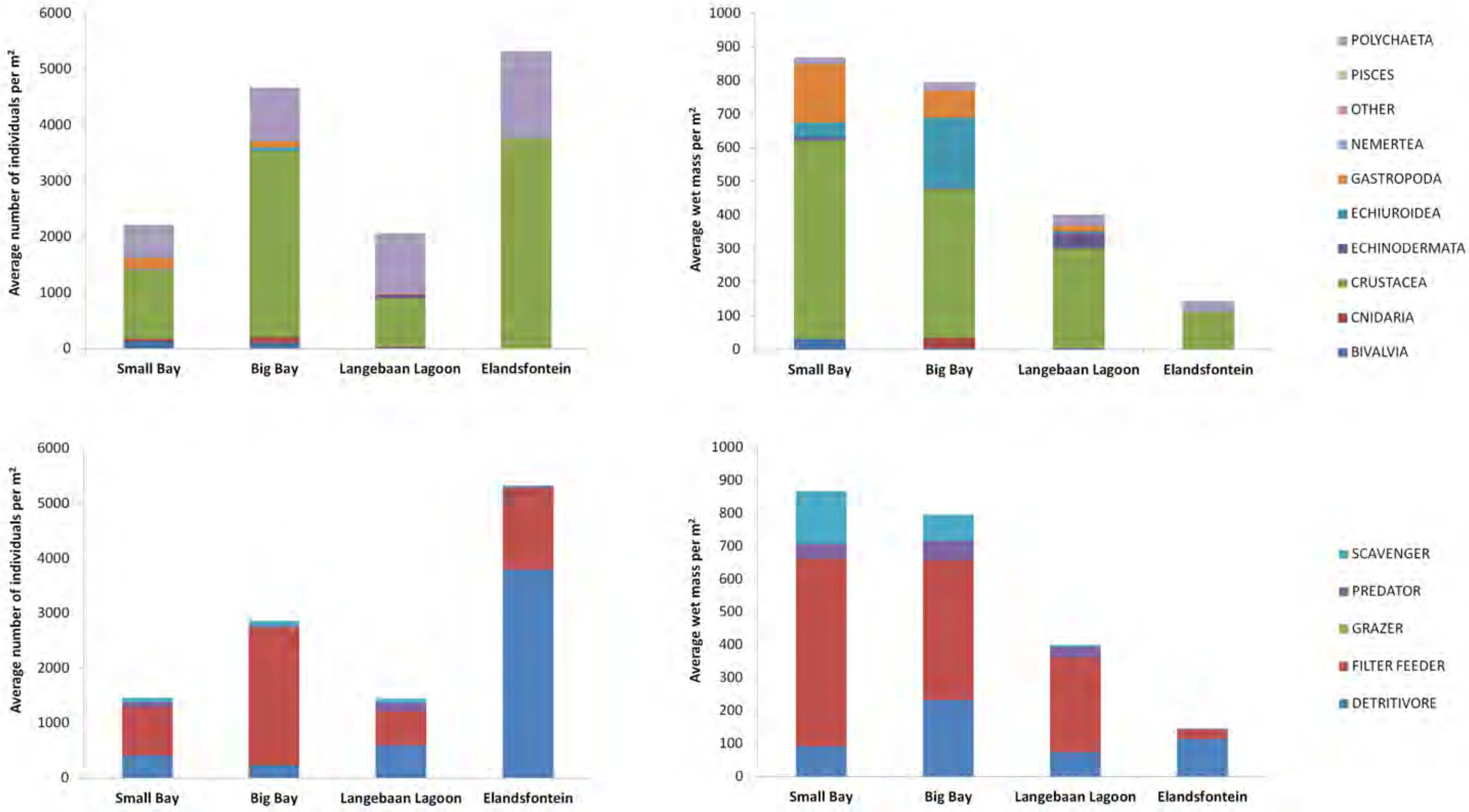


Figure 9.3 **Average abundance and biomass (g/m^2) of benthic macrofauna by functional and taxonomic group in Big Bay, Small Bay, Langebaan Lagoon and Elandsfontein in 2017.**

9.5 Changes in abundance, biomass and community structure over time

9.5.1 Species richness

Variation in the total number of macrofauna species recorded in Small Bay, Big Bay, Langebaan Lagoon and Elandsfontein during each annual survey from 1999 to 2017 is shown in Figure 9.4. While there appears to be a slight increase in the numbers of species recorded over time, this is more than likely 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 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 iron ore terminal for the construction of the *multi-purpose 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 iron 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, 2013-2017).

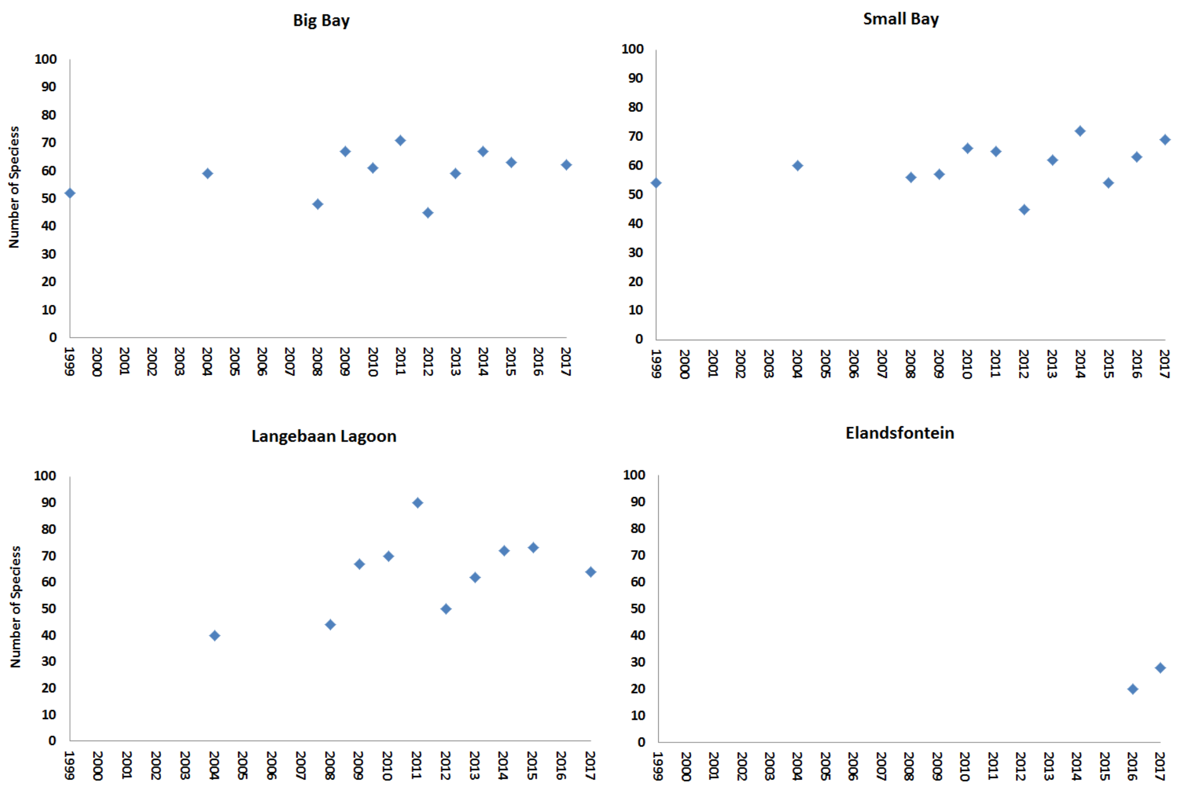


Figure 9.4 Variation in the number of species recorded at Small Bay, Big Bay, Langebaan Lagoon (1999 – 2017) and Elandsfontein (2016 – 2017).

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 tonnes 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.

Species richness at Elandsfontein is low in comparison to rest of the system and although this is likely a result of high natural disturbance (variation in temperature and salinity) it may also be an artefact of low cumulative sampling effort, this being the second survey conducted in this area. Additional species are likely to be detected with subsequent surveys (albeit at a decreasing rate) until a point is reached where adequate cumulative sampling effort has resulted in the detection of most species present. As it stands, an additional eight species were recorded here in 2017.

9.6 Abundance, biomass and community composition

Changes in the abundance and biomass of benthic macrofauna in Small Bay are shown in Figure 9.5. 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. There does not appear to be any obvious trend over time when looking at Small Bay alone. The only major perturbation (trough) evident is that in 2012 which could possibly be a delayed environmental response to the dredging event which took place in 2009 and 2010 when 7300 m^3 of material was removed from the Saldanha Side of the iron ore terminal but we cannot be certain of this. In 2016 both abundance and biomass increased slightly in Small Bay with no significant change observed in 2017. There are some subtle 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 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 2008 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. This happens to coincide with the second major dredging event to have occurred since construction of the port in 1973, where 50 000 m^3 of seabed material was removed from the area of the Mossgas Quay and the Multi-purpose Terminal in 2007/2008. 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 periods of reduced abundance and/biomass may be linked to major dredging events that have taken place in the Bay.

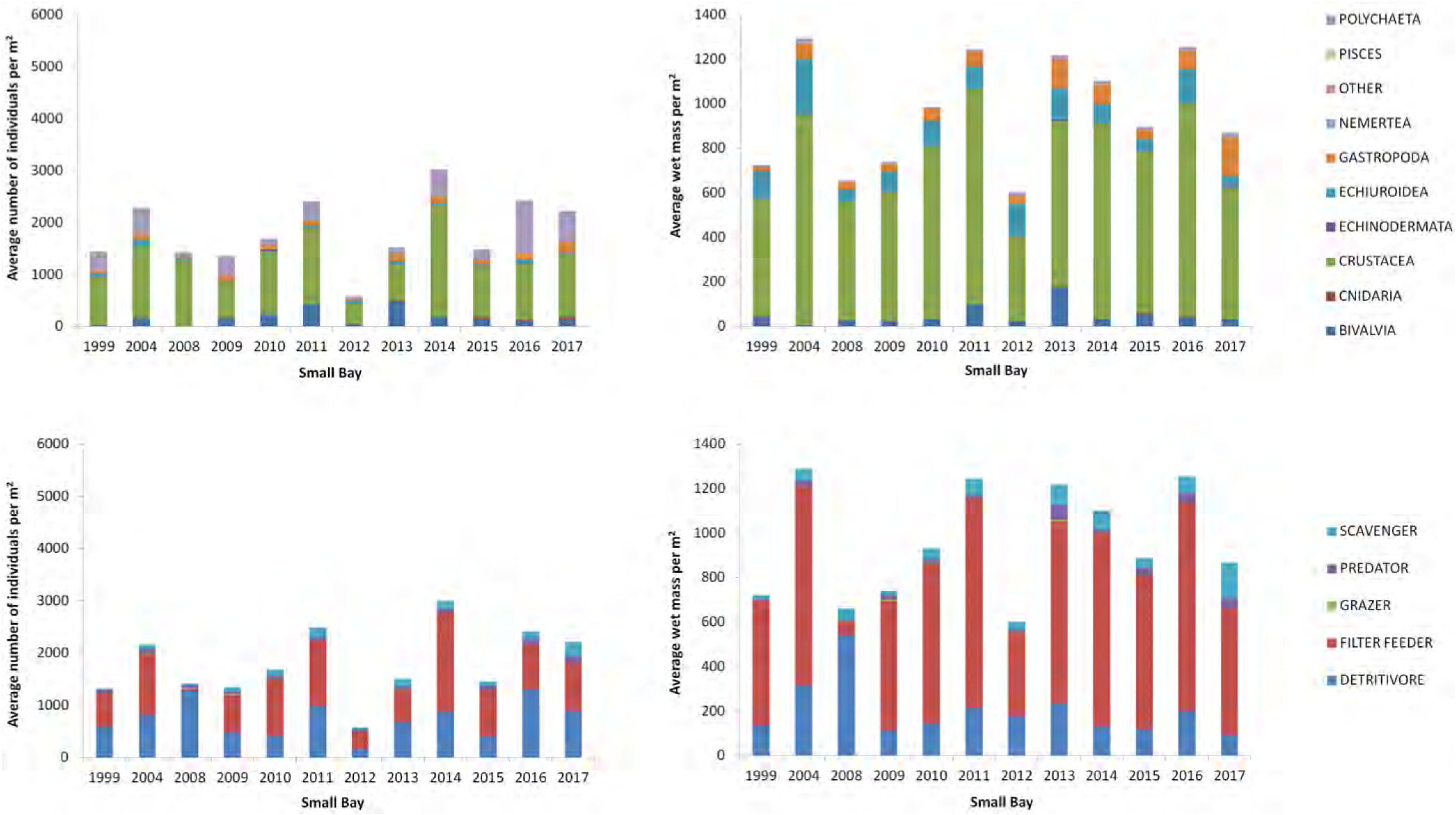


Figure 9.5 Overall trends in the abundance and biomass (g/m^2) of benthic macrofauna in Small Bay as shown by taxonomic and functional groups.

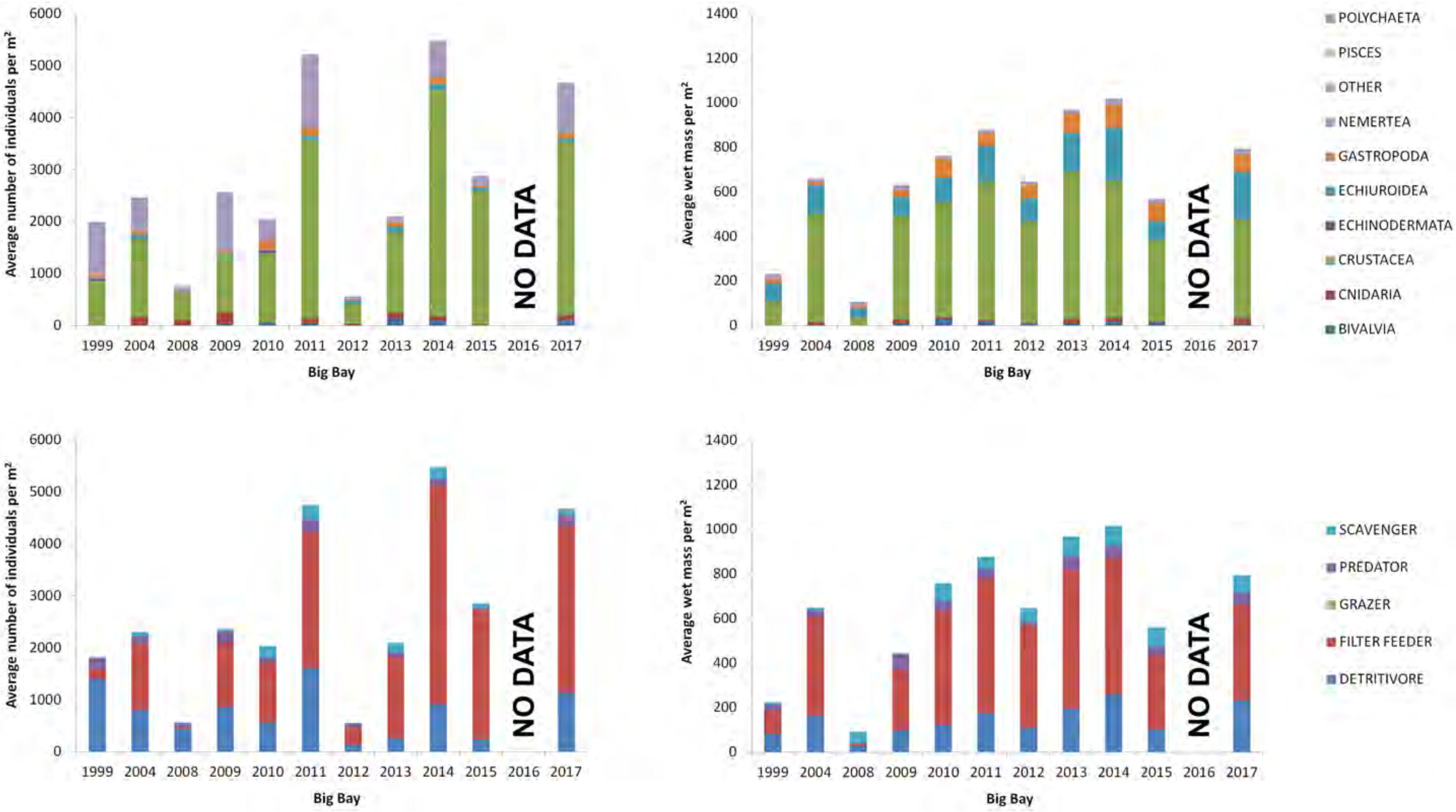


Figure 9.6 **Overall trends in the abundance and biomass (g/m2) of benthic macrofauna in Big Bay as shown by taxonomic and functional groups.**

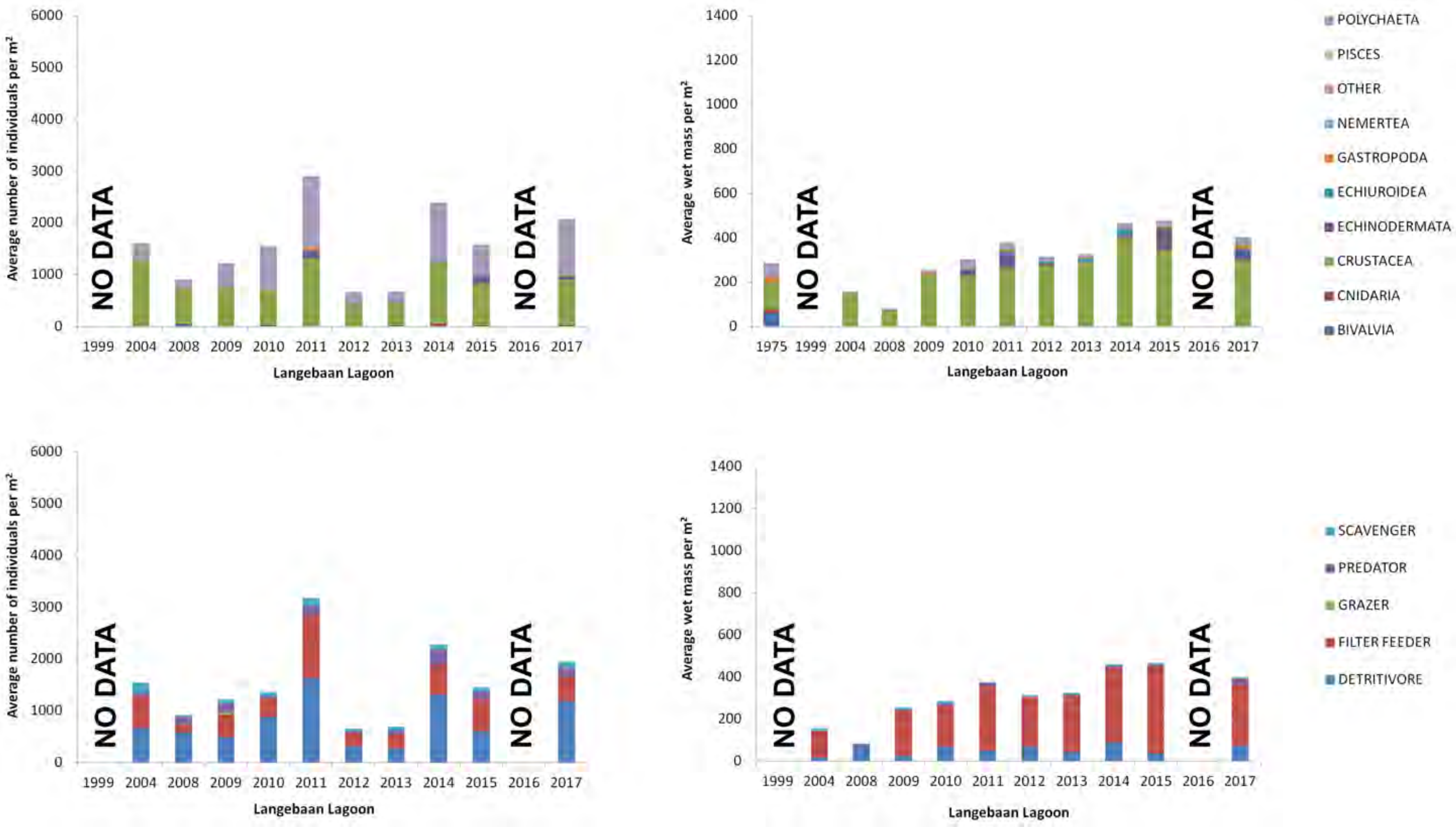


Figure 9.7 Overall trends in the abundance and biomass (g/m2) of benthic macrofauna in Langebaan Lagoon as shown by taxonomic and functional groups.

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 reportedly "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 albeit in small numbers only. 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.

9.7 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. 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 abundance data collected in all years since 2004 was undertaken separately for Small Bay, Big Bay and Langebaan Lagoon.

9.7.1 Small Bay

The Small Bay ordination plot (a technique that groups samples with similar macrofaunal communities close together and separates dissimilar samples), shows clear separation of all samples collected during 2008 from samples collected in all other years (Figure 9.8). 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 tongue worm *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 were rare or absent in 2008 samples.

As mentioned above, these changes in macrobenthic community structure are thought to be related to the extensive dredging activities undertaken during 2007 and early 2008 that appeared to have had Bay-wide impacts, resulting a temporary loss of less tolerant species and a shift in community composition to one dominated by more tolerant species. Multivariate analysis of the macrobenthic samples collected over the period 2009-2016 suggests that the smaller 2009 dredging event had a limited impact with little change in macrobenthic community structure over the last six years.

9.7.2 Big Bay

The 2008 Big Bay macrobenthos samples also clustered separately from all other years on the ordination plot indicting that they were dissimilar to the others in some way (Figure 9.8). 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*.

9.7.3 Langebaan Lagoon

The 2008 samples were also outliers in the Langebaan Lagoon ordination plot (Figure 9.8). 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 are thought to be related to the extensive dredging activities undertaken during 2007 and early 2008 that appeared to have had Bay-wide impacts, resulting a temporary loss of less tolerant species and a shift in community composition to one dominated by more tolerant species. Multivariate analysis of the macrobenthic samples collected over the period 2009-2017 suggests that the smaller 2009 dredging event had a limited impact with little change in macrobenthic community structure over the last eight years.

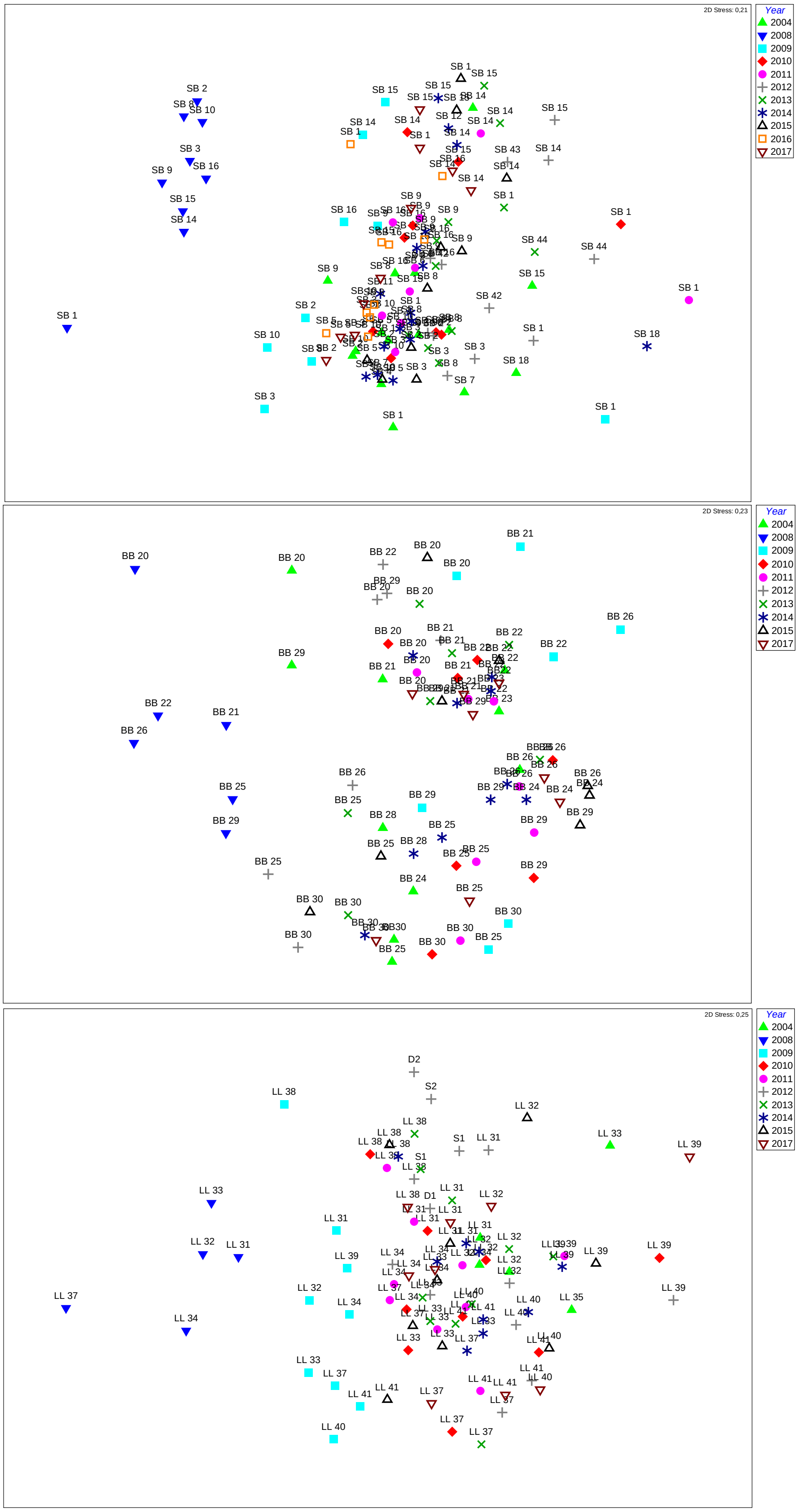


Figure 9.8. **MDS plots based on macrofunal abundance data from samples collected in Small Bay (top), Big Bay (middle) and Langebaan Lagoon (bottom) during the period 2004-2017.**

9.8 Elandsfontein 2017 baseline survey results

The State of the Bay monitoring activities have been expanded to include monitoring of benthic macrofauna at three new sampling sites near the head of the Lagoon at Elandsfontein. Concern has been raised around potential impacts that the proposed phosphate mine at Elandsfontein may have on groundwater quality and flows to Langebaan Lagoon. Hence the objective to establish an appropriate baseline of the present benthic macrofauna community structure against which any potential future changes in the Lagoon can be benchmarked. The second set of baseline results are presented here and are assessed in context of the entire Saldanha Bay/Langebaan Lagoon system.

Ordination plots prepared from the 2017 macrofauna abundance data, are presented in Figure 9.2. It is evident that significant spatial dissimilarities in macrofaunal community composition exist between samples from Saldanha Bay (Small Bay and Big Bay), Langebaan Lagoon and Elandsfontein with each area forming a distinct cluster. The Langebaan Lagoon cluster falls directly between the Saldanha Bay and Elandsfontein clusters which means that the macrofaunal community composition at the Elandsfontein sites are most similar to that present in Langebaan Lagoon (76.1% dissimilarity) and in turn are most dissimilar to those in Small Bay (88.2%) and Big Bay (87.1%). This suggests that a spatial trend in macrofaunal communities exists from the marine dominated Saldanha Bay through the sheltered lagoon to the very sheltered, shallow and possibly freshwater/estuarine influenced Elandsfontein habitat.

In total, 28 species (consisting of polychaetes, crustaceans and a cnidarian - Figure 9.9) were recorded at Elandsfontein, of which five are found nowhere else in the system namely the polychaetes *Caulleriella acicula* and *Scoloplos johnstonei*; the crabs *Danielella edwardsii* and *Paratylodiplax algoensis*; and the isopod *Notanthura caeca*.

Macrofaunal abundance and biomass results for Elandsfontein, broken down into taxonomic and functional feeding groups, are shown in Figure 9.9. There does not appear to be any significant difference in abundance and biomass of macrofauna at each of the three sites, however, on a community composition level, Site Eland_3 does form a separate cluster to Eland_1 and Eland_2 (Figure 9.10). A simper analysis reveals >60% dissimilarity with the amphipod, *Urothoe grimaldii*, the prawns *Upogebia africana* and *Callichirus kraussi*, and the polychaetes *Notomastus latericeus, Marphysa depressa, Telothelepus capensis* and *Orbina angrapequensis* contributing >40% to this dissimilarity. This is likely to be explained by the difference in physical conditions present at each of the sites. From Figure Figure 9.1, it can be seen that Eland_3 is situated directly opposite the "mouth" of the channel from Langebaan Lagoon and appears to be mostly marine, whereas Eland_1 and Eland_2 are located further east, closer to the source of freshwater in what appears to be a more estuarine habitat. Interpretation of water quality data from a conductivity, temperature and depth (CTD) instrument deployed in the vicinity and further sampling in years to come would provide further insight into our findings thusfar.

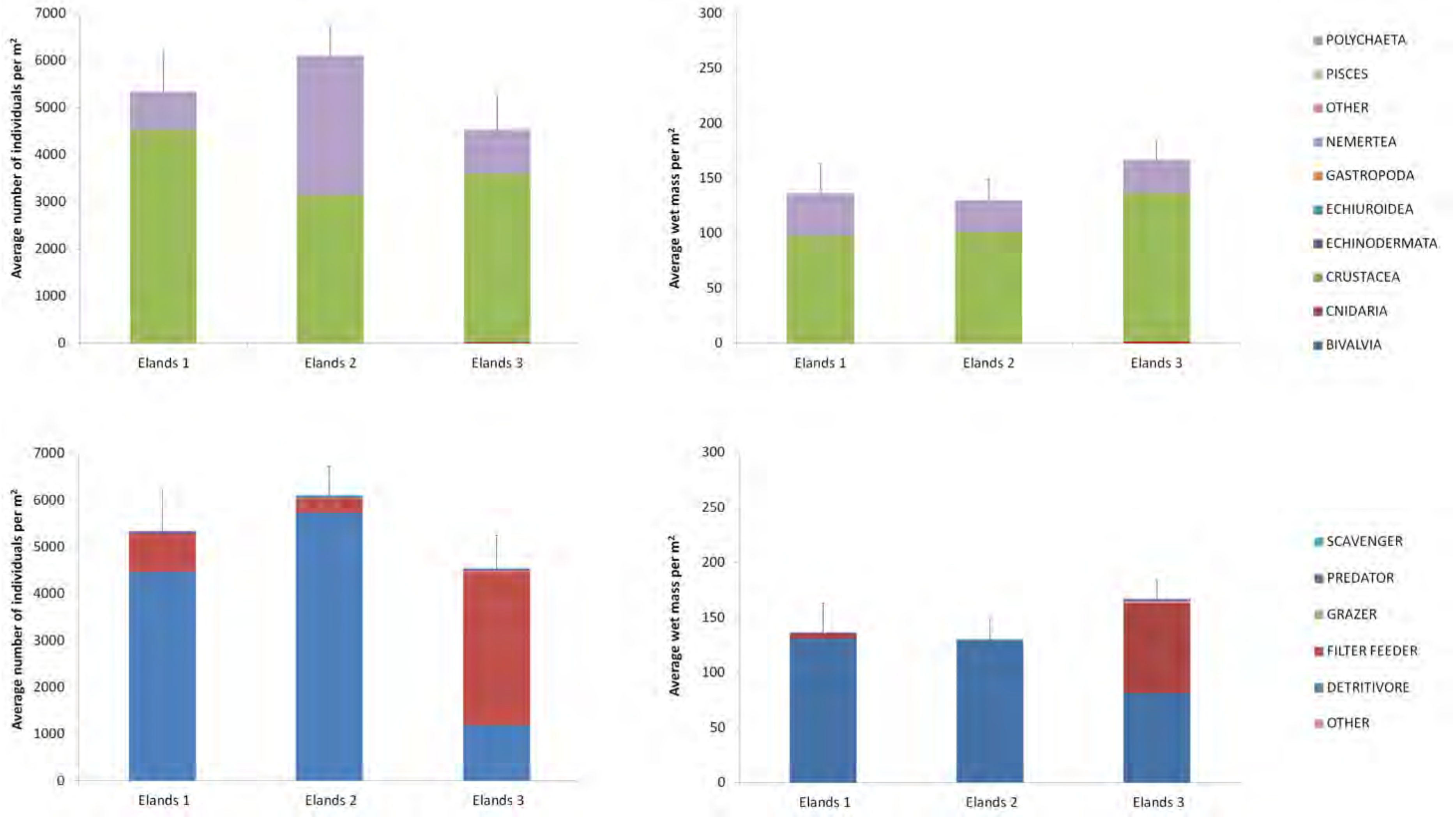


Figure 9.9 **Average abundance and biomass (g/m2) of benthic macrofauna by functional and taxonomic from sampling sites at Elandsfontein in 2017 - error bars are + 1 Standard Error (n=5).**

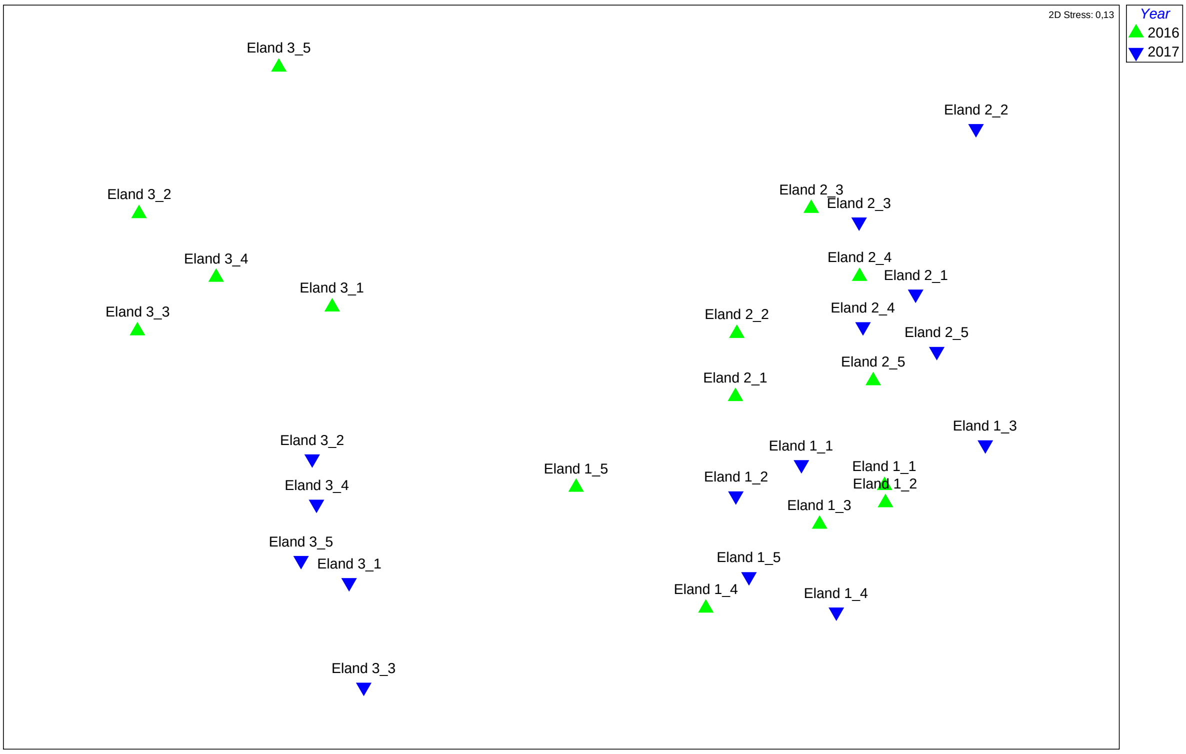


Figure 9.10 **MDS plot based on macrofaunal abundance data from samples collected at Elandsfontein in 2016 and 2017.**

9.9 Summary of benthic macrofauna findings

Macrofaunal 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 iron 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, rising again in 2013 and 2014 and then remaining fairly stable up to the present 2017 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 2010-2016) 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) in 2013 and 2014 was taken as a very positive sign and points to an overall increase in the health of the Bay. The slight decrease observed in the 2017 data is not of major concern as overall community structure remains largely unchanged. Results from the Elandsfontein baseline survey show that the macrofaunal community present at these sites are most similar to that present in Langebaan Lagoon. A spatial comparative analysis revealed clear trend macrofaunal communities from the marine dominated Saldanha Bay through the sheltered Lagoon to the very sheltered, shallow and possibly freshwater/estuarine influenced Elandsfontein habitat. Furthermore physical habitat and associated macrobenthic biota appear to be driving dissimilarity with the Elandsfontein sites themselves. In terms of the concerns raised around potential impacts that the proposed phosphate mine at Elandsfontein may have on groundwater quality and flows to Langebaan Lagoon, ongoing collection of baseline data on macrobenthic communities in Elandsfontein to capture natural variability, is essential for objective and quantitative assessment of any impacts should they occur.

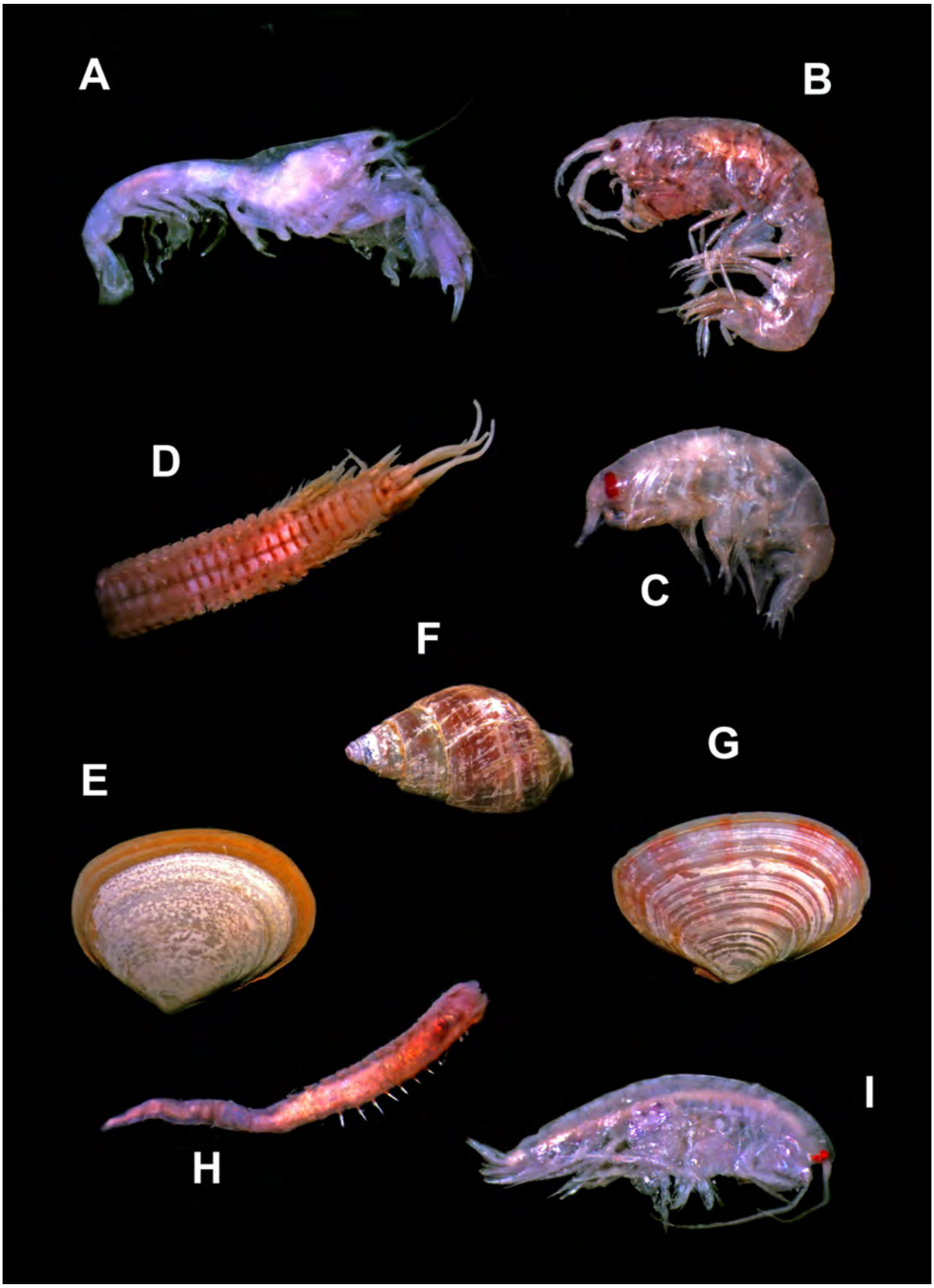


Figure 9.11. **Benthic macrofauna species frequently found to occur in Saldanha Bay and Langebaan Lagoon, photographs by: Aiden Biccard. A – *Upogebia capensis*, B – *Idunella lindae*, C – *Hippomedon normalis*, D – *Diopatra monroi*, E – *Macoma c. ordinaria*, F – *Nassarius vinctus*, G – *Tellina gilchristi,* H – *Sabellides luderitzi*, I – *Ampelisca anomola.***

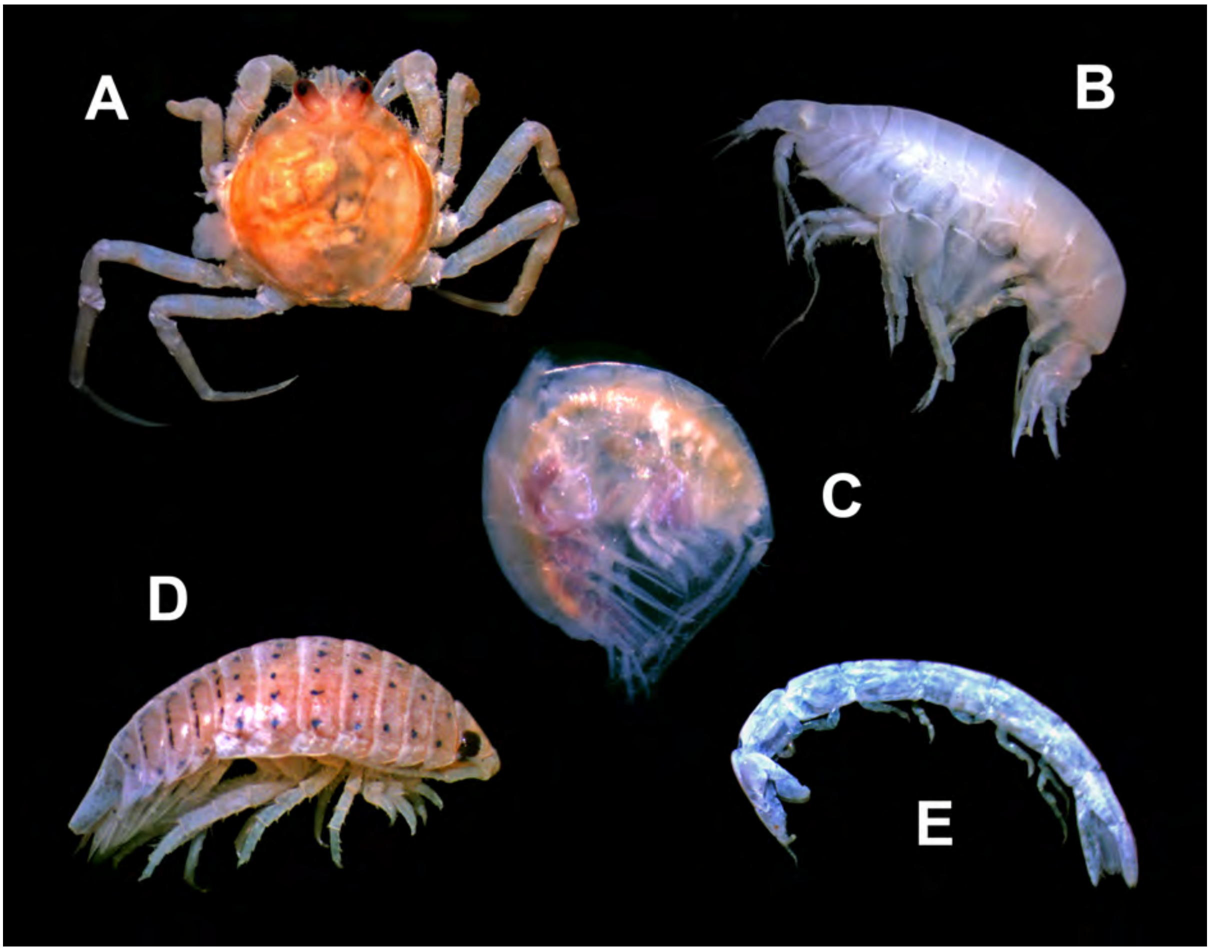


Figure 9.12. Benthic macrofauna species frequently found to occur in Saldanha Bay and Langebaan Lagoon, photographs by: Aiden Biccard. A – *Hymenosoma obiculare,* B – *Socarnes septimus*, C – *Ampelisca palmata,* D – *Eurydice longicornis,* E – *Centrathura caeca*.

10 ROCKY INTERTIDAL COMMUNITIES

10.1 Background

Limited 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 and they provide 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 on 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 2005 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 have been repeated annually from 2008 to 2015, however, due to financial constrains a survey was not conducted in 2016 and a two year survey strategy has since been adopted.

The baseline survey report concluded that wave exposure is the primary physical driver shaping intertidal rocky shore communities across the study area. More sheltered shores were dominated by seaweeds, while sites exposed to higher wave energy were dominated 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, however.

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 was also considered to be important, for example, sampling stations on 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 from seabird guano that favours algal growth. Generally, the Saldanha Bay communities were healthy but the presence of a number of alien invasive species, including the Mediterranean mussel *Mytilus galloprovincialis* and the three barnacles *Balanus glandula*, *Perforatus perforatus* (Aiden Biccard *pers. comm.* 2017) and *Amphibalanus amphitrite amphitrite* were noted.

This chapter presents results from the tenth annual monitoring survey conducted in March 2017.

10.2 Approach and methodology

10.2.1 Study sites

The locations of the eight rocky shore sampling sites are shown in Figure 10.1. The Dive School and Jetty sites are situated along the northern shore in Small Bay. The Marcus Island, iron ore terminal 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 10.1 Location of the eight rocky shore study sites in Saldanha Bay indicated by red dots.

The sampling sites were specifically chosen to cover the different rocky shore habitats found in the Saldanha Bay system and incorporate 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 10.2). Schaapen Island East (SE) is situated in a little baylet and is relatively sheltered and mostly flattish with some ragged rock sections. Schaapen Island West (SW) is a little less sheltered and mostly flat with some elevated topography.

The site at the iron ore terminal (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 rock surface at this site comprises medium-sized broken boulders that are piled up to support a side arm of the iron ore terminal, 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. North Bay (NB) is exposed with a relatively flat high and mid shore. 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 10.2 **Rocky shore study sites in Saldanha Bay. Dive School and Jetty are situated in Small Bay, Schaapen Island East and West are in Langebaan Lagoon, Iron ore Jetty and Lynch Point are in Big Bay, and North Bay and Marcus Island are in Outer Bay.**

10.2.2 Methods

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 171 smaller squares with 231 points 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%. Percentage cover refers to the space that organisms occupy on the rock surface, while abundance refers to the number of organisms present. The survey protocol has remained consistent for all surveys.

Sampling was non-destructive, *i.e.* the biota were 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 were not recorded by this survey protocol. Some algae and invertebrates that could not be easily identified to generic or species level in the field were recorded under a general heading (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.

10.2.3 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 provide 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 are successively clustered 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 a Bray-Curtis resemblance matrix was used.

Statistical comparisons of *a priori* defined groups of samples (e.g. sites, 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 community structure. Diversity indices include:

- *Species number (S)* - total number of species present.
- *Percentage/biotic 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 (H'[loge] or 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.

10.3 Results and discussion

10.3.1 Spatial variation in community composition

In 2017, a total of 114 taxa were recorded from all rocky shore sites, of which 65 taxa were invertebrates (57%) and 49 (43%) algae. The faunal component was represented by 22 filter feeding taxa, 24 grazers, and 19 predators/scavengers. The algal component comprised 36 corticated (foliose) seaweeds, eight ephemerals, five encrusting algae, and two kelp species. Coralline taxa are likely underestimated 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, 2014, 2015). 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).

Figure 10.3 Photographs of a typical high, mid and low rocky shore site in Saldanha Bay (from left to right).

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). An ANOSIM confirmed that there was a significant difference between shore heights in 2017 (R=0.58, p=0.01), while a SIMPER analysis between the species found at different shore heights affirmed that high, mid and low shores in Saldanha Bay were relatively dissimilar among the sites (Figure 10.4).

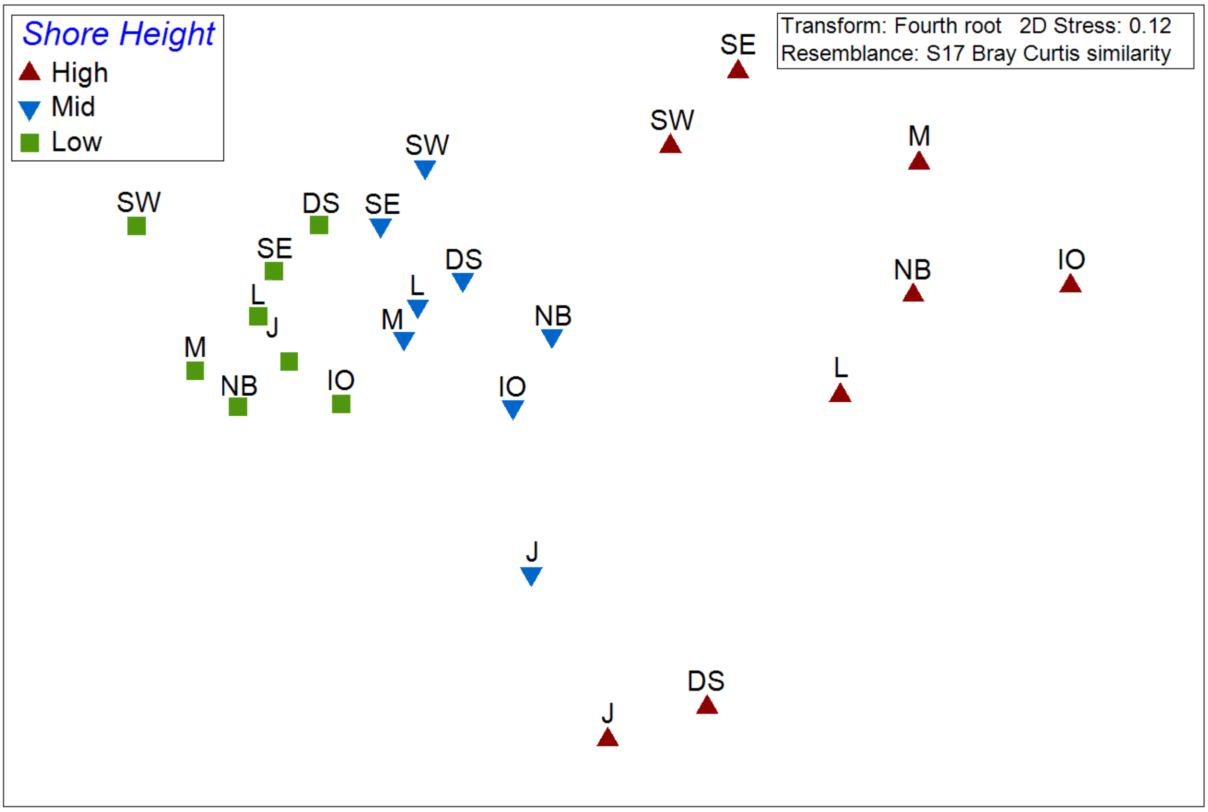


Figure 10.4 MDS plot showing differences in shore height amongst rocky shore assemblages in Saldanha Bay in 2017.

10.3.1.1 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.

In agreement with the above, previous State of the Bay reports showed that very few mobile species occurred on the high shore at all Saldanha Bay sites (Anchor Environmental Consultants 2015). It was also found that at the very sheltered boulder shores (Dive School and Jetty), considerable amounts of sand and gravel accumulated amongst the boulders (Anchor Environmental 2015). A typical species found at the high shore 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 (Anchor Environmental 2015). The latter typically accumulated in moist cracks and crevices at Lynch Point, Marcus Island and North Bay (Anchor Environmental 2015).

Field data collected in 2017 showed that Jetty and Dive School were less similar to the other high shore sites due to the presence of the barnacle *Oxystele antoni* (Figure 10.4). Most quadrats were largely barren with 80% of the similarity collectively attributed to the periwinkle *A. knysnaensis*, the alien barnacle *Balanus glandula* and the encrusting algal *Hildenbrandia* spp. The alien barnacle *Balanus glandula* occurred in the high shore zone at the Dive Schoool, iron ore terminal, Lynch Point and North bay but with a relatively low average coverage (<10%). Barren rock accounted for >80% at most high shores, while algal cover was extremely sparse, except at Lynch Point which had >3% cover of *Porphyra capensis.*

10.3.1.2 Mid shore

Following the trend on the high shore, the mid shore at the sheltered sites was also relatively barren; while the exposed sites had higher biotic cover (Anchor Environmental Consultants 2015). The dwarf cushion starfish *Parvulastra exigua* was typically found in moist rock-depressions and small pools, while the whelk *Burnupena* spp. and the periwinkle *Oxystele variegata* were frequently observed sheltering in depressions created by mussel carpets. In previous years, a tube-building polychaete living deeply cemented in a compact matrix of sand was common at sheltered sites (Anchor Environmental Consultants 2011), but in 2012 the worm had declined at the mid shore and was only recorded from lower down the shore albeit with low cover.

Field data collected in 2017 showed that ephemeral algae *Ulva* spp., the periwinkle *Oxystele variegata*, the whelk Burnupena spp., the cushion starfish Parvulastra exigua, the limpet *Cymbula granatina*, the encrusting algal Coralline spp. and Hildenbrandia spp. together accounted for 50% of the similarity between mid shore sites. Algal presence was generally low in the mid shore with some ephemeral cover.

With increasing wave force across sites, the mid shores were dominated by filter feeders, particularly two alien invasive species; the mussel *M. galloprovincialis* and the barnacle *Balanus glandula*. Both were particularly abundant at the semi-exposed site iron ore terminal in 2017 with an average cover of 20% and 26% respectively. In contrast, neither of these species was present on the mid shore at both Schaapen Island sites. The tiny periwinkle *A. knysnaensis* was found nestling in amongst the barnacles at sites inundated with *B. glandula*. This snail is normally abundant primarily in the upper intertidal where it congregates in crevices to escape the heat of the day, emerging at night or on moist days to feed (Branch *et al.* 2010). 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).

10.3.1.3 Low shore

At the very sheltered sites (Dive School and Jetty) average faunal cover was only 28% in comparison with the exposed sites (North Bay and Marcus Island), which had 47% cover. Algal cover at sheltered sites was much lower than that at exposed sites (9% compared to 32% respectively), and consisted primarily of the brown alga, *Ralfsia verrucosa*, the foliose seaweed *Gigartina bracteata*, and various species of encrusting coralline. At the sheltered Schaapen Island sites, the ground cover was dominated by a diverse array of up to 31 different algae species, a variety of corallines being the most common.

The following invertebrates together accounted for 20% of the similarity attributed between low shore sites: the mussels *M. Galloprovincialis* and *Aulacomya atra*, the whelk *Burnupena* spp., and the limpet *Crepidula porcellana*. The sea urchin *Parechinus angulosus* was exclusively found in crevices hidden under pieces of shell or gravel in the low shore, although not in high abundance. The pear-shaped limpet *Scutellastra cochlear* (always surrounded by narrow gardens of fast-growing, fine red algae) is found exclusively in the low shore zone and was present at Lynch Point, Marcus Island and North Bay. *Scutellastra cochlear* was clearly restricted to wave swept shores where it lived in patches of dense aggregations.

Aulacomya atra can be found living deep down in *Mytilus* beds, taking advantage of the moisture within the overlaying dense mussel matrix. In 2011, the indigenous ribbed mussel *Aulacomya atra* was fairly prominent at the low shore at Marcus Island and could locally supersede the alien mussel (Anchor Environmental Consultants 2012b) but during the 2017 survey, the ribbed mussel contributed <2% 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.

Reflecting known zonation patterns, total biotic cover generally increased from high to low shore. As an example, total cover on the high shore at Lynch Point was only 15% compared to 83% at the low shore. Differences in community structure are thus most pronounced at the low shore where the wave energy is greatest.

10.3.2 Temporal analysis

10.3.2.1 Temporal analysis of diversity indices

Diversity indices provide insight into the way in which the total number of individuals in a community 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 (calculated using the Shannon-Weiner diversity index) and equability (evenness). Species richness refers to the total number of species present, while evenness expresses how uniformly 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.

As previous reports showed no clear trend in diversity indices over time (Anchor Environmental 2015), temporal biotic cover data were averaged across years from 2005 to 2017 at each site (Figure 10.5). Sites were sorted from left to right according to increase in wave force and the indices are calculated for the whole shore across all zones. Marcus Island had the highest average number of species over this period, while Jetty had the lowest; although there was no clear trend across the wave exposure gradient. In contrast, average biotic cover increased among the shores with intensifying wave force from 12% cover at Jetty to 60% cover at Marcus Island. This trend was not evident for evenness and Shannon-Wiener diversity, although the site at the iron ore terminal had the lowest values for both these indices. This indicated low overall diversity but higher variation in communities over the years, which may be an indication of disturbance.

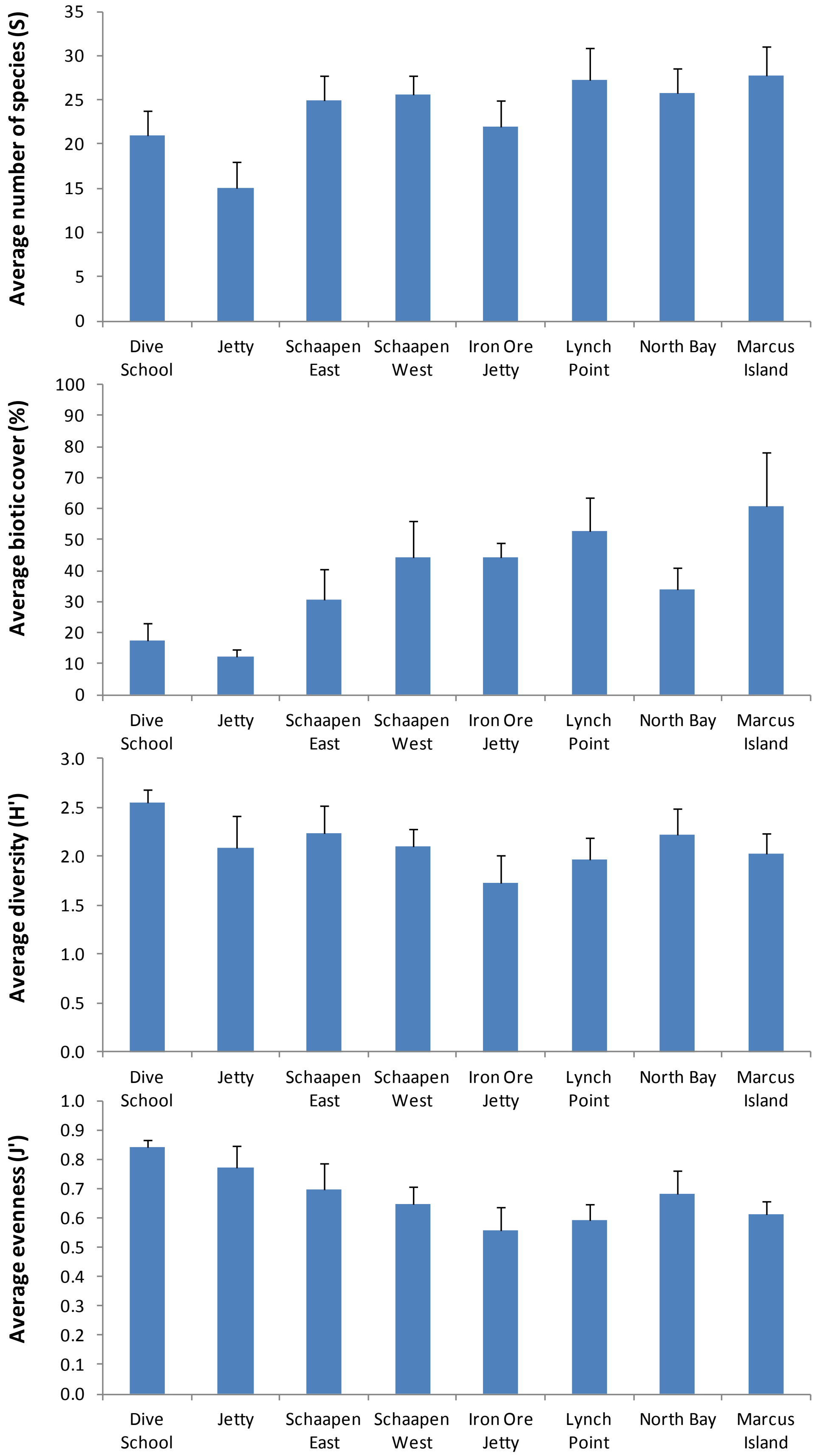


Figure 10.5 **Temporal biotic cover data from 2005 – 2017 averaged across years and displayed as biotic indices of 'species number' (S), 'biotic cover' (N), 'diversity' (d) and 'evenness' (J'). Error bars indicate standard error.**

10.3.2.2 Temporal trends in rocky shore community patterns

PERMANOVA tests conducted for each site confirmed 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 were significant.

Temporal trends in rocky shore community patterns are illustrated in the MDS plot (Figure 10.6). Consistent for all years is the grouping according to wave exposure, with the cluster on the left of the MDS plot grouping all samples from the more exposed sites (iron ore terminal, Lynch Point, North Bay, and Marcus Island), a cluster in the centre grouping the semi-exposed sites (Schaapen Island East and West), and a cluster on the right grouping samples from the sheltered sites (Dive School and Jetty. Within the exposed cluster, a separation of iron ore terminal 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 on the right of the cluster, while those from 2005 are on the left (Figure 10.6). The greatest within-site variability (or patchiness) occurs at the boulder site Jetty where the replicates per year often disperse widely. Due to the high stress level of 0.22, the MDS plot needs to be interpreted with caution, but there is good agreement with the pattern observed between years, suggesting that the representation is fairly reasonable.

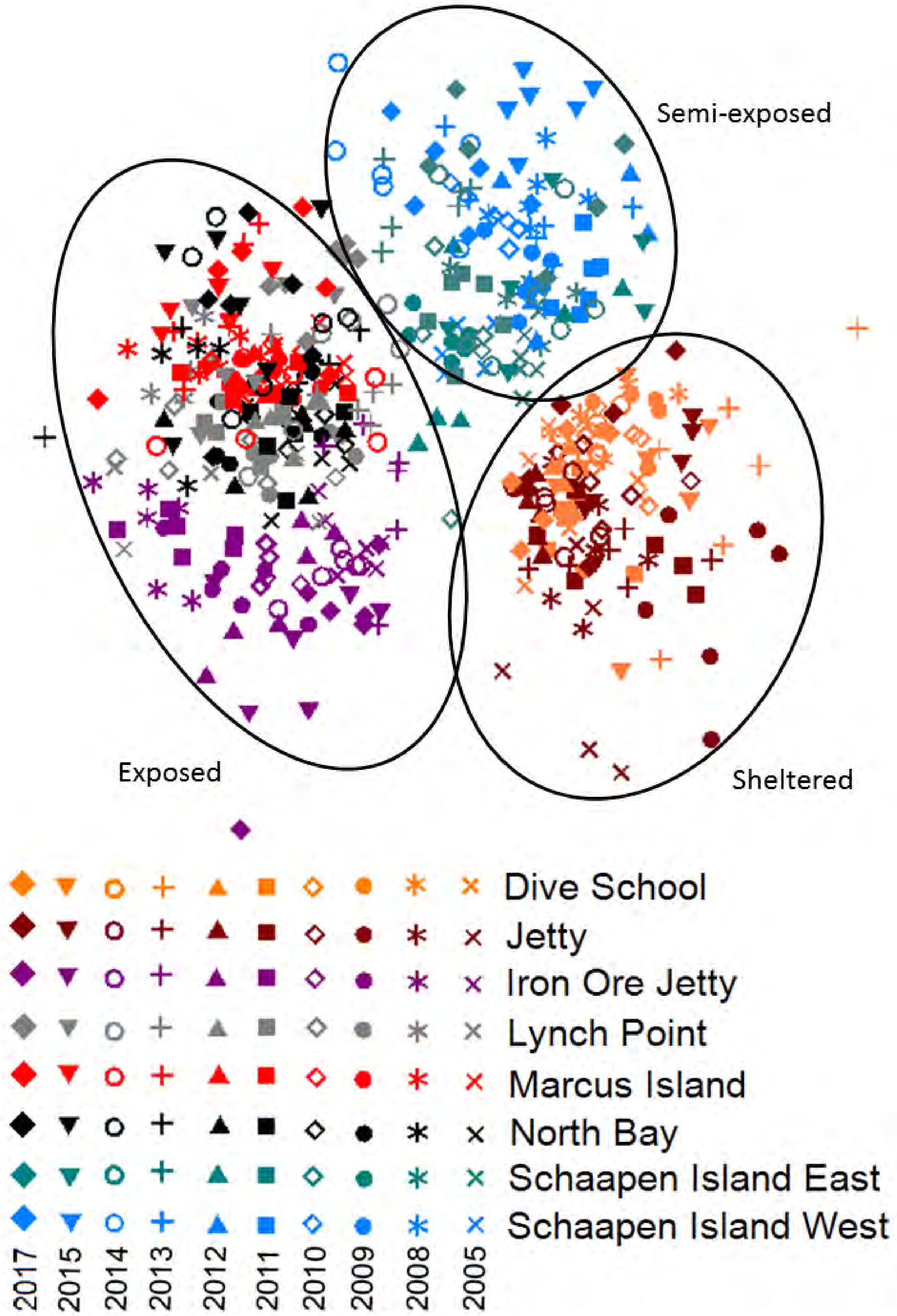


Figure 10.6 **Multi-dimensional scaling (MDS) plot of the rocky shore communities at the eight study sites from 2005 to 2017. The circles delineate a 40% similarity level and the plot has with a 2D stress of 0.2.**

10.3.2.3 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 >4% to the dissimilarity at any specific site and only comparisons between 2015 and the current dataset from 2017 are presented (Table 10.1). At most of the sites only two or three species contributed largely (>4%) to the differences in community structure between 2015 and 2017, except for Jetty where five species contributed and the exposed sites (Lynch Point and Marcus Island) where no single species contributed >4% (Table 10.1). For the latter sites, the species contributing the most to the dissimilarity was listed.

Algae were common contributors to differences between years as a majority of the species listed in Table 10.1 were seaweeds. Of the 9 algal species listed, one was ephemeral algae, six were corticated algae, and two were encrusting algae. The only animals listed were three filter-feeding species, the white dwarf barnacle *Notomegabalanus algicola*, introduced mussel Mytilus galloprovincialis and barnacle *Balanus glandula*, and the predatory anemone *Bunodactis reynaudi*. Percentage cover of the alien barnacle *Balanus glandula* has increased from 2015 to 2017 at the Dive School and the Jetty sites.

The presence of diatoms contributed to differences between the years at the North Bay rocky shore site. 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 was seen in Saldanha Bay in previous year with visible increases in the percentage of macroalgal species on the shore at all sites except at Dive School (Anchor Environmental Consultants 2015). Guano run-off from Schaapen Island, together with favourable environmental conditions is likely to be responsible for them intertidal algal growth in that area (Bosman *et al.* 1986, Bosman & Hockey 1986, 1988).

The increase in cover of *Gigartina polycarpa* contributed largely to the difference between the years at Dive School, Jetty, Schaapen East and Lynch Point. A decrease in *Notomegabalanus algicola* cover was mainly responsible for changes at the Jetty. At Marcus Island and Schaapen West, the increase in Green turf contributed to the differences between the years at both sites. At the iron ore terminal there were notable increases in Red turf algae and *Grateloupia longifolia* making them the best indicators of dissimilarity between the years.

Table 10.1 SIMPER results listing the species that contribute >4% to the dissimilarity between 2015 and 2017 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	2015 %cover	2017 %cover	Diss/SD	% Contribution	Ave. dissimilarity
Dive School	*Gigartina polycarpa*	0	0.89	4.03	5.23	52.26
	Balanus glandula	0	1.98	2.07	4.10	
Jetty	*Gigartina polycarpa*	0.12	1.27	3.76	6.84	52.78
	Red turf	0.00	1.04	2.19	6.11	
	Notomegabalanus algicola	0.99	0.00	6.21	5.92	
	Gigartina bracteata	0.90	0.00	2.13	5.34	
	Balanus glandula	0.00	0.71	3.21	4.28	
Schaapen East	Hildenbrandia spp.	0.00	1.43	8.05	5.83	59.26
	Gigartina polycarpa	0.00	1.09	4.84	4.39	
Schaapen West	Green turf	0.00	1.38	1.30	4.87	53.48
iron ore terminal	Red turf	0.19	1.34	1.91	5.51	60.04
	Grateloupia longifolia	0.00	1.01	1.62	4.74	
Lynch Point*	*Plocamium spp.*	0.95	0.00	3.60	3.38	52.30
	Gigartina polycarpa	0.00	0.81	2.02	2.84	
	Cochlear Garden	0.80	0.00	6.37	2.81	
	Balanus glandula	0.63	0.67	1.20	2.79	
North Bay	Diatoms	1.58	0.19	2.96	5.08	53.57
	Hildenbrandia spp.	0.00	1.29	3.12	4.70	
Marcus Island*	*Mytilus galloprovincialis*	1.88	1.19	1.87	2.94	51.54
	Green turf	0.00	0.64	0.94	2.74	
	Bunodactis reynaudi	0.72	1.07	1.22	2.70	

* Note that at sites marked with an asterisk none of the species contributed >4% to the dissimilarity. The species with the highest contribution is thus listed.

10.3.2.4 Temporal variations in abundance of functional groups

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, favouring 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.

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, micro-topography 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, McGuinness & 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).

The biotic cover of the various functional groups across the shores with regard to exposure is depicted in Figure 10.7 with sites arranged from very sheltered to exposed. 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.

At the two sheltered sites (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 terminal 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 but decreasing again in 2015. 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. This substantial increase in 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. Ephemeral algae increased substantially at Schaapen Island West, iron ore terminal and Marcus Island in 2017.

Overall, none of the sites indicated a temporal change in their rocky shore communities that would suggest a dramatic alteration 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). Percentage cover of ephemerals recorded in 2017 was consistent with the surveys prior to the low cover recorded in 2015. It is unlikely that the low cover recorded in 2015 was due to the occurrence of any disturbance or pollution events close to the study sites as fluctuations of functional groups over the years are likely to be a natural seasonal and inter-annual phenomenon.

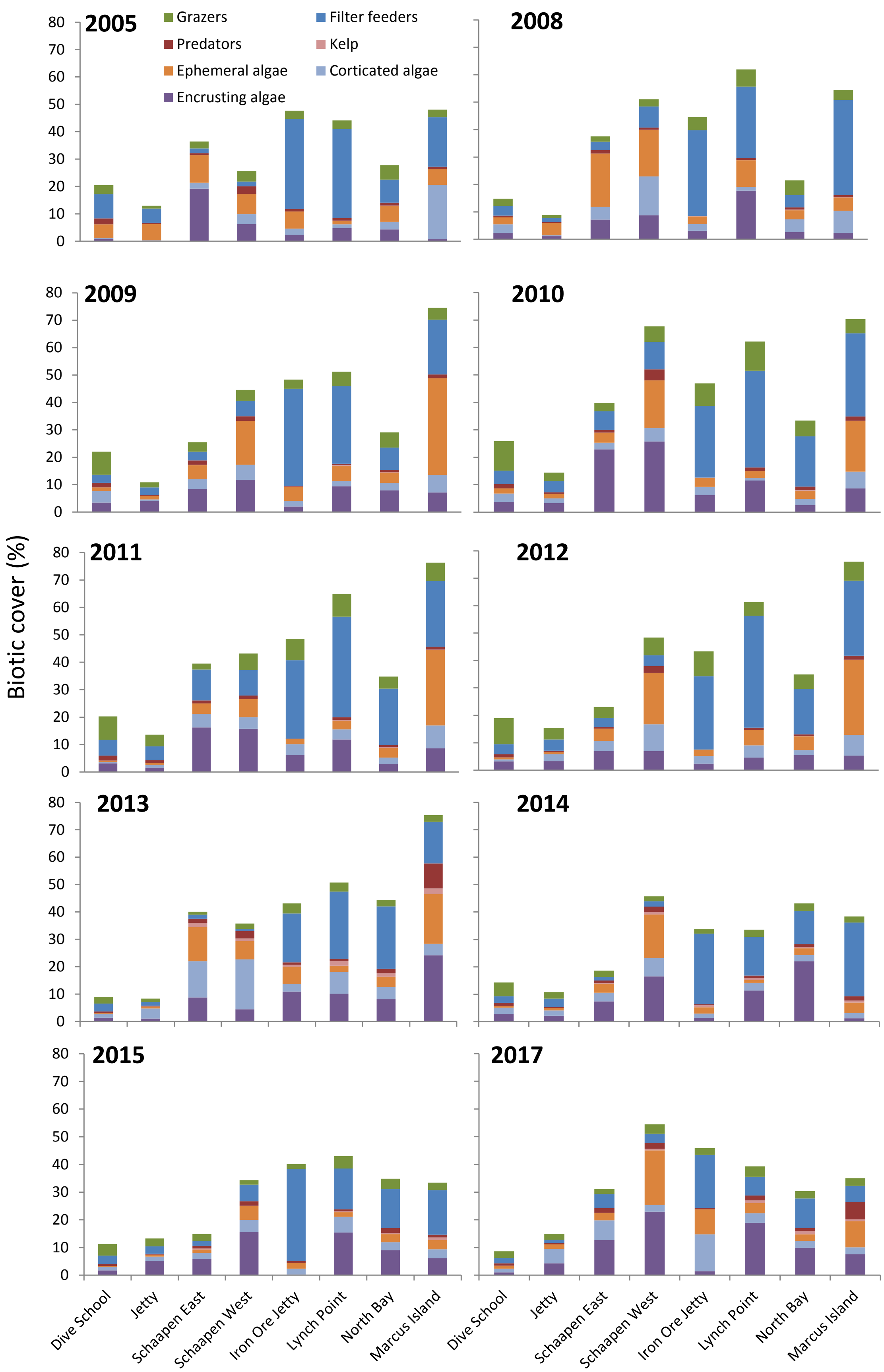


Figure 10.7 Total percentage cover (averaged across the whole shore) of the seven functional groups at the eight study sites from 2005 to 2017.

10.3.3 Summary of findings

In 2017, a total of 114 taxa were recorded from the eight study sites, most of which had been found in previous survey years. The faunal component was represented by 22 species of filter-feeders, 24 species of grazers, and 19 species of predators and scavengers combined. The algal component comprised 34 corticated (foliose) seaweeds, eight 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*, the North American acorn barnacle *Balanus glandula*, and the two alien barnacle species *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 sites in Small Bay separate out 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 terminal 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 (see Chapter 12 for detailed information on invasive species).

11 FISH COMMUNITY COMPOSITION AND ABUNDANCE

11.1 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 1600s 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 tonnes 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 smooth hound 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 amount 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 to 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 tonnes 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 *pers. comm.*).

Recent studies 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 observed increases in fishing pressure (Arendse 2011, Parker in press.). Arendse (2011) 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. Parker *et al.* (in press) provide an updated analysis of angler survey data, commercial linefish catch returns and the juvenile white stumpnose catch in the seine net surveys, that conclusively demonstrate substantial declines in both adult and juvenile abundance estimates over the last decade. These authors also urge that a reduction in bag limit and increase in size limit are required to sustain the Saldanha Bay white stumpnose fishery.

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 2008-2017 as part of the monitoring of ecosystem health "State of the Bay" programme. Seine-net surveys were conducted during late summer to early autumn, as this was the timing of peak recruitment of juveniles to the near-shore environment, as well as the timing of most of the earlier surveys. Since 2008, seine-net surveys have therefore been conducted during March-April of each year. These studies have made a valuable contribution to the understanding of the fish and fisheries of the region. This chapter presents and summarises the data for the 2017 seine-net survey and investigates trends in the fish communities by comparing this with data from previous seine-net surveys (1986/87, 1994, 2005, 2008-2016) in the Saldanha- Langebaan system.

11.2 Methods

11.2.1 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 deployed from a small inflatable boat 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. Since the 2013 survey, a sixteenth site was added in the lagoon at Rietvlei (Figure 11.1). Large hauls were sub-sampled on site, the size of the sub-sample estimated visually and the remainder of the catch released alive.

11.2.1.1 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, larval fish to Family level) 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 and average abundance 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 five most ubiquitous species in the system over all survey years was calculated and plotted for each sampling site.

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 the software package STATISTICA 13. Abundance data for all sites throughout the Bay were log (x + 1) transformed to account for heteroscedacity (unequal variance) prior to analysis.

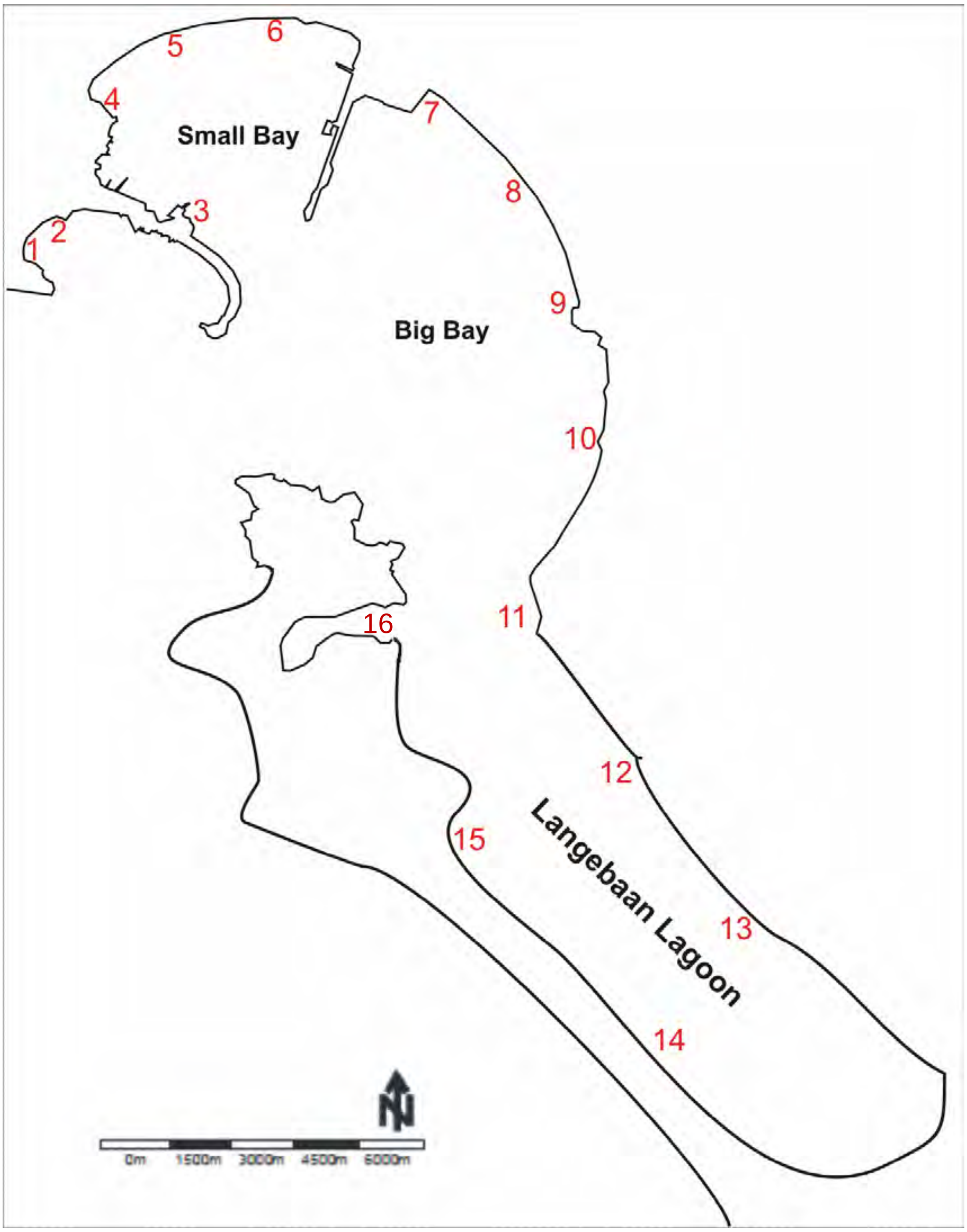


Figure 11.1. Sampling sites within Saldanha Bay and Langebaan lagoon where seine net hauls were conducted during the 2005 and 2007-2017 annual sampling events. 1: North Bay west, 2: North Bay east, 3:Small craft harbour, 4: Hoedjiesbaai, 5: Caravan site, 6: Blue water Bay, 7: Sea farm dam, 8: Spreeuwalle, 9: Lynch point, 10: Strandloper, 11: Schaapen Island, 12: Klein Oesterwal, 13: Bottelary, 14: Churchaven, 15: Kraalbaai, 16: Rietbaai.

11.3 Results

11.3.1 Description of inter annual trends in fish species diversity

The total species count in all surveys to date now stands at 50 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, however, they have been grouped at the generic level for data presented reports since 2008. Catch composition and abundance of each species caught in Small Bay, Big Bay and the Lagoon during each of the different surveys are shown in Figure 11.4 - Figure 11.7. Considering data from all surveys conducted to date, a greater diversity of species has been captured in Big Bay (37) and in Small Bay (36), than the Lagoon (26). Species richness is typically similar in Small Bay and Big Bay, although the number of species sampled has been less variable over time in Small Bay (Figure 11.2.). 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 11.2.). In the 2017 samples fish diversity was similar to that recorded in earlier surveys and overall there is no clear trend in species richness over time in any of the three parts of the Bay (Figure 11.2.).

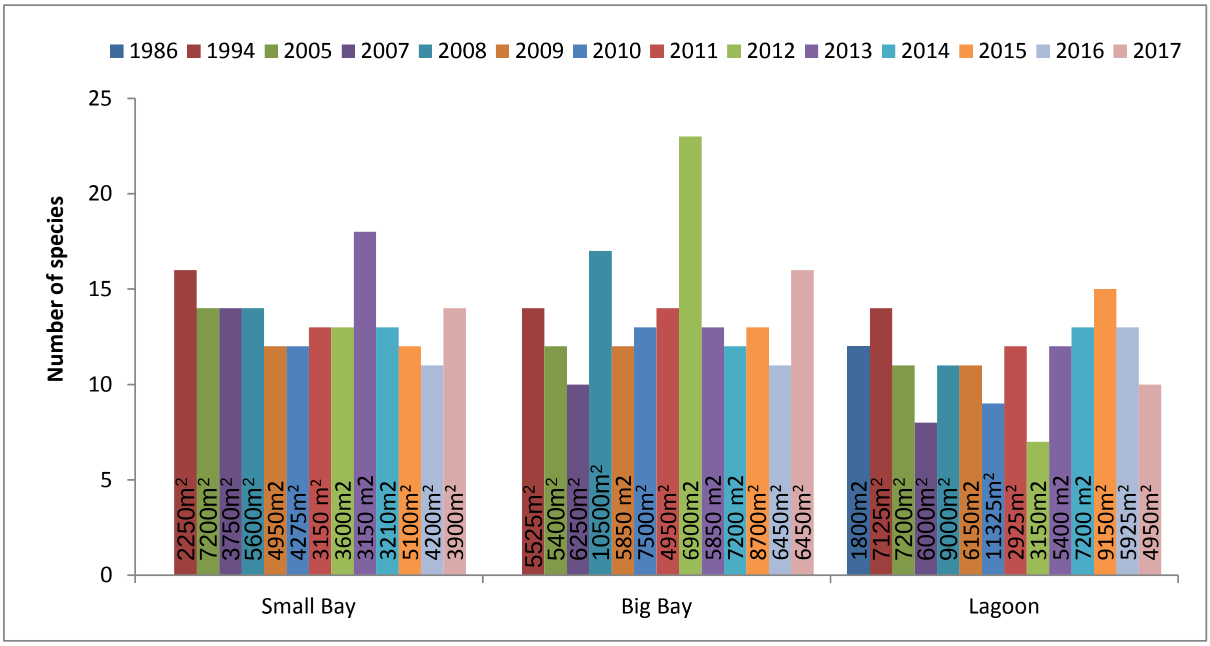


Figure 11.2. **Fish species richness during 14 seine-net surveys in Saldanha Bay and Langebaan lagoon conducted over the period 1986-2017. The total area netted in each area and survey is shown. Note: The low species richness for Langebaan lagoon during 2012 is an artefact due to low sampling effort.**

The actual species composition in the different areas does change substantially between years, but the same ubiquitous species occur in nearly all surveys. Within Small Bay, eight species occurred in all earlier surveys, but blacktail was absent for the second time in 2017 having first been absent in 2015 samples, whilst pipefish was absent in the 2005 and 2015 samples. Gurnard captured in all of the first six surveys, but not over the period 2011-2014, was again sampled at three sites in Small Bay during the 2015 and 2017 surveys. Interesting occurrences in 2017 Small Bay catches include a silverfish *Argyrozona argyrozana* which is typically an east coast, reef associated Sparid species, although it has been reported in occasional catches from St Helena Bay (Brouwer & Griffiths 2005); and a blaasop *Amblyrhychotes honkenii* which is also an Indo-Pacific species that is occasionally reported from the west coast.

Four of the 37 species recorded in Big Bay occurred in all surveys (gurnard, Cape sole, harders and white stumpnose). Three more species silversides, False Bay klipvis and elf are only absent in one survey each (2007, 1994, 2009 and 2014 respectively). Sand sharks were not caught in Big Bay during the 2014 and 2016 surveys, but all these species were caught during the 2017 survey. Similarly, six of the 26 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 14 sampling events average species richness has been similar in Small Bay and Big Bay (14 species) and slightly lower in the lagoon (11 species) (Figure 11.2.).

11.3.2 Description of inter-annual trends in fish abundance 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 11.3.). Harders and to a lesser extent silversides, numerically dominated the catches for all surveys and large variation in the catches of these abundant shoaling species is the main 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 and remained lower than any of the earlier surveys in both Small Bay and Big Bay, but was higher than average in Langebaan Lagoon. Over the years 2014-2017 the overall abundance of fish has compared favourably with earlier surveys (Figure 11.3.).

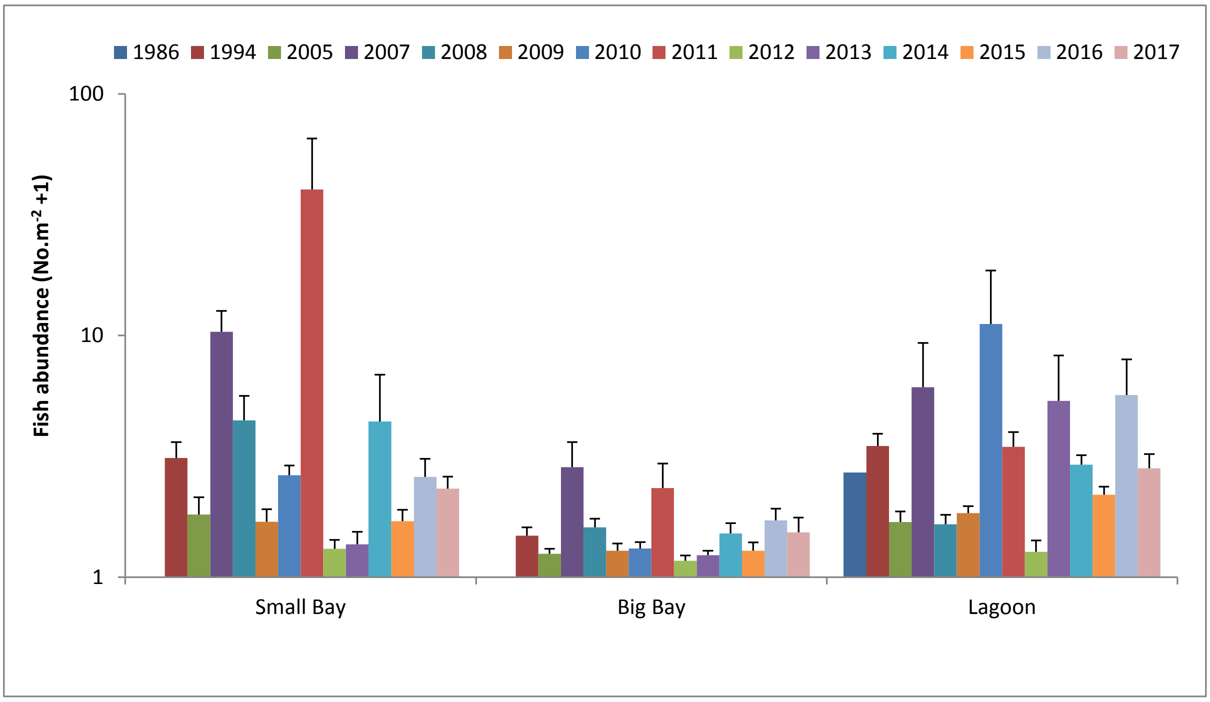


Figure 11.3. Average fish abundance (all species combined) during 14 seine-net surveys conducted in Saldanha Bay and Langebaan lagoon. (Error bars show one Standard Error of the mean). The data are transformed (x + 1) and displayed on a logarithmic axis.

Abundance of white stumpnose, nude goby and blacktail abundance in seine net hauls that was above average in Small Bay during the 2007 and 2008 surveys, has remained below these maxima in this region since 2009 (Figure 11.4.). 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. The concerning trend in white stumpnose and blacktail abundance over the 2012-2015 period in Small Bay appeared to have reversed with the third highest white stumpnose abundance and second highest blacktail abundance recorded in 2016 Small Bay samples. Unfortunately blacktail juveniles were, for only the second time in the sampling history, entirely absent from Small Bay catches in 2017 and white stumpnose abundance was slightly down from that recorded during 2016.

Within Big Bay too, average harder density observed during the 2013-2016 sampling was comparable to earlier surveys, but the abundance of white stumpnose and Cape sole remain low (Figure 11.4.). White stumpnose abundance within Big Bay had recovered from the very low 2013 and 2014 estimates, but remained well below the long-term average (Figure 11.4.). After an absence in seine net catches for two years, elf juveniles returned in good numbers in 2016 and 2017, with the highest abundance estimates to date in the 2017 samples. After a period of relatively poor recruitment for many species spanning 2009-2015, the 2016 & 2017 samples revealed better recruitment of most species to surfzone nursery habitats in all areas of the Bay and Lagoon. The initially encouraging the improved white stumpnose and blacktail abundance estimates in Small Bay however, appears to have not continued through to 2017. On the other hand, the continued increase in elf recruits in Big Bay suggests this stock is doing well. The estimated abundance of the more common species in Langebaan lagoon during 2017 compared favourably with earlier surveys (Figure 11.4.). The exception in all three areas of the system is still white stumpnose. White stumpnose estimated abundance in Small Bay in 2017 - approximately 1 fish in every 10 m^2 of surfzone habitat, was still well below (one fiftieth) the 2007 peak abundance of 5 $fish.m^{-2}$, whilst Big Bay and Langebaan lagoon abundance estimates remained low compared to the average recorded during earlier surveys.

Naturally high variability in recruitment strength is common for marine fish species and it is often natural environmental fluctuations rather than anthropogenic factors that caused the poor recruitment in 2009 and 2012, as abundance was low throughout the system. The lower than average recruitment into the surf zones suggests that these were “poor” years 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 improved recruitment of most species seen during the 2016 and 2017 survey suggests improved environmental conditions that facilitated survival of eggs, larvae and juveniles during the preceding summer. The continued low abundance estimates of juvenile white stumpnose however, indicates that the spawning capacity of the adult stock remains compromised.

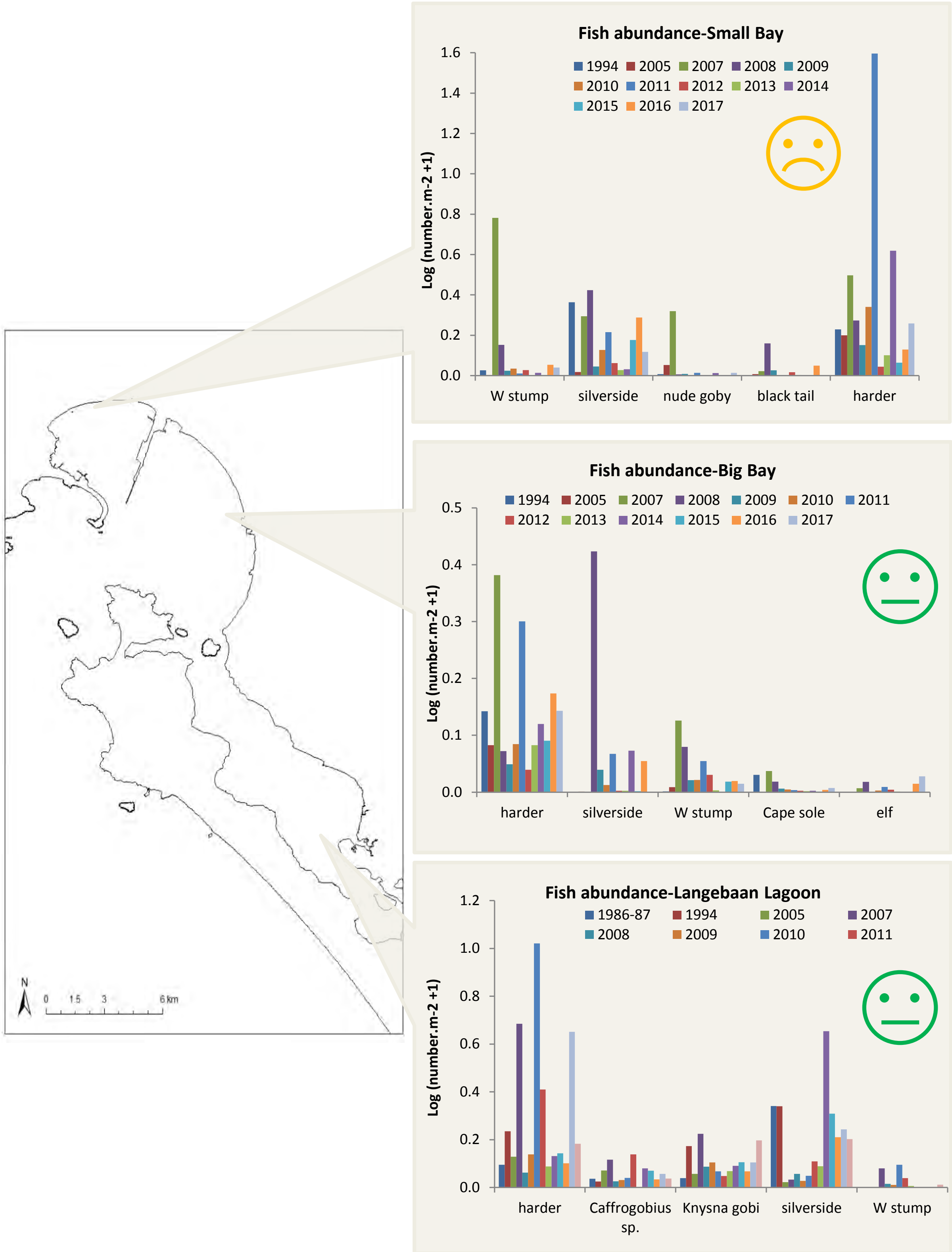


Figure 11.4. **Abundance of the most common fish species recorded in annual seine-net surveys within Saldanha Bay and Langebaan Lagoon (1986/87, 1994, 2005 & 2007-2017).**

11.3.3 Status of fish populations at individual sites sampled in 2016/2017

The average abundance of the four most common species in catches made during all earlier surveys and the most recent 2017 survey at each of the sites sampled is shown in Figure 11.5., Figure 11.6. and Figure 11.7. 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 average abundance of silversides at most Small Bay sites in the 2017 survey were comparable to those recorded in earlier surveys, whilst harder abundance was lower than average at all sites except for Bluewater Bay where relatively large catches were made in 2017 (Figure 11.5.). The average abundance of gobies at all sites remains significantly lower than the average recorded over the previous thirteen surveys. White stumpnose abundance during the 2017 survey was lower than the historical average at all sites, with the exception of the Small craft harbour site where catches were greater than the historical average (catches at this relatively exposed site are however, typically an order of magnitude lower than at the other Small Bay sites).

At all the Big Bay sites, catches of harders during the 2017 survey were either less than, or greater than, the historical average with no clear spatial trend; whilst silversides were absent from nearly all sites (Figure 11.6.). White stumpnose catches the Big Bay sites were similar to or less than the long-term average (Figure 11.6.). Catches of silversides, harders and gobies at lagoon sites during 2017 were similar to the long term average; whilst white stumpnose density was significantly lower at four of the sites and greater than the long-term average at Kraalbaai and Rietbaai (Figure 11.7).

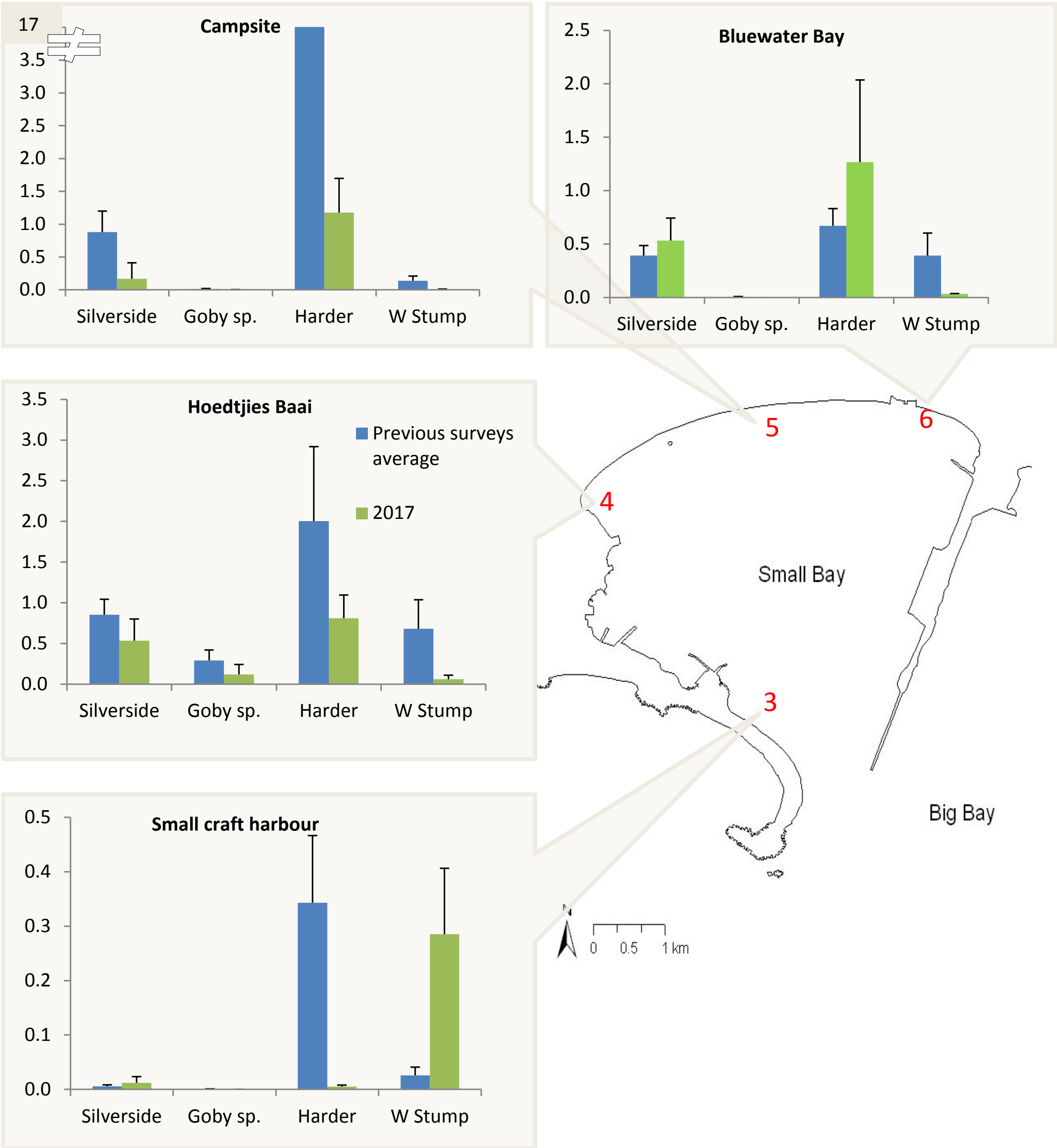


Figure 11.5. Average abundance (No.fish.m^{-2}) of the four most common fish species at each of the sites sampled within Small Bay during the earlier surveys (1994, 2005, 2007-2016) and during the 2017 survey. Errors bars show plus 1 Standard error.

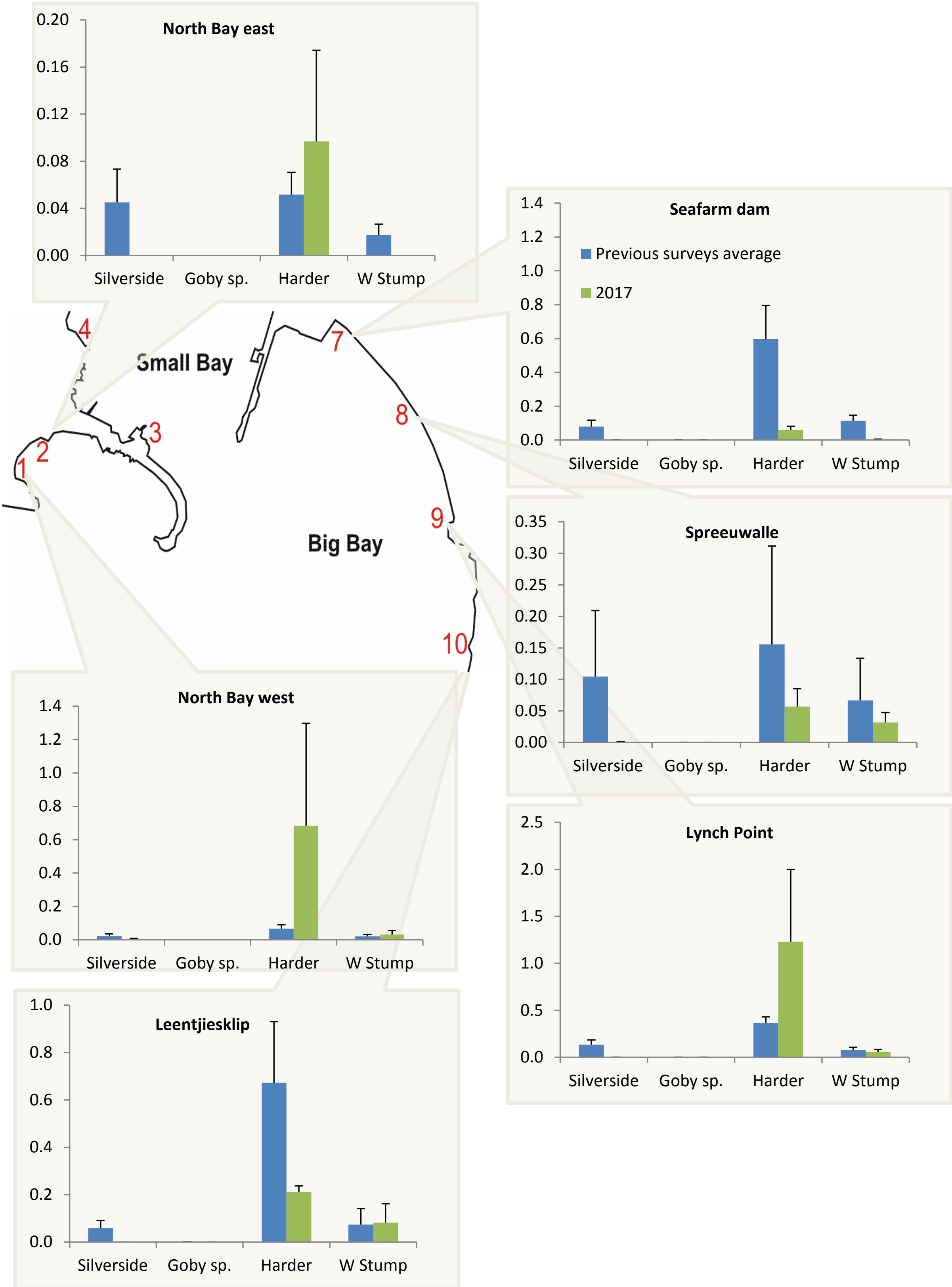


Figure 11.6. **Average abundance (#fish.m^{-2}) of the four most common fish species at each of the sites sampled within Big Bay during the earlier surveys (1994, 2005, 2007-2016) and during the 2017 survey. Errors bars show plus 1 Standard error.**

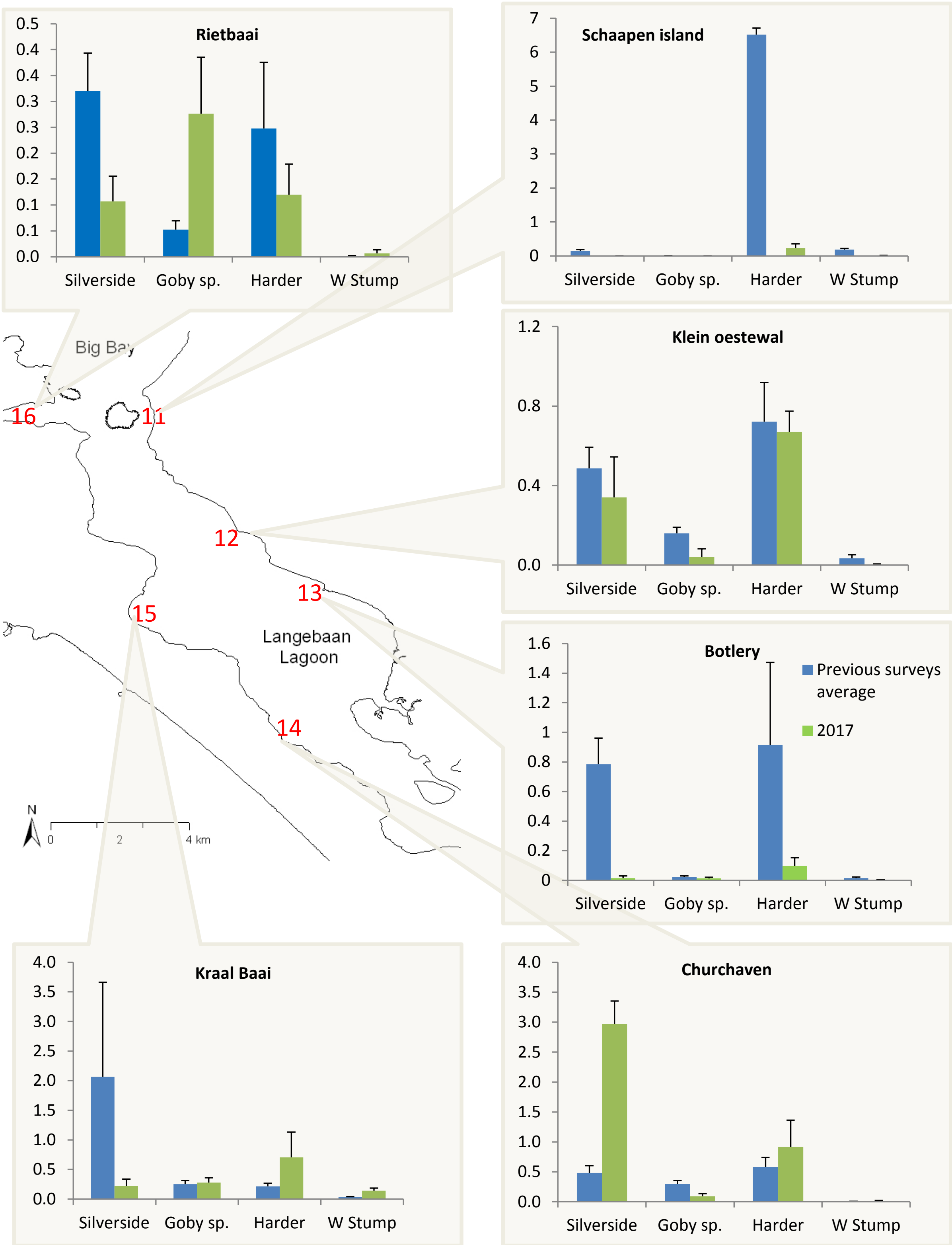
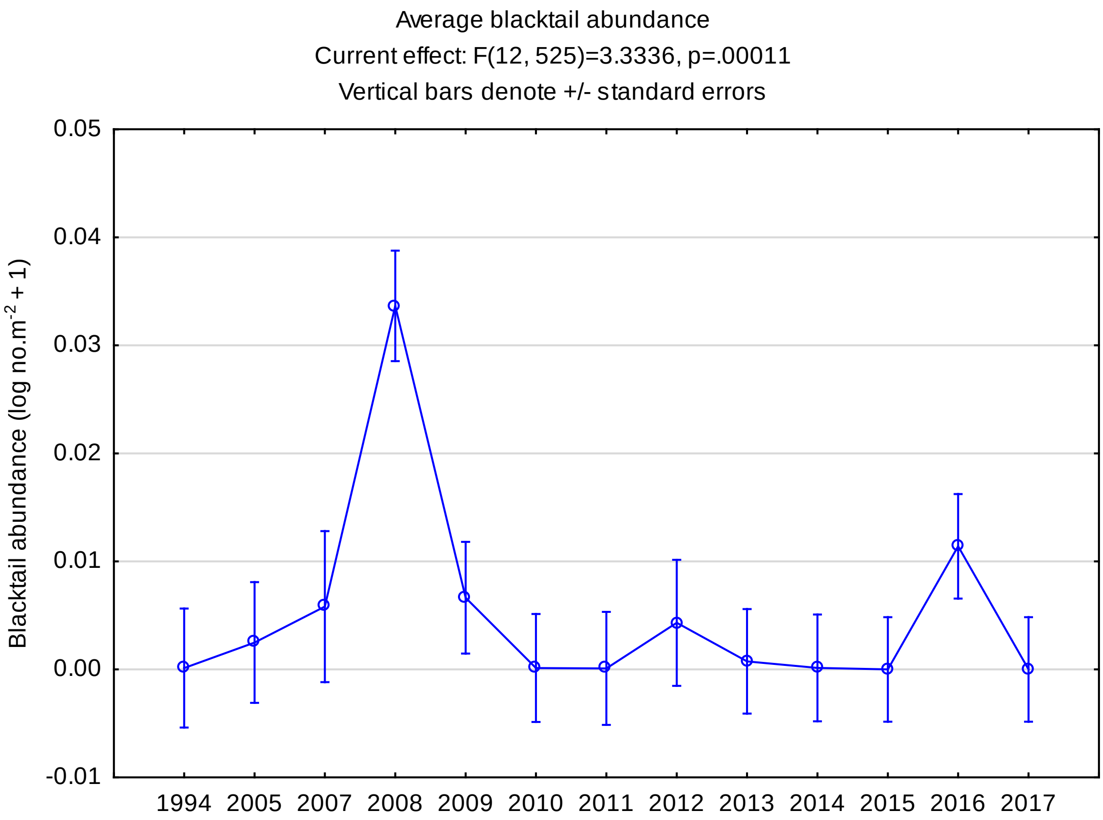


Figure 11.7. **Average abundance (#fish.m^{-2}) of the four most common fish species at sites sampled within Langebaan lagoon during the earlier surveys (1994, 2005, 2007-2016) and during the 2017 survey. Error bars show plus 1 standard error.**

11.4 Temporal trends in key fishery species

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 surveys over the period 2008-2015 and a notable decrease in white stumpnose abundance throughout the system over this same period. The 2016 survey revealed some encouraging signs of increased white stumpnose recruitment in Small Bay, but 2017 catches were again lower than average. 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 in abundance 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 stumpnose, but not in the average density of elf and steentjies (Figure 11.9, Figure 11.10).

The density of blacktail juveniles in sampled habitats was significantly higher in 2008 than in all other years and there was an absence of blacktail recruits in the 2015 and 2017 samples (Figure 11.8). 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). The abundance of juvenile harders in 2016 and 2017 hauls was higher than average and only significantly less than that recorded in 2011. Estimated white stumpnose abundance in 2007 was significantly greater than all other years, whilst the estimated abundance during 2013-2015 surveys was less than during nearly all other survey years. Despite a small increase in abundance of juvenile white stumpnose in 2016, the 2017 white stumpnose abundance estimates remained low, and were not significantly different from the abundance estimates recorded post-2008. 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, 2012, 2016 and 2017 (the highest recorded to date). 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.



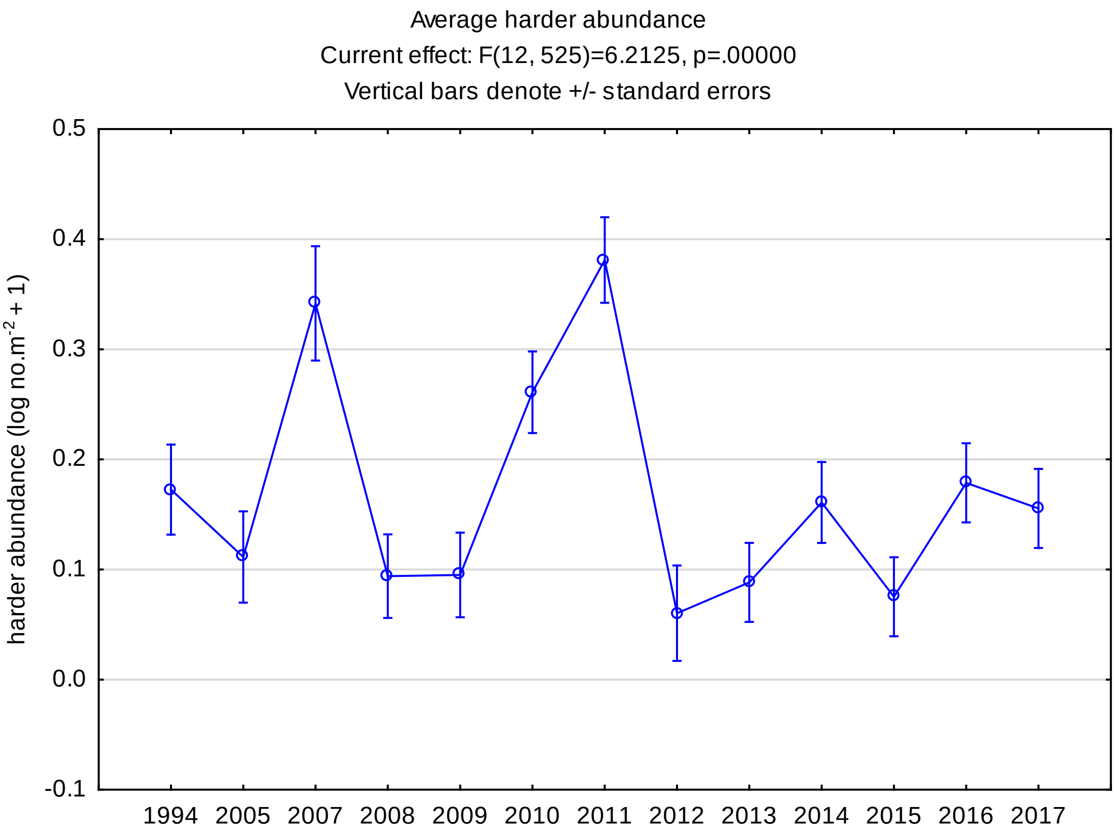
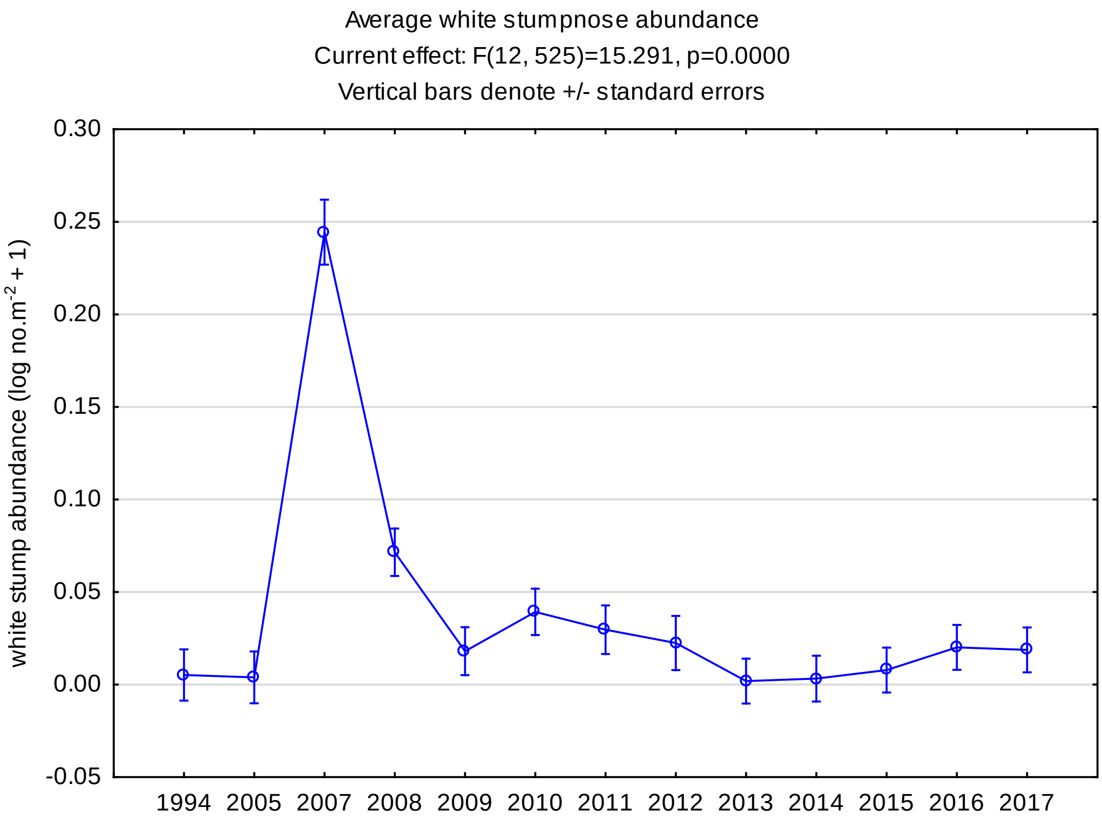


Figure 11.8. ANOVA results comparing the average annual density of blacktail and harders at all sites sampled in all surveys (1994-2017).



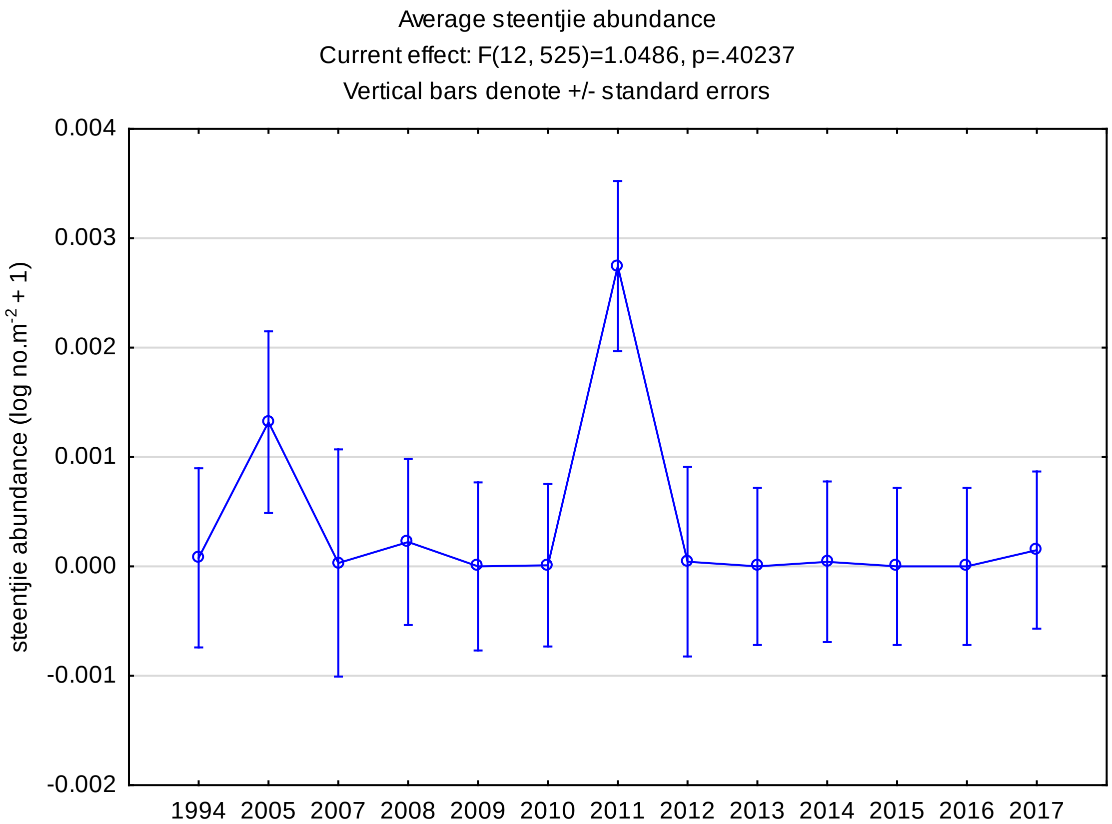


Figure 11.9. ANOVA results comparing the average annual density of white stumpnose and steentjies at all sites sampled in all surveys (1994-2017).

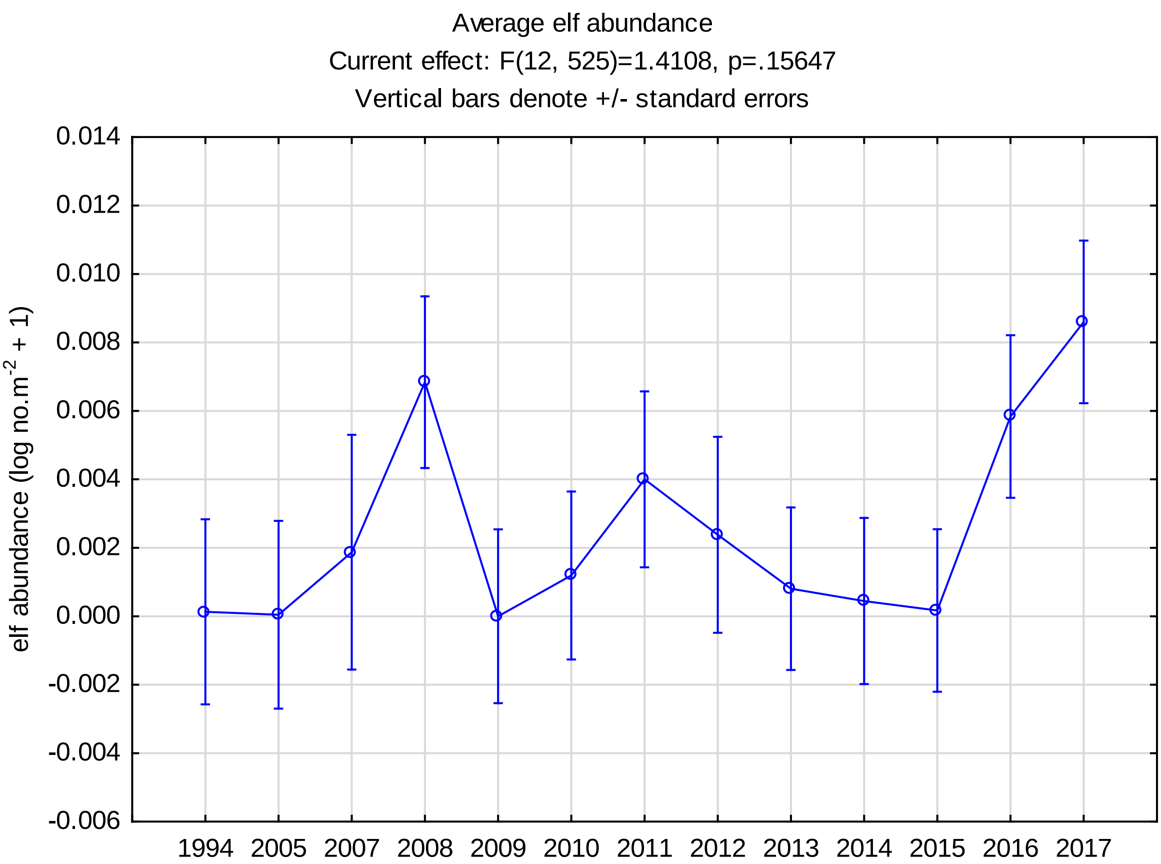


Figure 11.10. ANOVA results comparing the average annual density of elf at all sites sampled in all surveys.

11.5 Stock status of harder fishery

The 2016 SOB report provided a synopsis of the observed decline in both juvenile (seine net data) and adult white stumpnose abundance in Saldanha Bay over the last decade and reiterated calls for bag and size limit adjustments to ensure the sustainability of the Saldanha Bay and Langebaan lagoon white stumpnose fishery(Parker *et al.*, in press). In this year's report we present an analysis of harder size composition in commercial gill net catches provided by Dr Steve Lamberth from the Department of Agriculture Forestry and Fisheries (DAFF) (Figure 11.11). These data show a substantial shift towards a smaller size class of harders being landed over the time period. This probably reflects increased fishing effort and "fishing down" (or reduction in numbers) of the larger size fish in the population due to the increase in the number of gill net rights allocated as part of the interim relief process. Healthy juvenile harder abundance was, however, still recorded in the recent 2016 and 2017 surveys, which suggests that recruitment overfishing is not taking place. The observed shift towards a smaller size class of harders in catches does suggest though that growth overfishing is occurring and further increases in fishing pressure will probably lead to declines in overall yield (catch in terms of mass) from the fishery. There has been considerable pressure (including a court case where DEA and SAN Parks were respondents) in a bid to open the restricted Zone B within the Langebaan MPA to all commercial gill net fishers resident in Saldanha and Langebaan (currently 2-3 permit holders resident in Churchaven are permitted to fish in this zone). Permitting increased fishing effort within Zone B would drive further declines in average harder size which has a disproportionate negative impact on the reproductive output of the stock as large female fish spawn exponentially more eggs as the grow. This would negatively impact the productivity of the harder stock in the Saldanha-Langebaan system and may lead to further long-term declines in the overall fishery catch. We recommend that the SBWQFT opposes attempts to open Zone B to further fishing effort.

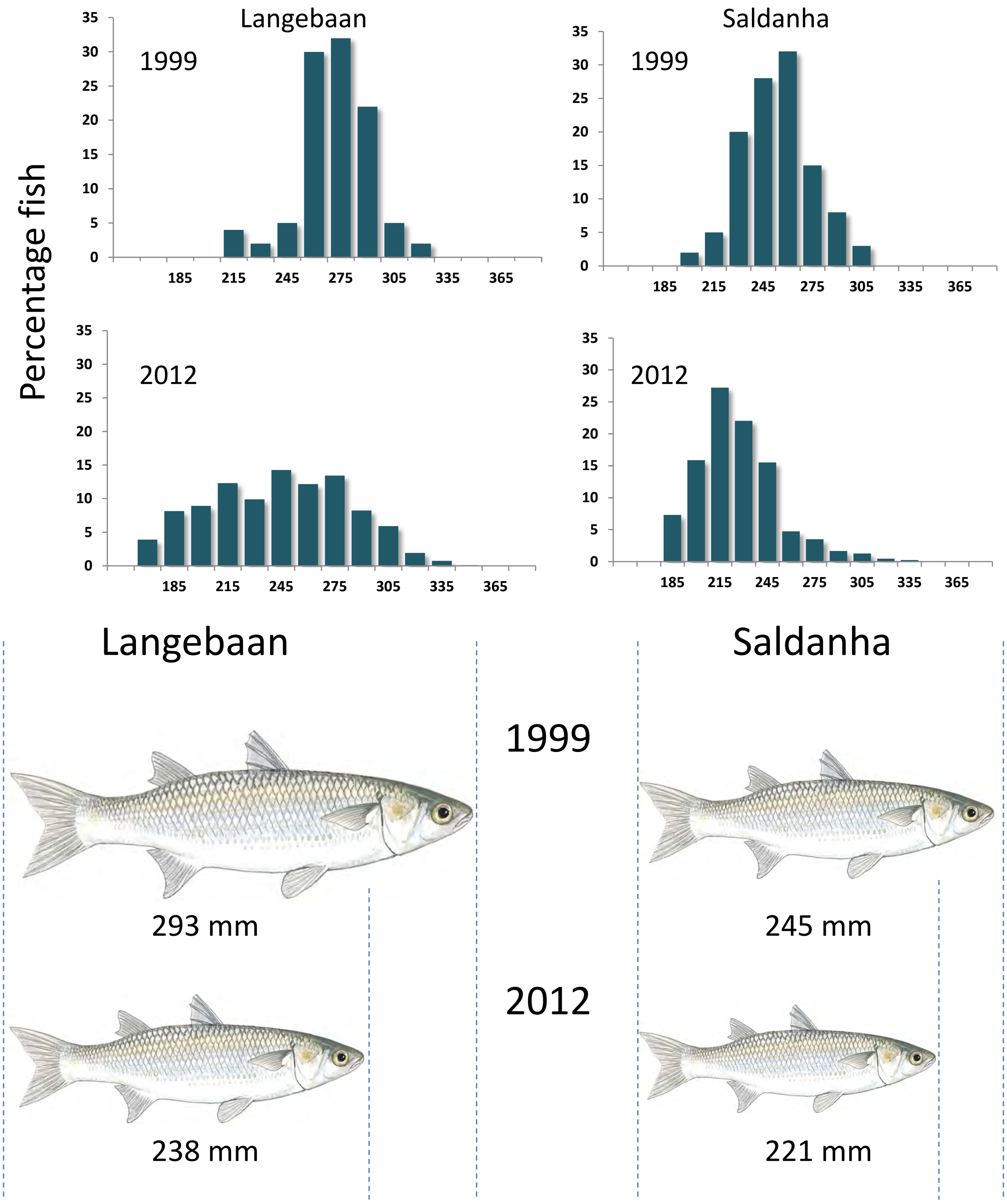


Figure 11.11. Evidence of a decline in the average size of harders caught in the commercial gill net fishery in Saldanha Bay and Langebaan lagoon over the period 1999 to 2012. Source (S.J. Lamberth DAFF).

11.6 Conclusion

With the exception of white stumpnose, the current status of juvenile fish communities within Big Bay-Langebaan lagoon appears satisfactory. The encouraging signs of recovery of white stumpnose and blacktail in Small Bay in 2016 have unfortunately not continued through to 2017, with a complete absence of blacktail and reduced white stumpnose catches. The abundance of gobies in Small Bay also has also remained low since the 2007 survey. The decline in gobies cannot be attributed to fishery impacts, but may be related to water quality or habitat changes. Fish diversity and overall abundance does not, however, show a declining trend in Small Bay and this suggests that the habitat quality remains good as a juvenile fish nursery. The strong elf recruitment in Big Bay evident in the 2016 and 2017 sampling, bodes well for the recreational fishery for this species in coming years. Other species common in Big Bay catches were present in comparable numbers to earlier surveys.

A consistent long-term negative trend, since fish sampling began in 1986-87 has, with the exception of white stumpnose, has not been detected for the principal species found in Saldanha 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 pressure to reduce this protection by allowing access to Zone B for commercial gill net permit holders should be resisted. This not only poses a threat to the productivity of the harder stock but also to other fish species that will be caught as bycatch.

The significant declines in juvenile 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. Arendse (2011) found the adult stock to be overexploited using data collected during 2006-08 already, and the evidence from the seine net surveys conducted since then certainly suggest that recruitment overfishing has occurred. 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 stumpnose abundance in the nursery surf-zone habitats since 2007, and the observed declines in commercial linefish CPUE, 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. This is the fourth time Anchor Environmental are making this recommendation in the State of the Bay Report and these recommendations are now also supported by a more statistically comprehensive analysis of fishery dependent and survey data (Parker *et al.* in press.).

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. Over the period 2005-2010, the average white stumpnose density calculated from all seine net surveys was 1.1 fish.m^{-2} in Small Bay, over the period 2011-2017 this dropped to 0.05 fish.m^{-2} compared with the long term average of 0.08 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 stumpnose nursery habitat is improved.

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. These benefits should be quantified by an economic study of the recreational fisheries. The value of Small Bay as a fish nursery and the economic value of the resultant fisheries could then be quantitatively considered when the environmental impacts of the proposed future industrial developments within Small Bay are assessed.

The monitoring record from the annual seine net surveys will prove increasingly valuable in assessing and mitigating the impacts of future developments on the region's ichthyofauna. Extending the seine net monitoring record would also facilitate analysis of the relationship between recruitment to the near shore nursery habitat and future catches in the commercial and recreational fisheries in the Bay. A preliminary investigation of this relationship was undertaken for white stumpnose and harders in the 2011 and 2012 reports, respectively and investigated again in the 2015 report for the commercial white stumpnose fishery. 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. We think that point arrived at least four years ago for the Saldanha-Langebaan white stumpnose fishery and recommended that resource users lobby the authorities to implement the recommended harvest control measures. Regional species specific fishery management has been implemented elsewhere in South Africa (e.g. Breede River night fishing ban to protect dusky kob). White stumpnose in Saldanha Bay appear to be an isolated stock and there is good on site management presence in the form of SANParks and DAFF, and we think this approach would work well in Saldanha-Langebaan. We again recommend the reduction of bag limit and an increase in size limit for white stumpnose in the Saldanha Bay Langebaan region. Although recruitment overfishing appears to have been taking place for several years now, the stock is not extirpated and the situation is reversible. Reductions in fishing mortality can be achieved by effective implementation of more conservative catch limits and have an excellent chance of improving the stock status, catch rates and the size of white stumpnose in the future fishery.

12 BIRDS

12.1 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 saltonnes per annumns 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 Knysna.

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 bird species have been recorded within the boundaries of the West Coast National Park (Birdlife International 2011). At least 56 non-passerine waterbird species commonly use the area for feeding or breeding (University of Cape Town, Animal Demography Unit Coordinated Waterbird Counts); 11 breed on the islands of Malgas, Marcus, Jutten, Schaapen and Vondeling alone. These islands support nationally-important populations of African Penguin, Cape Gannet, Swift Tern, Kelp and Hartlaub's Gull, and four species of marine cormorant, as well as important populations of the endemic African Black Oystercatcher. The lagoon is an important area for migratory waders and terns, as well as for numerous resident waterbird species. Waterbirds are counted annually on all the islands, and bi-annually in Langebaan Lagoon.

12.2 Birds of Saldanha Bay and the islands

12.2.1 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), Jutten (43 ha), Meeuw (7 ha), Caspian (25 ha) and Marcus (17 ha), support important seabird breeding colonies and make up 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 (recently up-listed to Endangered under IUCN's red data list criteria), White-breasted Cormorant, Crowned Cormorant (Near Threatened), Bank Cormorant (Endangered), Kelp and Hartlaub's gulls, Caspian Tern 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.

The Department of Environmental Affairs (DEA) conducts ongoing bird counts on all islands to track population trends of each of these species over time. Each island is visited several times a year to ensure that each species is counted during its peak breeding season. The maximum counts for each species obtained in a calendar year are then used to estimate population sizes. All islands are visited roughly three times per calendar year with the exception of Malgas (nine times) and Vondeling (less than three times due to accessibility) (Rob Crawford, Department of Environmental Affairs, *pers. comm.* 2016). Section 12.2.1.1 shows long-term trends of each of these important seabirds and the African Black Oystercatcher, using the data collated by the DEA.

12.2.1.1 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 numerous factors including pollution (from oil spills), changes in the abundance and distribution of small pelagic fish populations, competition with commercial fisheries and seals for food and predation pressure from Kelp Gulls and Cape Fur Seals (David *et al.* 2003, Pichegru *et al.* 2009, Crawford 2009, Birdlife International 2011, Crawford *et al.* 2011, 2014, Weller *et al.* 2014, 2016, De Moor & Butterworth 2015, Gremillet *et al.* 2016). 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).

Throughout South Africa, the African Penguin population declined from an average of 48 000 pairs over the period 1979-2004 to just 17 000 pairs in 2013 (Crawford *et al.* 2014). The number of African penguins breeding in the Western Cape decreased in a similar fashion 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 256 breeding pairs in 2016 (Figure 12.1.). 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.

The changes in African Penguin population size at the 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 has been linked 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 abundant, 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). The reduced abundance of anchovy in the 1980s may partly explain the decrease in the African penguin population evident from 1987 to 1993 clearly reflected in the Saldanha data (Figure 12.1.). Subsequently the penguin population at Saldanha bay increased in tandem with a “boom” period for the South African sardine stock that increased from less than 250 000 tonnes in 1990 to over four million tonnes in 2002 (Figure 12.1, Figure 12.2). Anchovy biomass also increased from the late 1990s, peaked at over 4 million tonnes in 2001 and has remained relatively high (compared to the 1980s and 1990s) at between 2-4 million tonnes in most years since then (Figure 12.2). Although both anchovy and sardine were still abundant along the west coast during the “boom’ period around the turn of the century, much of the growth in biomass in these small pelagic stocks occurred to the east of Cape Agulhas benefiting seabirds at colonies along the south and east coast. Subsequently, the sardine stock crashed over the period 2004-2007 and the proportion of the sardine stock along the west coast declined dramatically at this time. The numbers of African Penguins on the Saldanha Bay Islands followed a similar trajectory, despite anchovy remaining abundant off the West Coast and an increase in the proportion of the sardine stock west of Cape Agulhas in the last decade (Figure 1.1, Figure 12.2). Several studies have identified addittional drivers of African Penguin populations at the colony level; these include oiling and predation by seals and kelp gulls, with the importance fishing and food availability decreasing at small colony size (<3 500 breeding pairs) (Ludynia et al. 2014, Weller *et al.* 2014, 2016).

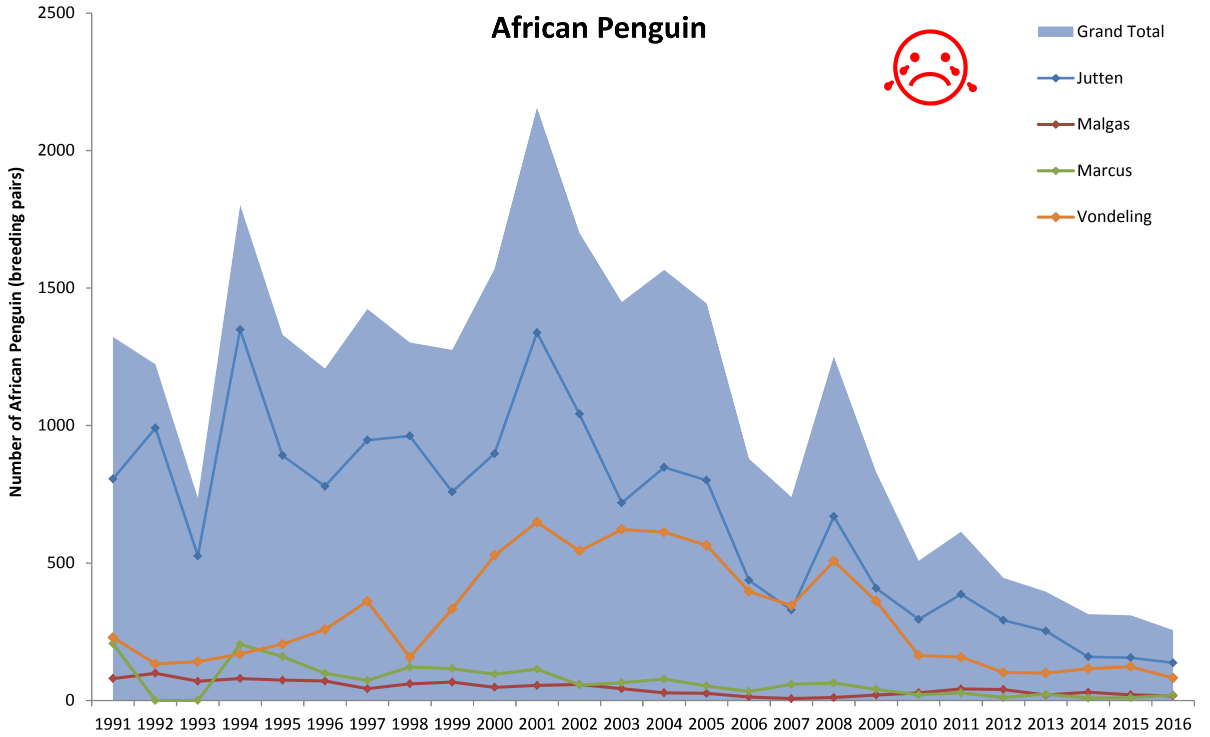


Figure 12.1. Trends in African Penguin populations at Jutten, Malgas, Marcus and Vondeling islands in Saldanha Bay from 1991-2016 measured in number of breeding pairs (Data source: Department of Environmental Affairs: Oceans & Coasts).

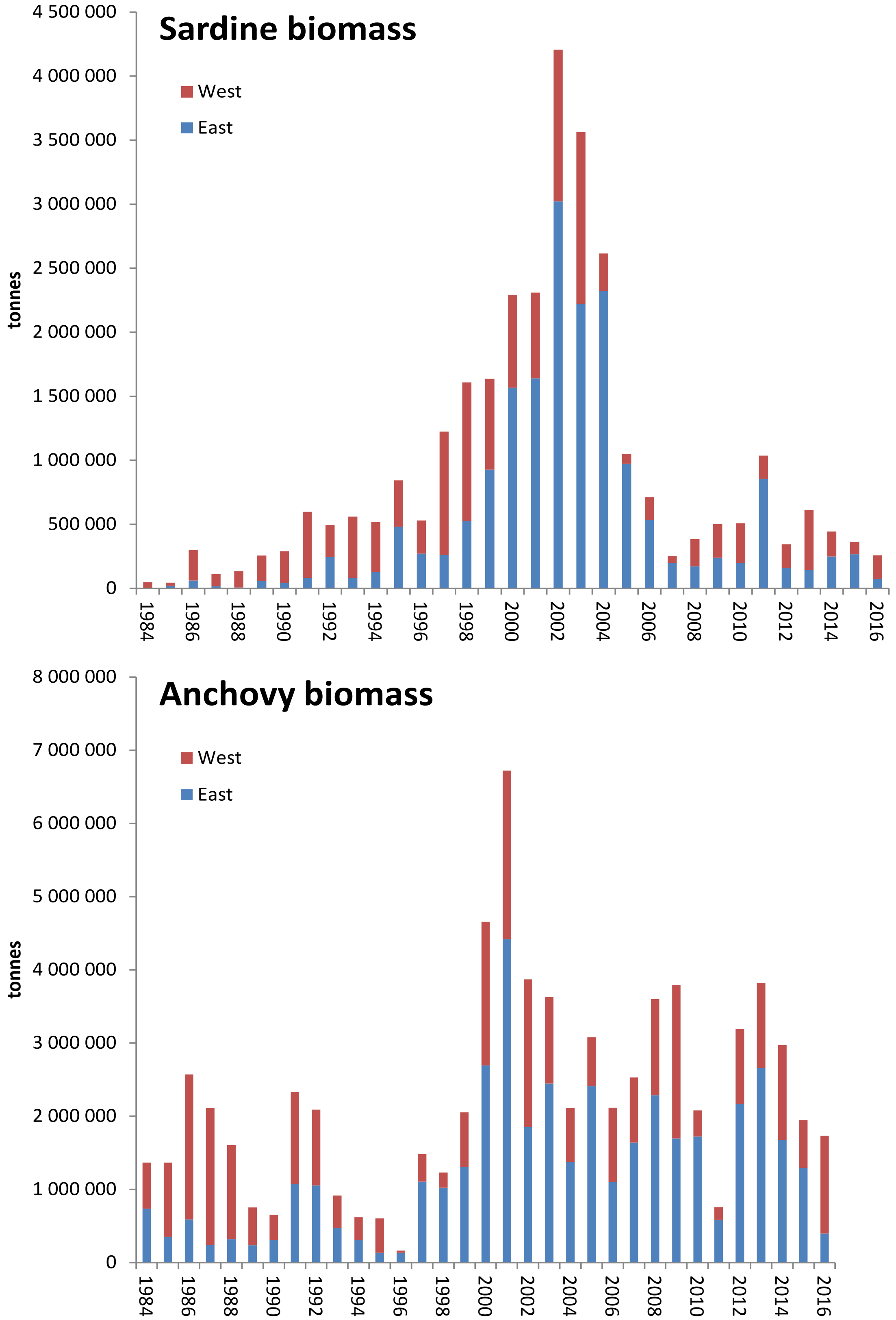


Figure 12.2. Long term trends in the biomass of small pelagic fish (sardine and anchovy) to the west and east of Cape Agulhas based on hydro acoustic surveys conducted bi-annually from 1984-2016 (Data source: Department of Agriculture Forestry and Fisheries).

There is considerable uncertainty around the causes of African penguin population decreases which is a result of multiple pressures, some operating throughout the species range and others operating at different intensities at different colonies. 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 presented immediate benefits for the African penguin population 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 2 000 pairs and gull predation on penguin eggs almost certainly 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. 2006, 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 12.3.), 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). 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 12.3.). Recent counts show that Kelp Gull numbers remain below those at the start of the comprehensive counting period. This probably reflects the continued impacts of Pelican predation as well as the effects of a reduced food supply due to the observed reduction in the abundance of *M. galloprovincialis* as rocky shore ecosystems reach a new equilibrium.

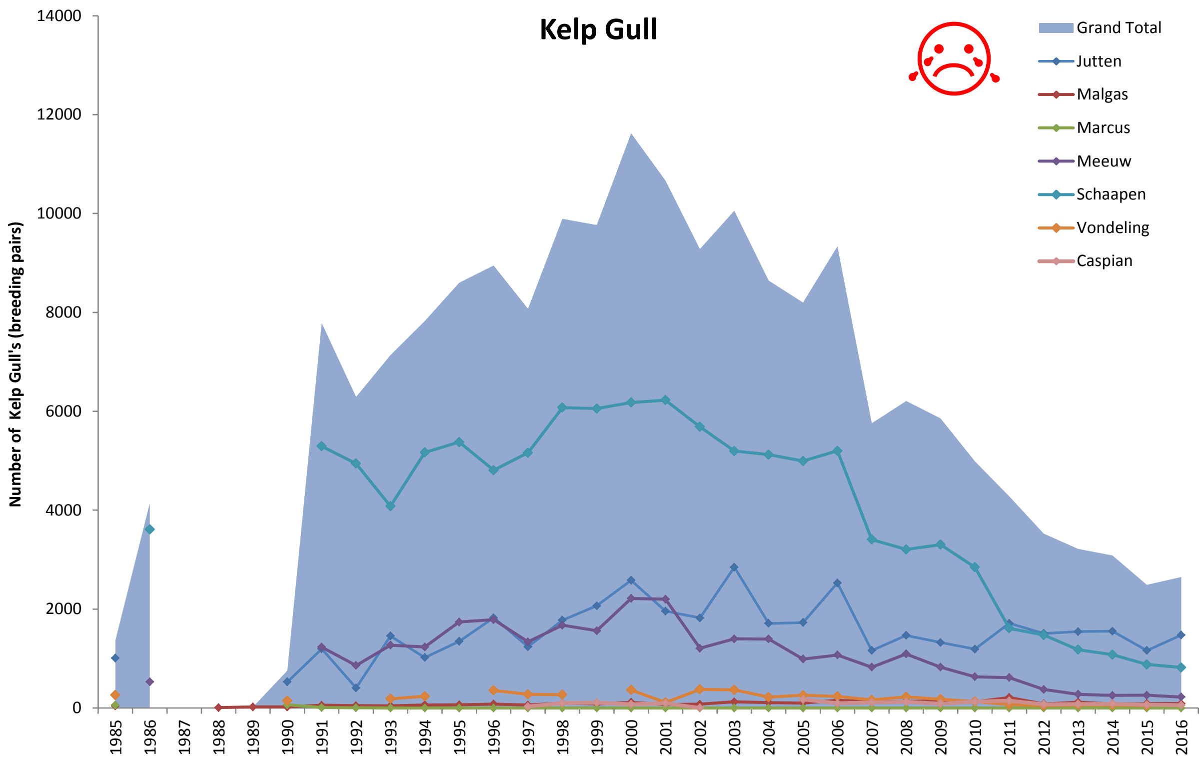


Figure 12.3. Trends in breeding population of Kelp gulls at Jutten, Malgas, Marcus, Meeuw, Schaapen, Vondeling and Caspian Islands in Saldanha Bay from 1985 – 2016 measured in number of breeding pairs (Data source: Department of Environmental Affairs: Oceans & Coasts).

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 1998 and last in 2006 when 30 pairs were recorded. They have also been recorded breeding on Meeuw Island in 1996, from 2002 to 2004 and again for during 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 discernible 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 2 pairs in 2016 (Figure 12.4.). The total number of breeding pairs recorded in 2016 was 303 found almost exclusively on Malgas Island.

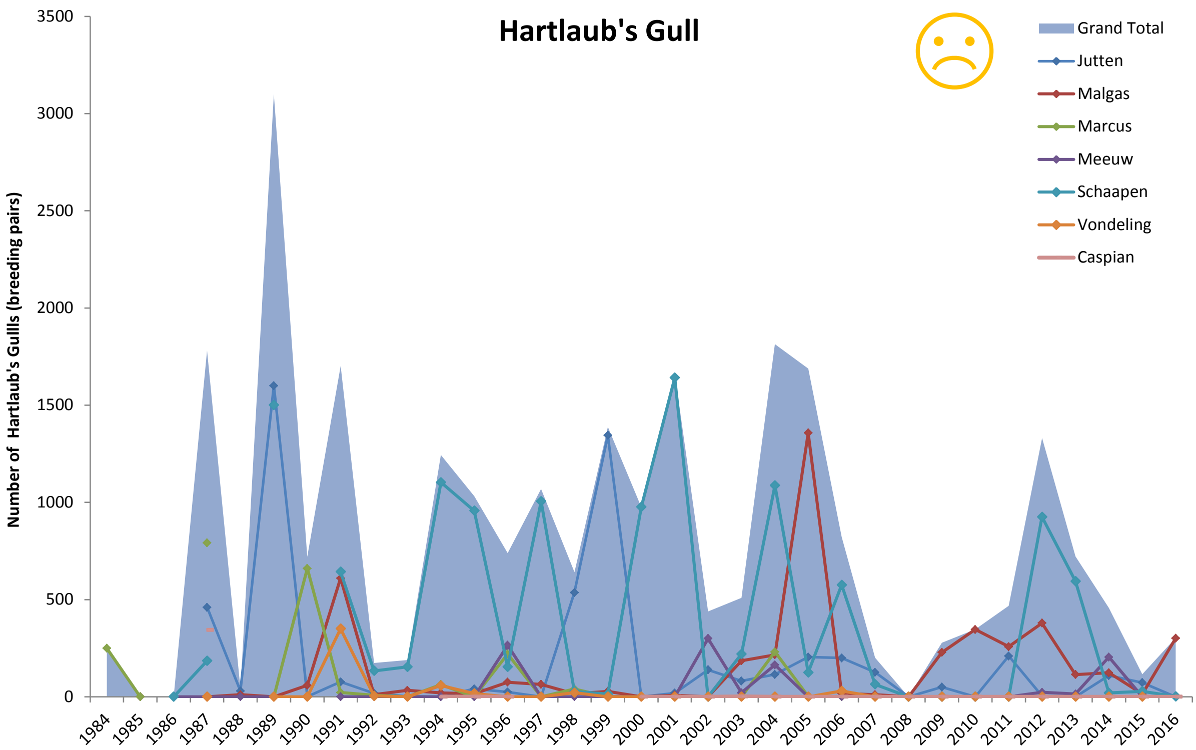


Figure 12.4. Trends in breeding population of Hartlaub's Gulls at Jutten, Malgas, Marcus, Meeuw, Schaapen, Vondeling and Caspian Islands in Saldanha Bay from 1984 – 2016 measured in number of breeding pairs (Data source: Department of Environmental Affairs: Oceans & Coasts).

The Swift Tern, *Thalasseus 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. The steady increase in Swift Tern numbers between 2002 and 2005 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, 2014).

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 three years following this, the longest absence on record. It is encouraging therefore that the birds retuned again in 2011-2016, with 75-1 755 breeding pairs recorded on Malgas, Jutten and Schaapen Islands over this period (Figure 12.5.).

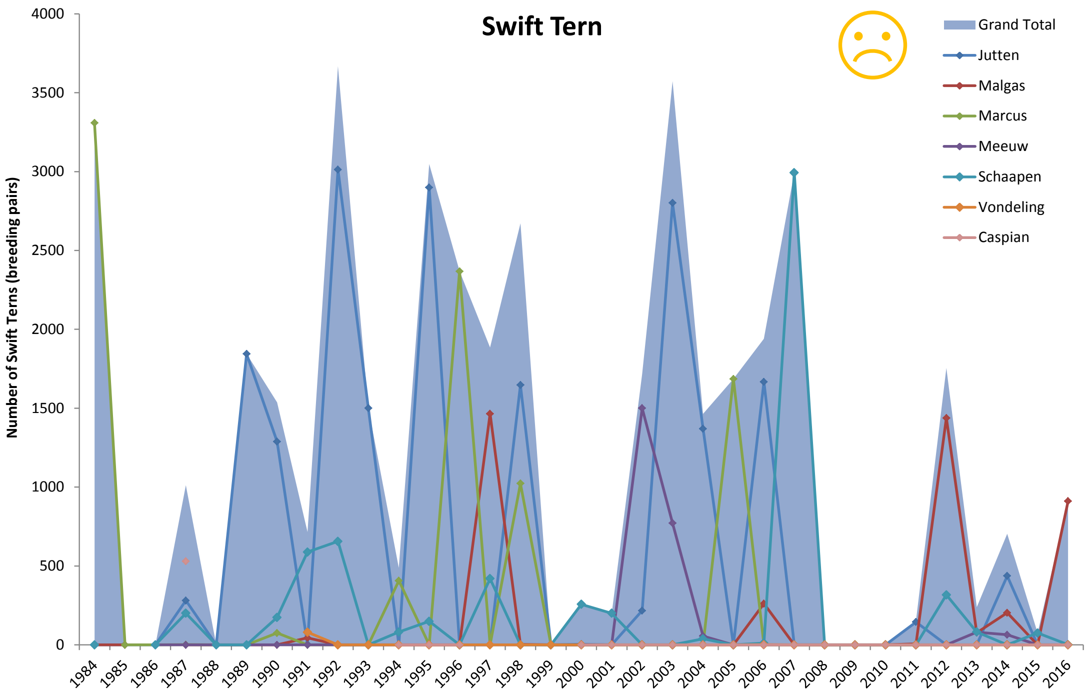


Figure 12.5. Trends in breeding population of Swift Terns at Jutten, Malgas, Marcus, Meeuw, Schaapen, Vondelig and Caspian Islands in Saldanha Bay from 1984 - 2016 measured in number of breeding pairs (Data source: Department of Environmental Affairs: Oceans & Coasts).

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 and fish stocks in Saldanha Bay should therefore not have a significant effect on the Cape Gannet population.

The bird colony at Malgas Island has shown substantial population fluctuation since the early 1990's and a steady decline since 1996 (Figure 12.6.). The 2012-2016 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 respond to the population dynamics of small pelagic fish (particularly sardines), with the number of breeding pairs averaging at 123 thousand pairs since 1995 (Crawford *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, they 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 hake fishery discards does not seem to compensate for the absence of natural prey and a study of foraging energetics suggested that Gannets tracked from Malgas Island were not maintaining their energy budget during feeding flights (Pichegru *et al.* 2007, Gremillet *et al.* 2016). Despite only a small documented overlap (13%) in Cape Gannet foraging zones from Malgas Island with the purse-seine fishery, the total fishery catch was estimated at 41% of the food requirements of the colony (Okes *et al.* 2009). Some of these studies have called for increased restrictions on purse-seine fishing in the vicinity of bird colonies, but these conclusions have been challenged by fishery scientists who point out that small pelagic fish biomass was actually increasing in the area at the time the Cape Gannet numbers started declining (Figure 12.2). Gannets with their extensive foraging range and diverse diets have proved adaptable to the changes in pelagic fish distribution and nationally numbers have not declined (Crawford 2014).

Possibly of greater significance for the Malgas Island Cape Gannet Colony and of more concern at a local level, are high rates of predation by Cape fur seals *Arctocephalus pusilus pusillus*, Kelp Gulls and until recently, the Great White Pelican *Pelecanus onocrotalus* (Makhado *et al.* 2006, Pichegru *et al.* 2007). Kelp Gull predation accounts for between one and two thousand gannet breeding failures per season in average years (Pelican Watch *pers. comm.* 2017). Furthermore, Cape Fur Seals prey on fledgling sea birds that land in the waters around their home islands for the first time (David *et al.* 2003, Makhado *et al.* 2009). Seal numbers nationally increased at an average of 3.5% per annum since 1971 until 1993 when aerial census of seal colonies was undertaken (David *et al.* 2003). In Saldanha waters, seal numbers have increased dramatically since 2000 when they started re-colonizing Vondeling Island. A census in 2014 recorded over 23 000 seal pups on the island and the consequent increase in competition for already depleted food resources has led groups of young male seals to augment their normal diet by hunting cormorant and gannet fledgling on their first forays from the islands (Pelican Watch *pers. comm*. 2017). Estimates of Cape Gannet mortality caused by Cape Fur Seals were 6 000 fledglings around Malgas Island in the 2000/01 breeding season, 11 000 in 2003/04 and 10 000 in 2005/06 (Makhado *et al.* 2006). This amounted to about 29%, 83% and 57% of the overall production of fledglings at the island in these breeding seasons respectively, despite an ongoing "problem" seal culling programme around Malgas Island that was initiated in 1993 (David *et al.* 2003, Makhado *et al.* 2009). These seal predation rates were considered unsustainable and largely responsible for the 25% decline in the Malgas Island Cape Gannett population between 2001 and 2006 (Makhado *et al.* 2006). Seal predation of seabirds is ongoing and it was estimated by the Department of Environmental Affairs seal culling team that in January 2016 "… all young gannets landing on the waters around Malgas were taken by seals…" (Pelican Watch *pers. comm.* 2017). These recent findings have changed the overall health of the Gannet population on Malgas Island from Fair to Poor based on the ongoing predation by fur seals. 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 suggesting that predation and other pressures such as food availability remain problematic.

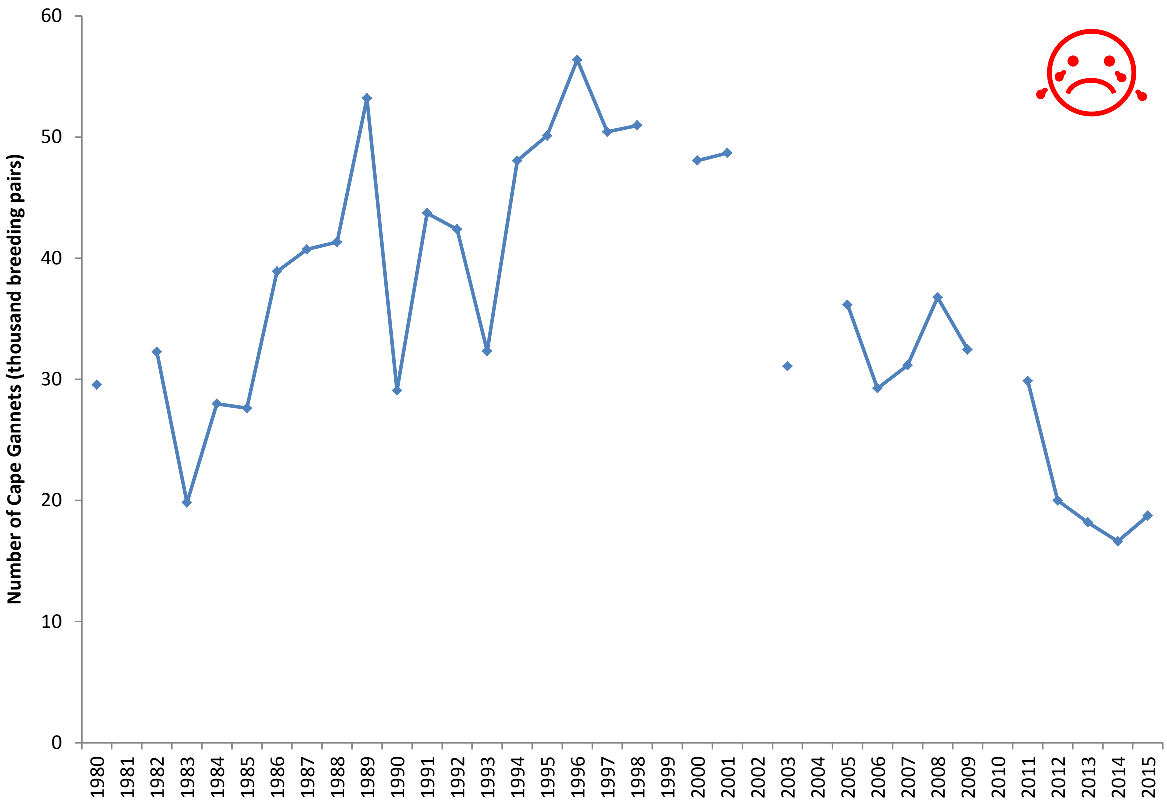


Figure 12.6. Trends in breeding population of Cape Gannets at Malgas Island, Saldanha Bay from 1980 – 2015 measured in number of breeding pairs (Data source: Department of Environmental Affairs: Oceans & Coasts).

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 east 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).

Key colonies of the Cape Cormorant in South Africa and Namibia have undergone very rapid population declines over the past three generations and the Cape Cormorant has therefore been uplisted to Endangered (BirdLife International 2015). Declines are primarily believed to have been driven by collapsing pelagic fish stocks (BirdLife International 2015). However, pelagic fish stocks increased greatly in the late 1990s and early 2000s, and although sardine biomass subsequently crashed, anchovy biomass remains high (Figure 12.2). This suggests that other factors are also involved in declining Cape Cormorant numbers. The species is susceptible to oiling and avian cholera outbreaks. This trend currently shows no sign of reversing, and immediate conservation action is required to prevent further declines (Crawford et al. 2013, 2015).

In South Africa, numbers decreased 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). A semi-systematic count by the Pelican Watch on Jutten in December 2015, suggests that about 3,000 young Cape Cormorants were taken by seals during the fledging period. There are large inter-annual fluctuations in breeding numbers due to breeding failure, nest desertion and mass mortality related to the availability 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 12.7.). Overall, the number of breeding pairs has declined gradually since the 1990s. In 2013, a total of only 801 breeding pairs were recorded, representing the lowest level recorded to date (Figure 12.7.). However, numbers of breeding pairs recovered over the period 2014-2016 with most pairs nesting on Jutten and Malgas Islands in 2016.

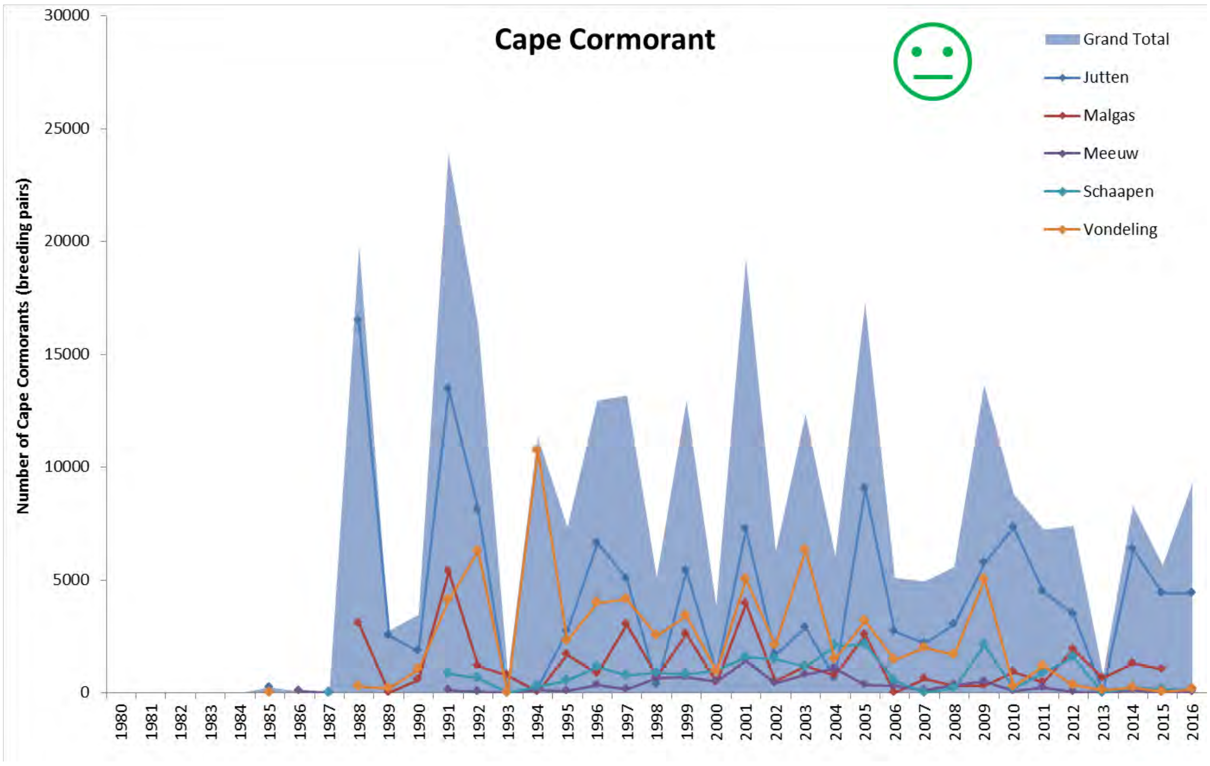


Figure 12.7. Trends in breeding population of Cape Cormorants at Jutten, Malgas, Meeuw Schaapen, and Vondeling islands in Saldanha Bay from 1980 – 2016 measured in number of breeding pairs (Data source: Oceans & Coasts, Department of Environmental Affairs).

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 species of 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 9 000 breeding pairs in 1975 to less than 5 000 pairs in 1991-1997, to 2 800 pairs in 2006 (Kemper *et al.* 2007). The South African population approximately halved from 1 500 pairs in 1978-1980 to 800 pairs in 2011-2013 (Crawford *et al.* 2015). 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 2015). 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 has declined steadily since 2003 on all the islands. Overall, the population in Saldanha Bay has declined drastically by approximately 93% since 1990 (Figure 12.8.). These 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.

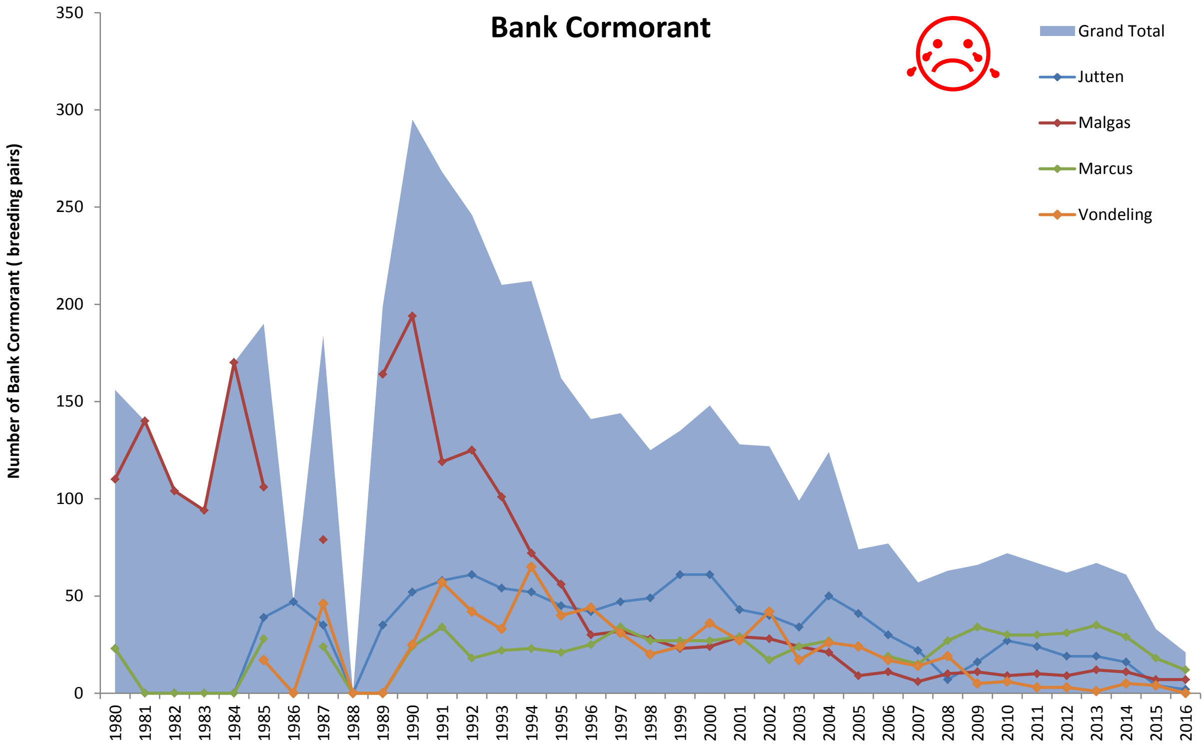


Figure 12.8. Trends in breeding population of Bank Cormorants at Jutten, Malgas, Marcus and Vondeling islands in Saldanha Bay from 1980 – 2016 measured in number of breeding pairs (Data source:, Oceans & Coasts, Department of Environmental Affairs).

The **White-breasted Cormorant** *Phalacrocorax lucidus 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 and fishing activities (Hockey *et al.* 2005).

Within Saldanha Bay, breeding effort has occasionally shifted between islands. White-breasted Cormorants 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 12.9.). Overall were more or less stable until 2013, but have declined steeply since then. Three of the last four annual counts have been the lowest on record.

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). White Breasted Cormorants also predate on fish caught in gill nets utilized in the harder fishery and risk becoming entangled in the gear and drowning. Effort in the harder fishery has increased in recent years and the average size of harders in the Saldanha- Langebaan fishery has decreased (See Chapter 11 for more information), potentially negatively affecting foraging opportunities for White Breasted Cormorants in the Bay. Due to Schaapen Islands' close proximity to the town of Langebaan, the high boating, kite-boarding and other recreational uses of the area may be an important source of disturbance 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.

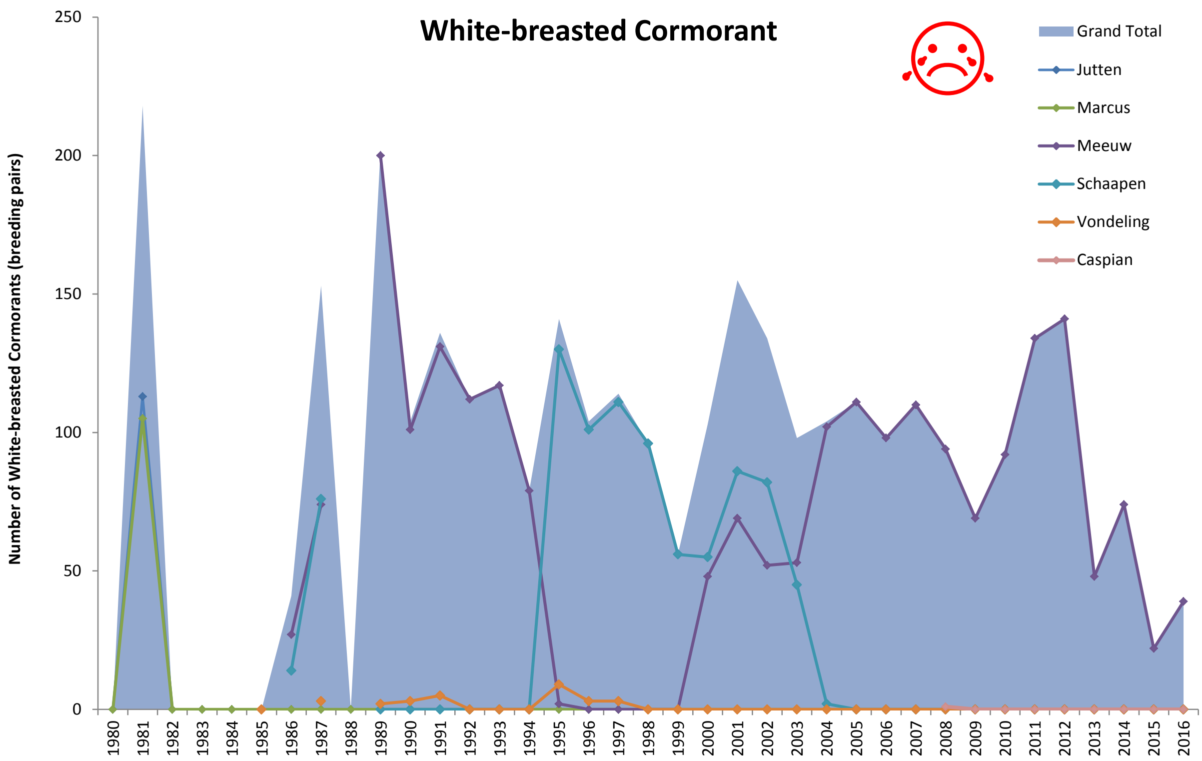


Figure 12.9. **Trends in breeding population of White-breasted Cormorants at Jutten, Marcus, Meeuw, Schaapen, Vondeling and Caspian islands in Saldanha Bay from 1980 – 2016 measured in number of breeding pairs (Data source: Department of Environmental Affairs: Oceans & Coasts).**

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 12.10.). Since then, numbers have shown considerable interannual variations with an overall slow but decreasing trend (Figure 12.10.).

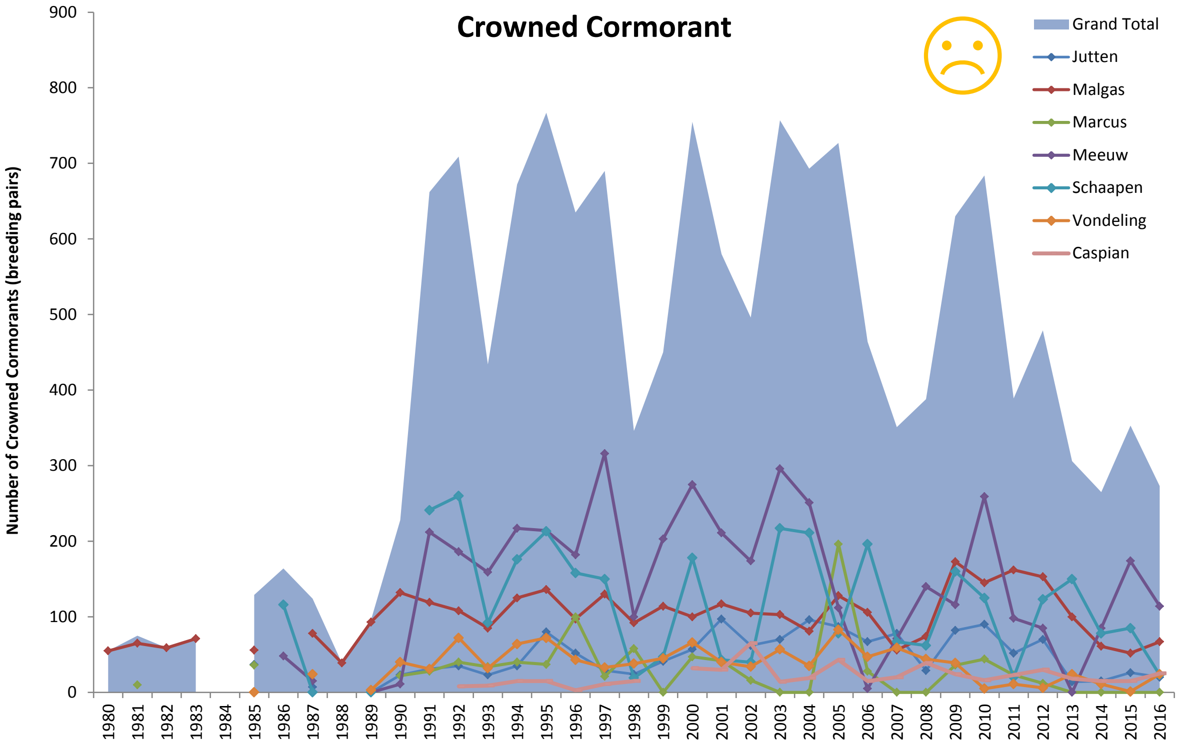


Figure 12.10. Trends in breeding population of Crowned Cormorants at the Jutten, Malgas, Marcus, Meeuw, Schaapen, Vondeling, and Caspian islands in Saldanha Bay from 1980 – 2016 measured in number of breeding pairs (Data source: Department of Environmental Affairs: Oceans & Coasts).

The **African Black Oystercatcher** *Haematopus moquini* is endemic to southern Africa. It is listed as Near Threatened in the IUCN Red Data List, owing to its small population and limited range (Birdlife International 2011). The African black oystercatcher breeds in rocky intertidal and sandy beach areas from Namibia to southern KwaZulu-Natal. Their global numbers increased dramatically from the 1980s, which was attributed primarily to the introduction and proliferation of the alien mussel *Mytilus galloprovincialis,* as well as due to the enhanced protection of the Oystercatcher throughout much of its range (Loewenthal 2007).

African Black Oystercatchers are resident on the islands, where highest numbers are encountered at Marcus, Malgas and Jutten Islands (Figure 12.11.). The islands in Saldanha Bay contribute a fair proportion to the global population that was estimated at 6 670 in 2007 (Loewenthal 2007). The population stabilised in the early 2000s and has been more or less constant since then (Figure 12.11.). This possibly reflects stabilization in the alien Mediterranean mussel biomass as the island rocky shore ecosystems settle into their new equilibrium. Oystercatchers could be affected by water quality in Saldanha Bay 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. Threats to the breeding success of these birds include human-induced habitat degradation, uncontrolled dogs predating on chicks and the drowning of chicks hiding from humans and their associated pets (Loewenthal 2007).

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 are now conducted by the DEA.

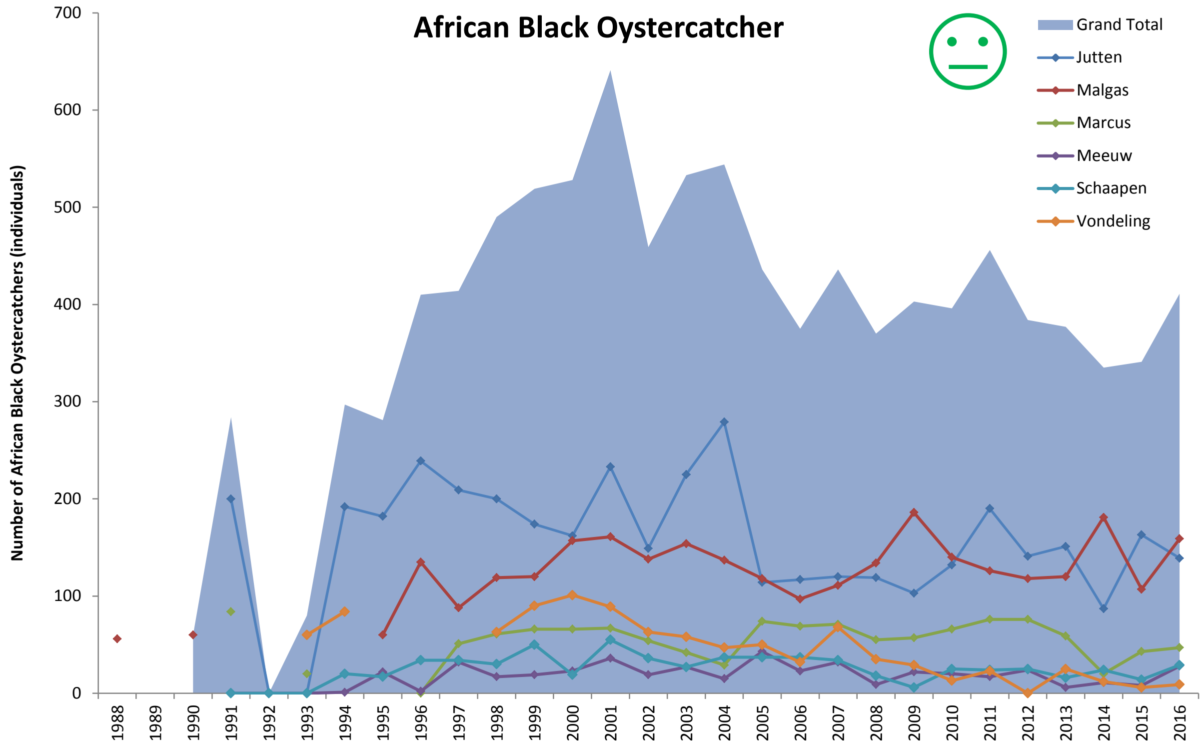


Figure 12.11. Trends in breeding population of African Black Oystercatchers on Jutten, Malgas, Marcus, Meeuw, Schaapen, and Vondeling Islands from 1988 - 2016. (Data source: Department of Environmental Affairs: Oceans & Coasts).

12.3 Birds of Langebaan Lagoon

12.3.1 National importance of Langebaan Lagoon for waterbirds

Langebaan Lagoon, with its warm, sheltered waters and abundance of prey, supports a high diversity and abundance of waterbirds, especially in summer when it is visited by thousands of migratory waders from the northern hemisphere. A number of commonly found migratory waders are globally recognised as Near Threatened and include Red Knot *Calidris canutus,* Curlew Sandpiper *Calidris ferruginea,* Bar-tailed Godwit *Limosa lapponica* and Eurasian Curlew *Numenius arquata*. Langebaan Lagoon represents a critical 'wintering' area for migratory waterbirds in South Africa (Underhill 1987) and is recognised as an internationally important site under the Ramsar Convention on Wetlands of International Importance, to which South Africa is a signatory.

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, 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). With regard to density and biomass of waders, Langebaan Lagoon compared favourably to other internationally important coastal wetlands in West Africa and Europe.

Waterbird numbers on Langebaan Lagoon have, however, declined dramatically since monitoring began in the 1970s. Decreases in both migratory and resident wader numbers are a common trend around the South African coast. Decreases in numbers of migrants can be attributed to loss of breeding habitat and hunting along their migration routes as well as human disturbance and habitat loss on their wintering grounds. The fact that numbers of resident waders may also be declining suggests that local human disturbance is also to blame at Langebaan Lagoon. In 1985, Langebaan Lagoon was declared a National Park (West Coast National Park), and recreational activities such as boating, angling and swimming have since been controlled within the Lagoon through zonation. Nevertheless, the dramatic increases in visitor numbers to the area over the last two decades and the more recent increases in sporting activities on the lagoon impact on some of the important feeding areas in the lagoon.

12.3.2 The main groups of birds and their use of habitats and food

The waterbirds of Langebaan Lagoon can be grouped into seven categories, namely (1) Cormorants, darters, and pelicans; (2) wading birds; (3) waterfowl; (4) waders (5) gulls and terns (6) kingfishers; and (7) birds of prey (Table 12.1). The relative contribution of the various bird groups to the bird numbers in the lagoon differs substantially in summer and winter, due to the prevalence of migratory birds in summer (Figure 12.12). Currently, waders account for about 51% of the birds on Langebaan Lagoon during summer, nearly all of these being migratory. In winter, the contribution by resident waders increase to 9%, and numbers of wading birds increase from 21% to represent 61% of total bird 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 in early April, but the immature birds of many of these species remain behind representing approximately 14% of the total waterbird numbers. 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 filter in from August, and numbers rising rapidly during September to November. In the 1970s, 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).

Table 12.1 Major waterbird groups found in Langebaan Lagoon, and their defining features.

Bird group	Defining features, typical/dominant species
Cormorants, darters & pelicans	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.
Wading birds	This group comprises the egrets, herons, ibises, flamingos and spoonbill. Loosely termed piscivores, their diet varies, with fish usually dominating, but often also includes other vertebrates, such as frogs, and invertebrates. The ibises were included in this group, though their diet mainly comprises invertebrates and is fairly plastic. They tend to be tolerant of a wide range of salinities. Wading piscivores prefer shallow water up to a certain species dependant wading depth.
Waterfowl	This group includes waterfowl in the orders Podicipediformes (Grebes), Anseriformes (Ducks, geese) and Gruiformes (Rails, crakes, gallinules, and coots). 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. Piscivorous waterfowl comprises the Grebes. Herbivorous waterfowl are dominated by species that tend to occur in lower salinity or freshwater habitats, such as the Southern Pochard and the rallids, and are therefore not common in the lagoon. The omnivorous waterfowl comprises ducks which eat a mixture of plant material and invertebrate food such as small crustaceans. Species include the Yellow-billed Duck, Cape Teal, Red-billed Teal and Cape Shoveller. Although varying in tolerance, these species are fairly tolerant of more saline conditions.
Waders	This group includes all the waders in the order Charadriiformes (e.g. Greenshank, Curlew Sandpiper). 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. 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 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	This group comprises the rest of the Charadriiformes, and includes all the gull and tern species occurring in the lagoon. These species are primarily piscivorous, but also feed on invertebrates. 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.
Kingfisher	Kingfishers prefer areas of open water with overhanging vegetation. They are largely piscivorous but also take other small prey. Common species to the lagoon include the Pied Kingfisher.
Birds of prey	This group are not confined to a diet of fish, but also take other vertebrates and invertebrates. Species in this group include African Fish Eagle, Osprey and African Marsh Harrier.

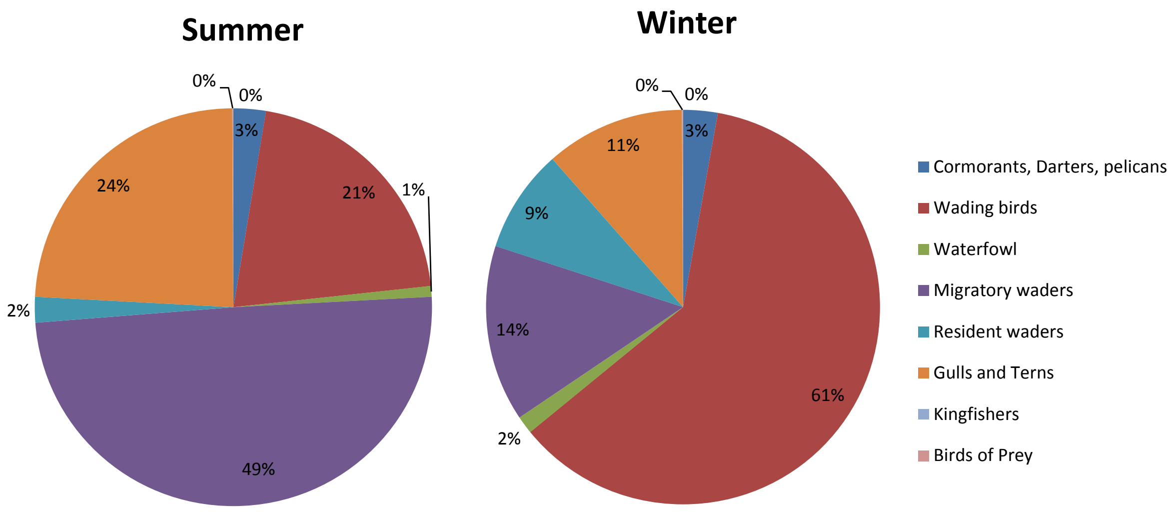


Figure 12.12 Present average numerical composition of the waterbirds on Langebaan Lagoon during summer (left) and winter (right) and winter (2012-2017) (Data source: CWAC data, Animal Demography Unit at the University of Cape Town).

Approximately 56 non-passerine waterbird species are regularly recorded at Langebaan Lagoon. About two thirds of these waterbird species are waders, of which 20 species are regular migrants from the Palaearctic region of Eurasia. 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 waterbirds of Langebaan Lagoon are comprised of ten different taxonomic orders (Table 12.2.). A total of 115 bird species (i.e. including rare vagrants, terrestrial bird species, and passerines) have been recorded at Langebaan Lagoon as part of the CWAC surveys, of which 62 are South African resident waterbird species and 25 are migrant waterbird species. The most species-rich order, the Charadriiformes, include a total of 31 wader species, three gull species and seven tern species (Table 12.2.). There are 14 resident wading bird species which include flamingos, herons, egrets, ibises and spoonbills. Other birds that commonly occur on the lagoon include passerine species such as the Cape Wagtail *Motacilla capensis* and the Brown-throated Martin *Riparia paludicola*, as well as the Hadeda Ibis *Bostrychia hagedashn* (order Ciconiiformes). These species have been excluded from the waterbird categories due to their widespread distribution in non-coastal habitats. For a full species list and the average and maximum counts of non-passerine waterbirds for the period 1976-2017 see Table 16.4 in the Appendix (Chapter 16).

Table 12.2. Taxonomic composition of non-passerine waterbirds in Langebaan Lagoon (excluding rare vagrants) (Data source: CWAC data, Animal Demography Unit at the University of Cape Town).

Common groupings	Order	No. of SA resident species	No. of migrant species
Cormorants, darters, pelicans	Pelecaniformes (Cormorants, darters, pelicans)	7	
Wading birds	Ciconiiformes (Herons, egrets, ibises, spoonbill, etc.)	14	
	Phoenicopteriformes (Flamingos)	2	
Waterfowl	Podicipediformes (Grebes)	3	
	Anseriformes (Ducks, geese)	8	
	Gruiformes (Rails, crakes, gallinules, coots)	5	
Waders	Charadriiformes	11	20
Gulls	Charadriiformes	3	
Terns	Charadriiformes	3	4
Kingfishers	Alcediniformes	3	
Birds of prey	Falconiformes	2	1
	Strigiformes	1	
Total		62	25

12.3.3 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). 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 Animal Demography Unity (ADU) at the University of Cape Town. These data sets provide the opportunity to examine the long term trends in waterbird numbers at Langebaan Lagoon up to the present day.

Waterbird numbers on Langebaan Lagoon have declined dramatically since monitoring began in the 1970s. This is largely due to changes in the numbers of waders, which used to account for more than 90% of bird numbers (Figure 12.13). In the 1970s and 1980s, migratory waders commonly numbered over 35 000 during summer, and over 10 000 in winter. Summer numbers have since decreased significantly to fewer than 4 000 (Figure 12.14) and today, waders make up only 30-50% of summer bird numbers (Figure 12.13).

Migratory wader numbers crashed in summer 2009 and reached an all-time minimum in 2011 with just over 2 300 birds and have not recovered since then. The estimated population of 3 721 birds in summer 2017 is approximately 89% down from the pre-1990 average of ~33 000 birds. Drastic population declines in four species, including the Ruddy Turnstone, Red Knot, Grey Plover, and Curlew Sandpiper (Figure 12.15) signified this downward trend in summer migratory bird numbers. Most importantly, Curlew Sandpiper numbers have dropped from a pre-1990 average of just over 20 000 birds to 1 829 birds in 2017. Prior to 1990, this species accounted for almost two thirds of the total summer migratory wader numbers in the lagoon.

Resident wader numbers have fluctuated widely over time, reaching a near maximum only recently in 2013 with 1273 birds (Figure 12.14). This notwithstanding, resident bird numbers appear to be on a negative trajectory since 2007 and it remains to be seen whether bird numbers will recover.

The reasons for these declines, particularly in migratory wader numbers, 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 seems to 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). Conditions at Langebaan Lagoon could also have contributed to the decline in waders numbers over the last two decades. 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 8), and human disturbance, which has been shown to have a dramatic impact on bird numbers in other estuaries (Turpie & Love 2000). In 1985, Langebaan Lagoon was declared a National Park (West Coast National Park), and recreational activities such as boating, angling and swimming have since been controlled within the Lagoon through zonation. Nevertheless, some important feeding areas lie within the zones that are highly utilised for recreation.

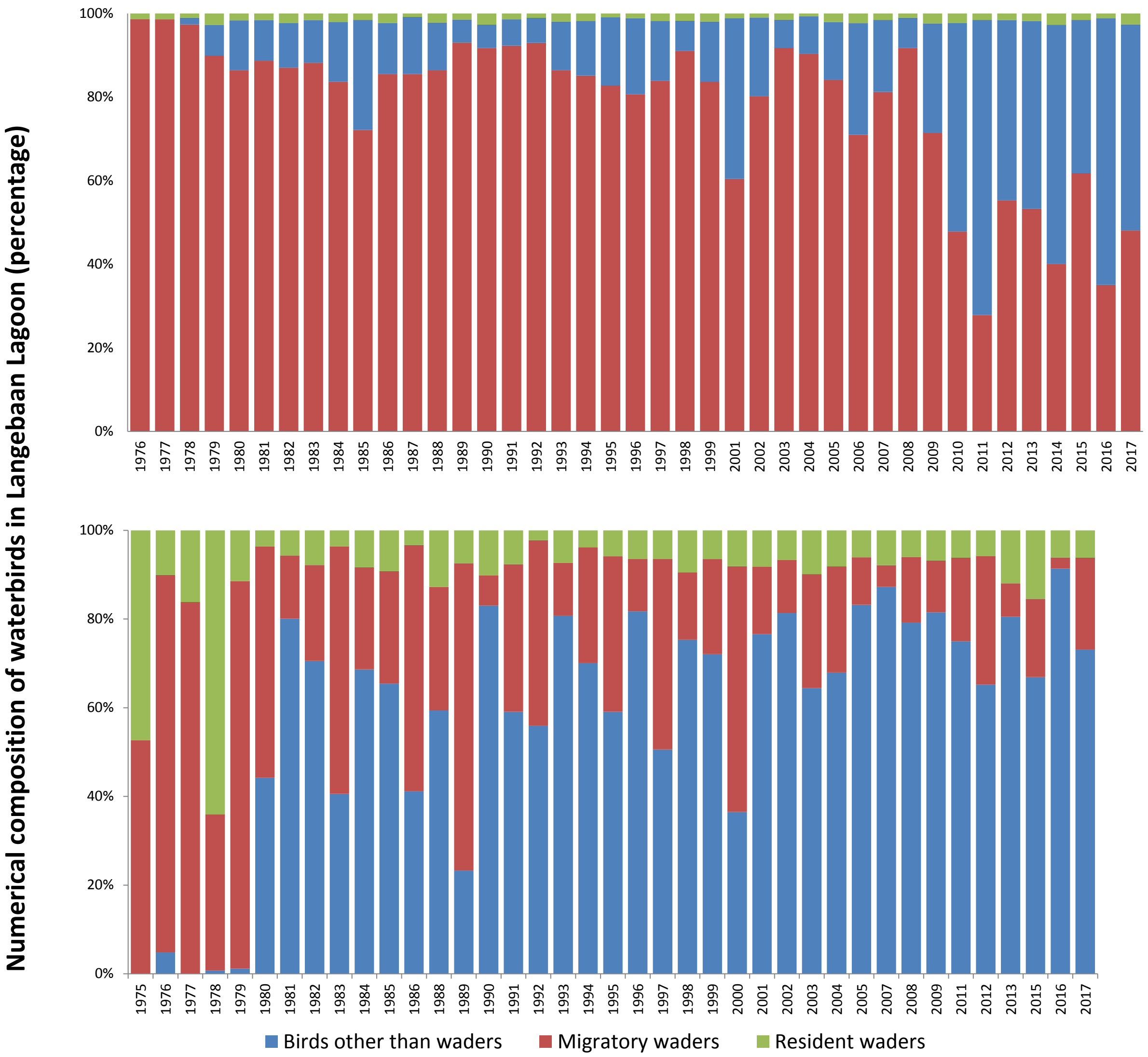


Figure 12.13. Long-term trend in the numerical composition of waterbirds in the Langebaan Lagoon during summer (top) and winter (bottom) (1976-2017). Note that no data was collected in the summer of 1975 and 2000, as well as in the winter of 1987, 2006, 2010, and 2014 (Data source: Coordinated Waterbird Count data, Animal Demography Unit at the University of Cape Town 2017).

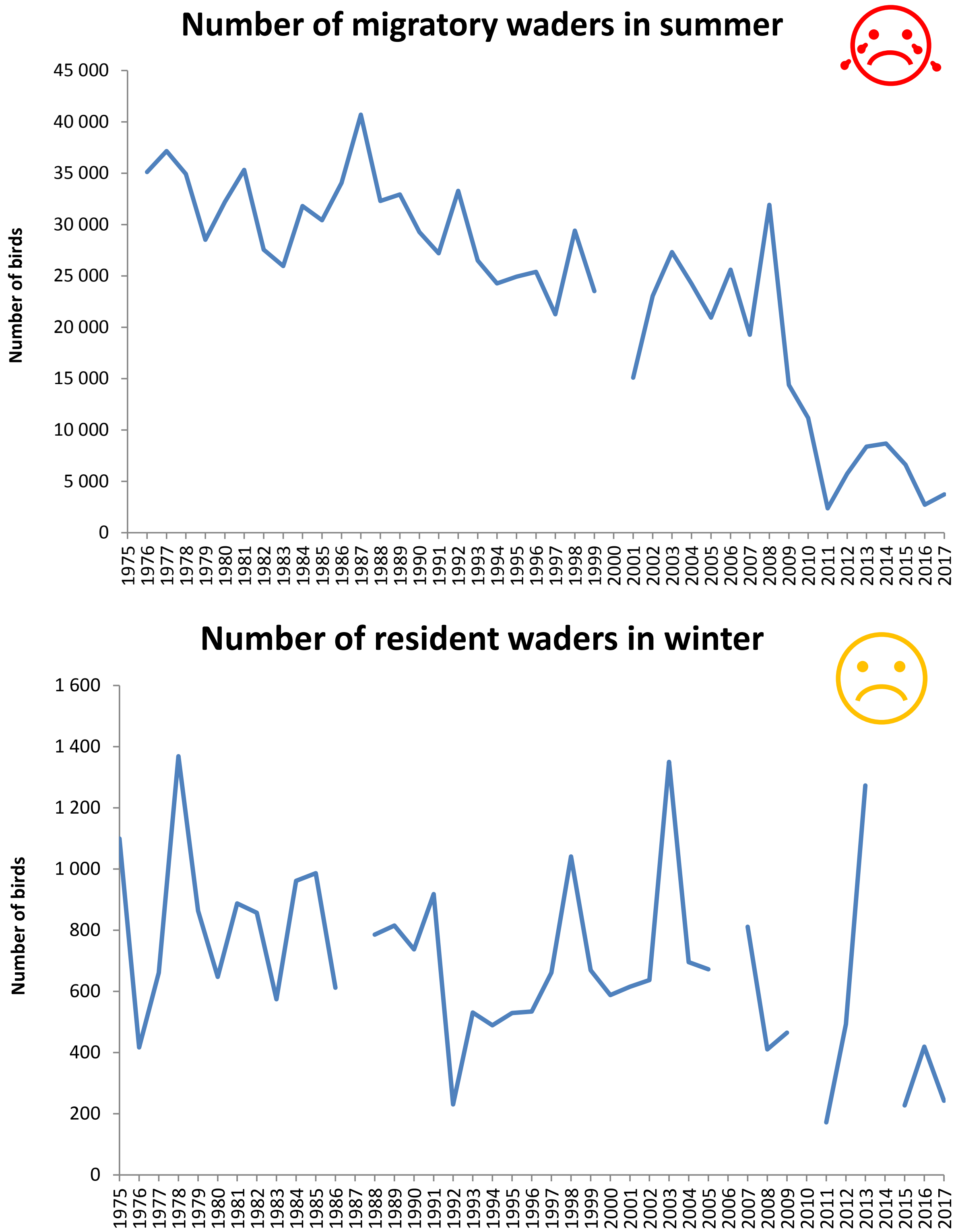


Figure 12.14. Long term trends in the numbers of summer migratory (top) and winter resident (bottom) waders on Langebaan Lagoon for the years 1976-2017 (Data source: Coordinated Waterbird Count data, Animal Demography Unit at the University of Cape Town).

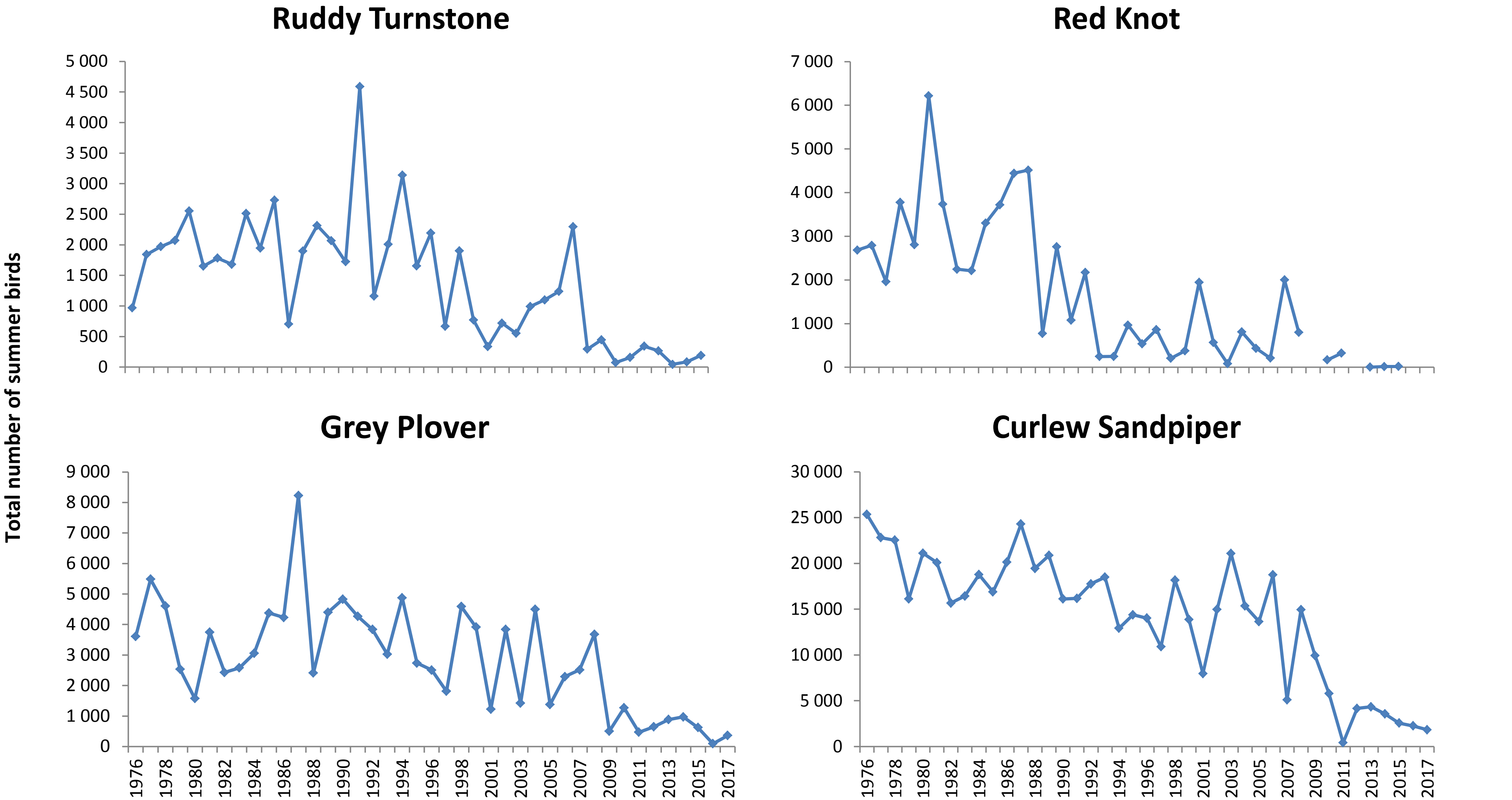


Figure 12.15 **Long term trends in the numbers of four summer migratory waders (Ruddy Turnstone, Red Knot, Grey Plover and Curlew Sandpiper) on Langebaan Lagoon for the years 1976-2017. (Data source: Coordinated Waterbird Count data, Animal Demography Unit at the University of Cape Town).**

12.4 Overall status of birds in Saldanha Bay and Langebaan Lagoon

With the exception of the cormorants, the populations of the other seabirds that breed on the islands of Saldanha Bay were on an increasing trajectory from the start of monitoring in the 1980s and 90s until around 2000. Factors that probably contributed to this include the reduction and eventual cessation of guano collecting in 1991, banning of egg collecting, increases in the biomass of small pelagic fish particularly sardines over this period, and in the case of the African Black Oystercatcher the increase in mussel biomass as a result of the arrival and spread of the Mediterranean mussel.

On the islands of Saldanha Bay, populations of all of these species then started to decline, particularly, the penguins, gannets and gulls, which have declined to 12%, 39% and 22%, respectively of their populations at the turn of the century. Declines in the numbers of seabirds breeding on the Saldanha Bay Islands can be attributed to a number of causes. These include (1) emigration of birds to colonies further south and east along the South African coast in response to changes in the distribution and biomass of small pelagic fish stocks, (2) starvation as a result of a decline in the biomass of sardines nationally, and particularly along the west coast over the last decade, (3) competition for food with the small pelagic fisheries within the foraging range of affected bird species, (4) predation of eggs, young and fledglings by Great White Pelicans, Kelp Gulls and Cape Fur Seals, and (5) collapse of the West Coast Rock Lobster stock upon which Crowned Cormorants feed.

However, because populations are so depressed, conditions at the islands in Saldanha, particularly predation by Cape Fur Seals and Kelp Gulls, have now become the major factors in driving current population decreases for many seabird species. Direct amelioration actions (*Pelican Watch*, problem seal culling) to decrease these impacts at the islands have had mixed results, with the former proving more effective than the latter. Cape Fur Seal and Kelp Gull predation continue to pose a major threat to seabird survival at the Saldanha Bay Island colonies.

Decreasing numbers of migrant waders utilising Langebaan Lagoon reflects a global trend, which can be attributed to loss of breeding habitat and hunting along their migration routes as well as human disturbance and habitat loss on their wintering grounds. In Langebaan Lagoon, drastic population declines in four species, including the Ruddy Turnstone, Red Knot, Grey Plover, and Curlew Sandpiper have signified this downward trend in summer migratory bird numbers. Most importantly, Curlew Sandpiper numbers have dropped from a pre-1990 average of just over 20 000 birds to 1 829 birds in 2017. Prior to 1990, this species accounted for almost two thirds of the total summer migratory wader numbers in the lagoon. The fact that numbers of resident waders may also be declining suggests that unfavourable conditions persisting in Langebaan Lagoon as a result of anthropogenic impacts may be partly to blame. Although wader numbers have not dropped below the lowest numbers as observed in 2011, it remains to be seen if winter resident wader populations remain stable, and if perhaps migratory waders are also stabilising at current levels. 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.

13 ALIEN AND INVASIVE SPECIES IN SALDANHA BAY-AND LANGEBAAN LAGOON

Human induced biological invasions have become a major cause for concern worldwide. The life history characteristics of the alien species, the ecological resilience of the affected area, the presence of suitable predators and many other factors determine whether an alien species becomes a successful invader. Biological invasions can negatively impact biodiversity and can result in local or even global extinctions of indigenous species. Furthermore, alien species invasions can have tangible and quantifiable socio-economic impacts. Until recently, alien species were therefore recognised as invasive if they were found to have an environmental impact. However, much debate has occurred around the definition of environmental impacts in relation to an alien species (impact intensity, frequency, significance, positive versus negative etc.) and consequently only few studies have attempted to determine whether an alien species can in fact be considered invasive (Robinson *et al.* 2016). The revised, internationally accepted approach recognises an alien species as invasive if the species has expanded its range beyond the point of introduction (Wilson et al. 2009; Blackburn *et al.* 2011; Richardson *et al.* 2011). This approach has been proposed for South African marine invasion biology research going forward (Robinson *et al.* 2016).

By applying the above mentioned framework, marine invasion biology research published in 2016 (based on data collated up until 2014), reported 36 alien and 53 invasive marine and estuarine species occurring in South African waters (Robinson *et al.* 2016). The species list published five years ago by Mead *et al.* (2011) had identified 85 introduced species, without determining their status (i.e. alien versus invasive) (refer to previous editions of this report). Four species were removed from the 2011 alien species list. The polychaete *Hydroides elegans,* for example, was reassigned as cryptogenic (Çinar 2013), while the oyster *Ostrea edulis* and the urchin *Tetrapygus niger* were removed from the list as these populations no longer exist in mariculture dams previously surveyed (Mabin *et al.* 2015). Finally, the dune plant *Ammophila arenaria* was also removed as it is covered by the terrestrial alien plant list. Six species were added to the list, including the barnacle *Austrominius modestus* (Sandison 1950), the amphipod *Ericthonius difformis* (Peters *et al.* 2014), the crab *Pinnixa occidentalis* (Clark and Griffiths 2012), the polychaete *Polydora* cf. *websteri* (Simon 2015), and the red algae *Asparagopsis armata* and *A. taxiformis* (Bolton et al. 2011). Three name changes were also noted. First, the polychaete *Neanthes succinea,* which has been assigned to the genus *Alitta* (Read and Glasby 2017), and second, the hydrozoan *Moerisia maeotica,* which has been assigned to the genus *Odessia* (Schuchert 2017). Finally, the widespread tunicate *Ciona intestinalis* was found to represent two morphologically separate species, namely *C. intestinalis* and *C. robusta.* Of these two species, *C. robusta* is in fact the species that occurs in South Africa (Brunetti *et al.* 2015; Robinson *et al.* 2016).

At least 28 alien and 42 invasive species occur along the West Coast of South Africa. Twenty five of these species have been confirmed from Saldanha Bay and/or Langebaan Lagoon, of which all but one are considered invasive (Table 16.5.). For example, the invasive 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), are commonly found in the study area.

Interestingly, the abundance of *B. glandula* and *M. galloprovincialis* on rocky shores in Saldanha Bay has been decreasing in the last few years (Sections 13.1 and 13.2). This trend may reflect a new ecosystem equilibrium as predator numbers have probably responded to the new food source and now exert more control over the abundance of this invasive species.

Additionally, since 2014, the presence of the barnacle *Perforatus perforates* (Biccard and Griffiths *pers. comm*. 2017), the Japanese skeleton shrimp *Caprella mutica* (Peters and Robinson 2017), and the European porcelain crab *Porcellana platycheles* (Prof. George Branch *pers. obs.*) – have been confirmed in Saldanha Bay and Langebaan Lagoon. It still remains uncertain though, whether these can be considered alien or invasive and more research will be required to ascertain their status (Table 16.5.). One of these species, the European porcelain crab *Porcellana platycheles* found in 2012 on Schaapen Island (Prof. George Branch *pers. obs.*), has now been confirmed to occur in the study area (See Section **Error! Reference source not found.**).

An additional 41[10] 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 (Table 16.5.). Comprehensive genetic analyses are urgently required to determine the definite status of these cryptogenic species (Griffiths *et al.* 2008).

Most of the introduced marine 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. Both land- and sea-based mariculture have also been identified as important vectors for the introduction of alien marine species.

[10] Note: Mead *et al.* 2011a identified 39 species as cryptogenic. Robinson *et al.* 2016 re-classified the polychaete *Hydroides elegans* as a cryptogenic (previously considered introduced). It is unknown why Mead et al. 2011 excluded the cryptogenic barnacle *Amphibalanus amphitrite amphitrite* in the species list despite the fact that it occurs in South African marine waters. This brings the total number of cryptogenic species to 41 to date.

Future surveys in Saldanha Bay will be used to confirm the presence of listed species and 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 in the Appendix (Table 16.5.). 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).

13.1 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).

13.2 Acorn barnacle *Balanus glandula*

The presence of *B. glandula*, which originates from the Pacific coast of North America, was first recognized in 2008 (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 13.1). *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 2010 but it is very likely, however, that it had been present during the baseline surveys in 2005 and 2008-2009 but was identified as the indigenous barnacle species.

Figure 13.1 Acorn barnacle *Balanus glandula* (Photo: Prof. C.L. Griffiths)

Data from the State of the Bay surveys since 2010 suggest that *B. glandular* occurs mostly on the mid shore and was most successful on the semi-exposed rocky shores sites in Saldanha Bay, with highest abundance found at the iron ore terminal and Lynch Point (note that *B. glandular* has not been found at the semi-exposed Schaapen West site since 2010) (Figure 13.2). *B. glandular* was very abundant when it was first detected in 2010, reaching a maximum of 74% at the iron ore terminal in 2011. Since then, abundance has decreased by two thirds at the iron ore terminal and this species was no longer detected at Lynch Pont in the 2017 survey. It remains to be seen whether this species has disappeared from this site. This trend may reflect a new ecosystem equilibrium as predator numbers have probably responded to the new food source and now exert some control on the abundance of the invasive species. The State of the Bay surveys and studies conducted elsewhere suggest that this species competes directly with other alien species for space on the shore. Nevertheless, it remains one of the more abundant species on the shore in Saldanha Bay and is still of significant concern.

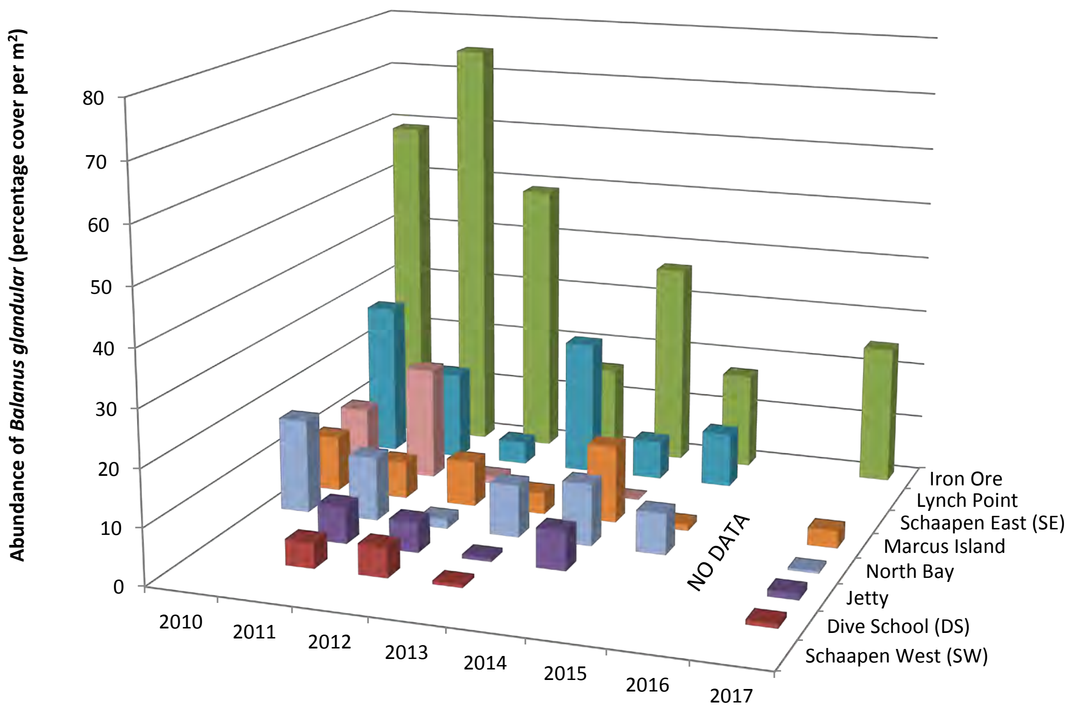


Figure 13.2. Changes in the abundance (% cover) of the acorn barnacle *Balanus glandula* at eight rocky intertidal sites on the high shore in Saldanha Bay over the period 2010-2017. Data are shown as an average of percentage cover on the mid and low shore. No samples were collected in 2006, 2007 and 2016. Information of the locations of these sampling stations is provided in Chapter 8.

13.3 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 invaded temperate harbour. It is small and occurs in high densities and is probably a valuable food source for fish and other predators.

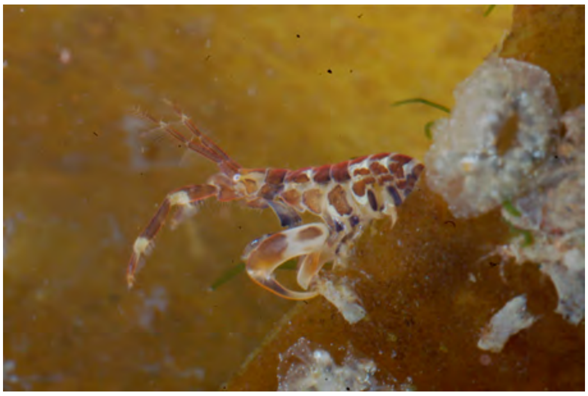


Figure 13.3 Hitchhiker amphipod *Jassa slatteri* (Photo: Prof. C.L. Griffiths)

13.4 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 13.4). 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 13.4 European shore crab *Carcinus maenas.* (Photo: Prof. C.L. Griffiths).

13.5 Western pea crab *Pinnixa occidentalis*

The Western Pea crab *Pinnixa occidentalis* (Figure 13.5) was originally described from California by MJ 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 three sites in Big Bay and at one site in Small Bay (detection rate of 30% and 6% respectively). Since then, the detection rate in Big Bay has increased over time to nearly 70% in 2017 and has remained more or less stable at around 30% since 2009 in Small Bay (Figure 13.6). Despite the increase in detection rate in Big Bay, abundance and biomass at both sites fluctuate over time, showing no apparent upward or downward trend (i.e. no significant difference between the years, which is demonstrated by the overlapping standard error) (Figure 13.7). Overall, *P. occidentalis* is most prevalent in Big Bay. No recruitment trends of this species can be picked up from the abundance and biomass trends over time (Figure 13.7).

P. occidentalis put in a brief appearance at one site in Langebaan Lagoon in 2009 and again in 2014 (at two sites), but abundance at these sites was very low with only four individuals per square metre (Figure 13.6.

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). Danger Bay was only sampled in 2014 and 2015. It is noticeable that the species was absent in the first survey, but was found in 2015 at one out of 13 sites sampled, at a density of eight animals per square metre.

In conclusion, these data suggest that *P. occidentalis* is now well established in Big Bay and Small Bay and may be in the process of expanding into more exposed and deeper habitats outside of the Bay, including Danger Bay.

Figure 13.5 Western pea-crab *Pinnixa occidentalis* (Photograph: Anchor Environmental Consultants).

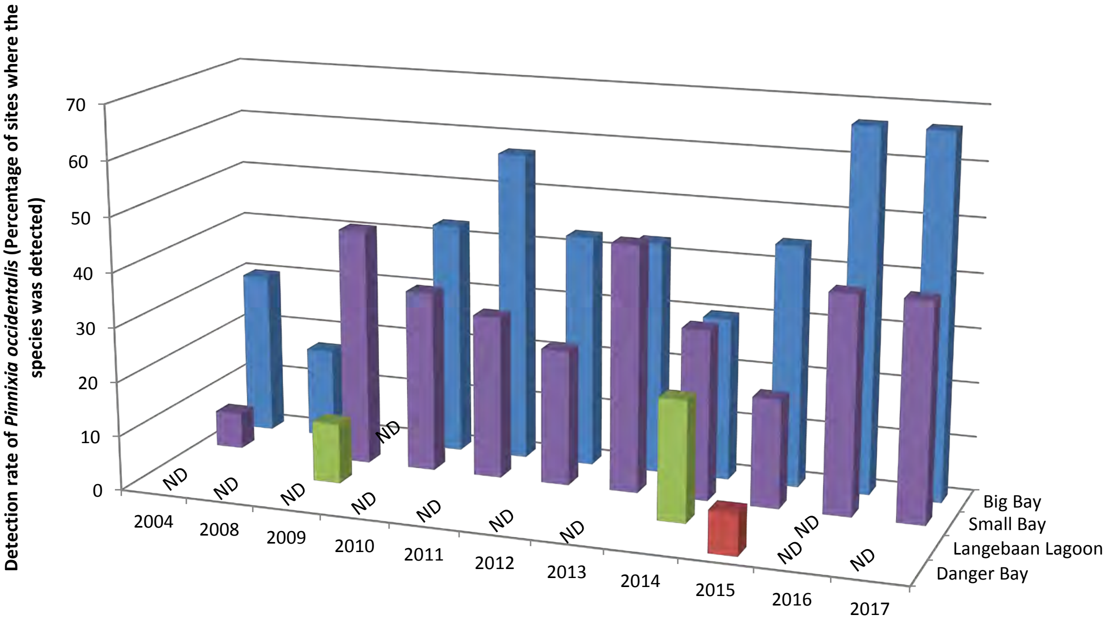


Figure 13.6 **The detection rate (percentage of sites where the species was detected) of the Western Pea crab *Pinnixia occidentalis* in Saldanha Bay, Langebaan Lagoon and Danger Bay in the period 1999-2017. Note that Langebaan Lagoon and Danger Bay were first sampled in 2004 and 2014 respectively. No data were collected in the period 2005-2007. 'ND' denotes that no data collected in the region for that year.**

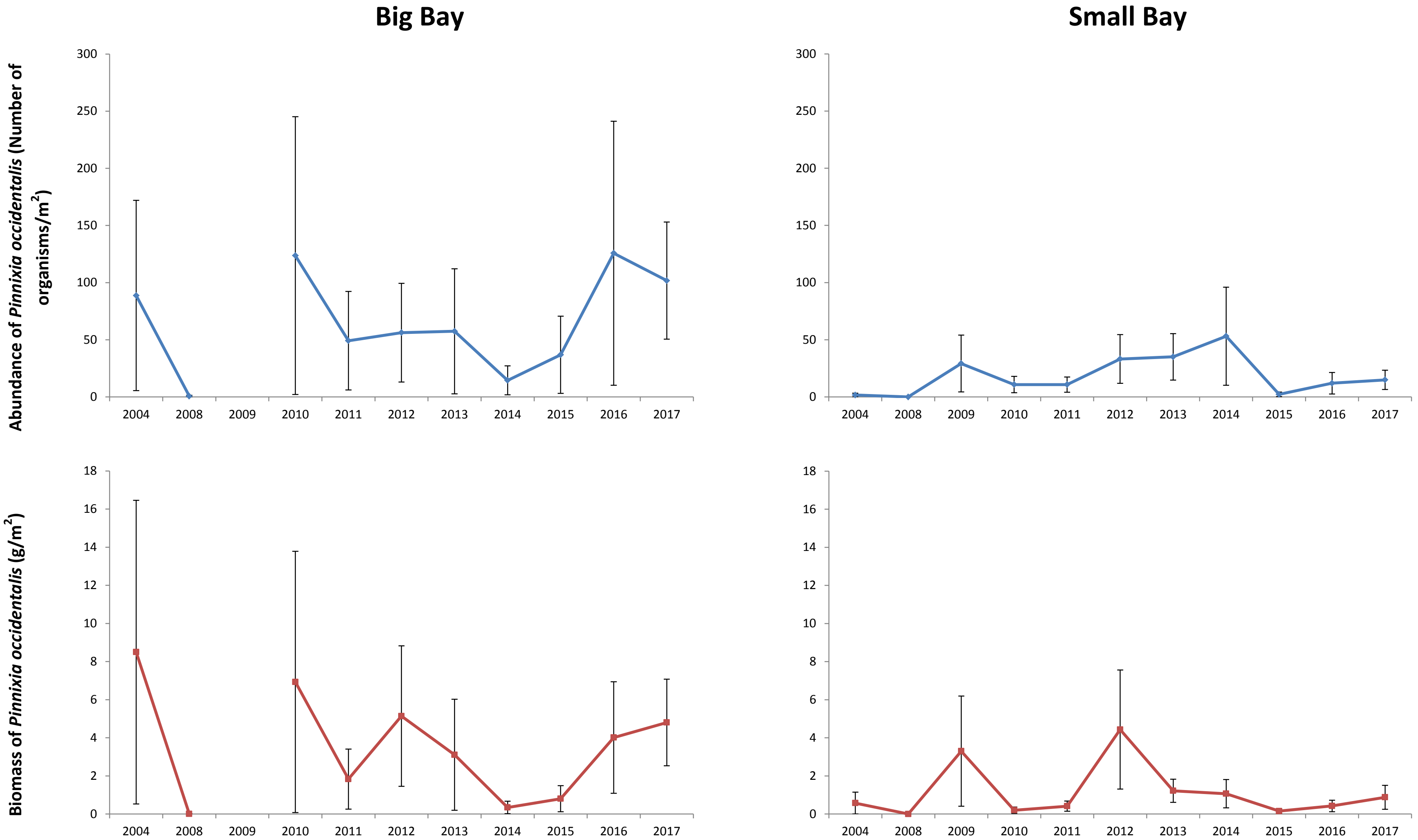


Figure 13.7 Average abundance (top) and biomass (bottom) of the Western Pea crab *Pinnixia occidentalis* in Saldanha Bay, Big Bay (left) and Small Bay (right) from 1999-2017. No data were collected in the period 2005-2007.

13.6 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.

Figure 13.8 Lagoon snail *Littorina saxatilis* (Photo: Prof. C.L. Griffiths)

13.7 Pacific oyster Crassostrea gigas

Crassostrea gigas is considered native to Japan and South East Asia. *C. gigas* was introduced to the Knysna Estuary in South Africa in the 1950s with the intention to farm. The species has been farmed in the Kowie and Swartkops estuaries as well as at three marine locations, Algoa Bay, Saldanha Bay and Alexander Bay (Robinson et al. 2005).

Initially, the species was never considered an invasive threat as the oysters seemed unable to reproduce and settle successfully under the local environmental conditions which differ from its native habitat. However, the farmed populations have spread within the country. Through the use of DNA sequencing, Robinson *et al.* (2005b) confirmed the presence of three naturalised populations of *C. gigas* in South Africa (specifically the Breede, Knysna and Goukou estuaries) (Figure 3). The highest densities of individuals were found in the Breede Estuary (approximately 184 000 individuals). *C. gigas* were originally farmed in the Seafarm dam east of the iron ore terminal and are now farmed in baskets moored in the Bay. Feral populations of this oyster have established inside the dam, which is open to Big Bay. However, self-sustaining populations outside of the dam have not been noted to date.

13.8 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 its distribution range as far as East London (Robinson *et al.* 2005). It is suspected that *M. galloprovincialis* 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 13.9). 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).

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 centre 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 eight 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.

Figure 13.9 European mussel *Mytilus galloprovincialis.* (Photo: Prof. C.L. Griffiths.)

Data from the State of the Bay surveys suggest that *M. galoprovincialis* occurs mainly on exposed rocky shores in Saldanha Bay (i.e. Lynch Point, Marcus Island, iron ore terminal, North Bay) and is present in low numbers at the more sheltered sites (Dive School, Jetty and Schaapen Island East and West). At exposed sites, *M galloprovincialis* is by far the most dominant faunal species on the rocky shore, and can cover up to 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.

Since the start of the surveys *M. galloprovincialis* increased steeply in abundance at the exposed sites, reaching maximum abundance at Marcus Island in 2009 (37%), at Lynch Point (58%) and North Bay (23%) in 2012, and at the iron ore terminal in 2015 (40%). Since then, *M. galloprovincialis* abundance has decreased to levels lower than were observed in 2005. The iron ore terminal site represents an exception, where abundance peaked only two years ago and is expected to drop lower in future surveys. This trend may reflect a new ecosystem equilibrium as predator numbers have probably responded to the new food source and now exert more control on the abundance of this invasive species.

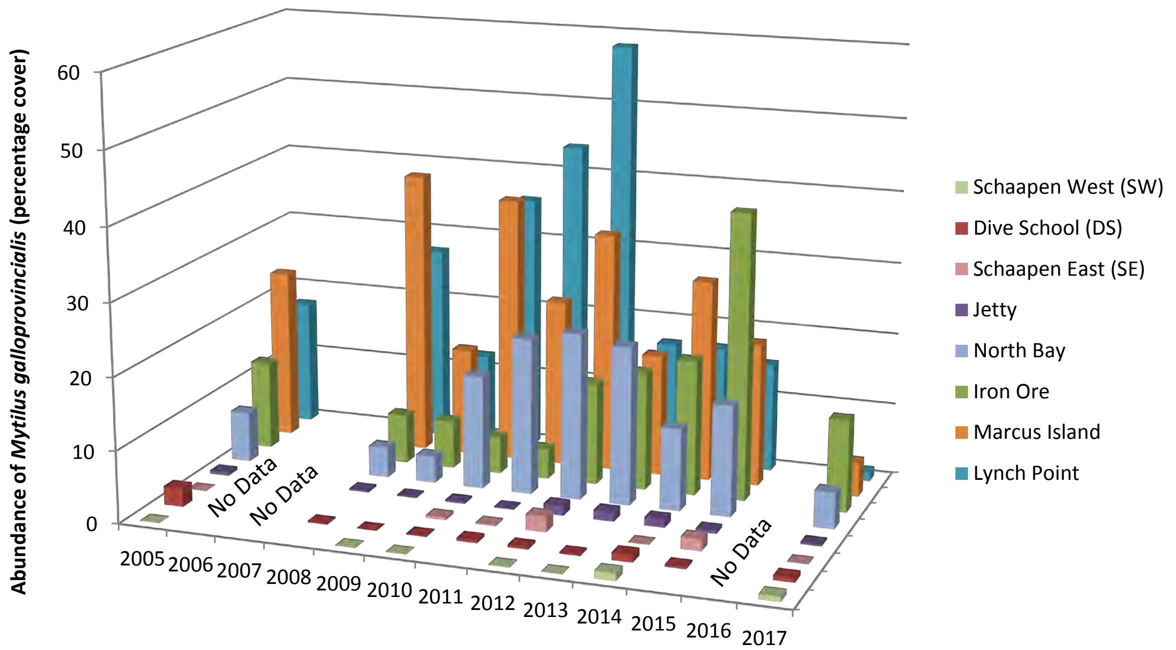


Figure 13.10. Changes in the abundance (% cover) of the Mediterranean mussel *Mytilus galloprovincialis* at eight rocky intertidal sites in Saldanha Bay over the period 2005-2017. Data are shown as an average of percentage cover on the mid and low shore. No samples were collected in 2006, 2007 and 2016. Information of the locations of these sampling stations is provided in Chapter 8.

13.9 Pacific South American mussel *Semimytilus algosus*

Figure 13.11 Pacific South American mussel *Semimytilus algosus* (Photo: Prof. C.L. Griffiths)

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 originates from Chile and has been long known from Namibia (since the 1930s, Kensley & Penrith 1970) but was only recently (2010) found in South Africa. It is unknown when *S. algosus* arrived in 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 (de Greef *et al.* 2013). The present geographic range of *S. algosus* in South Africa extends some 500 km, from Bloubergstrand in the south to Groenriviersmond in the north (de Greef et al. 2013). It proliferates on the low shore, numerically dominating intertidal organism abundance, with extremely dense beds constituting a significant proportion of the total intertidal biomass (de Greef et al. 2013). This species shows a strong preference for wave exposed shores 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.

13.10 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 13.12). 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 13.12 Disc lamp shell *Discinisca tenuis* (Photo: Prof. C.L. Griffiths)

13.11 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 13.13). 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 13.13 ***Ascidiella aspersa*** **is often found covered in epibionts (Photograph: Arjan Gittenberger).**

13.12 Vase tunicate *Ciona robusta*

C. robusta was initially misidentified as *C. intestinalis,* which was recently found to represent two morphologically separate species, namely *C. intestinalis* and *C. robusta.* Of these two species *C. robusta* is in fact the species that occurs in South Africa (Brunetti et al. 2015; Robinson *et al.* 2016). *C. robusta* 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 13.14). 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 13.14 **A typical aggregation of *Ciona robusta* (Photo: National Museums Northern Ireland).**

13.13 Jelly crust tunicate *Diplosoma listerianum*

Diplosoma listerianum is a colonial sea squirt that forms thin, fragile, yellow to dark grey jelly-like sheets up to 50 cm in diameter that grow over all types of substrata on sheltered shores between Alexander Bay and Durban (Monniot *et al.* 2001, Picker & Griffiths 2011). It is believed to have been accidentally introduced from Europe prior to the 1949, probably as a fouling organism.

Figure 13.15 Jelly crust tunicate *Diplosoma listerianum* (Photo: Prof. C.L. Griffiths).

13.14 Brooding anemone *Sagartia ornata*

The only known records of the brooding anemone *Sagartia ornata* in South Africa are from Langebaan Lagoon (West Coast National Park), where it occurs intertidally in seagrass beds, attached to rocks covered by sand, and in loose rocks resting on fossilized oyster beds (Acuña *et al.* 2004, Robinson *et al.* 2004, Picker & Griffiths 2011, Robinson & Swart 2015). *S. ornata* was first detected in 2001 (Acuña *et al.* 2004) and was probably introduced unintentionally through shipping via the Saldanha Bay harbour (Robinson *et al.* 2004). Its home range extends throughout Western Europe, Great Britain and the Mediterranean (Manuel 1981), where it occurs in crevices on rocky shores and on kelp holdfasts (Gibson *et al.* 2001). Introduced species commonly exploit novel habitats, which may reflect the adaptive ability of *S. ornata.*

Robinson & Swart (2015) recently established the current status and distribution of this alien anemone, which represents the first comparison to the baseline data collected in 2001 (Robinson *et al.* 2004). The distribution of *S. ornata* has changed within the lagoon and the species is now found in *Nanozostera capensis* (Cape eelgrass) instead of in *Spartina maritime* (spiky cord grass) beds. No apparent reason explains the increase in *S. ornata* abundance compared to 2001 (increasing from 426±81 to 508±218 individuals per m^2). Invaded sandy-shore areas support a higher invertebrate abundance, biomass and diversity, as well as altered community structures and appear to be impacted by *S. ornata,* less so through its role as a predator, but rather as a result of impacts on the habitat

Figure 13.16 Brooding anemone *Sagartia ornata* (Photo: Prof. C.L. Griffiths)

structure and associated indirect impacts on native biota (Robinson & Swart 2015). *S. ornata* consolidates sand and traps coarse sediment (Robinson *pers. obs.)*, which has the potential to significantly change the soft sediment system by altering abiotic factors (e.g. water movement, sediment characteristics) (Ruiz et al. 1997, Berkman et al. 2000, McKinnon et al. 2009).

The habitat types currently preferred by *S. ornata* in South Africa are geographically restricted and limit the potential of this alien species to significantly affect indigenous biota within the WCNP. This species has been categorised as 'naturalised', which means that it has established self-sustaining populations at the point of introduction, but has failed to expand its range beyond Langebaan Lagoon. However, 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 (Robinson & Swart 2015).

13.15 Alien barnacle *Perforatus perforatus*

This species is known only by its scientific name *Perforatus perforatus* (Note previously misidentified and reported as *Minesiniella regalis*) and as yet has not been assigned a common name. The presence of *P. perforatus* 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 algae. 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 13.17).

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).

Figure 13.17 ***Menesiniella regalis*** **(Pilsbry, 1916) (Photograph: Dr. Nina Steffani)**

13.16 *Amphibalanus amphitrite amphitrite*

This cryptogenic 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*, cryptogenic 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 13.18). *A.amphitrite amphitrite* is easily confused with another 'purple-pink striped' species which has not yet been identified (Biccard 2012).

Figure 13.18 *Amphibalanus amphitrite amphitrite* (Photo: Prof. C.L. Griffiths)

13.17 European porcelain crab *Porcellana platycheles*

The European porcelain crab *Porcellana platycheles* commonly occurs on boulder beaches in the lower mid-shore level (Smaldon 1972) in the Mediterranean Sea and east Atlantic (WoRMS 2015). In 2012, *P. platycheles* was found in some numbers for the first time in South Africa on Schaapen Island, Langebaan Lagoon (Prof. George Branch, 2012, *pers. obs*.). *P. platycheles* is euryhaline and can therefore adapt to a wide range of salinities (Davenport 1972). Not much else is known about its potential to adapt to novel environments and so far, no invasions of *P. platycheles* have been recorded outside its native range. *P. platycheles* occurs intertidally under boulders in the colder east Atlantic and the warm Mediterranean Sea and this species may therefore have the potential to establish and spread in similar habitats along the coastline of South Africa (Figure 13.19). Professor Charles Griffiths (Department of Zoology at the University of Cape Town) is intending to follow up on this discovery and establish its current distribution in Saldanha Bay and Langebaan Lagoon.

Figure 13.19 European porcelain crab *Porcellana platycheles* (Photo: Prof. C.L. Griffiths).

14 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 escalations in the rate of development in the area surrounding the Bay and Lagoon and concerns over declining health of 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.

14.1 The management of activities and discharges affecting the health of the Bay

Continuously accelerating urban and industrial development is a major cause of fragmentation and loss of ecological integrity of remaining marine and coastal habitats in Saldanha Bay and Langebaan. The challenge of addressing cumulative impacts in an area such as Saldanha is immense. The current and future desired state of the greater Saldanha Bay area is polarised, where industrial development (Saldanha Bay IDZ and associated industrial development) and conservation areas (Ramsar Site, MPAs and National Park) are immediately adjacent to one another. Furthermore, the Saldanha Bay environment supports conflicting uses including industry, fishery, mariculture, recreation and the natural environment itself. This situation necessitates sustainable development that is steered towards environmentally more resilient locations and away from sensitive areas.

Concerns have been raised that cumulative impacts on the marine environment in Saldanha Bay have not been adequately addressed by many of recent development proposals. This applies especially to the cumulative impacts that will arise from future development within the Saldanha Bay IDZ and Aquaculture Development Zone (ADZ). Furthermore, the impact on the Saldanha Bay marine environment from projects that are primarily land-based, such as storage facilities for crude oil and liquid petroleum gas, has often been underestimated or even ignored. It has been proposed that a more holistic management strategy is needed to deal with piece meal Environmental Impact Assessments (EIAs). Various environmental management instruments have been proposed for the Greater Saldanha Bay Area, including (1) a generic Environmental Management Programme (EMPr), (2) an Environmental Management Framework (EMF), (3) a Strategic Environmental Assessment (SEA), and (4) the declaration of a Special Management Area. An Intergovernmental Task Team (IGTT) has been established to consider these and other proposals. If these management instruments are indeed implemented, we are confident that measures for the conservation alongside rapid development of the Saldanha Bay area will be addressed more effectively.

14.1.1 Human settlements, water and waste 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 2.7% in Saldanha over the period 2001 to 2011 (Statistics South Africa 2014). Numbers of tourists visiting the Saldanha Bay and Langebaan Lagoon area are constantly rising, especially those visiting the West Coast National Park (WCNP) (Average rate of 18% per annum since 2005). This rapid population and tourism 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.

Recent upgrades of the Saldanha Bay Waste Water Treatment Works to service the Saldanha Bay Industrial Development Zone and the greater Saldanha area appear promising in that effluent quality has improved since January 2017, however. Demand for freshwater in the region is increasing though and available freshwater resources are clearly not going to be able to satisfy this demand for much longer. Industry and local government are working together to investigate the feasibility of reclaiming industry-grade and potable freshwater from treated sewage in Saldanha Bay. Major infrastructural changes are required for the re-cycling of treated sewage and are associated with significant initial as well as ongoing fiscal investments. Budgetary constraints experienced by local municipalities are significant, and a public-private partnership is likely to be required to ensure successful implementation.

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 stormwater is not adequately monitored (there is no monitoring of storm water quality or quantity from Saldanha or Langebaan), nor is it adequately controlled at present. The contribution to trace metal and organic loading in the Bay from these sources is thus largely unknown, and remains of concern.

Disturbance from increasing numbers of people recreating in Saldanha Bay and Langebaan Lagoon is taking its toll of sensitive habitats and species, especially seagrass, water birds and fish in Langebaan Lagoon.

14.1.2 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 discernible 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 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 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.

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. Recently published research suggests that dredging operations conducted during the Port construction programme may be contributing to this problem as well. This research highlights the fact that much of the sediment used to build the causeway to Marcus Island was dredged from the historic ebb tide delta that existed at the mouth of Langebaan (an area where sediment derived from Langebaan Lagoon had been deposited over many thousands of years). Removal of sediment from this area has reduced the extent to which incoming waves are refracted and has increased in the wave energy density along the shoreline by around 50%. This in turn seems to be contributing to the observed erosion of the shoreline in this area.

14.1.3 Fish factories

The Department of Environmental Affairs is currently in the process of issuing Coastal Waters Discharge Permits to facilities discharging waste water into Saldanha Bay. Sea Harvest was issued a CWDP on 26 June 2017. This permit authorises the disposal of industrial effluent into the Saldanha Bay harbour through an existing marine outfall. This CWDP authorises Sea Harvest to dispose a maximum quantity of 420 480 m^3 per annum at a maximum daily discharge volume of 1 152 m^3. Sea Harvest is committed to meeting effluent quality thresholds and environmental monitoring requirements as stipulated in the permit. At present, 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. Data since 2010 shows that Sea Harvest fish Processing Plant has been non-compliant in terms of the revised General Discharge Limit for TSS, ammonia nitrogen, COD and oil and grease. Some improvements can be observed for TSS and ammonia nitrogen in the effluent however further drastic improvements are required to meet the new CWDP effluent quality requirements for chemical oxygen demand as well as oil and grease.

14.1.4 Mariculture

Saldanha Bay is a highly productive marine environment and constitutes the only natural sheltered embayment in South Africa. These favourable conditions have facilitated the establishment of an aquaculture industry in the Bay. A combined 430 ha of sea space are currently available for aquaculture production in Outer Bay, Big Bay and Small Bay. With the support of finances and capacity allocated to the Operation Phakisa Delivery Unit, the Department of Agriculture Forestry and Fisheries is proposing to establish a sea-based Aquaculture Development Zone (ADZ) in Saldanha Bay. The proposed ADZ areas comprise five precincts, totalling 1 404 ha of new aquaculture areas in Saldanha Bay for a total ADZ comprising 1 872 ha (currently farmed areas will be incorporated into the ADZ). 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. The scale of the proposed ADZ is significant and if this development is approved by the Department of Environmental Affairs, environmental monitoring of the Bay should be intensified to prevent significant ecological impacts, as well as loss to the mariculture sector itself.

14.1.5 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. Also of 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 is unknown, given that the concentrations of these contaminants in ballast water discharges has not been assessed in recent years.

To address environmental impacts and risks from the discharge of ballast water, the International Convention for the Control and Management of Ship's Ballast Water and Sediments of 2004 (BWM Convention) was ratified by 30 states, including South Africa. It took almost a decade until the first Draft Ballast Water Management Bill was published in the *Government Gazette* in April 2013 (Notice 340 of 2013), aimed at giving effect to the provisions of the BWM Convention. The Draft Bill was published in the Government Gazette for comment again in 2017 but it is unknown when it will be finalised. The Bill sets out how ballast water is to be discharged, all ships are expected to have a ballast water management plan, and to keep an up to date ballast water record book. Vessels constructed after 2009 are required to be designed such that accumulation of sediments is prevented and removal is facilitated.

14.1.6 Recommendations

Urgent management interventions are required to limit further degradation of the environment from the growing pressures and should focus on the following issues:

- Ensure that all discharges to the Bay, including discharges into rivers entering the marine environment, are properly licensed and monitored (both effluent volume and quality) to confirm that conditions at the edge of the mixing zone are compliant with South African Water Quality Guidelines for the Coast Zone and any other legislative requirements;
- Existing and any future increases in use of groundwater from the Langebaan Road and Elandsfontein Aquifers need to be considered very carefully, especially in the light of effects that this may have on Saldanha Bay and Langebaan Lagoon.
- Wastewater volumes that enter Saldanha Bay must be reduced. Wastewater recycling offers the perfect opportunity to achieve this. With the ongoing drought in the Western Cape, industry and local government are coming together to investigate the feasibility of reclaiming potable freshwater from treated sewage in Saldanha Bay. The Saldanha Bay Municipality is encouraged to expedite this process for the benefit of a wide range of stakeholders. Options for diverting existing wastewater stream out of the Bay also need to be explored.

- The Saldanha Bay Municipality should re-evaluate the effectiveness of shoreline erosion mitigation measures implemented in Saldanha and Langebaan taking into account possible impacts associated with dredging that was undertaken as part of the port construction operations in the 1970s and how this can be reversed.
- Coastal management (development setback) lines also need to be established around the perimeter of the Bay and Lagoon and these must allow for adequate protection of the environment and infrastructure from current and future (i.e. climate change) pressures;
- The Draft Ballast Water Management Bill (2017) needs to be finalised and implemented as a matter of urgency; and
- Declaration of Saldanha Bay and Langebaan Lagoon as a Special Management Area in terms of ICMA should continue to be pursued.

14.2 Water quality

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. The SBWQFT has recently commenced with monitoring of water temperature in Small Bay and temperature and salinity in Langebaan Lagoon. These activities are yielding valuable insights into the functioning and health of the Bay but urgently ned to be expanded to other areas and need to be extended to include a range of other parameters such as dissolved oxygen, turbidity, nutrients, chlorophyll a (as measure of phytoplankton production)

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 the programme has since been discontinued. Since 2014, the SBWQFT has been collecting mussel samples from the same five sites during the field survey for trace metal analysis. The mussel samples collected from the shore and port infrastructure are analysed for the metals cadmium (Cd), copper (Cu), lead (Pb), zinc (Zn), iron (Fe) and manganese (Mn). Data on trace metals concentrations in shellfish from the mariculture farms in the Bay are also obtained from the DAFF (courtesy of the farm operators).

Concentrations of trace metals in marine filter feeders in Saldanha Bay indicate that concentrations of trace metals are high along the shore and are consistently above published guidelines for foodstuffs. Concentrations reported for mariculture operations that are located offshore are much lower. 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. However, there is no recent trace metal data available for cultured mussels and oysters and the discrepancy between the mussel watch data and the mariculture data needs to be addressed. Testing (or reporting) of trace metals in mariculture mussels and oysters should be increased so that trends can be properly monitored.

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 Programme be revamped and possibly extended to cover other species as well (e.g. fish). As the high level of trace metals in nearshore bivalves in Small Bay is a human health concern, signs warning of the health risks of consuming coastal mussels in this area and discouraging their collection should be posted in areas where these bivalves are easily accessible (e.g. Hoedjiesbaai).

Water samples collected from 20 stations in Saldanha Bay and Langebaan Lagoon are collected and analysed fortnightly for faecal coliform and E. coli concentrations courtesy of the SBWQFT and the WCDM. 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 60% of the sites exceeding the levels for safe mariculture practices, and three sites bordering on minimum requirements for safe recreational activities in 2016. Faecal coliform counts at all four sites in Big Bay were well within both the 80th percentile limits for mariculture in 2016 and likewise the Langebaan sites all met recreational water quality standards (and have done so for the at least the last decade at most sites).

The older DWAF water quality guidelines for recreational use have 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.

14.3 Sediments

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. While there was a general decrease in trace metal concentrations in most sites sampled in 2017, Cd and Cu still remain above ERL guidelines in Small Bay (Yacht Club Basin) and enrichment factors for Cd, Pb and Cu remain extremely high. These contaminants are typically associated with the finer sediment fraction and are highest in areas adjacent to the iron ore terminal near the Mussel Farm and the Yacht Club.

Sediment monitoring (particle size, total organic carbon (TOC), total organic nitrogen (TON) 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) when budg*et al.*lows. When budgetary constraints are in place, as in 2016, a sub-set of sites in Small Bay and Big Bay should continue to be monitored so that continuity in monitoring high impact areas is maintained. Dredging in the Bay should be avoided if at all possible, and appropriate precautions need to be taken when dredging becomes necessary to ensure that suspended trace metals do not contaminate cultured and wild seafood in the Bay.

Poly-aromatic hydrocarbons (PAH) were considered to pose no threat since the first survey was conducted in 1999. Assessment undertaken in 2017 suggested that this is still the case, however, considerable fluctuations in TPH levels have been recorded in recent years. High concentrations of TPH have been recorded at sites adjacent to the iron ore terminal in the past (2014), and it is likely that this was associated with a pollution incident of some sort. TPH levels have remained the same in 2017 and present no major concern, however, it is recommended that TPH and PAH monitoring continues on an annual basis as a precautionary measure.

14.4 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. 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. Similarly it is recommended that a programme to monitor changes in reeds (Phragmites) be initiated as this will assist in identifying any changes in groundwater inflows to Langebaan Lagoon in future. Preliminary monitoring of temperature, salinity and the macrobenthos at the head of the Lagoon has commenced. Areal extent of the target Phragmites should also be mapped over time.

14.5 Benthic macrofauna

Monitoring of benthic macrofaunal communities over the period 1999-2017 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. 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.

14.6 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 114 taxa were recorded from the eight study sites, most of which had been found in previous survey years. The faunal component was represented by 22 species of filter-feeders, 24 species of grazers, and 19 species of predators and scavengers combined. The algal component comprised 34 corticated (foliose) seaweeds, eight ephemerals, five species of encrusting algae, and two species of kelp.

In general, rocky shore communities have remained relatively stable with only minor changes over the years. However, 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. The establishment of new alien species can potentially have negative impacts on native rocky shore species and thus must be monitored closely through continued rocky shore surveys.

14.7 Fish

Long-term monitoring of juvenile fish assemblages by means of experimental seine-netting in the surf zone has revealed some concerning trends. Significant declines in white stumpnose abundance at all sites over the last decade suggests that the protection afforded by the Langebaan MPA has not been enough to sustain the fishery at the high (and increasing) effort levels. A recent analysis of commercial and recreational linefish catch data and the net survey data by a team of fisheries scientists strongly recommends the implementation of additional harvest control measures, namely a reduction in the bag limit to 5 fish person^{-1} day^{-1} and an increase in the minimum size (to 30 cm TL). It is also recommended that monitoring of fish sticks, catch and effort in the Bay be intensified, and that an economic study be undertaken to assess the value of the recreational fishery and the impacts of different management options.

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. 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 stumpnose nursery habitat is improved.

Fish sampling surveys should be conducted annually at the same sites selected during the 2017 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 has apparently been restarted by SANParks and we look forward to access to this information in the future as it will contribute to an improved understanding of the overall health of fish populations in the Bay.

14.8 Birds

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.

Saldanha Bay and particularly Langebaan Lagoon are of tremendous importance in terms of the diversity and abundance of waterbird populations supported. At least 56 non-passerine waterbird species commonly use the area for feeding or breeding; 11 breed on the islands of Malgas, Marcus, Jutten, Schaapen and Vondeling alone. These islands support nationally-important populations of

African Penguin, Cape Gannet, Swift Tern, Kelp and Hartlaub's Gull, and four species of marine cormorant, as well as important populations of the endemic African Black Oystercatcher. The lagoon is an important area for migratory waders and terns, as well as for numerous resident waterbird species. Waterbirds are counted annually on all the islands (Department of Environmental Affairs: Oceans and Coasts), and bi-annually in Langebaan Lagoon (Avian Demography Unit of the University of Cape Town).

Declines in the numbers of seabirds breeding on the Saldanha Bay Islands can be attributed to a number of causes. These include (1) emigration of birds to colonies further south and east along the South African coast in response to changes in the distribution and biomass of small pelagic fish stocks, (2) starvation as a result of a decline in the biomass of sardines nationally, and particularly along the west coast over the last decade, (3) competition for food with the small pelagic fisheries within the foraging range of affected bird species, (4) predation of eggs, young and fledglings by Great White Pelicans, Kelp Gulls and Cape Fur Seals, and (5) collapse of the West Coast Rock Lobster stock upon which Crowned Cormorants feed. However, because populations are so depressed, conditions at the islands in Saldanha, particularly predation by Cape Fur Seals and Kelp Gulls, have now become the major factors in driving current population decreases for many seabird species. Direct amelioration actions (*Pelican Watch*, problem seal culling) to decrease these impacts at the islands have had mixed results, with the former proving more effective than the latter. Cape Fur Seal and Kelp Gull predation continue to pose a major threat to seabird survival at the Saldanha Bay Island colonies. Current conservation initiative must continue to protect seabird populations in Saldanha Bay.

Decreasing numbers of migrant waders utilising Langebaan Lagoon reflects a global trend, which can be attributed to loss of breeding habitat and hunting along their migration routes as well as human disturbance and habitat loss on their wintering grounds. In Langebaan Lagoon, drastic population declines in four species, including the Ruddy Turnstone, Red Knot, Grey Plover, and Curlew Sandpiper signified this downward trend in summer migratory bird numbers. Most importantly, Curlew Sandpiper numbers have dropped from a pre-1990 average of just over 20 000 birds to 1 829 birds in 2017. Prior to 1990, this species accounted for almost two thirds of the total summer migratory wader numbers in the lagoon. Shrinking wader populations at Langebaan Lagoon are primarily signified by declining populations of a handful of migratory species. Conservation research and efforts should be prioritised for these species and conducted on international scale.

Locally, unfavourable conditions persisting in Langebaan Lagoon as a result of anthropogenic impacts should also be managed more effectively to protect resident and migratory waders that do arrive in the lagoon. 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.

14.9 Alien invasive species

A recent update on the number of alien marine species present in South Africa lists 89 alien species as being present in this country, of which 53 are considered invasive i.e. population are expanding and are consequently displacing indigenous species. At least 28 alien and 42 invasive species occur along the West Coast of South Africa. Twenty five of these species have been confirmed from Saldanha Bay and/or Langebaan Lagoon, of which all but one are considered invasive. For example, the invasive 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), are commonly found in the study area. Interestingly, the abundance of *B. glandula* and *M. galloprovincialis* on rocky shores in Saldanha Bay has been decreasing in the last few years. This trend may reflect a new ecosystem equilibrium as predator numbers have probably responded to the new food source and now exert more control over the abundance of this invasive species.

The presence of three new alien species – the barnacle *Perforatus perforatus*, the Japanese skeleton shrimp *Caprella mutica*, and the European porcelain crab *Porcellana platycheles* – have been confirmed in Saldanha Bay and Langebaan Lagoon since 2014. Other noteworthy invasive alien species that are present in Saldanha Bay include the Mediterranean mussel *Mytilus galloprovincialis*, the Pacific mussel *Semimytilus algosus*, and the recently detected barnacle *Balanus glandula*.

An additional 41 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.

Alien species 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 and regularly monitored to measure the impacts that they have on the native biota.

14.10 Summary of environmental monitoring results

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	Rating
WATER QUALITY			
Physical aspects (temperature, salinity, dissolved oxygen, nutrients and chlorophyll)	1974-2000, 2010-2011, 2014-2017	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	1975 vs. 2017	Reduced wave energy, and impaired circulation and rate of exchange in Small Bay. Increased wave action in parts of Big Bay and at Langebaan Beach causing coastal erosion. Increased current strength alongside obstructions (e.g. ore terminal)	
Microbiological (faecal coliform)	1999-2017	Faecal coliform counts in Small Bay frequently exceed guideline levels and although there have been improvements at some sites, others remain a concern. Big Bay and Langebaan Lagoon mostly remain within safety levels for faecal coliform pollution. However, faecal coliform may underestimate actual harmful microbiological concentrations. There is a need to monitor intestinal *Enterococci* as well.	
Trace metal contaminants in water	1997-2008, 2014-2017	Concentrations of cadmium, lead and zinc in mussel flesh are consistently above the safety guidelines for food stuffs. Any future dredging events should be prevented as far as possible owing the likely mobilization of trace metals from sediments.	
SEDIMENTS			
Particle size (mud/sand/gravel)	1974-2017	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.	
Total organic carbon (TOC)	1974-2017	Elevated levels of TOC at the Yacht Club basin and near the mariculture rafts (negative impacts) are of particular concern.	
Total organic nitrogen (TON)	1974-2017	Similar trends as for TOC. Elevated levels of TON at the Yacht Club basin and near the mariculture rafts (negative impacts) are of particular concern.	
Trace metal contaminants in sediments	1980-2017	Cadmium, lead, and copper are currently elevated considerably above historic levels. Concentrations were highest in 1999 following major dredge event. Pb, Cu, Ni	

Parameter monitored	Time period	Anthropogenic induced impact	Rating
		elevated in 2008-2016 and Cd and Cu in 2017 at Yacht Club and *multi-purpose terminal*, which may be related to shipping activities and maintenance dredging.	
AQUATIC MACROPHYTES			
Seagrasses, salt marsh, reeds and sedges	2016-2017	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	
BENTHIC MACROFAUNA			
Species abundance, biomass, and diversity	1999-2017	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 2008.	
ROCKY INTERTIDAL AND INTRODUCED SPECIES			
Impact of alien mussel and barnacle introductions	1980-2017	Alien mussel and barnacle have displaced the local mussel and other native species from much of the shore leading to decreased species diversity (negative). One new alien barnacle species found in 2014. The establishment of this species must be closely monitored.	
FISH			
Community composition and abundance	1986-2017	White stumpnose abundance and fishery landings have declined dramatically over the last decade. Abundance of some other species in the Bay and Lagoon (e.g. harders) have also been declining for several years, and this is of some concern	
BIRDS			
Population numbers of key species in Saldanha Bay and islands	1977-2017	Populations of seabirds breeding on the Saldanha Bay Islands are declining rapidly. This trend is attributed to: (1) emigration of birds to colonies further south and east along the South African coast in response to changes in the distribution and biomass of small pelagic fish stocks, (2) predation of eggs, young and fledglings by Great White Pelicans, Kelp Gulls and Cape Fur Seals; (3) starvation as a result of a decline in the biomass of sardines nationally, and particularly along the west coast over the last decade, (4) competition for food with the small pelagic fisheries within the foraging range of affected bird species, and (5) collapse of the West Coast Rock Lobster stock upon which Crowned Cormorants feed	
Population numbers of key species in Langebaan Lagoon	1976-2017	Populations of migrant 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. Numbers of resident waders have also declined and is likely due to changes in the lagoon itself.	

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16 APPENDIX

The Chapter contains supplementary information for the Fish, Bird, and Alien and Invasive Species Chapters in table format (Table 16.1- Table 16.4)

Table 16.1. Average abundance of fish species (number.m^{-2}) recorded during annual beach seine-net surveys in Small 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	Apr-15	Mar-16	Mar-17
Amblyrhychotes honkenii	evil eye blassop													0.00056
Argyrozona argyrozona	silverfish								0.0002					
Atherina breviceps	silverside	1.3084	0.0410	0.9690	1.6505	0.1088	0.3397	0.6420	0.1539	0.0644	0.0745	0.5024	0.9408	0.3113
Caffrogobius sp.	goby	0.0160	0.1294	1.0888	0.0162	0.0194	0.0039	0.0307	0.0007	0.0011	0.0295	0.0011	0.0052	0.03111
Callorhinchus capensis	St Joseph													0.0006
Cancelloxus longior	snake eel								0.0002	0.0008		0.0003		
Cheilidonichthys capensis	gurnard	0.0022	0.0082	0.0003	0.0004	0.0006	0.0007					0.0014		0.0033
Chorisochismus sp?	suckerfish sp.									0.0006				
Clinus heterodon	West coast Klipvis									0.0072				
Clinus latipennis	False Bay Klipvis					0.0004	0.0006			0.0017			0.0087	0.0039
Clinus robustus	Robust Klipvis									0.0008				
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	0.0003	0.0157	0.0067
Clinus venustris	Bluntnose klipvis									0.0017				
Cynoglossus capensis	Toungue fish											0.0003		
Dasyatis chrysonota	blue Stingray									0.0011				
Diplodus sargus capensis	black tail	0.0022	0.0178	0.0532	0.4437	0.0617	0.0011	0.0007	0.0390	0.0069	0.0014		0.12176	
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	0.0258	0.0108	0.0185	0.0042	0.0039	0.0053	0.0192	0.0082	0.03769
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	0.1601	0.3457	0.8147
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	0.0008		
Poroderma africanum	striped catshark	0.0009												
Psammogobius knysnaensis	Knysna sand gobi						0.0028		0.0037	0.0011	0.0071	0.0088	0.0186	0.01813
Raja clavata	thornback skate			0.0011										

Year/species	Common name	Apr-94	Oct-05	Apr-07	Apr-08	Apr-09	Apr-10	Apr-11	Apr-12	Apr-13	Apr-14	Apr-15	Mar-16	Mar-17
Rhabdosargus globiceps	white stumpnose	0.0618	0.0079	5.0564	0.4191	0.0562	0.0822	0.0244	0.0640	0.0019	0.0318	0.0074	0.13148	0.09713
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	0.0013	0.0007	0.0011
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		0.0012	0.0003
Trachurus trachurus	horse mackerel				0.0094									0.0004
Total		**2.1098**	**0.81**	**9.37**	**3.46**	**0.70**	**1.64**	**39.25**	**0.31115**	**0.37**	**3.40**	**0.70**	**1.60**	**1.33**
Number of species	**47**	**16**	**14**	**14**	**15**	**12**	**12**	**13**	**13**	**18**	**13**	**12**	**11**	**14**
Number of hauls	**139**	**5**	**12**	**6**	**12**	**12**	**12**	**12**	**9**	**12**	**11**	**12**	**12**	**12**
Total area sampled(m^2)	**54335**	**2250**	**7200**	**3750**	**5600**	**4950**	**4275**	**3150**	**3600**	**3150**	**3210**	**5100**	**4200**	**3900**

Table 16.2. **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	Apr-15	Mar-16	Mar-17
Argyrozona argyrozona	silverfish											0.0001		0.0002
Atherina breviceps	silverside	0.0003	0.0025		0.1257	0.0946	0.0289	0.1679	0.0059	0.0061	0.1830	0.0037	0.1342	0.0009
Blennophis	blenny sp.		0.0001		0.0001									
Brama brama	angelfish								0.0001					
Caffrogobius sp.	goby				0.0002	0.0031		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	0.0001	0.0002	0.0006
Cheilidonichthys capensis	gurnard	0.0021	0.0079	0.0005	0.0054	0.0022	0.0001	0.0063	0.0001	0.0007	0.0014	0.0014	0.0005	0.0003
Cheilidonichthys kumu	bluefin gurnard								0.0002					
Chorisochismus sp?	suckerfish sp.				0.0001									
Clinus latipennis	False Bay Klipvis		0.0017	0.0003	0.0007	0.0007	0.0002	0.0002	0.0009	0.0006	0.0032	0.0011	0.0005	0.00154
Clinus sp. larvae	Klipvis larvae				0.0027					0.0002	0.00194			
Clinus superciliosus	super klipvis	0.0037			0.0017	0.0006	0.0002		0.0011	0.0012		0.0001	0.0002	0.0020
Cynoglossus capensis	Toungue fish											0.0002		
Dasyatis chrysonota	blue Stingray					0.0004	7E-05							
Diplodus sargus capensis	black tail			0.0004	0.0009								0.0004	
Engraulis japonicus	anchovy						0.0002							
Galeichthyes feliceps	barbel								0.0001					

Year/species	**Common name**	**Apr-94**	**Oct-05**	**Apr-07**	**Apr-08**	**Apr-09**	**Apr-10**	**Apr-11**	**Apr-12**	**Apr-13**	**Apr-14**	**Apr-15**	**Mar-16**	**Mar-17**
Gonorhynchus gonorhynchus	beaked sand eel	0.0005								0.0004				0.0002
Haploblepherus pictus	dark Shy Shark					0.0002								
Heteromycteris capensis	Cape sole	0.0725	0.0014	0.0897	0.0433	0.0141	0.0107	0.0086	0.0058	0.00425 9	0.00542	0.00265	0.0095	0.0167
Liza richardsonii	harder	0.3877	0.2098	1.4077	0.1805	0.1201	0.2153	0.9968	0.0951	0.2099	0.3185	0.2319	0.4918	0.3900
Mustelus mustelus	smoothhound shark	0.0013	0.0001						0.00038					
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	0.0005	0.0348	0.0664
Psammogobius knysnaensis	Knysna sand gobi			0.0006				0.0006				0.00012		
Rhabdosargus globiceps	white stumpnose	0.0030	0.0207	0.3358	0.2012	0.0501	0.051	0.1341	0.07222	0.00703 7	0.00056	0.04356	0.0424	0.0349
Rhabdosargus holubi	Cape stumpnose							0.0007	0.0046				0.0040	
Rhinobatos blockii	bluntnose guitar fish	0.0066	0.0022	0.0029	0.0019	0.0001	0.0009	0.0009	0.0013	0.0002		0.0001		0.0005
Sardinops sagax	sardine								0.0007					
Sarpa salpa	streepie								0.0002					0.0015
Solea turbynei	blackhand sole													0.0001
Spondyliosoma emarginatum	steentjie	0.0004	0.0004		0.0003				0.0002					0.0009
Syngnathus temminckii	pipe fish	0.0002			0.0004	0.0002	0.0002	0.0002	0.0007	0.0002	0.0004			
Trachurus trachurus	horse mackerel				0.0001				0.0002		0.0003			0.0142
Zeus faber	John dory								0.0002					
Total		**0.4800**	**0.2500**	**1.8500**	**0.6100**	**0.2900**	**0.3100**	**1.3400**	**0.1700**	**0.2300**	**0.5200**	**0.2900**	**0.7185**	**0.5307**
Number of species	**37**	**14**	**12**	**10**	**17**	**12**	**13**	**14**	**23**	**13**	**12**	**13**	**11**	**16**
Number of hauls	**210**	**14**	**12**	**6**	**18**	**18**	**18**	**18**	**16**	**18**	**18**	**18**	**18**	**18**
Total area sampled(m^2)	**87 525**	**5525**	**5400**	**6250**	**10500**	**5850**	**7500**	**4950**	**6900**	**5850**	**7200**	**8700**	**6450**	**6450**

Table 16.3. **Average abundance of fish species (number.m^{-2}) recorded during annual beach seine-net surveys in Langebaan Lagoon.**

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	Apr-15	Mar-16	Mar-17
Atherina breviceps	silverside	1.1916	1.1865	0.0524	0.0786	0.1416	0.0654	0.1206	0.2857	0.2280	3.5085	*1.0384*	*0.6246*	0.7501	0.5957
Blennophis	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	*0.1763*	*0.0819*	0.1397	0.0910
Cheilidonichthys capensis	gurnard		0.0020	0.0038		0.0001					0.0004	*0.0003*	*0.0006*	0.0020	
Clinus heterodon	West coast Klipvis										0.0339		*0.0004*		
Clinus latipennis	False Bay Klipvis			0.0163		0.0001	0.0002					*0.0002*	*0.0001*		0.0002
Clinus sp. larvae	Klipvis larvae											*0.0280*			
Clinus superciliosus	super klipvis	0.0698	0.0063	0.0006			0.0031						0.0136	0.0080	0.0004
Diplodus sargus capensis	black tail	0.0120					0.0003							0.0016	
Heteromycteris capensis	Cape sole		0.0009	0.0014	0.0027	0.0331	0.0145	0.0148	*0.0032*	0.0003	0.0024	*0.0093*	*0.0357*	0.0020	0.0065
Lichia amia	leervis		0.0002												
Lithognathus sp	steenbras sp.														0.0005
Liza richardsonii	harder	0.2452	0.7182	0.3452	3.8468	0.1548	0.3750	9.5032	*1.5720*	0.2239	0.3548	0.3895	0.2621	3.4799	0.5237
Myliobatis aquila	eagle ray												0.0006		
Parablennius cornutus	blenny						0.0002					0.0001	0.0002		
Pomatomus saltatrix	elf		0.0001					0.0002	0.0013		0.0024			0.0060	
Poroderma africanum	striped catshark								0.0010						
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	0.2758	0.1694	0.2724	0.5753
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	0.0039	0.0048	0.0275
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	0.0001	0.0004	0.0004
Sarpa salpa	streepie										0.0204				
Solea turbynei	blackhand sole		0.0006		0.0004	0.0003		0.0001	0.0003				0.0001	0.0002	
Spondyliosoma emarginatum	steentjie	0.0001				0.0009		0.0001	0.0006			0.0001			
Syngnathus temminckii	pipe fish	0.0063	0.0007								0.0015	0.0003	0.0001	0.0016	
Trachurus trachurus	horse mackerel		0.0001								0.0013				
Total		**1.71**	**2.49**	**0.69**	**5.12**	**0.65**	**0.84**	**10.15**	**2.47**	**0.27**	**4.36**	**1.92**	**1.19**	**4.67**	**1.82**
Number of species	**26**	**9**	**14**	**11**	**8**	**11**	**11**	**9**	**12**	**7**	**12**	**14**	**15**	**13**	**10**
Number of hauls	**224**	**30**	**20**	**12**	**9**	**15**	**13**	**15**	**14**	**6**	**18**	**18**	**18**	**18**	**18**
Total area sampled(m^2)	**104700**	**18000**	**7125**	**7200**	**6000**	**9000**	**6150**	**11325**	**2925**	**3150**	**5400**	**8400**	**9150**	**5925**	**4950**

Table 16.4 **List of non-passerine waterbird species occurring in Langebaan Lagoon (Note that this species list excludes rare vagrants, exotic species and terrestrial species) (Source: CWAC data, Animal Demography Unit at the University of Cape Town). (Data source: CWAC data, Animal Demography Unit at the University of Cape Town).**

Common name	Scientific name	Average count	Maximum count
African Black Oystercatcher	*Haematopus moquini*	19	163
African Darter	*Anhinga rufa*	2	3
African Fish-Eagle	*Haliaeetus vocifer*	1	2
African Marsh-Harrier	*Circus ranivorus*	2	9
African Purple Gallinule	*Porphyrio madagascariensis*	2	2
African Rail	*Rallus caerulescens*	2	3
African Sacred Ibis	*Threskiornis aethiopicus*	112	720
African Snipe	*Gallinago nigripennis*	4	19
African Spoonbill	*Platalea alba*	24	137
Arctic Tern	*Sterna paradisaea*	35	35
Bank Cormorant	*Phalacrocorax neglectus*	10	29
Bar-tailed Godwit	*Limosa lapponica*	227	3000
Black Crake	*Zapornia flavirostra*	2	2
Black-crowned Night-Heron	*Nycticorax nycticorax*	3	6
Black-headed Heron	*Ardea melanocephala*	3	29
Black-necked grebe	*Podiceps nigricollis*	1	1
Blacksmith Lapwing	*Vanellus armatus*	20	78
Black-tailed Godwit	*Limosa limosa*	1	1
Black-winged Stilt	*Himantopus himantopus*	37	180
Cape Cormorant	*Phalacrocorax capensis*	88	2289
Cape Shoveler	*Anas smithii*	13	70
Cape Teal	*Anas capensis*	23	154
Caspian Tern	*Sterna caspia*	8	53
Cattle Egret	*Bubulcus ibis*	8	45
Chestnut-banded Plover	*Charadrius pallidus*	57	581
Common Greenshank	*Tringa nebularia*	119	1175
Common Moorhen	*Gallinula chloropus*	2	5
Common Redshank	*Tringa totanus*	14	76
Common Ringed Plover	*Charadrius hiaticula*	102	548
Common Sandpiper	*Actitis hypoleucos*	4	34
Common Tern	*Sterna hirundo*	528	9658
Common Whimbrel	*Numenius phaeopus*	168	2000
Crowned Cormorant	*Phalacrocorax coronatus*	31	142
Crowned Plover	*Vanellus coronatus*	4	8
Curlew Sandpiper	*Calidris ferruginea*	3377	25347
Egyptian Goose	*Alopochen aegyptiaca*	16	433
Eurasian Curlew	*Numenius arquata*	83	1373
Giant kingfisher	*Megaceryle maximus*	1	1
Glossy Ibis	*Plegadis falcinellus*	15	54
Goliath Heron	*Ardea goliath*	3	3

Common name	Scientific name	Average count	Maximum count
Great Crested Grebe	*Podiceps cristatus*	2	2
Great White Egret	*Egretta alba*	2	3
Great White Pelican	*Pelecanus onocrotalus*	28	262
Greater Flamingo	*Phoenicopterus roseus*	899	8724
Greater Sand Plover	*Charadrius leschenaultii*	7	35
Grey Heron	*Ardea cinerea*	8	83
Grey plover	*Pluvialis squatarola*	733	8228
Grey-headed Gull	*Larus cirrocephalus*	5	19
Hartlaub's Gull	*Larus hartlaubii*	228	1881
Kelp Gull	*Larus dominicanus*	155	2445
Kittlitz's Plover	*Charadrius pecuarius*	55	545
Lesser Flamingo	*Phoeniconaias minor*	213	1606
Lesser Sand Plover	*Charadrius mongolus*	7	19
Little Egret	*Egretta garzetta*	24	126
Little Grebe	*Tachybaptus ruficollis*	12	21
Little Stint	*Calidris minuta*	143	858
Little Tern	*Sterna albifrons*	9	64
Malachite Kingfisher	*Alcedo cristata*	1	2
Marsh Owl	*Asio capensis*	2	5
Marsh Sandpiper	*Tringa stagnatilis*	10	55
Osprey	*Pandion haliaetus*	2	5
Pied Avocet	*Recurvirostra avosetta*	53	521
Pied Kingfisher	*Ceryle rudis*	5	16
Pink-backed Pelican	*Pelecanus rufescens*	26	26
Purple Heron	*Ardea purpurea*	1	3
Red Knot	*Calidris canutus*	977	6219
Red-billed Teal (Duck)	*Anas erythrorhyncha*	5	22
Red-knobbed Coot	*Fulica cristata*	34	277
Reed Cormorant	*Phalacrocorax africanus*	22	277
Ruddy Turnstone	*Arenaria interpres*	559	4587
Ruff	*Philomachus pugnax*	25	237
Sanderling	*Calidris alba*	594	4950
Sandwich Tern	*Thalasseus sandvicensis*	34	1474
South African Shelduck	*Tadorna cana*	14	131
Southern Pochard	*Netta erythrophthalma*	4	4
Spur-winged Goose	*Plectropterus gambensis*	7	71
Swift Tern	*Thalasseus bergii*	38	1538
Terek Sandpiper	*Xenus cinereus*	43	266
Three-banded Plover	*Charadrius tricollaris*	6	38
Water Thick-knee	*Burhinus vermiculatus*	2	3
White-breasted Cormorant	*Phalacrocorax lucidus*	12	89
White-fronted Plover	*Charadrius marginatus*	86	473
White-winged Tern	*Chlidonias leucopterus*	4	17
Wood Sandpiper	*Tringa glareola*	3	9

Common name	Scientific name	Average count	Maximum count
Yellow-billed Duck	*Anas undulata*	49	335
Yellow-billed Egret	*Ardea intermedia*	4	31

Table 16.5. **List of alien, invasive, naturalised and cryptogenic species that are likely to occur on the West Coast of South Africa or have been confirmed to occur in 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) and Robinson et al. 2014, and recent published and unpublished research.**

Taxon	Occurrence in Saldanha/Langebaan	Status	Origin	Vector	Reference
PROTOCTISTA					
Mirofolliculina limnoriae	Likely	Alien	Unknown	SB	Mead et al. 2011
DINOFLAGELLATA					
Alexandrium minutum	Likely	Alien	Europe	BW	Mead et al. 2011
Alexandrium tamarense-complex	Likely	Alien	N Atlantic/N Pacific	BW	Mead et al. 2011
Dinophysis acuminata	Likely	Alien	Europe	BW	Mead et al. 2011
PORIFERA					
Suberites ficus	Likely	Invasive	Europe	SF	Samaai and Giboons 2005
CNIDARIA					
ANTHOZOA					
Metridium senile	Likely	Alien	N Atlantic/N Pacific	SF/OR	Mead et al. 2011
Sagartia ornata	Confirmed	Naturalised	Europe	SF/BW	Robinson and Swart 2015
HYDROZOA					
Coryne eximia	Confirmed	Invasive	N Atlantic/N Pacific	SF/BW	Mead et al. 2011
Gonothyraea loveni	Likely	Alien	North Atlantic	SF/BW	Mead et al. 2011
Laomedea calceolifera	Likely	Alien	North Atlantic	SF/BW	Mead et al. 2011
Obelia bidentata	Likely	Naturalised	Unknown	SF/BW	Mead et al. 2011
Obelia dichotoma	Likely	Naturalised	Unknown	SF/BW	Mead et al. 2011
Obelia geniculata	Likely	Naturalised	Unknown	SF/BW	Mead et al. 2011
Pachycordyle navis	Likely	Alien	Europe	SF/BW	Mead et al. 2011
Pinauay larynx	Likely	Naturalised	North Atlantic	SF/BW	Mead et al. 2011

Taxon	Occurrence in Saldanha/Langebaan	Status	Origin	Vector	Reference
Pinauay ralphi	Likely	Alien	North Atlantic	SF/BW	Mead et al. 2011
ANNELIDA					
POLYCHAETA					
Boccardia proboscidea	Confirmed	Invasive	Eastern Pacific	M	David and Simon 2014; CAS unpublished data
Capitella sp.	Likely	Cryptogenic	Unknown	SF/BW	Mead et al. 2011
Dodecaceria fewkesi	Likely	Naturalised	North American Pacific	SF/BW	Peters et al. 2014
Ficopomatus enigmaticus	Likely	Invasive	Australia	SF	McQuaid and Griffiths 2014
Janua pagenstecheri	Likely	Alien	Europe	SF/BW	Mead et al. 2011
Neodexiospira brasiliensis	Confirmed	Invasive	Indo-Pacific	SF/BW	Mead et al. 2011
Simplicaria pseudomilitaris	Likely	Alien	Unknown	SF/BW	Mead et al. 2011
Polydora hoplura	Confirmed	Invasive	Europe	SF/BW	Simon 2011; David and Simon 2014
Polydora cf. *websteri*	Likely	Alien, in potentially open facility	Unknown	M	Simon 2015; Williams 2015
Hydroides elegans	Likely	Cryptogenic	Unknown	SF/BW	Robinson et al. 2016
CRUSTACEA					
CIRRIPEDIA					
Amphibalanus amphitrite amphitrite	Confirmed (AEC 2014)	Cryptogenic	Unknown	SF/BW	Mead et al. 2011
Amphibalanus venustus	Likely	Invasive	North Atlantic	SF	Mead et al. 2011
Balanus glandula	Confirmed	Invasive	North American Pacific	SF/BW	Robinson et al. 2015
Perforatus perforatus	Confirmed	To be confirmed	North American Pacific	SF/BW	Biccard and Griffiths (*Pers Comm. 2017)*
COPEPOD					
Acartia (Odontacartia) spinicauda	Likely	Alien	Western North Pacific	BW	Mead et al. 2011

Taxon	Occurrence in Saldanha/Langebaan	Status	Origin	Vector	Reference
ISOPODA					
Dynamene bidentata	Likely	Invasive	Europe	SF/BW	Mead et al. 2011
Ligia exotica	Likely	Cryptogenic	Unknown	SB	Mead et al. 2011
Limnoria quadripunctata	Likely	Alien	Unknown	SB	Mead et al. 2011
Limnoria tripunctata	Likely	Alien	Unknown	SB	Mead et al. 2011
Paracerceis sculpta	Likely	Alien	Northeast Pacific	SF/BW	Mead et al. 2011
Synidotea hirtipes	Confirmed	Cryptogenic	Indian Ocean	SF/BW	Mead et al. 2011
Synidotea variegata	Confirmed	Cryptogenic	Indo-Pacific	SF/BW	Mead et al. 2011
AMPHIPODA					
Caprella equilibra	Likely	Cryptogenic	Unknown	SF/BW	Mead et al. 2011
Caprella mutica	Likely	Alien	North-east Asia	SF	Peters and Robinson 2017
Caprella penantis	Likely	Cryptogenic	Unknown	SF/BW	Mead et al. 2011
Chelura terebrans	Confirmed	Invasive	Pacific Ocean	SF/SB	Mead et al. 2011
Cerapus tubularis	Confirmed	Invasive	North American Atlantic	BS	Mead et al. 2011
Cymadusa filosa	Likely	Cryptogenic	Unknown	BS	Mead et al. 2011
Erichthonius brasiliensis	Likely	Invasive	North Atlantic	SF/BW	Mead et al. 2011
Ericthonius difformis	Likely	Alien	Unknown, northern hemisphere	SF	Peters *et al.* 2014
Ischyrocerus anguipes	Likely	Invasive	North Atlantic	SF/BW	Mead et al. 2011
Jassa marmorata	Likely	Naturalised	North Atlantic	SF/BW	Conlan 1990; Mead et al. 2011
Jassa morinoi	Likely	Invasive	Eastern North Pacific	SF/BW	Conlan 1990; Mead et al. 2011
Jassa slatteryi	Confirmed	Invasive	North Pacific	SF/BW	Conlan 1990; Mead et al. 2011
Paracaprella pusilla	Likely	Cryptogenic	Unknown	SF/BW	Mead et al. 2011

Taxon	Occurrence in Saldanha/Langebaan	Status	Origin	Vector	Reference
Orchestia gammarella	Confirmed	Invasive	Europe	BS	Mead et al. 2011
DECAPODA					
Carcinus maenas	Confirmed (G. Branch *pers. comm.*)	Invasive	Europe	SF/BW/OR	Robinson et al. 2005
Pinnixa occidentalis	Confirmed (Anchor 2011)	Invasive	North American Pacific	BW	Clark and Griffiths 2012
Porcellana platycheles	Confirmed (Branch and Griffiths *pers. comm.2015)*	To be confirmed	Mediterranean	BW	Unpublished
Xantho incicus	Likely	Alien	France	M	Haupt et al. 2010
INSECTA					
COLEOPTERA					
Cafius xantholoma	Likely	Invasive	Europe	BS	Mead et al. 2011
MOLLUSCA					
GASTROPODA					
Catriona columbiana	Likely	Alien	North Pacific	SF/BW	Mead et al. 2011
Littorina saxatilis	Confirmed	Invasive	Europe	BS	Mead et al. 2011
Tritonia nilsodhneri	Likely	To be confirmed	Europe	SF/BW	Zsilavecz 2007
Kaloplocamus ramosus	Likely	To be confirmed	Unknown	SF/BW	Zsilavecz 2007
Thecacera pennigera	Likely	Cryptogenic	Unknown	SF/BW	Mead et al. 2011
Anteaeolidiella indica	Confirmed	Cryptogenic	Unknown	SF/BW	Mead et al. 2011
BIVALVIA					
Bankia carinata	Likely	Cryptogenic	Unknown	SB	Mead et al. 2011
Bankia martensi	Likely	Cryptogenic	Unknown	SB	Mead et al. 2011
Crassostera gigas	Confirmed	Invasive	Japan	M	Haupt *et al.* 2010; Keightley et al. 2015
Dicyathifer manni	Likely	Cryptogenic	Unknown	SB	Mead et al. 2011

Taxon	Occurrence in Saldanha/Langebaan	Status	Origin	Vector	Reference
Lyrodus pedicellatus	Likely	Alien	Unknown	SB	Mead et al. 2011
Mytilus galloprovincialis	Confirmed	Invasive	Europe	SF/BW	Robinson et al. 2005
Semimytilus algosus	Confirmed	Invasive	South Pacific	SF/BW	de Greef *et al.* 2013
Teredo navalis	Likely	Invasive	Europe	SB	Mead et al. 2011
Teredo somersi	Likely	Cryptogenic	Unknown	SB	Mead et al. 2011
BRACHIOPODA					
Discinisca tenuis	Confirmed	Invasive	Namibia	M	Haupt *et al.* 2010; Peters *et al.* 2014
BRYOZOA					
Bugula flabellata	Likely	Invasive	Unknown	SF	Florence et al. 2007
Bugula neritina	Likely	Invasive	Unknown	SF	Florence et al. 2007
Conopeum seurati	Confirmed	Invasive	Europe	SF	McQuaid and Griffiths 2014
Cryptosula pallasiana	Confirmed	Invasive	Europe	SF	Mead et al. 2011
Watersipora subtorquata	Confirmed	Invasive	Caribbean	SF	Florence et al. 2007; Mead et al. 2011
CHORDATA					
ASCIDIACEA					
Ascidia sydneiensis	Likely	Invasive	Pacific Ocean	SF	Mead et al. 2011; Rius et al. 2014
Ascidiella aspersa	Likely	Invasive	Europe	SF	Mead et al. 2011; Peters *et al.* 2014; Rius et al. 2014
Botryllus schlosseri	Likely	Invasive	Unknown	SF	Mead et al. 2011; Peters *et al.* 2014; Rius et al. 2014
Ciona robusta (formally known as *Ciona intestinalis*)	Confirmed (Picker & Griffiths 2011)	Invasive	Unknown	SF	Mead et al. 2011; Rius et al. 2014; Brunetti et al. 2015
Clavelina lepadiformis	Confirmed (Picker & Griffiths 2011)	Invasive	Europe	SF	Mead et al. 2011; Rius et al. 2014
Cnemidocarpa humilis	Likely	Invasive	Unknown	SF	Mead et al. 2011
Corella eumyota	Confirmed	Cryptogenic	Unknown	SF	Mead et al. 2011

Taxon	Occurrence in Saldanha/Langebaan	Status	Origin	Vector	Reference
Diplosoma listerianum	Confirmed	Invasive	Europe	SF	Mead et al. 2011; Rius et al. 2014
Microcosmus squamiger	Likely	Invasive	Australia	SF	Mead et al. 2011; Rius et al. 2014
Trididemnum cerebriforme	Confirmed	Cryptogenic	Unknown	SF	Mead et al. 2011
PISCES					
Cyprinus carpio	Likely	Invasive	Central Asia to Europe	I	Mead et al. 2011
RHODOPHYTA					
Antithamnionella spirographidis	Confirmed	Invasive	North Pacific	SF/BW	Mead et al. 2011
Antithamnionella ternifolia	Likely	Cryptogenic	Australia	SF/BW	Mead et al. 2011
Asparagopsis armata	Likely	Invasive	Australia	Unknown	Bolton et al. 2011
Schimmelmannia elegans	Likely	Alien	Tristan da Cunha	BW	De Clerck et al. 2002
CHLOROPHYTA					
Codium fragile fragile	Confirmed	Invasive	Japan	SF/BW	Mead et al. 2011

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Water Quality Trust

Bivalve Shellfish Farmers' Association
Saldanha

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