

**THE STATE OF  
SALDANHA BAY AND LANGEBAAN LAGOON  
2018**



**October 2018**



**ANCHOR**  
*environmental*



# THE STATE OF SALDANHA BAY AND LANGEBAAN LAGOON 2018

**Technical Report**

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## 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 19 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 2018 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 (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***

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.

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 increase of 15% 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 of.

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. However, the Transnet Port Terminals have thus far been unsuccessful in obtaining a variation to their existing Air Emission License (AEL) applicable to the Iron Ore Terminal for the storage and handling of the ore. The latest application was for the increase of handling and storage of coal and ore to 67 million tonnes per annum and was accompanied by an impact assessment and public participation process. The competent authority denied TPT the amendment concluding that environmental impacts at the current production level are already too high.

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. Until recently sewage discharge was 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 industrial 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 were overcome by means of a public-private partnership. Arcelor Mittal now represents the highest consumer of treated wastewater from the Saldanha Bay Waste Water Treatment Works. Arcelor Mittal constructed a Reverse Osmosis plant, which treats wastewater such that it can be used for cooling steel production equipment.

Ballast water discharges are by far the highest in terms of volume and also continuous due to constant and increasing shipping traffic. Ballast water discharges were more or less static until 2016 and have since increased, which is directly correlated to increased 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. Although no domestic legislation is currently in place to regulate ballast water discharge, the Transnet National Port Authority in Saldanha Bay has implemented a number of mechanisms to track and control the release of ballast water into the harbour.

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. 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 currently in the process of establishing a sea-based Aquaculture Development Zone (ADZ) in Saldanha Bay. The ADZ areas comprise four precincts (Small Bay, Big Bay North, Outer Bay North and South) totalling 420 ha of new aquaculture areas in Saldanha Bay for a total ADZ comprising 884 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 environmental monitoring of the Bay should be intensified to prevent significant ecological impacts, as well as loss to the mariculture sector itself.

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.

## **Groundwater**

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<sup>3</sup> 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 where to date, two years of baseline data have been collected.

## **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 in Small Bay, while wave exposure has increased in some areas of Big Bay leading to coastal erosion.

Regular monitoring of microbiological indicators at 20 stations in the Bay (ten in Small Bay, five in Big Bay and five in Langebaan Lagoon) was initiated by the Saldanha Bay Water Quality Forum Trust (SBWQFT) in 1999 and has continued with the assistance of the West Coast District Municipality. These data indicate that chronic faecal coliform pollution was present in the early parts of the record but that conditions have improved considerably over time. Currently, 14 of the 20 monitoring stations in the Bay are rated as having 'Excellent' water quality, two sites (Langebaan North and Langebaan Yacht Club) are rated as 'Good', three sites are rated as 'Fair' (Sea Harvest, Hoedtjies Bay Hotel and Caravan Park) whilst 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 fairly frequently. Efforts should focus on waste water treatment prior to discharge into the Bok River. Four of the ten monitoring sites within Small Bay did not meet the 80<sup>th</sup> percentile faecal coliform limits for mariculture in 2017. Faecal coliform counts at three out of four sites in Big Bay were well within the 80<sup>th</sup> percentile limits for mariculture in 2017 as were five out of the six Langebaan 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 (with the inclusion of intestinal *Enterococci*), to assess the effectiveness of adopted measures, is also required and should be undertaken at all sites on a bimonthly basis. Reuse of wastewater from the Saldanha WWTW by Arcelor Mittal, which commenced in 2018, is expected to result in a considerable improvement in water quality in Small Bay and will hopefully be reflected in results for next year.

Concentrations of trace metals in marine organisms (mostly mussels) in Saldanha Bay have historically been routinely monitored 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 annual State of the Bay surveys. Data show that concentrations of trace metals are higher along the shore (particularly for lead and cadmium and in 2017, Zinc). Concentrations of trace metals in cultured mussels offshore have in the past been lower (according to data supplied by operators); although concentrations of lead and cadmium were on occasion above the limit for foodstuff, which is concerning. 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 concentration lead points to the need for management interventions to address this issue, as metal contamination poses a serious risk to the health of people consuming mussels. 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, however these have decreased in the latest 2018 survey.

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 2018 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 ( $\leq 0.2\%$ ) 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 2018 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 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 between 2016 and 2018. Key areas of concern regarding trace metal pollution within Small Bay include the Yacht Club Basin where cadmium and copper exceeded recommended thresholds four 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 remain highly enriched relative to historic levels. Recent increases in the concentration of manganese around the ore terminal are also a little concerning. Regular monitoring of trace metal concentrations is thus 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 2018 remain unchanged from 2017 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 1999-2018 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 constraints no survey was conducted in 2016. In the 2018 survey, a total of 99 taxa were recorded from the eight study sites, most of which had been found in previous surveys. The faunal component was represented by 18 species of filter-feeders, 26 species of grazers, and 14 species of predators/scavengers. The algal component comprised 27 corticated (foliose) seaweeds, seven ephemerals, five species of encrusting algae, and two species of kelp. These species are common along much of the South African west coast and many have been recorded by other studies conducted in the Saldanha Bay area. 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 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**

The 2018 seine net survey revealed some concerning trends in juvenile fish populations within the Saldanha Bay and Langebaan Lagoon system. The encouraging signs of recovery of white stumpnose and blacktail in Small Bay in 2016 did not continue through to 2017 and 2018, and white stump abundance remains low throughout the system. 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. Overall fish diversity and overall abundance remains mostly unchanged in Small Bay but overall abundance is dominated by harders, which appear resilient to changes in water quality. Despite the strong elf recruitment in Big Bay evident in the 2016 and 2017 sampling, none were caught in 2018 sampling which suggests that these strong year classes are not yet contributing juveniles to the stock in significant numbers. Silversides were absent in Big Bay in 2018 samples but other species common in Big Bay catches (harders, white stump and Cape sole) were present in comparable numbers to earlier surveys. Harders were present in Langebaan lagoon samples in similar numbers to previous surveys, but catches of all other common species were amongst the lowest recorded to date.

Previously, fish abundance at sites within or in close proximity to the Langebaan MPA appeared to be stable within the observed limits of inter-annual variability. This reflects natural and human induced impacts on the adult population size, recruitment success and natural variations 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 Bay as a whole. 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. Harder recruitment to nearshore nursery areas appears not to have changed significantly over the monitoring period since 1994. A recent stock assessment (Horton 2018) has, however, indicated that the Saldanha-Langebaan harder stock is overexploited and recommended that fishing pressure on this stock need to be reduced (thought effort reduction) and that commercial net gear changes should be implemented to rebuild the stock.

This is similar to the results obtained by Arendse (2011), who found that stock of white stumpnose in the Bay were also severely overexploited, using data collected nearly 10 years ago (2006-2008). 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.* 2017).

The recent discovery of rainbow trout in Kraalbaai (almost certainly escapees from the pilot fish cage farming in Big Bay) is another threat to the indigenous fish fauna in the region. These predatory fish will prey on indigenous invertebrates and fish and could cause irrevocable ecosystem level impacts. These alien fish are highly unlikely though to establish self-sustaining populations in the bay and lagoon due to the lack of suitable spawning habitat (cool, clear fresh water rivers) in the region. At the current experimental scale of fish farming, the number of escapees are not expected to be having highly significant impacts on indigenous fauna. However, at the proposed commercial scale, which also allows for the introduction of salmonids to the bay, impacts of escapees are likely to become far more significant. Given the importance of the nearshore waters of Saldanha Bay and Langebaan lagoon as nursery areas for a number of vulnerable indigenous fishery species, it is recommended that finfish cage farming be restricted to the outer Bay area only, and mitigation measures to minimise escapes from cages should be strictly enforced.

There is now compelling scientific evidence that the stocks of the two most commercially important fish in the Saldanha–Langebaan system, namely white stump and harders, are overexploited. 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 five 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 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. We also support the recommendation of Horton (2018) for a reduction in harder fishing effort and gear changes (increase in minimum mesh size) to facilitate stock recovery which will have socio-economic and ecological benefits.

## **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.

It was not possible to obtain island bird data for the calendar year 2017 from the Department of Environmental Affairs due to a change in the procedure governing the release of data. This component of the chapter was therefore not updated for this year's edition.

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 2 635 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 – 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 recently detected barnacle *Balanus glandula* and the Pacific mussel *Semimytilus algosus*. The latter species was recently shown to occur exclusively sub-tidally in sheltered areas such as Saldanha Bay (Skein *et al.* 2018). Indeed, *S. algosus* is absent in the intertidal zone in Saldanha Bay but has previously been observed on mussel rafts in the Bay. It is therefore recommended that sub-tidal surveys are conducted to ascertain whether populations have indeed established in Saldanha Bay.

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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.

## 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 occurred over the last few decades. Long-term decreases in populations of fish (e.g. white sturgeon) 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.
Groundwater	Water held underground in the soil or in pores and crevices in rock.
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.
Macrophyte	An aquatic plant large enough to be seen by the naked eye.
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.
Paleo-channel	Old or ancient river channels often infilled with coarse fluvial deposits which can store and transmit appreciable quantities of water.
Rhizome	A modified subterranean plant stem that sends out roots and shoots from its nodes.
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 State of the Bay report in 2008, and then annually from this time onwards. This (2018) report is the 11<sup>th</sup> 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 (2017). 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, 2016 and 2017).

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 2018 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 (2017) 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 2017 for more details. Additional and updated information included in the sections of this chapter are listed below:

- Numbers of visitors to the West Coast National Park;
- Metal exports from the Saldanha Bay Multipurpose and iron ore terminals;
- Information on new and existing development proposals for Saldanha (Zandheuveld phosphate mine, and the development of additional vessel repair facilities in the Port of Saldanha);
- Shipping traffic and ballast water discharges;
- Effluent discharges into Saldanha Bay:
  - the volumes and quality of waste water discharged into the Bay from the Saldanha and Langebaan Water Treatment Works, including the details on the effort of the Saldanha Bay Municipality to reclaim freshwater from treated waste water
  - fish processing establishments in Saldanha (new information on environmental monitoring data for Sea Harvest)
- Mariculture industry in Saldanha, including an update on the development of the Aquaculture Development Zone.

### **Chapter 4: Coastal and Environmental Management**

- A summary of the Chapter with reference to previous reports. No update on the individual components is available.

### **Chapter 5: Groundwater**

This is the second year that this new addition appears in 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 and highlights current data from relevant groundwater modelling and literature as well as our own continuous water quality monitoring data.

### **Chapter 6: Water quality**

- New information on variations in temperature, salinity, dissolved oxygen and turbidity in the Bay.
- New updated information on levels of microbial indicators (faecal coliforms and *E. coli.*) in the Bay.
- New updated information on levels of trace metals in mussels on the shoreline and offshore mariculture facilities.
- Trace metals accumulated in bivalve tissue (Bezuidenhout et al. 2015)

### ***Chapter 7: Sediments***

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

### ***Chapter 8: Aquatic macrophytes***

- No new information available.

### ***Chapter 9: Benthic macrofauna***

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

### ***Chapter 10: Intertidal invertebrates (Rocky Shores)***

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

### ***Chapter 11: Fish***

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

### ***Chapter 12: Birds***

- New information on species composition, abundance and health of birds breeding and feeding in Langebaan Lagoon.

### ***Chapter 13: Alien invasive species***

- New information on the number, distribution and abundance of alien invasive marine species in Saldanha Bay and Langebaan Lagoon.
- New published information on relevant alien species ecology, spread, abundance and their ability to impact biodiversity as ecosystem engineers.

## **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 exist 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.

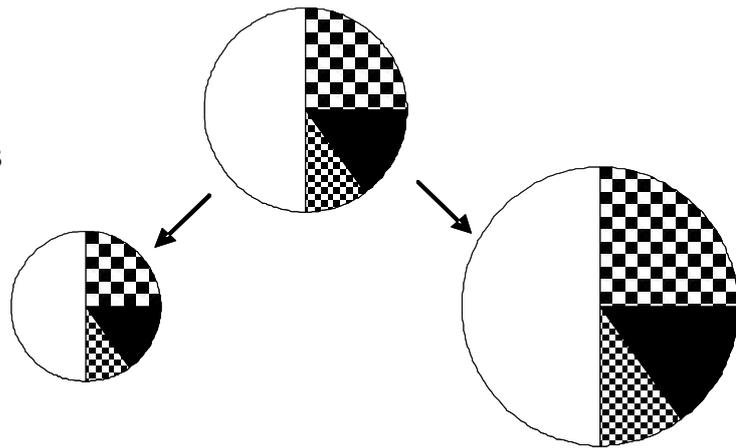
Various physical, chemical and biological factors influence the overall health of the environment. Environmental parameters or indices were selected that can be used to represent the broader health of the environment and are feasible to measure, both temporally and spatially. The following environmental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

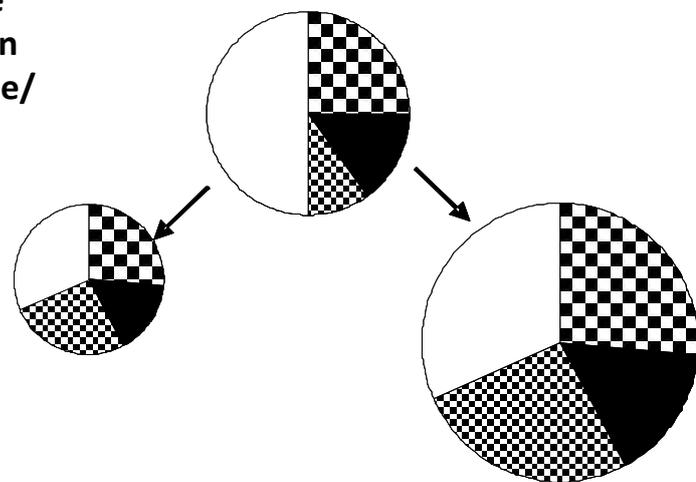
**Water Quality:** Water quality is a measure of the suitability of water for supporting aquatic life and the extent to which key parameters (temperature, salinity, dissolved oxygen, nutrients and chlorophyll a, faecal coliforms and trace metal concentrations) have been altered from their natural state. 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.

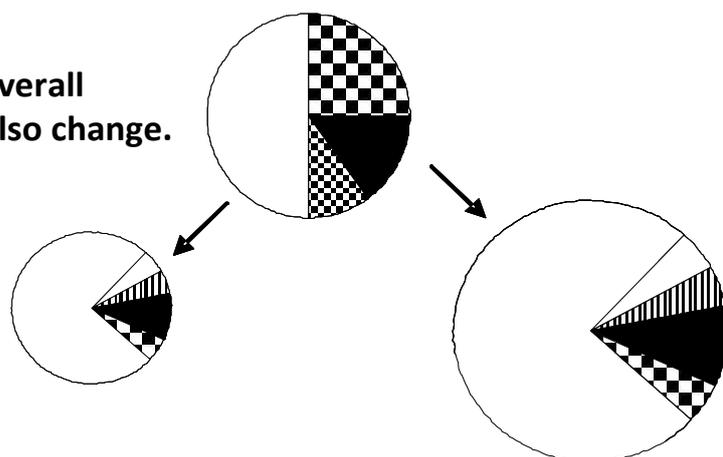
**(a) Species composition remains the same and overall abundance/biomass changes**



**(b) Species present remain the same, community composition changes and overall abundance/biomass may also change.**



**(c) Species and community composition changes and overall Abundance/biomass may also change.**



**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. However, the Transnet Port Terminals have thus far been unsuccessful in obtaining a variation to their existing Air Emission License (AEL) applicable to the Iron Ore Terminal for the storage and handling of coal and ore. The latest application was for the increase of handling and storage of coal and ore to 67 million tonnes per annum and was accompanied by an impact assessment and public participation process. The competent authority denied TPT the amendment concluding that environmental impacts at the current production level are already too high.

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. Until recently sewage discharge was 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 industrial 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 were overcome by means of a public-private partnership. Arcelor Mittal now represents the highest consumer of treated wastewater from the Saldanha Bay Waste Water Treatment Works. Arcelor Mittal constructed a Reverse Osmosis plant, which treats wastewater such that it can be used for cooling steel production equipment.

Ballast water discharges are by far the highest in terms of volume and also continuous due to constant and increasing shipping traffic. Ballast water discharges were more or less static until 2016 and have since increased, which is directly correlated to increased 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. Although no domestic legislation is currently in place to regulate ballast water discharge, the Transnet National Port Authority in Saldanha Bay has implemented a number of mechanisms to track and control the release of ballast water into the harbour.

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. Transnet intends to construct new port infrastructure to support the Industrial Development Zone (IDZ) and dredging activities are likely to commence in the near future.

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 establishing a sea-based Aquaculture Development Zone (ADZ) in Saldanha Bay. The ADZ areas comprise four precincts totalling 420 ha of new aquaculture areas in Saldanha Bay. Currently farmed areas will be incorporated into the ADZ comprising 884 ha set aside for mariculture (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 environmental monitoring of the Bay should be intensified to prevent significant ecological impacts, as well as loss to the mariculture sector itself.

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 were 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 Bay 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.

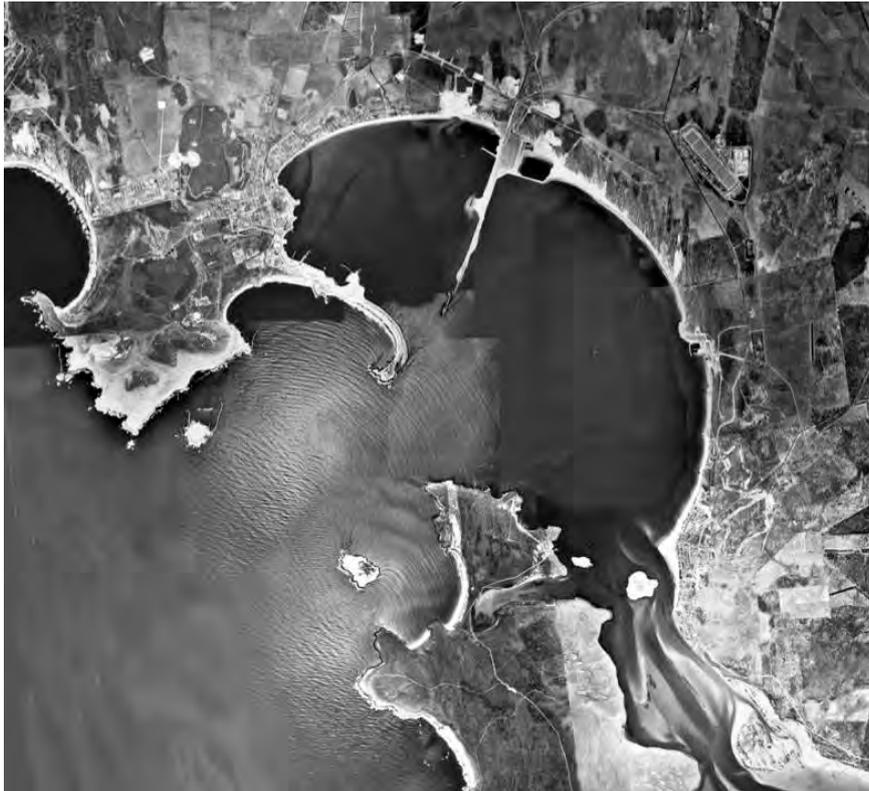


Figure 3.2. Composite aerial photo of Saldanha Bay and Langebaan Lagoon taken in 1989 (Source Department of Surveys and Mapping). Note the presence of the ore terminal, the causeway linking Marcus Island with the mainland, and expansion of settlements at Saldanha and Langebaan.



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.

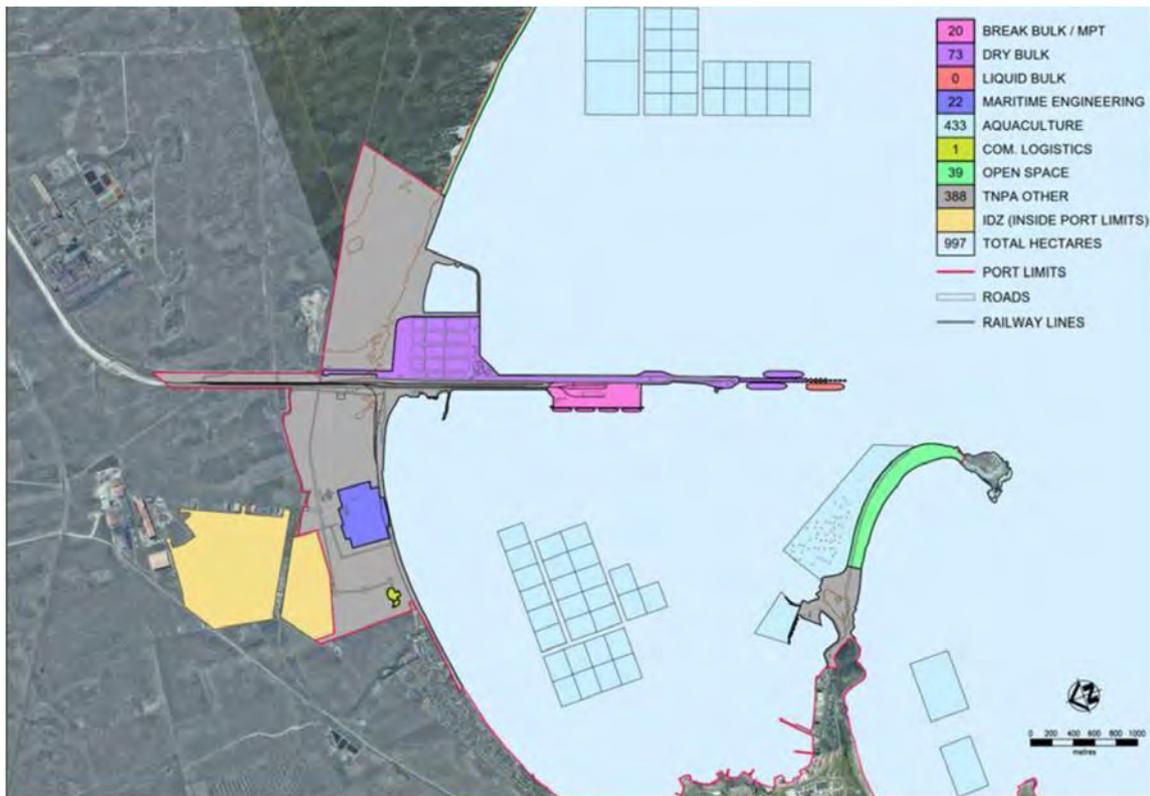


Figure 3.4. Current layout of Transnet Saldanha Bay Port (Source: Transnet National Port Authority 2015, National Port Plans).

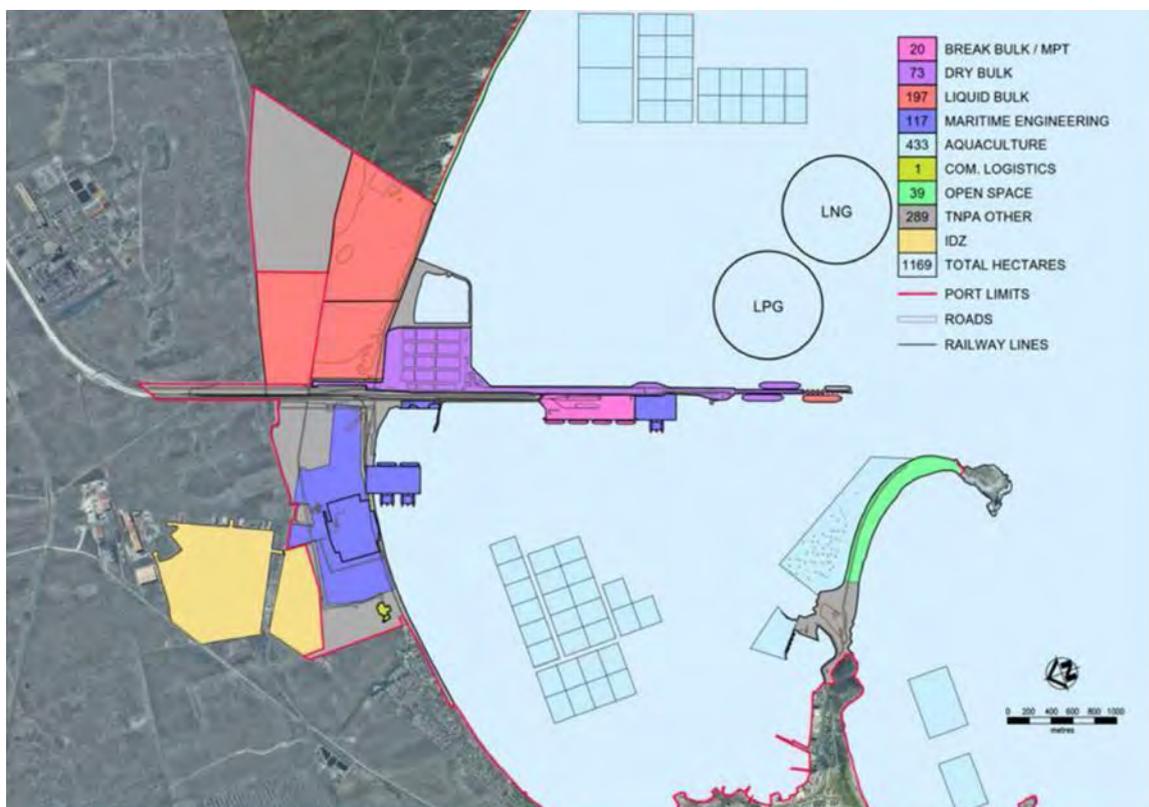


Figure 3.5. Short term layout (2021) of Transnet Saldanha Bay Port (Source: Transnet National Port Authority 2015, National Port Plans 2015).

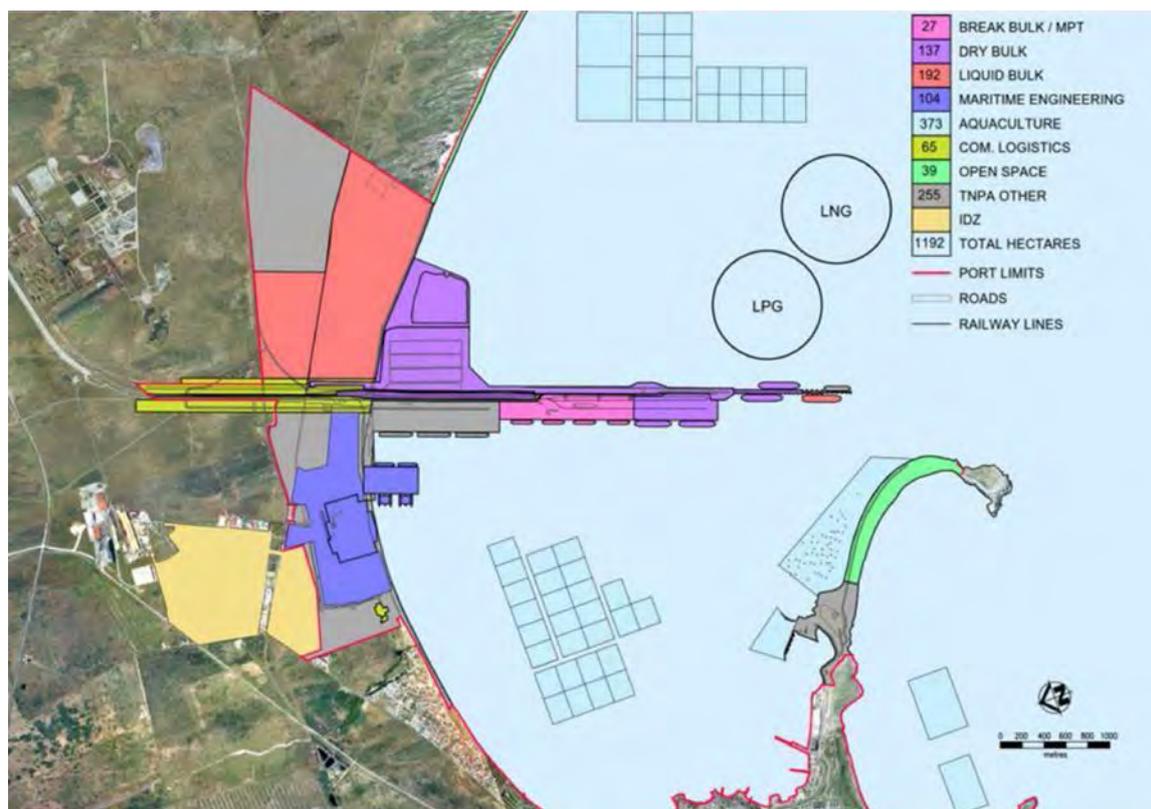


Figure 3.6. Long term layout (2044) of Transnet Saldanha Bay Port (Source: Transnet National Port Authority 2015, National Port Plans 2015).

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%/year) (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.**



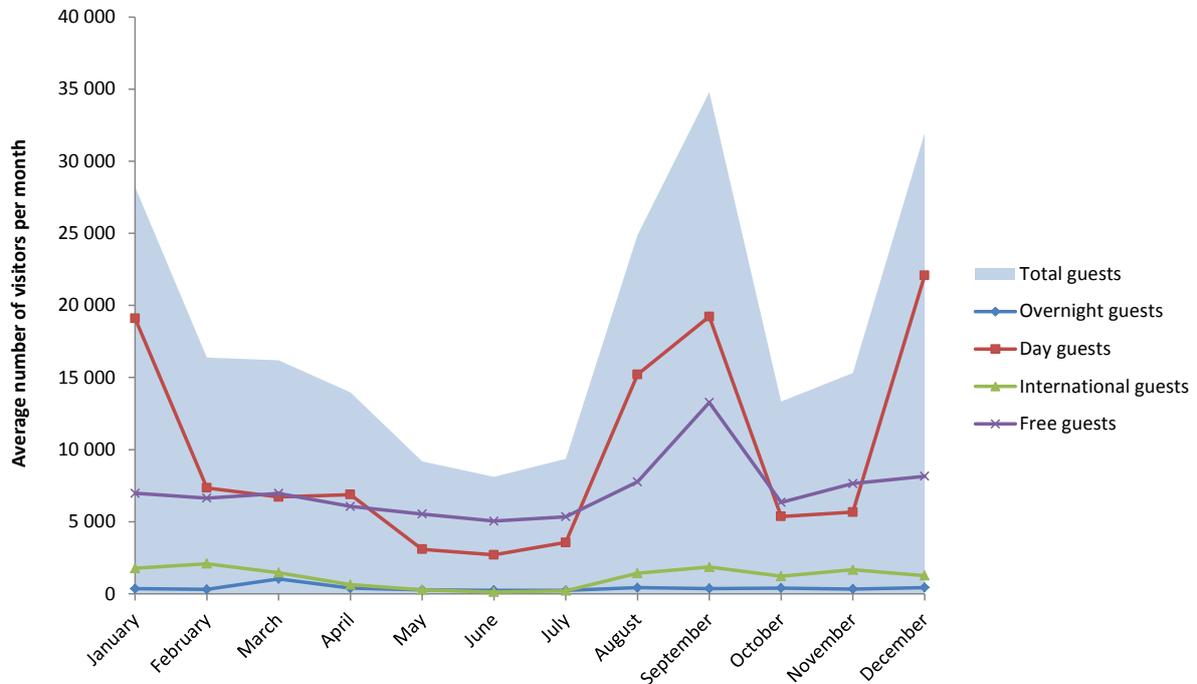
**Figure 3.8.** Composite aerial photograph of Langebaan showing absence of development set-back zone between the town and the lagoon. Source: Department of Surveys & Mapping, South Africa.

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 (2005-2018) 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<sup>1</sup> 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 15% per annum since 2005<sup>2</sup>, peaking in the 2016-2017 period with a total of just over 337 000 visitors (Figure 3.10). The number

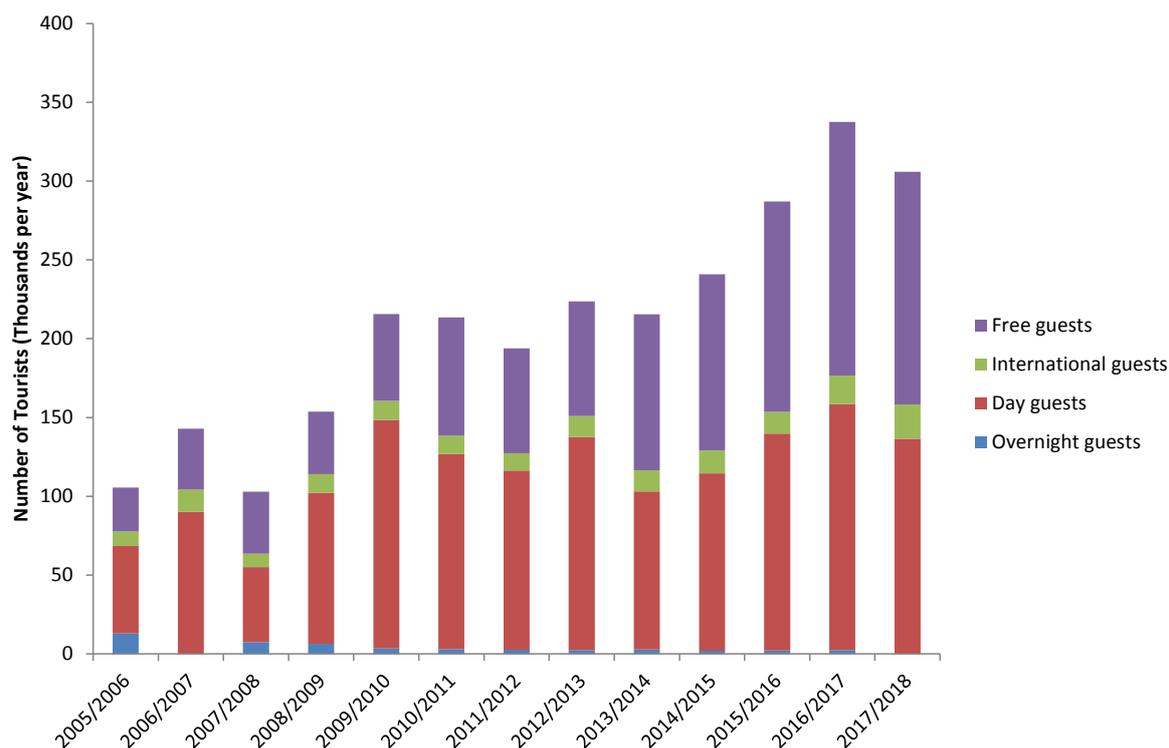
<sup>1</sup> These include Wild Card, school class, military personnel, official visit, staff, residents and 'other' entries.

<sup>2</sup> 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 2018.

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 after 2009, reaching lowest numbers in 2015/2016 with 2 041 guests. However, overnight visitor numbers have increased over the last two years, reaching 4633 visitors in 2017/2018.



**Figure 3.9.** Monthly average numbers of tourists visiting the West Coast National Park between July 2005 and June 2018. 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 2018. 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 of the Industrial Development Zone Programme Regulations (R.1224 of the Manufacturing Development Act (No. 187 of 1993) 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 Licensing 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 adequately 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
<ul style="list-style-type: none"> <li>Maintenance, repair, upgrade and conversion of rigs and other vessels (floating repairs, dry docking)</li> <li>Repair of parts and structures</li> <li>Inspection, certification</li> </ul>	<ul style="list-style-type: none"> <li>Structures, subsea manifolds</li> <li>Spare parts</li> </ul>
Communal Services	Supply & other Services
<ul style="list-style-type: none"> <li>Property development</li> <li>Customs clearance</li> <li>Marketing &amp; administrative functions</li> <li>Security, medical, food &amp; retail</li> <li>Utilities, waste management, transport</li> <li>Road and quay access</li> </ul>	<ul style="list-style-type: none"> <li>Bonded warehousing / storage -</li> <li>Scheduling &amp; forecasting</li> <li>Logistics and transport – sourcing and forwarding (air, ship, rail and road)</li> <li>Lifting, stacking, moving</li> <li>Fuel bunkering</li> <li>Pipe coating &amp; upsetting</li> <li>Tugging / piloting</li> <li>Project and engineering services (e.g. EPC)</li> </ul>

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 were completed this year, which increased the capacity of the plant to 5 ML per day (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 include 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 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.

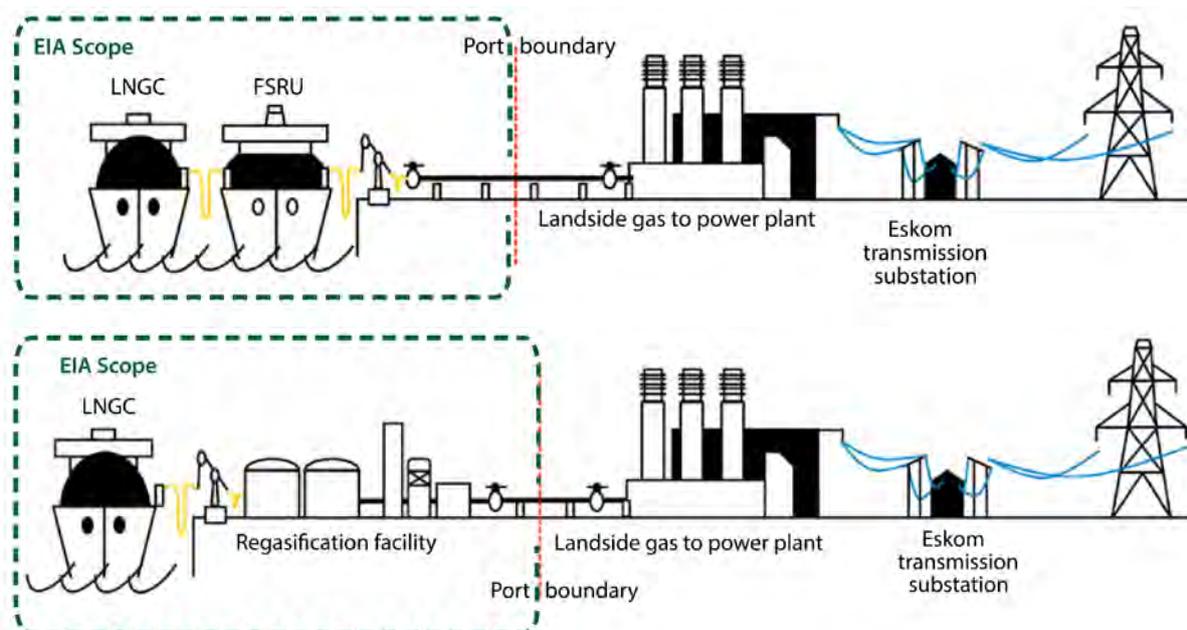


Figure 3.12 An illustration of the floating (top) and land-based (bottom) regasification technology (Source: Background Information Document, ERM 2015a).

### 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 12 km to the east of Langebaan (Braaf 2014). The proposed mining area is located on the Elandsfontyn Aquifer System (EAS) and in close proximity to the Langebaan Road Aquifer System (LRAS). These aquifer systems are defined by palaeo-channels that have been filled with gravels of the Elandsfontyn Formation and represent preferred groundwater flow paths (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 Elandsfontein, 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 halted 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. Kropz intends to recommence operations in late 2019.

Kropz Elandsfontein has adopted a precautionary approach and is carefully monitoring 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. The results are presented in the groundwater and benthic macrofauna chapters (Chapters 5 and 9).

### 3.2.8 Zandheuvel phosphate mine

Adelaide Ruiters Mining & Exploration intends to develop a new phosphate mine 3 km outside of Louwville and 4.5 km north of Bluewater Bay. The intention is to mine phosphate on the Zandheuvel farm Portions 126 and 124, as well as on Witteklip and Yzervarkrug farms. The Mining Right application also includes apatite, quartz, calcite, feldspar, hematite/goethite, ilmenite, rutile, zircon, monazite, schorl (tourmaline), garnet, titanium oxide, limestone, sandstone, rare Earth elements and aggregates. These minerals are likely to be found on site as they are associated with the phosphate deposit in this area. The proposed mining methods are conventional truck and shovel open pit mining and will not include blasting. Backfilling and rehabilitation will decrease the overall environmental footprint of the project.

Water requirements will be met by municipal treated wastewater to reduce the impact of the mining activities on availability of potable water in the area. The mine will require approximately 2 ML per day. The proposed project will include the mine itself, offices, a processing plant and an upgrade to the existing access road to the R79.

The Draft Scoping Report was submitted to the Department of Mineral Resources (DMR) in August 2018. Stakeholders had until 19 September 2018 to comment on the proposed development.

### 3.2.9 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 3.2.9.1-3.2.9.3. The potential impacts on the marine environment associated with the VRF and the Mossgas Jetty are also summarised in Section 3.2.9.4. 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<sup>3</sup>. 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).

### 3.2.9.1 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.

### 3.2.9.2 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).

### **3.2.9.3 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.

### **3.2.9.4 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.



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).

### 3.3 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 3.15). 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 and Figure 3.16). Initially only lead, copper and zinc were exported from the MPT, with lead comprising the largest proportion of the exported material in 2011 (Figure 3.16). 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 134 thousand tonnes (Figure 3.16). Individual annual export volumes for lead, copper and zinc are only available since 2010/11 (Figure 3.16). 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 3.16). 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 MPT. Up until 2016, iron ore comprised on average 58% of the total exports from the MPT, although thereafter the MPT has been primarily used for Manganese exports.

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) and has increased by more than one third each year, totalling nearly 4.5 million tonnes in the 2018 financial year (Figure 3.15), comprising 97% of the total metal exported from the MPT. In 2016, manganese exports from the Saldanha Bay MPT represented 15% of the total amount exported from South Africa.

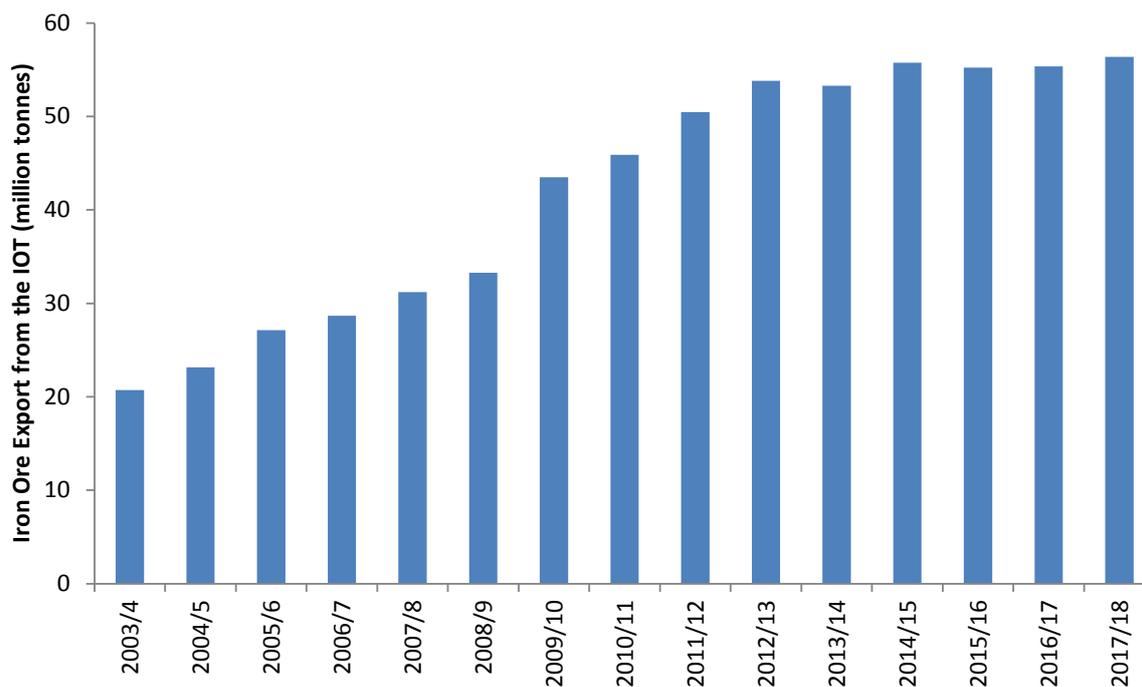


Figure 3.14 Annual exports of iron ore from the iron ore terminal at the Port of Saldanha between April 2003 and March 2018. (Data provided by Rejean Viljoen, Transnet Port Authority 2018).

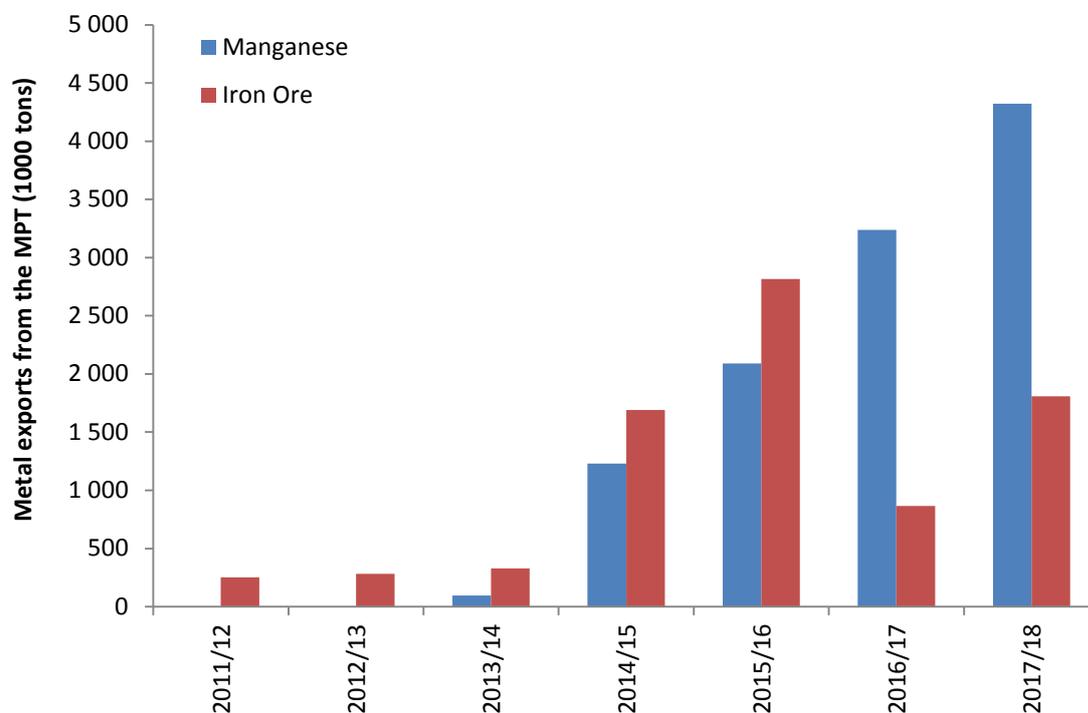


Figure 3.15 Annual exports (April 2011 – March 2018) of manganese and iron ore from the multi-purpose terminal at the Port of Saldanha Bay (Data provided by Rejean Viljoen, Transnet Port Authority 2018).

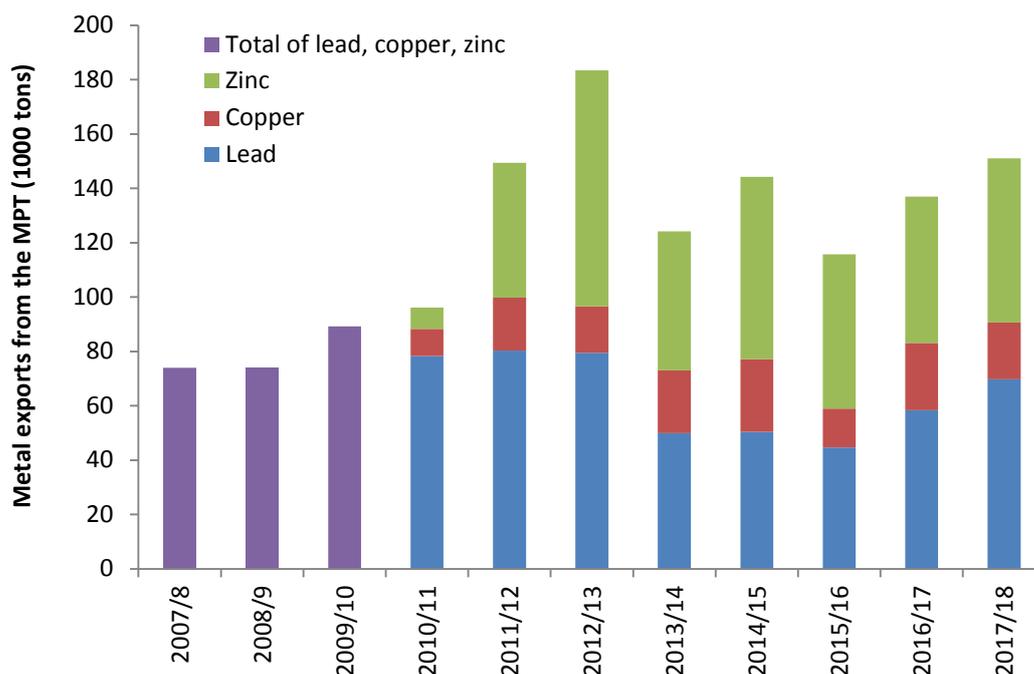


Figure 3.16 Annual exports (April 2007 – March 2017) of lead, copper and zinc from the *multi-purpose terminal* at the Port of Saldanha Bay. Note that separate data for these commodities was only available for April 2010–March 2017 (Data provided by Rejean Viljoen, Transnet Port Authority 2017).

### 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.

The main atmospheric emissions originate from the Iron Ore Terminal and the TPT currently holds a license for the storage and handling of 60 million tons of iron ore per annum. In line with the planned expansions of the iron ore export business, the TPT submitted an application for a variation to the existing AEL to increase the throughput from 60 to 67 million tons on 12 June 2018. As part of this application, TPT was required to submit an Air Quality Assessment Report (dated February 2018) and to conduct a public participation process. The application was denied by the competent authority on 12 September 2018 based on the following reasons. Most importantly, the impact assessment report demonstrated that during the monitoring period, National Dust Control Regulations for residential and non-residential fallout dust rates of 600 and 1200 mg/m<sup>2</sup> per day respectively were exceeded. It was concluded that cumulative impacts going forward would be unacceptable considering the current impact of dust emissions. Furthermore, a total of approximately 400 complaints relating to property staining and 11 complaints regarding spillages were lodged between 2016 and 2018.

Transnet currently holds a Provisional Air Emission License (PAEL) for the storage and handling of ore and coal at the Multi-Purpose Terminal (MPT), which was issued on 26 September 2018 and is valid for period of 12 months. According to the conditions of the PAEL, the holder of the license is entitled to an AEL when the commissioned facility has been in full compliance with conditions and requirements of the PAEL for a period of at least six months. The holder of the license may also choose to extend or renew the PAEL. It is currently not known if Transnet Port Terminals will apply for an AEL. The air quality impact assessment for the MPT conducted by WSP in December 2017 indicated that the annual average and 99<sup>th</sup> percentile of PM<sub>10</sub> (coarse particles smaller than 10 micrometres in diameter) and PM<sub>25</sub> concentrations associated with the storage of manganese remain well below the relevant National Ambient Air Quality Standard in Saldanha Bay. However, the study also found that annual average manganese concentrations are predicted to exceed the annual World Health Organisation manganese guidelines at Bluewater Bay and the Saldanha Caravan Park, with annual average concentrations remaining below the guideline for other sites in the Bay.

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 18<sup>th</sup> 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<sup>3</sup> of sediment was dredged during the establishment of the ore terminal;
- 1996-1997: 2 million m<sup>3</sup> of sediment was removed for the expansion of the multi-purpose terminal;

- 2005-2007: 380 000 m<sup>3</sup> sediment removed from Big Bay for the nourishment of Langebaan Beach
- 2007-2008: 50 000 m<sup>3</sup> of sediment was removed for maintenance of the Moss gas quay and multi-purpose terminal; and
- 2009-2010: 7300 m<sup>3</sup> 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<sup>3</sup> 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<sup>3</sup> 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 Moss gas 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).

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 6 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 for information).

**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

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 Draft Bill has not yet been promulgated and was recently released for public comment (extension was granted on 10 February 2017). The Department of Transport is the authority responsible for administration of this Act.

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

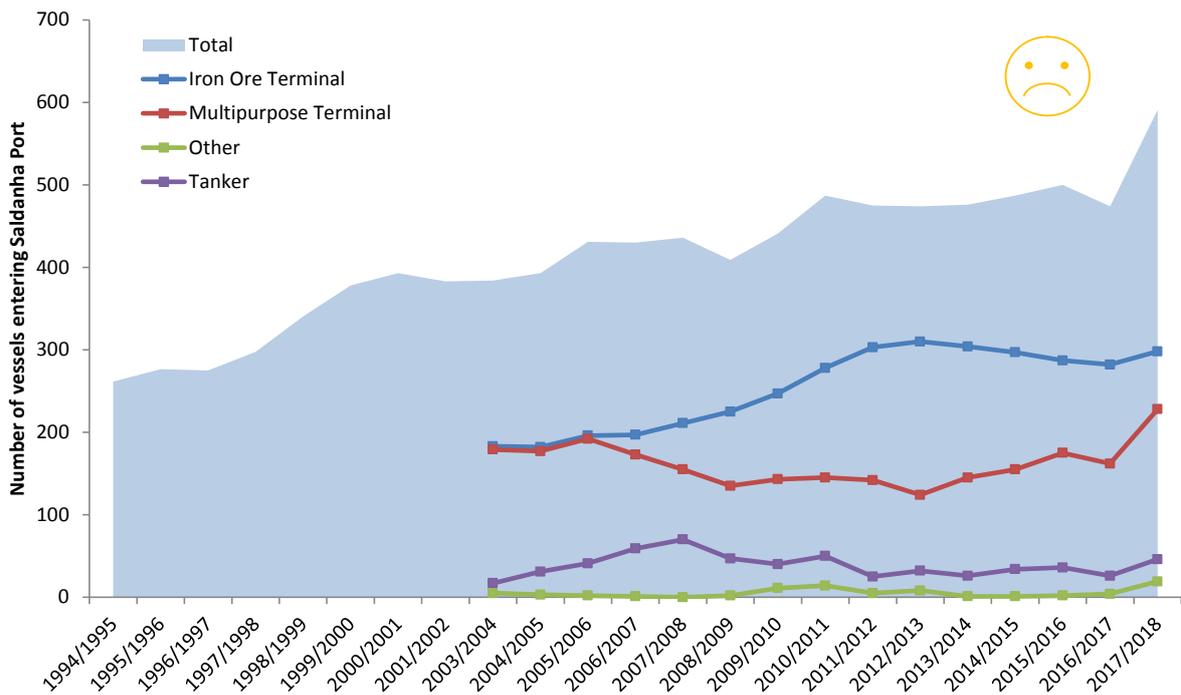
Although no domestic legislation is currently in place to regulate ballast water discharge, the Transnet National Port Authority in Saldanha Bay implements the following measures to control the release of alien species into the harbour:

Procedure to follow when granting permission for international vessels to enter the Port of Saldanha:

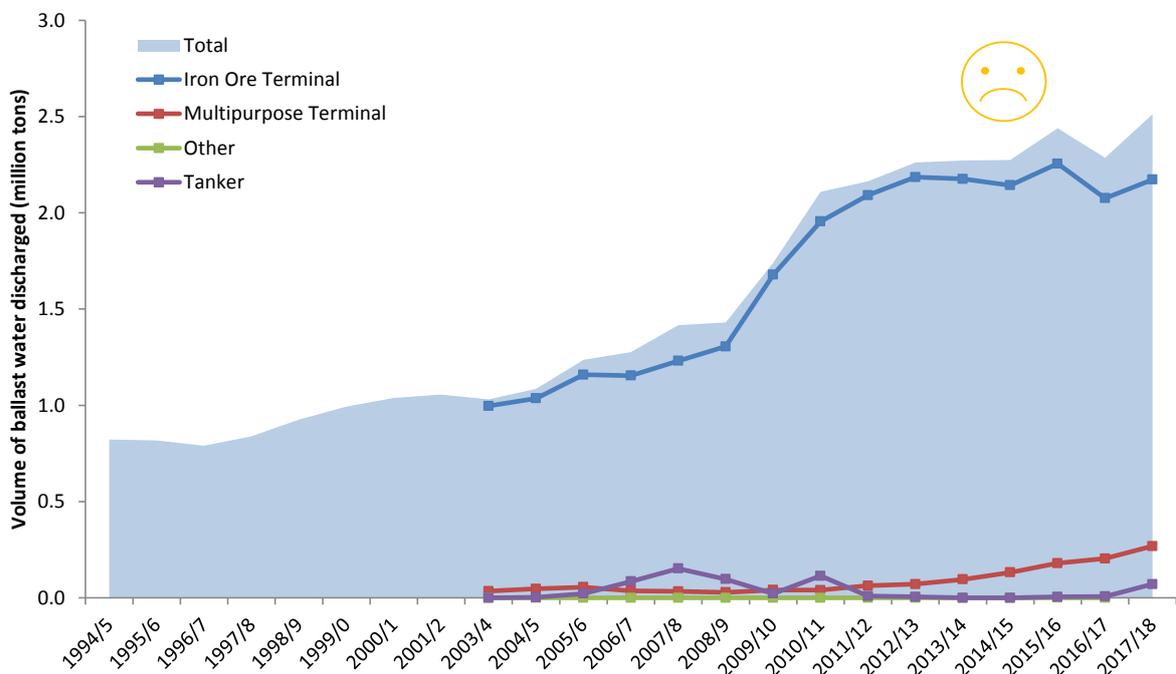
1. The agent shall request, 72 hours in advance, permission for de-ballasting operations.
2. The TNPA Pollution Officer or the Marine Safety Specialist shall grant or declined permission after scrutinizing the Ballast Water Reporting Form, Ship Particulars & Port of Call list.
3. The TNPA must confirm the ballast water intake location.
4. The Pollution Officer shall board the vessel and check the relevant documentation and seal all overboard valves with a unique TNPA seal.
5. TNPA may board the vessel and check the running hours of the ballast water pump against the ballast water logbook should there be any concern regarding the ballast water of the vessel.
6. Should the vessel not comply with the Harbour Master's written Instructions or the IMO requirements, the TNPA shall request the Captain of the vessel to comply before permission is granted to conduct de-ballasting operations at the Port of Saldanha.

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 more than doubled in the last two decades with 591 ships visiting the port between July 2017 and June 2018 (Figure 3.17). The number of vessels entering the port stabilised between 2011 and 2017 and increased by over 100 vessels last year. 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 25.1 million tonnes of ballast water being discharged between July 2017 and June 2018 (Figure 3.18). 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 3.17 and Figure 3.18).



**Figure 3.17.** The numbers and types of vessels entering Saldanha Port. The total number of vessels entering Saldanha Port between July 1994 and June 2018 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 3.18** Volumes of ballast water discharged into Saldanha Port. The total amount of ballast water discharged in Saldanha Port between the years 1994 and June 2018 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 aculeatus*) (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 3.5.). 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. The revised Water Quality Guidelines will be published for comment within the next few months.

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.

Effluent discharges into the coastal waters were previously regulated in terms of the National Water Act (Act No 36 of 1998) (NWA). The NWA categorised the discharging of waste or water containing waste into a “water resource through a sea outfall or other conduit” as a “water use” for which a “licence” was required, unless such use was authorised through a “general authorisation” indicated by a notice published in the *Government Gazette*.

With the promulgation of the National Environmental Management: Integrated Coastal Management Act (No. 24 of 2008) (ICMA) (as amended<sup>3</sup>), 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 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<sup>4</sup>), and required that they applied for a CWDP within three years of promulgation of the ICMA. In practice though, not all operations that

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<sup>3</sup> ICMA was amended by the National Environmental Management: Integrated Coastal Management Amendment Act, 2014 (Act No. 36 of 2014) (ICMAA).

<sup>4</sup> The latest revision of the General Authorisation was promulgated on 6 September 2013 (Government Gazette No. 36820).

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 for the receiving environment. 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 implementing a permitting system for such effluent discharges. The Assessment Framework for the Management of Effluent from Land Based Sources Discharged to the Marine Environment (AEC 2015) provided a road map for the development of regulations for the permitting system. 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).

In March 2018 the DEA:O&C published Draft Regulations for comment. The new draft regulations seek to provide an administrative framework to implement Section 69 of the ICMA and stipulate time-frames, renewal application processes, applicable fees and information to be submitted as part of an application for a CWDP. The regulations have not yet been promulgated.

To date, five CWDPs have been issued to companies discharging effluent into Saldanha Bay and three applications are currently pending. A list of these and other relevant information has been included in Table 3.4.

**Table 3.4 Pending applications for Coastal Waters Discharge Permit and issued permits for effluent discharges into Saldanha Bay.**

Applicant/permit holder	Status	Type of discharge	Impact level	Compliance
OTMS Mogs Saldanha	Permit granted	Hydrostatic testing	low	N/A
ArcelorMittal Saldanha Steel	Permit granted	Reverse Osmosis	low	No compliance monitoring results submitted
Sea Harvest Corporation (Pty) Ltd	Permit granted	Fish processing effluent and brine	Medium-high	Non-compliant, looking into alternative discharge location following a dispersion modelling study
Sunrise Energy (Pty) Ltd	Permit granted	Once off discharge	low	N/A
Transnet State Owned Company (SOC) Ltd	Permit granted	Desalination (brine)	Medium-high	No compliance monitoring results submitted
Saldanha Oyster	Decision pending	Holding facility	low	N/A
Oceana Lobster Saldanha	Decision pending	Unknown (processing/holding facility?)	Unknown	N/A
Saldanha Municipality WWTW – Proposed upgrade	Pending (incomplete application)	Treated wastewater	Medium-high	N/A

**Table 3.5. 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 $\pm 1$ °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)	<p>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;</p> <p>Water should not contain materials from non-natural land-based sources which will settle to form putrescence;</p> <p>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</p>			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	<p>Should not be more than 35 <i>Hazen units</i> above ambient concentrations (colour)</p> <p>Should not reduce the depth of the euphotic zone by more than 10 % of ambient levels measured at a suitable control site (turbidity)</p>			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 <sup>-1</sup> (99 % of the time) and below 6 mg l <sup>-1</sup> (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 <sup>-1</sup> (99 % of the time) and below 6 mg l <sup>-1</sup> (95% of the time)	N/A

	Natural Environment	Industrial Use	Mariculture	Recreational Use
NUTRIENTS				
Ammonium	600 (NH <sub>3</sub> plus NH <sub>4</sub> <sup>+</sup> )	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 <i>Dissolved oxygen</i>		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 <i>Dissolved oxygen</i>			
Nitrate				
Reactive phosphate				
Reactive silicate				
INORGANIC CONSTITUENTS				
Ammonia	20 µg N l <sup>-1</sup> (as NH <sub>3</sub> ) 600 µg N l <sup>-1</sup> (as NH <sub>3</sub> plus NH <sub>4</sub> <sup>+</sup> )	-	20 µg N l <sup>-1</sup> (as NH <sub>3</sub> ) 600 µg N l <sup>-1</sup> (as NH <sub>3</sub> plus NH <sub>4</sub> <sup>+</sup> )	N/A
Cyanide	12 µg l <sup>-1</sup>	-	12 µg l <sup>-1</sup>	
Fluoride	5000 µg l <sup>-1</sup>	-	5 000 µg l <sup>-1</sup>	
Chlorine	-	-	-	
Hydrogen sulphide	-	-	-	
Arsenic	12 µg l <sup>-1</sup>	-	12 µg l <sup>-1</sup>	
Cadmium	4 µg l <sup>-1</sup>	-	4 µg l <sup>-1</sup>	
Chromium	8 µg l <sup>-1</sup>	-	8 µg l <sup>-1</sup>	
Copper	5 µg l <sup>-1</sup>	-	5 µg l <sup>-1</sup>	
Lead	12 µg l <sup>-1</sup>	-	12 µg l <sup>-1</sup>	
Mercury	0.3 µg l <sup>-1</sup>	-	0.3 µg l <sup>-1</sup>	
Nickel	25 µg l <sup>-1</sup>	-	25 µg l <sup>-1</sup>	

	Natural Environment	Industrial Use	Mariculture	Recreational Use
Silver	5 µg l <sup>-1</sup>	-	5 µg l <sup>-1</sup>	
Tin	-	-	-	
Zinc	25 µg l <sup>-1</sup>	-	25 µg l <sup>-1</sup>	
ORGANIC CONSTITUENTS				
Organotins (Tributyltin)	-	-	-	N/A
Total petroleum hydrocarbons	-	-	-	
Polycyclic aromatic - hydrocarbons	-	-	-	
MICROBIOLOGICAL INDICATOR ORGANISMS				
Faecal coliforms (including <i>E. coli</i> .)	-	-	Maximum acceptable count per 100 ml: 20 in 80 % of the samples 60 in 95 % of the samples	
Intestinal Enterococci <sup>1</sup>				
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)
<i>Escherichia coli</i> <sup>1</sup>				
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 <sup>2</sup>				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 3.6. 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 plants

Reverse Osmosis is used to re-claim potable water from fresh, brackish or saline water. Desalination specifically 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 if potable water is reclaimed from seawater 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 dibromonitripropionamide 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 Voëlvllei 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<sup>3</sup> (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<sup>3</sup>/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.

### **3.6.2.3 ArcelorMittal RO plant**

ArcelorMittal is a largely export-focussed steel plant, producing high quality ultra-thin Hot Rolled Coil (UTHRC) and located close to the deep-sea port of Saldanha ArcelorMittal Saldanha operations currently require approximately 6 500 m<sup>3</sup>/day of freshwater at present, representing approximately 25% of Saldanha Bay municipality potable water total usage. ArcelorMittal Saldanha modified its existing water treatment infrastructure to partially replace its current fresh water supply with treated municipal sewage waste water (from the Saldanha Waste Water Treatment Works (WWTW)) and groundwater. The intention is to use 3600 m<sup>3</sup> wastewater from the Saldanha WWTW.

Under normal circumstances installation of such a plant would require an application for Environmental Authorisation in terms of the National Environmental Management Act (NEMA) – i.e. an Environmental Impact Assessment (EIA). However, owing to the prevailing drought in the Western Cape and the fact that the Saldanha Bay Municipal Area was declared a Disaster Area by the Saldanha Bay Council on 15 June 2017, the Department of Environmental Affairs and Development Planning (DEA&DP) has issued a S30A Directive which exempts private sector water provision interventions from having to undertake EIAs for projects of this nature (if their project is included on the Municipality's Water Intervention Plan which is a separate process). However a Coastal Waters Discharge Permit (CWDP) is still required for disposal of the effluent to the marine environment in terms of the NEMA: Integrated Coastal Management Act (ICMA 2009).

The effluent produced by the Reverse Osmosis plant is near fresh and any contaminants (including harmful pathogens) are removed in the treatment process. Sludge that is produced during the groundwater and wastewater treatment process is discarded at a registered landfill site. ArcelorMittal has been granted a CWDP for the discharge of the effluent into Saldanha Bay off the "Oyster Dam" wall. Phase two of this project will involve the construction of an additional Reverse Osmosis (RO) plant, and the amendment of the current CWDP for additional discharge through their existing infrastructure.

### 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<sub>2</sub>/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 growth, 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 as 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  $\mu\text{mol}$  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 and Langebaan

There are two wastewater treatment works (WWTW) that produce treated effluent which used to enter the Saldanha/Langebaan marine environment, namely the Saldanha WWTW and the Langebaan WWTW. 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. 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). 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 in Sections 3.6.3.3 and 3.6.3.4, which present data on monthly trends in the effluent produced 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

In the case of the Saldanha Bay WWTW, 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 3.6.).

As the global climate pattern termed El Niño Southern Oscillation<sup>5</sup> weakens, most of the country has been able to recover from the worst drought since 1904. The Western Cape, however, continues to struggle to meet water demands in the province. Water shortages will be a reality for many years to come, as several years of above-average rainfall conditions and continued conservative use of drinking water 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 (SBM). This critical situation brought industry and local municipalities together to investigate the feasibility of re-using treated wastewater and/or reclaiming industrial grade or even potable freshwater from treated sewage by means of further treatment. Initially wastewater was supplied without further treatment to be used for dust suppression at various construction sites (total allocation of 540 m<sup>3</sup>/day), the Blouwaterbaai Lodge (60 m<sup>3</sup> per day), and Saldanha Sports Grounds (300 m<sup>3</sup> per day).

Industry in Saldanha Bay also expressed the need for high quality recycled water and motivated for the supply of free treated wastewater by the SBM, which would then be treated by means of Reverse Osmosis to suit the needs of industry. Similar projects implemented elsewhere in South Africa demonstrated that major infrastructural changes were required for the re-cycling of treated sewage and were associated with significant initial as well as ongoing fiscal investments (Refer to AEC 2017 for more detail on the water reclamation project implemented by Veola Water Services in Durban). Local municipalities experience significant budgetary constraints, and a public-private partnership has been the key for successful implementation in Saldanha Bay. Considering the water shortage and the environmental impacts associated with the discharge of WWTW effluent, this was conceived as an attractive opportunity.

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<sup>5</sup> 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.

In Saldanha Bay the most important partnership for the re-use of treated effluent was established between the SBM and ArcelorMittal Saldanha Works (Refer to Section 3.6.2.3 for more information). In June 2018 the SBM announced that all effluent, with the exception of 60 m<sup>3</sup> discharged into the Bok River for Blouwaterbaai Lodge would be supplied to ArcelorMittal. Due to the agreement between ArcelorMittal and the SBM, little to no treated effluent originating from the Saldanha Bay Waste Water Treatment Works currently enters the marine environment.



**Figure 3.19** Emergency generators that have been installed at various pump stations in Saldanha Bay and Langebaan Lagoon (Source: SBM, Gavin Williams, 2016).

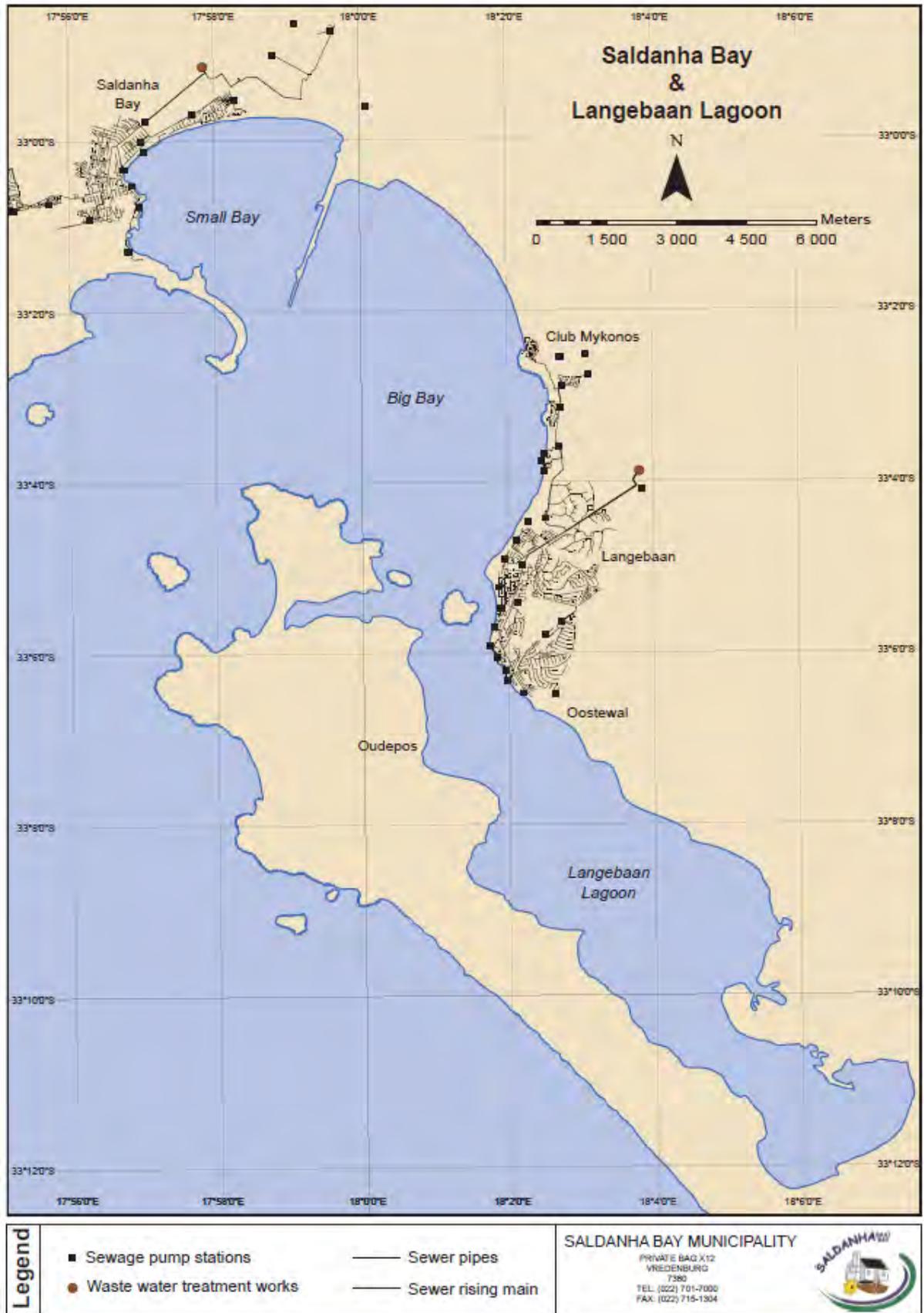


Figure 3.20. Location of wastewater treatment works, sewage pump stations and sewer pipes in the Saldanha and Langebaan area in 2014 (Source: Saldanha Bay Municipality, Elmi Pretorius 2014).

### 3.6.3.3 Saldanha Wastewater Treatment Works

The Saldanha Bay WWTW treats raw sewage by means of activated sludge with mechanical aeration and drying beds. 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

The effective functioning of WWTW is largely dependent on the quality of contributor effluent and sewage that is directed into the plant. Local by-laws control to which extent industries have to treat their effluent before it is directed into municipal wastewater treatment works. New by-laws have been put in place, which requires contributors to agree on the amount and quality of effluent to be discharged into the municipal stream. Strict monitoring of effluent volumes and quality has been implemented and penalties are levied for transgression of the signed agreement (Gavin Williams *pers. comm.* 2018).

The capacity of the Saldanha Bay WWTW was increased to 5 ML to accommodate the projected increase wastewater production, especially with the establishment of the Saldanha Bay Industrial Development Zone (IDZ). Various other improvements to the plant were also implemented to ensure that the treated wastewater is of acceptable quality (refer to AEC 2017 for more details). The IDZ funded and managed this project. Fire damage to the newly installed Motor Control Centre (MCC) in October 2017 has been causing operational problems at the plant. The MCC is currently being manufactured and will be installed as soon as possible.

The plant now requires an updated Water Use License (WUL) to ensure compliance with the NWA. Originally, 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<sup>3</sup> 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 3.6.). The SBM has applied for a new Water Use License for the upgrades required to accommodate the Industrial Development Zone.

The WWTW in Saldanha originally disposed of all their treated effluent into the Bok River which drains into Small Bay adjacent to the Blouwaterbaai Resort and has been dry for at least the last ten years. However, in response to the serious drought that the Western Cape has been experiencing since 2014, the SBM has made the treated wastewater available for irrigation, dust suppression, water features, and industrial cooling processes. Little to no effluent has entered the marine environment as a result.

Before 2008, the average daily volume discharged never exceeded the average daily limit of 2625 m<sup>3</sup>, but volumes of effluent released increased steadily over time (Figure 3.21.). Between the years 2008-2012, the Saldanha WWTW was non-compliant only during the winter months. Between January 2013 and March 2018 however, the average daily limit was exceeded 70% of the time, reaching unprecedented levels of 3452 m<sup>3</sup> effluent in August 2014. It is important to note though that the WWTW plant capacity was upgraded to 5000 m<sup>3</sup> some time ago, which means that the effluent quality was not compromised despite regular exceedance of the legal limit. Finally, wastewater volumes treated at the Saldanha Bay WWTW decreased in 2017/2018 due to the water restrictions implemented by the SBM.

The annual State of the Bay Report normally reports on the amount of effluent produced and therefore discharged into the Bay. Together with the effluent volumes, the report also shows a long-term trend in effluent quality and compliance with the GA. However, it is currently unknown when exactly the SBM started allocating treated effluent to different users, thereby dramatically reducing the amount of effluent that is discharged into the otherwise dry Bok River. Overall, based on the information provided by Gavin Williams and ArcelorMittal it appears that the SBM has not been producing enough wastewater to meet the demand by the various users. It is therefore assumed that only 60 m<sup>3</sup> of effluent has been released into the Bok River per day for the abstraction by the Bluewater Bay Lodge downstream. The SBM intends to start monitoring the effluent quantity that is released into the Bok River, which has been dry for at least the last 10 years. It is recommended that Blouwatersbay Lodge starts recording the amount extracted as soon as possible, as this would assist in more accurate estimation of the actual effluent entering the marine environment per day. It is noteworthy that with the new wastewater management scheme, the amount of wastewater entering the marine environment is likely to be negligible and that contribution to pollution will be insignificant. The changes implemented by the SBM are therefore significantly positive and in future interpretation of water quality results must take into account that very little effluent is entering the marine environment.

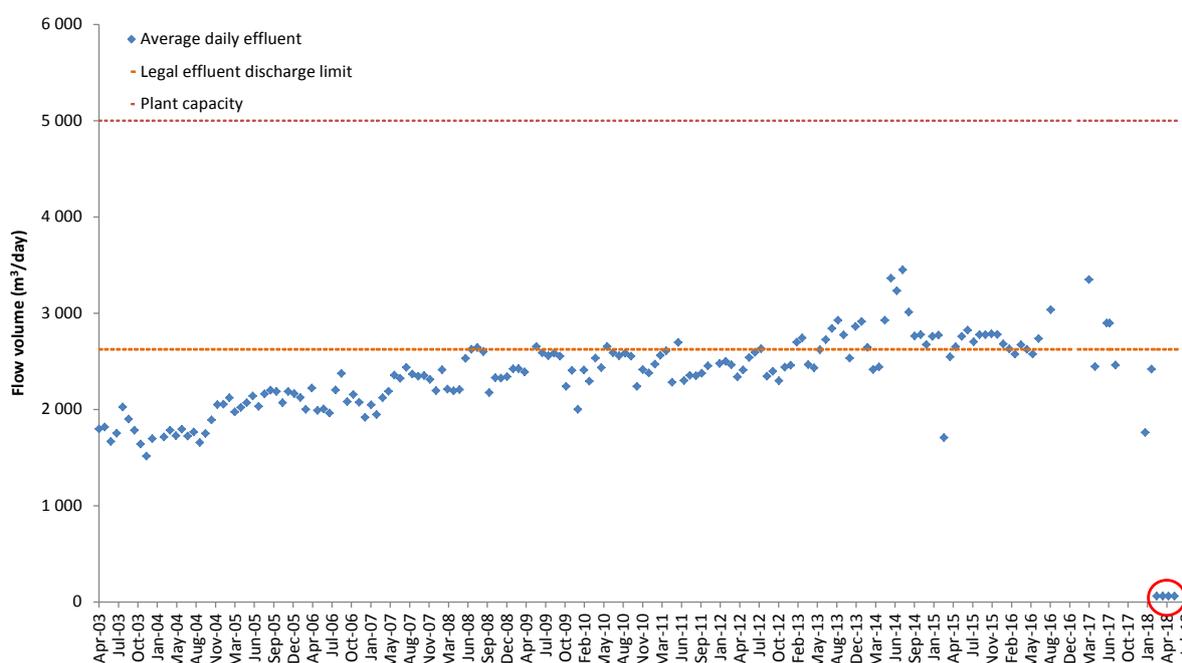
The annual State of the Bay report will continue to report on the effluent quality of the WWTW over time. This year's results in relation to historic data are shown in the graphs below.

Concentrations of faecal coliforms in the effluent from the WWTW exceeded the allowable limit of 1000 org/100 ml on 39 occasions since 2003 (22% of the time) (Figure 3.22). The frequency of non-compliance increased dramatically in 2008, although at a lower concentration (3000 org/100 ml) than previously recorded. Allowable limits for faecal coliforms in the effluent were exceeded on 16 occasions since January 2013, 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).

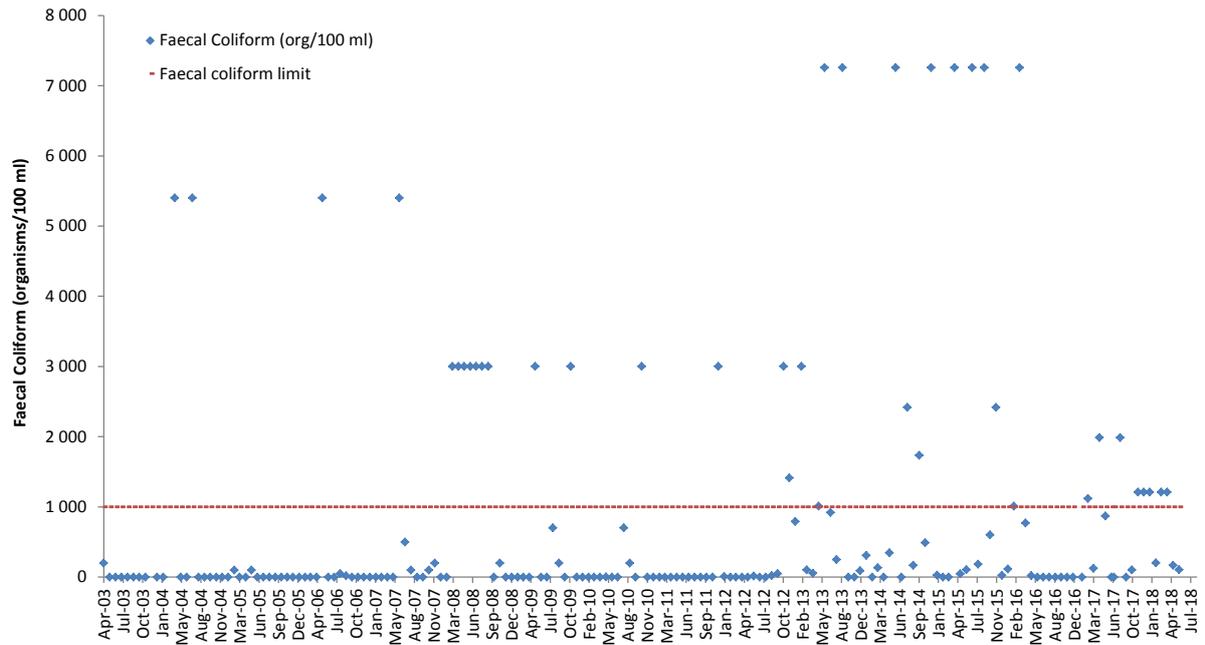
Although some improvement was evident for the period July 2016-June 2017, the legal limit was exceeded on 6 occasions, which means that the Saldanha Bay WWTW was only compliant 50% of the time (Figure 3.22).

Allowable limits for total suspended solids (TSS) of 25 mg/l have been exceeded 17% of the time since April 2003 (Figure 3.36). While compliance clearly improved between 2008 and 2014, the allowable limit has been exceeded 44% of the time since December 2014. Overall, some improvement is evident since July 2016, except for readings in November and December 2016 and 2017, where TSS levels reached around 50 mg/L (overall compliance is 71%). Major improvements would still be required to prevent exceedance of the legal limit.

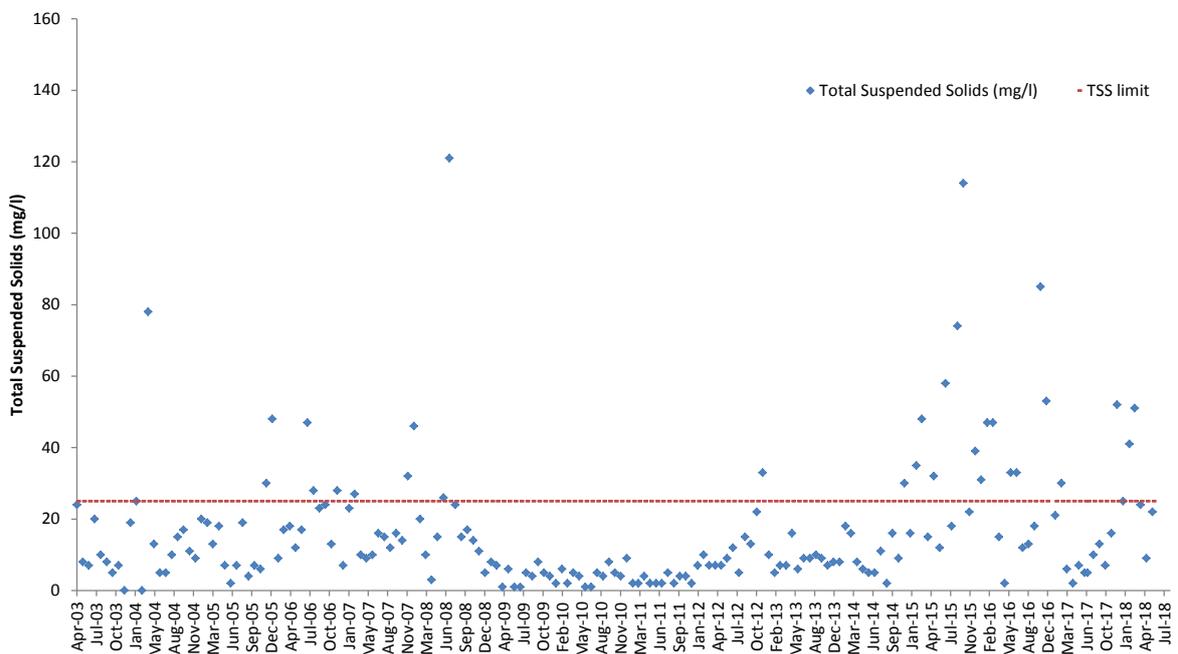
Chemical oxygen demand (COD) in filtered effluent exceeded the allowable limit of 75 mg/l 16% of the time since April 2003 (Figure 3.24). COD is commonly used to indirectly measure the amount of organic material in water. COD was highest from June-October 2008 peaking at 260 mg/l in July 2008. This trend coincided with the high faecal coliform counts in the effluent over the same period. Overall, compliance improved substantially between January 2009 and June 2017 where the allowable limit was only exceeded on ten occasions at a much lower magnitude than in 2008. However, the effluent has not met the COD limit since November 2017, with an average of  $78.65 \pm 29.31$  mg/L. These observations are congruent with high ammonia nitrogen, faecal coliform and free chlorine levels.



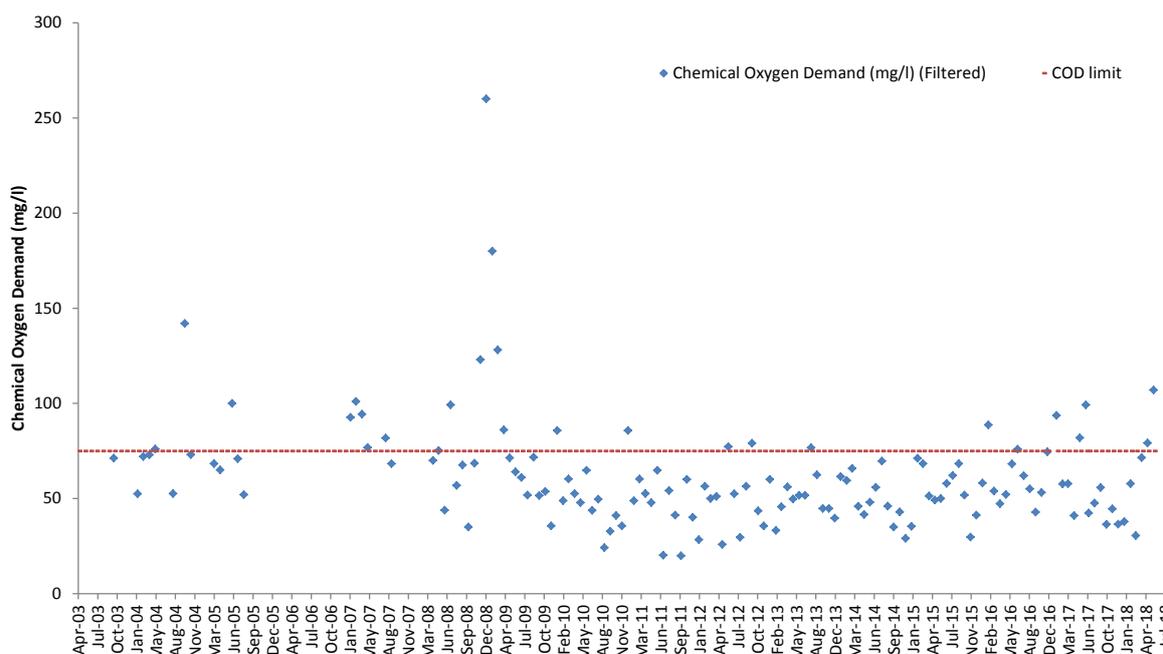
**Figure 3.21.** Trend in average daily effluent ( $\text{m}^3/\text{month}$ ) released from the Saldanha Wastewater Treatment Works, April 2003-June 2018. Allowable discharge limits in terms of the exemption issued by DWS under the National Water Act (No. 36 of 1998) are represented by the dashed orange line and the design capacity of the plant by the red line (Source: Saldanha Bay Municipality). The data points circled in red represent the estimated effluent discharged into the Bok River ( $60 \text{ m}^3$  per day) (*pers. comm.* Gavin Williams 2018).



**Figure 3.22** Monthly trend in Faecal Coliforms (org/100ml) 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 3.23** 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 3.24** 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 treated wastewater of the Saldanha WWTW as readings exceed the allowable limit of 6 mg/l, 80% of the time (Figure 3.25). Ammonia levels reached the highest concentration ever recorded at the beginning of 2018 (Jan, Feb and Mar) reaching 89 mg/L in two consecutive months. These levels are even higher than those recorded in 2016 (65 mg/L). The Saldanha Bay WWTW has not been compliant with the legal limit since August 2017 (average reading of  $48.2 \pm 34.6$  mg/L). Although only very little effluent is released, ammonia is toxic to aquatic organisms and such high concentrations should not be permitted to be released into the Bok River.

The Nitrate-Nitrogen limit of 15 mg/l was exceeded 16% 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 3.26). 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 non-toxic Nitrate-Nitrogen by means of bacterial treatment processes. Conversely, low nitrate nitrogen levels since August 2017 mirror extremely high levels of ammonia nitrogen indicating the lack of bacterial treatment.

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 six occasions, most recently in August to October 2017 (Figure 3.27). However, concentrations have remained just below the legal limit since then.

Permissible chlorine levels of 0.25 mg/l have been exceeded 62% of the time (Figure 3.28) 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.

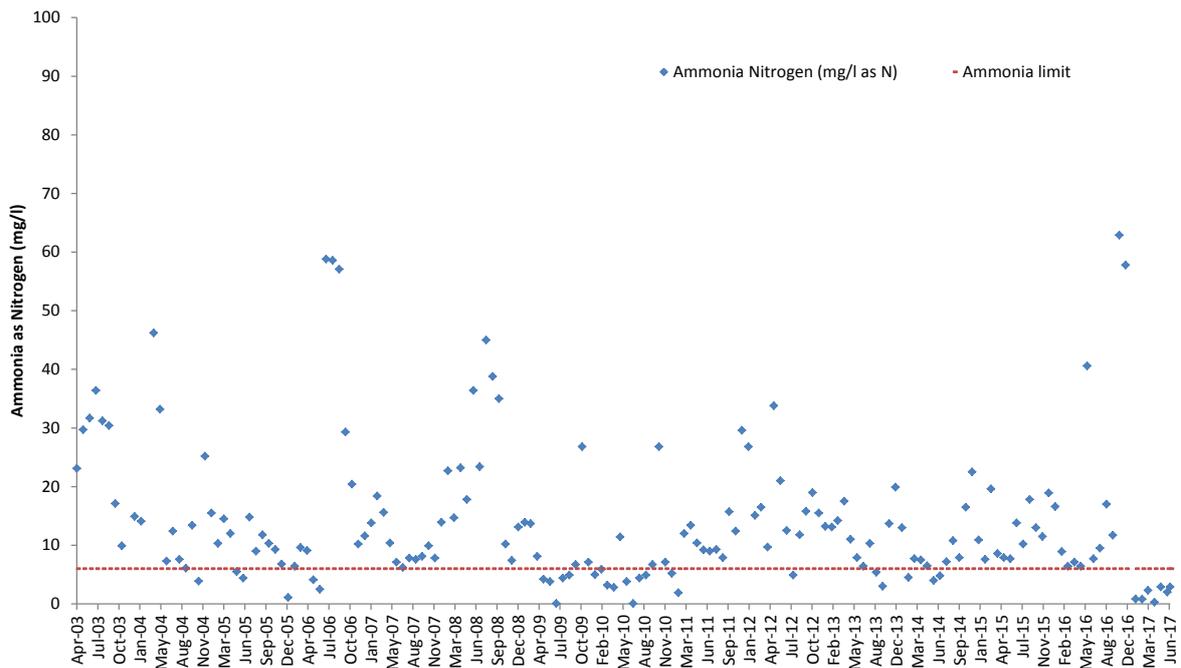
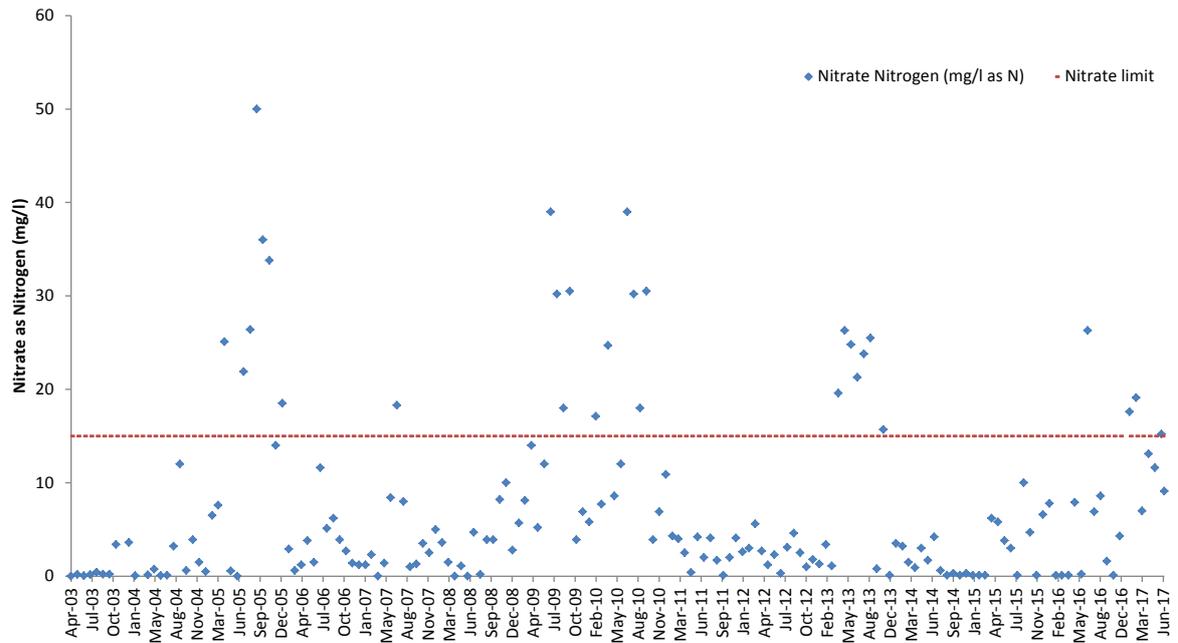
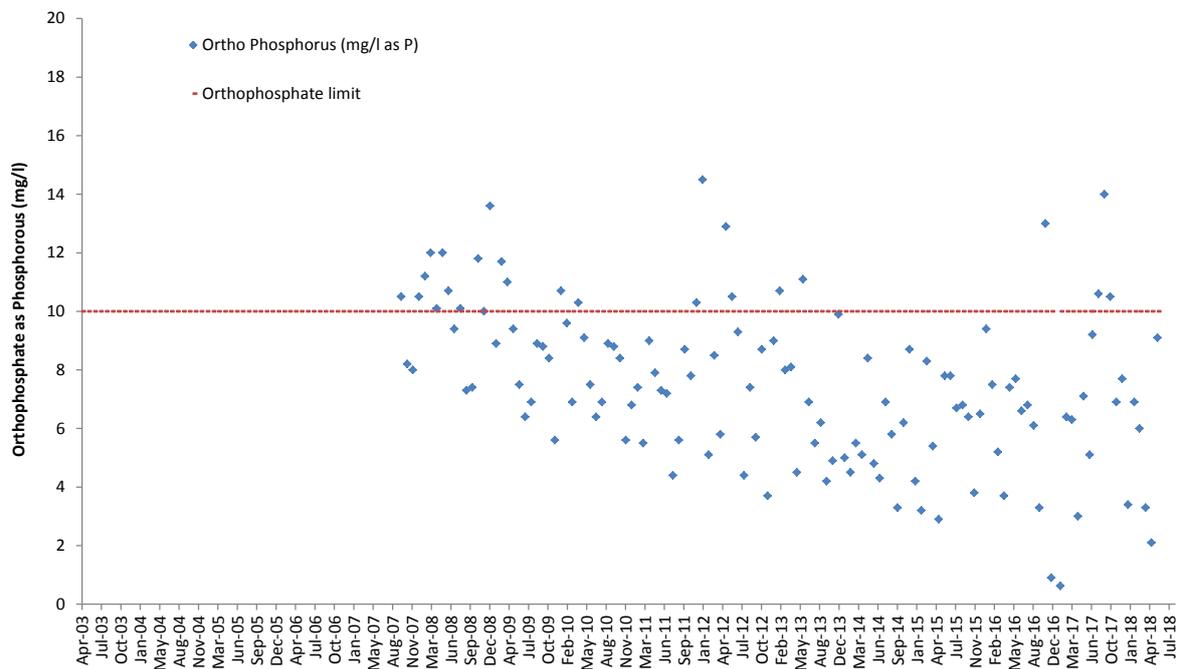


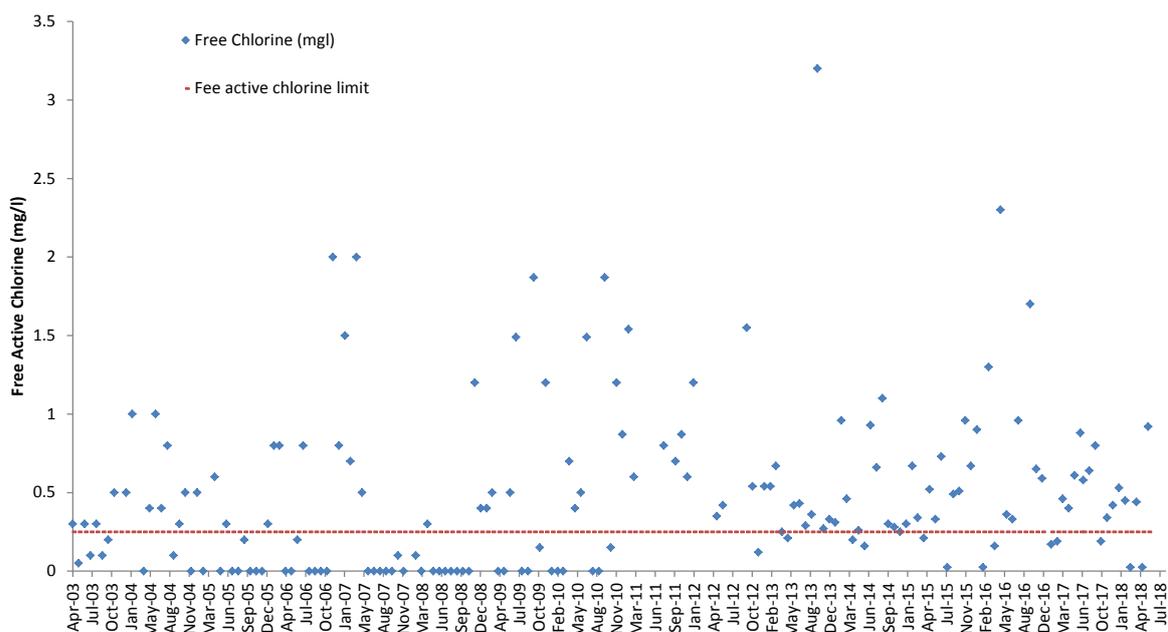
Figure 3.25. Monthly trends in Ammonia Nitrogen (mg/l as N) in effluent released from the Saldanha Wastewater Treatment Works April 2003-June 2017. Allowable limits in terms of a General Authorisation under the National Water Act (No. 36 of 1998) are represented by the dashed red line (Source: Saldanha Bay Municipality).



**Figure 3.26** 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 3.27** 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 3.28** 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

The Langebaan WWTW treats sewage by means of activated sludge with BNR and drying ponds. However, as is the case with effluent from the Saldanha WWTW, SBM has for quite some time been favouring alternative uses of wastewater from the Langebaan WWTW over discharge to the marine environment. Most recently, the SBM obtained permission from the Department of Water and Sanitation (DWS) to use a maximum of 200 m<sup>3</sup> for the irrigation of lawn on the WWTW premises as well as the flower beds along Oosterwal Rd leading into Langebaan. Furthermore, the majority of wastewater produced by the Langebaan WWTW is diverted to the Langebaan Country Estate for the irrigation of the golf course. Prior to irrigation, the wastewater is further treated by means of 11 polishing ponds. Wastewater is exposed to UV radiation in these ponds, reducing harmful pathogen populations.

While at first all the wastewater was used for irrigation, increasing volumes of effluent received by the Langebaan WWTW was yielding more water than required for irrigation of the golf course, especially during winter. Consequently more and more excess wastewater was discharged into the Langebaan Lagoon Marine Protected Area (MPA). However, since the implementation of water restrictions, wastewater produced by the Langebaan WWTW has been decreasing considerably, which means that only very small quantities of wastewater overflow into the MPA chiefly during the winter months (SBM, *pers. comm.* 2018).

The overflow from the storage dams was noticed by the Department of Environmental Affairs: Branch Oceans & Coasts, which identified this as an illegal activity in terms of the National Environmental Management: Protected Areas Amendment (Act No 21 of 2014) (NEMPAAA).

Section 48A (d) 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 was issued to the SBM to stop releasing effluent into the Langebaan Lagoon MPA. The DEA: O&C made it clear to the SBM that a CWDP would not be issued for this discharge and that alternative measures should be implemented instead to prevent overflow. The SBM is experiencing a high demand for wastewater, especially during summer for irrigation purposes. The SBM therefore conducted a comprehensive study regarding the re-use of treated effluent from the Langebaan WWTW and other WWTW. Options that emerged from this study included storage of surplus effluent during the winter months for use in summer, supply of wastewater to industry throughout the year and reclamation of potable water by means of reverse osmosis. Alternative options will be investigated for their feasibility and implemented once upgrades to the Langebaan WWTW have been completed (see more detail below).

While the SBM is responsible for ensuring that an appropriate amount of treated sewage is supplied to the Langebaan Country Estate to prevent non-compliance with the ICMA, the Langebaan Country Estate must ensure compliance with the National Water Act (Act 36 of 1998 as amended) NWA in terms of the storage and irrigation of wastewater. The Langebaan Country Estate is currently in the process of registering as a water user for these very water uses.

#### **Legislative requirements applicable to the Saldanha Bay Municipality**

The Department of Water and Sanitation (DWS) confirmed in January 2018 that the SBM was successfully registered as a water user in terms of Section 22(1)(a)(iii), which prescribes that “A person may only use water without a licence if that water use is permissible in terms of a general authorisation issued under Section 39.” (Refer to AEC 2017 for more information on previous authorisations/exemptions). The Langebaan WWTW is permitted to irrigate up to 73 000 m<sup>3</sup> (daily maximum of 200 m<sup>3</sup> per day) of wastewater per annum on 12.68 ha (water use as prescribed in NWA Section 21(e)). Furthermore, the SBM is permitted to store treated effluent for irrigation purposes in ponds with a maximum storage capacity of 4 485 m<sup>3</sup> (water use as prescribed in NWA Section 21(g): “disposing of waste in a manner which may detrimentally impact on a water resource.”). The conditions of the General Authorisation applicable to the above described water uses are prescribed in Regulations 1 and 3 of the *GN 665 Government Gazette 36820* dated 6 September 2013. Regulation 1 prescribes that specific wastewater quality limit values are applicable depending on the volume of wastewater irrigated. The SBM intends to irrigate more than 50 m<sup>3</sup> but less than 500 m<sup>3</sup> per day. The applicable limits are shown in Table 3.7. The General Authorisation also specifies that:

- 1) Water user must follow acceptable construction, maintenance and operational practices to ensure the consistent, effective and safe performance of the wastewater irrigation system, including the prevention of -
  - a. waterlogging of the soil and pooling of wastewater on the surface of the soil;
  - b. nuisance conditions such as flies or mosquitoes, odour or secondary pollution;
  - c. waste, wastewater or contaminated stormwater entering into a water resource;
  - d. the contamination of run-off water or stormwater;
  - e. the unreasonable chemical or physical deterioration of, or any other damage to, the soil of the irrigation site;

- f. the unauthorised use of the wastewater by members of the public; and
  - g. people being exposed to the mist originating from the irrigation of the wastewater.
- 2) Suspended solids must be removed from any wastewater, and the resulting sludge disposed of according to the requirements of any relevant law or regulation, including the document Guidelines for the Utilisation and Disposal of Wastewater Sludge, Volumes 1-5, Water Research Commission Reports TT 261/06, 262/06, 349/09, 350/09, 351/09, as amended from time to time (obtainable from the responsible authority upon written request).
  - 3) All reasonable measures must be taken to provide for mechanical, electrical, operational, or process failures and malfunctions of the wastewater irrigation system.
  - 4) All reasonable measures must be taken for storage of the wastewater used for irrigation when irrigation cannot be undertaken, of which the storage must be in accordance with general authorisation in section 3 of this Notice.
  - 5) All reasonable measures must be taken to collect contaminated stormwater or runoff emanating from the area under irrigation and to retain it for disposal of which the disposal must be in accordance with general authorisation in section 3 of this Notice.
  - 6) Upon the written request of the responsible authority the registered user must ensure the implementation of any additional construction, maintenance and operational practices that may be required in the opinion of the responsible authority to ensure the consistent, effective, safe and sustainable performance of the wastewater irrigation system.

The SBM is also obligated to establish monitoring programmes for the quantity and quality of wastewater to be used for irrigation prior to commencement and thereafter, in the following manner:

- a. The quantity must be metered and the total recorded weekly; and
- b. the quality of water irrigated must be monitored once every month by taking a grab sample at the point at which the wastewater enters the irrigation system for all parameters listed in paragraph 1.7(1)(i), (ii) and (iii) and results submitted to the responsible authority.

More detailed information can be requested by the DWS from the SBM.

**Table 3.7 Wastewater limit values applicable to the irrigation of any land or property up to 500 cubic metres (National Water Act 36 of 1998, GN 665 Government Gazette 36820 dated 6 September 2013).**

Variables	Limits
pH	Not less than 6 of more than 9 pH units
Electrical conductivity	Not exceed 200 milliSiemens per metre (mS/m)
Chemical Oxygen Demand (COD)	Does not exceed 400 mg/L after removal of algae
Faecal coliforms	Do not exceed 100 000 per 100 mL
Sodium Adsorption Ratio (SAR)	Does not exceed 5 for biodegradable industrial wastewater

Regulation 3.14 prescribes the conditions applicable with regards to record-keeping and disclosure of information for the storage of wastewater. The SBM is required to conduct monthly monitoring of water quantity and quality. Water quality parameters are not specified in Regulation 3 and it is therefore assumed that the parameters as specified in Table 3.7 are applicable (the wastewater is not discharged into a water resource and those limits are therefore not applicable in terms of the GA).

Regulation 3 of the General Authorisation also specifies that:

- 1) The water user must follow acceptable design, construction, maintenance and operational practices to ensure the consistent, effective and safe performance of the wastewater discharge system, including the prevention of -
  - h. nuisance conditions such as flies or mosquitoes, odour or secondary pollution;
  - i. the contamination of run-off water or stormwater;
  - j. contaminated stormwater entering into a water resource; and
  - k. the unauthorised use of the wastewater by members of the public.
- 2) Suspended solids must be removed from any wastewater, and the resulting sludge disposed of according to the requirements of any relevant law or regulation.
- 3) All reasonable measures must be taken to prevent wastewater overflowing from any wastewater disposal system or wastewater storage dam.
- 4) All reasonable measures must be taken to provide for mechanical, electrical, or operational failures and malfunctions of any wastewater disposal system or wastewater storage dam.
- 5) Sewage sludge must be removed from any wastewater and the resulting sludge disposed of according to the requirements of any relevant law and regulation, including –
- 6) Guidelines for the Utilisation and Disposal of Wastewater Sludge, Volumes 1-5, Water Research Commission Reports TT 261/06, 262/06, 349/09, 350/09, 351/09, as amended from time to time; and
- 7) "Guide: Permissible utilisation and disposal of treated sewage effluent", 1978, Department of National Health and Population Development Report No. 11/2/5/3, as amended from time to time (obtainable from the Department upon written request).

### **Planned upgrades to the Langebaan WWTW**

Various upgrades are required to improve the overall performance of the treatment plant (SBM, Gavin Williams, *pers. comm.* 2016). The first phase included the construction of a new reactor basin, installation of new aeration equipment and new sludge drying beds and was completed in the last financial year. The upgrades have increased the plant capacity to 3.5 ML. The next phase is due to start in the 2018 financial year and will include an additional aeration basin, new clarifier and drying beds, and new inlet works. The total cost for the second phase are estimated at R20 million. Future upgrades will include new infrastructure to increase the capacity of the plant to 5-7 ML (SBM, Gavin Williams, *pers. comm.* 2016 and 2017). An aerial view of the Langebaan WWTW is shown in Figure 3.29.

Once upgrades to the WWTW have been completed and over time more effluent than currently absorbed by the Langebaan Country Club will be produced. The municipality is planning to use excess effluent to irrigate the lawn at the Langebaan Sports Complex. It appears that the demand for wastewater is high enough to absorb the excess effluent. Most importantly, however, water users would have to be identified prior to the expansion of the plant to prevent non-compliance with the ICMA as described above.



Figure 3.29 Construction activities for the upgrade of the Langebaan Waste Water Treatment Plant to increase treatment capacity and improve treatment processes.

### **Treated wastewater quality monitoring**

The annual State of the Bay Report has been reporting water quality parameters measured prior to the transfer of the effluent to the Langebaan Country Club. It is noteworthy that the effluent is further treated prior to irrigation by means of 11 polishing ponds. However, water quality is currently not monitored prior to irrigation and therefore the actual water quality of the treated wastewater entering the MPA via the illegal overflow is currently unknown. This report therefore continues to describe the water quality trend over time as measured at the end of pipe at the Langebaan WWTW. Note that the legal water quality limits as per GA in terms of Section 21(f): *“Discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit”* are no longer applicable as the **sea outfall** is now regulated by the ICMA by means of CWDPs. Accordingly, the GA of 2013 (*GN 665 Government Gazette 36820* dated 6 September 2013) specified that the GA is no longer applicable to sea outfalls.

Trends of water quality parameters in the effluent released into the Langebaan Lagoon MPA between 2009 and 2018 are therefore no longer compared to the GA limits for **wastewater discharge**. Instead, where monitoring information is available, the results have been compared to GA limits for **irrigation** as shown in Table 3.7. These parameters include pH, electrical conductivity, Chemical Oxygen Demand, and Faecal Coliforms. No data is currently available for Sodium Adsorption Ration (SAR).

In addition to the above, due to occasional discharges of effluent into the MPA, the effluent monitoring results will be compared to a limit that is more relevant to the inshore marine environment. As part of the Assessment Framework for the Management of Effluent from Land Based Sources Discharged to the Marine Environment that was recently developed by Anchor for the DEA: O&C (AEC 2015), recommendations were made regarding the applicability of General Discharge Authorisations and what type of effluents should qualify. The overflow into the MPA would not be considered to fall under a GDA (and the DEA: O&C indicated that a CWDP would not be issued for a new outfall in an MPA), however, the GDA special limits as recommended in the Assessment Framework are more applicable to the marine environment than limits derived for irrigation or wastewater discharges into freshwater resources. Wastewater monitoring results have therefore been compared to the recommended special limits purely to provide context.

Long-term trends in water quality are shown in Figure 3.32 - Figure 3.40. It is noteworthy that for quite some time, the amount of wastewater entering the marine environment has been very low and is unlikely to have contributed significantly to pollution of the receiving environment (although due to the lack of water quality and quantity data this is impossible to say with confidence). The changes implemented by the SBM are therefore mainly positive and interpretation of water quality results must take into account that volumes are likely to be low and of better quality than indicated in the graphs below.

The previous exemption permitted the irrigation of the local golf course with 1 611 m<sup>3</sup> treated effluent per day, which was exceeded 92% of the time between 2009 and December 2017 (Figure 3.30.) (Note that conditions changed in January 2018). 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 2 840 m<sup>3</sup> with a maximum daily flow of 5 545 m<sup>3</sup>) (Figure 3.30.). The legal limit for effluent production increased to 4 485 m<sup>3</sup> in January 2018 when the SBM was issued with a new General Authorisation permission. Shortly thereafter, plant capacity was increased to 3 500 m<sup>3</sup>. Since then the Langebaan WWTW has been compliant in terms of the legal effluent volume limit as well as plant capacity.

The Langebaan WWTW has been recording pH since 2009. The monitoring data shows that the wastewater always falls within the pH range to be met in terms of the GA for the irrigation of <500 m<sup>3</sup> wastewater (6-8 Figure 3.32). The pH of the wastewater effluent used to be more acidic than recommended for the protection of the inshore marine environment. However, more recently (since mid-2016) the pH has largely been falling within the recommended range (7.3 and 8.2) (AEC 2015).

The Langebaan WWTW has also been recording electrical conductivity (in mS/m) since 2009. Electrical conductivity has decreased significantly since 2009 from values measuring up to 600 mS/m down to values fluctuating around 200 mS/m. Since electric conductivity reached lower levels in December 2014, the limit was exceeded on 13 occasions (30% of the time). To ensure compliance with the applicable GA for irrigation of wastewater, the SBM needs to ensure that electric conductivity is reduced more consistently to even lower levels than currently observed.

COD in filtered effluent exceeded the allowable limit of 75 mg/l 34% of the time since June 2009, reaching an all-time maximum of 235 mg/l in January 2018 (). While an improvement could be observed between 2015 and 2016, recent measurements show that COD is unacceptably high for the protection of the inshore marine environment. However, in terms of the limit imposed by the GA applicable for irrigation, the SBM is compliant as COD is always lower than 400 mg/L ().

To date concentrations of faecal coliforms in the effluent from the Langebaan WWTW have not exceeded the limit of 100 000 organisms per 100 mL imposed by the GA applicable to irrigation (Figure 3.35). In terms of recreational and mariculture concerns, 100 000 org/100 mL in the overflow would be completely unacceptable. The wastewater has stayed well below this limit with a maximum of 7258 org/100 mL frequently measured from 2013-2015. Overall, however, it would be desirable to faecal coliform readings to stay below 1 000 org/100 mL as prescribed in the GA applicable to the discharge of wastewater into freshwater resources. Faecal coliform measurements have been fluctuating around the 1 000 org/100 mL mark since 2017 (Figure 3.35).

No Total Suspended Solids (TSS) limit is prescribed by the GA applicable to irrigation of wastewater. Overall the water user is required to remove all suspended solids prior to irrigation of the wastewater. The SBM will be required to remove TSS prior to the irrigation of their own premises and the flower beds on Oosterwal Road. The polishing ponds on the Langebaan Country Estate are likely to act as settlement ponds and TSS is likely to be lower than shown here. TSS values exceeded the recommended special limit for the protection of the inshore marine environment of 10 mg/L on 56 occasions since 2009 (51% of the time) (Figure 3.36).

Overall, TSS levels were highest at the beginning of 2015, frequently exceeding the recommended limit and reaching a maximum of 198 mg/l in March 2015. Although TSS level decreased temporarily, recently worse conditions have been observed, where the limit of 10 mg/L was constantly exceeded since July 2016 (Figure 3.36) (92% exceedance). TSS levels roughly follow the trends observed in average daily flow volumes where TSS values are higher when flow is greater.

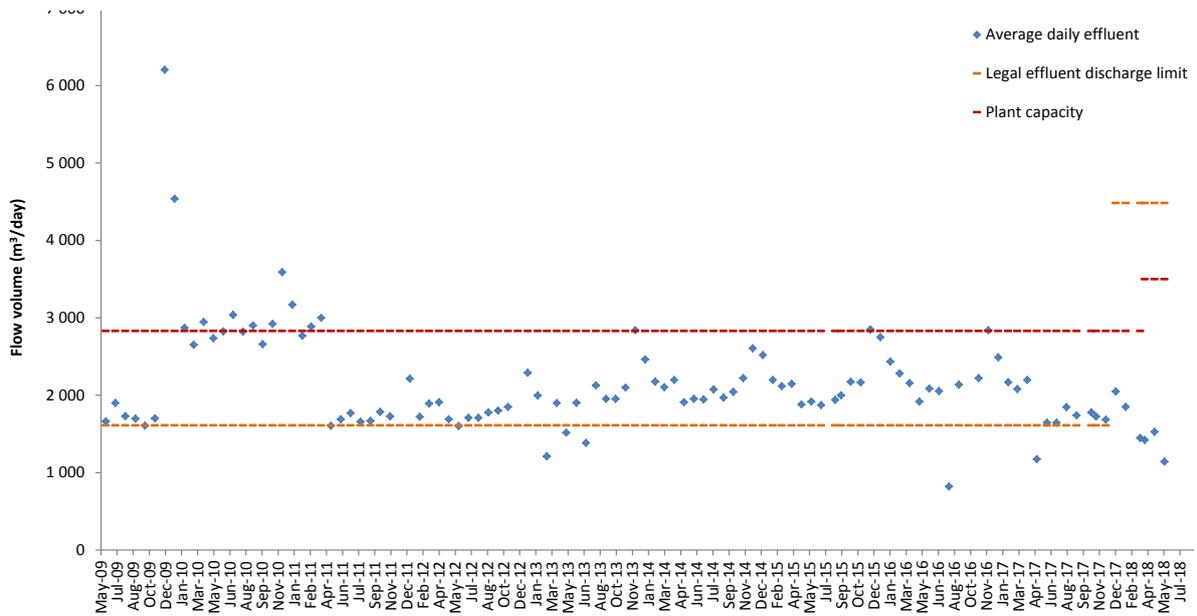


Figure 3.30. Trends in average daily effluent volume (m<sup>3</sup>/month) released from the Langebaan Wastewater Treatment Works, June 2009 - June 2018. Allowable discharge limits in terms of the exemption issued by DWAF under the National Water Act (No. 36 of 1998) are represented by the dashed orange line and the design capacity of the plant by the red line (Source: Saldanha Bay Municipality).

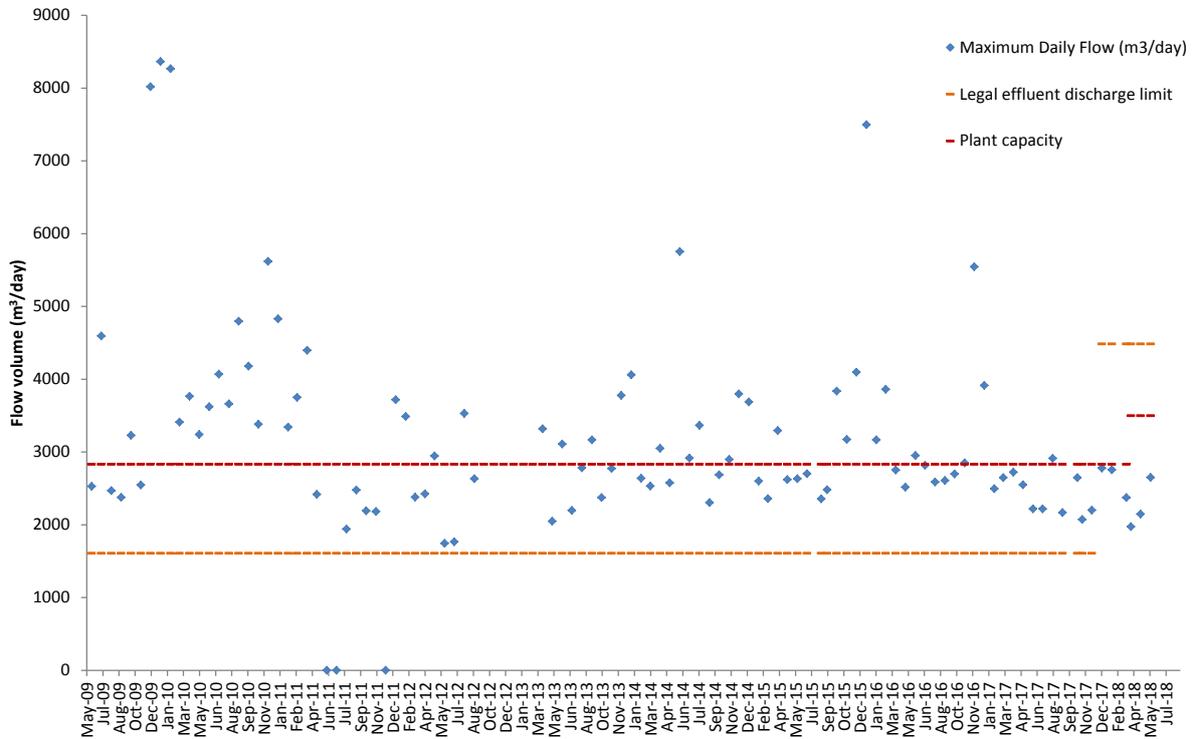
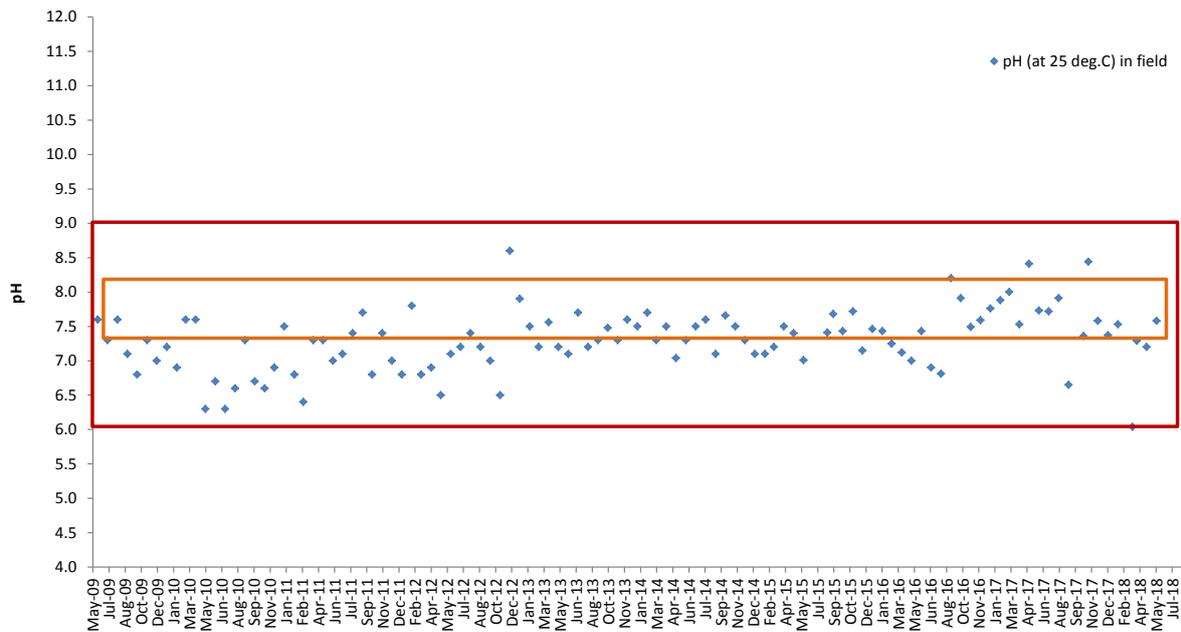
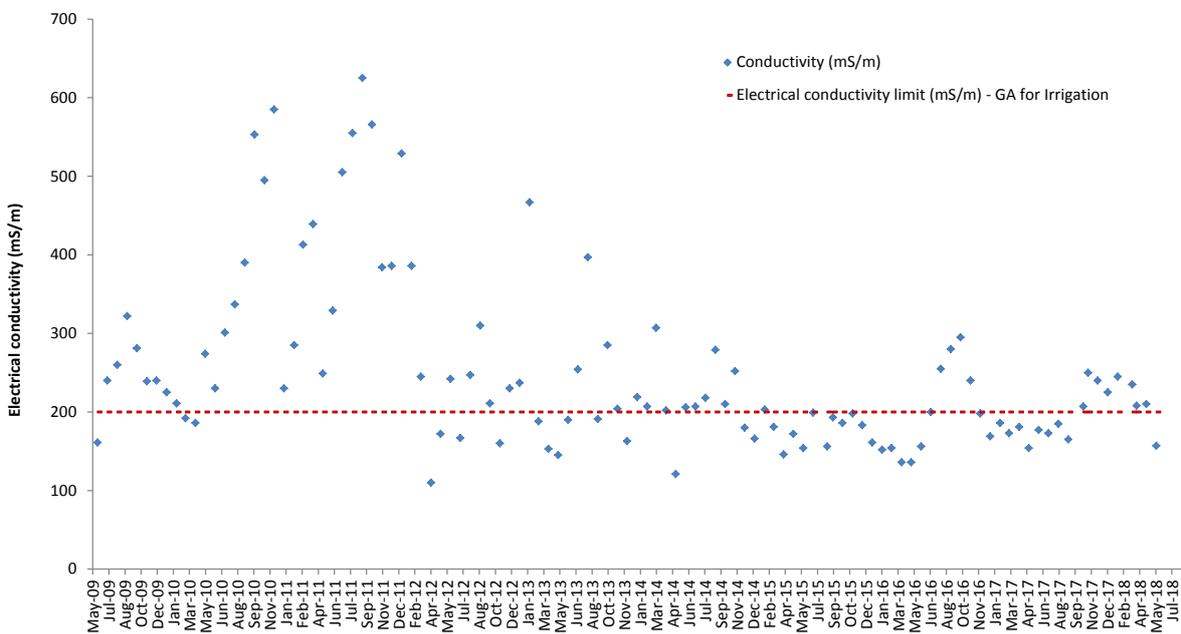


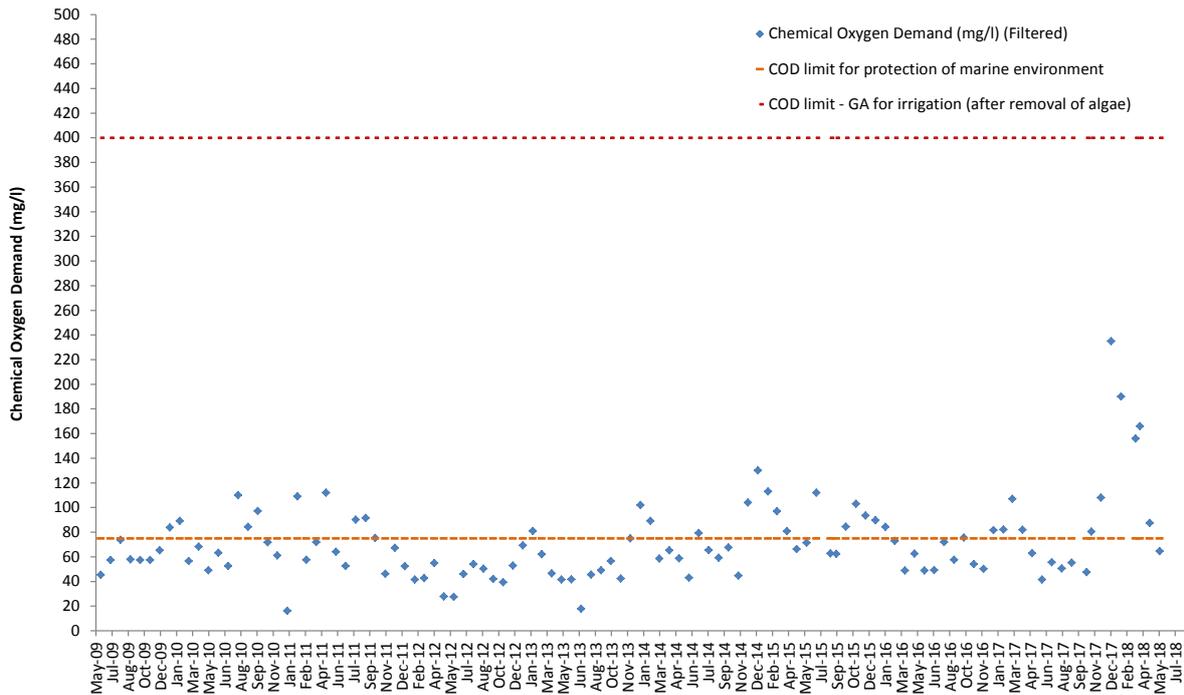
Figure 3.31. Trends in maximum daily effluent volume (m<sup>3</sup>/month) released from the Langebaan Wastewater Treatment Works, June 2009 - June 2018. Allowable discharge limits in terms of the exemption issued by DWAF under the National Water Act (No. 36 of 1998) are represented by the dashed orange line and the design capacity of the plant by the red line (Source: Saldanha Bay Municipality).



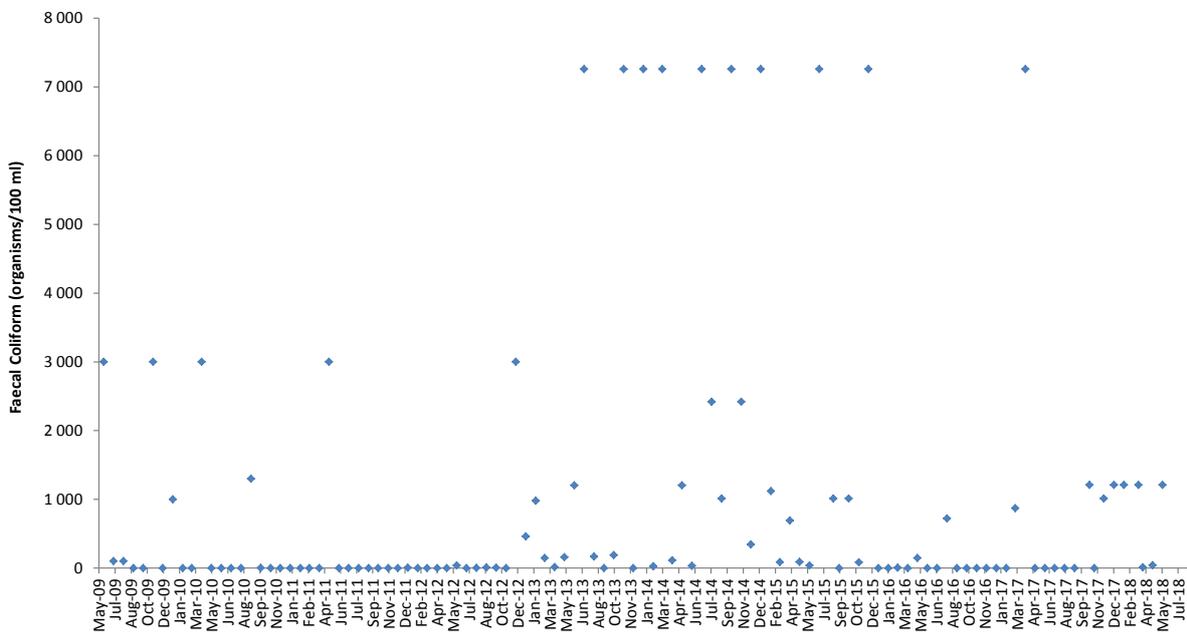
**Figure 3.32.** Monthly trends in pH of effluent from the Langebaan Wastewater Treatment Works, June 2009 - June 2018. The allowable range in terms of the General Authorisation for irrigation purposes under the National Water Act (No. 36 of 1998) is 6-9 and is depicted by the red square. The recommended range to protect marine inshore environments is 7.3-8.2 and is depicted by the orange square (AEC 2015) (Source: Saldanha Bay Municipality).



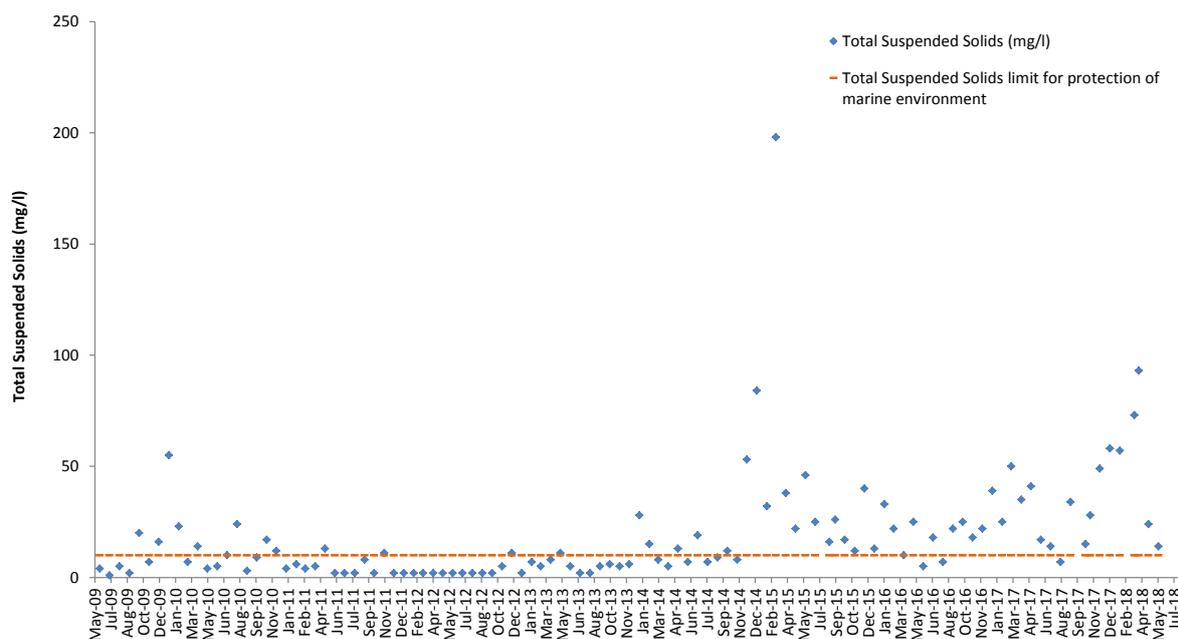
**Figure 3.33.** Monthly trends in conductivity of effluent from the Langebaan Wastewater Treatment Works, June 2009 - June 2018. The allowable limit in terms of the General Authorisation for irrigation purposes under the National Water Act (No. 36 of 1998) is 200 mS/m and is depicted by the red line (Source: Saldanha Bay Municipality).



**Figure 3.34** Monthly trends in chemical oxygen demand (mg/l filtered) in effluent released from the Langebaan Wastewater Treatment Works, June 2009 - June 2018. 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. The recommended limit to protect marine inshore environments is shown by the orange dashed line (AEC 2015) (Source: Saldanha Bay Municipality).



**Figure 3.35** Monthly trends in Faecal Coliforms (org/100ml) in effluent released from the Langebaan Wastewater Treatment Works, June 2009 - June 2018. The allowable limit in terms of a General Authorisation for irrigation purposes under the National Water Act (No. 36 of 1998) is 100 000 organisms per 100 ml. (Source: Saldanha Bay Municipality).



**Figure 3.36** Monthly trends in total suspended solids (mg/l) in effluent released from the Langebaan Wastewater Treatment Works, June 2009 - June 2018. The recommended limit to protect marine inshore environments is shown by the orange dashed line (AEC 2015) (Source: Saldanha Bay Municipality).

No ammonia nitrogen limit is prescribed by the GA applicable to irrigation of wastewater. Ammonia is very toxic to marine life as it acts as a biocide. The recommended ammonia nitrogen limit for the inshore marine environment is 3 mg/l (Figure 3.37.). The water quality guidelines for the coastal environment specify a target of 0.6 mg/L to prevent chronic toxicity. Ammonia levels have increased constantly over the last five years with an average of  $60 \pm 34$  mg/L measured since July 2018. Considering the above, the levels of ammonia in the Langebaan WWTW effluent is alarming and any amount of effluent released into the nearshore marine environment is likely to have a significant negative effect on marine biota.

Nitrate Nitrogen is not toxic to marine life but is a primary nutrient (usually marine systems are nitrogen limited) and could stimulate nuisance algae growth near the outfall point and. No nitrate nitrogen limit is prescribed by the GA applicable to irrigation of wastewater. The recommended nitrate nitrogen limit for the inshore marine environment is 1.5 mg/L. This limit has been exceeded on 44 occasions since June 2009 (40% of the time) (Figure 3.38), however, nitrate levels have decreased significantly in recent times. Toxic ammonia nitrogen is converted to non-toxic nitrate nitrogen by means of bacterial treatment in WWTWs. The recently observed very low levels are congruent with the extremely high ammonia levels in the effluent. This means that the bacterial treatment is not effective.

Orthophosphate is usually not the limiting nutrient for primary production in the marine environment. The recommended limit applicable for discharges into the inshore marine environment is 1 mg/L. No orthophosphate limit is prescribed by the GA applicable to irrigation of wastewater. Orthophosphate concentrations fluctuate in a seasonal pattern similar to that seen at the Saldanha WWTW (Figure 3.39). Orthophosphate levels have steadily increased since 2013, reaching the highest value recorded to date at 19 mg/L in May 2018. Overall, the orthophosphate concentration in the Langebaan WWTW effluent is considerably higher than 1 mg/L (95% exceedance).

No free active chlorine limit is prescribed by the GA applicable to irrigation of wastewater. Free active chlorine is very toxic to marine life as it acts as a biocide. The recommended limit to protect the inshore marine environment is 0.5 mg/L. Concentrations have been fluctuating over time, showing an increasing trend since September 2015 (Figure 3.40). As observed at the Saldanha WWTW, free active chlorine levels are always higher immediately after a rise in faecal coliforms. Readings have been consistently high in the last 12 months with an average of  $1.2 \pm 1.3$  mg/L. These levels are significantly higher than what would be considered acceptable in the nearshore environment and more careful dosing of chlorine should be implemented.

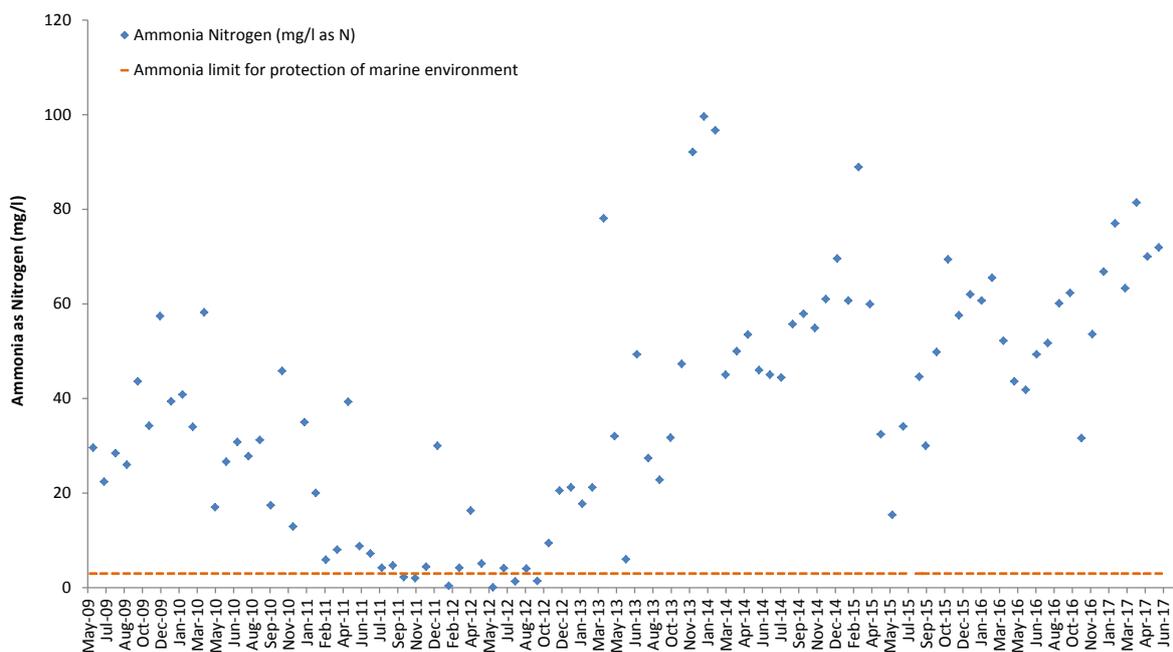
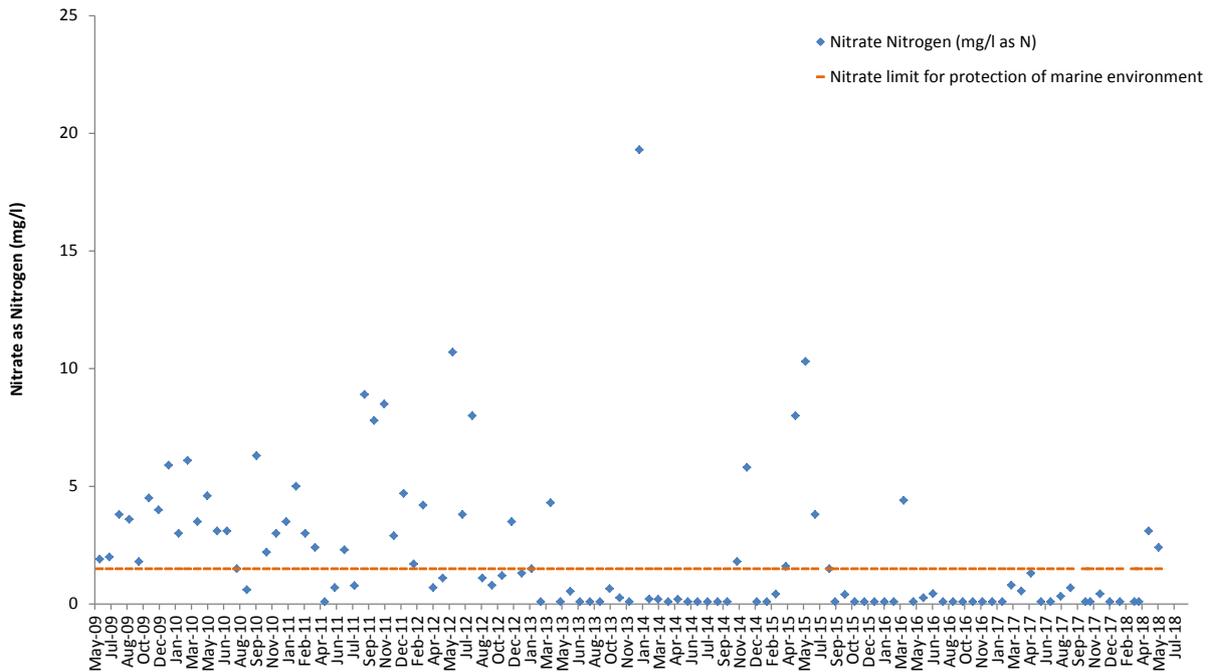
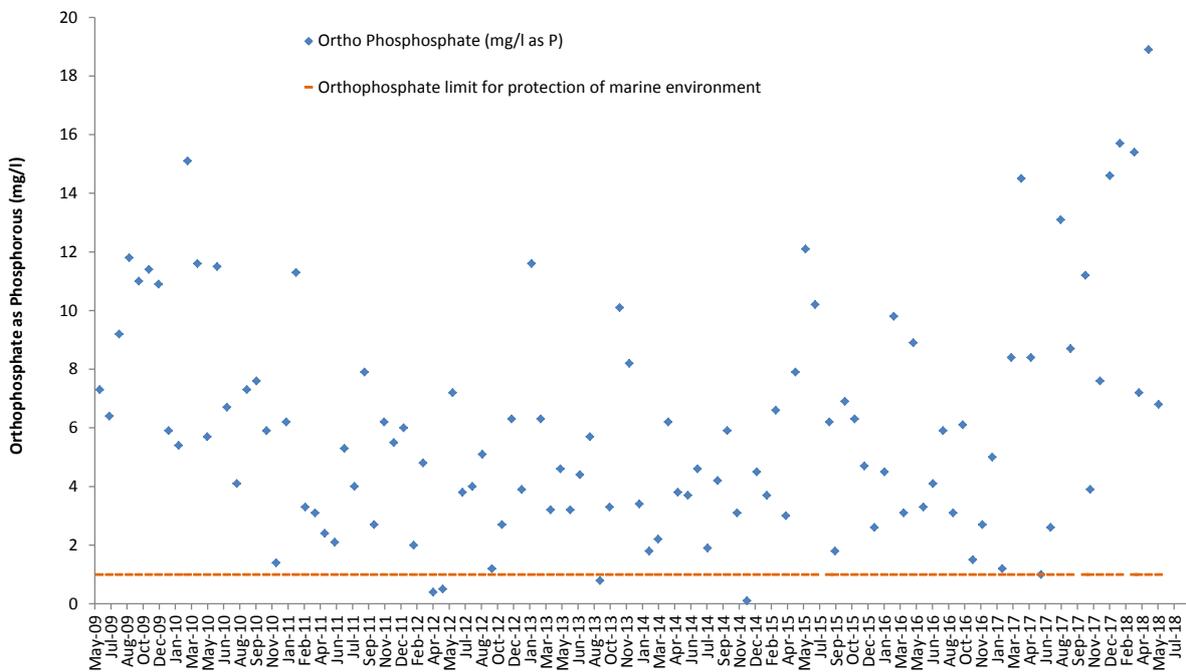


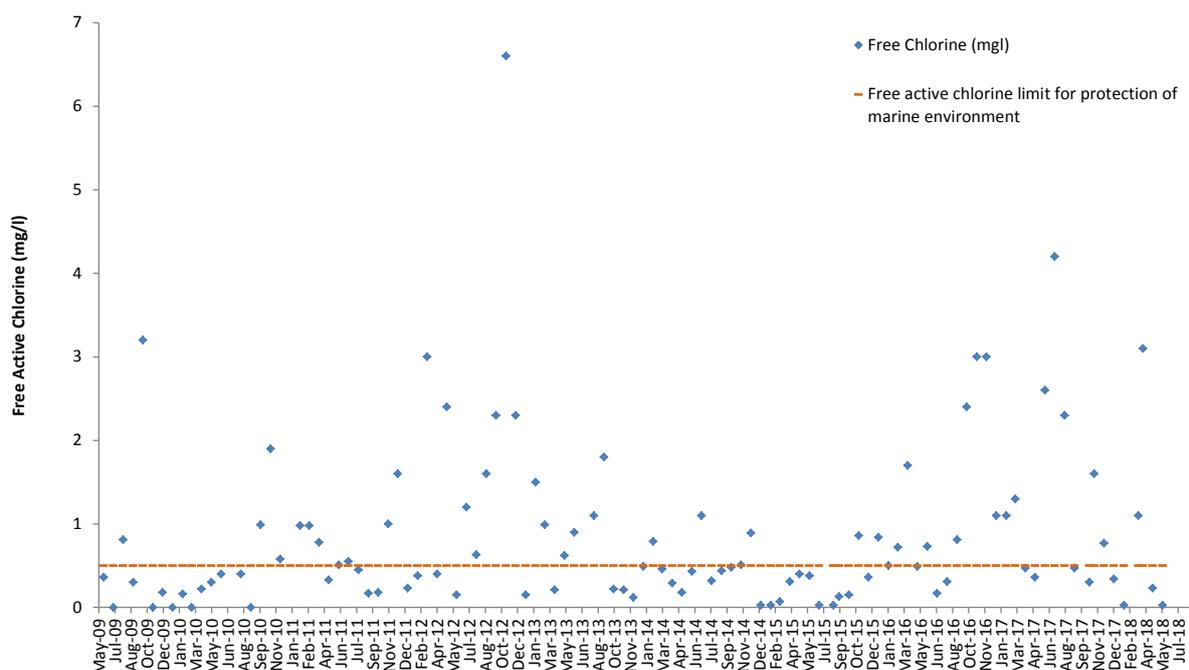
Figure 3.37. Monthly trends in Ammonia Nitrogen (mg/l as N) in effluent released from the Langebaan Wastewater Treatment Works June 2009 - June 2018. The recommended limit to protect marine inshore environments is shown by the orange dashed line (AEC 2015) (Source: Saldanha Bay Municipality).



**Figure 3.38** Monthly trends in Nitrate Nitrogen (mg/l as N) in effluent released from the Langebaan Wastewater Treatment Works June 2009 - June 2018. The recommended limit to protect marine inshore environments is shown by the orange dashed line (AEC 2015) (Source: Saldanha Bay Municipality).



**Figure 3.39** Monthly trends in Orthophosphate (mg/l as P) in effluent released from the Langebaan Wastewater Treatment Works June 2009 - June 2018. The recommended limit to protect marine inshore environments is shown by the orange dashed line (AEC 2015) (Source: Saldanha Bay Municipality).



**Figure 3.40** Monthly trends in Free Active Chlorine (mg/l) in effluent released from the Langebaan Wastewater Treatment Works June 2009 - June 2018. The recommended limit to protect marine inshore environments is shown by the orange dashed line (AEC 2015) (Source: Saldanha Bay Municipality).

### 3.6.3.5 Summary

The Saldanha Bay Municipality (SBM) has made a considerable effort over the last few years to re-use treated wastewater to save precious potable water where possible. Treated wastewater has been supplied for irrigation, industrial use (e.g. cooling processes) and dust suppression at construction sites. Overall it appears that, especially in summer, the demand for treated wastewater is very high and the SBM is unable to meet the demand at current wastewater treatment capacity. Very small volumes of effluent have entered the marine environment from both WWTWs since early 2018, which is expected to continue in the foreseeable future. Despite this new effluent discharge pattern, effluent quality monitoring results will continue to be compared to relevant legal and/or recommended limits. When interpreting these results the reader must remain cognisant of the fact that very small volumes are entering the marine environment and impacts are likely to be limited (over time, extent and magnitude).

The SBM has been implementing improvements at both WWTWs, which has reduced the effectiveness of the plants for the duration of the construction. Furthermore, a fire at the Motor Control Centre (MCC) of the Saldanha Bay WWTW has significantly impacted the ability of the plant to function adequately. This is strongly reflected in the results for effluent quality.

Overall, the data shows that the Saldanha Bay and Langebaan WWTWs are experiencing difficulties in keeping water quality parameters within allowable limits and conditions as set out in the NWA (Government Gazette No. 36820, 6 September 2013) as well as within recommended special limits for the protection of the inshore marine environment (AEC 2015) (Table 3.6. and Table 3.7).

The data shows that the Saldanha WWTW is receiving greater volumes of effluent for treatment than permitted. However it should be noted that plant capacity is nearly double that of the legal limit and that plant capacity is rarely exceeded. The Langebaan WWTW was recently upgraded to 3 500 m<sup>3</sup> and was issued permission to store 4 485 m<sup>3</sup> in January 2018. Neither capacity nor legal limit has been exceeded since. Furthermore, with the implementation of water restrictions, wastewater volumes treated by both plants have decreased to volumes that were recorded approximately 10 years ago.

Excessive ammonia nitrogen concentrations found in the effluent from the both WWTWs remain of great concern and need to be addressed as soon as possible. While improvements were observed at the Saldanha Bay WWTW between July 2016 and June 2017, in the last year (July 2017-June 2018) effluent quality has deteriorated once again. Poor effluent quality at the Saldanha Bay WWTW is likely to have been due to fire damage to the MCC in October 2017, which has been causing problems at the plant since. A new MCC will be installed within the next few months.

### 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).

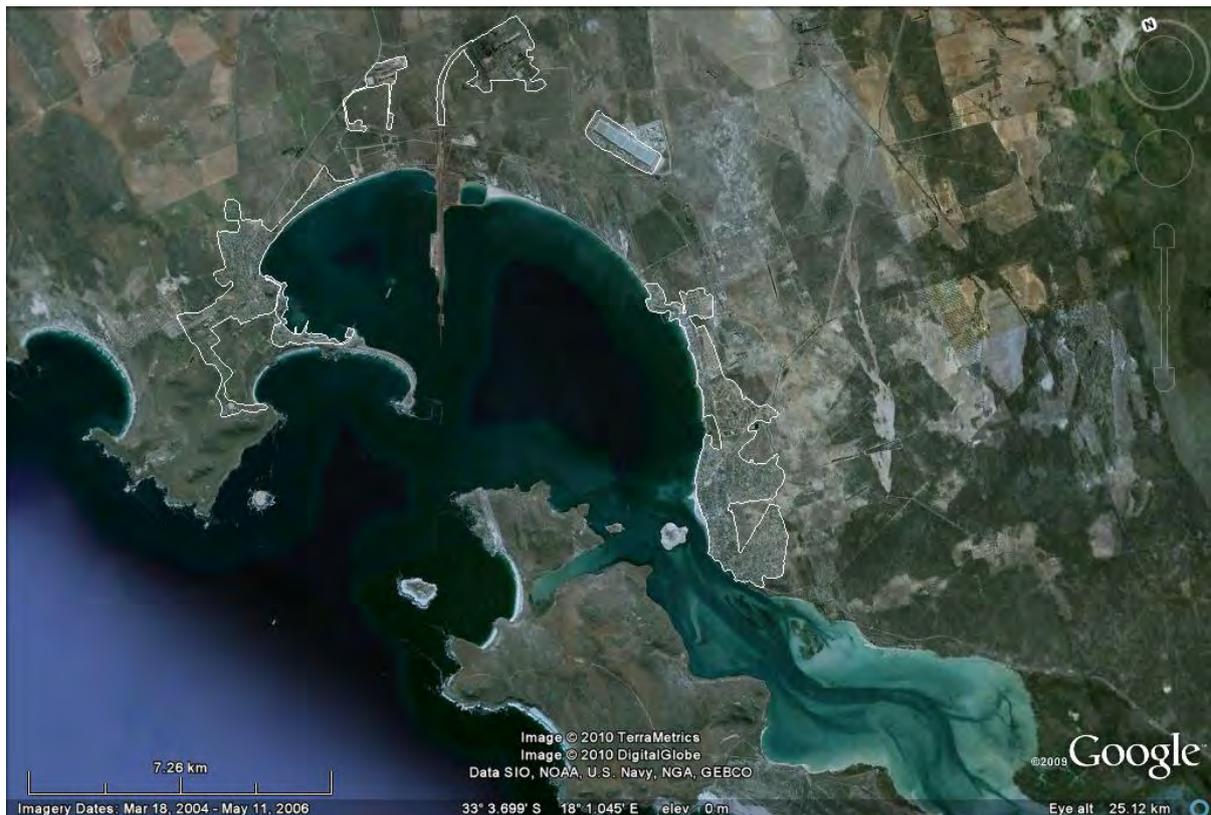
It is very difficult to characterise and treat storm water runoff prior to discharge, and this is due to the varying composition of the discharge as well as the large number of discharge points. The best way of dealing with contaminants in storm water runoff is to target the source of the problem by 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 3.8.). 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 3.8.** 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**



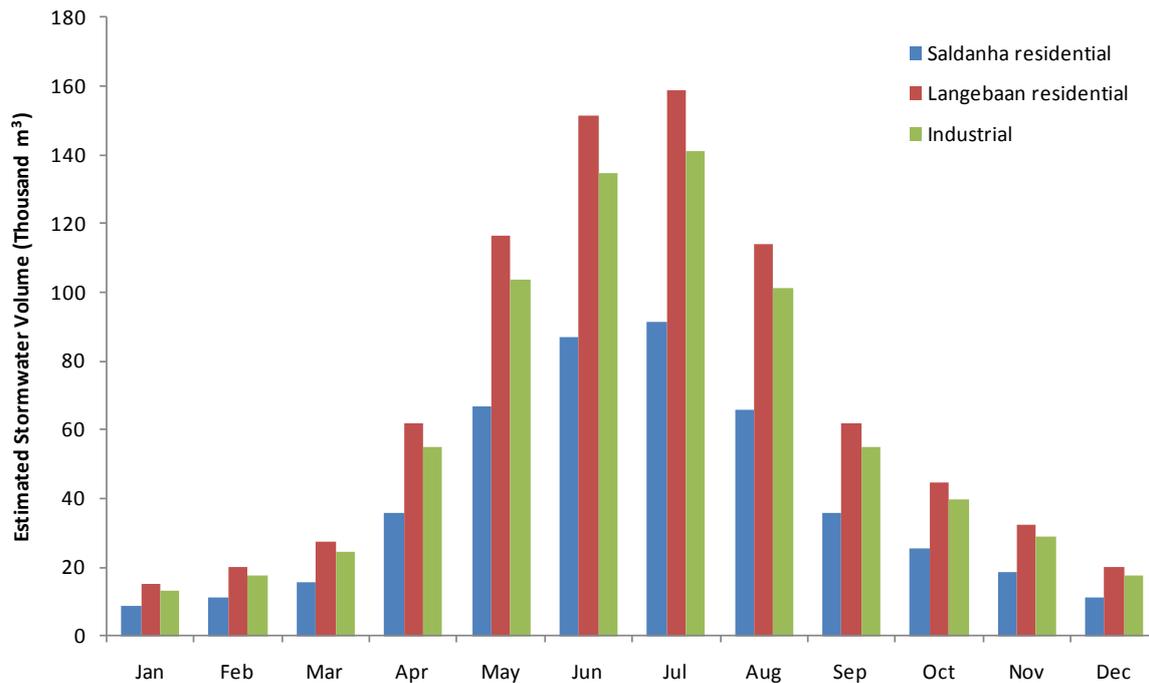
**Figure 3.41.** Spatial extent of residential and industrial areas surrounding Saldanha Bay and Langebaan Lagoon from which storm water runoff is likely to enter the sea (areas outlined in white). Note that runoff from the Port of Saldanha and ore terminal have been excluded as this is now reportedly 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 3.41.). 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 3.41. and Table 3.9.). 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 3.9. 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 3.42.** 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 3.43). 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 3.43** 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 Oosterwal 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.

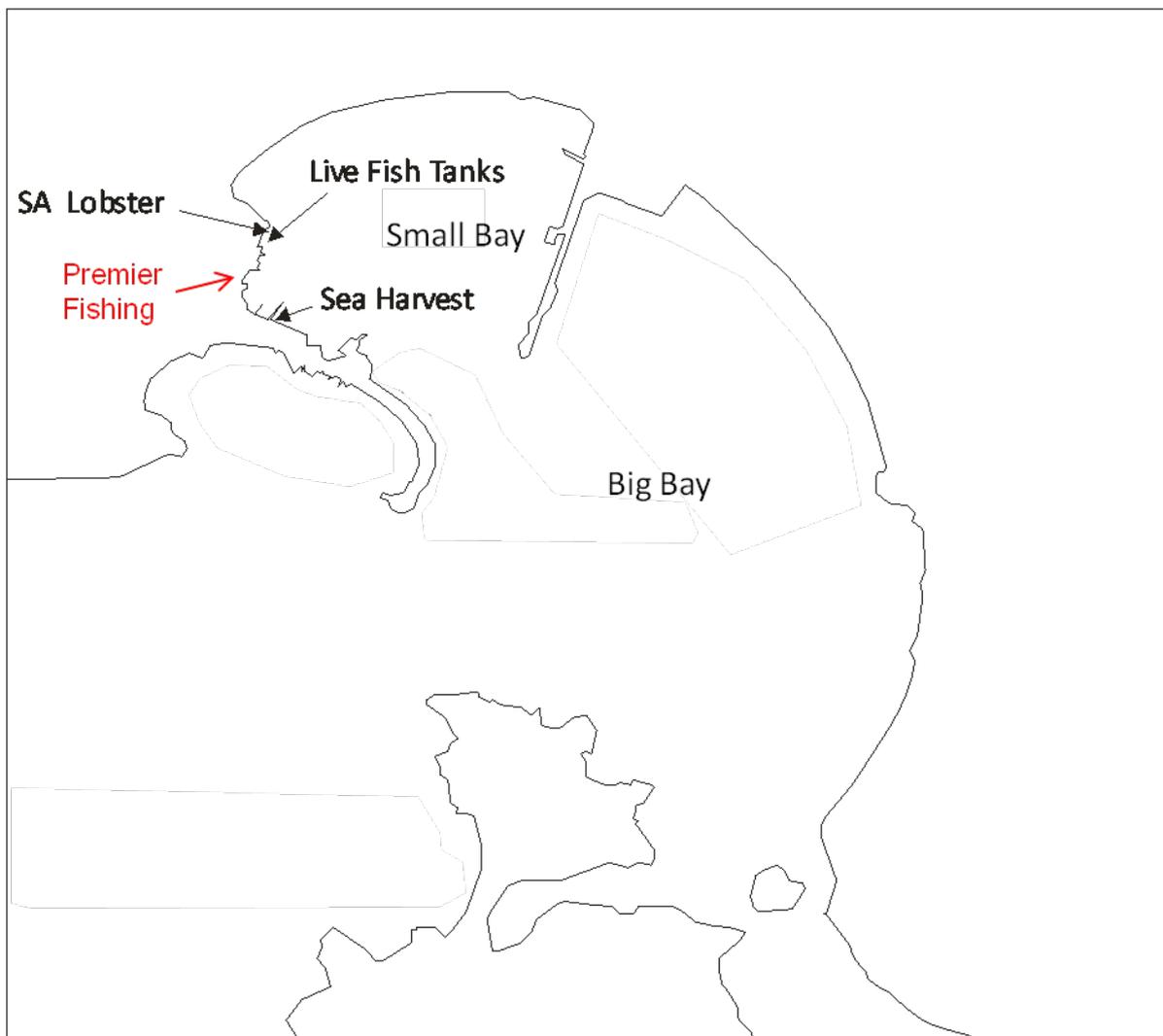
As a result of these concerns, a Stormwater Management Master Plan was drafted and is amended as new issues arise (living document) (Saldanha Bay Municipality 2014). A Stormwater Management Plan is a necessary precursor to an action plan for improving stormwater management in Saldanha. However, the importance 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 3.44. 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<sup>3</sup>, 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 3.44.** 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 (*Merluccius 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 2017 for a detailed description of the improvements made).

Sea Harvest requires high volumes of potable water for the processing of fish. With the implementation of water restrictions, Sea Harvest implemented a Reverse Osmosis (RO) plant for the reclamation of potable water from seawater and potentially fish processing waste water. The RO plant is expected to produce 42 m<sup>3</sup> per hour of potable water. The effluent consisting of RO brine, FFP factory effluent (i.e. process seawater is used to keep the floor drains flowing, to save potable water, to rinse ice off fish and to hose down floors etc.) and Added Value factory effluent from the DAF plant (10 m<sup>3</sup>/h) will be diluted with sea water before discharge. The RO plant also requires Sea Harvest to abstract more seawater than before. Sea Harvest is currently not compliant with the CWDP and is required to discharge the effluent further offshore to facilitate dispersion of the effluent.

#### Coastal Waters Discharge Permit

Sea Harvest Corporation (Pty) Ltd was issued with a Coastal Waters Discharge Permit (CWDP) in terms of Section 69 of the Integrated Coastal Management Act (2009) for discharge of effluent into Saldanha Bay on 26 June 2017. The effluent from the RO plant as described above was incorporated into the CWDP by means of an amendment issued by the DEA: O&C on 9 March 2018.

The current CWDP 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<sup>3</sup> per annum at a maximum daily discharge volume of 1152 m<sup>3</sup>. 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 3.10. 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 Table 3.10. The receiving environment must be monitored every two years and includes water quality, sediment quality and benthic macrofauna. 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. *The list of parameters to be met in the receiving environment 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.*

**Table 3.10** 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 <sup>3</sup>	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	250 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

### **Environmental monitoring and dispersion modelling**

Anchor Environmental Consultants Pty (Ltd) was appointed by Sea Harvest to undertake scientific assessments required to meet the requirements of the permit conditions. The marine specialist study covered the following aspects:

1. Design of a monitoring programme to address the requirements of the CWDP;
2. Water column profile sampling;
3. Collection of sediment and macrofauna samples from all monitoring stations plus one control station (n = 8) and analysis of these samples for grain size, composition, percentage organic carbon and nitrogen, macrofauna species composition, abundance and biomass;
4. Dispersion modelling to establish the plume behaviour, assimilative capacity of the receiving environment and confirm a reasonable mixing zone;
5. Assessment of potential impact resulting from the effluent discharges on the receiving environment, the effectiveness of management strategies and actions to ensure compliance with the permit conditions, trends, status and changes in the environment related to the ecological health and designated beneficial uses of the system and whether the environmental quality limits are complied with in the area from the end of the mixing zone
6. Provision of recommendations on an effluent improvement plan to reduce the impacts of effluent in the marine environment.

A summary of the results of this study are presented below (refer to Wright *et al.* 2018).

#### ***Proposed monitoring programme***

To fulfil the requirements of the CWDP, environmental monitoring of both physical and biological parameters is required. The CWDP prescribes that the following receiving environment monitoring plans be implemented that at minimum address:

- the potential marine impact resulting from the saline concentrate discharge;
- trends, status and changes in the receiving environment related to the health of important ecosystems and designated beneficial uses; and
- changes, if any, in the benthic macrofauna within the vicinity of the discharge point.

It is a requirement that defined management interventions be initiated should the discharge be non-compliant in terms of receiving water quality guidelines (DWAF 1995, or revisions thereof in Anchor 2015), or there is evidence of deteriorating environmental attributes linked to the discharge.

The proposed monitoring programme focuses specifically on the environmental monitoring of both physical and ecological parameters. It is considered critically important that monitoring conducted for the Sea Harvest outfall ties in as closely as possible with the Saldanha Bay Water Quality Trust (SBWQT) State of the Bay monitoring programme as the latter programme provides coverage of a large number of monitoring stations in Saldanha Bay and as such provides much useful background or control data against which monitoring data from Sea Harvest can be benchmarked. This will also address the requirement for monitoring at control stations.

To this end, it is important that methods used for collection of the Sea Harvest samples and the timing of their collection align with that of the State of the Bay programme. Thus, a suite of environmental parameters were sampled at the stations shown in Figure 3.45 during the 2018 State of the Bay survey and will continued to be collected in accordance with the requirements of the CWDP (Table 3.10). A short summary of the different environmental sampling methods are listed below:

- Water column profile sampling is conducted using a CTD, an instrument that measures conductivity (to determine salinity), temperature, and pressure of seawater (to determine depth). Stations 1, 2 3 and 5 indicated in Figure 3.45 will be sampled every 12 months.
- Sediment samples are collected at stations indicated in Figure 3.45 every 12 months. Seven effects stations will be sampled – one at pipe end, two 25 m and two 50 m away from the end of pipe, and two 100 m away from end of pipe. Sediment will be analysed for grain size and composition, as well as percentage organic carbon and nitrogen.
- Benthic macrofauna biological indicators, such as species abundance, biomass and diversity, 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 a marine environment as they are relatively non-mobile, short lived and their community composition responds rapidly to environmental change. They also tend to be directly affected by pollution, are easy to sample quantitatively, and are scientifically well-studied compared to other sediment-dwelling components. Samples are collected at sites indicated in Figure 3.45 using methods that correspond exactly with those employed in the 1999, 2004 and 2008-2017 SOB studies and thus facilitate comparisons between these sets of data.

These results (and additional monitoring undertaken by the SBWQFT) will be used to inform the assessment of potential impact resulting from the effluent discharges on the receiving environment, the effectiveness of management strategies and actions to ensure compliance with the permit conditions, trends, status and changes in the environment related to the ecological health and designated beneficial uses of the system and whether the environmental quality limits are complied with in the area from the end of the mixing zone, and to provide recommendations on an effluent improvement plan to reduce the impacts of effluent in the marine environment.

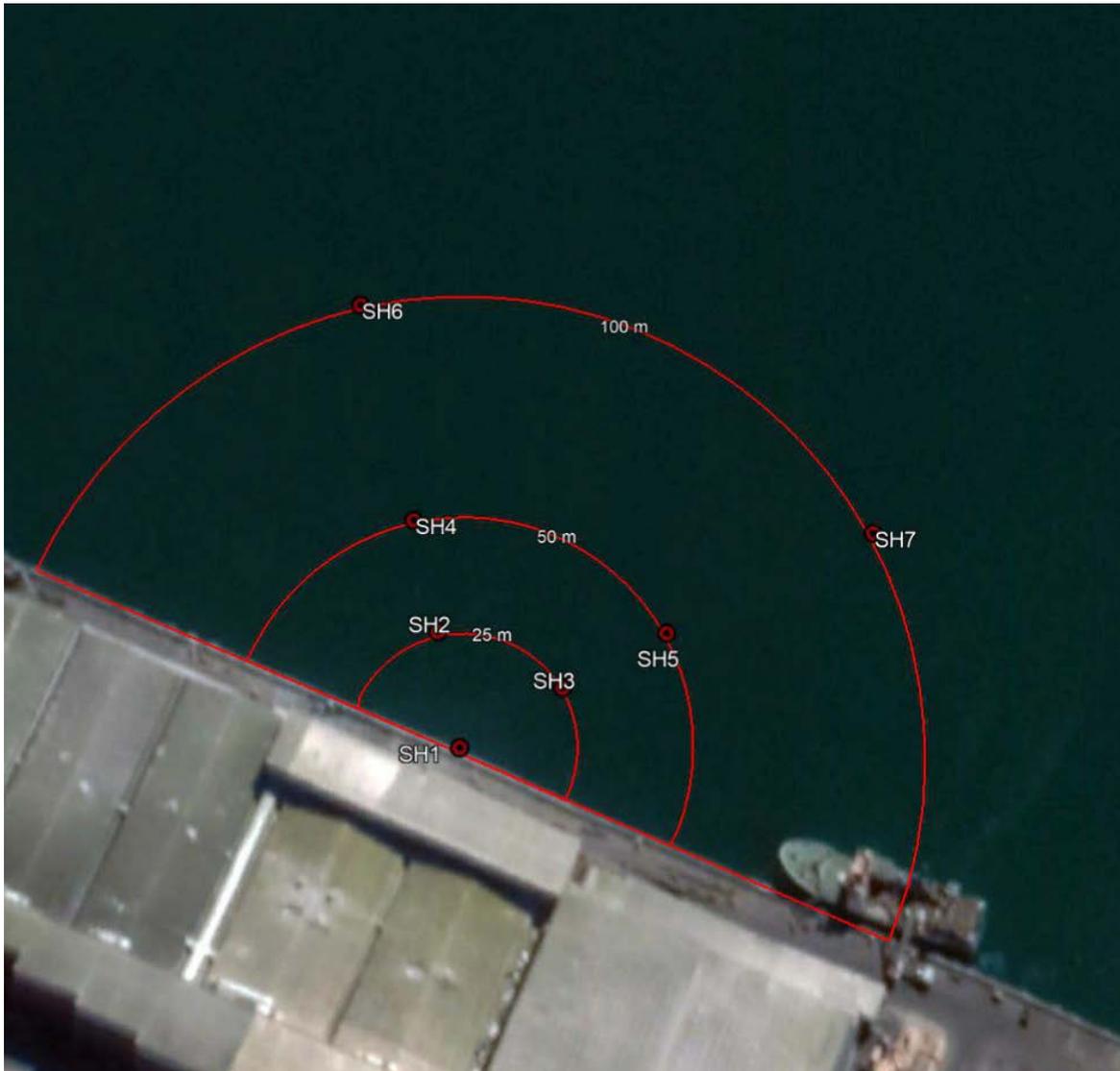


Figure 3.45 Impact monitoring stations for water quality, sediment quality, and benthic macrofauna sampling in the receiving environment surrounding the effluent outfall from the Sea Harvest fish processing plant.

#### ***Environmental effects monitoring***

Sediment particle size in the area surrounding the Sea Harvest outfall is comparable to sediment collected from the greater SBWQFT Small Bay and Big Bay habitats, and is comprised predominantly of sand (~85%) with a small percentage of mud (~15%). TOC and TON percentages were greatest at the site closest to the outfall, but were similar to levels recorded at other Small Bay and Big Bay SBWQFT sediment monitoring at all other stations.

The average species diversity ( $H'$ ) at the Sea Harvest effluent monitoring sites was lower than those observed at SBWQFT monitoring program sites, and is attributed to impacts already present around the current Sea Harvest effluent pipe. The benthic macrofaunal communities were significantly different to those found in Small Bay, Big Bay and Langebaan Lagoon (Figure 3.46). The differentiation of macrofaunal assemblages at the effluent monitoring sites can be attributed to the high abundance of small detritivore polychaete species that dominate due to the organic input from the existing Sea Harvest effluent pipe and the absence of other species usually common within Small bay and Big Bay.

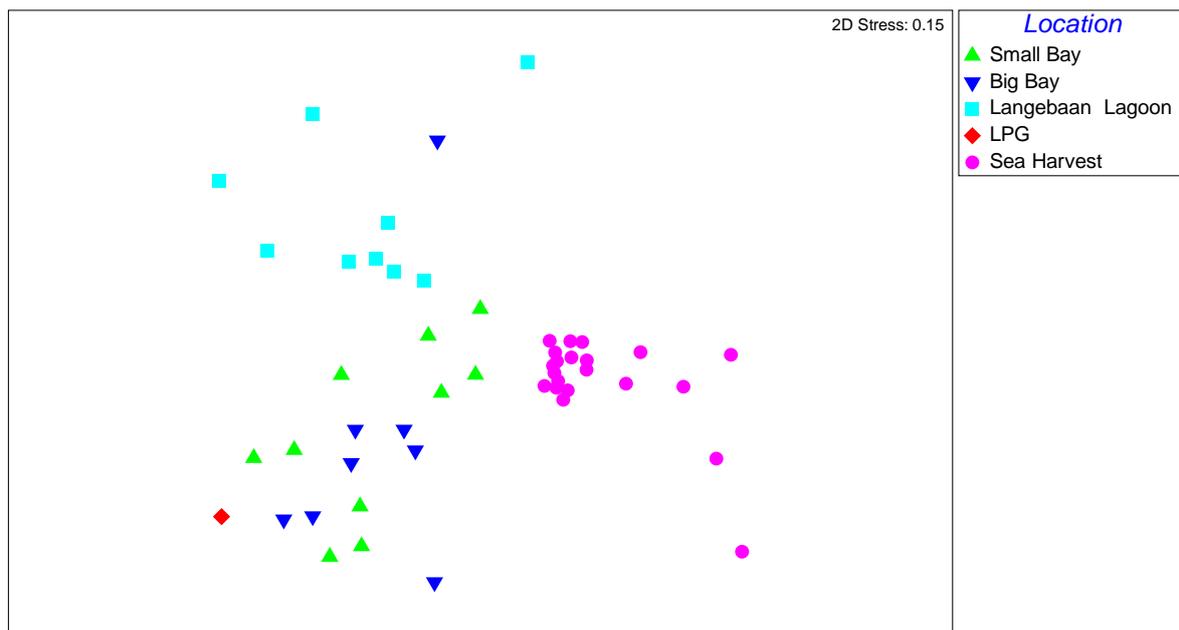


Figure 3.46 MDS plot of macrofaunal abundance throughout the Saldanha-Langebaan system based on the Bray-Curtis resemblance matrix.

### **Effluent modelling**

For marine outfalls that do not meet the requirements of a General Discharge Authorisation (GDA), a CWDP application including the results of dilution and dispersion modelling relating to the worst case scenario (maximum expected pollutant levels during emergency situations) are a prerequisite. Pollutant levels at the edge of the Recommended Mixing Zone (RMZ) are expected to comply with published Water Quality Guidelines (WQGs) according to the beneficial users of the receiving environment. Numerical modelling was performed using the Cornell Mixing Zone expert system (CorMix) to predict the geometry and dilution characteristics within the RMZ of each discharge scenario and to determine the minimum discharge depth required to achieve compliance with regional WQGs. The radius of each RMZ was determined according to the recently revised “Assessment Framework for Effluent Discharged from Land Based Sources” (Anchor 2015a).

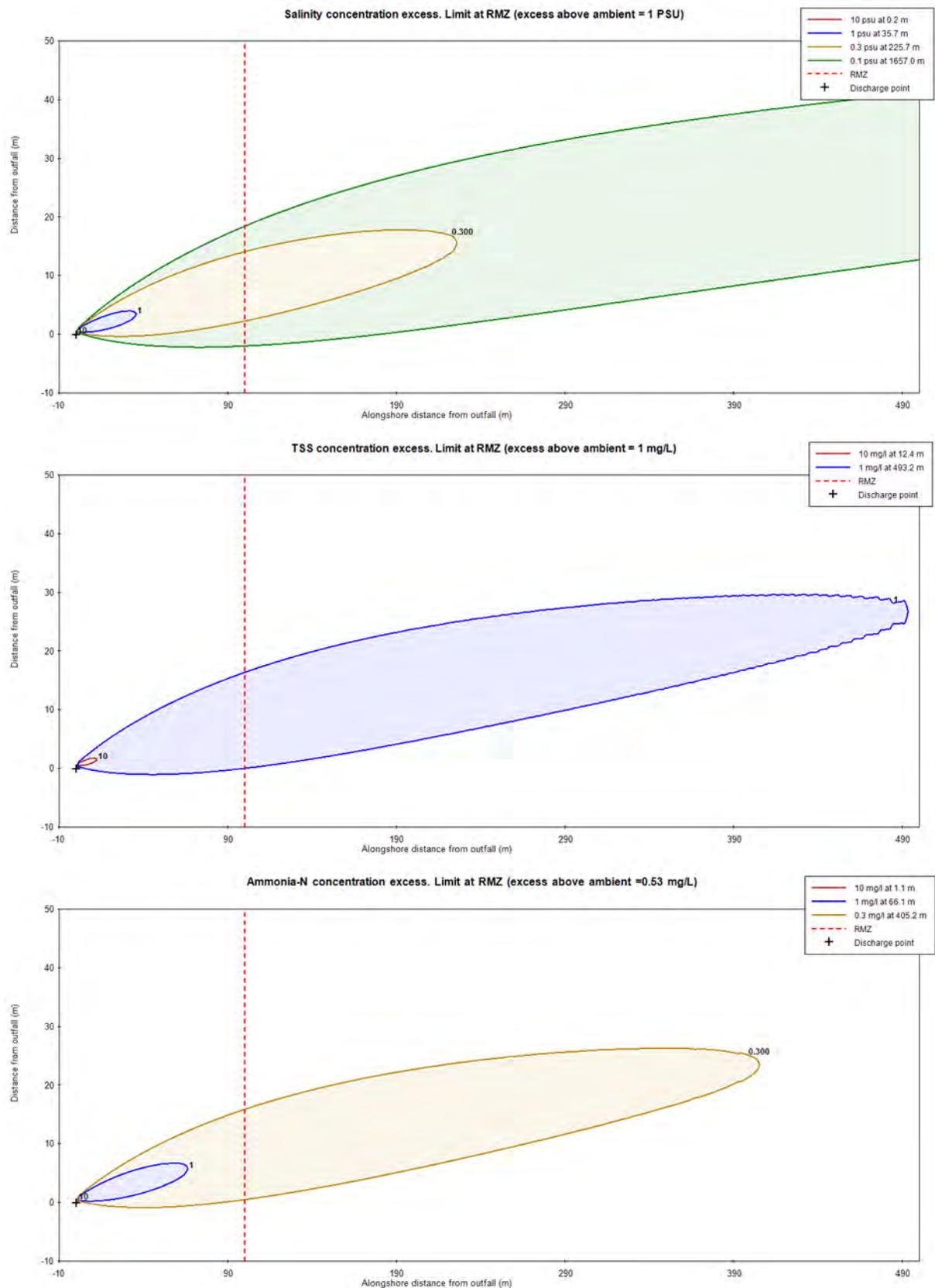
Two scenarios were modelled, and three outfalls were considered. Scenario 2 was modelled to include a 50% dilution of the effluent using process seawater prior to discharge. The port for the Outfall A was modelled as a surface discharge 1 m seaward of chart datum (CD), while Outfall B was modelled as a diffuser type design with ten separate ports 45 m apart over a distance of 450 m. Outfall C was modelled as a bottom discharge with a port 0.7 m above the seafloor, angled up at 45° to facilitate mixing.

Predicted concentrations at the edge of the RMZ were compared to the South African Water Quality Guidelines for Coastal Marine Waters for the Natural Environment (DWAF 1995). Data indicating the likelihood of this criterion being met for Scenario 1 and Scenario 2 for a range of different constituents (salinity, ammonia-N and TSS), under south-south east current conditions.

The effluent density will be greater than the surrounding ambient water, and therefore, the effluent will be negatively buoyant and will tend to sink towards the bottom. Predicted salinity values met the South African Water Quality Guidelines for Coastal Marine Waters for the Natural Environment (DWAF 1995) at the edge of the 100 m RMZ. TSS and ammonia-N concentrations met WQG limits for Outfall C in modelled Scenario 1 and Scenario 2, but not for Outfall A or B.

**Table 3.11** Predicted concentrations of effluent at the edge of the Recommended Mixing Zone (RMZ). Values that do not comply with water quality standards are highlighted in red. All distances and concentrations are measured from the plume centreline. Note that for Outfall B, the values provided are for one port (of ten in total).

Scenario		Unit	1			2		
Outfall option			A	B	C	A	B	C
Distance from Chart Datum (m)			1	1	150	1	1	150
Ammonia-N	Concentration at pipe end	mg/l	15.21			14.78		
	Limit at edge of RMZ		0.60			0.60		
	Concentration at edge of RMZ		0.80	0.78	0.10	0.77	0.71	0.10
TSS	Concentration at pipe end	mg/l	60.19			64.08		
	Limit at edge of RMZ		11			11		
	Concentration at edge of RMZ		12.43	12.67	10.15	12.65	12.46	10.10
Salinity	Concentration at pipe end	PSU	45.85			44.01		
	Limit at edge of RMZ		36			36		
	Concentration at edge of RMZ		35.33	35.28	34.82	35.25	34.95	34.84
Approximate depth at discharge location		m	5	5	7.2	5	5	7.2
Discharge velocity		m/s	12.33	1.23	12.33	14.92	1.49	14.94
Plume thickness at edge of RMZ		m	0.81	0.54	1.57	0.82	0.52	1.68
Plume width at edge of RMZ		m	15.86	7.70	184.4	16.48	7.06	198.82
Bank interaction (downstream of outfall)		m	n/a	n/a	n/a	n/a	n/a	n/a



**Figure 3.47** CorMix outputs depicting predicted Scenario 1 Outfall A. Effluent plumes for modelled (top) salinity, (middle) TSS, and (bottom) ammonia-N dilutions. Pollutant concentrations are represented as excess above background. The red dotted line indicates the position of the RMZ in relation to the outfall. The blue arrow indicates current direction.

**Assessment of potential impact on the marine environment by the effluent discharge**

After mitigation, none of the impacts are assessed as being above 'low' significance. However, high levels of ammonia-N and TSS present in the discharged effluent via Outfalls A and B is an impact rated as 'high' and represents a fatal flaw in the design of this project without mitigation. Given the known toxicity and negative impacts highly elevated concentrations of both ammonia-N and TSS have on the marine environment, every effort must be made to reduce ammonia-N and TSS levels prior to discharge into the marine environment, or improve dilution through discharge into deeper water (i.e. discharge via Outfall C). The assessment of these impacts before and after recommended mitigation is summarised in the table below (Table 3.12). Impacts expected in the decommissioning phase are addressed in the construction phase.

**Table 3.12 Summary of impacts identified and significance before and after mitigation for the effluent discharge from the Sea Harvest fish processing plant.**

Phase	Impact identified	Significance before mitigation	Significance after mitigation
Construction	Impact 1: Permanent loss or alteration of subtidal soft sediment habitat.	LOW	VERY LOW
	Impact 2: Temporary disturbance of pelagic open water habitats.	INSIGNIFICANT	n/a
	Impact 3: The effect of increased noise and vibration from construction on marine organisms.	VERY LOW	INSIGNIFICANT
	Impact 4: Waste generation and disposal during construction.	MEDIUM	LOW
	Impact 5: The effect of the spillage of hazardous substances on estuarine biota.	LOW	VERY LOW
	Impact 6: Water quality impacts associated with disturbance of the estuarine sediments.	INSIGNIFICANT	n/a
Operation	Impact 7: Disturbance and/or mortality of estuarine biota due to the intake of water from Saldanha Bay.	MEDIUM	LOW
	Impact 8: Sediment scouring and shifts in sediment movement patterns.	INSIGNIFICANT	n/a
	Impact 9: Reduced physiological functioning due to changes in salinity	INSIGNIFICANT	n/a
	Impact 10: Reduced physiological functioning due reduced pH.	INSIGNIFICANT	n/a
	Impact 11: The impacts of elevated levels of ammonia-N and TSS on marine biota.	HIGH	LOW
	Impact 12: The impacts of discharged biocides on marine biota.	MEDIUM	VERY LOW

Further mitigation measures, both best practise and essential, include: subjecting mobile equipment, vehicles and power generation equipment to noise tests at commencement and periodically throughout the construction phase; informing all staff about sensitive marine species and the suitable disposal of waste; reduce, reuse, recycle; the intentional disposal of any substance into the marine environment must be strictly prohibited, while accidental spillage must be prevented, contained and reported immediately; a rigorous environmental management and control plan (including procedures for remediation) should be implemented; all fuel and oil must be stored with adequate spill protection, and no leaking vehicles are to be permitted on site.

Based on the impacts assessed in this report, it is recommended that the proposed development proceed with the implementation of strict environmentally responsible practices as outlined in the mitigation measures.

### ***Effluent quantity and quality monitoring results***

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 3.13). Sea Harvest had 1 691 operational days since 15 July 2013 and readings were only taken 40% of the time.

In the last year (July 2017-June 2018) effluent meter readings were only recorded 46% of the time due to a broken meter (Table 3.13). This is an improvement compared to the previous year when readings were only taken 20 % of the time. Higher compliance would be desirable as on more than 50% of the days effluent volume discharge remains unmonitored. However, the recorded data is considered reliable and indicates that Sea Harvest was compliant with permissible daily effluent limits since July 2013 (only 6% exceedance). However, with the implementation of the new daily limit of 1152 m<sup>3</sup>, non-compliance increased to 27% since July 2018 (Table 3.13)<sup>6</sup>.

It is noteworthy that Sea Harvest has submitted an application for an amendment of their CWDP to accommodate greater seawater abstraction effluent discharge volumes.

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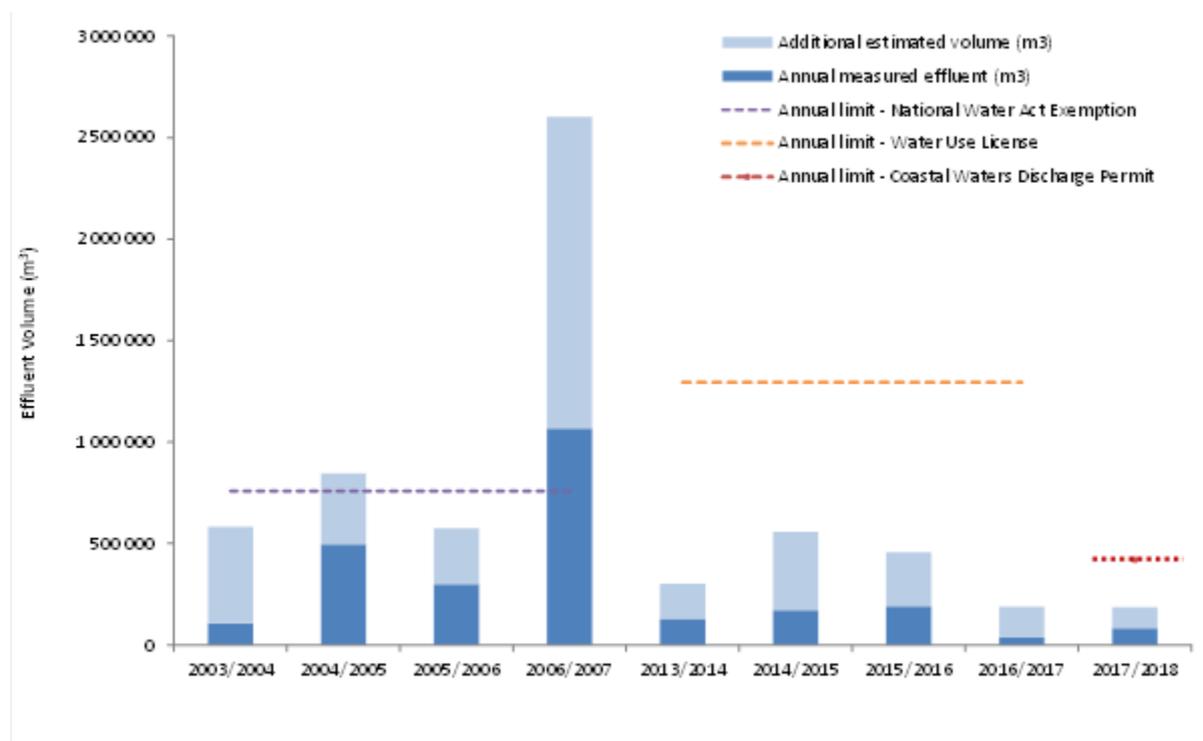
<sup>6</sup> Effluent volume is calculated by subtracting the previous day's reading. The first reading after a gap (public holiday or weekend) cannot be used to calculate an effluent volume for the day as the volume represents several days of effluent discharge. These data gaps do not occur in a reliable 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<sup>3</sup> was therefore only calculated using a subset of effluent volumes calculated from reliable effluent volume readings.

**Table 3.13** 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 2017- June 2018
Number of operational days	1424	1619	283
Number of readings	651	674	130
Readings taken relative to number of operational days (%)	46	40	46
Number of days where effluent volume was recorded <sup>A</sup>	571	605	128
Legal daily effluent volume limit (m <sup>3</sup> )	2000	3546	1152
Exceedance of legal effluent volume limit (count)	225	37	34
<b>Exceedance of legal effluent volume limit relative to number of operational days (%)</b>	<b>39</b>	<b>1</b>	<b>0</b>

Average effluent discharged per day was 3 285 m<sup>3</sup> in 2003/4, increased to 7 312 m<sup>3</sup> in 2006/7 and has dropped to 529 m<sup>3</sup> in 2016/17 and has remained approximately the same for 2017/2018. Annual effluent discharge was estimated from the average daily effluent volume<sup>7</sup> and compared to the prescribed annual effluent limits over time (Figure 3.48). Estimated total annual fish processing effluent volumes discharged into Small Bay between July 2003 and June 2018 by Sea Harvest is shown in Figure 3.48. 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. However, the 2017/2018 data shows that Sea Harvest is currently able to meet the new annual limit of 420 480 m<sup>3</sup> as specified in the CWDP conditions. The daily maximum discharge limit, however, seems to be inadequate.

<sup>7</sup> Average daily effluent volume was calculated by dividing the measured annual volume by the number of measurements taken.



**Figure 3.48** Estimated Fresh fish processing effluent volume discharged into Small Bay per year by Sea Harvest from July 2004 - June 2018. 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. (Source: Frank Hickley, Risk Control Manager at Sea Harvest fish Processing Plant).

Until this CWDP was issued 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.

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 3.49). Trends in TSS since 2010 suggest that concentrations fluctuate over time and it appears that peak concentrations are decreasing in magnitude (Figure 3.49). The CWDP issued on 26 June 2017 specifies a legal limit of 230 mg/L. Since June 2017, TSS concentration in the effluent exceeded the legal limit six times, which means that Sea Harvest is compliant only 50% of the time.

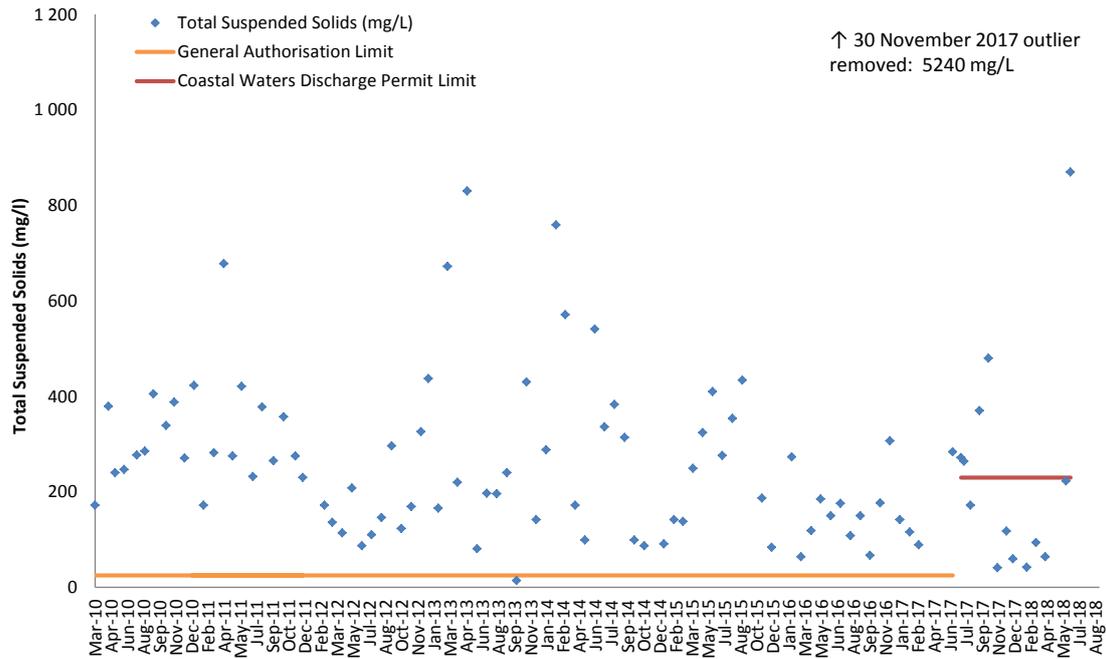
Sea Harvest was required to comply with the revised General Discharge Limit for ammonia nitrogen of 6 mg/l until the CWDP was issued on 26 June 2017. This limit was very conservative considering that the water quality guidelines for the coastal environment specify a target of the same value (DAFF 1995). 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.

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 3.51). 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 has been meeting comfortably in the preceding year.

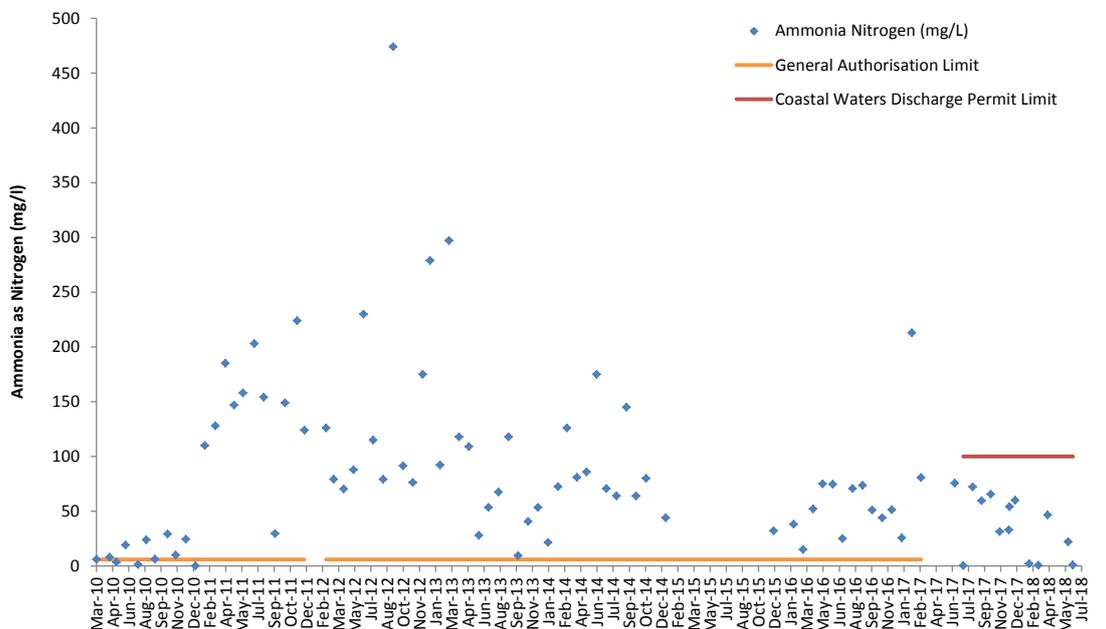
Sea Harvest has been measuring Chemical Oxygen Demand (COD) since November 2015. COD is extremely high measuring on average  $1\,121 \pm 618$  mg/l since July 2017. The highest value was recorded in June 2018 with 2 957 mg/l. The results suggest that a large amount of oxygen is required to breakdown the organic waste in the effluent. Sea Harvest has not been able to meet the requirements of the new CWDP (<200 mg/L) under current effluent treatment methods (Figure 3.52). 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 3.53). Values exceeded the General Authorisation limit of 2.5 mg/l at all times, with a very high average of  $27 \pm 25$  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 was therefore reinstated in June 2017. Sea Harvest was compliant with the legal limit only on five occasions since July 2017. Furthermore, a reading taken in July 2018 measured 17 472 mg of oil and grease per litre. This result is not considered reliable and was removed from the monitoring results.

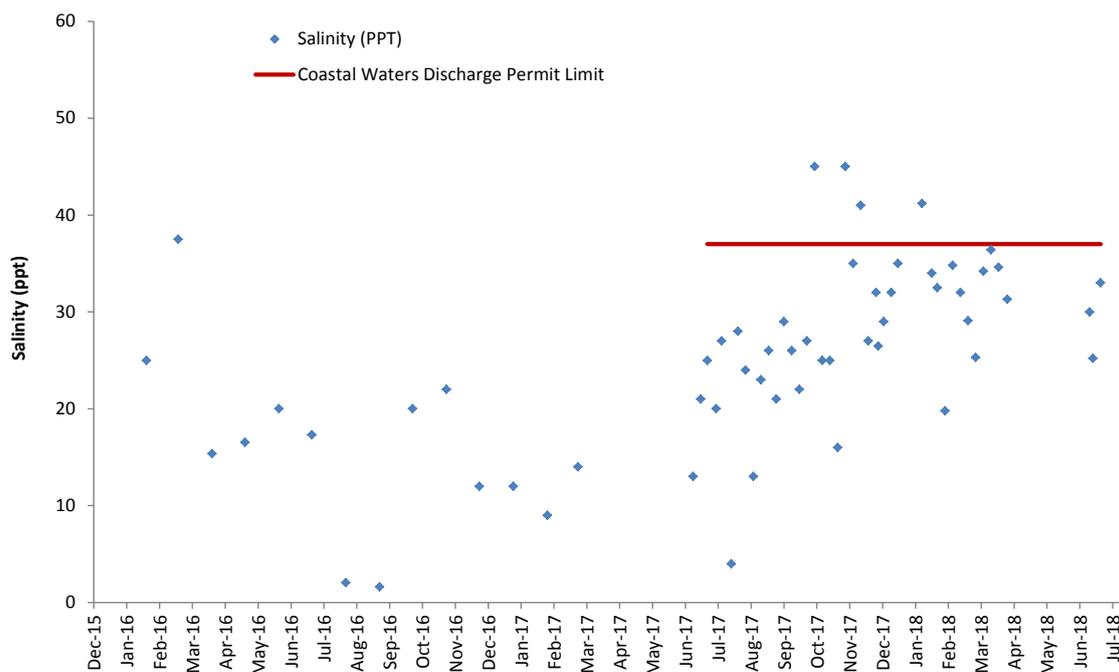
Sea Harvest monitored pH between March 2010 and December 2014. The current CWDP requires the monitoring of pH, which was resumed in July 2017. The results from 2017/18 demonstrate that the effluent has been compliant with the legal limit with the exception of one occasion when pH measured 4.8 in July 2017.



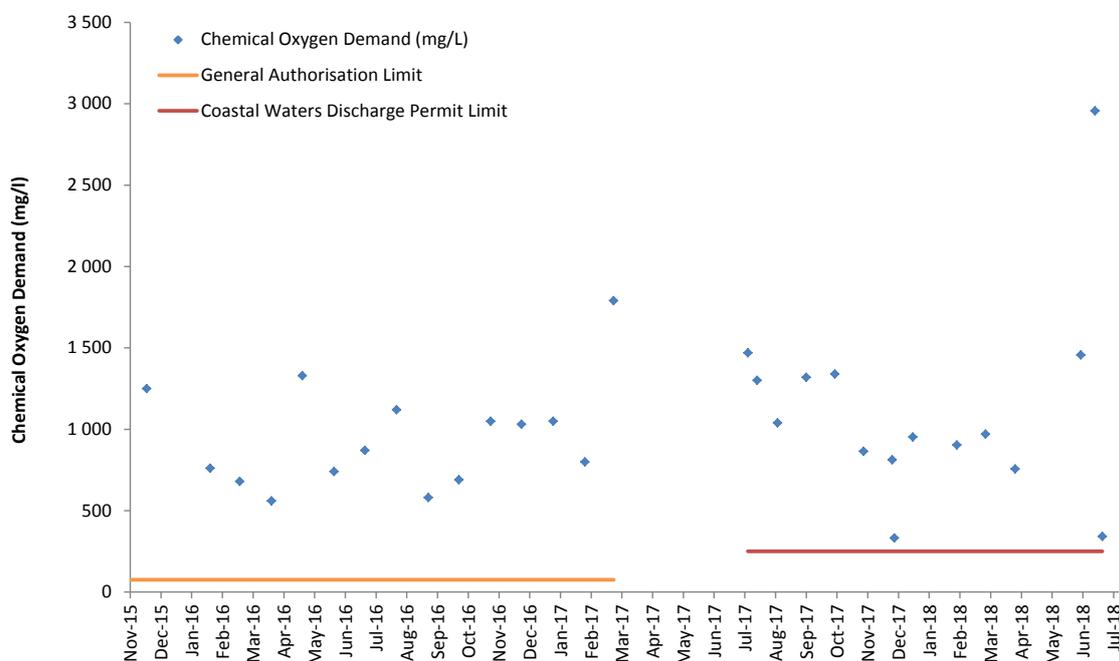
**Figure 3.49** Monthly trends in total suspended solids (TSS) (mg/l) in the effluent discharged from the Sea Harvest fresh fish processing (FFP) plant into Small Bay in the period March 2010 to June 2018 (concentration measured at the end of pipe). No data is available between April and June 2017. The orange 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). Sea Harvest was granted a Coastal Waters Discharge Permit on 26 June 2017, which prescribes a limit of 230 mg/L (depicted as the red line). (Source: Frank Hickley, Risk Control Manager at Sea Harvest fish Processing Plant).



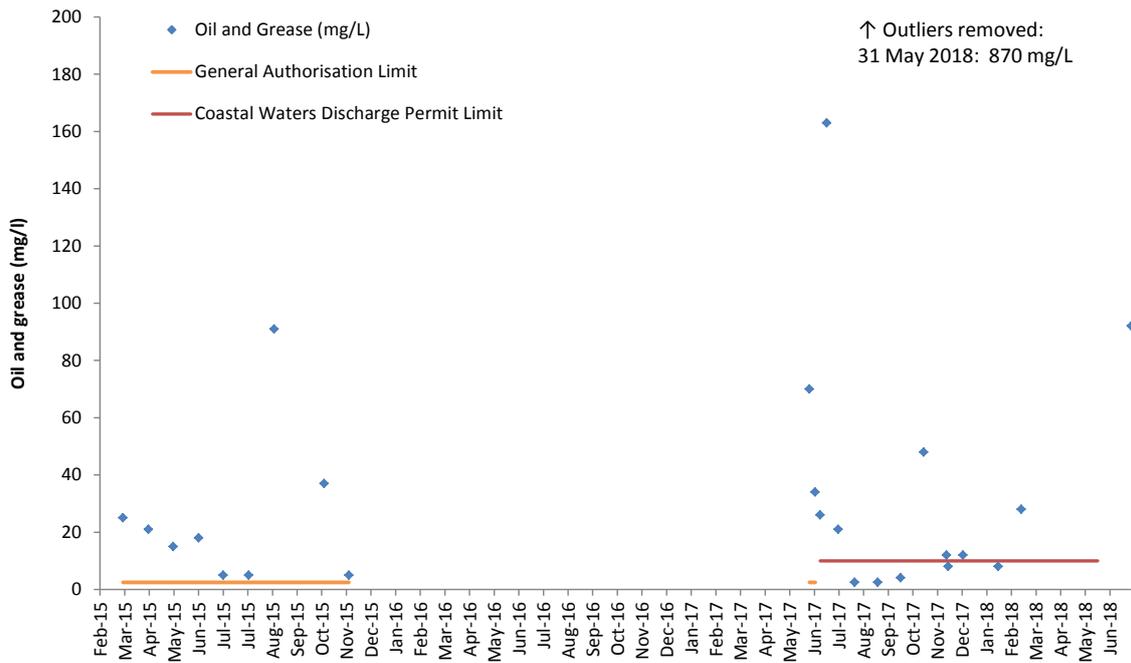
**Figure 3.50** Monthly trends in ammonia nitrogen (mg/l) in the effluent discharged from the Sea Harvest fresh fish processing (FFP) plant into Small Bay in the period March 2010 to June 2018 (concentration measured at the end of pipe). No data is available between April and June 2017. The orange line 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). Sea Harvest was granted a Coastal Waters Discharge Permit on 26 June 2017, which prescribes a limit of 100 mg/L (depicted as the red line). (Source: Frank Hickley, Risk Control Manager at Sea Harvest fish Processing Plant).



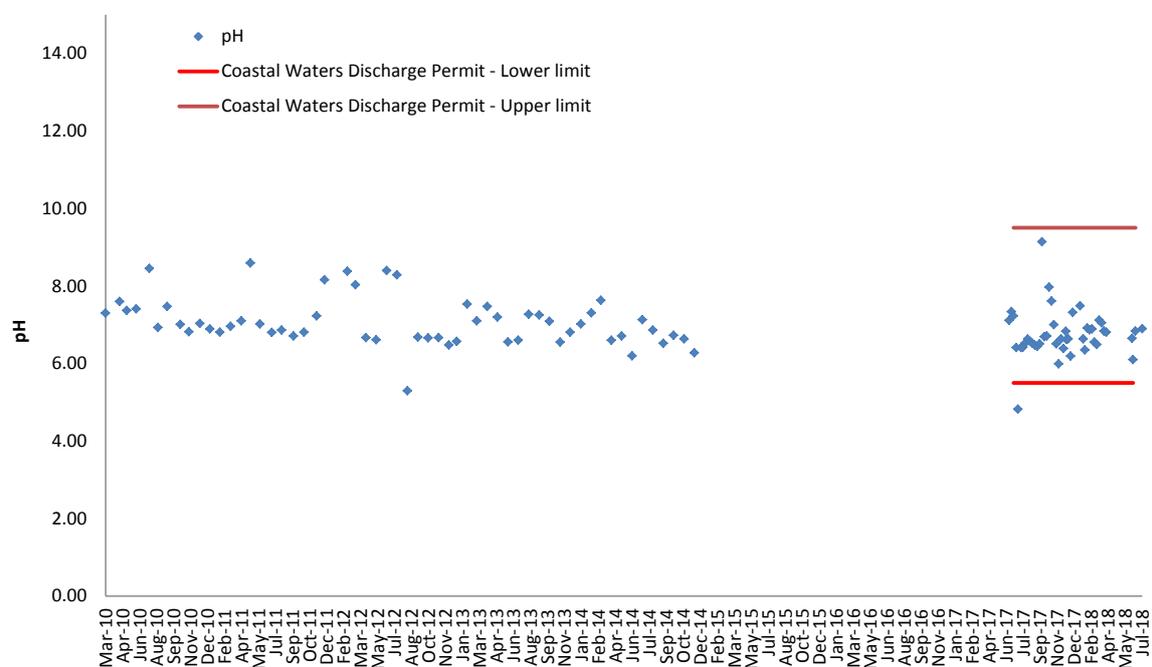
**Figure 3.51** Monthly salinity (ppt) trends in the effluent discharged from the Sea Harvest fresh fish processing (FFP) plant into Small Bay in the period January 2015 to June 2018 (concentration measured at the end of pipe). No data is available between April and June 2017. Sea Harvest was granted a Coastal Waters Discharge Permit on 26 June 2017, which prescribes a limit of 37 ppt (depicted as the red line). (Source: Frank Hickley, Risk Control Manager at Sea Harvest fish Processing Plant).



**Figure 3.52** 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 2018 (concentration measured at the end of pipe). The orange 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 red line). No data is available from April 2017 onward. (Source: Frank Hickley, Risk Control Manager at Sea Harvest fish Processing Plant).



**Figure 3.53** 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 and from June 2017 to June 2018 (concentration measured at the end of pipe). The orange 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). Sea Harvest was granted a Coastal Waters Discharge Permit on 26 June 2017, which prescribes a limit of 10 mg/L (depicted as red line) (Source: Frank Hickley, Risk Control Manager at Sea Harvest fish Processing Plant).



**Figure 3.54** Monthly trends of the pH measured in the effluent discharged from the Sea Harvest fresh fish processing (FFP) plant into Small Bay in the period March 2010 to December 2014 and from June 2017 to June 2018. The red dashed lines indicate the lower and upper limits prescribed by the Coastal Waters Discharge Permit dated 26 June 2017. (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 reclaims potable water by means of a Reverse Osmosis plant with the intention to save municipal water and to improve effluent quality (Frank Hickley, Sea Harvest *pers. comm.*, 2018). Some improvement can be observed in the last year for TSS, ammonia and COD, although levels are still extremely high and in some cases exceed the legal limit prescribed by the CWDP.

### **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).

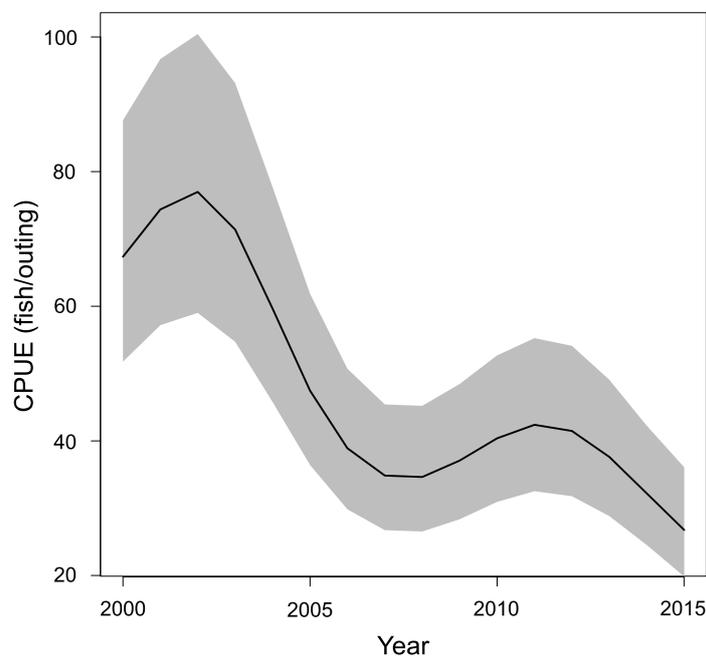
## **3.7 Fisheries**

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 stumponose catch-per-unit-effort has declined considerably in the last 15 years, whilst recruitment has also crashed (Figure 3.55). This Saldanha - Langebaan white stumponose 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 they 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 3.55** Annual Catch Per Unit Effort (CPUE) estimates ( $\pm 95\%$  Confidence Interval) of white stumponose 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 aquaculture 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 3.56), of which 316.5 ha have been leased to 14 individual mariculture operators (Table 3.14 and Figure 3.56). Just over seventy percent of these concession areas are actively farmed for mussels, oysters and finfish, mostly in Small Bay (Table 3.14). The DEA recently issued Environmental Authorisation to the DAFF for an Aquaculture Development Zone, which include four precincts (Small Bay, Big Bay North, Outer Bay North and South) totalling 420 ha of new aquaculture areas in Saldanha Bay. Currently farmed areas will be incorporated into the ADZ comprising 884 ha set aside for mariculture. More details on progress made in establishing the ADZ are summarised in Section 3.8.1.

**Table 3.14.** 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).

Company	Products							Area (Location*)	Duration of right
	Mussels	Oysters	Abalone	Scallops	Red Bait	Seaweed	Finfish		
Blue Ocean Mussel (previously trading as Blue Bay Aquafarm (Pty) Ltd.	x	x						52.1 ha (SB)	2017-2032
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
Saldanha Bay Oyster Company (previously trading as 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

Company	Products							Area (Location*)	Duration of right
	Mussels	Oysters	Abalone	Scallops	Red Bait	Seaweed	Finfish		
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 3.56.** 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 has been given Environmental Authorisation 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. Refer to AEC 2017 for a detailed description and potential impacts of the proposed ADZ.

The ADZ project triggered activities listed in terms of Listing Notice 1 of the EIA Regulations, 2014, required 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 competent authority (Department of Environmental Affairs) granted three separate Environmental Authorisations (EAs) for the sea-based ADZ and the Southern Cross fish farm (combined application) and the Molapong Aquaculture farm on 8 January 2018. Four appeals to the EA were received from interested and affected parties. The appeal decision by DEADP was issued on 7 June 2018 and stated that appeals were overturned by the Minister and that the EA was upheld. DAFF set up a Consultative Forum and stakeholders have been invited to register. Furthermore, the inaugural meeting for the Aquaculture Management Committee (AMC) was held on 27<sup>th</sup> July 2018. Ecosense was appointed as the Environmental Control Officer for the Aquaculture Development Zone on 6<sup>th</sup> September 2018. The DAFF has outsourced the drafting of the marine monitoring programme (sampling plan) and has engaged with the Saldanha Bay Water Quality Forum Trust in an effort to combine sampling efforts.

### 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 3.14). 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.

Overall the drive is to farm indigenous species 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. However, in some cases indigenous species may be economically less viable. The DAFF therefore included alien trout species in their application for EA. Consequently, the Environmental Authorisation issued to DAFF for the ADZ includes the following alien finfish:

- Atlantic salmon (*Salmo salar*)
- Coho salmon (*Oncorhynchus kisutch*)
- King/Chinook salmon (*Oncorhynchus tshawytscha*)
- Rainbow trout (*Oncorhynchus mykiss*)
- Brown trout (*Salmo trutta*)

Biodiversity Risk and Benefit Assessments have been conducted for all five salmon and trout species and generally the risk for establishment of this species is considered low due to the fact that these species will be farmed in the sea and rivers in this region are not suitable for successful reproduction of salmonids. Arguably the greatest risk of salmonid cage culture is the transfer of diseases and parasites to indigenous fish species.

Other new indigenous species include Abalone (*Haliotis midae*), South African scallop (*Pecten sulcicostatus*), white stumpnose (*Rhabdosargus globiceps*), kabeljou (*Argyrosomus inodorus*) and yellow tail (*Seriola lalandi*).

### 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 3.57). 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). Both mussel and oyster production reached a peak in 2016 and decreased in 2017 (Figure 3.57 and Figure 3.58.)

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.

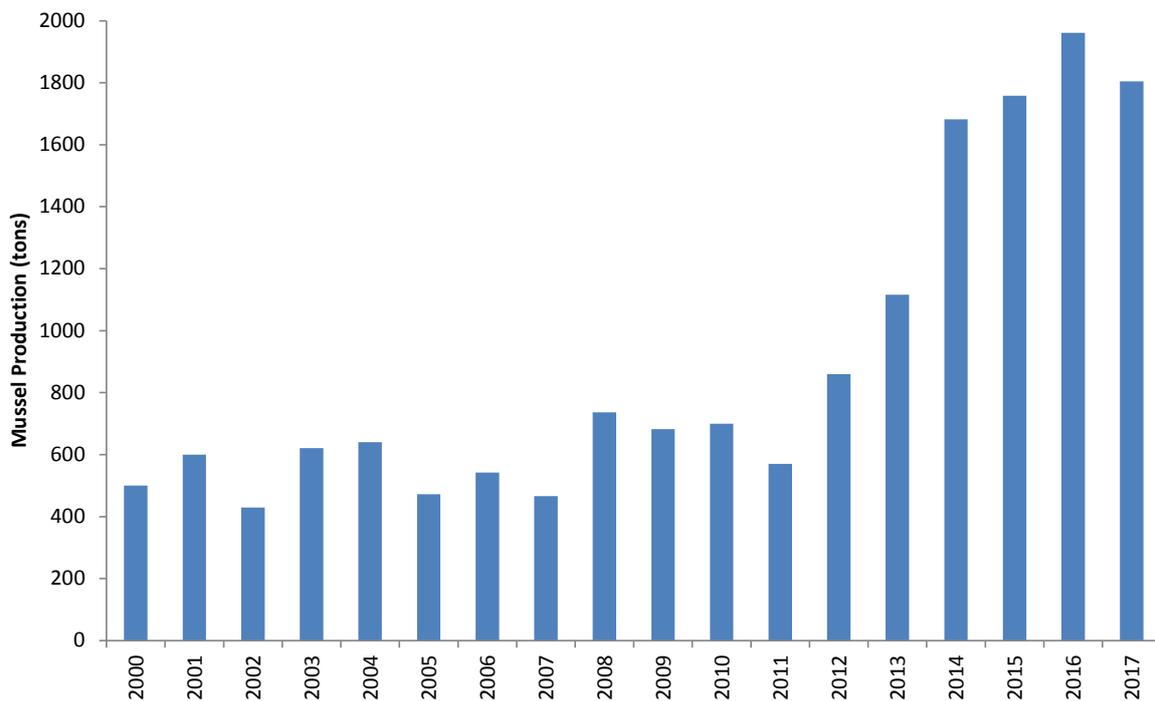


Figure 3.57. Annual mussel production (tonnes) in Saldanha Bay between 2000 and 2017 (source: Department of Agriculture, Forestry and Fisheries 2017 unpublished data, which may be subject to change).

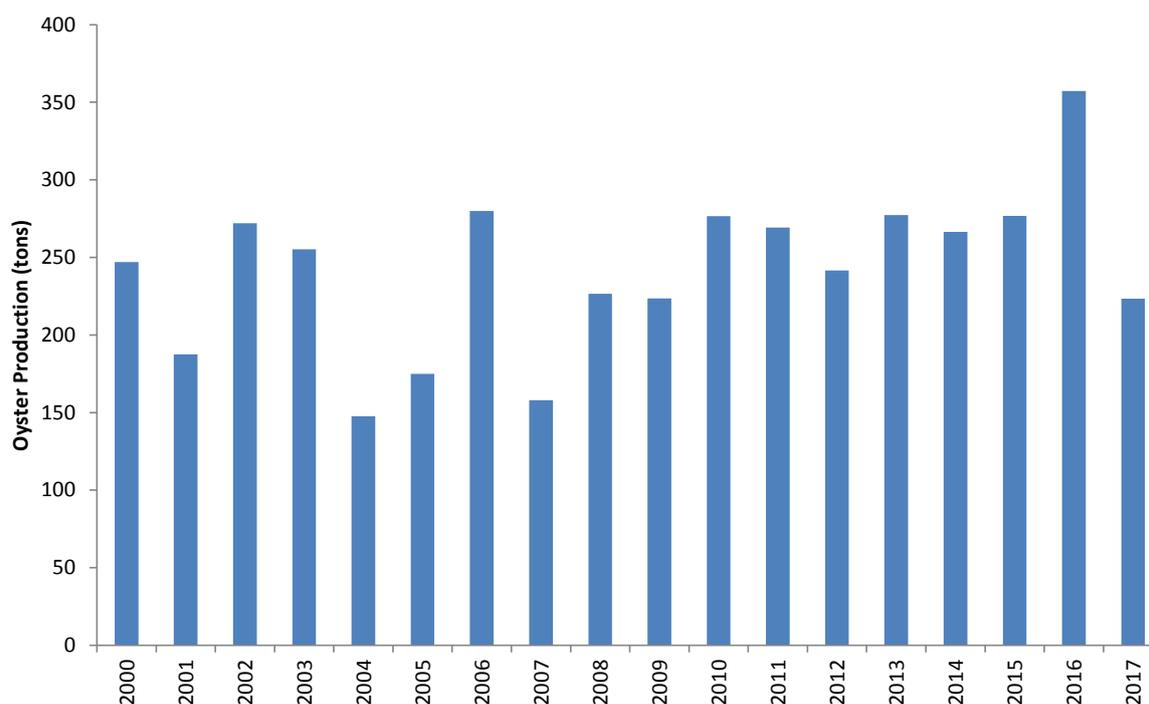


Figure 3.58. Annual oyster production (tonnes) in Saldanha Bay between 2000 and 2017 (source: Department of Agriculture, Forestry and Fisheries 2017 unpublished data, which may be subject to change).

### 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 (*Oncorhynchus 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. Environmental Authorisation was issued on 8 June 2018 for the following project phases:

- 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.

Southern Cross Salmon Farming (Pty) Ltd was also issued with an Environmental Authorisation on 8 January 2018 for the production of shellfish in the Outer Bay North Site (20 ha) to total production not exceeding 2500 tons (graded) on long-line. Furthermore permission was granted to produce 1000 tons of marine finfish per annum on 10 ha (at full production) within the Outer Bay South site by means of floating cages. Southern Cross Salmon Farming (Pty) Ltd is permitted to farm the same species that were authorised for the Aquaculture Development Zone.

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 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, Heggoy *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 3.59). 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 3.60, Figure 3.61). 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 3.62). 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 3.59. Position of the original shoreline at Langebaan Beach in 1975 (Source: Fleming 2016).

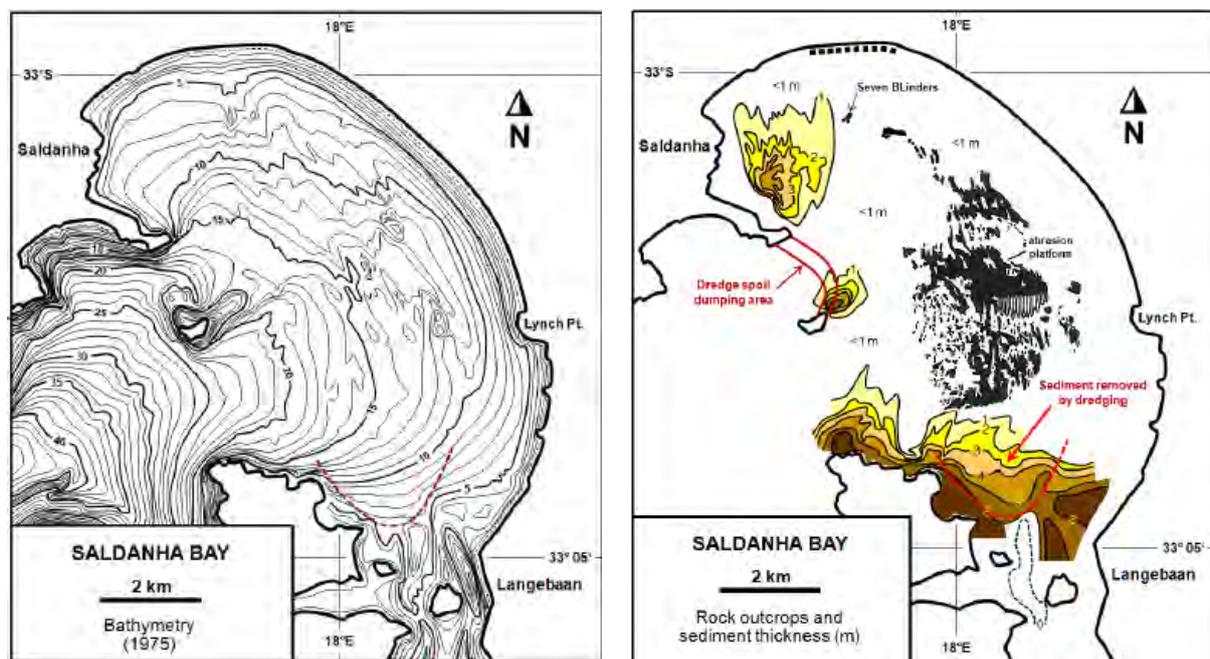


Figure 3.60. Ebb tide delta at the entrance to Langebaan Lagoon where sediment was dredged for construction of the causeway between Marcus Island and the mainland in the late 1970s. Source: Fleming (2016).

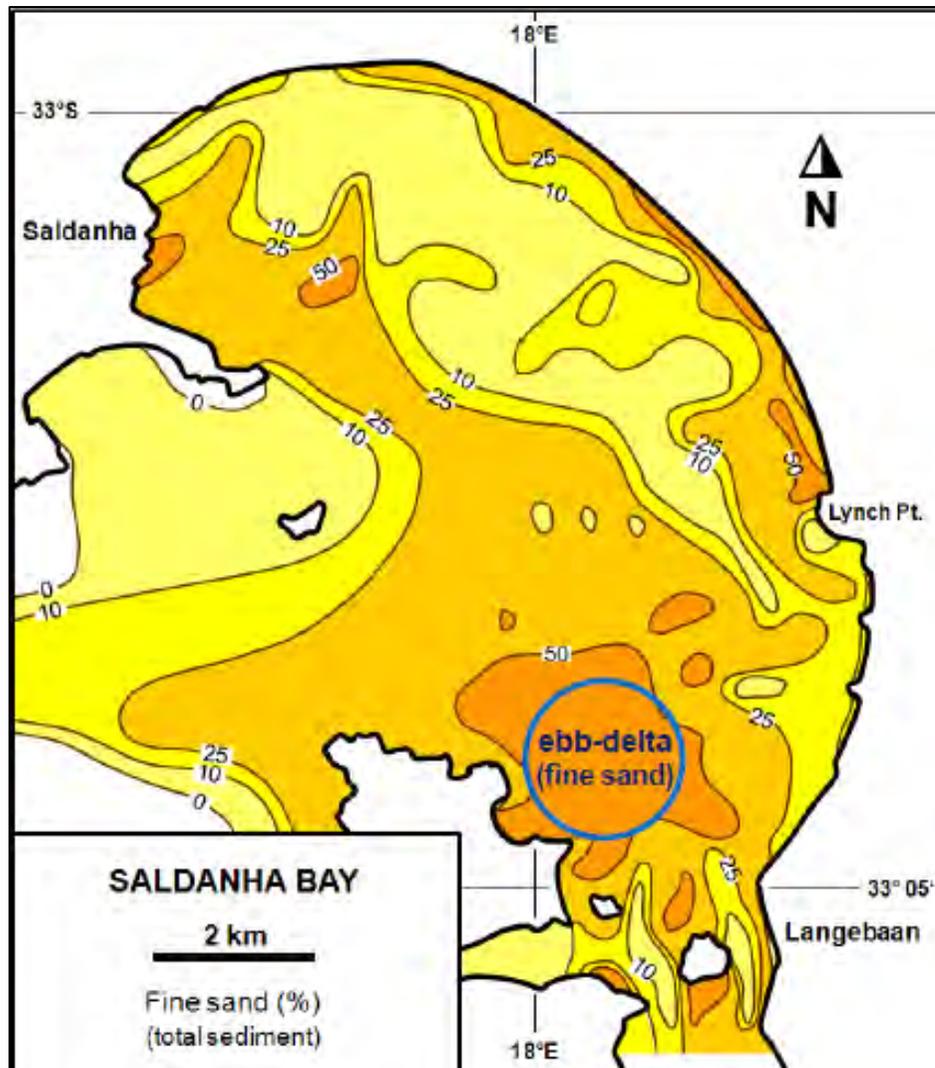


Figure 3.61. Ebb tide delta at the entrance to Langebaan Lagoon where sediment was dredged for construction of the causeway between Marcus Island and the mainland in the late 1970s. Source: Flemming (2016).

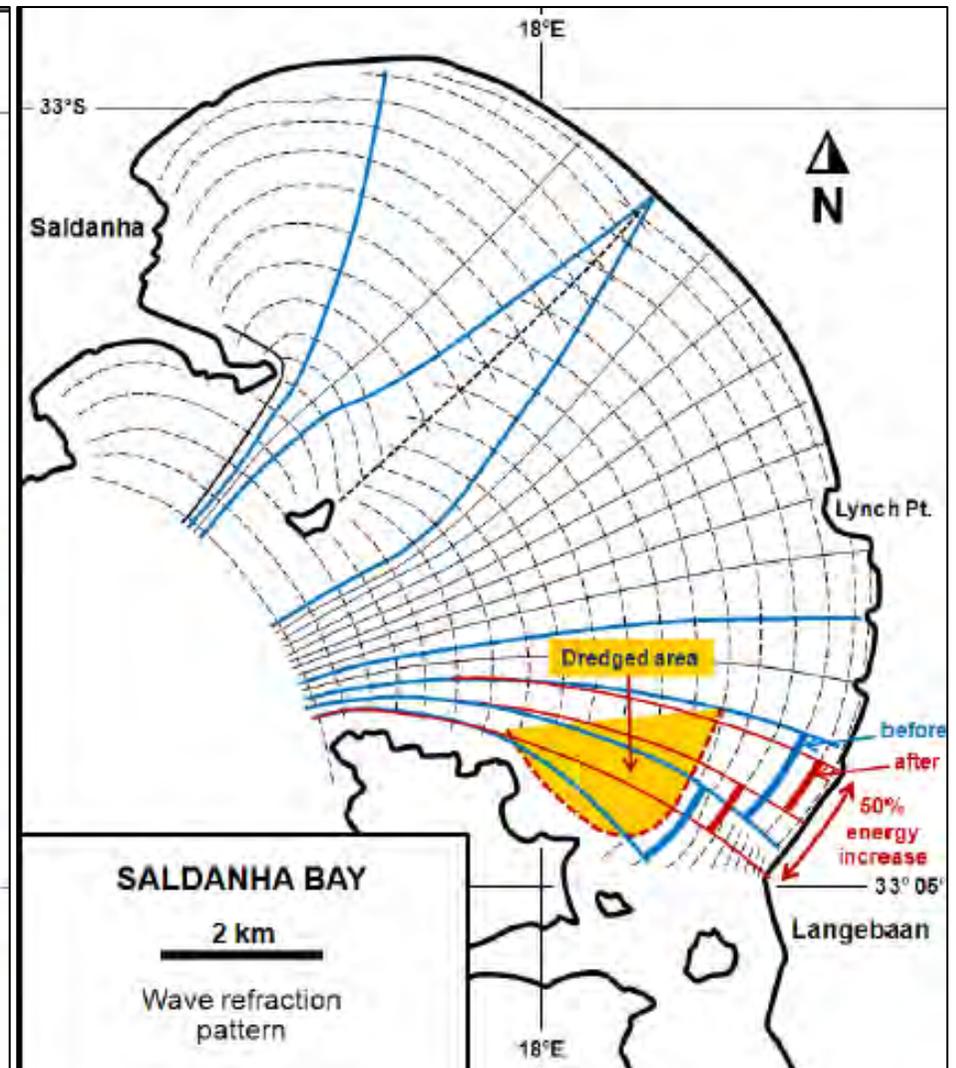


Figure 3.62. Changes in wave refraction patterns and a consequent increase in wave energy density at the shoreline at Langebaan Beach - a result of sediment removal during the construction of the causeway linking Marcus Island with the mainland. Source: Flemming (2016).

### 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 be 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 3.63. Groynes and rock revetment at Langebaan North beach. Source: Google Earth.

## 4 MANAGEMENT AND POLICY DEVELOPMENT

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 of 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 GROUND WATER

### 5.1 Introduction

Langebaan Lagoon is a unique 'estuary' in that it is not fed by runoff from a river but receives its fresh water from a groundwater aquifer – a palaeochannel from an old river. The classification of the 16 km long Langebaan Lagoon that adjoins Saldanha Bay on the West Coast has been debated for some time. Langebaan Lagoon has many of the characteristics of an estuary. This includes the calm coastal waters that are protected from marine wave action and biota that includes many species that are typically found in estuaries. The system lacks a conventional estuarine salinity gradient because of the absence of an inflowing river. Groundwater flows into the lagoon in certain sections, however, and it is possible that it functions as a subterranean aquifer, as there is variation in the salinity of the dug wells along the coast of the lagoon during the day.

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 because it does receive freshwater inflow from land drainage (input from the aquifer), and also has typical estuarine biota. This would place the Langebaan Lagoon in a class of its own, separating it from "estuarine bays" which are fed by rivers.

The areas that surround Langebaan Lagoon are covered mostly by natural vegetation, waterbodies or wetlands, especially the areas that fall within the West Coast National Park. The areas outside the National Park are mostly cultivated – dryland farming, with urban and industrial development in the Saldanha area (Figure 5.1).

The Saldanha area is in an arid area with a low average rainfall, which is facing growing pressure from industrial developments and residential growth. The current drought has highlighted the risk of relying on surface water for the water supply to the area, especially since the municipality is one of the last recipients of water from the Western Cape Water Supply System and the problems of maintaining the Misverstand Weir at the levels required to provide water when the river is not flowing at its normal levels. Groundwater has the potential to provide water resources to the Saldanha area, if managed sustainably, thereby relieving the pressure on the surface water supply. The National Water Act of 1998 (Act 36 of 1998) (DWAF, 1998) considers groundwater as a national resource to be managed by the Department of Water and Sanitation in a sustainable manner, with the cooperation of the municipalities and other water users. The Water Services Act (Act 108 of 1997) (DWAF, 1997) provides the framework for the delivery of water services by the Water Services Providers (the West Coast District Municipality and the Saldanha Bay Local Municipality in this case). These two Acts cover the legal obligations, rights, responsibilities and constraints for the sustainable development and management of the water resources in South Africa (Pietersen, 2006).

Groundwater 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 pores spaces or fractures and voids in rocks become completely saturated with water, is called a water table or water level.

Groundwater is recharged by rainwater that infiltrates the subsurface to reach the saturated parts, or from surface water bodies like rivers and dams. Groundwater then flows below the surface and will eventually reach the surface again and discharge to seeps, wetlands, springs and rivers.

Groundwater is also abstracted for agriculture – mostly stock watering, municipal and industrial use with boreholes equipped with pumps and wind pumps. Groundwater is often cheaper, more convenient, locally available, and less vulnerable to pollution than surface water. It is often used for public water supply. Polluted groundwater is less visible than surface water, but it is more difficult to clean up. Groundwater pollution is most often the result of improper disposal of waste 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 waste water from mines, industrial fracking, oil field brine pits, leaking underground oil storage tanks and pipelines, sewerage sludge and septic systems. In addition to pollution, over abstraction can severely alter or irreparably damage an aquifer to such an extent that it will no longer function properly and in severe cases, cause land subsidence.

The West Coast District Municipality (WCDM) operates a wellfield on the Langebaan Road Aquifer that is licenced to abstract 1.46 million m<sup>3</sup> of groundwater per annum. The operations of the wellfield began in December 1999. The abstraction of the groundwater from the aquifer resulted in a bigger decline in water levels than what was expected. Models only predicted a 5 m water level decline but water levels declined by between 10 and 11 m from the original levels. There was a concern on how this may affect the groundwater discharge to Saldanha Bay, and the monitoring committee decided on a modest reduction of 10% in the abstraction rate.

Phosphate has been deposited in the Langebaan Road Aquifer Unit, as well as the Elandsfontein Aquifer Unit of the West Coast Aquifer System<sup>8</sup>. Phosphate was mined at the Chemfos mine (now the West Coast Fossil Park) from the 1960s till the 1980s, when operations were ceased, and the mine was closed. Small scale phosphate mining still takes place in the area of the Langebaan Road by Geckofert. Phosphate mining again made headlines in the area when Elandsfontein Exploration and Mining (Pty) Ltd (EEM), now known as Kropz Elandsfontein, began phosphate mining activities in the Elandsfontein area (Farm Elandsfontein 349, situated between the town of Hopefield and the Langebaan Lagoon area). A water use authorisation was issued for the mine in April 2017. The mine was placed under care and maintenance following some permitting delays, technical issues, and a falling phosphate price. Kropz intends to recommence operations in late 2019.

Kropz Elandsfontein intends to implement the 'roll over' mining method to access the phosphate ore, allowing the concurrent surface rehabilitation to take place. Ore will be mined at a rate of 5 Mtpa for approximately 14 years. The targeted phosphate resource lies below the natural water table. For 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. The extracted ground water is then fully recharged back into the aquifer downstream of the mining activities, via a dedicated, closed system.

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<sup>8</sup> The West Coast Aquifer System consists of the Adamboerskraal Aquifer Unit, the Langebaan Road Aquifer Unit, the Elandsfontein Aquifer Unit, and the Grootwater Aquifer Unit. The different aquifer units are multilayer systems, made up of different cenozoic deposits overlaying basement rock of granite and shale.

Processing water for the phosphate operations will largely be supplied from the Saldanha Bay Municipality. Kropz is in discussions to treat municipal effluent water for industrial reduce in order to eliminate their demand on the municipal water system. A number of groundwater specialist studies have been completed to understand and mitigate the mining activities on the potential impacts of the mine on the underlying aquifer. Despite the findings of the studies, which suggest that impacts can be mitigated by means of the proposed mining methods, residual concerns have been expressed over potential impacts that the proposed phosphate mine at Elandsfontein may have on groundwater quality and flows to Langebaan Lagoon.

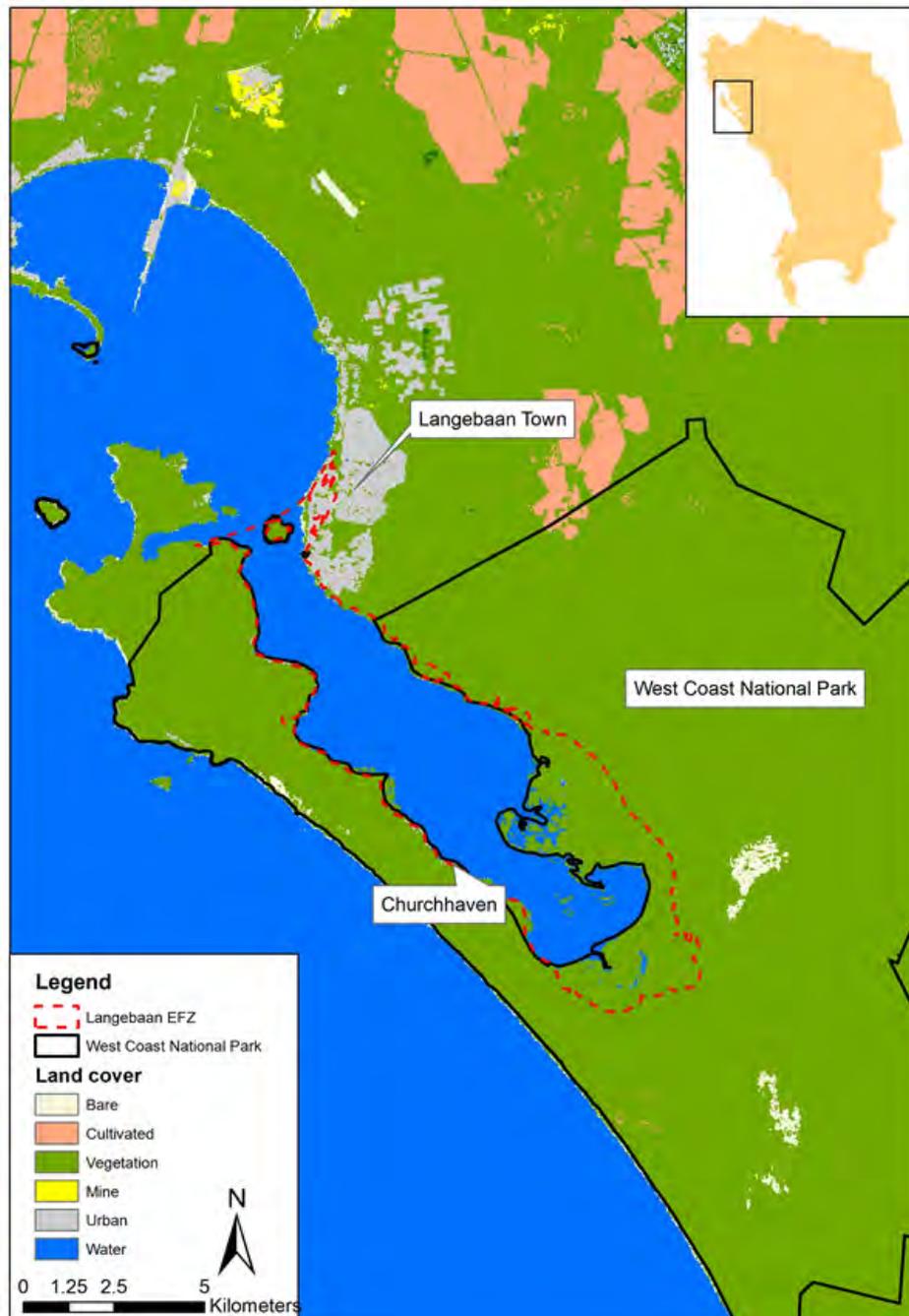


Figure 5.1 Basic landuse map surrounding Langebaan Lagoon.

## 5.2 Aquifer description and climatic setting

Saldanha Bay is in the winter rainfall region of the Western Cape, where most rain normally falls between May and October. There are marked geographic variations in rainfall in this region, with the most rain falling in the south-western part, decreasing towards the Berg River in the north and east (Figure 5.2). This naturally influences recharge rates for the aquifer system in this area. Temperatures are the highest during the summer months, typically peaking in February and March. This means that the potential for evapotranspiration is at its highest during the summer months.

The surface geology of the area is dominated by fine to medium grain sand and calcrete (limestone), with granite outcrops and the Colenso Fault System being the other important features in the geology of the area (Figure 5.3). The latter is playing an important role in the groundwater flow in the area, but it is not fully understood at the moment.

A summary of the lithostratigraphy of the Cenozoic (sand) deposits in this area (i.e. classification of these deposits based on the properties of the strata and their geographical distributions) is presented in Figure 5.1. These deposits are found in paleo-channels that were cut out of the basement rocks of granite and shale. These paleo-channels were formed by rivers, such as the Berg River, which has changed its flow path and direction several times in the past.

The orientation of these paleo-channels in the basement rocks is shown in (Figure 5.4) (Roberts and Siegfried, 2014). This shows that the Adamboerskraal, Langebaan Road and Elandsfontein Aquifer Units are linked, and that there may be flow between these different units. The link with the Grootwater Aquifer Unit to the south of the map is inferred, but the level of connection is not clear. Data on water levels measured in the Elandsfontein Aquifer Unit also suggest that there must be a link between the Langebaan Road and the Elandsfontein Aquifer Units. There was a time delay of about one to two years in the response of the water levels in the Elandsfontein Aquifer Unit to the abstraction of groundwater from the lower layer of the Langebaan Road Aquifer wellfield.

Figure 5.6 shows a cross section along the R27 in the area of Geelbek, giving an indication of the geology of the Elandsfontein palaeochannel. The Elandsfontyn clay layer is still present in BH4 just inside the West Coast National Park, but it is not present in the boreholes closer to the Langebaan Lagoon. The clay layer thins out near the sides of the palaeochannels (both in the Langebaan Road and Elandsfontein Aquifer Units) and may even be absent at the edges. It also seems to be absent to the west of the R27 for both aquifer units, which means that the upper and lower aquifer layers are in direct contact without a confining layer separating them.

Figure 5.6 provides some idea of the mean annual effective recharge from rainfall as well as water level elevation and flow in the lower confined layers of the two aquifer units, as understood by Woodford and Fortuin (2003). There is, however, some uncertainty on the recharge of the aquifer, as recent work by Smith (2017) has shown that recharge may not be derived from local rainfall at all. The map also provides an estimation by Woodford and Fortuin (2003) on the volumes of water that may be discharged to the surface bodies in the area. This includes discharge to the Langebaan Lagoon (3.854 Mm<sup>3</sup>/a), Saldanha Bay (0.785 Mm<sup>3</sup>/a), Berg River (0.730 and 0.525 Mm<sup>3</sup>/a) and the various springs and wetlands (0.394 Mm<sup>3</sup>/a).

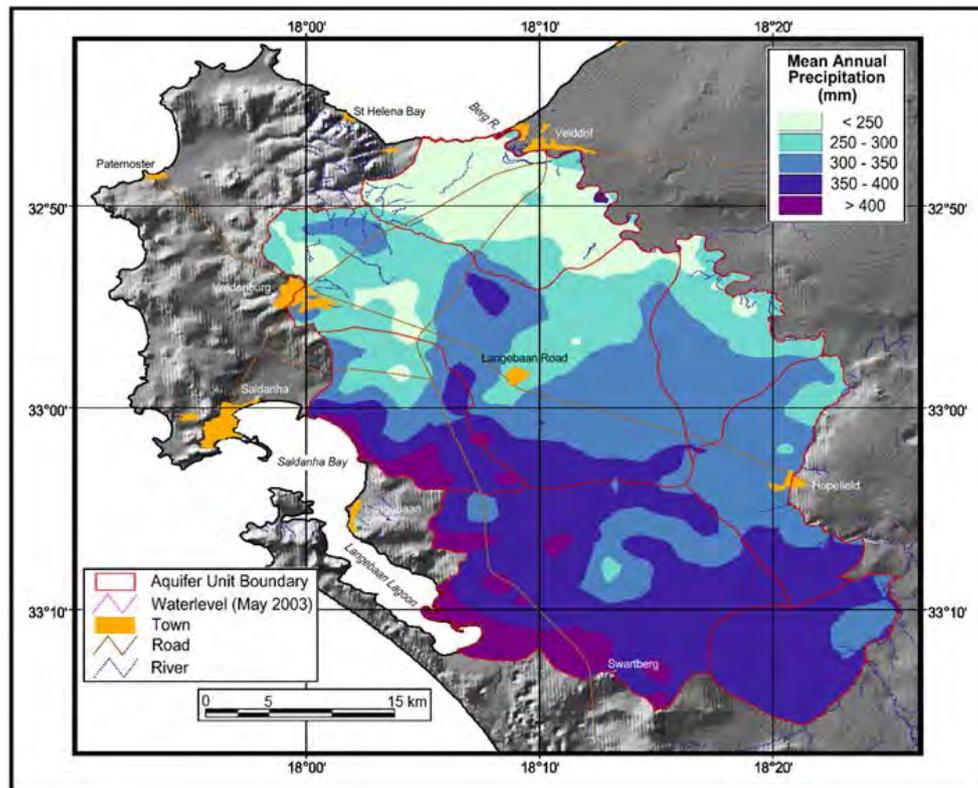


Figure 5.2 Mean annual precipitation for the Langebaan Road/Elandsfontein aquifer unit area (Woodford and Fortuin 2003).

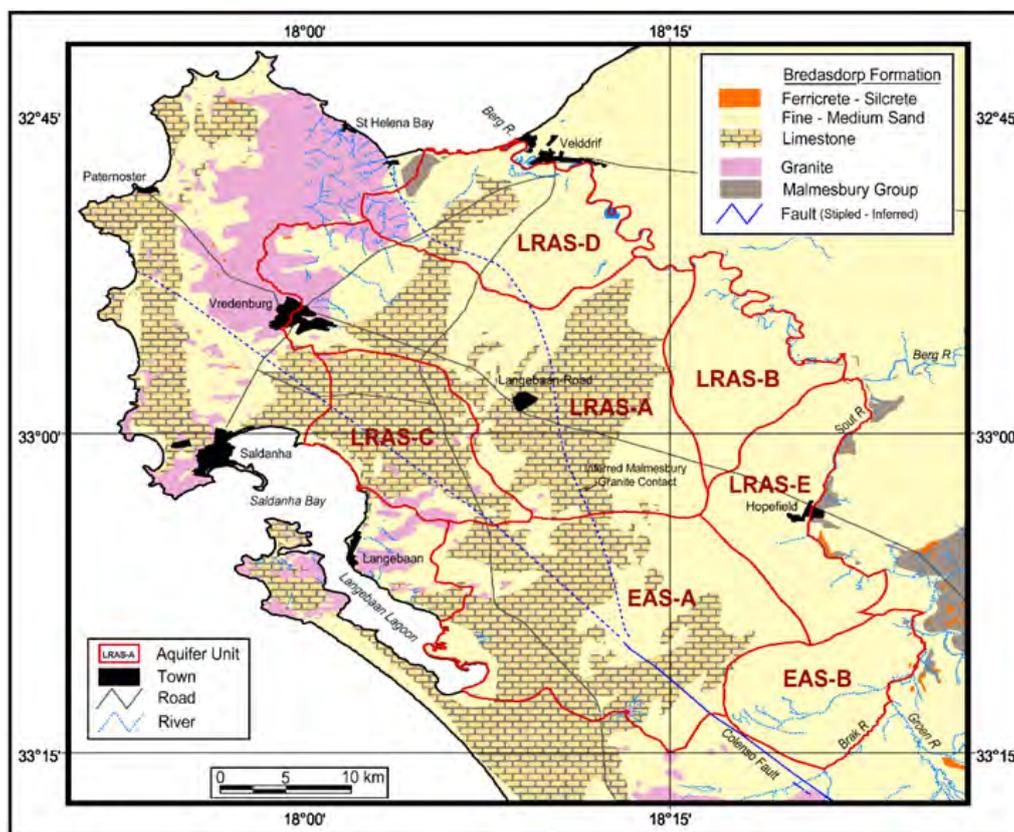


Figure 5.3 Surface geology for the Langebaan Road/Elandsfontein aquifer unit area (Woodford and Fortuin 2003).

**Table 5.1 Lithostratigraphy of the Cenozoic deposits (after Woodford and Fortuin, 2003).**

Epoch	Age	Lithostratigraphic Unit		Description	Depositional environment
		Formation	Member		
Holocene – Pleistocene	1.7	Bredasdorp	Witzand	Calcareous dune sands.	Aeolian.
			Langebaan	Calcretized limestone.	Aeolian.
			Velddrif	Shelly sand.	Marine.
			Springfontyn / Noordhoek	Silica to peaty sand.	Aeolian.
Pliocene	5.2	Varswater	CSM	Calcareous sands.	
			PPM (Duynefontein)	Muddy sand with pelletal phosphorite.	Marine.
			QSM	Quartzose sand.	Marine.
			SGM (Silwerstroom)	Shelly gravel.	Marine.
Late Miocene	10	'Saldanha'		Gravels.	Marine.
Miocene	22	Elandsfontyn		Predominantly coarse sand and gravel, interbedded silty, clayey and peaty layers.	Fluviatile.

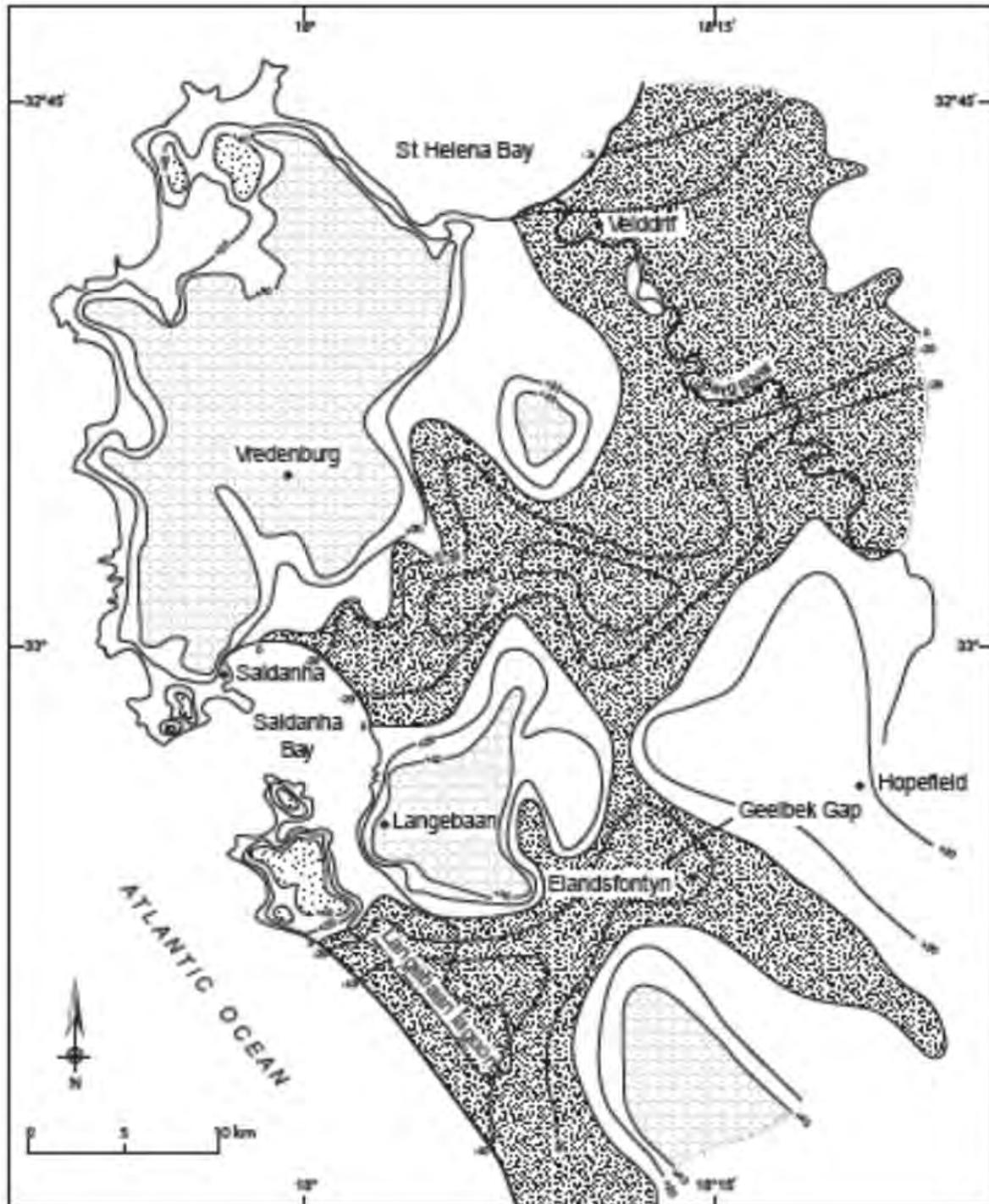


Figure 5.4 Pre-Cenozoic basement topography of the Saldanha, Vredenburg and Velddrif sheets. Light stipple: elevations greater than +40m; heavy stipple: elevations below present sea level. Data from Rogers (1980), Timmerman (1988), Cole and Roberts (1996) and from recent drilling (Roberts and Siegfried, 2014).

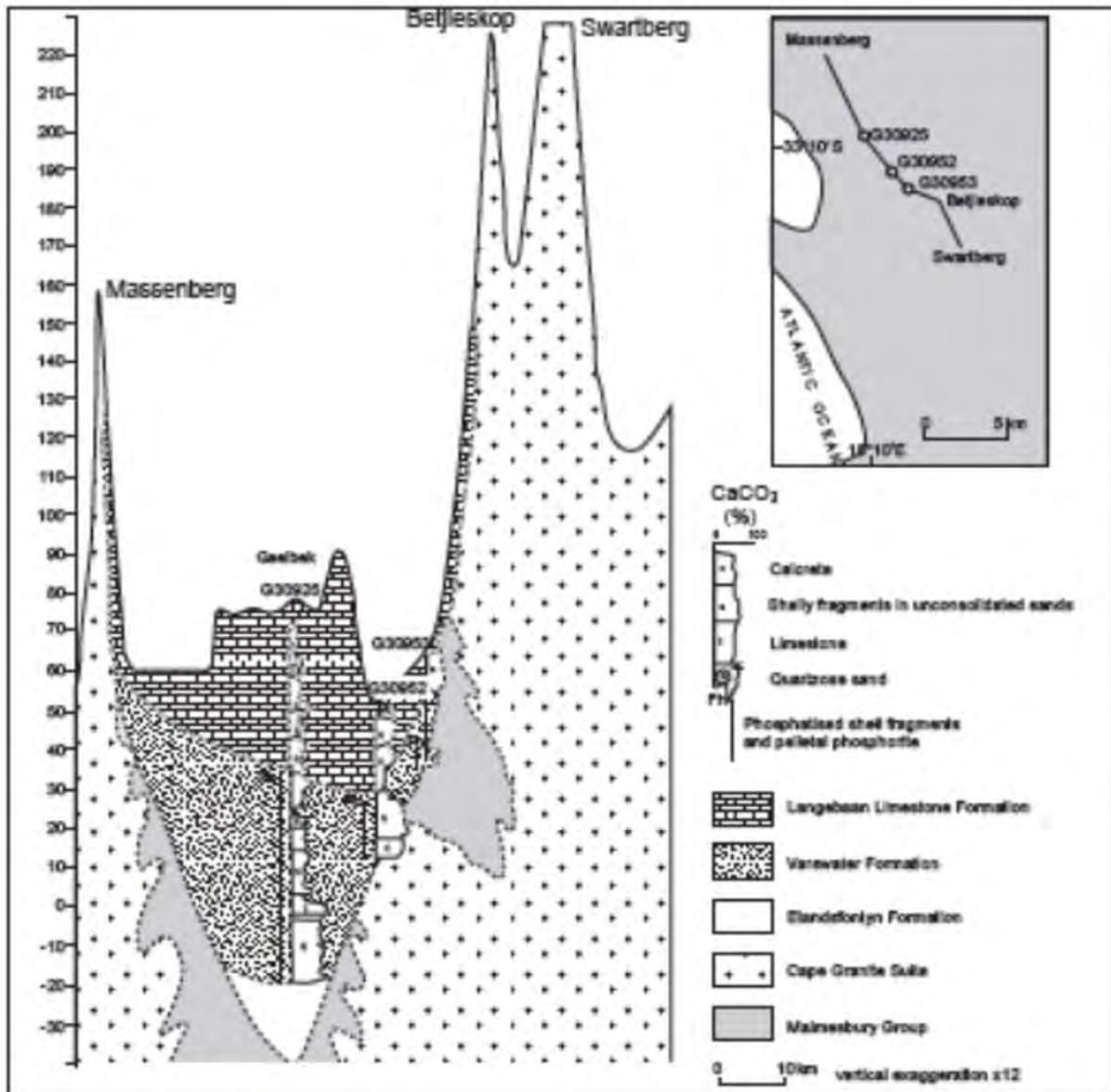


Figure 5.5 Cross-section through Cenozoic strata on the Saldanha sheet (from Rogers 1980) (Roberts and Siegfried, 2014).

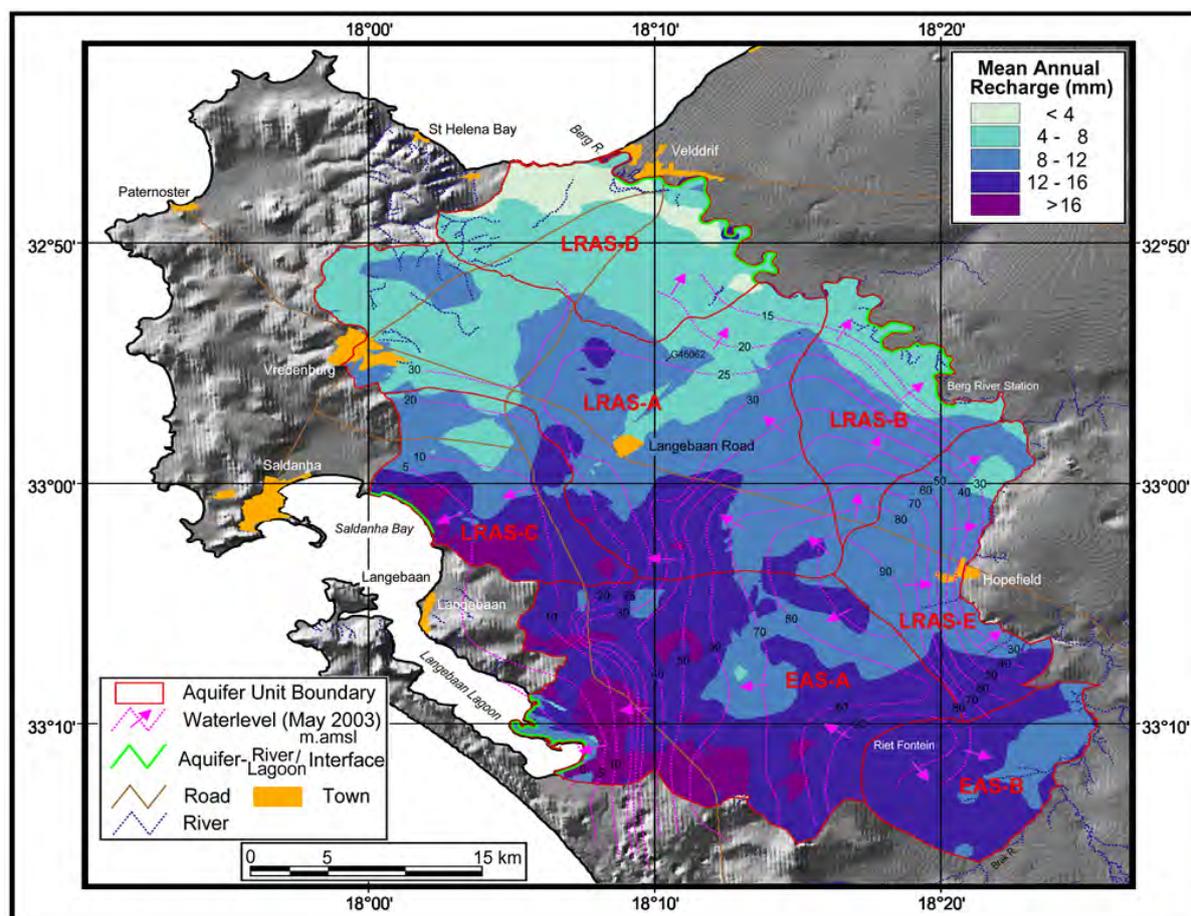


Figure 5.6 Mean Annual Effective Recharge (mm) from rainfall and water level elevation in the Lower Confined Layers of the Langebaan Road and Elandsfontein Aquifer Units with the estimated discharge to the different surface water bodies in the area (Woodford and Fortuin, 2003).

### 5.3 The importance of groundwater for Langebaan Lagoon

Groundwater plays a very significant role in sustaining marsh ecosystem surrounding Langebaan 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. Notably, the flow rates are high within the calcrete zone, although calcrete is typically 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 5.7 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 12 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). Notably there were 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 the geological cross-section that is corrected for elevation differences (Figure 5.9). It is clear from this cross section that 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 exists 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 5.8). 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 5.9, it's evident that the groundwater flow occurs in the Upper Aquifer Unit.

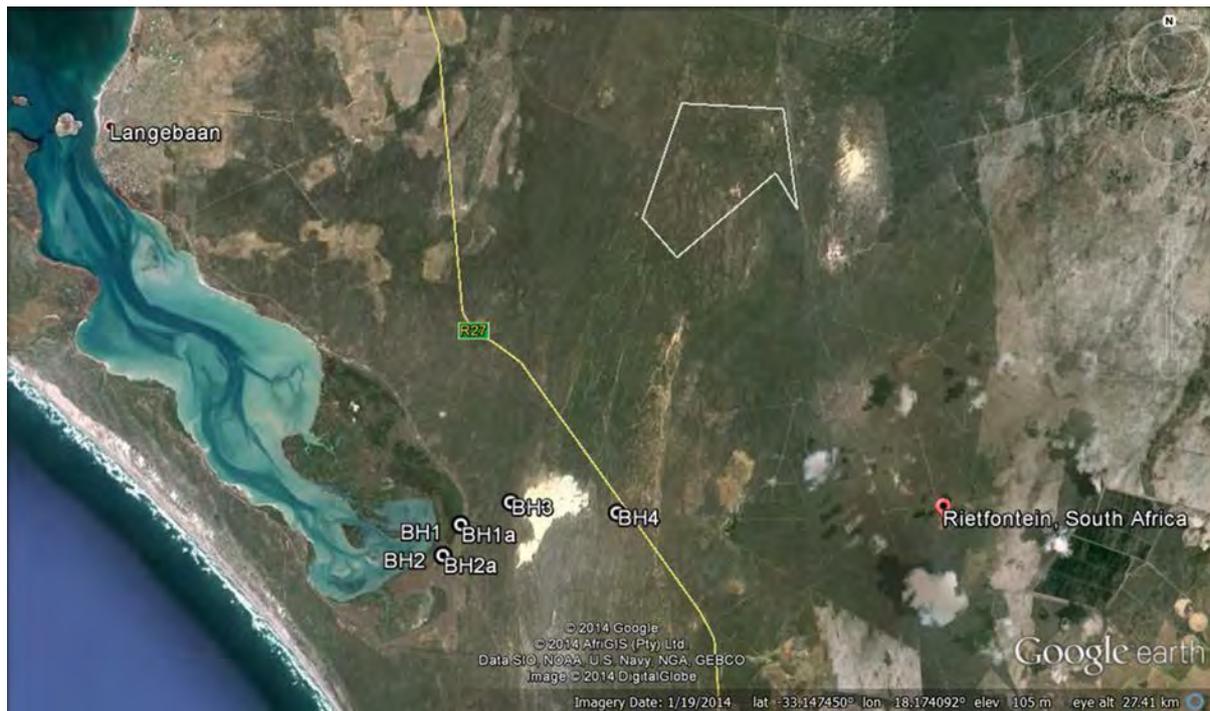


Figure 5.7 CSIR bore holes in relation to Langebaan Lagoon and Elandsfontein (depicted by white polygon).

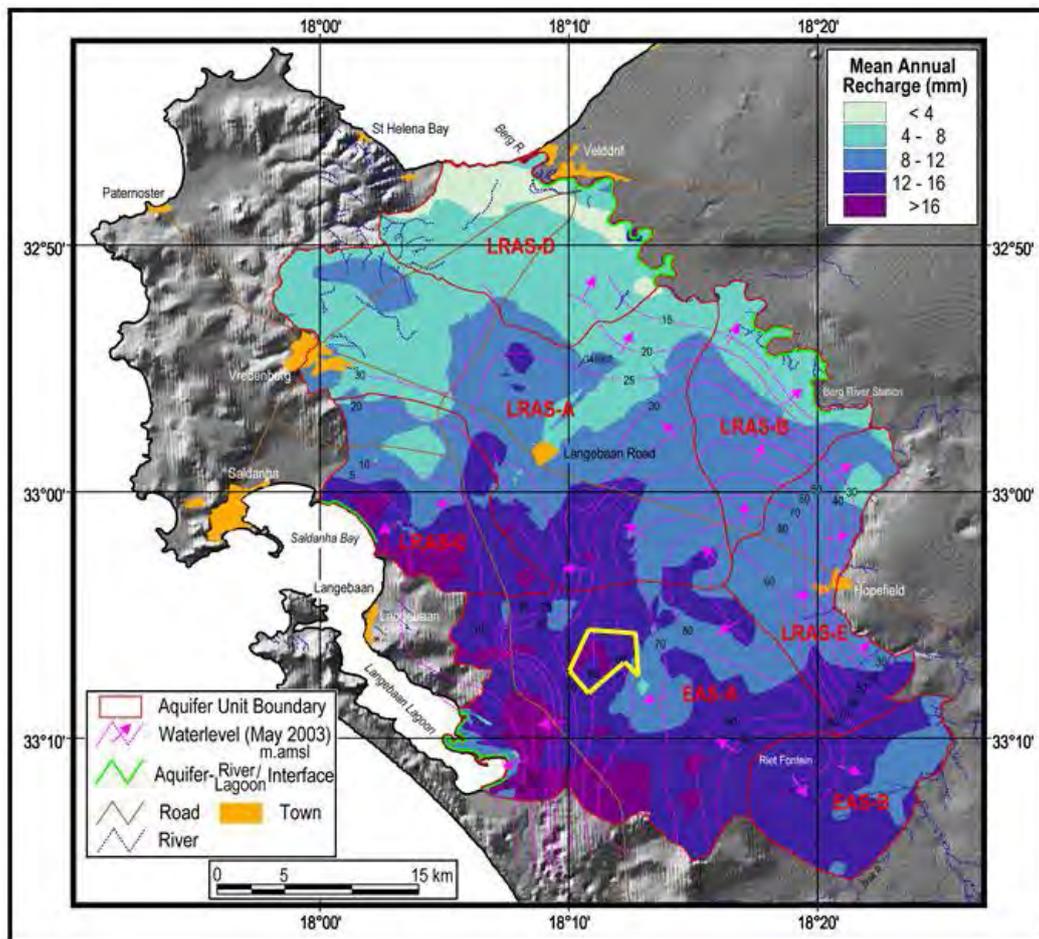


Figure 5.8 Groundwater recharge map indicating Rietfontein and the groundwater flow direction towards Geelbek (Woodford & Fortuin, 2003).

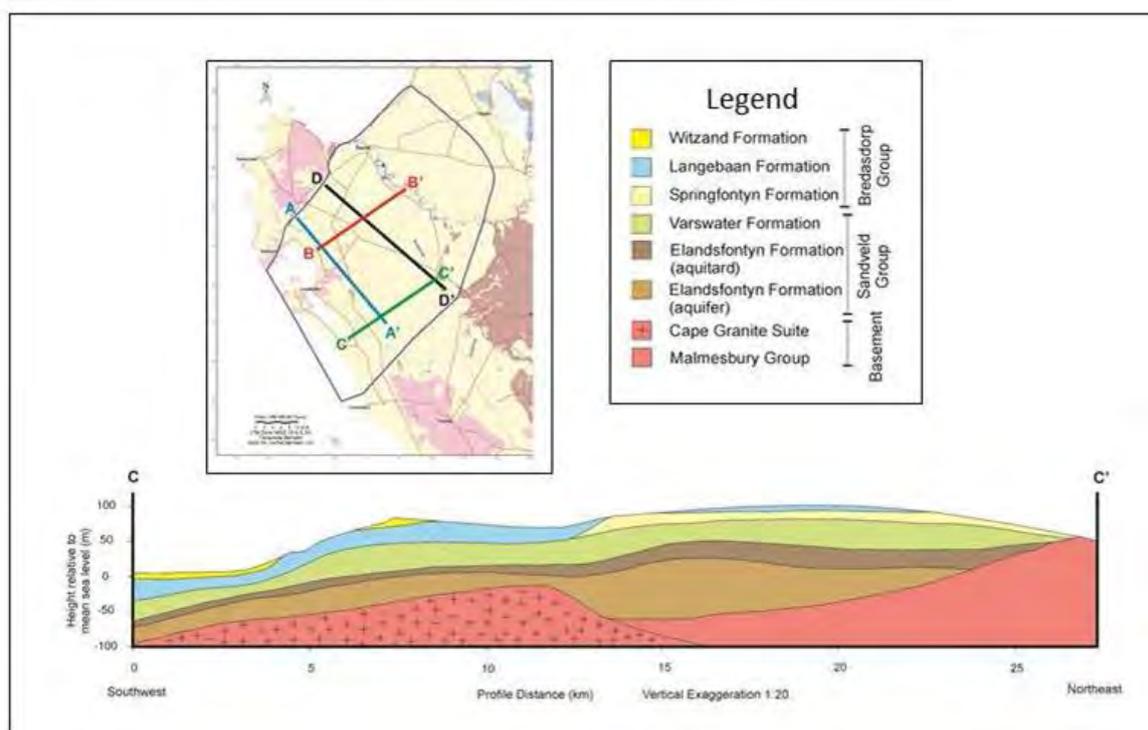


Figure 5.9 Geological cross-section (C-C') beneath the Geelbek area (DWAF 2008)

## 5.4 Current situation

The Department of Water and Sanitation (DWS) is monitoring about 200 boreholes in the West Coast Aquifer System. The West Coast Aquifer System is also currently the subject of a WRC project that is meant to support DWS with the management of the groundwater and the Saldanha Bay Local Municipality with water supply options. The general trend in the water levels in the area is downwards for both the upper and lower layers of the Langebaan Road and Elandsfontein Aquifer Units. This may be linked to lower rainfall in the area – a trend that goes further back than the most recent drought. This may give an indication of the predicted drier conditions on the West Coast as a result of climate change. Other possibilities also exist, but will need additional analysis of the data and more research.

Time series data on water levels for one of these boreholes (G33327, located near the West Coast Fossil Park) is shown on Figure 5.10. This borehole was drilled in 1984 into the lower layer (Elandsfontyn Formation) of the Langebaan Road Aquifer. It was selected for this report to give an indication of how boreholes at a distance from the wellfield react to abstraction at the wellfield. Figure 5.10 shows changes in water levels from the time that the borehole was drilled until June 2018, with a data gap from 1991 to 1998. A sharp fall in water levels is evident from early 2000 (the wellfield began operations in December 1999). Some recovery took place in 2004, when the pumps at the wellfield had to go in for repairs and the wellfield was not operational for 3 months, but water levels drop again after the wellfield goes into operation again, falling lower than the level before the pumps went for repairs, even though the abstraction volume was voluntarily cut by 10%. The water levels recovered slightly in 2007 as a result of the good rain that fell that year.

Additional recharge took place in 2008 and 2009 when the CSIR experimented with Artificial Recharge (AR) Pilot Test at the wellfield. The water levels dropped again when the wellfield became operational after the AR Pilot Test. This drop in the water levels was reversed in April 2013 when vandals destroyed the wiring of the wellfield. It is not clear what caused the falling water levels from August 2015, as the wellfield was apparently not properly operational and was hit by additional repeated vandalism. This will have to be investigated.

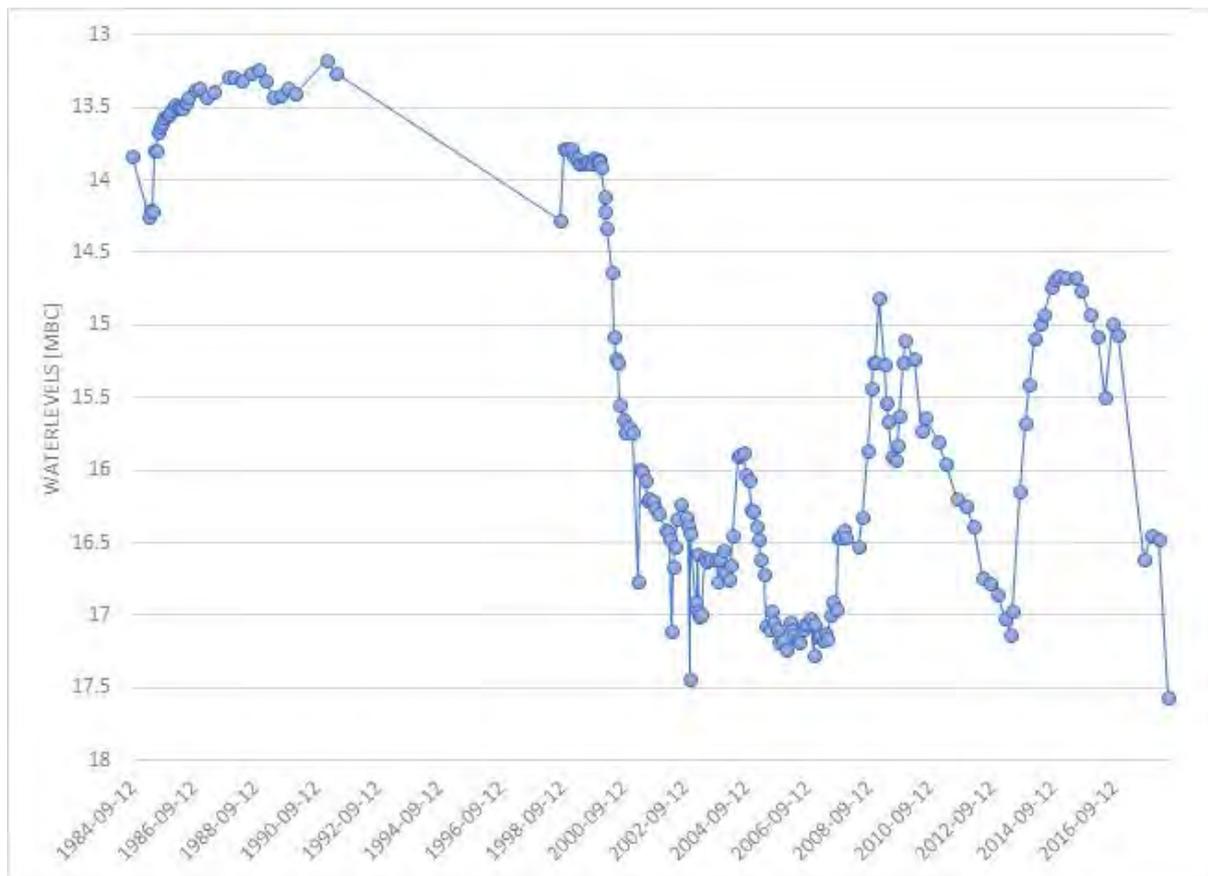


Figure 5.10 Time series graph of water levels for borehole G33323.

Figure 5.11 was plotted using the historical data from 2012 to 2018 to calculate percentile bands like those used for the management of dams. This is plotted in hydrological cycles, beginning on the 1st of October to the 30th of September. Water levels for the last six years are plotted on top of the background. The 2012-13 line shows that it was very close to the bottom of the historical record and began recovering after the vandalism. The 2013-14 curve continues the recovery, with the 2014-15 curve reaching the 90th percentile on the historical record. The 2015-16 curve fluctuates between the 50th and 80th percentile, but the effects of the drought and possible additional abstraction can clearly be seen in the 2016-17 curve which drops down to the 20th percentile. The 2017-18 curve is dipping below the historical record.

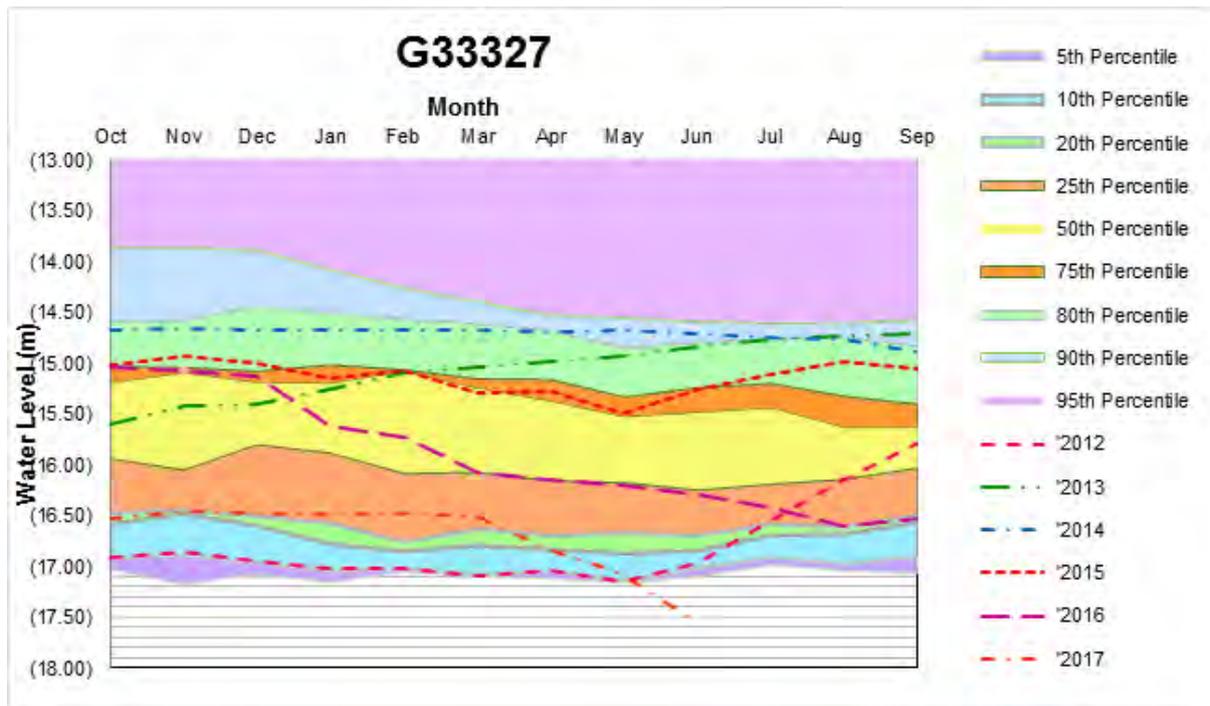


Figure 5.11 Annual water level fluctuations for the last 6 years on the historical water level record of borehole G33327 from 2000 to present.

Figure 5.12 shows the water levels of G33327 with the volumes pumped from the wellfield. It is very clear that the abstraction at the wellfield affected the water levels. Some of the data for the abstraction at the wellfield was not available for the plotting of this graph. There is also private abstraction that has not been included, and the meter on borehole 176/1B have been removed, so it has not been possible to get any indication of the abstraction from this borehole. Under the Government Gazette that has been published on the 12th of January 2018 it is now compulsory to install electronic metering devices on all boreholes to measure groundwater abstraction.

Figure 5.13 shows the water levels for G33327 with the rainfall as measured at some of the DWS rain gauges in the area. It is very clear from this borehole that there is no direct link between the rainfall and the water levels for the boreholes in the lower aquifer layer of the Langebaan Road Aquifer Unit.

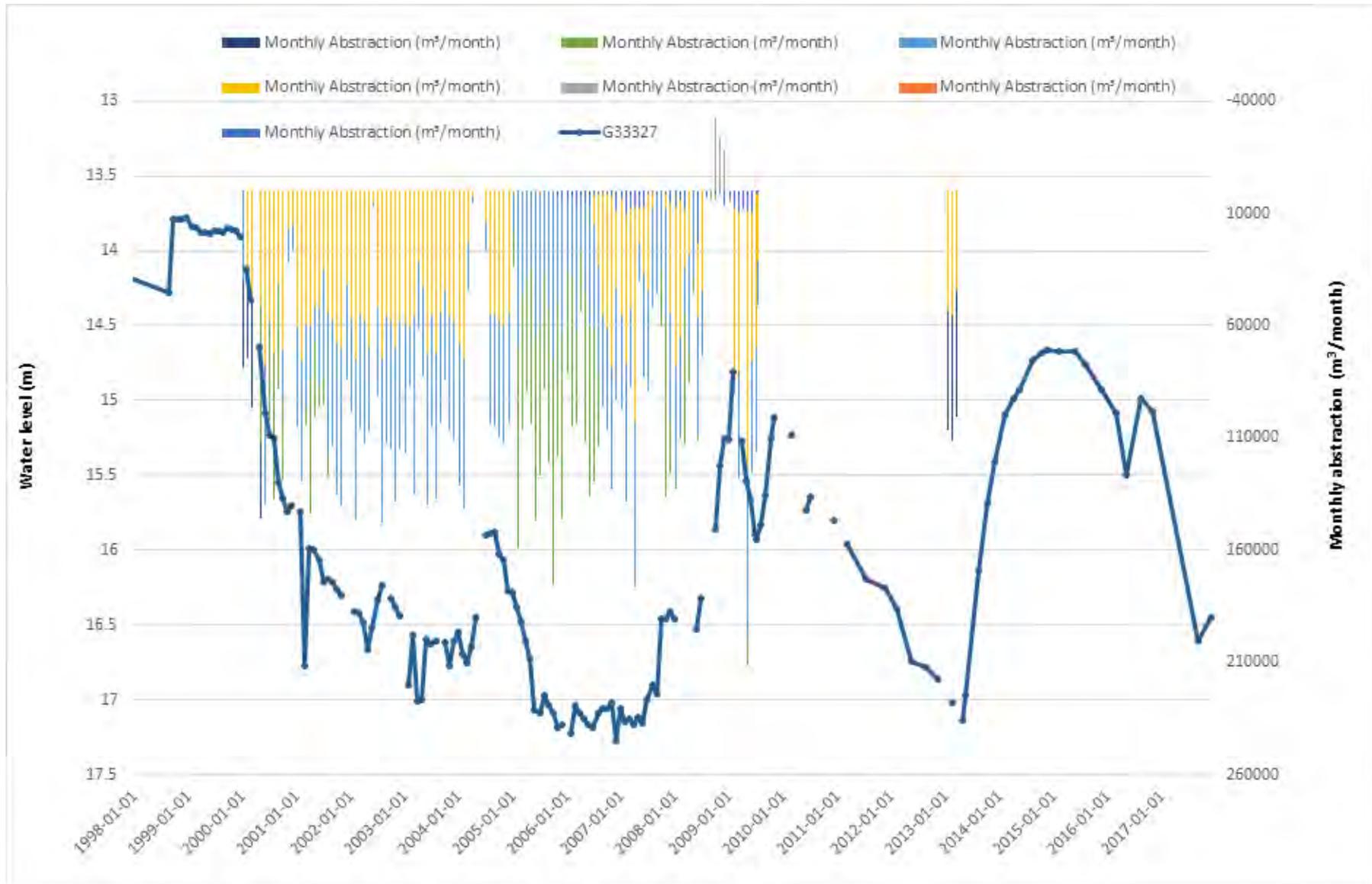


Figure 5.12 Water levels for borehole G33327 with the abstraction record of the production boreholes at the Langebaan Road wellfield.

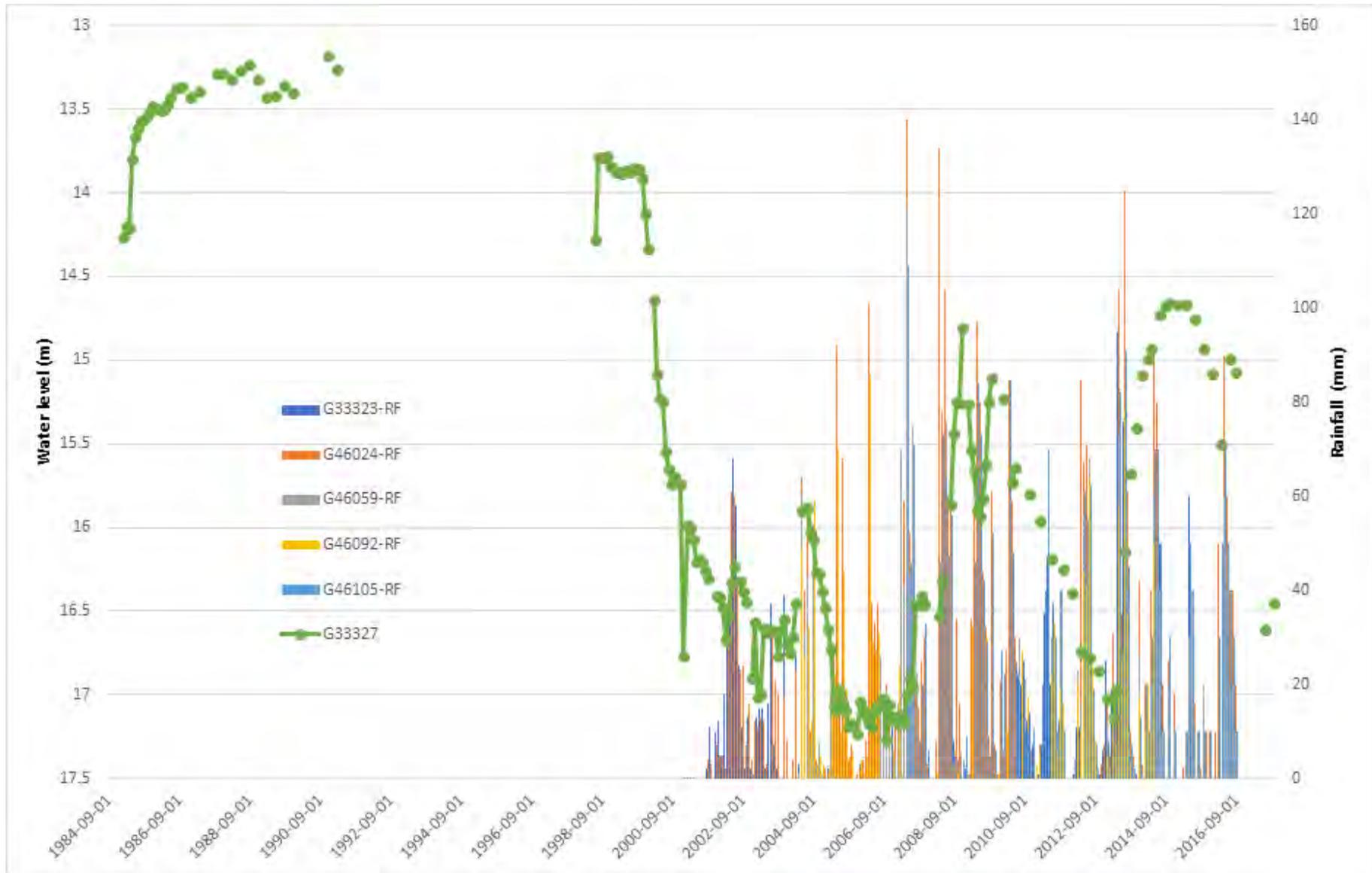


Figure 5.13 Water levels for borehole G33327 with the rainfall record as recorded by DWS rain gauges in the vicinity.

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 5.2). The volume of water abstracted from the aquifer increased from around 4.94 million  $Mm^3/a$  under the base case scenario to a combined 18.53 million  $Mm^3/a$  under Scenario 5 (Table 5.3). 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 5.4. 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.

**Table 5.2** 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 $m^3/a$ )	Dispersed abstraction (million $m^3/a$ )
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 5.3** 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 5.4** Modelled groundwater flow results for base case and future scenarios. See Table 5.2 for details on scenarios (Source Seyler et al. 2016).

Aquifer Flux	Base case	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	million Mm <sup>3</sup> /a	million Mm <sup>3</sup> /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%

## 5.5 Potential impacts associated with Phosphate Mining

The Elandsfontein phosphate deposit is the second biggest known resource in South Africa. The deposit is located on the farm Elandsfontein 349, approximately 12 km to the east of Langebaan (Figure 5.14) (Braaf 2014). Kropz Elandsfontein intends to implement the 'roll over' mining method to access the phosphate ore, allowing the concurrent surface rehabilitation to take place. Ore will be mined at a rate of 5 Mtpa for approximately 14 years. The mining will take place in a number of discrete phases, which will reduce the overall mining foot print:

- a. topsoil is removed and stockpiled;
- b. overburden layer is stripped and stockpiled;
- c. phosphate ore is mined; then
- d. the strip is backfilled with the overburden and slimes from the plant; and
- e. the topsoil returned to the strip and rehabilitated.

The targeted phosphate resource lies below the natural water table. For 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. The extracted ground water is then fully recharged back into the aquifer downstream of the mining activities, via a dedicated, closed system. Processing water for the phosphate operations will largely be supplied from the Saldanha Bay Municipality. Kropz is in discussions to treat municipal effluent water for industrial reduce in order to eliminate their demand on the municipal water system.

The primary environmental impacts assessed prior to the commissioning of the mine included (1) the reduction of inflow of freshwater into Langebaan Lagoon causing hypersaline conditions in the lagoon resulting in negative impacts on fauna and flora sensitive to salinities in excess of normal seawater; and (2) contamination of the groundwater as a result of the re-injection process. A number of groundwater specialist studies have been completed to understand and mitigate these potential impacts on the aquifer (DWAF 2008, Braaf 2014, GEOSS Draft Report 2014, GEOSS Report 2017). Despite the findings of the studies, which suggest that the mining activities are highly unlikely to have any impact on the groundwater flow, residual concerns have been expressed over potential impacts that the proposed phosphate mine at Elandsfontein may have on groundwater quality and flows to Langebaan Lagoon. Kropz Elandsfontein has therefore 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.

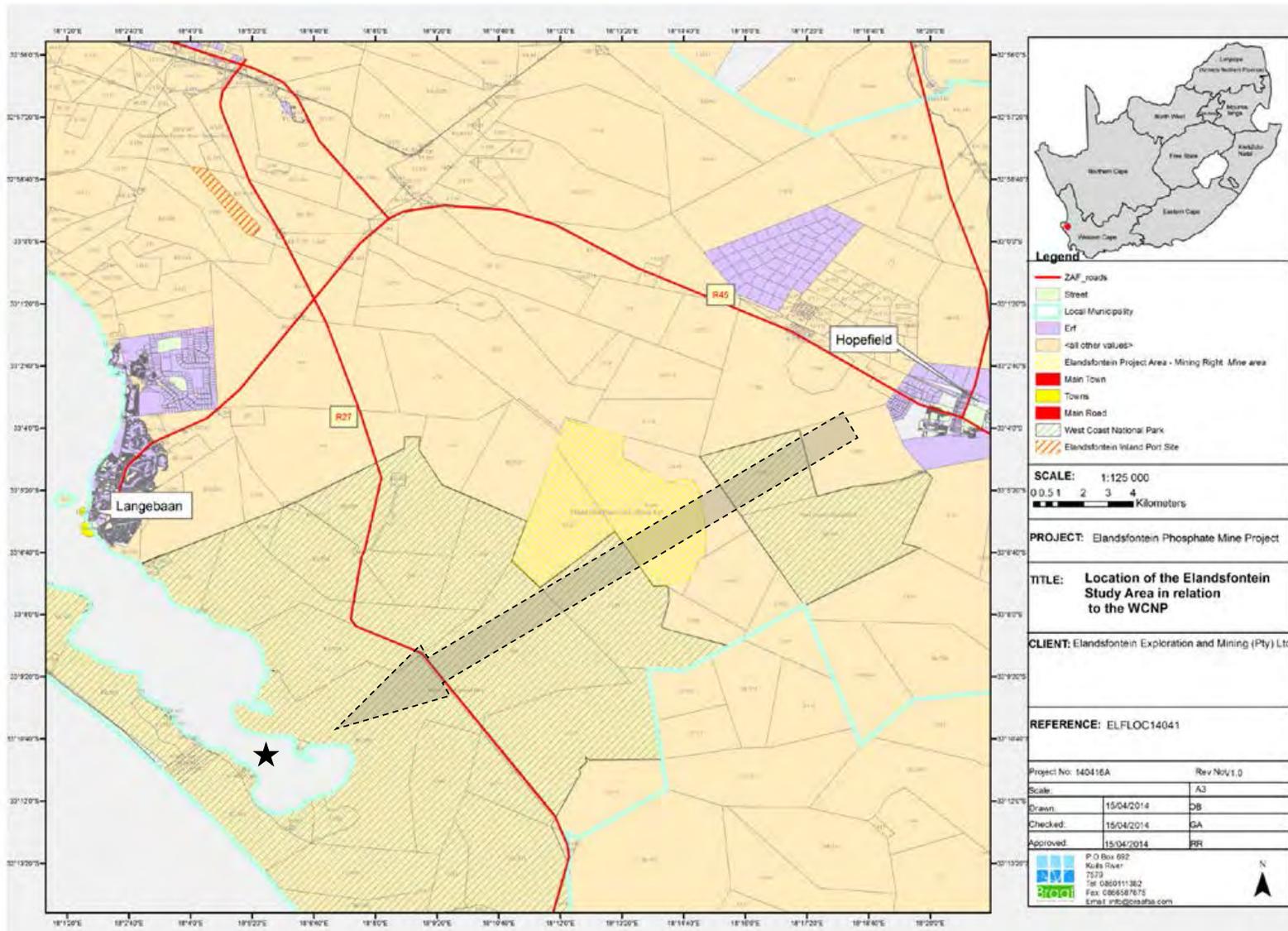


Figure 5.14 Location of the Elandsfontein Study Area (Source: Braaf 2014). The arrow indicates direction of groundwater flow and the star location of salinity and macrofauna monitoring sites in Langebaan Lagoon.

The methodology that is being used for this monitoring work and a summary of the water quality monitoring results collected to date is presented below.

Monitoring of temperature and salinity at the head of the lagoon was initiated in September 2016 using a Star ODDI Salinity, Conductivity, Temperature and Depth Logger. This instrument has been configured to take measurements of temperature, salinity and depth at intervals of approximately 10 minutes apart. The instrument has been retrieved, data downloaded and redeployed on numerous occasions since it was first deployed. Some modifications to the mooring and its deployment site were necessary for reasons outlined below.

The instrument was initially fixed to a mooring block on the edge of the channel near Geelbek at the head of the lagoon. The instrument was retrieved and data downloaded for the first time in December 2016. Data from this deployment are shown in Figure 5.15 below. Data on water depth indicated a clear diurnal and bi-weekly neap-spring- tidal signal as expected but also that the instrument was exposed to the air at times on spring low tide (Figure 5.15). The tidal signal corresponded with that recorded by the South African Navy Hydrographer (SANHO) at the Port of Saldanha (Figure 5.15). The temperature signal displayed a clear diurnal pattern, with temperatures peaking in the early afternoon and dropping to their lowest levels in the early hours of the morning as expected. Variations in tidal height seemed to have very little influence on temperature. In the initial part of the record salinity levels were fairly constant, measuring around 34.0-35.5 PSU which is within the range for normal seawater. However, readings soon (within the first few days) became very erratic (corresponding with the first period of exposure to the air) and later dropped abruptly on at least two occasions (the first after 2 weeks and the second a one month later). It is believed that this was a result of exposure to the air which had introducing air bubbles into the sensor head and caused it to read and record inaccurately.

The instrument was cleaned, recalibrated and the mooring was moved to the deepest part of the channel, the mooring line extended, and weights added above and below the CTD to keep the instrument upright in the water and submerged at all times, regardless of tidal height. A 'check-in' retrieval and data download after one week (26 January 2017) indicated that the instrument was recording accurately at that time (Figure 5.16). Little variation in depth was evident since the instrument was now floating more or less freely on a tether, only dropping below the surface for short periods at spring high tide. Variations in temperature displayed a simple diurnal pattern as before (grey bars are included on Figure 5.16 to highlight day-night periods). Salinity displayed a low amplitude semidiurnal periodicity that seemed to be linked to tidal variation, oscillating between 35.0 and 36.0 PSU. Salinity rose as the tide receded and dropping off again when the tide turned. Normal seawater is in the range of 34.5-35.0 and this corresponds to values measured at high tide. The elevated values recorded at low tide thus, seem to be linked to saline water flowing out of the salt marshes at this location. This water would have been subjected to intense warming by the sun and loss of freshwater through evaporation is the most likely explanation for this.

The instrument was left for a further three months and retrieved again in April 2017. Data that had been collected in the preceding period was downloaded but proved to be highly erratic and showed significant "drift". Discussion with the manufacturer resulted in the instrument being recalled and replaced. A replacement instrument was deployed in May 2017 but this was subsequently also recalled when it was clear that this instrument was also faulty.

A third instrument was deployed for a week long test period from 30 June to 7 July, 2017, and was evidently working well (data for this period is shown on Figure 5.17), aside from a short period when measurements became a little erratic due to biofouling (an isopod had crawled into the housing containing the conductivity sensor). It was immediately redeployed but when we returned to retrieve it on 25 August 2017 it was discovered that the instrument had been stolen and the data from 20 July to 25 August was lost.

A fourth new instrument was deployed on 31 August and was retrieved again on 20 October 2017. Data from this deployment were good with clear diurnal variations evident in the temperature. Again, there was minimal variation in depth as the instrument was only submerged for a brief period on the spring high tide which corresponded with tidal changes measured by SANHO (Figure 5.18). The salinity data was also good and displayed some familiar high frequency (semi-diurnal) periodicity that seemed to be linked to tidal fluctuations but also some longer term variations spanning the range of 27 to 35 PSU. This longer term variation seemed to be independent of tidal state and also rainfall (rainfall data sourced from the SA Weather Bureau are also plotted on Figure 5.18) and may be linked to some changes in groundwater outflow into the lagoon. Measurement data became erratic again toward the end of this deployment period and is again thought to be linked to biofouling (small larval organisms are able to enter through the mesh cover surrounding the sensor head, settle on the sensor and as they grow start to interfere with the readings).

The instrument was redeployed immediately (20 October 2017) and left to record again until 5 December 2017. Data for this deployment are shown on Figure 5.19. Patterns are very similar to the last deployment with temperature showing small daily oscillations within a range of 13 and 25°C, salinity showing semidiurnal oscillations in the range 28 and 35.0 PSU, but again with no clear links between the longer period changes and rainfall or tide. Following this, the instrument was redeployed immediately for the period 6 December 2017 (Figure 5.20) until 10 February 2018 and again from 13 February 2018 to 21 June 2018 (Figure 5.21) and again on 22 June 2018 to 24 September 2018 (data still being processed). Data from these deployments are again very similar to that collected previously aside from what appeared to be a major drop in salinity that occurred in January 2018 (Figure 5.20) which we attribute to a large ascidian (tunicate) that settled on the probe and proceeded to grow over the entire sensor head.

Overall, from the results it is clear that there are some very interesting short term variations in temperature and salinity in the lagoon which are driven by semi-diurnal tidal fluctuations, diurnal (day-night) variations in air temperature and other longer term changes that are possibly linked to changes in groundwater outflow and/or rainfall. These in turn, are confounded by biofouling episodes that affect the accuracy of the data. From a large scale perspective, a spring high tide, represented by the maximum crest of the plotted tidal data over a two week period, seems to be linked with a shift to sea based salinity (around 35.5 PSU). If the ambient condition in the lagoon is fresher this will be associated with an increase in salinity and vice versa if a hyper saline condition exists. Rain (in large volumes) can lead to a lagged decrease in salinity, which could be compounded by an outgoing tide that would draw more fresh water from the areas of ground water inflow across the CTD measuring location, and alternatively dampened by an incoming spring tide that is associated with a sea based 35.5 PSU as mentioned above. These scenarios could be slightly offset by seasonal and diurnal evaporation rates.

For example, the highest recorded salinities (37+ PSU) coincides with the highest temperatures (25+°C) recorded in early December 2017 and mid-February 2018 (Figure 5.19 and Figure 5.20 respectively). In addition to these compounding factors is the likelihood, at some stage, that the CTD will become biofouled which sends the salinity reading into an erratic state as can be seen in Figure 5.20, with a rapid decline in salinity until the sensor is cleaned and re-set.

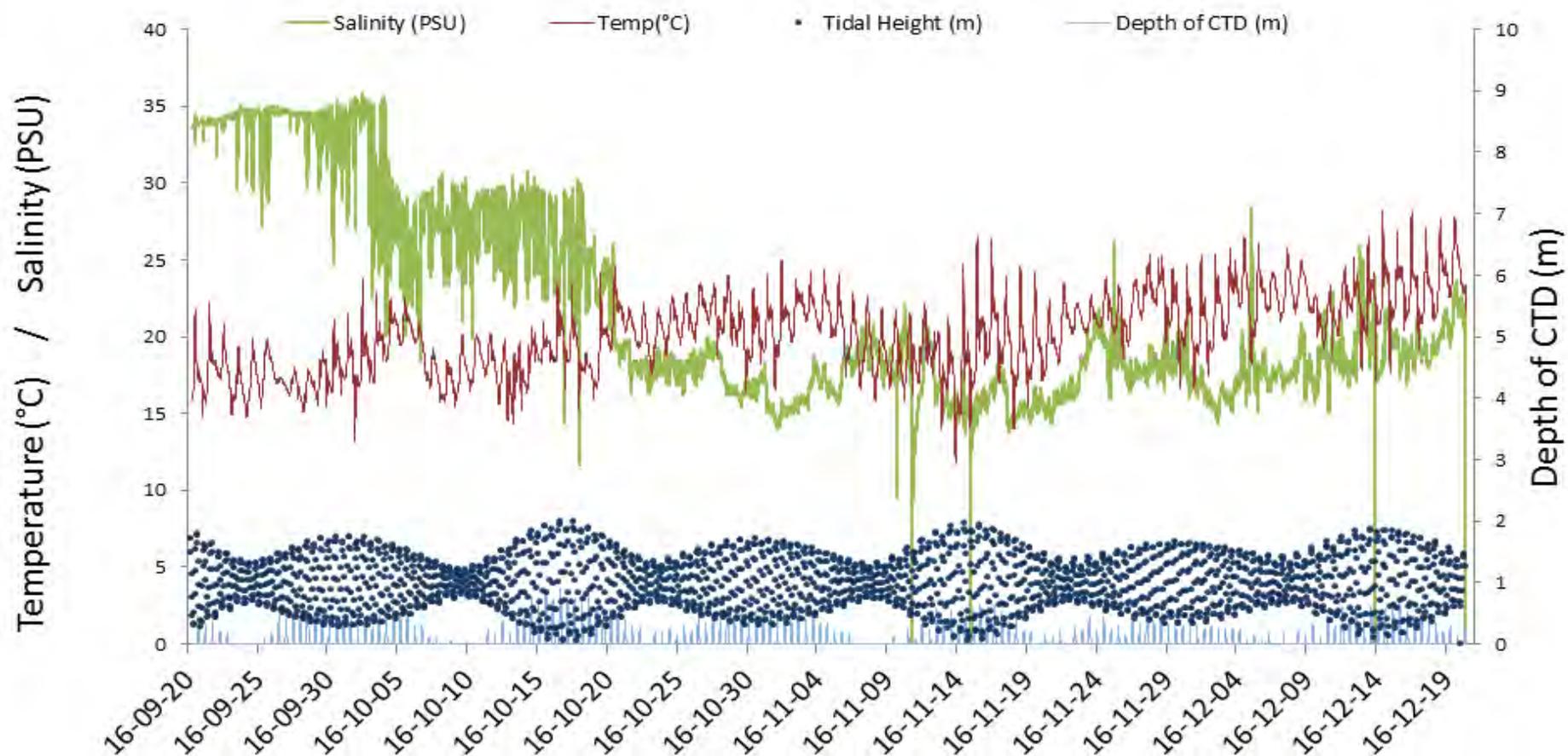


Figure 5.15 Salinity (green line, left axis, units PSU), temperature (red line, left axis, units °C) and instrument depth (light blue) in ten minute intervals over a three month period from September through December. Tidal data (dark blue points, right axis, units m) are in hourly intervals over the same time period (tidal data provided by hydrographer, SA Navy).

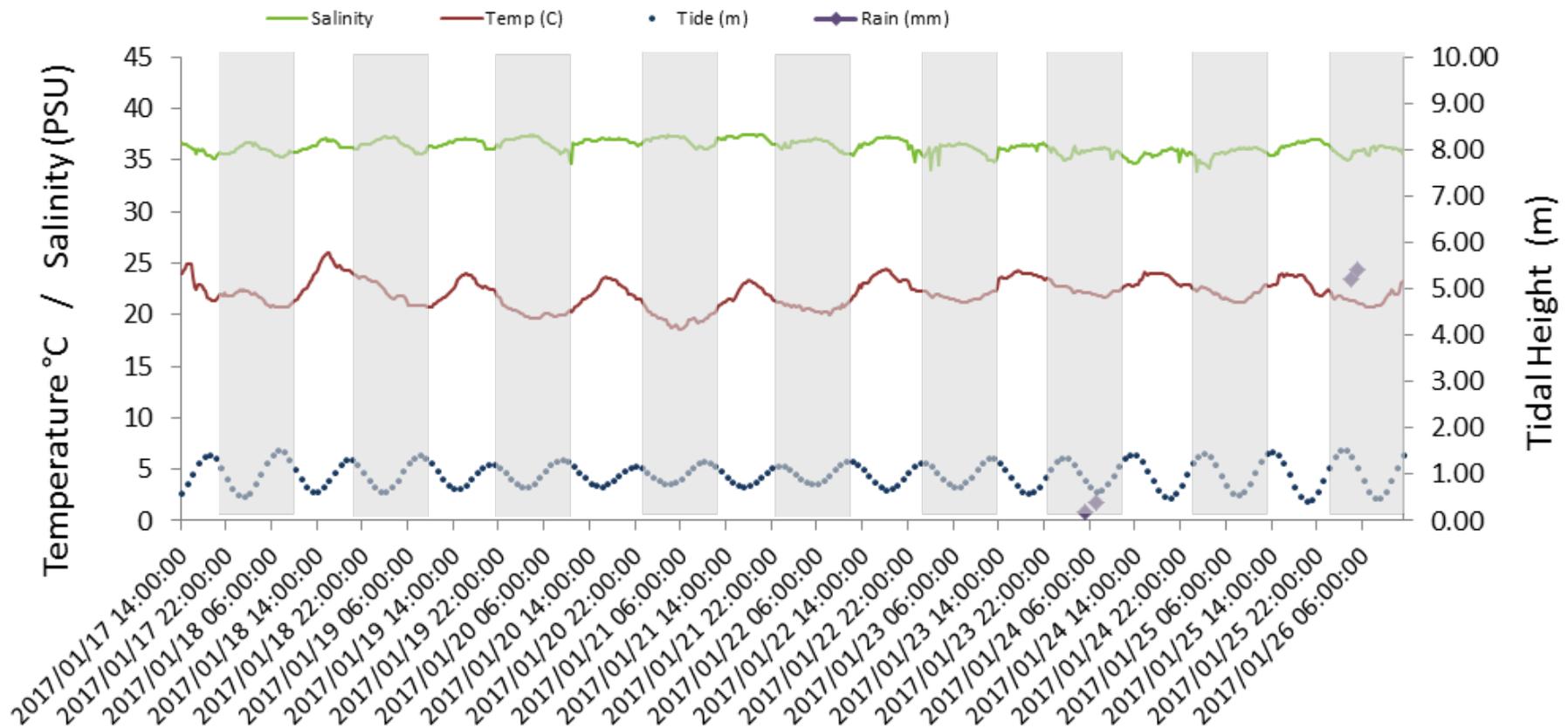


Figure 5.16 Salinity (green line, left axis, units PSU), temperature (red line, left axis, units °C) and instrument depth (light blue) in twenty minute intervals over a nine day period in January 2017. Tidal data (dark blue points, right axis, units m) are in hourly intervals over the same time period (tidal data provided by hydrographer, SA Navy). Grey shaded blocks indicate day-night cycle. Rain data (purple diamonds, right axis, units mm) are in hourly intervals over the same time period (rain data provided by WeathersA).

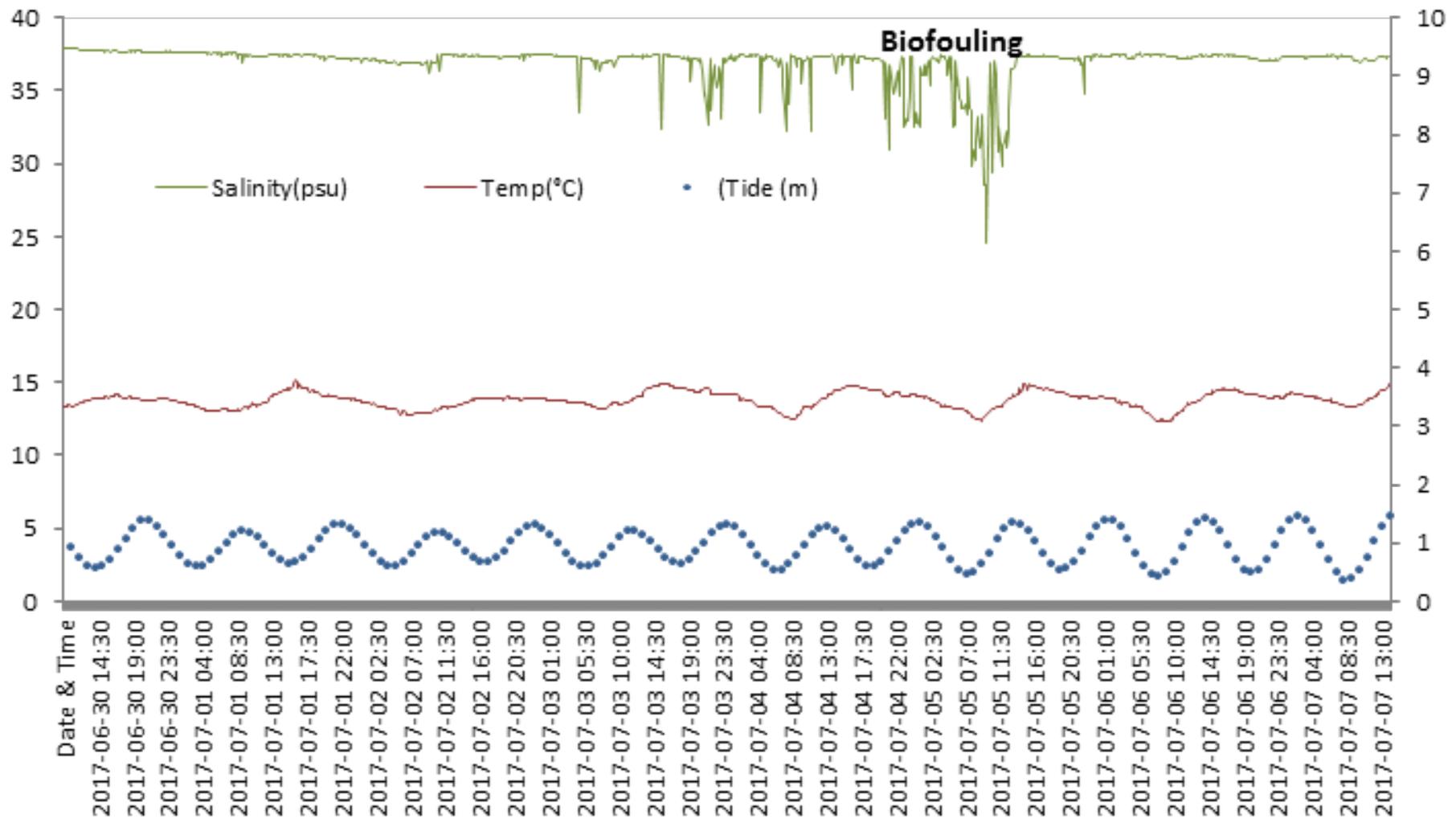


Figure 5.17 Salinity (green line, left axis, units PSU), temperature (red line, left axis, units °C) in ten minute intervals over a 1 week period in 30 June 2017 through 7 July 2017. Tidal data (dark blue points, right axis, units m) and rain (purple, right axis, units mm) are in hourly intervals over the same time period (tidal data provided by hydrographer, SA Navy). No rain recorded during this period.

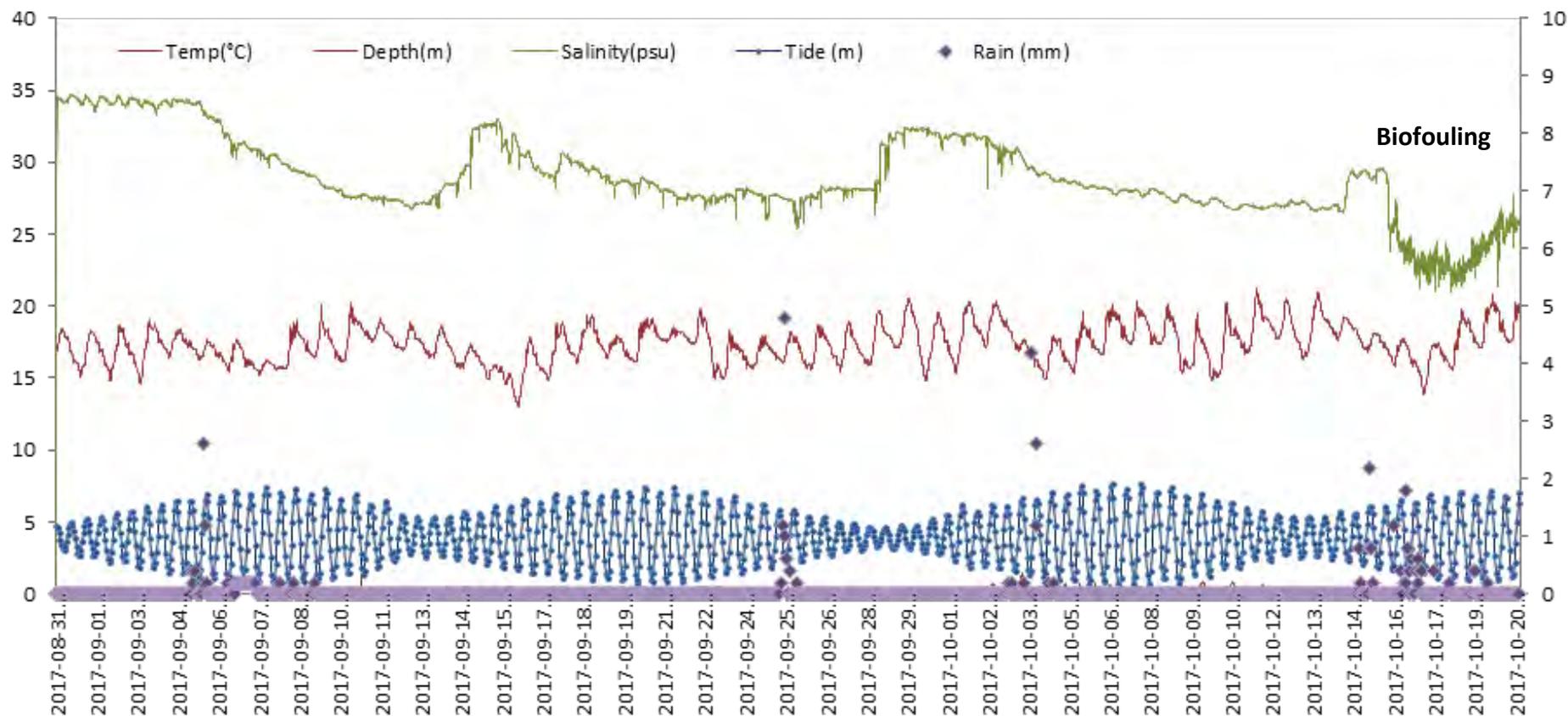


Figure 5.18 Salinity (green line, left axis, units PSU), temperature (red line, left axis, units °C) in ten minute intervals over a 2 month period in 31 August 2017 through October 2017. Tidal data (dark blue points, right axis, units m) and rain (purple, right axis, units mm) are in hourly intervals over the same time period (tidal data provided by hydrographer, SA Navy, rain data by WeatherSA).

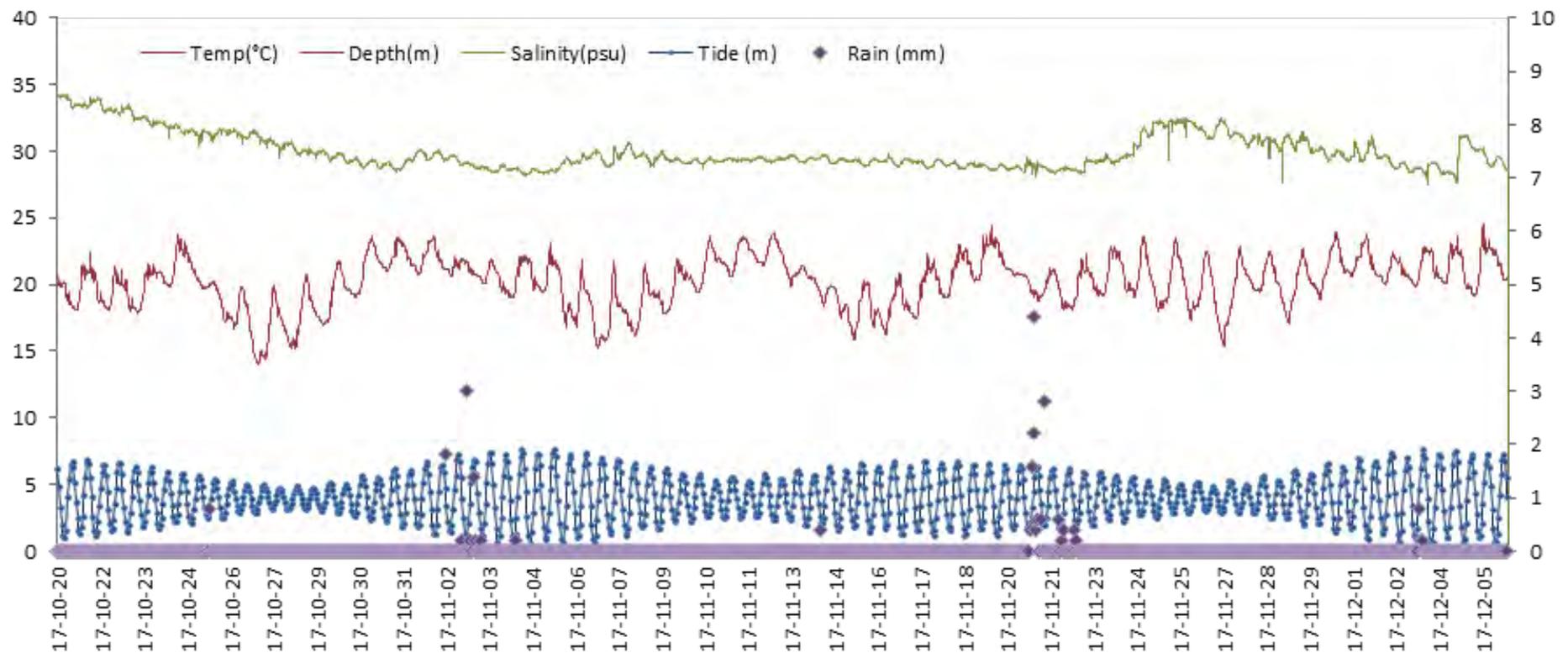


Figure 5.19 Salinity (green line, left axis, units PSU), temperature (red line, left axis, units °C) in twenty minute intervals over a 3 month period in October 2017 through December 2017. Tidal data (dark blue points, right axis, units m) and rain (purple, right axis, units mm) are in hourly intervals over the same time period (tidal data provided by hydrographer, SANHO, rain data by WeatherSA).

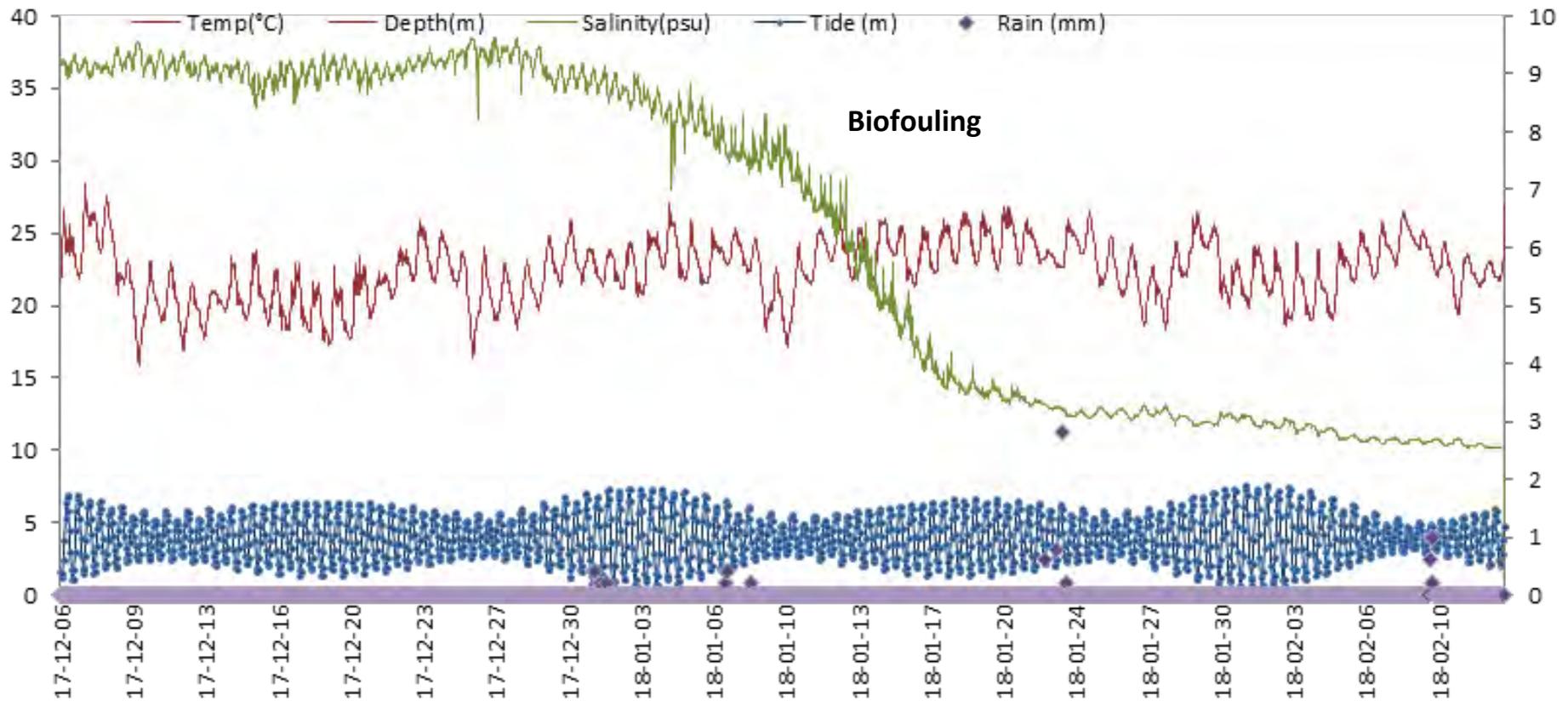


Figure 5.20 Salinity (green line, left axis, units PSU), temperature (red line, left axis, units °C) in twenty minute intervals over a 3 month period in October 2017 through December 2017. Tidal data (dark blue points, right axis, units m) and rain (purple, right axis, units mm) are in hourly intervals over the same time period (tidal data provided by hydrographer, SANHO, rain data by WeatherSA)

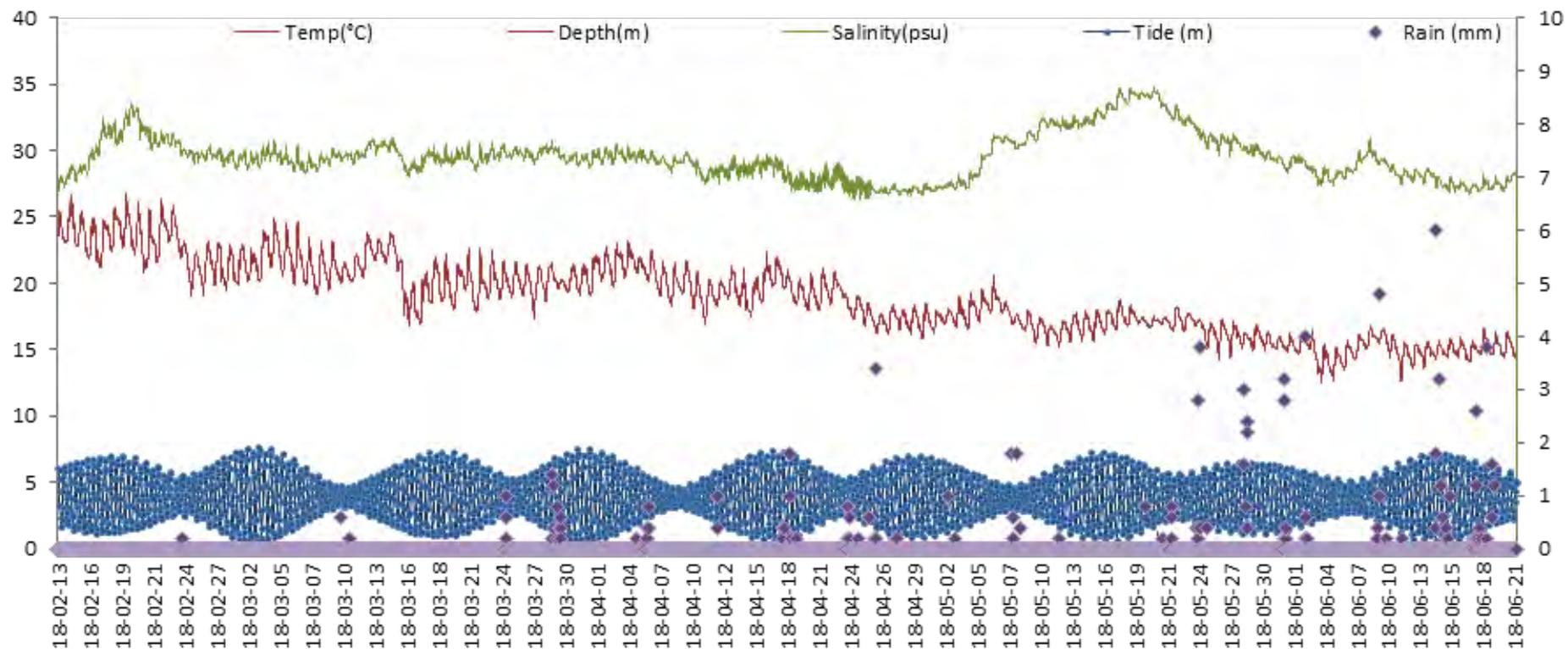


Figure 5.21 Salinity (green line, left axis, units PSU), temperature (red line, left axis, units °C) in twenty minute intervals over a 3 month period in October 2017 through December 2017. Tidal data (dark blue points, right axis, units m) and rain (purple, right axis, units mm) are in hourly intervals over the same time period (tidal data provided by hydrographer, SANHO, rain data by WeatherSA)

## 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 (RO) desalination plant (data for the period 2010-2011). A trial deployment of a conductivity temperature and depth (CTD) instrument from 3 April to 13 May 2017 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 Consultants on behalf of the SBWQFT. This array is retrieved and maintained during the annual field survey and data are included in this report. Current data were collected by an Acoustic Doppler Current Profiler (ADCP) from 7 to 10 April 2017 at a site adjacent to the Sea Harvest processing factory in Small Bay as well as at Club Mykonos Beach in Big Bay from 14 February to 28 February 2018. 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).

### 6.2 Circulation and current patterns

Circulation patterns and current strengths in Saldanha Bay prior to development in 1974/1975 were investigated using various techniques (drogues, dye-tracing, drift cards and sea-bed drifters). Surface currents within the upper five meters were found to be complex and appeared to be dependent on wind strength and direction as well as tidal state. Within Small Bay, currents were weak ( $5\text{-}15\text{ cm}\cdot\text{s}^{-1}$ ) 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 ( $10\text{-}20\text{ cm}\cdot\text{s}^{-1}$ ) and current directions within the main channels were dependent on tidal state. The strongest tidal currents were recorded at the mouth of Langebaan Lagoon ( $50\text{-}100\text{ cm}\cdot\text{s}^{-1}$ ), these being either enhanced or retarded by the prevailing wind direction. Currents within the main channels in Langebaan Lagoon were also relatively strong ( $20\text{-}25\text{ cm}\cdot\text{s}^{-1}$ ). 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 strengths and direction at 5 m depth were similar to those at the surface, but were less dependent on wind direction and velocity and appeared to be more influenced by tidal state. Currents at 10 m depth at the mouth of the Bay were found to be tidal (up to  $10\text{ cm}\cdot\text{s}^{-1}$ , either eastwards or westwards) and in the remainder of the Bay, a slow ( $5\text{ cm}\cdot\text{s}^{-1}$ ) 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 ( $5\text{-}20\text{cm}\cdot\text{s}^{-1}$ ), 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.

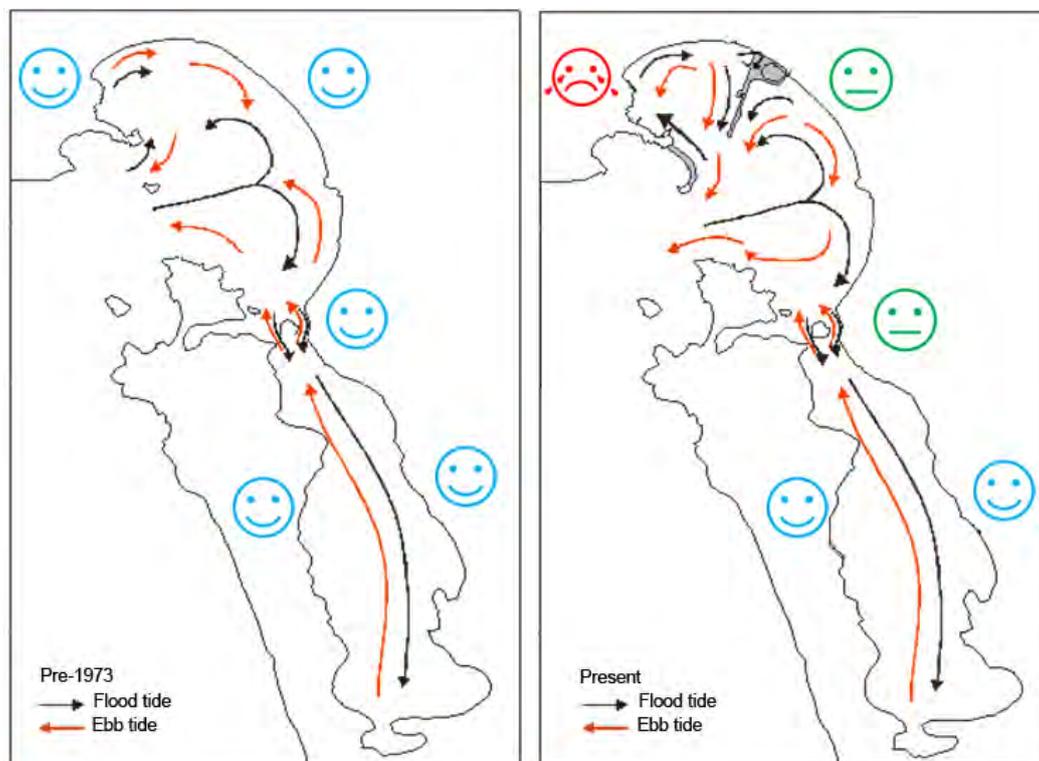


Figure 6.1 Schematic representation of the surface currents and circulation of Saldanha Bay prior to harbour development (pre-1973) and after construction of the causeway and iron ore terminal (present) (Adapted from: Shannon & Stander 1977 and Weeks *et al.* 1991a).

An ADCP was deployed from 7 to 10 April 2017 at Sea Harvest in Small Bay (see Figure 6.2 - left) to inform a Coastal Waters Discharge Permit (CWDP) application for a proposed RO Plant outfall. The data were analysed as a dynamic cell, moving with the tide, in 7 m water depth. This enabled quantification of typical current velocities and directions under the prevailing wind conditions. The data are summarised in a current rose that shows the prevailing current moving alongshore in a SSE direction (Figure 6.2 - right). Current velocities recorded at the deployment site over the sampling period indicated that calms were measured 29.9% of the time and current velocities of 1-5 cm/s were measured 64.6% of the time (Figure 6.2 - right). The maximum current speed recorded was 15.14 cm/s (Wright *et al.* 2018a).

Currents were found to be primarily wind driven, rather than tidally driven (Figure 6.3). A reasonably strong correlation ( $r^2 = 0.3$ ) was found between current speed and wind speed - a period of strong wind resulted in a corresponding peak in current speed, while a relaxation of the wind forcing led to a decrease in current speed (Figure 6.3). A wide range of wind speeds was experienced during the four day deployment period, ranging from 3-16 knots (1.5 to 8 m/s) with winds consistently blowing from the south.

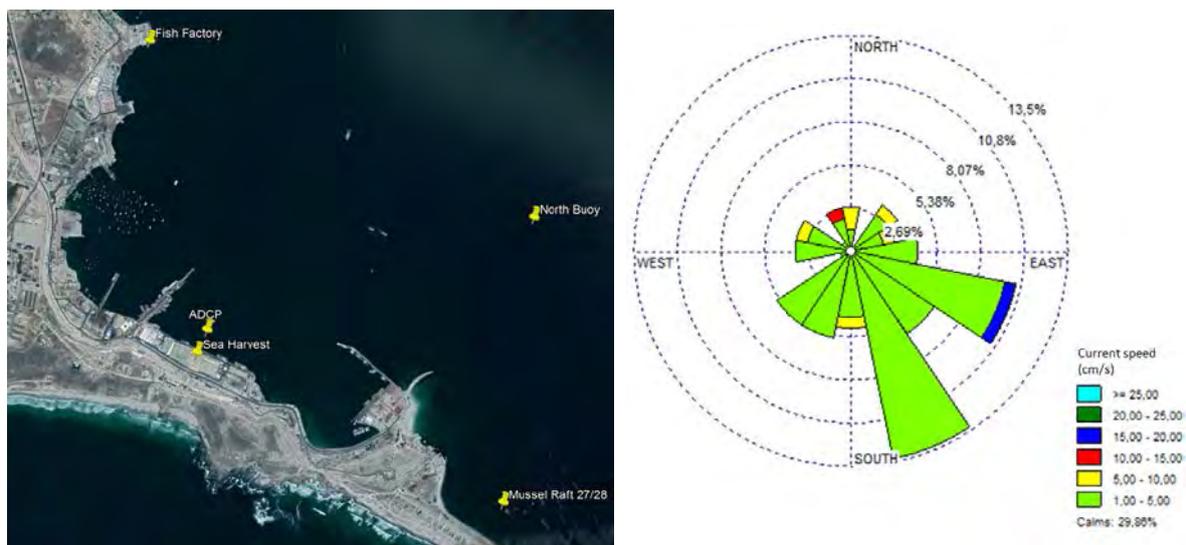
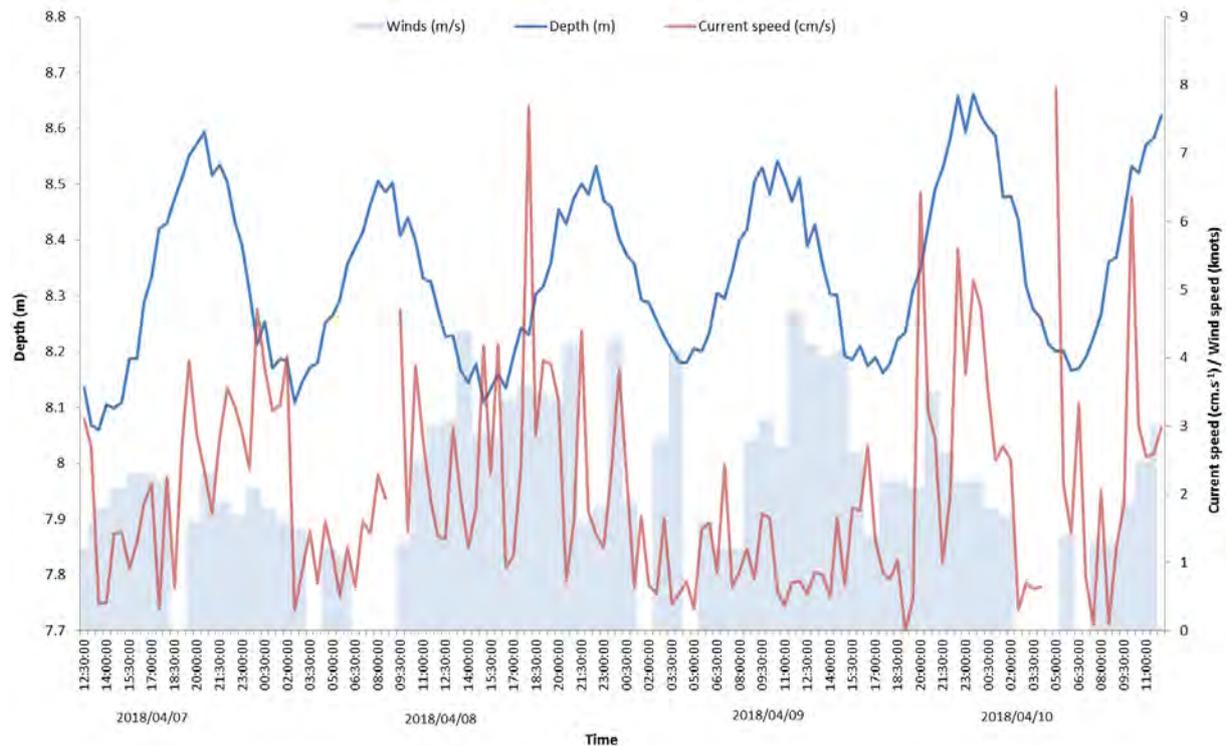


Figure 6.2. Location of the Sea Harvest ADCP (left) and current rose depicting current direction and strength at -7 m water depth (right). (Source: Wright *et al.* 2018a).



**Figure 6.3.** ADCP data collected every 30 minutes for depth (m), indicating the tidal cycle current speed (cm/s), and wind speed (m/s) over the four days of ADCP deployment at Sea Harvest in Small Bay in April 2018 (Source: Wright *et al.* 2018a).

A current rose depicting the strength, frequency and direction of currents was constructed from ADCP data collected from 14 February to 28 February 2018 at the proposed Club Mykonos RO discharge site in Big Bay (33°2'50.48"S; 18°1'59.71"E) (Figure 6.4). The data for the dynamic cell that recorded currents at 8.5 m water depth show the prevailing current moving alongshore in a northeasterly direction (Figure 6.4). Less frequently, currents were recorded flowing in a northerly direction. Again, currents appeared to be primarily wind driven rather than tidally driven. Of the current velocities measured, 35.6% fell between 10 and 15 cm/s, while current speeds between 5 and 10 cm/s were recorded 20.4% of the time (Figure 6.4). Maximum and average current speeds were recorded as 27.7 cm/s and 11.23 cm/s respectively (Wright *et al.* 2018b). Wind speeds during the deployment period ranged from 2 to 22 knots (1 to 11 m/s) and were consistently from the south.

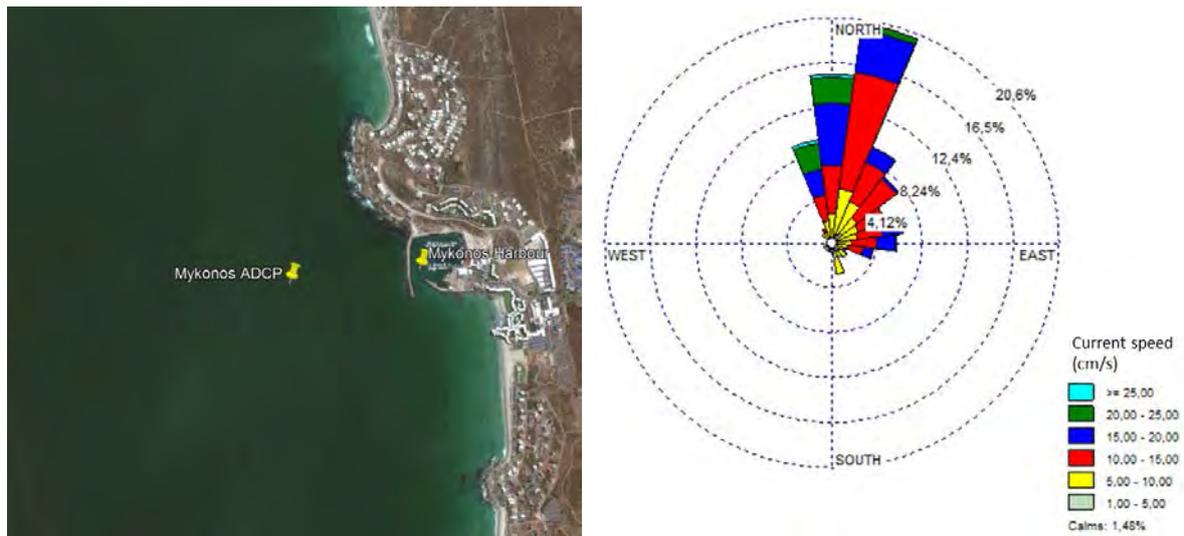


Figure 6.4. Location of the Mykonos ADCP (left) and the resulting current rose showing current direction and strength data at -8.5 m water depth (Wright *et al.* 2018b).

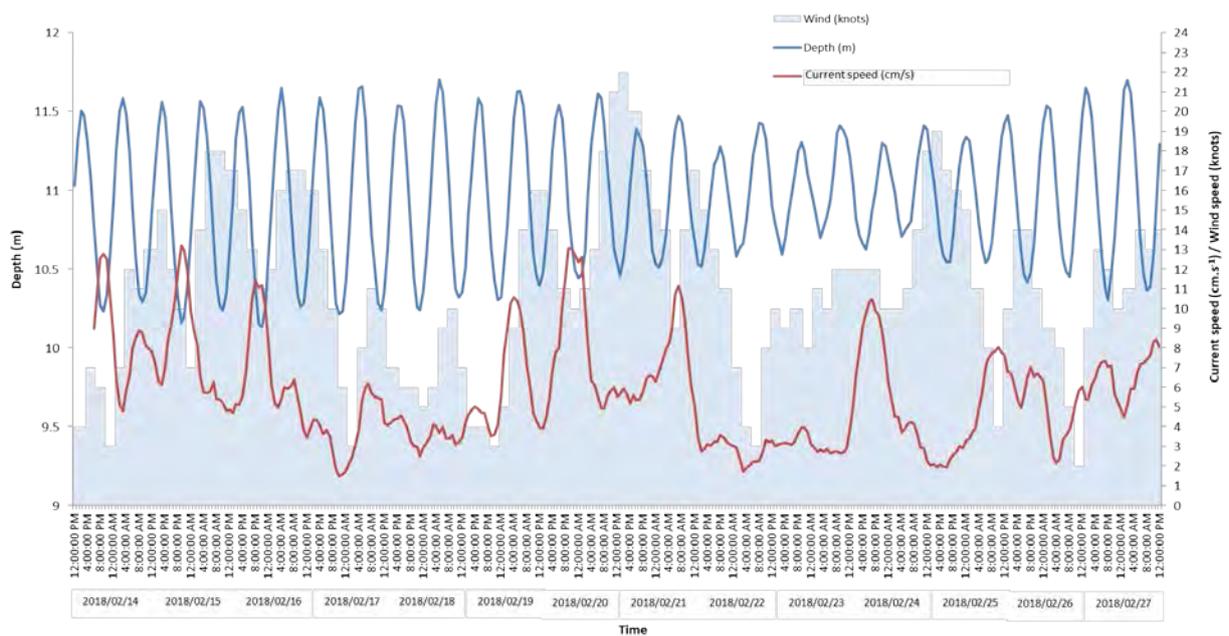


Figure 6.5. ADCP data collected every hour over a 14 day ADCP deployment period in February 2018 showing current speed (cm.s<sup>-1</sup>) and wind speed (knots). Depth (m) indicates the tidal cycle (blue line). (Source: Wright *et al.* 2018b).

### 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 6.6 left). 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 6.6 right). 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).

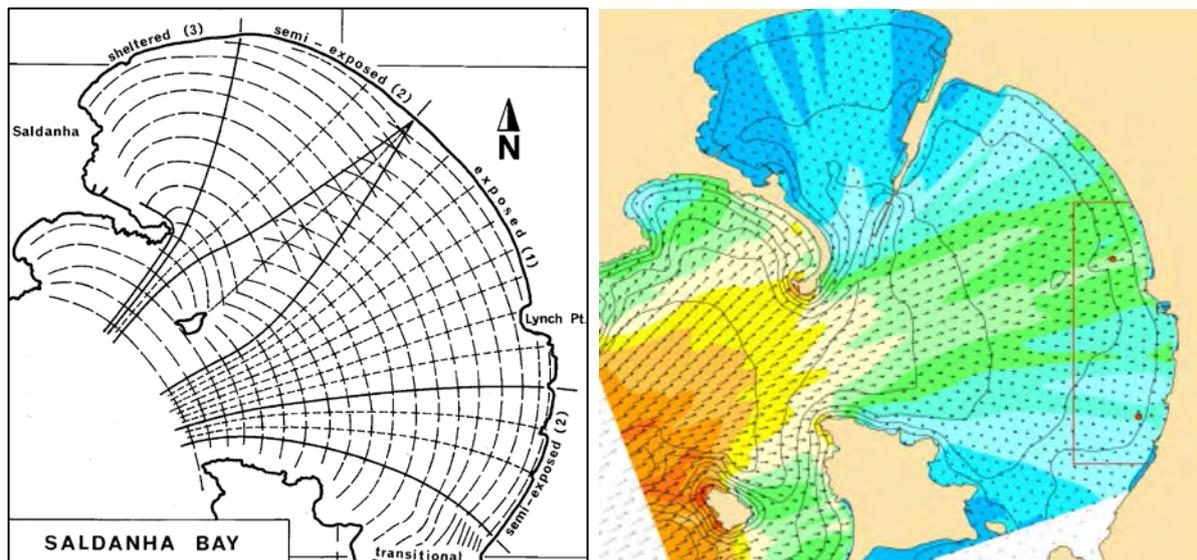


Figure 6.6 Predicted wave fields in Saldanha Bay showing wave height and direction prior to (left) and post (right) harbour development. Orange shading indicates wave heights >1.4 m, while blue shading indicates wave heights <0.6 m (Sources: Flemming 1977 and WSP Africa Coastal Engineers 2010).

## 6.4 Water temperature

Water temperature records for Saldanha Bay and Langebaan Lagoon were first collected during 1974/1975 as part of a detailed survey by the then Department of Industries - Sea Fisheries branch, later renamed the Department of Environmental Affairs and Tourism (DEAT) - Marine and Coastal Management (MCM), and now known as Department of Environmental Affairs - Oceans and Coasts (DEA-O&C). 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 to 18.5°C during summer (January 1975) and 14.5 to 16°C during winter (July 1975).

For the duration of sampling, higher temperatures were measured in the northern part of Small Bay and within Langebaan Lagoon, whilst cooler temperatures were measured at sampling stations in Outer Bay and Big Bay.

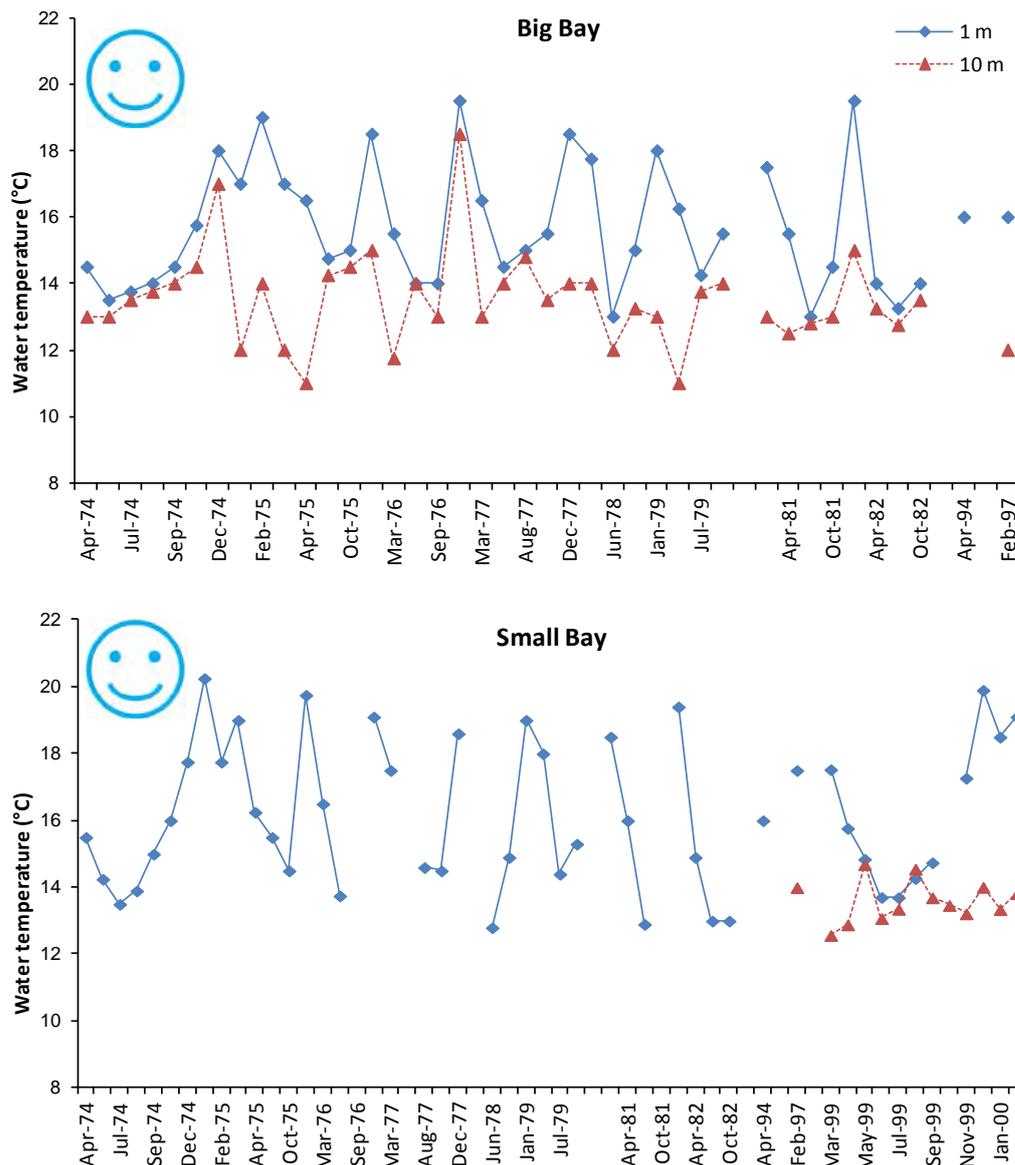
The water column was found to be fairly uniform in temperature during winter and spring (i.e. temperature did not change dramatically with depth) and the absence of a thermocline (a clear boundary layer separating warm and cool water) was interpreted as evidence of wind driven vertical mixing of the 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 “sloping backwards and forwards tidal motion”.

The Sea Fisheries Research Institute continued regular quarterly monitoring 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 6.7. 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 6.7). 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 6.7). 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 6.7).

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 6.11), 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 6.7) 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 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.

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. It revealed that the summer thermocline is not a long-term feature, but has a six to eight 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 six to eight 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 6.7** Water temperature time series at the surface and at 10 m depth for Big Bay and Small Bay in 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 to February 2000. This was the most intensive long-term temperature record to date, with continuous measurements (every 30 minutes) taken at one meter 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 6.7. These data confirmed the pattern evident in earlier data, showing a stratified (layered) water column from spring to summer caused by wind driven upwelling, with the water column being more or less isothermal (of equal temperatures) during the winter (Figure 6.7). 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. This “warm water event” 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). However, since the water column remained stratified, the magnitude of this event was not as great as the December 1974 and 1976 events.

The CSIR undertook baseline monitoring in Saldanha Bay on behalf of Transnet before the implementation and operation of the Transnet Reverse Osmosis (RO) desalination plant in 2012 (van Ballegooyen *et al.* 2012). Monitoring of sea water temperature, salinity and dissolved oxygen took place over a period of 10 months (July 2010 to March 2011) at one site immediately adjacent to the proposed desalination plant outfall (an underwater mooring). Water column profiling was 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 6.8. The combination of continuous monitoring and discrete profiling measurements was designed to address seasonal (every 3 months), event (3 to 10 days), and diurnal (daily) scales of temporal variability in the Bay.

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 moving seawards along the dredged shipping channel.
- WRO1 and WRO2 to monitor potential plume excursions out of the dredge channel and towards Small and Big Bay.
- Mussel Farm (MF) and Intermediate Dredge Site (IDS) to couple WRO1 and WRO2 to data measured previously. The MF site was also considered to be a sensitive location, while the IDS lies roughly on a line between the proposed RO Plant discharge and the MF.
- 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 to act as a control site.

**Table 6.1** Location and details of sites sampled during the water column profiling surveys undertaken by the CSIR between July 2010 and March 2011.

Site	Latitude	Longitude	Depth (m)	Distance from discharge (m)	Location
North Buoy (NB)	33° 1.114'S	17°58.130'E	12.5	1 875	Outside channel
Mussel Farm (MF)	33° 1.794'S	17° 58.247'E	16.0	1 400	Outside channel
Intermediate Dredge site (IDS)	33° 1.889'S	17° 58.642'E	16.0	880	Outside channel
WRO3	33° 1.935'S	17° 59.030'E	26.5	525	Inside channel
WRO4	33° 1.721'S	17° 59.127'E	28.5	105	Inside channel
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 dredge channel berthing areas
WRO1	33° 1.688'S	17° 59.215'E	18.0	85	Outside channel
East Buoy (Big Bay)	33° 3.188'S	18° 0.433'E	15.5	3450	Outside channel



**Figure 6.8** Water quality monitoring stations adopted for the RO plant baseline survey undertaken by the CSIR (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 6.9. 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 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.

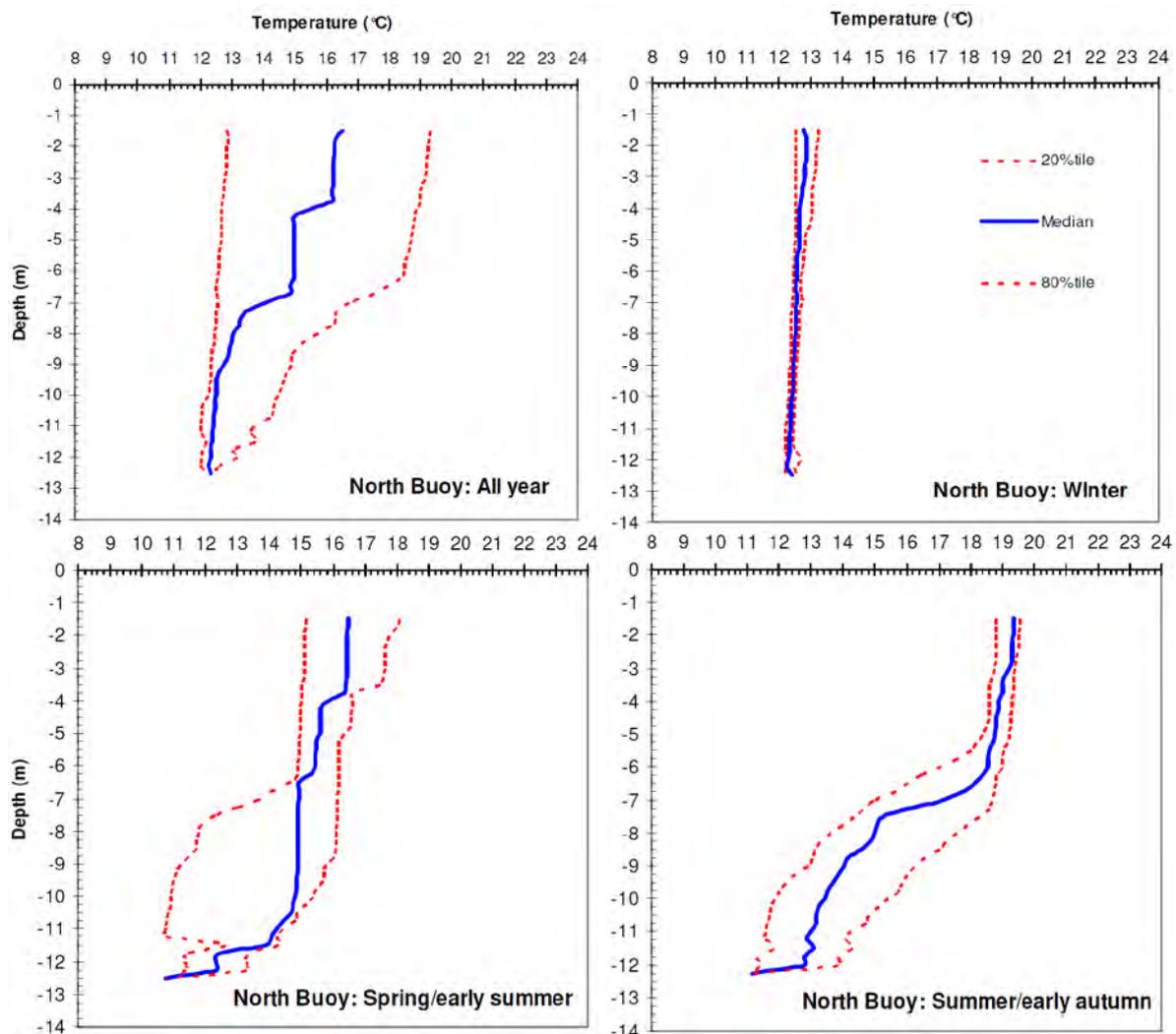


Figure 6.9 Seawater temperature median profiles at North Buoy for all four seasons. The 20<sup>th</sup> and 80<sup>th</sup> percentile limits of the profiles are indicated by the dotted red lines (Source: van Ballegooyen *et al.* 2012).

With a view to continuing the long term temperature data set at North Buoy, five Vemco mini-loggers, programmed to record temperature every hour were deployed at 2 m, 4.5 m, 7 m, 9.5 m and 12 m depth on the 12 April 2014. These thermistors are retrieved and serviced annually and average daily temperature data are shown in Figure 6.10.

The data from 12 April 2014 to 10 April 2018 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 6.10). 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 to early summer and again in late summer to 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 6.7). There also appears to be a trend of seawater cooling over time. 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 that would have significant impacts on ecosystem productivity and health.

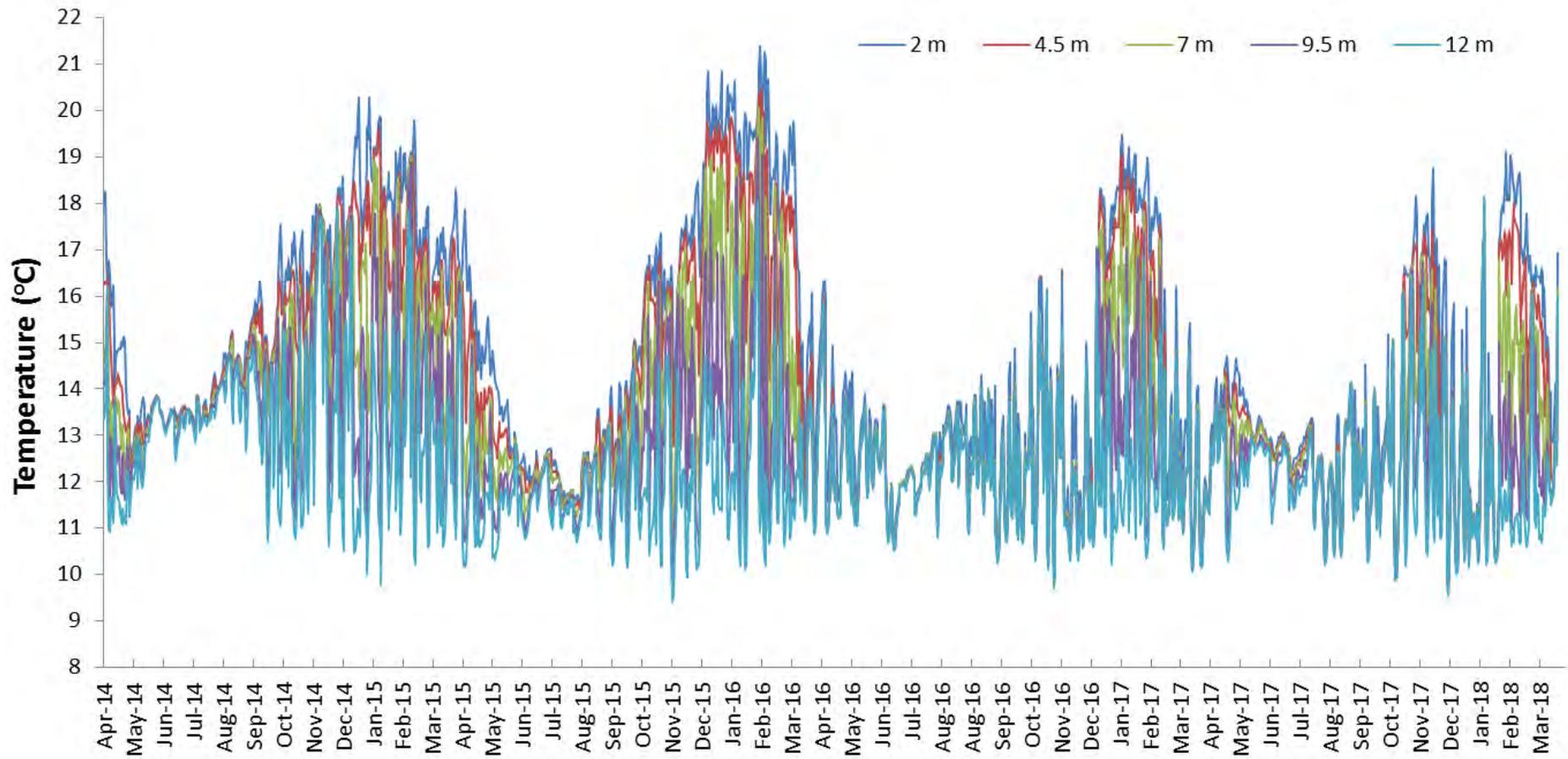


Figure 6.10 North buoy temperature time series for the period 12 April 2014 - 10 April 2018. Temperature was recorded every hour and the average daily temperature is shown here.

## 6.5 Salinity

Salinities of the inshore waters along the west coast typically vary between 34.6 and 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. Salinity data at 10 m depth were extracted from the studies of Shannon & Stander (1977), Monteiro & Brundrit (1990), Monteiro *et al.* (1990) and Monteiro *et al.* (2000) and are presented in Figure 6.11. There was little variation in salinity with depth. Under summer conditions when the water column is stratified, surface salinities may be slightly elevated due to evaporation, therefore, salinity measurements from deeper water more accurately reflects those of the source water.

The salinity time series at 10 m depth shows salinity peaks in December 1974 and 1976 which reflect the warm water inflows that occurred at this time (Figure 6.11). 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, limiting primary production (i.e. 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 6.12). 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 to 1979) and 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 6.13 (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).

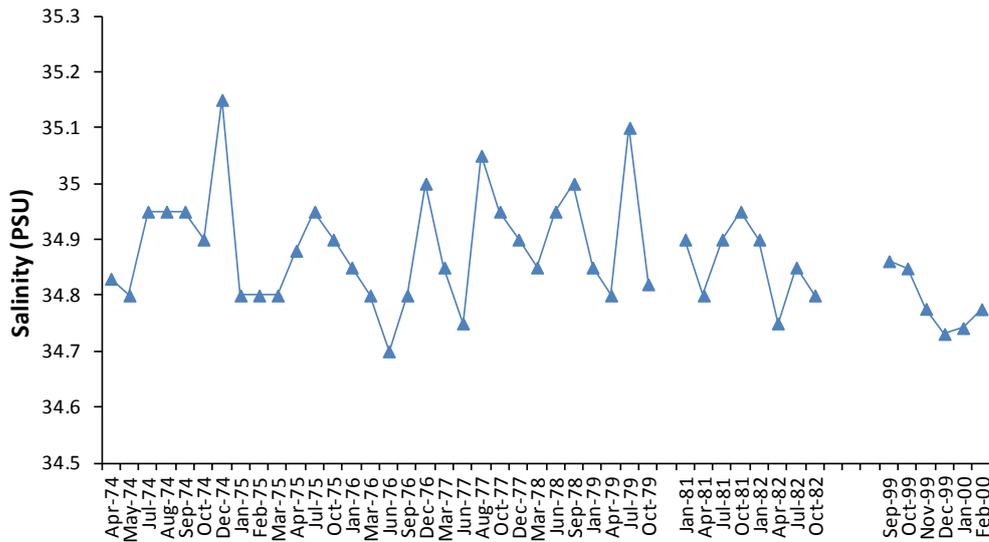


Figure 6.11 Time series of salinity records for Saldanha Bay. (Data sources: Shannon & Stander 1977, Monteiro & Brundrit 1990, Monteiro *et al.* 1990 and Monteiro *et al.* 2000).

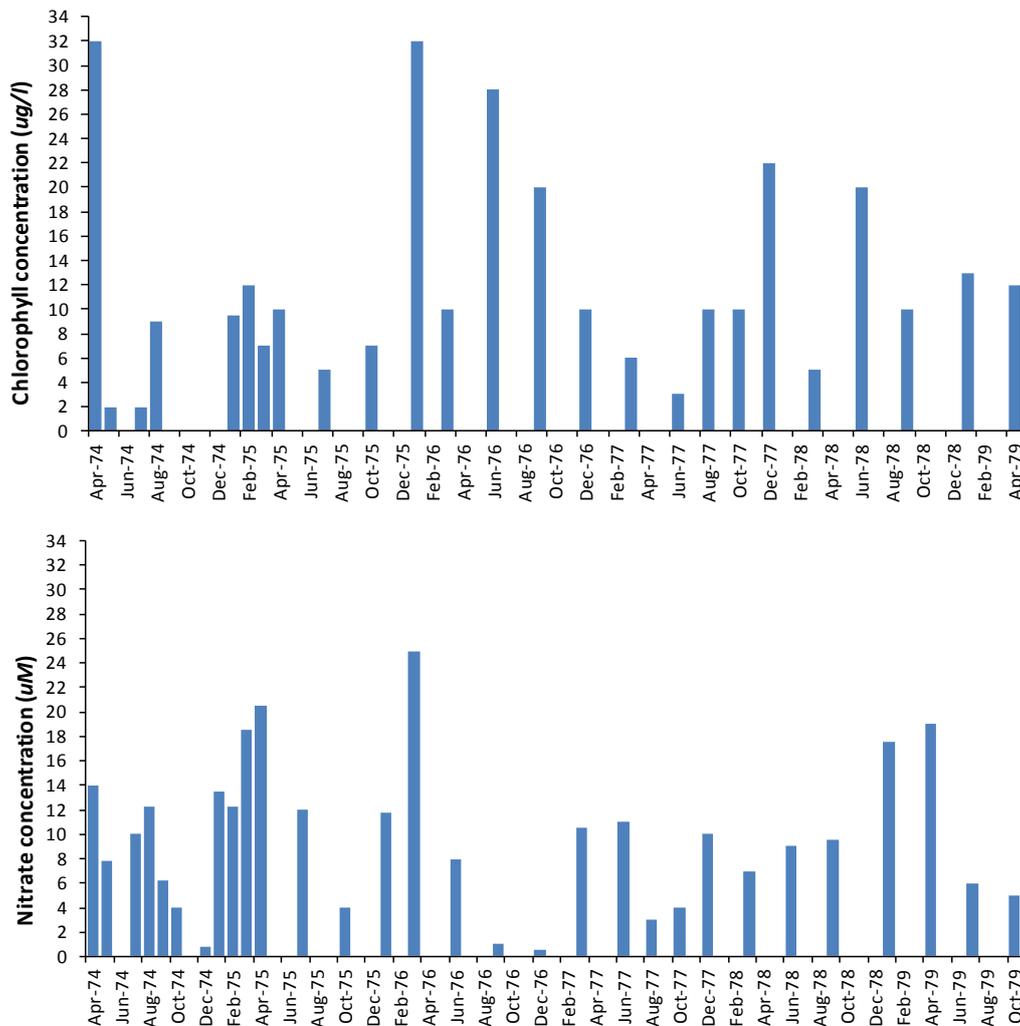


Figure 6.12 Time series of chlorophyll and nitrate concentration measurements for Saldanha Bay. (Data source: Monteiro & Brundrit 1990).

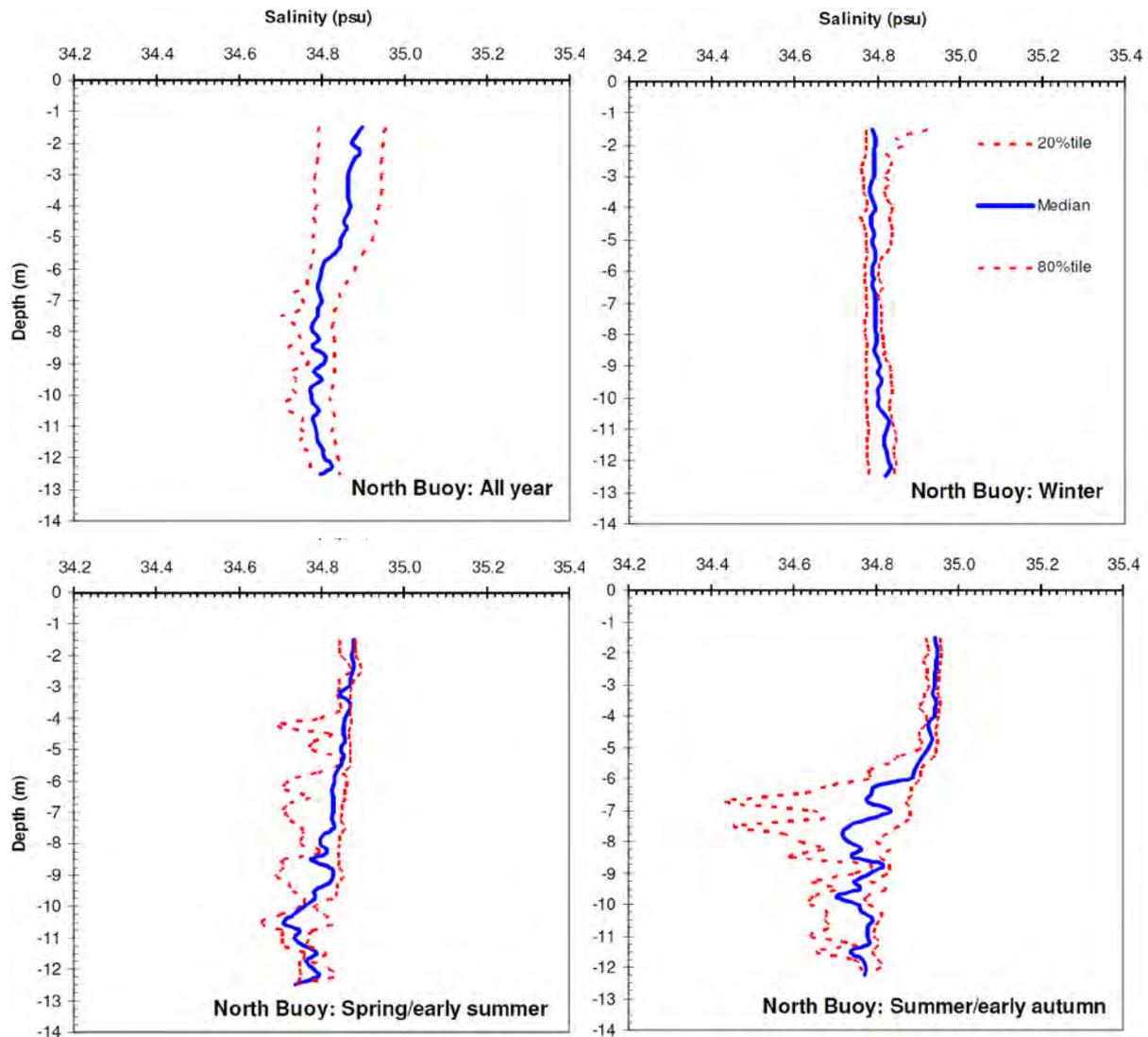


Figure 6.13 Salinity median profiles at North Buoy in Small Bay for all seasons (winter, spring/early summer and summer/early autumn). The 20<sup>th</sup> and 80<sup>th</sup> percentile limits of the profiles are indicated by the dotted red lines. (Source: van Ballegooyen *et al.* 2012).

## 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 mortalities of numerous marine species that occasionally occur along the west coast results 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) is 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 6.14). More recent data on oxygen concentrations in Small Bay (covering the period September 1999 to 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 monthly averages are plotted in Figure 6.12.

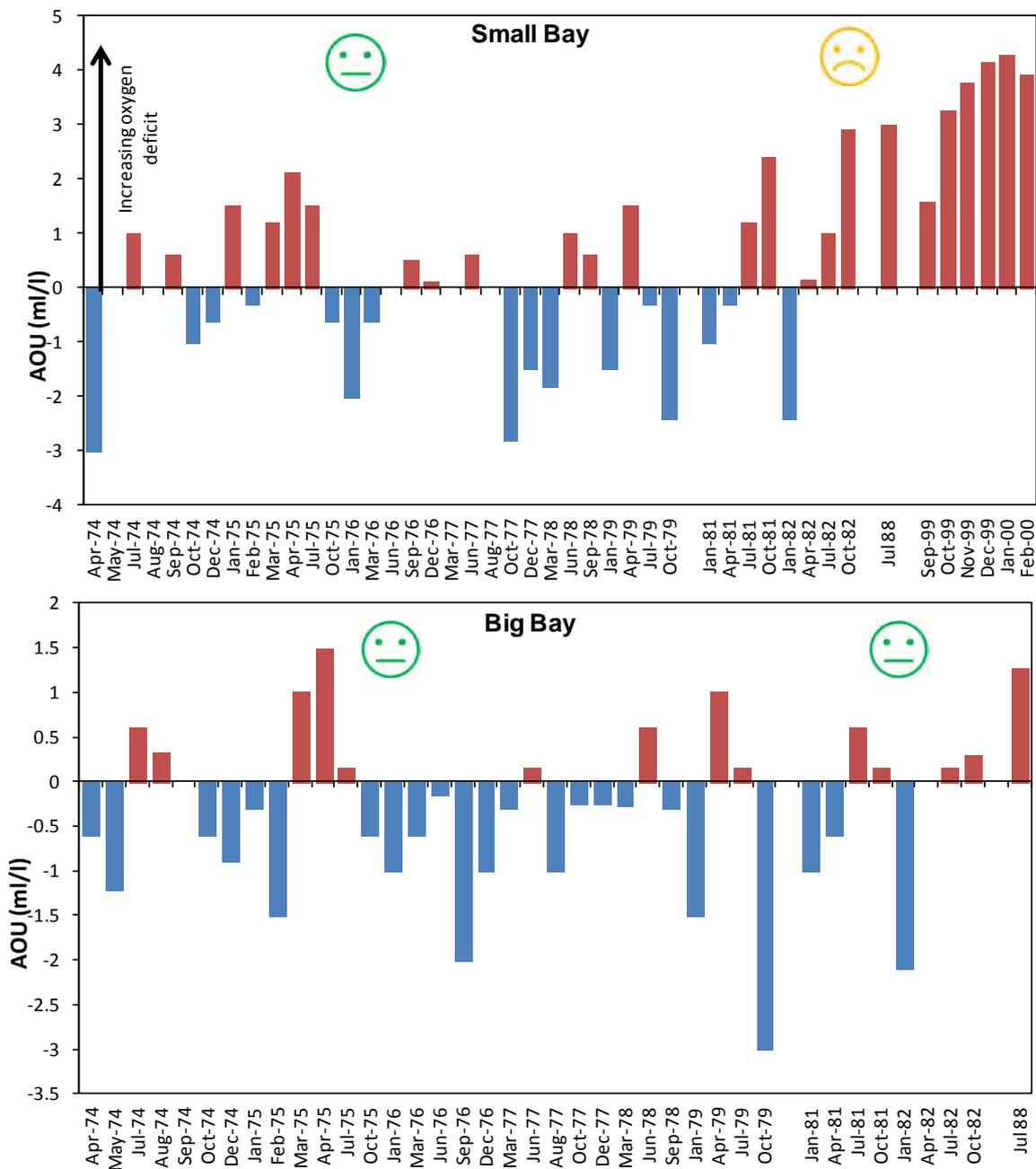


Figure 6.14 Apparent oxygen utilization time series for Small Bay and Big Bay in Saldanha Bay. Positive values in red indicate an oxygen deficit (Data sources: Monteiro *et al.* 1990 and 2000).

There is no clear trend evident in the AOU time series, as low oxygen concentrations (high AOU values) occur during both winter and summer months (Figure 6.14). 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 to February 2000) indicate a persistent and increasing oxygen deficit as summer progresses (Figure 6.14). 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 6.15 (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 for dissolved oxygen concentrations for the period April 1974 to October 1975 are as follows:

- $8.60 \pm 1.86$  (standard deviation) mg/l at the surface
- $7.96 \pm 1.63$  mg/l at -5m
- $6.85 \pm 1.54$  mg/l at -10 m
- $5.13 \pm 1.80$  mg/l at -20m

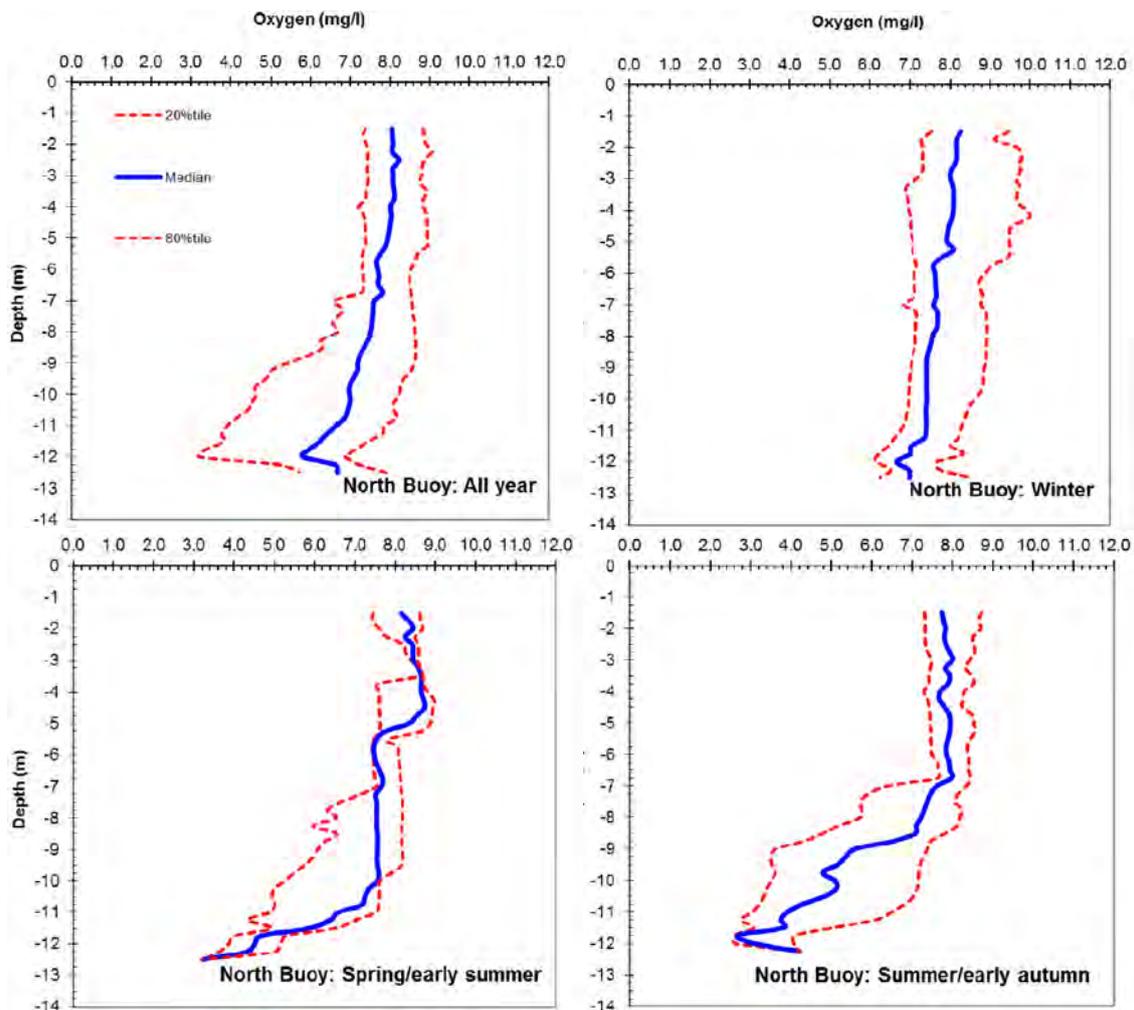


Figure 6.15 Dissolved oxygen concentration median profiles at North Buoy for all seasons (winter, spring/early summer and summer/early autumn). The 20<sup>th</sup> and 80<sup>th</sup> percentile limits of the profiles are indicated by the dotted red lines (Source: van Ballegooyen *et al.* 2012).

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 9 July 2012 to 23 March 2012 at a temporal resolution of 10 minutes (Figure 6.16). Observations highlighted by the CSIR (van Ballegooyen *et al.* 2012) from these data are as follows:

- The most obvious variability in the Bay is that which occurs over synoptic (weather) time scales.
- 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 insulated from the surface waters and the variability in temperature, salinity and dissolved oxygen of the bottom waters decreases compared to spring and early summer.
- The dissolved oxygen in the bottom waters decreases throughout summer to early autumn when the winter storms and vertical mixing of the water column alleviated these low oxygen conditions.

The CTD deployment during April/May 2017 in 22 m water depth on the Big Bay side of the RO Plant discharge was very close to the mooring deployed by the CSIR in 2010/2011. The instrument recorded depth, temperature, pH, salinity and dissolved oxygen at 20 minute intervals (Figure 6.17). 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 in 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 ( $1$  to  $2$   $\text{mg.l}^{-1}$ ) are below the level that is tolerable for many invertebrates and most fish species. 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 within 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 but it is not known if the RO Plant was operational during this period.

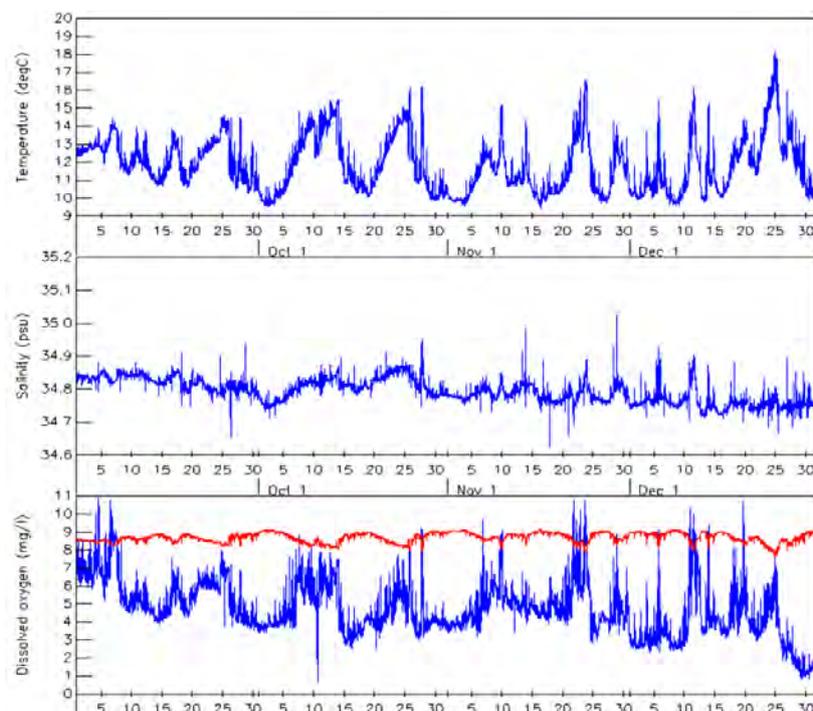


Figure 6.16. Time series of water temperature, salinity and dissolved oxygen concentrations from the mooring site ( $33^{\circ} 01.679'S$ ;  $17^{\circ} 59.143'E$ ) for spring/early summer (Source: van Ballegooyen *et al.* 2012).

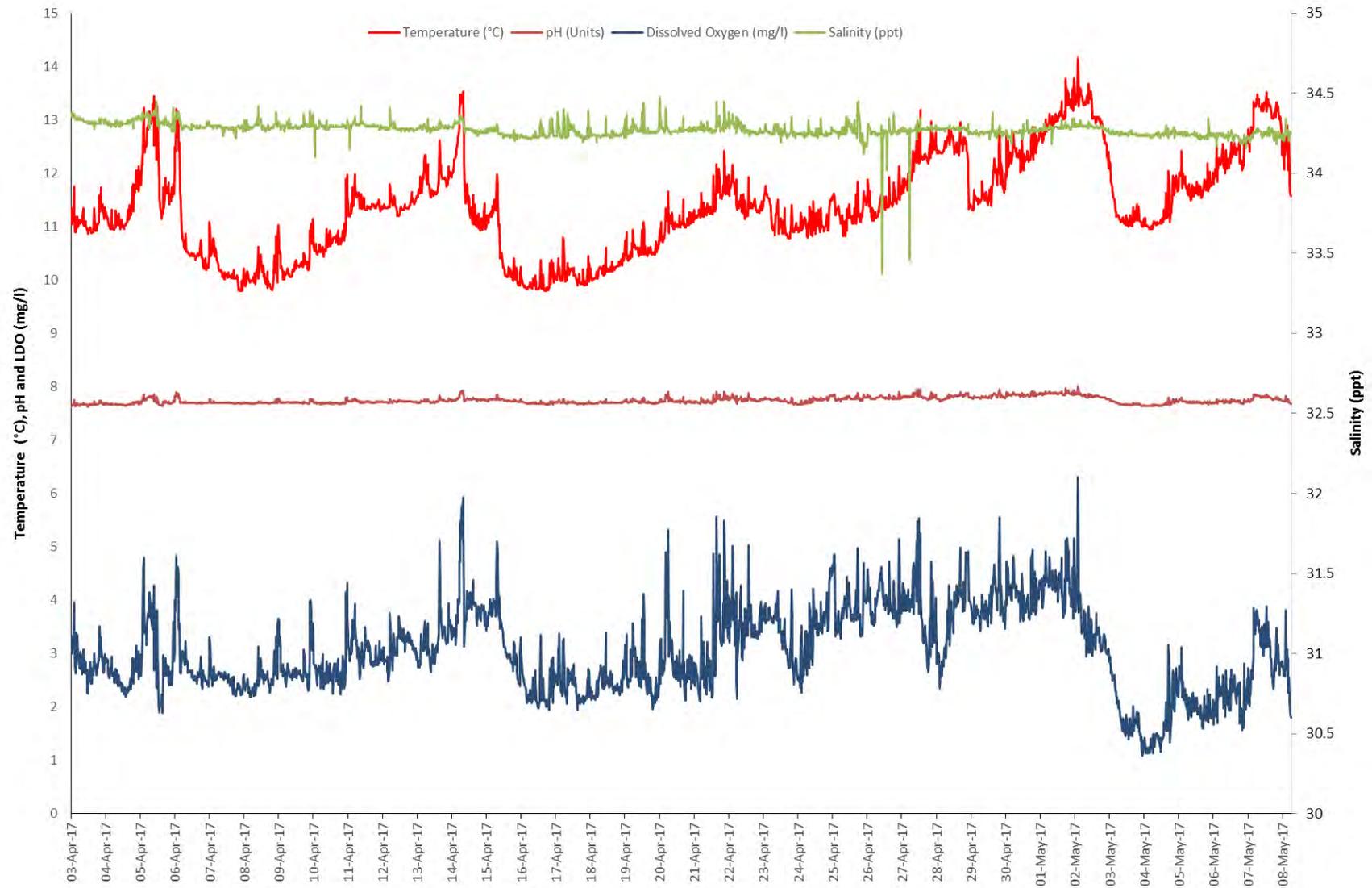


Figure 6.17. Temperature, salinity, pH and dissolved oxygen (DO) recorded by the CTD deployed in 23 m water depth adjacent to the RO plant discharge at the base of the iron ore terminal.

## 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 suspends particulate matter in the water column, particularly Big Bay). Langebaan Lagoon, however, typically remains very clear even when the winds are very strong. This is likely due to the coarse nature of the sediment in the Lagoon when compared to the finer sediment in Saldanha Bay. 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 ( $\pm 2.69$  mg/l SD) and peak at around 15.33 mg/l. Higher values caused by shipping movements (162 mg/l) 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 particulates in the water column) were collected at 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 6.18). In general TSS concentrations are greatest near the seabed, particularly at the shallower sites in and around Small Bay. Concentrations generally did not exceed 10 mg/l, except for a few occasions where higher TSS of between 10 mg/l and 40 mg/l were observed (typically in the near bottom waters at the Mussel Farm site, at East Buoy in Big Bay, and in the immediate vicinity of the berths along the iron ore terminal). A few values above 100 mg/l were recorded in the vicinity of the iron ore terminal, 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).

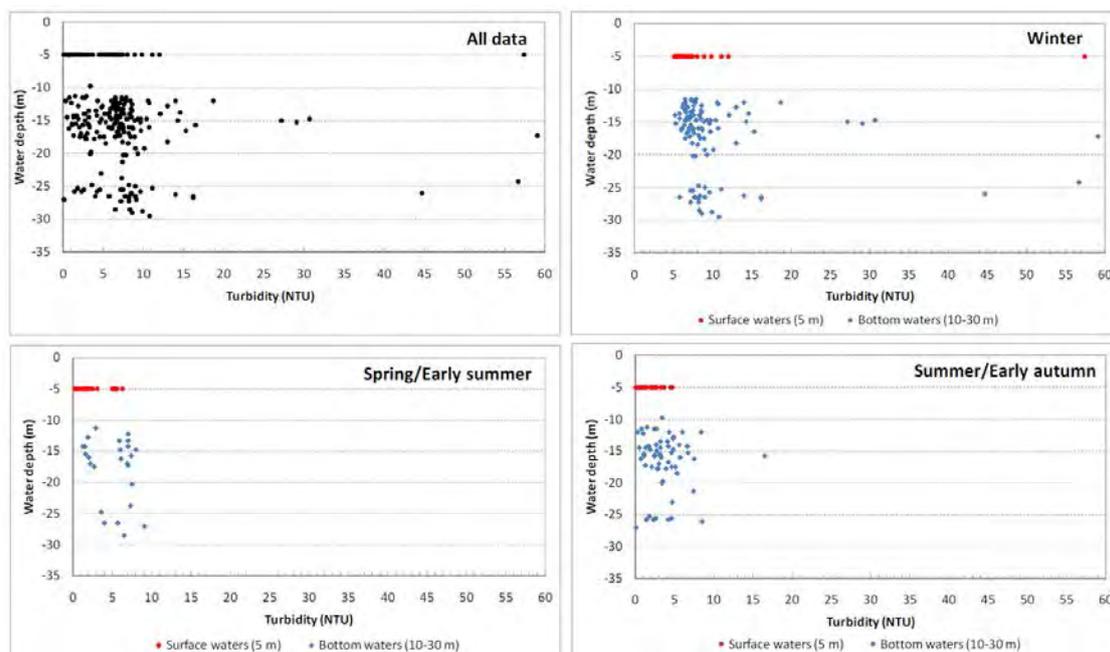


Figure 6.18 Turbidity (NTU) plotted as a function of depth and season (Source: van Ballegooyen *et al.* 2012).



Figure 6.19 Turbidity generated under high wind conditions (top) and by propeller wash (bottom) in Saldanha Bay (Source: van Ballegooyen *et al.* 2012).

## 6.8 Bromide

Measurements of bromide concentrations were collected at 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 to determine natural occurrence in Saldanha Bay. The purpose was to ensure that the biocide proposed for the RO plant (2,2-dibromo-3-nitrilopropionamide or its break-down products) do not change natural distributions of bromide. 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 (between 40 and 95 mg/l, Figure 6.20), with variability 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 terminal at the time.

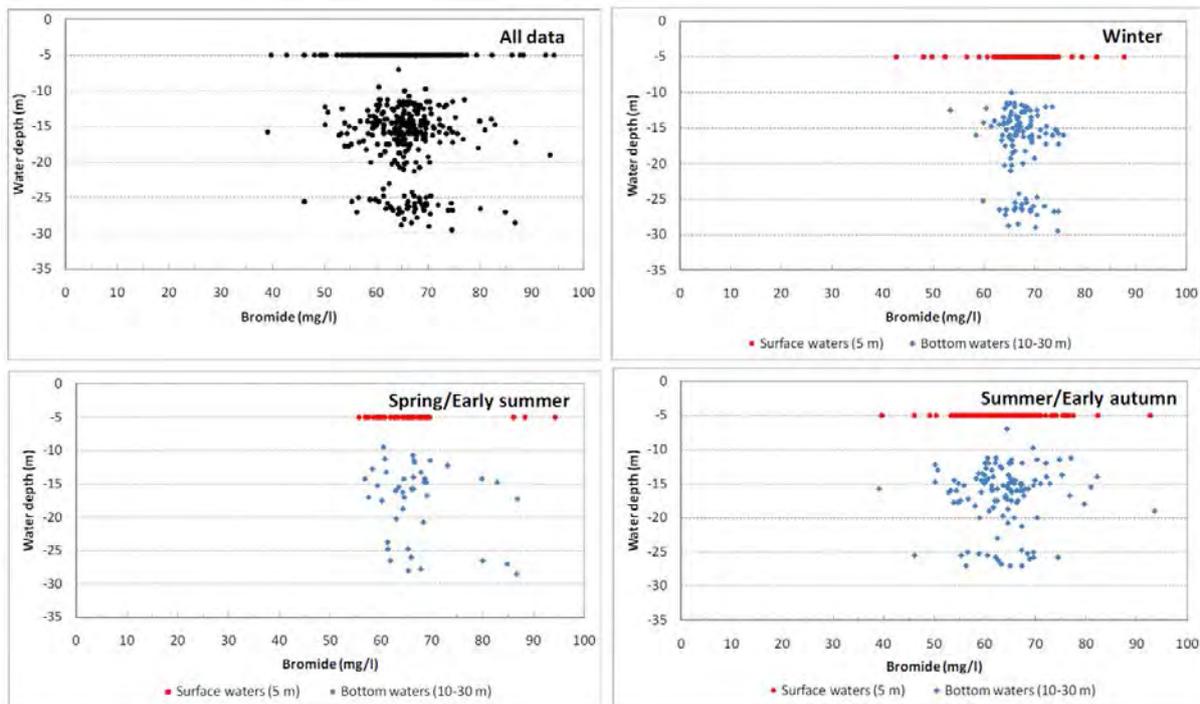


Figure 6.20 Bromide concentrations measured at all stations in winter, spring/early summer, and summer/early autumn (Source: van Ballegooyen *et al.* 2012).

## 6.9 Microbial indicators

Untreated sewage or storm water runoff may introduce disease-causing micro-organisms into coastal waters through faecal pollution. These pathogenic micro-organisms constitute a threat to recreational water users and consumers of seafood. Although faecal coliforms and *Escherichia coli* are used to detect the presence of faecal pollution, they provide indirect evidence of the possible presence of water borne pathogens and may not accurately represent the actual risk to water users (Monteiro *et al.* 2000). These organisms are less resilient than *Enterococci* (and other pathogenic bacteria), which can lead to risks being underestimated due to mortality occurring in the time taken between collection and analysis. To improve monitoring results, the enumeration of *Enterococci* should be included in water quality sampling programmes (DEA 2012).

### 6.9.1 Water quality guidelines

Marine water quality is assessed according to the most sensitive water use applicable to the specific area (e.g. mariculture vs. industrial use). For this study, WQGs for the natural environment (DWAF 1995a), industrial use (DWAF 1995c), and mariculture (DWAF 1995d) were used to assess water bodies not designated as recreational areas, while the evaluation of microbial data collected from Saldanha Bay and Langebaan Lagoon was undertaken in accordance with the revised guidelines for recreational use (DEA 2012) as described below.

### 6.9.1.1 Recreational Use

In the past, the DWAF (1995b) Water Quality Guidelines (WQGs) for coastal marine waters were used to assess compliance in respect of human health criteria for recreational use; however, these WQGs were replaced in 2012 by the revised *South African Water Quality Guidelines for Coastal Marine Waters Volume 2: Guidelines for Recreational Waters* (DEA 2012). The revised WQGs do not distinguish between different levels of contact recreation but rather evaluate aesthetics (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 hypothermia), and mechanical interference. Measurable indicators commonly monitored include 'objectionable matter', water temperature and pH as well as the levels of intestinal *Enterococci* (or less ideally concentrations of *E. coli* or faecal coliforms). Guidelines state that samples should be collected 15 to 30 cm below the water surface on the seaward side of a recently broken wave in order to minimise contamination and reduce sediment content (DEA 2012). Samples to be tested for *E. coli* counts should be analysed within six to eight hours of collection, and those to be tested for intestinal *Enterococci*, within 24 hours.

The Hazen non-parametric statistical method is recommended for dealing with long-term microbiological data that do not typically fit a normal (bell shaped) distribution. The data are ranked into ascending order and percentile values are calculated using formulae incorporated in the Hazen Percentile Calculator (McBride and Payne 2009). In order to calculate 95<sup>th</sup> percentiles, a minimum of ten data points are required, while the calculation of the 90<sup>th</sup> percentile estimates require only five data points. Rather than using a measure of actual bacterial concentrations, a compliance index is used to determine deviation from a fixed limit (DEA 2012). This method is being increasingly used across Europe to determine 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. Target limits, based on counts of intestinal *Enterococci* sp. and/or *E. coli*, for recreational water use in South Africa are indicated in Table 6.2.

**Table 6.2** Target limits for *Enterococci* sp. and *E. coli* based on the revised 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)	<i>E. coli</i> . (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)

### 6.9.1.2 Mariculture Use

Filter feeding organisms, such as shellfish, can accumulate pathogenic organisms in their bodies and thereby infect the people that consume them. The *Guidelines for Inland and Coastal Waters: Volume 4 Mariculture* (DWAF 1995d) provides target levels for faecal coliforms in water bodies used for mariculture as outlined in Table 6.3. These guidelines aim to protect consumers of shellfish from bacterial contamination. For mariculture, faecal coliform concentrations for the 80<sup>th</sup> and 95<sup>th</sup> percentiles were calculated.

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

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 recreational use (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) in Small Bay. Much lower faecal coliform counts were recorded at stations within Big Bay, with the exception of the 80<sup>th</sup> 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 West Coast District Municipality (WCDM). The available data cover the period February 1999 to December 2017 for 20 stations (ten in Small Bay, five in Big Bay and five 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 National Ports Authority) 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 cover a complete calendar year to account for seasonal differences, thus 2018 data will be included in the 2019 report. Compliance with mariculture guidelines were assessed by comparing faecal coliform counts to the DWAF 1995 guidelines (DWAF 1995d), whilst recreational use compliance was assessed by comparing *E. coli* count data to the revised recreational guidelines (DEA 2012).

### 6.9.2.1 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 6.21 and Figure 6.22 graphically depict these data for Langebaan Lagoon. Data from the microbial monitoring programme suggest that nearshore coastal waters in the system have improved considerably for recreational use since 2005 (Table 6.4). Based on the 2017 *E. coli* data, 14 of the 20 sampled stations were categorized as having excellent water quality. The only improvement in water quality in 2017 was recorded at Langebaan Yacht Club (Site 17), which upgraded from “Fair” to “Good”. Water quality at Sea Harvest (Site 3), Hoedtjies Bay Beach (Site 7), and Langebaan North (Site 15) all deteriorated slightly compared to 2016 results. Ongoing efforts to maintain “Excellent” water quality at the popular swimming and water sport sites (i.e. Mykonos Beach and Langebaan Main Beach) must be continued.

Considering that the majority of treated waste water from the Langebaan Wastewater Treatment Works (WWTW) was diverted to other uses (including industrial, construction and irrigation), these results are surprising. A number of infrastructure upgrades were also completed in the past financial year. It was expected that water quality would have improved in the system, which suggests that the contamination may be from other sources (e.g. storm water). Due to the lack of monitoring of treated effluent discharge volumes, it is difficult to draw a conclusion as to the source of the contamination. See Chapter 3 for further information regarding activities and discharges in the Saldanha Bay-Langebaan Lagoon System.

Reuse of wastewater from the Saldanha WWTW by Arcelor Mittal, which commenced in 2018, is expected to result in a considerable improvement in water quality in Small Bay and will hopefully be reflected in results for next year.

**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<sup>th</sup> and 95<sup>th</sup> 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	2017	
Small Bay	1. Beach at Mussel Rafts	Fair	Fair	Ex.																	
	2. Small Craft Harbour	Ex.	Fair	Good	Ex.	Ex.	Ex.	Good	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Good	Ex.	Ex.	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.	Ex.	Fair
	4. Saldanha Yacht Club	Poor	Poor	Poor	Fair	Poor	Poor	Poor	Ex.												
	5. Pepper Bay - Big Quay	Poor	Fair	Poor	Fair	Fair	Fair	Fair	Poor	Ex.	Ex.	Fair	Ex.	Ex.	Good	Ex.	Ex.	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.	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	Fair	
	8. Beach at Caravan Park	Fair	Fair	Fair	Poor	Ex.	Fair	Poor	Ex.	Good	Poor	Fair	Fair	Fair	Poor	Good	Fair	Ex.	Fair	Fair	
	9. Bok River Mouth - Beach	Poor	Fair	Poor	Poor	Poor	Poor	Poor	Ex.	Fair	Poor	Poor	Good	Ex.	Poor	Fair	Good	Ex.	Poor	Poor	
	10. General Cargo Quay - TNPA	Ex.	Fair	Ex.	Ex.	Ex.	Ex.	Ex.	Good	Ex.											
Big Bay	11. Seafarm - TNPA	Ex.	Fair	Ex.	Ex.	ND	ND	Ex.	Ex.	Ex.	ND	Ex.	ND	ND	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	
	12. Mykonos - Paradise Beach	Ex.	Fair	Ex.																	
	13. Mykonos - Harbour	Fair	Fair	Ex.	Ex.	Fair	Ex.	Fair	Ex.	Ex.	Good	Fair	Ex.	Ex.							
	14. Leentjiesklip	ND	ND	Good	Fair	Good	Ex.	Fair	Ex.	Good	Ex.	Ex.	Ex.								
Langebaan Lagoon	15. Langebaan North - Leentjiesklip	Ex.	Fair	Good	Ex.	Poor	Good	Ex.	Good	Ex.	Good										
	16. Langebaan - Main Beach	ND	ND	Fair	Ex.	Good	Ex.	Ex.	Ex.	Ex.	Ex.	Fair	Ex.	Ex.							
	17. Langebaan Yacht Club	ND	ND	ND	ND	ND	Poor	Ex.	Good	Ex.	Ex.	Fair	Good								
	18. Tooth Rock	ND	ND	ND	ND	ND	Fair	Ex.	Ex.	Ex.	Ex.	Fair	Ex.								
	19. Kraalbaai North	ND	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.													
	20. Kraalbaai South	ND	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.													

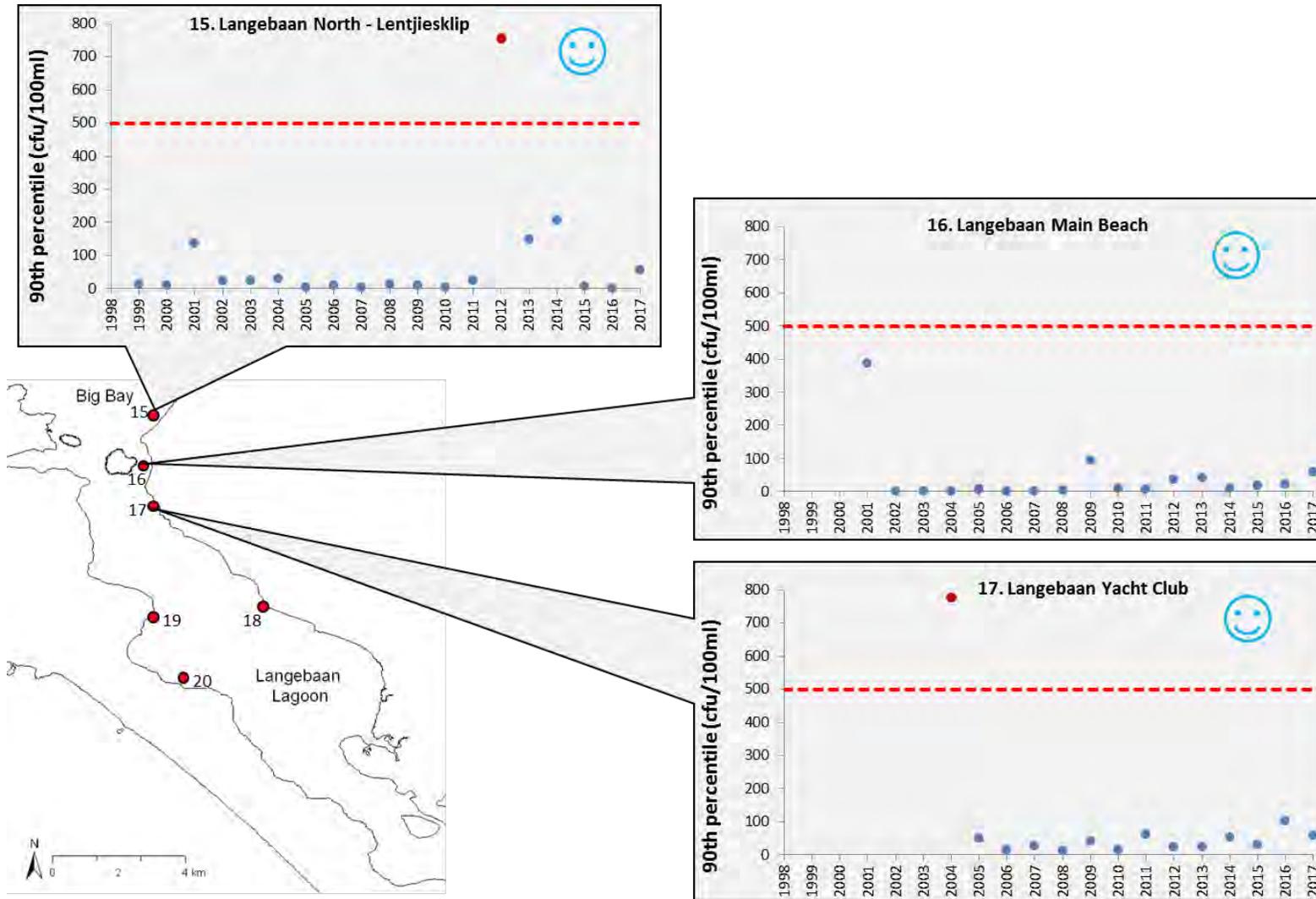


Figure 6.21 Hazen method 90<sup>th</sup> percentile values of *E.coli* counts at three of the six sampling stations within Langebaan Lagoon (Feb 1999 - Dec 2017). The red line indicates the Hazen method 90<sup>th</sup> percentile contact recreation limit of *E.coli* counts (500 colony-forming units/100 ml) above which water quality is ranked as 'Poor/Unacceptable'. Red data points indicate 90<sup>th</sup> percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The faces correspond to changes water quality over time.

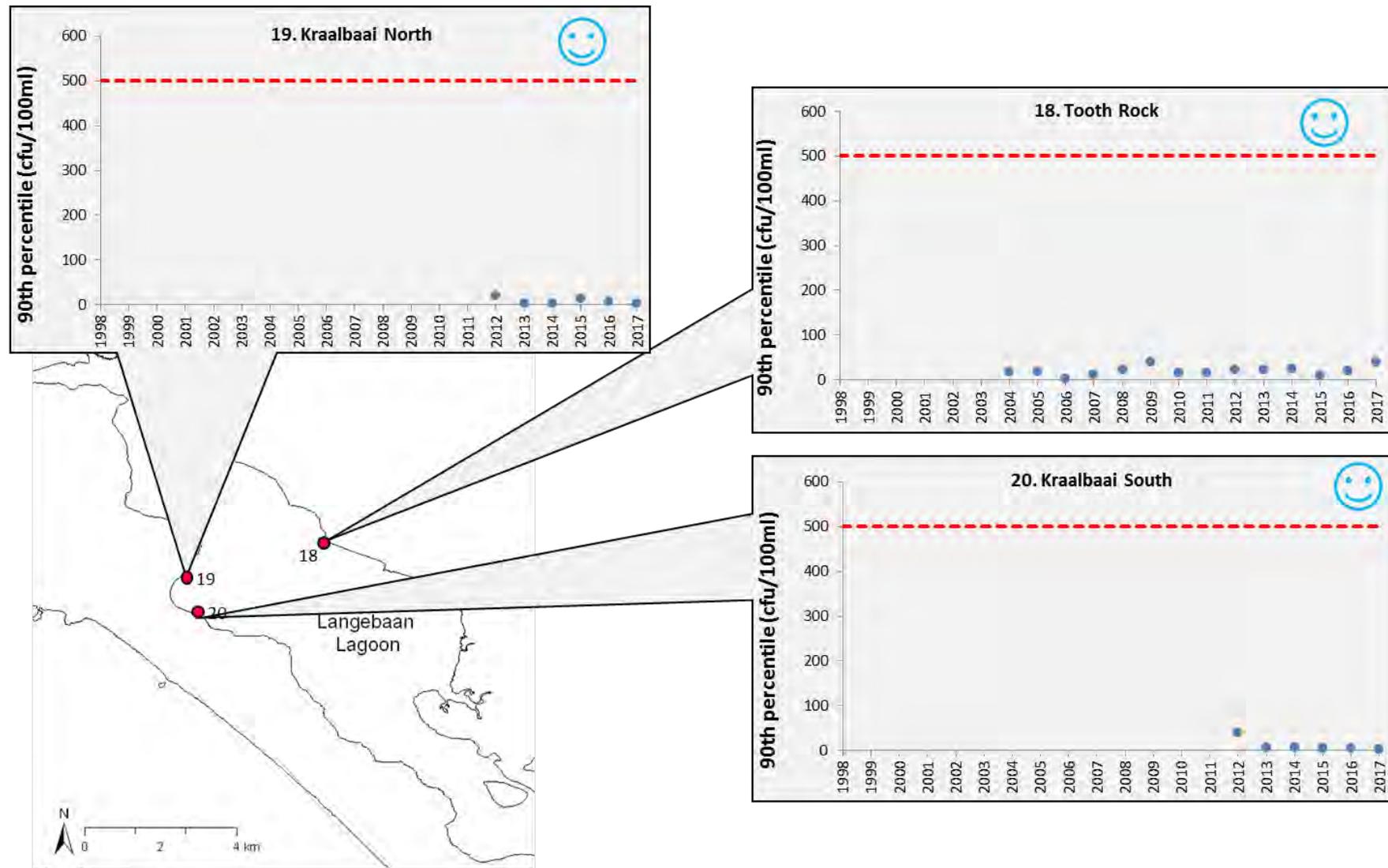


Figure 6.22 Hazen method 90<sup>th</sup> percentile values of *E.coli* counts at three of the six sampling stations within Langebaan Lagoon (Feb 1999 - Dec 2017). The red line indicates the Hazen method 90<sup>th</sup> percentile contact recreation limit of *E.coli* counts (500 colony-forming units/100 ml) above which water quality is ranked as 'Poor/Unacceptable'. The faces correspond to water quality over time.

### 6.9.3 Water quality for mariculture

Guideline limits for mariculture are much more stringent than recreational guideline limits and levels of compliance for mariculture are much lower than for recreational use. Concentrations of microbiological indicators in samples collected from shallow coastal waters close to sources of contamination (storm water drains etc.) were found to be higher than those further away from populated areas. At the start of the monitoring in 1999, nine out of the 10 sites in Small Bay (Sites 1-9) were non-compliant in respect of the 80<sup>th</sup> percentile mariculture guideline limits for faecal coliforms (Figure 6.23, Figure 6.24 and Figure 6.25). There has been some improvement over time, particularly at sites near the entrance to Small Bay (the beach at the Mussel Rafts, the Small Craft Harbour and the Saldanha Bay Yacht Club) as well as in areas elsewhere in Small Bay (the General Cargo Quay, the small quay at Pepper Bay, and the Beach at the Caravan Park) that all met the required standards in 2017. The remaining four sites within Small Bay, however, continue to exceed the mariculture guidelines (i.e. Sea Harvest, Hoedjies Bay Beach, the big quay at Pepper Bay and the Bok River Mouth). The areas of particular concern are Hoedjies Bay 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 6.24 and Figure 6.25).

Although a sustained improvement in levels of compliance with mariculture WQGs has occurred since the 1999-2005 period at most sites (Figure 6.23, Figure 6.24), these data indicate that there remains a serious issue of water quality with respect to mariculture operations within Small Bay, particularly in light of the proposed additional mariculture development in the area. The prevailing poor water quality in the near-shore waters of Small Bay may force sea water abstraction further offshore at an increased cost for land-based mariculture facilities within the Industrial Development Zone (IDZ).

Faecal coliform counts at three of the four sites sampled within Big Bay in 2017 were within the 80<sup>th</sup> percentile limit for mariculture (Figure 6.26). 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 in 2009, 2011 and recently in 2017. It is concerning to see a decrease in water quality at the popular swimming beach site of Mykonos and this should be carefully monitored.

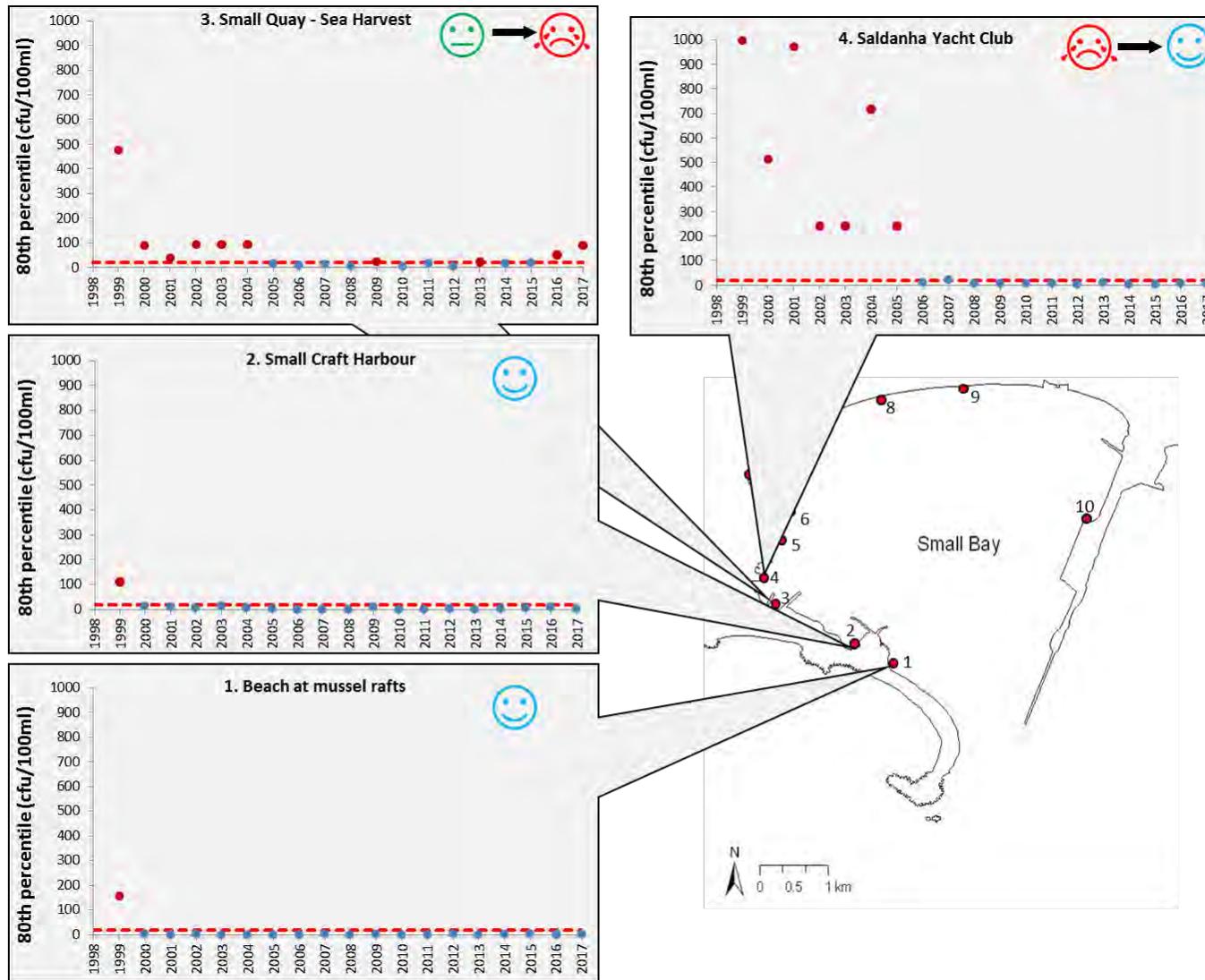


Figure 6.23 80<sup>th</sup> percentile values of faecal coliform counts at four of the 10 sampling stations within Small Bay (Feb 1999 - Dec 2017). The red line indicates the 80<sup>th</sup> percentile mariculture limit of faecal coliforms (20 colony-forming units/100 ml). Red data points indicate 80<sup>th</sup> percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The faces correspond to changes in water quality over time.

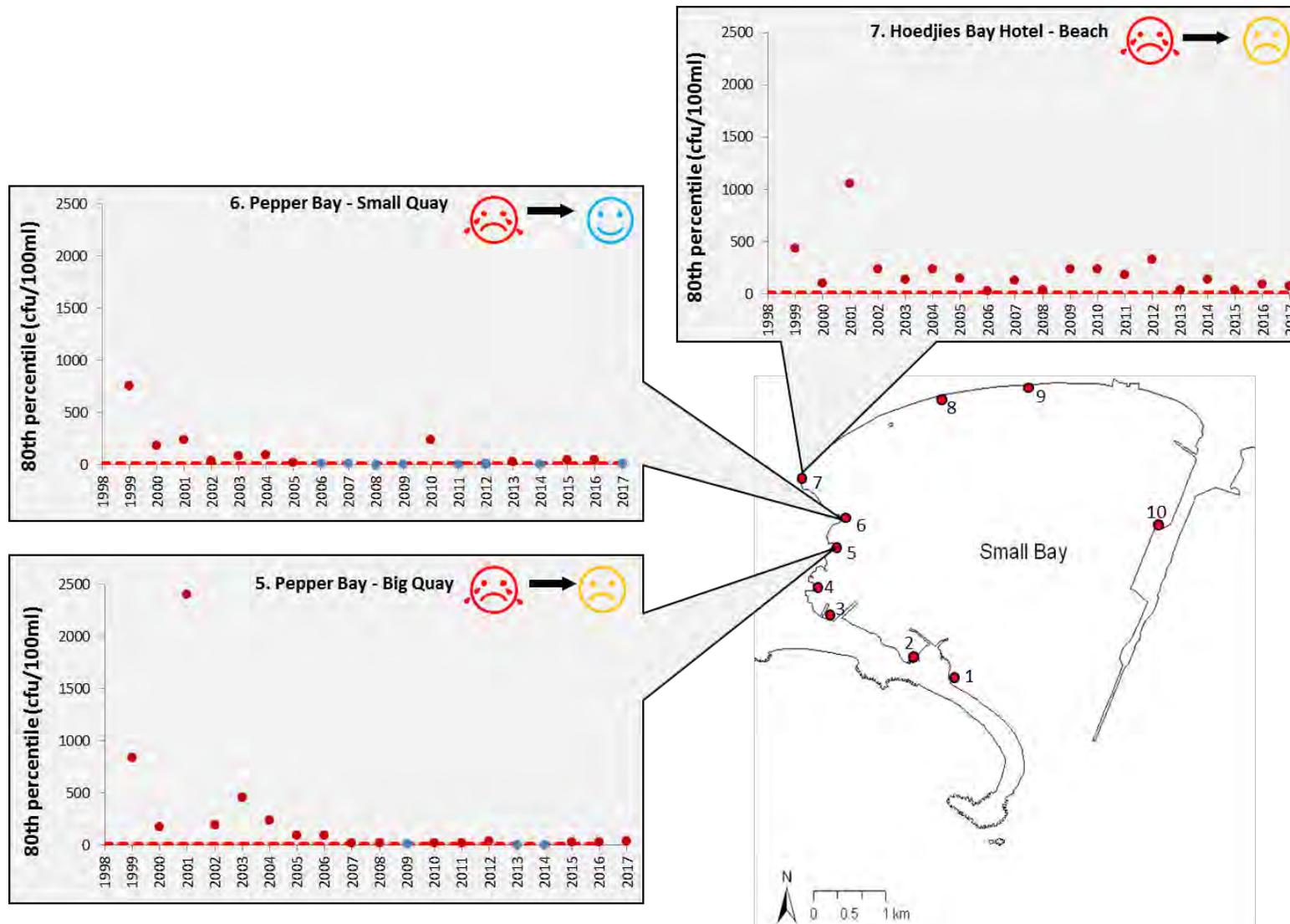


Figure 6.24 80<sup>th</sup> percentile values of faecal coliform counts at three of the 10 sampling stations within Small Bay (Feb 1999 - Dec 2017). The red line indicates the 80<sup>th</sup> percentile mariculture limit of faecal coliforms (20 colony-forming units/100 ml). Red data points indicate 80<sup>th</sup> percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The faces correspond to changes in water quality over time.

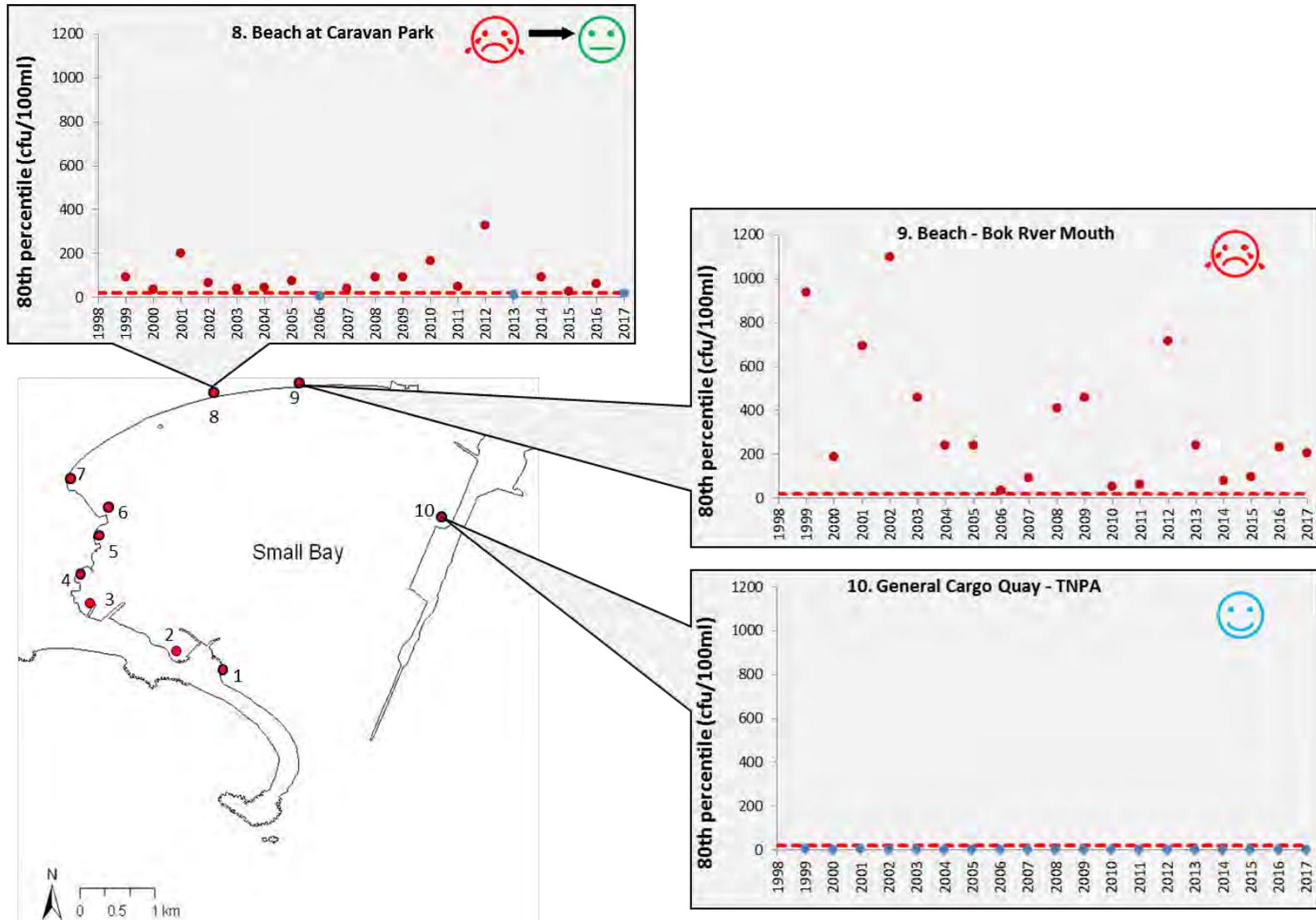


Figure 6.25 80<sup>th</sup> percentile values of faecal coliform counts at three of the 10 sampling stations within Small Bay (Feb 1999 – Dec 2017). The red line indicates the 80<sup>th</sup> percentile mariculture limit of faecal coliforms (20 colony-forming units/100 ml). Red data points indicate 80<sup>th</sup> percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The faces correspond to changes in water quality over time.

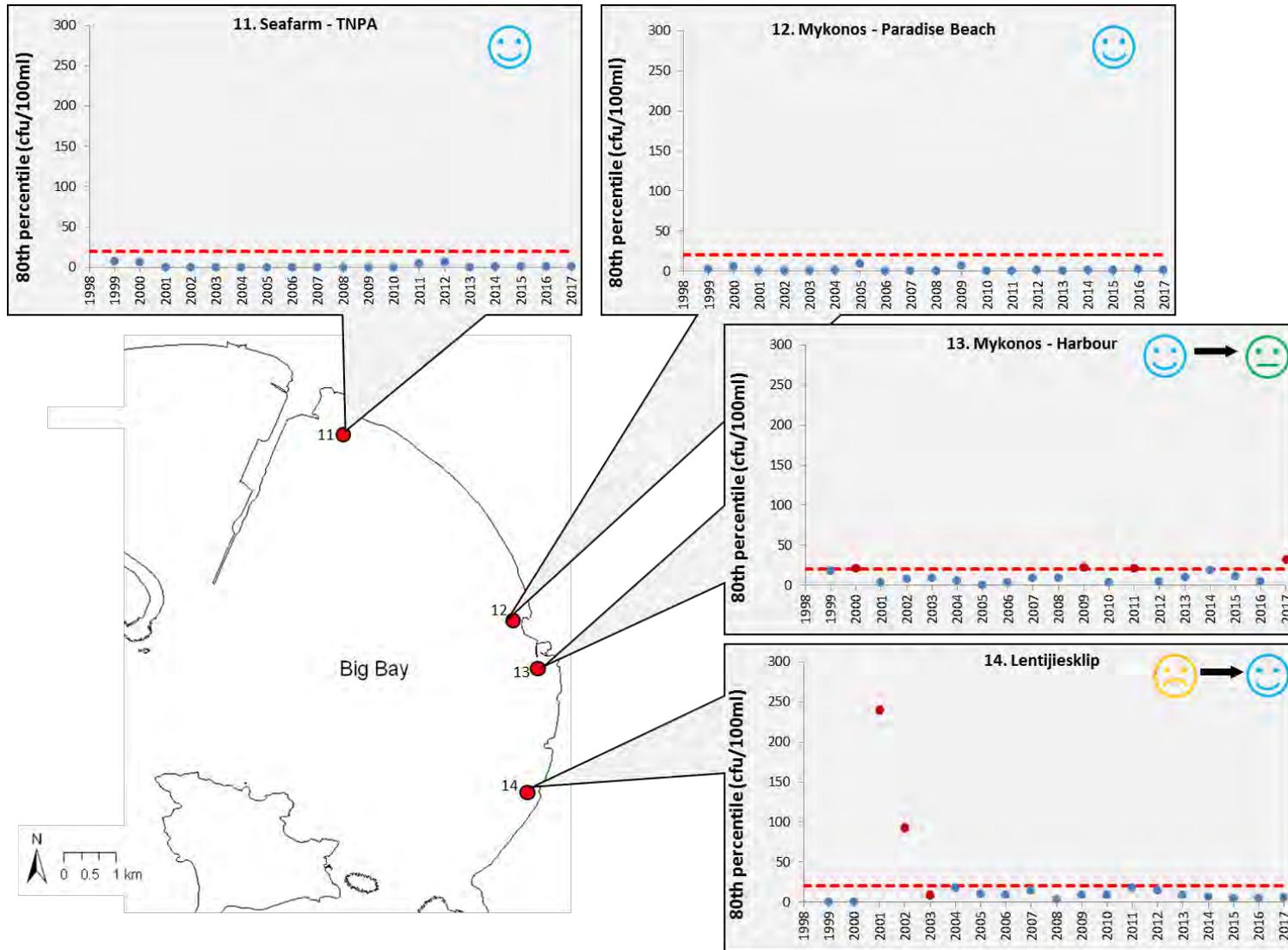


Figure 6.26 80<sup>th</sup> percentile values of faecal coliform counts at the four sampling stations within Big Bay (Feb 1999 - Dec 2017). The red line indicates the 80<sup>th</sup> percentile mariculture limit of faecal coliforms (20 colony-forming units/100 ml). Red data points indicate 80<sup>th</sup> percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The faces correspond to changes in water quality over time.

## 6.10 Heavy 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 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 are affected by both short-term and long-term trends in water quality. Monitoring the contaminant levels in mussels can 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 also 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 have the potential to be toxic to living organisms at elevated concentrations (Rainbow 1995). High 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. High levels of zinc are known to suppress the growth of bivalves at levels between 470 to 860 mg/l and can result in mortality of the mussels (DWAF 1995d).

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). Analysing dissolved metals in water is challenging as concentrations are typically low and difficult to detect, they have high temporal and spatial variability (e.g. with tides, rainfall events etc.) and most importantly they reflect the total metal concentration rather than the portion that is available for uptake by aquatic organisms (Rainbow 1995). Measuring metal concentrations in benthic sediments resolves 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. Analysing 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 detectable 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).

### 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. As the programme was discontinued in 2007, Anchor Environmental Consultants initiated sampling again in 2014 by collecting mussel samples from the same five sites during the annual 'State of the Bay' field survey. The most recent mussel samples were collected in April 2018 and analysed for the metals lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), iron (Fe), manganese (Mn) and mercury (Hg). Data from the Mussel Watch Programme and from the annual 'State of the Bay' field trips are represented in Figure 6.28 to Figure 6.33 below.

In July 2017 DAFF fisheries management branch published the South African live molluscan shellfish monitoring and control programme (DAFF 2017). This document states that "sampling for heavy metals, polychlorinated biphenyls (PCBs) and pesticides should be conducted annually, while tests for radionuclides should be conducted every three years or more frequently if there is reason to suspect contamination. Sampling for specific contaminants is recommended only when the sanitary survey reveals a potential problem, or if there is concern due to a paucity of data." Sampling remains the responsibility of aquaculture facilities (see Section 6.10.2).

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. All limits refer to concentrations of contaminants analysed relative to the wet weight of the flesh of the organism. Where limits have not been specified in national legislation, those adopted by other countries have been used (Table 6.5). Regulation No. 588 was updated on 15 June 2018 (Government Gazette No. 41704) to reduce the acceptable concentration of cadmium in marine bivalve molluscs from 3 to 2 mg/l or ppm. As concentrations of lead and arsenic in marine mollusc flesh were not mentioned, the 2004 regulations were applied for these metals.

**Table 6.5 Regulations relating to maximum levels for metals in molluscs (wet weight) in different countries.**

Country	Cu (ppm)	Pb (ppm)	Zn (ppm)	As (ppm)	Cd (ppm)	Hg (ppm)
South Africa <sup>1</sup>		0.5		3.0	2.0 <sup>11</sup>	0.5
Canada <sup>2</sup>	70.0	2.5	150.0	1.0	2.0	
Australia & NZ <sup>3</sup>		2.0			2.0	0.5
European Union <sup>4</sup>		1.5			1.0	0.5
Japan <sup>5</sup>		10.0			2.0	0.2
Switzerland <sup>2</sup>		1.0			0.6	0.5
Russia <sup>6</sup>		10.0			2.0	
South Korea <sup>2</sup>		0.3				
USA <sup>7,8</sup>		1.7			4.0	
China <sup>9</sup>					2.0	
Brazil <sup>10</sup>						0.5
Israel <sup>10</sup>						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.
11. Regulation No. 588 on 15 June 2018 (Government Gazette No. 41704) published under the Foodstuffs, Cosmetics and Disinfectants Act, 1972 (Act 54 of 1972)

Trace metal levels in bivalves in the 2018 edition of the 'State of the Bay' are relative to wet weights of bivalve tissue. Lead concentrations were found to exceed the regulatory limit for foodstuffs of 0.5 ppm at Portnet, Saldanha Bay North and the Fish Factory site in 2018 (Figure 6.28). Concentrations spiked to high levels in May 1999 (56 ppm) and October 2001 (159 ppm) at the Portnet site (situated on the Small Bay side of the base of the iron ore terminal), although values seem to have decreased somewhat over time since 2016. 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 2 ppm at the other sites, although values spiked to 55 ppm and 9 ppm at the Mussel Raft in 2000 and 2006, respectively. Although concentrations dropped to an average of 0.3 ppm over all the sites in 2014, they increased to around 1.7 ppm in 2015 and dropped again to an average of 0.9 in 2017. While the current situation is greatly improved relative to 2007, the average level of lead in mussels at the Portnet and Fish Factory sites was almost twice the level considered safe for human consumption, and five times the limit at Saldanha Bay North. This is extremely concerning considering that mussels farmed within Small Bay are sold for human consumption and may have toxic effects on their consumers.

Over the years, average cadmium levels in mussels ranged between 0.9 and 1.6 ppm, with a maximum value of 10.9 ppm in April 2007 at the Mussel Raft. In 2018 an average of 1.3 ppm was recorded, up from 1.1 ppm in the previous year. In 2018 a concentration of 3.7 ppm was measured at the mussel rafts, which is high relative to the safe limit of 2 ppm. All other sites fell below the limit (Figure 6.29). Average zinc concentrations recorded in 2018 were much lower than the 150 ppm regulatory limit listed by the Canadian Authorities (Table 6.5) - this metal only rose above the limit once (165 ppm in 2016, Figure 6.30). Maximum values in 2018 were measured at the Fish Factory (52 ppm), followed by Saldanha Bay North (34 ppm). Concentrations of copper remained well below the specified level of 70 ppm at all sites over the entire sampling period. The maximum value recorded in 2018 was 2.4 ppm at the Fish Factory. Mercury concentrations within mussel tissues were measured for the first time in 2016. To date, values have not exceeded the safe limit of 0.5 ppm (Figure 6.27).

No regulatory limits exist for manganese in mollusc flesh as elevated levels have not been shown to have an adverse effect on marine life. Manganese is an important micronutrient in the oceans and there is evidence that manganese deficiency may limit phytoplankton productivity in some oceanic upwelling systems (Sunda 1989, Brand *et al.* 1983). In 2018, concentrations were highest at the Portnet site (2.6 ppm), which is on a par with the concentration of 2.5 ppm recorded at this site in 2016 (Figure 6.32). Manganese export volume has been steadily increasing from 95 000 tonnes in 2013/2014 to just over 4.5 million tonnes in 2017/2018 (see Chapter 3), and manganese concentrations in mussel tissue appears to have matched that trend at the Portnet site. Although the manganese loading terminal is midway between the General Purpose Quay at the base of the iron ore jetty and the iron ore terminal, currents and onshore winds will cause manganese dust to move towards the base of the jetty and accumulate in this area. If this trend is seen to continue, measures should be put in place to prevent excessive amounts of manganese dust from entering the Bay.

In 2018 iron concentrations in mussel tissue had increased from 2017 values at three sites and decreased at two sites (Figure 6.33). Iron concentrations were highest at the Fish Factory site (58 ppm) and lowest at the Mussel Raft site (16 ppm). 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 but no cases of acute toxicity from regular foodstuffs (excluding supplements) has 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 dramatic increases over time.

The high level of lead in bivalve flesh remains a human health concern in Small Bay. Signboards 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).

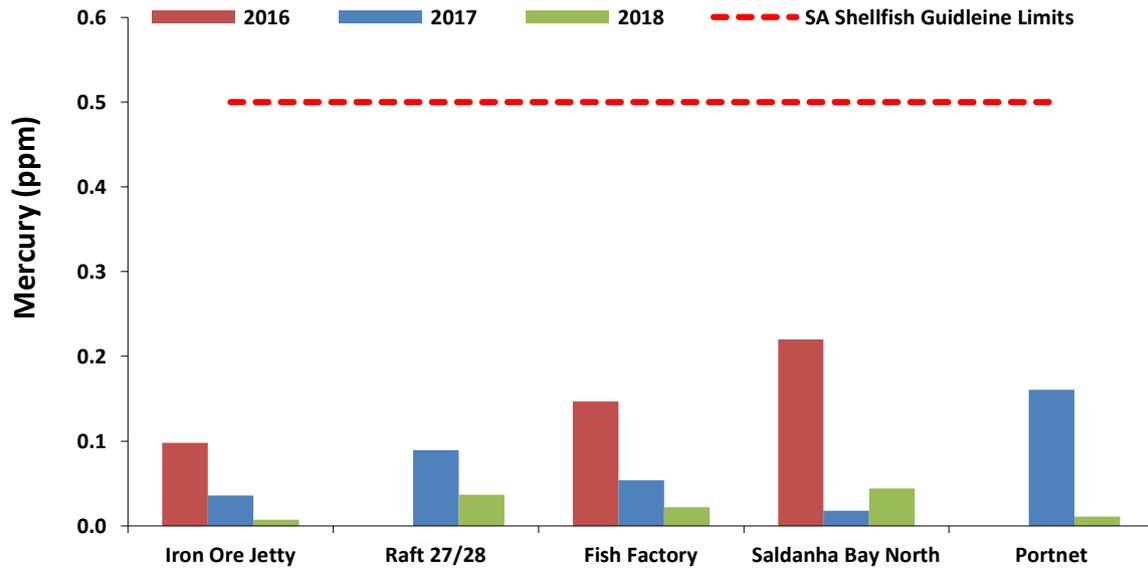


Figure 6.27 Mercury concentrations in wet mussel flesh collected by Anchor from five sites in Saldanha Bay in autumn 2016 to 2018. The recommended maximum limit for mercury in seafood (0.5 ppm) is shown as a dotted red line.

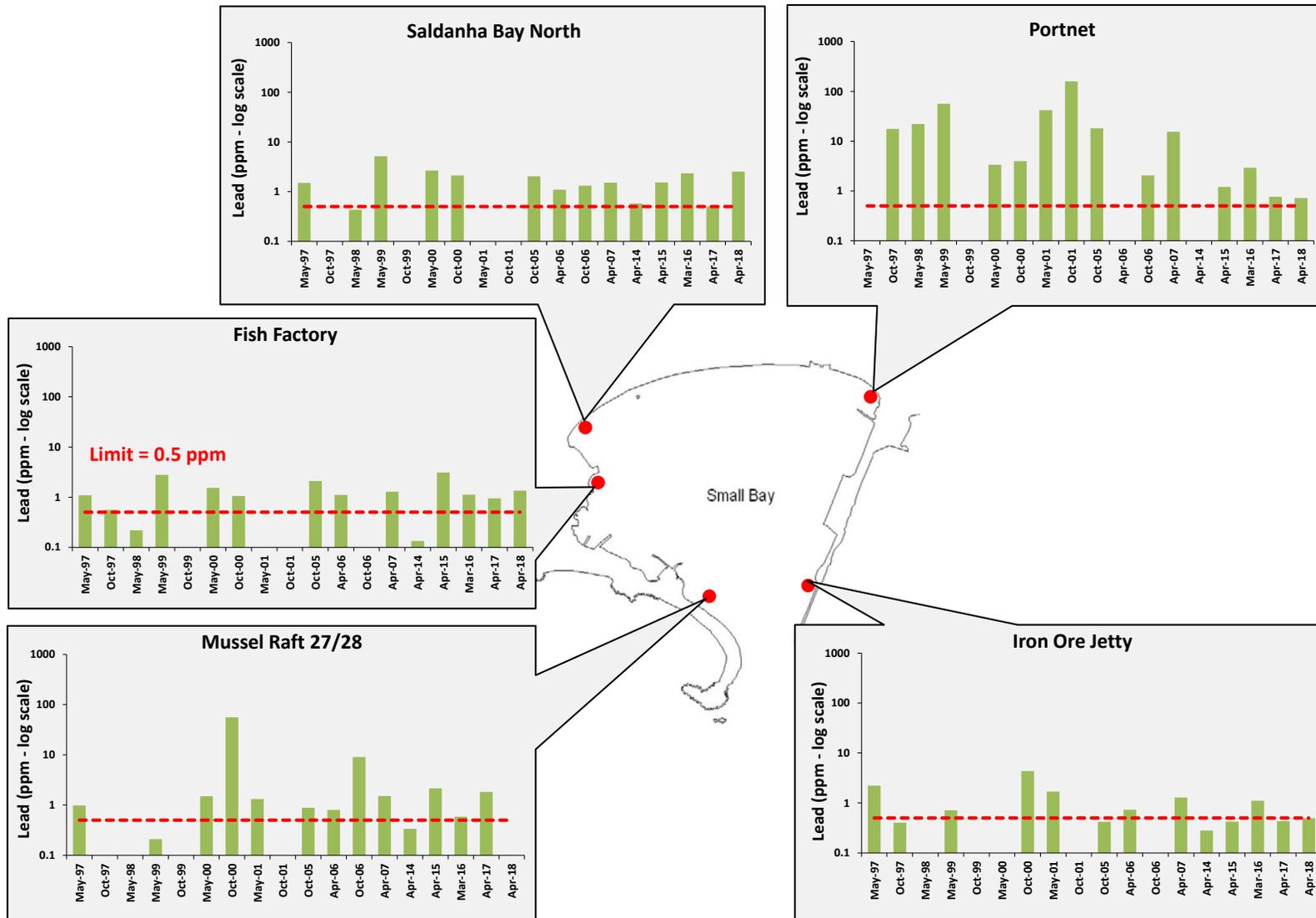


Figure 6.28 Lead concentrations in mussels (wet weight) collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (Source: G. Kiviets, Department of Environmental Affairs) and by Anchor from 2014 to 2018. The recommended maximum limit for lead in seafood (0.5 ppm) is shown as a dotted red line. Note that data are plotted on a log scale.

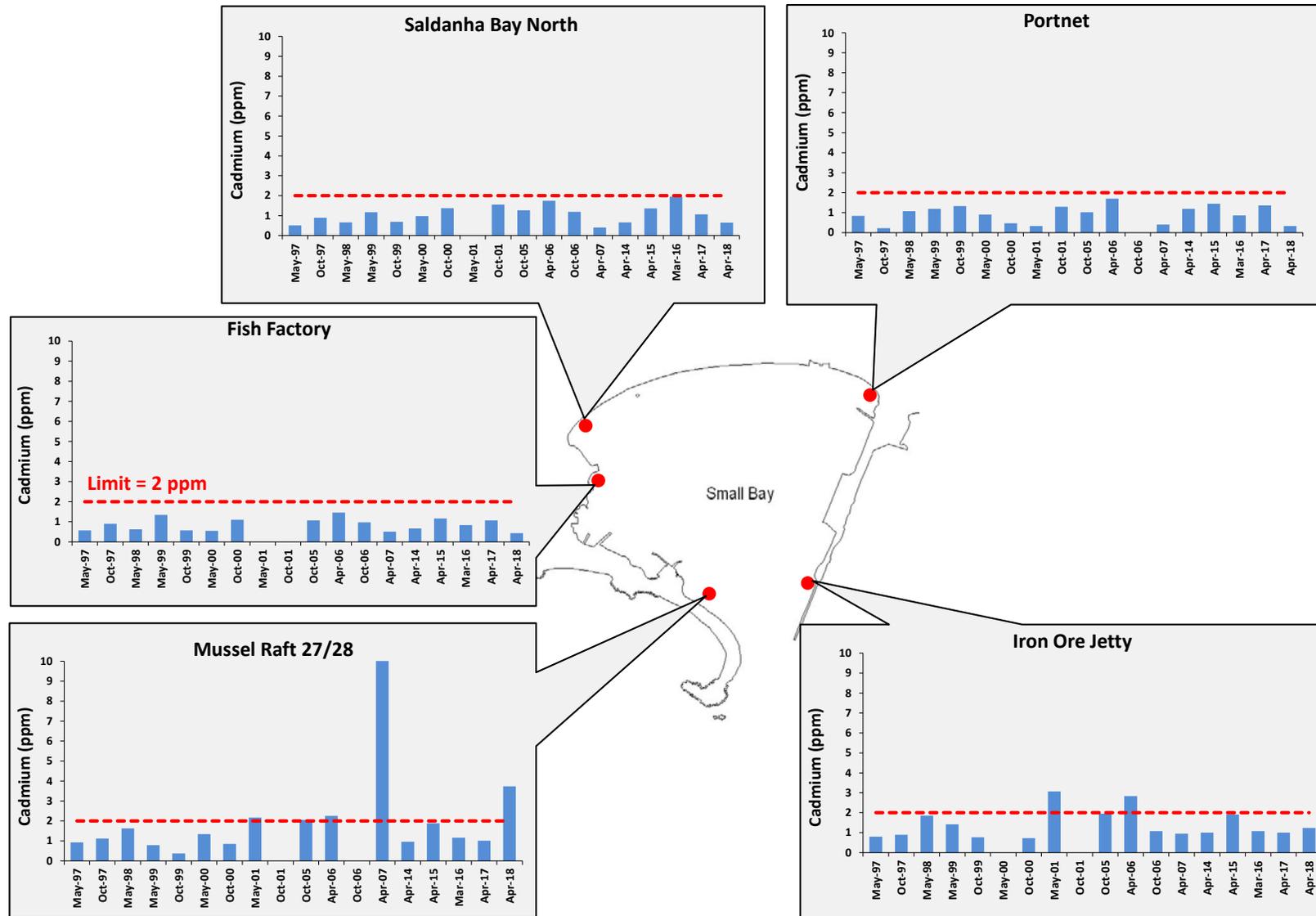


Figure 6.29 Cadmium concentrations in mussels (wet weight) collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (Source: G. Kiviets, DEA) and by Anchor from 2014 to 2018. The recommended maximum limit for cadmium in seafood was reduced to 2 ppm (dotted red line) in 2018.

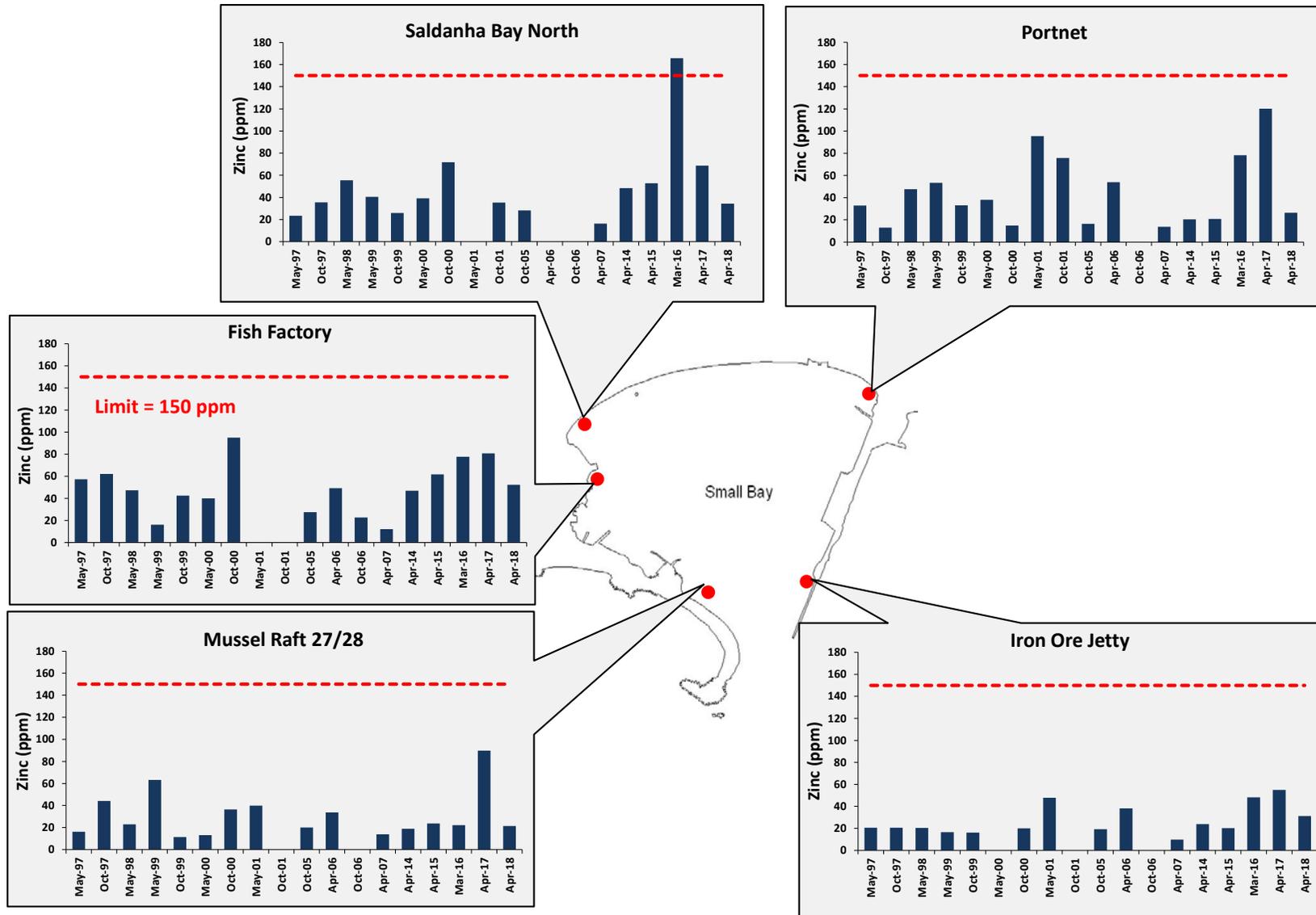


Figure 6.30 Zinc concentrations in mussels (wet weight) collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (source: G. Kiviets, Department of Environmental Affairs) and by Anchor from 2014 to 2018. The recommended maximum limit for zinc in seafood (150 ppm) is shown as a dotted red line.

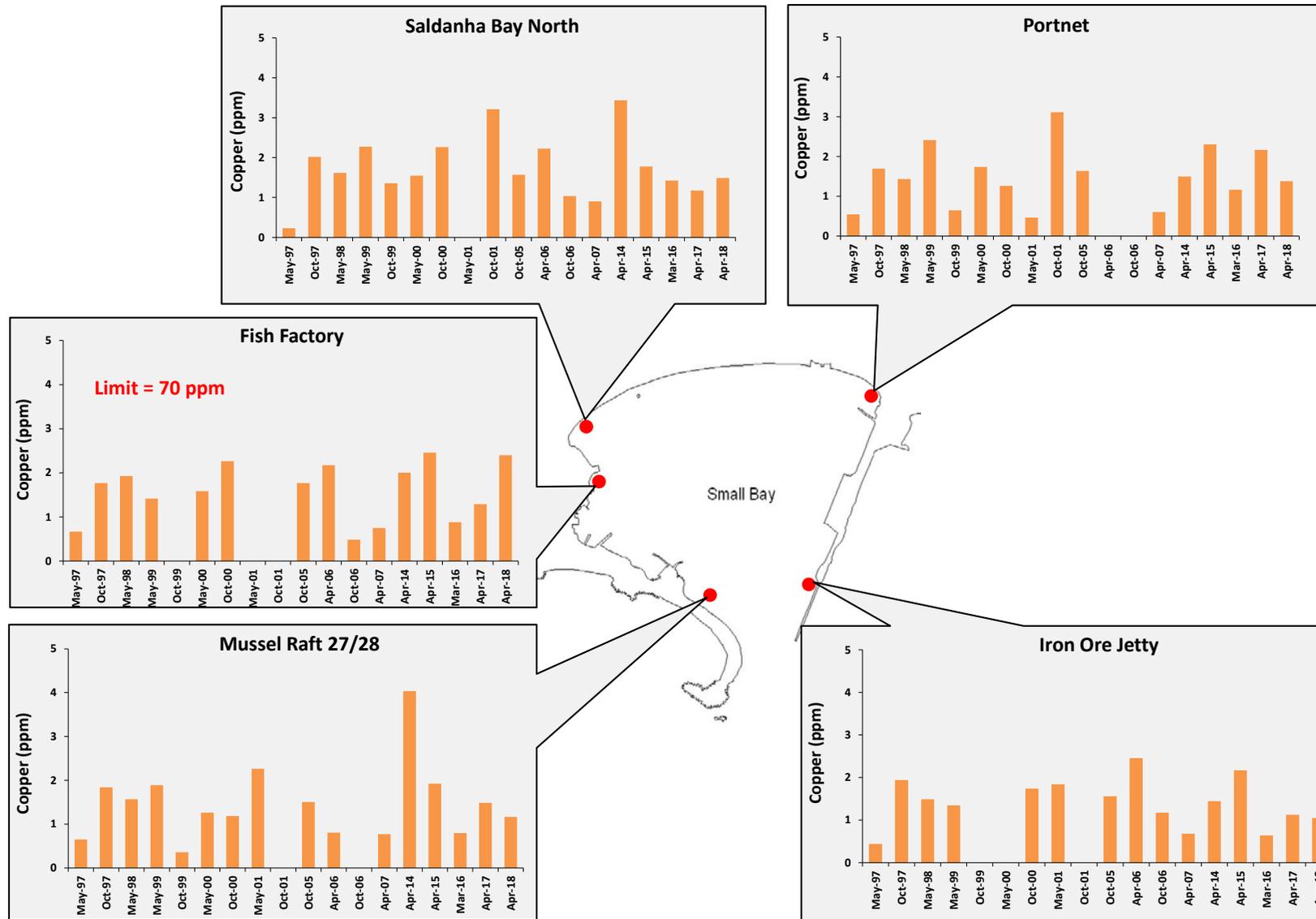


Figure 6.31 Copper concentrations in mussels (wet weight) collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (Source: G. Kiviets, Department of Environmental Affairs) and by Anchor from 2014 to 2018. The recommended maximum limit for copper in seafood is 70 ppm (not indicated on graphs).

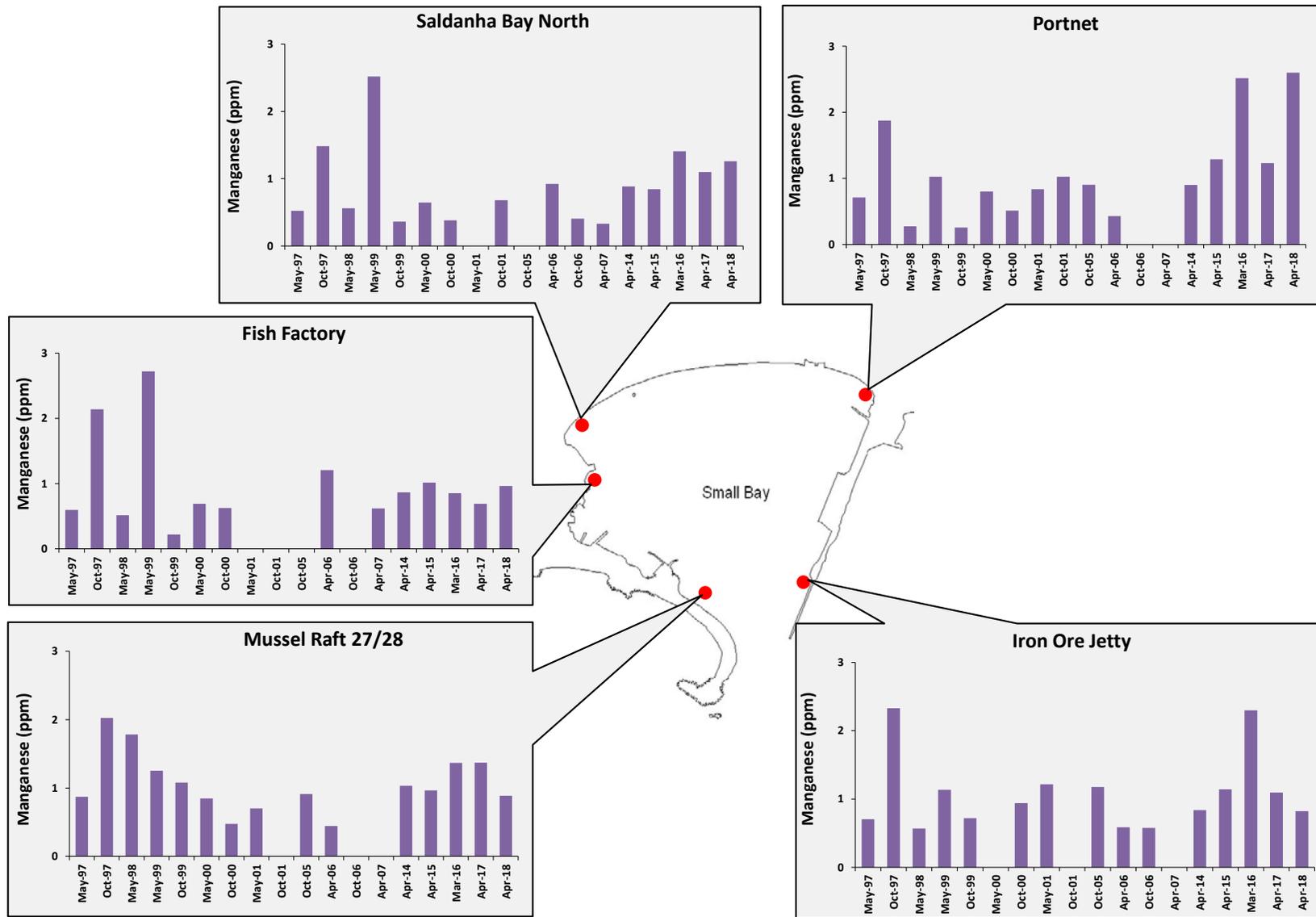


Figure 6.32 Manganese concentrations in mussels (wet weight) collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (Source: G. Kiviets, Department of Environmental Affairs) and by Anchor from 2014 to 2018. No limits are specified for manganese in seafood.

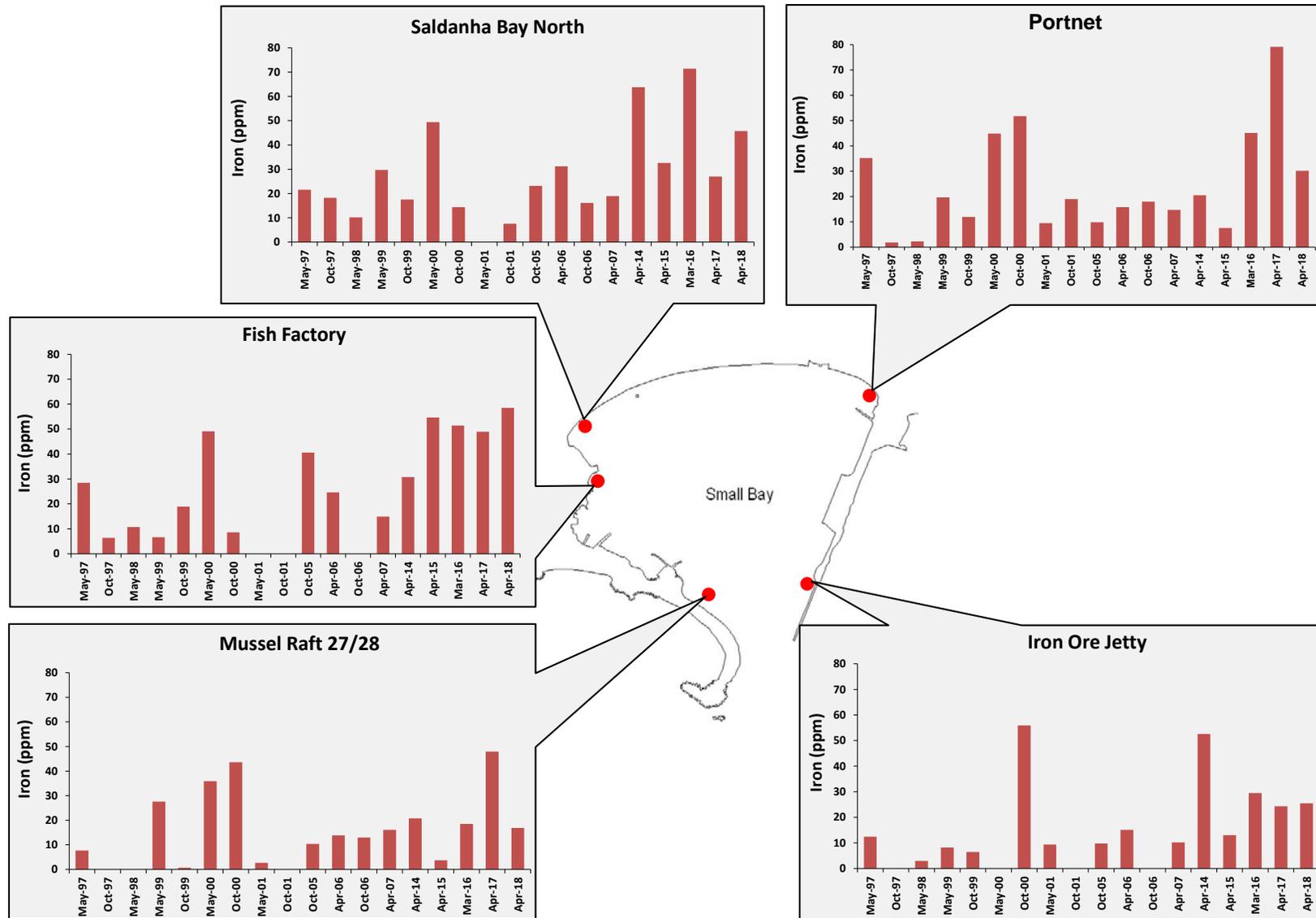


Figure 6.33 Iron concentrations in mussels (wet weight) collected from five sites in Saldanha Bay from 1997-2007 as part of the Mussel Watch Programme (Source: G. Kiviets, Department of Environmental Affairs) and by Anchor from 2014 to 2018. No limits are specified for iron in seafood.

## 6.10.2 Mariculture bivalve monitoring

A combined 430 ha of sea space are currently available for aquaculture production in Saldanha Bay, of which 316.5 ha have been leased to 14 individual mariculture operators for mussels, oysters, finfish and algae (see Chapter 3 for the layout of concession areas). Proposed expansion of the Aquaculture Development Zone (ADZ) includes an additional 1 404 ha of concessions in Outer Bay and Big Bay combined. Rights holders engaged in bivalve culture of mussels and oysters in South Africa are required to report on trace metal concentrations and bacterial indicators in harvested organisms on an annual basis. Data were obtained for four trace metal indicators (lead, cadmium, mercury and arsenic) from aquaculture farms in Saldanha Bay. Figure 6.34 shows data for mussels from 2009 to 2018 and Figure 6.36 shows data for oysters from 2005 to 2018. Data from the Mussel Watch Programme were added to the graphs as were data obtained from research conducted by Jacques Bezuidenhout (Bezuidenhout *et al.* 2015, Pavlov *et al.* 2015). Data were also included from an oyster monitoring programme initiated by Transnet Port Terminals (TPT) in Saldanha in June 2018. Gaps in the data exist depending on the frequency of monitoring and the year each company was founded.

### 6.10.2.1 Mussels farmed in Small Bay

Bezuidenhout *et al.* (2015) sampled the flesh of mussels in Saldanha Bay and Langebaan Lagoon on six occasions between March 2014 and March 2015. Distinct seasonal patterns were observed, with mussels accumulating higher metal concentrations in winter than in summer. Wild mussels demonstrated higher concentrations of arsenic, cadmium, iron, mercury and zinc than those that were farmed. Iron was most prevalent in soft mussel tissue, followed by zinc. Concentrations of magnesium and lead were especially high close to the iron ore jetty where ores are loaded onto vessels in the Port (Bezuidenhout *et al.* 2015, Pavlov *et al.* 2015).

Prior to 2000, concentrations of lead were generally above the regulatory limit with especially high levels in 1988 at Blue Bay Aquafarm (renamed Blue Ocean Mussels), West Coast Oyster Growers and Striker Fishing at 5.3 ppm, 14.1 ppm and 3.9 ppm respectively (Anchor 2016). From 2000 onwards, lead concentrations were mostly within the regulatory limit (i.e. less than 0.5 ppm); although mussels from West Coast Aquaculture and West Coast Oyster Growers exceeded this limit on numerous occasions. Exceedance was observed at West Coast Aquaculture in 2010, 2011, 2014 and 2015 with a maximum value of 0.99 ppm, and at West Coast Oyster Growers in 2014 and 2015 with a maximum value of 1.71 ppm (Figure 6.34). Although high, these values were still lower than the concentration of 2.52 ppm measured in nearshore mussel samples from Saldanha Bay North in 2018 (see Section 6.10.1, Figure 6.28).

Data received from mussel farms showed that cadmium concentrations only exceeded the prescribed limit of 2 ppm on three occasions, once at Blue Ocean Mussels in 2015, and twice at South Atlantic Sea Farms in 2018 (Figure 6.34), while data from mussels collected off Mussel Raft 27/28 by DAFF and Anchor showed that values exceeded this limit over successive years (Figure 6.34). This is confirmed by analyses run on mussels collected in 2014 and 2015 by Bezuidenhout *et al.* (2015). Reasons for this discrepancy are still to be determined.

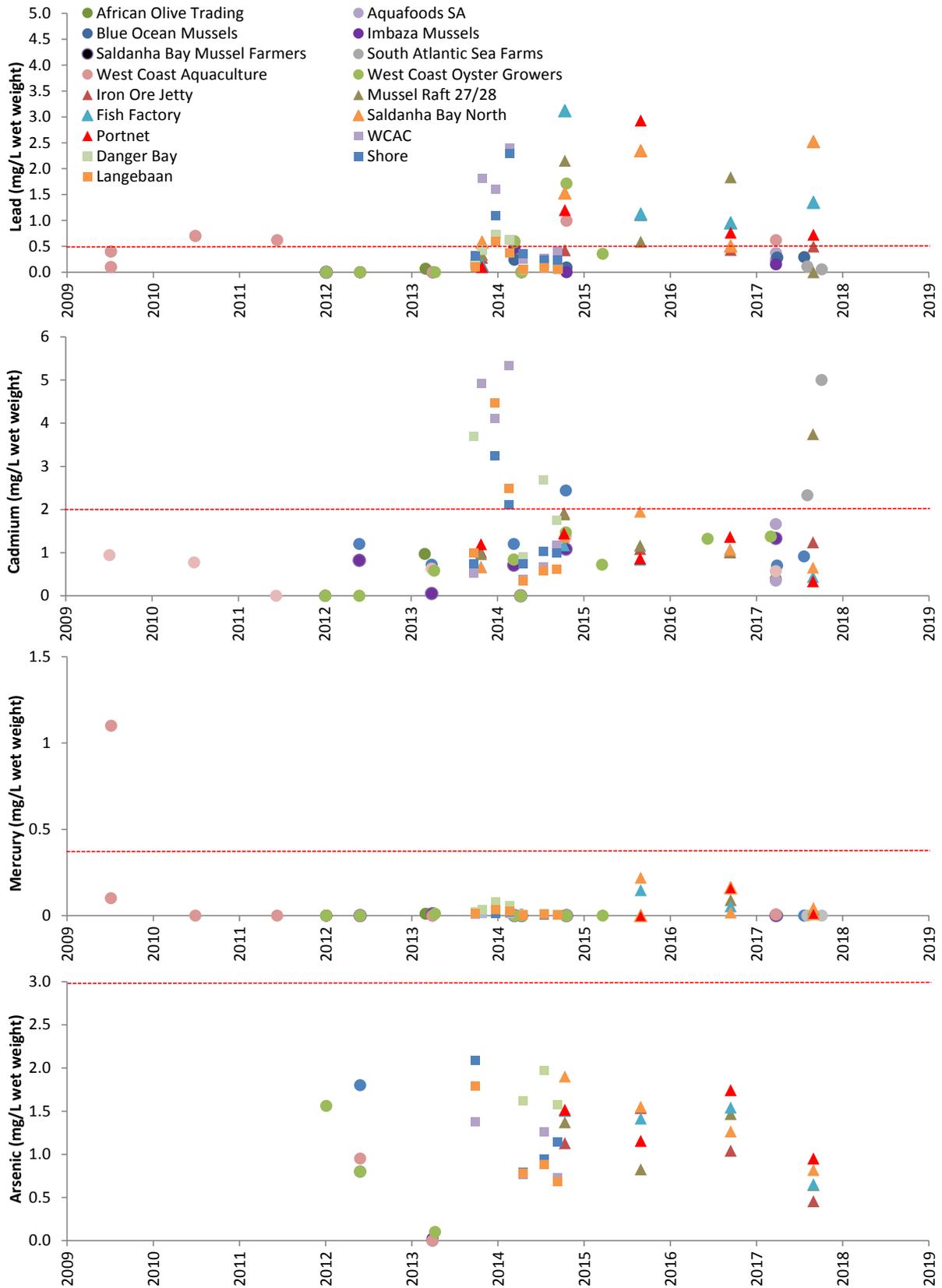


Figure 6.34 Trace metal concentrations (wet weight) in mussel tissue provided by aquaculture facilities, researchers (Bezuidenhout *et al.* 2015), and the Mussel Watch Programme (indicated by circles, squares and triangles respectively).

Mercury concentrations submitted to DAFF have largely been within the regulatory limit of less than 0.5 ppm, apart from one or two spikes above this level. These readings were recorded at Blue Ocean Mussels in 1994 and West Coast Aquaculture in 2009 (1.7 ppm and 1.1 ppm respectively). Since 2009, no exceedance has been recorded and all samples collected contained less than 0.02 ppm of mercury (Figure 6.34). Mussel samples were analysed for arsenic for the first time in 2012. Scant data exist for 2012 and 2013 and arsenic was dropped from the suite of aquaculture farm measurements in September 2013. All of the aquaculture farms assessed met the regulatory requirements (< 3 ppm) over this period, however, roughly 50% of the sites sampled for research on trace metal uptake exceeded the limit (Bezuidenhout *et al.* 2015).

Overall, data from the mussel farms discussed above suggest that trace metal contamination in the deeper parts of Saldanha Bay, where the aquaculture farms are located, is lower than in the nearshore coastal waters. Mussels are filter feeders which extract particulate matter out of the water column for food, thus, it is expected that organisms filtering clean water adjected into the Bay from offshore will accumulate fewer toxins than mussels filtering contaminated water close to the shore. The reasons for the lower concentrations of trace metals in farmed mussels compared with those on the shore may also be linked to higher growth rates experienced by the farmed mussels due to the availability of phytoplankton washing into the Bay, resulting in less time for the accumulation of toxins within the mussel tissue.

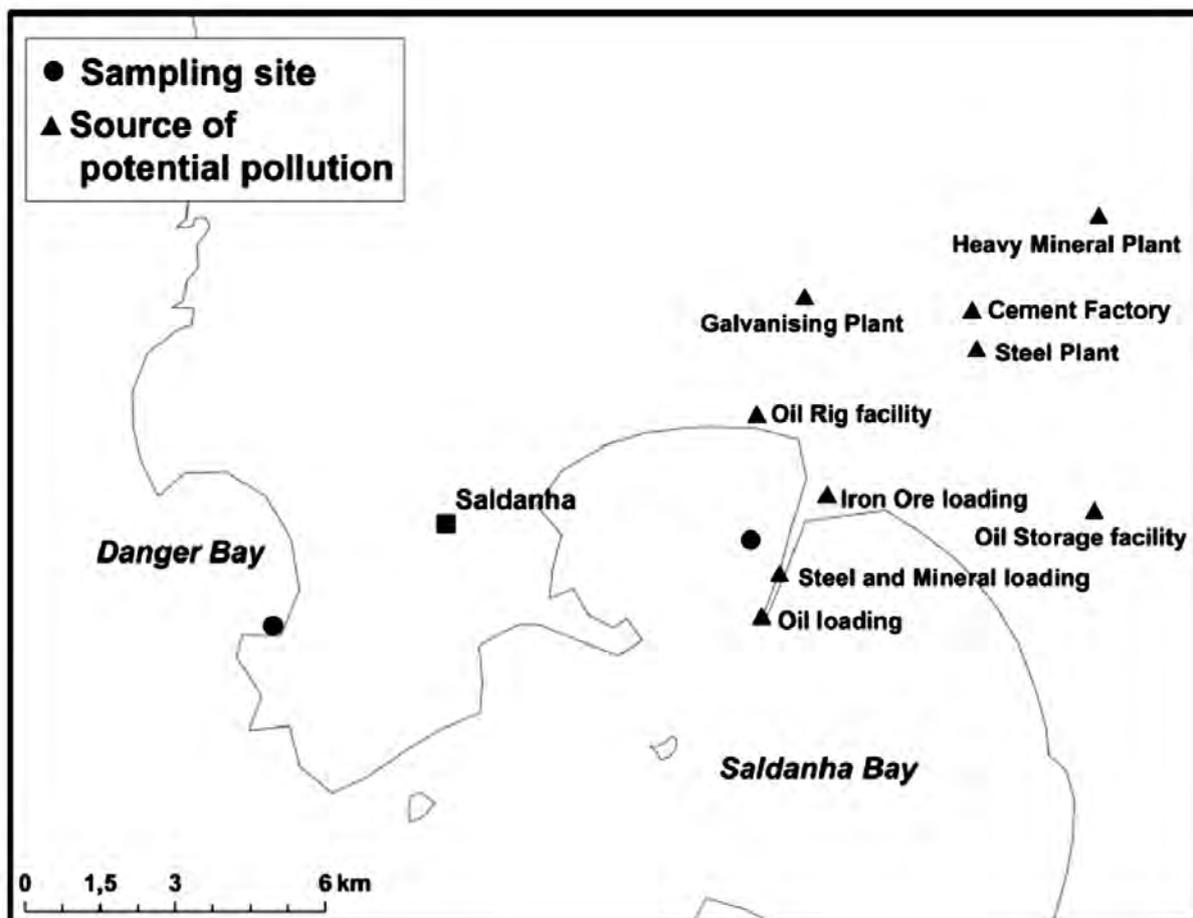


Figure 6.35 Potential sources of pollution around Saldanha Bay (Source: Bezuidenhout *et al.* 2015).

### 6.10.2.2 Oysters farmed in Small Bay

All oyster mariculture is currently situated in Big Bay and at the Marcus Island causeway (see Chapter 3). A regulatory limit of 0.5 ppm for lead applies to shellfish for human consumption and the two samples analysed in 1988 from Saldanha Bay Oyster Company and West Coast Oyster Growers were well above this concentration. Sampling in 2006 revealed that lead concentrations in oysters had decreased to almost zero; although these values rose above recommended levels in 2007 (Figure 6.36). Over recent years exceedance was observed at Blue Ocean Mussels (2010), West Coast Aquaculture (2014 & 2015) and frequently at West Coast Oyster Growers (2007, 2014 & 2015). Maximum lead concentration over this period was recorded at West Coast Oyster Growers with a value of 1.78 ppm. All samples collected as part of the Anchor Oyster Monitoring Programme were found to be below the limit.

Until 2011 concentrations of cadmium had not exceeded the regulatory limit of 2 ppm, but in November 2015 the maximum value of 6.44 ppm was recorded at West Coast Oyster Growers. The three other farms that submitted cadmium data at the time were unaffected and met target values. Subsequently, all values have fallen below the required concentration. Mercury concentrations have largely been within the regulatory limit of less than 0.5 ppm, apart from two spikes above this level. These readings were recorded at Blue Ocean Mussels in 2011 and the Saldanha Bay Oyster Company in 2007 (1.0 ppm and 1.1 ppm respectively). Since 2011, no exceedance has been recorded and all samples collected contained less than 0.05 ppm of mercury (Figure 6.36).

Samples were analysed for arsenic for the first time in 2012 but this metal was dropped from the suite of aquaculture farm measurements in 2014. Two out of the five aquaculture farms assessed met the regulatory requirements (< 3 ppm) between 2012 and 2013. During this time, both Saldanha Bay Mussel Farmers and Saldanha Bay Oyster Company exceeded the regulatory limit with concentrations of 10 ppm and 3.5 ppm respectively. Based on these data, it is recommended that the annual analysis of arsenic in the tissue of bivalves at all aquaculture farms within Saldanha Bay be reinstated.

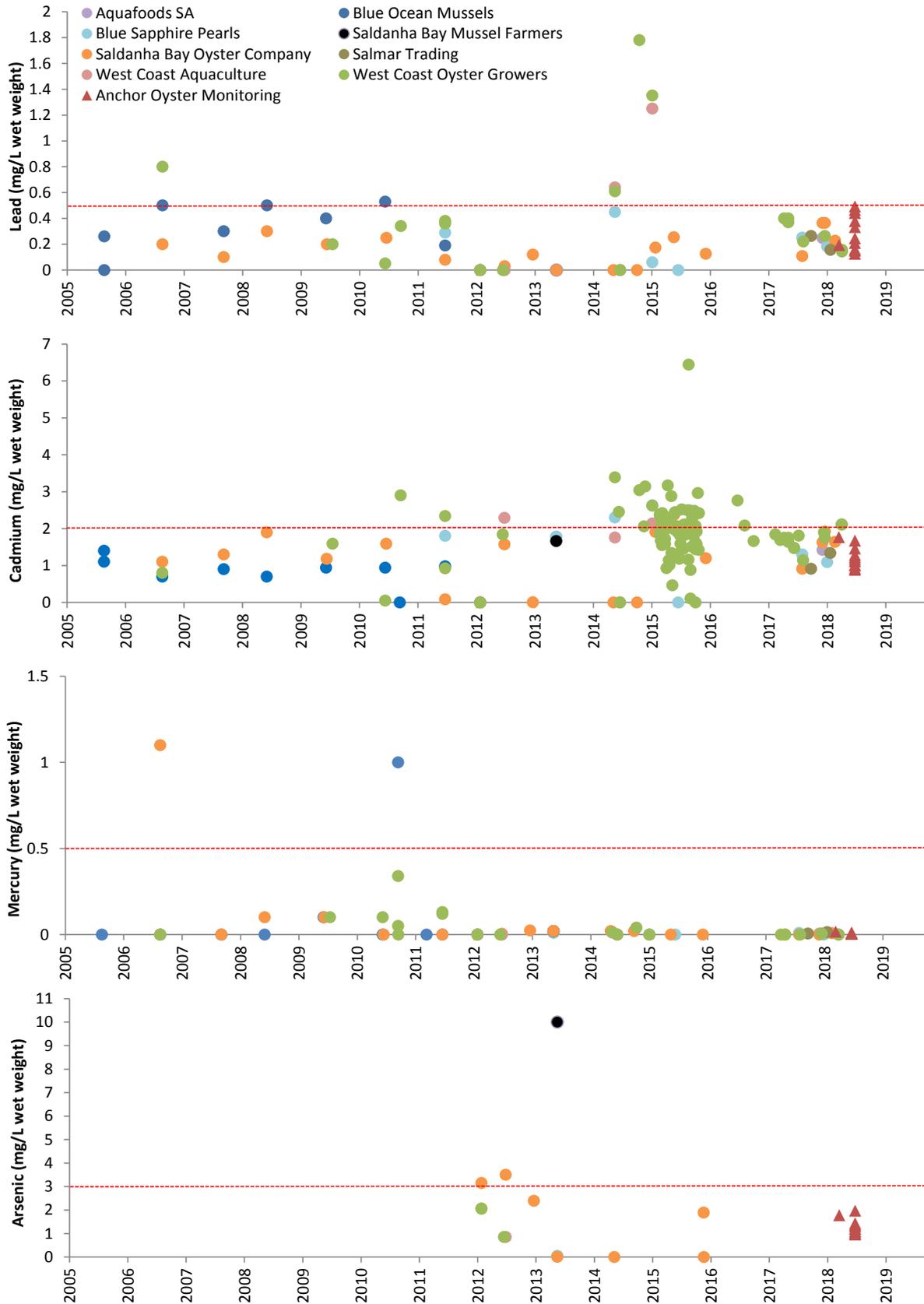


Figure 6.36 Trace metal concentrations (wet weight) in oyster tissue provided by aquaculture facilities and the Anchor Oyster Monitoring Programme (indicated by circles and triangles respectively).

## 6.11 Summary of water quality in Saldanha Bay and Langebaan Lagoon

There are no clear long term trends evident in the water temperature, salinity and dissolved oxygen data series that solely indicate anthropogenic causes. In the absence of actual discharges 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 with a slight decline from 2016 to 2017. In 2017, the last calendar year analysed, 14 of the 20 monitoring stations in the Bay are rated as having 'Excellent' water quality, two sites (Langebaan North and Langebaan Yacht Club) are rated as 'Good', while three are rated as 'Fair' and one "Poor" (Bok River Mouth). It is 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 80<sup>th</sup> 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), data collected as part of the State of the Bay Monitoring Programme, and recent research suggests that concentrations of trace metals are slightly elevated along the shore (particularly for lead at the Portnet site) and are frequently above published guidelines for foodstuffs for this heavy metal. In comparison, data collected by mariculture operators in Saldanha Bay show that concentrations offshore are slightly lower; although concentrations of lead and cadmium have recently risen above the limit for foodstuff which is concerning. Exceedance of these limits for trace metals 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. Aquaculture facilities must also ensure that laboratory testing limits are sensitive enough to provide informative results and care must be taken not to record false zeros.

## 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 these areas. 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 ( $n = \sim 500$ ) 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).

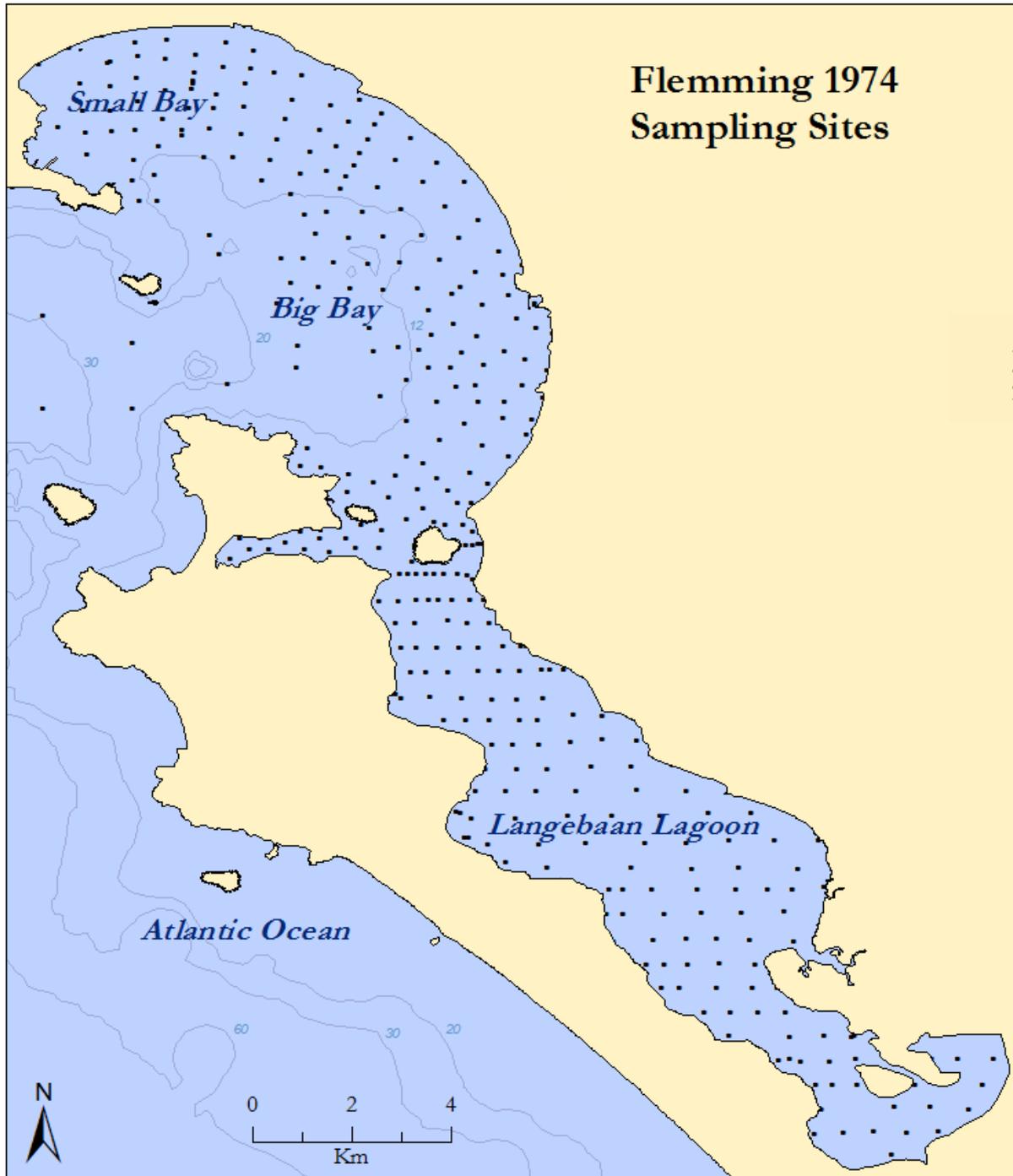


Figure 7.1 Stations sampled by Flemming (1977b) in Saldanha Bay and Langebaan Lagoon in 1974.

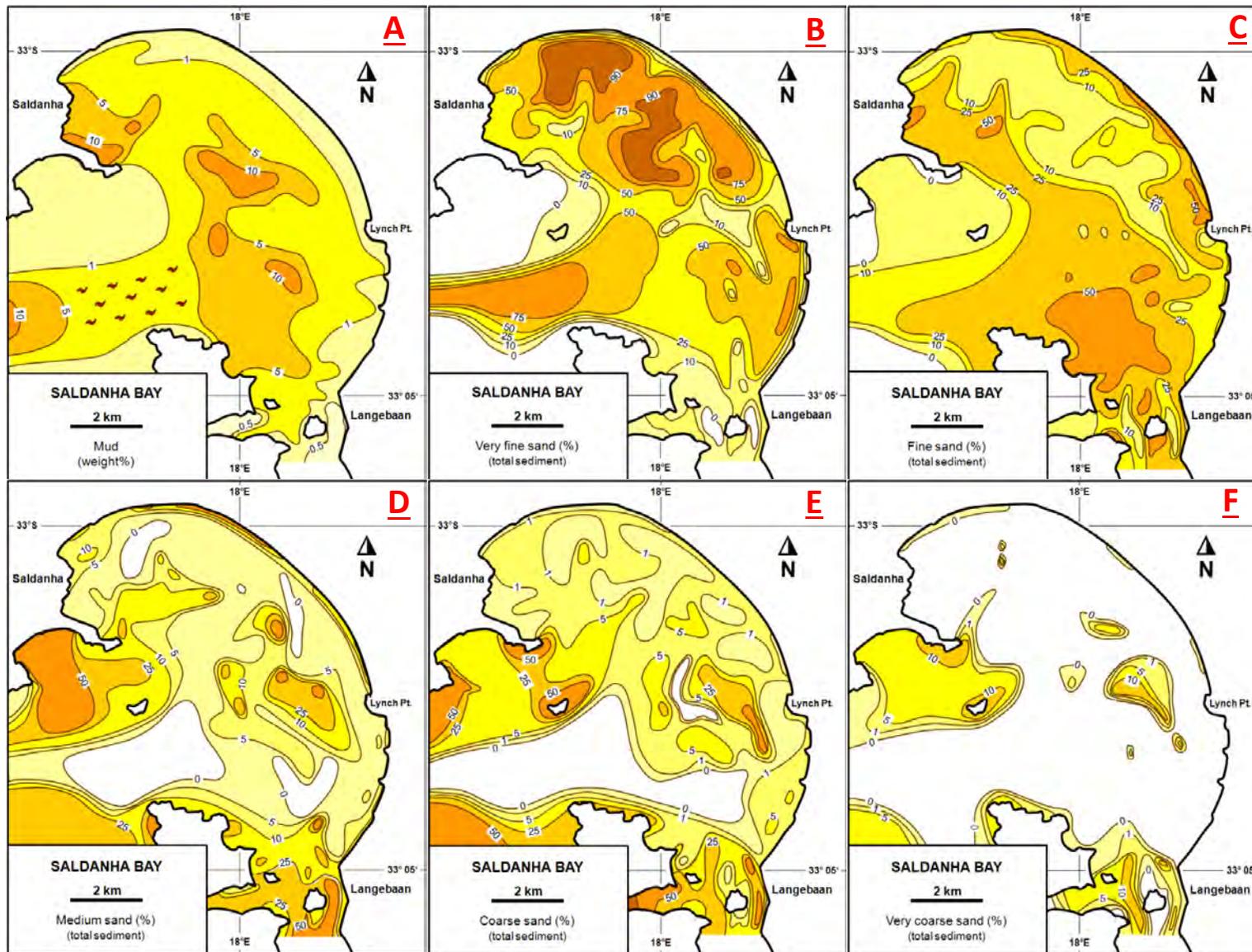


Figure 7.2 Distribution of different sediment types (% of total) in Saldanha Bay in 1975: (A) mud (<0.063 mm), (B) very fine sand (0.063-0.125 mm), (C) fine sand (0.125-0.25 mm), (D) medium sand (0.25-0.5 mm), (E) coarse sand (0.5-1.0 mm), (F) very coarse sand (1-2 mm). Source: Flemming (2015).

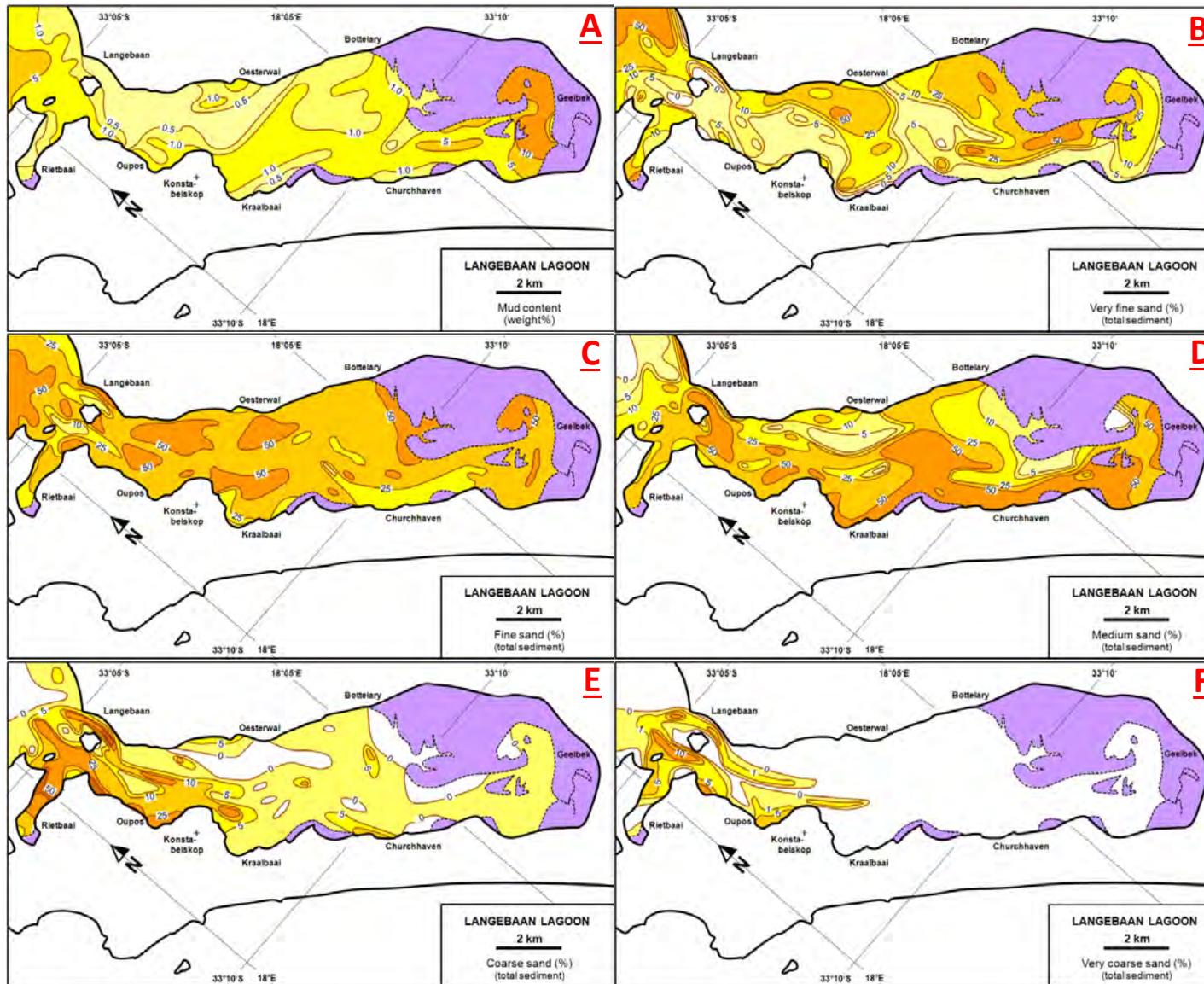


Figure 7.3 Distribution of different sediment types (% of total) in Langebaan Lagoon in 1975: (A) mud (<0.063 mm), (B), very fine sand (0.063-0.125 mm), (C) fine sand (0.125-0.25 mm), (D) medium sand (0.25-0.5 mm), (E) coarse sand (0.5-1.0 mm), (F) very coarse sand (1-2 mm). Source: Flemming (2015).

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 7.5).

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 7.5, 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, the end of the ore terminal, the Yacht Club Basin and in 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 7.5).

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 7.5). 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. This was probably due to the maintenance dredging that took place at the Moss gas 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<sup>3</sup> of material was removed from an area of approximately 3 000 m<sup>2</sup> between Caisson 3 and 4 near the base of the Iron ore terminal on the Saldanha side, and a 275 m<sup>2</sup> 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<sup>9</sup>. 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 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, Langebaan Lagoon and Elandsfontein in 2018 as part of the annual State of the Bay sampling programme (Figure 7.4). This

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<sup>9</sup> Data for six key sites surrounding the iron ore terminal and in Small Bay are shown on . The reader is referred to individual State of the Bay reports for each year for more detail on this.

included 10 sites in Small Bay, 9 in Big Bay and Langebaan Lagoon and 3 in Elandsfontein. Samples collected comprised predominantly of sand (particle size ranging between 63  $\mu\text{m}$  and 2000  $\mu\text{m}$ ). Sites located in Big Bay had on average the highest proportion of mud (1.42%), followed by Small Bay (1.19%) (Figure 7.4). An overall decrease in mud percentage in both Small and Big Bay sites are evident compared to 2017 results. No gravel (particles exceeding 2000  $\mu\text{m}$ ) was found across all samples sites (Figure 7.5).

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 the lies adjacent to the causeway linking Maruc Island to the mainland, 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.

A 2-way crossed PERMANOVA design was performed using Year (nine levels: 2009, 2010, 2011, 2013, 2014, 2015, 2016, 2017 and 2018) and Region (seven levels: Small Bay, Big Bay, Langebaan Lagoon, Elandsfontein, Sea Harvest and Danger Bay) as fixed factors. The results confirm that both factors have a significant effect on sediment composition (Year: Pseudo- $F_8 = 5.36$ ,  $p < 0.001$ ; Region: Pseudo- $F_6 = 23.95$ ,  $p < 0.001$ ). However, there was no significant interaction between Region and Year (Region  $\times$  Year: Pseudo- $F_{21} = 1.18$ ,  $p > 0.05$ ) which suggests that the extent of the differences in sediment composition does not vary with region from one year to the next and vice versa. The former results are illustrated in Multidimensional Scaling (MDS) plots (Figure 7.6) which depict the similarities/dissimilarities amongst sediment composition in each region in each year. What is striking, though, is that Langebaan Lagoon has consistently remained different in sediment composition (separate grouping) from the rest of the sites from 2009-2018. Sediments in Big Bay and Small Bay are mostly quite similar, but one site in Big Bay (the site adjacent to the LPG mooring point) was markedly different in 2017. This is most likely linked to disturbance (mainly dredging) that occurred near this site at that time. Sediments at this site have since reverted to a more natural profile since this time, however (Figure 7.6).

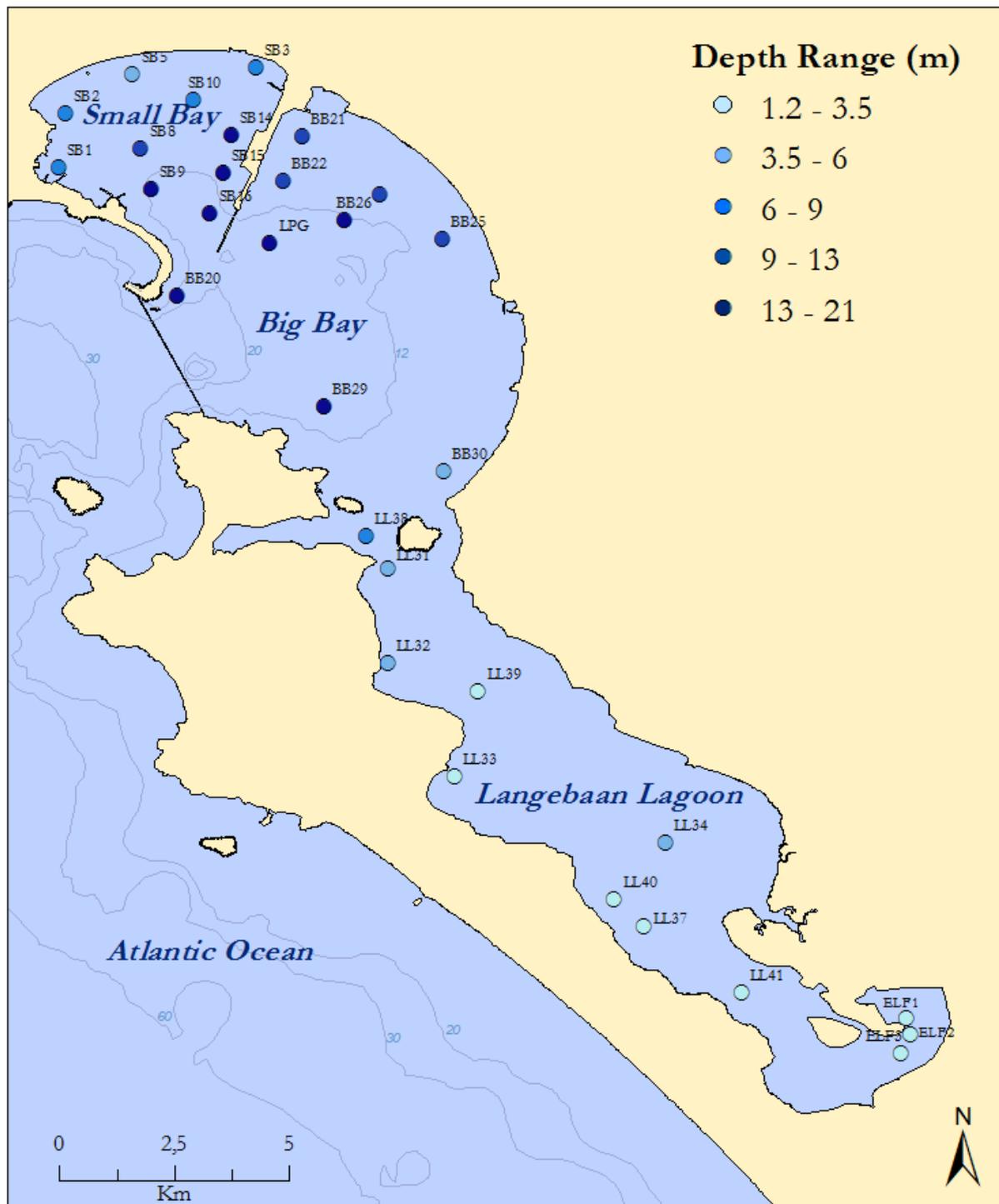
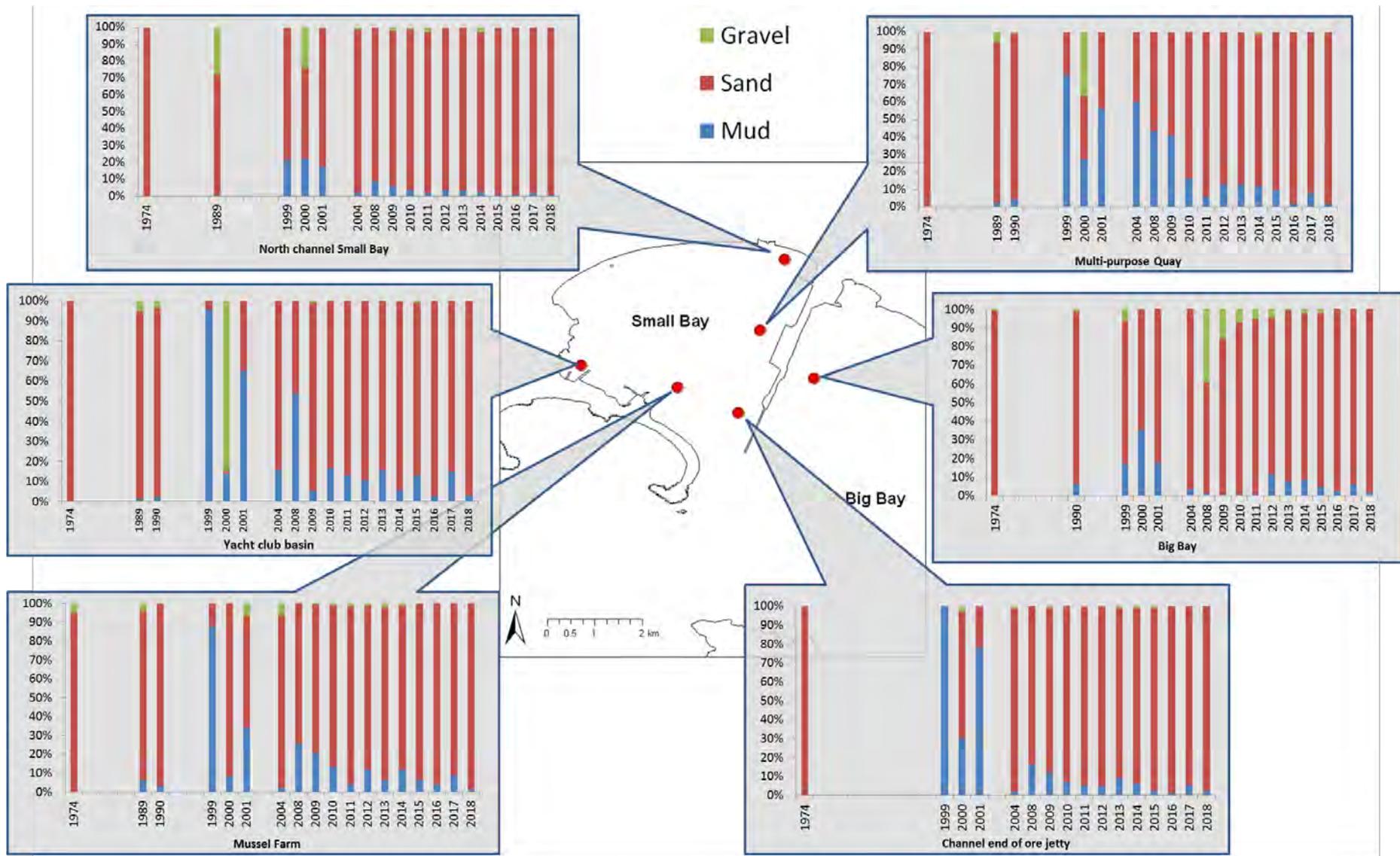


Figure 7.4 Sediment sampling sites and respective depth ranges (m) in Saldanha Bay and Langebaan Lagoon for 2018.

**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, Langebaan Lagoon and Elandsfontein in 2018 (Particle size analysed by Scientific Services and TOC and TON analysed by the Council for Scientific and Industrial Research).**

	Sample	Sand (%)	Mud (%)	TOC (%)	TON (%)	C:N
Small Bay	SB1	9.0	96.9	3.1	2.5	0.5
	SB2	7.0	99.7	0.3	0.3	0.1
	SB3	6.8	99.1	1.0	0.3	0.1
	SB5	5.9	100.0	0.0	0.2	0.0
	SB8	10.5	99.2	0.8	0.4	0.1
	SB9	15.3	98.7	1.3	0.7	0.1
	SB10	7.7	99.8	0.2	0.4	0.1
	SB14	16.0	97.9	2.1	1.8	0.3
	SB15	17.0	99.1	0.9	0.8	0.1
	SB16	17.5	97.7	2.3	0.4	0.1
	<b>Average</b>	<b>11.3</b>	<b>98.8</b>	<b>1.2</b>	<b>0.8</b>	<b>0.1</b>
Big Bay	BB20	21.0	99.7	0.3	0.3	0.1
	BB21	10.0	97.8	2.2	0.6	0.1
	BB22	12.6	98.5	1.5	0.7	0.2
	LPG	17.3	98.0	2.0	0.5	0.1
	BB24	13.2	98.1	1.9	0.6	0.1
	BB25	11.0	99.8	0.2	0.2	0.1
	BB26	16.3	96.8	3.2	0.6	0.1
	BB29	15.5	98.7	1.3	0.1	0.0
	BB30	4.5	99.9	0.1	0.2	0.0
		<b>Average</b>	<b>13.5</b>	<b>98.6</b>	<b>1.4</b>	<b>0.4</b>
Langebaan Lagoon	LL31	5.6	99.7	0.3	0.1	0.0
	LL32	4.0	99.9	0.1	0.1	0.0
	LL33	3.1	99.9	0.1	0.1	0.0
	LL34	5.3	99.6	0.4	0.1	0.0
	LL37	2.0	99.9	0.1	0.1	0.0
	LL38	6.6	99.1	0.9	0.1	0.0
	LL39	3.5	99.9	0.1	0.1	0.0
	LL40	3.2	100.0	0.0	0.3	0.1
	LL41	3.4	99.6	0.4	0.1	0.0
		<b>Average</b>	<b>4.1</b>	<b>99.7</b>	<b>0.3</b>	<b>0.1</b>
Elandsfontein	Eland 1	1.2	99.4	0.6	-	-
	Eland 2	1.2	99.5	0.5	-	-
	Eland 3	1.2	99.1	0.9	-	-
	<b>Average</b>	<b>1.2</b>	<b>99.3</b>	<b>0.7</b>	<b>-</b>	<b>-</b>



**Figure 7.5** Particle size composition (percentage gravel, sand and mud) of sediments at six localities in the Small and Big Bay area of Saldanha Bay between 1974 and 2018. Data sources: 1974: Flemming (1977b), 1899-1990: Jackson & McGibbon (1991), 1999-2017: SBWQFT.

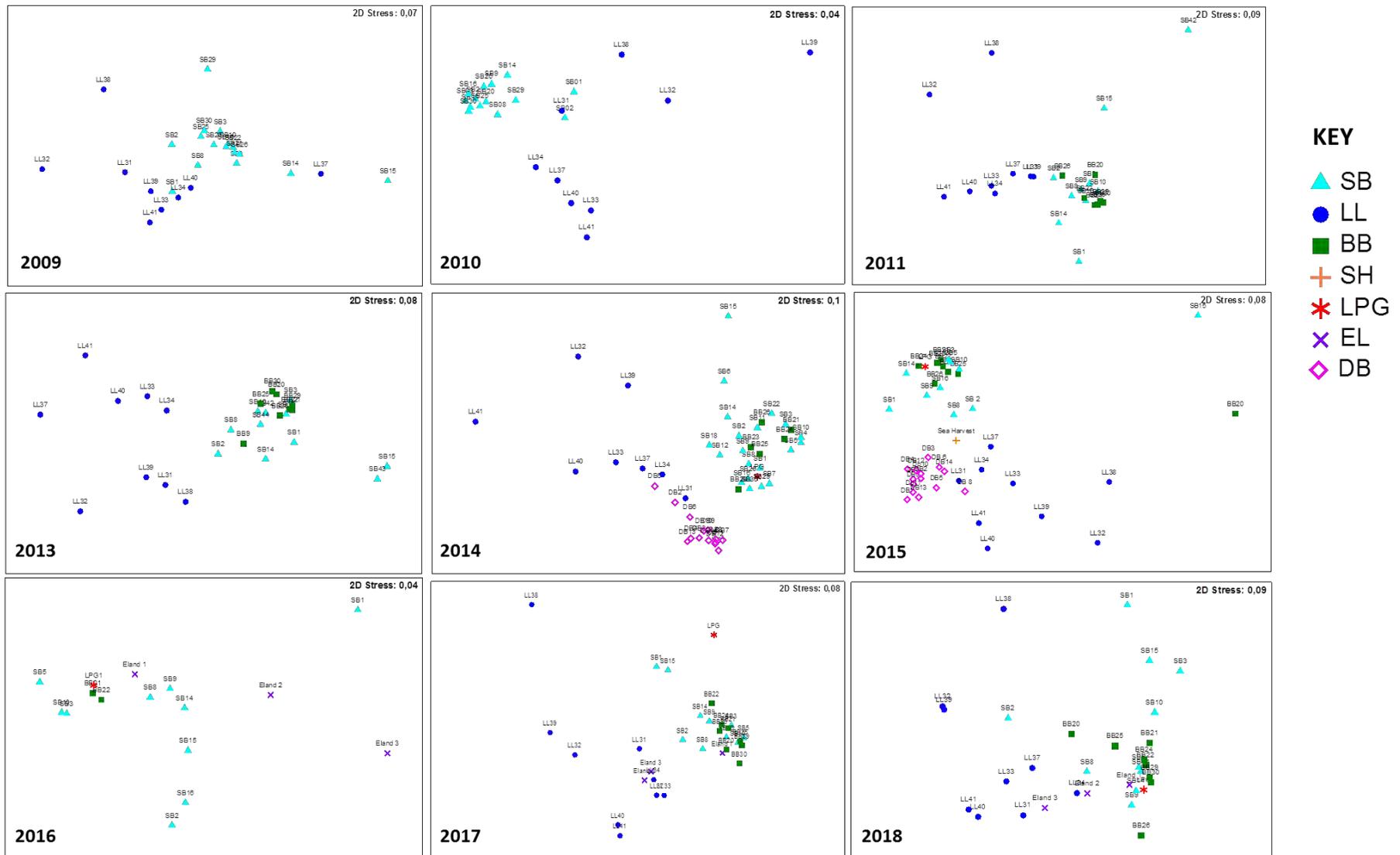


Figure 7.6 MDS plots of particle size distribution (PSD) from samples collected at sites from Saldanha Bay, Langebaan Lagoon and Elandsfontein from 2009-2018. Each region (SB: Small Bay, LL: Langebaan Lagoon, BB: Big Bay, SH: Sea Harvest, LPG: Liquid Petroleum Gas, EL: Elandsfontein and DB: Danger Bay) is represented by a unique symbol and colour.

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 2018 (Figure 7.7).

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.

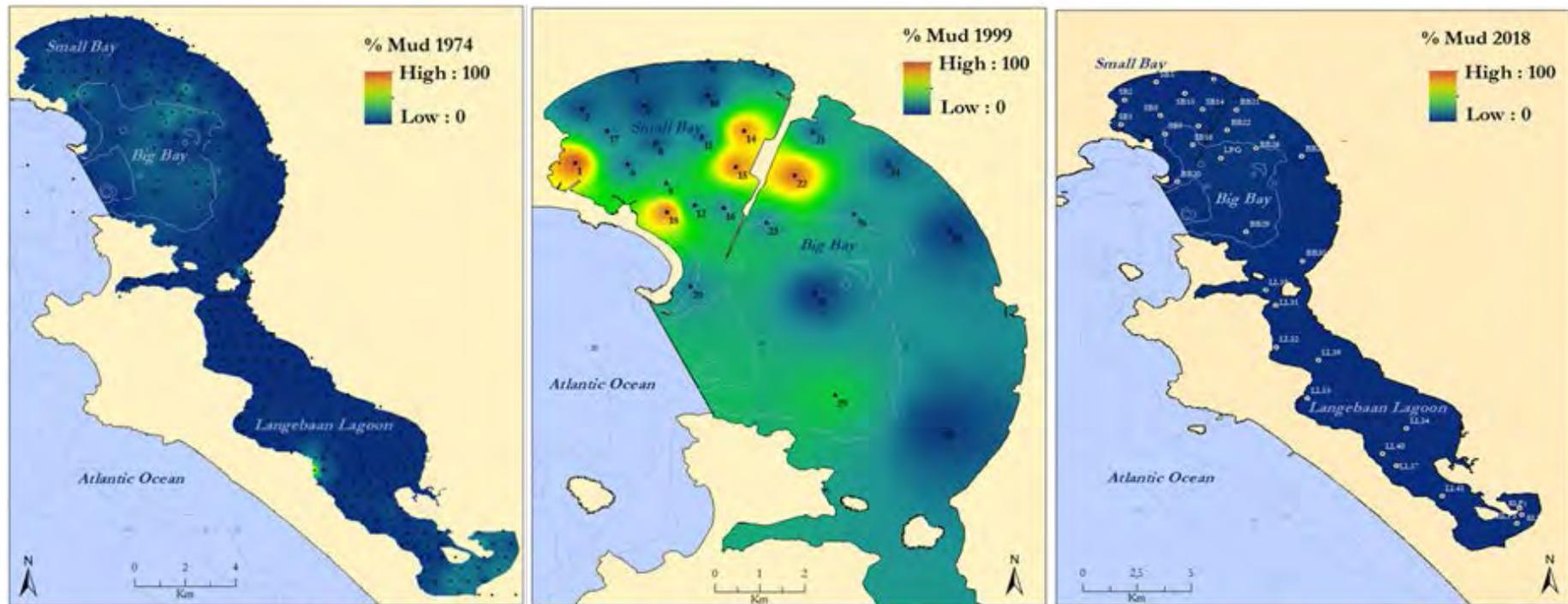


Figure 7.7 Change in the percentage mud in sediments in Saldanha Bay, and Langebaan Lagoon between 1974 (left), 1999 (centre) and 2017 (right) survey results.

## 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<sub>2</sub>S). Sediments high in H<sub>2</sub>S 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 7.8 and Figure 7.9).

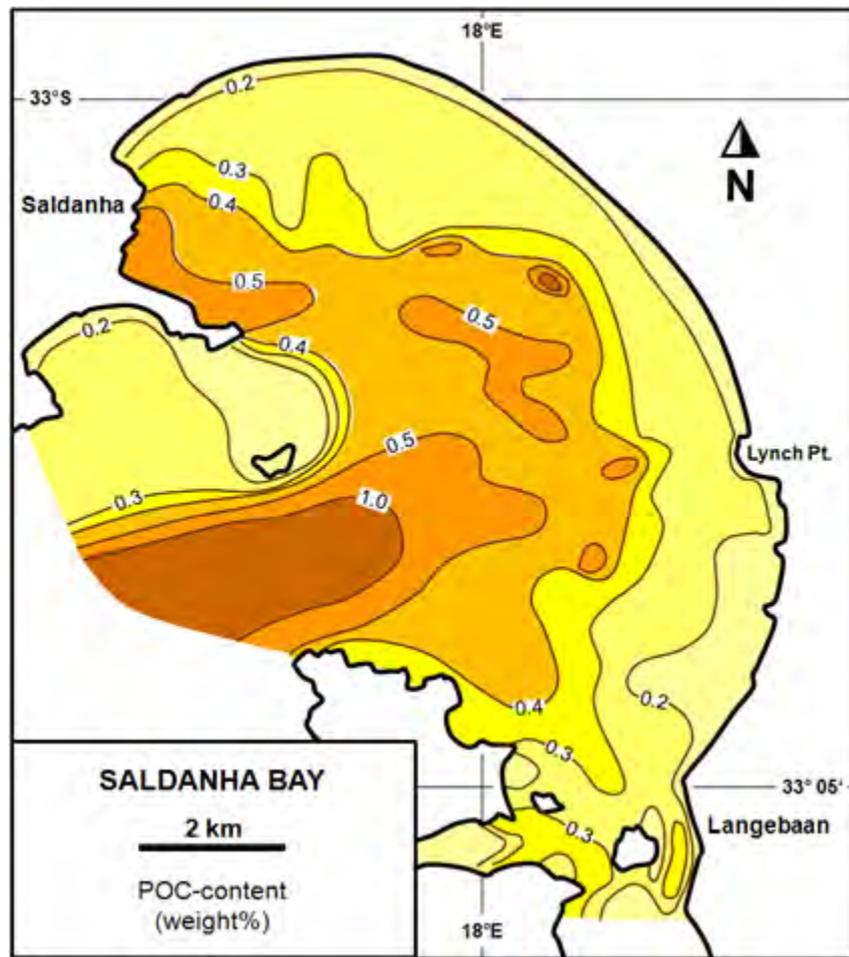


Figure 7.8 Levels of organic carbon in sediments Saldanha Bay in 1974. Source: Flemming (2015).

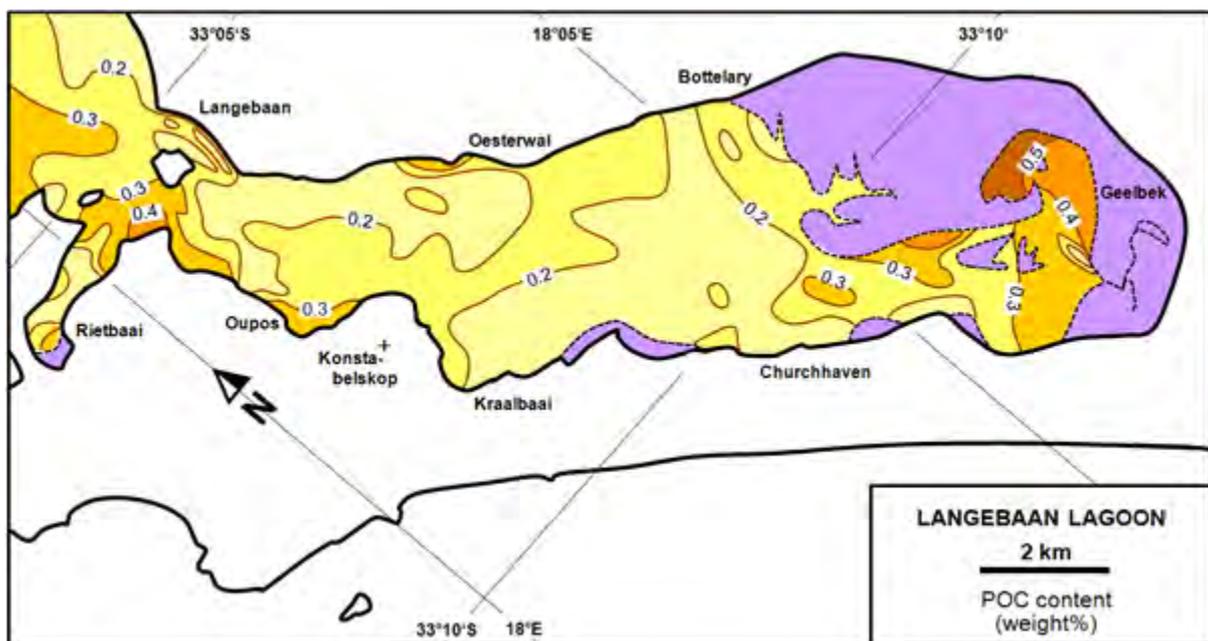


Figure 7.9 Levels of organic carbon in sediments in Langebaan Lagoon in 1974. Source: Flemming (2015).

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 7.11). By the time the next surveys had been undertaken in 1999 (CSIR 1999a, Figure 7.10, Figure 7.11) levels of TOC had increased still further at most sites in the Bay. Results from 2000 and 2001, which were restricted to Small Bay, showed a similar pattern (Figure 7.11). Data from subsequent surveys undertaken in 2004, and subsequent surveys between 2008 and 2018 are presented in the individual State of the Bay reports and are summarised in Figure 7.11. Data on the spatial distribution of TOC from 1999, 2017 and the most recent survey (2018) are shown in Figure 7.10. 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), but that levels have dropped slightly in the last few years. The latter patterns are also evident on the spatial variation of TOC within Saldanha Bay (Figure 7.10).

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), and have been monitored annually from 2004 onwards as part of the State of the Bay monitoring programme. TON levels in 1999 were low at most sites ( $\leq 0.2\%$ ) except for those in the Yacht Club Basin and near the mussel rafts in Small Bay (Figure 7.11). Levels were slightly or even considerably elevated at all sites in 2000 and 2001 (Figure 7.11). 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 7.11, see also the 2004 State of the Bay report). Results from the State of the Bay surveys conducted between 2008 and 2018 suggest that levels have dropped off slightly at many of the key sites in Small Bay but have remained more or less steady in other parts of the Bay and in the Lagoon; with the exception of some increases in TON in 2018 compared to 2017 for Big Bay (Figure 7.11). Spatial variation in TON levels recorded in the sediments in Saldanha Bay and Langebaan Lagoon in 1999, 2017 and 2018 are presented in Figure 7.10. Once again, concentrations are generally higher in Small Bay, particularly at the Yacht Club Basin and along the Iron Ore Terminal. However, 2018 TON concentrations were much lower than the 2017 survey; mirroring the patterns observed for TOC levels in the Bay (Figure 7.10). Overall, levels of TON at remaining sites in Small Bay 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, and sewage effluent from the wastewater treatment works. 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.

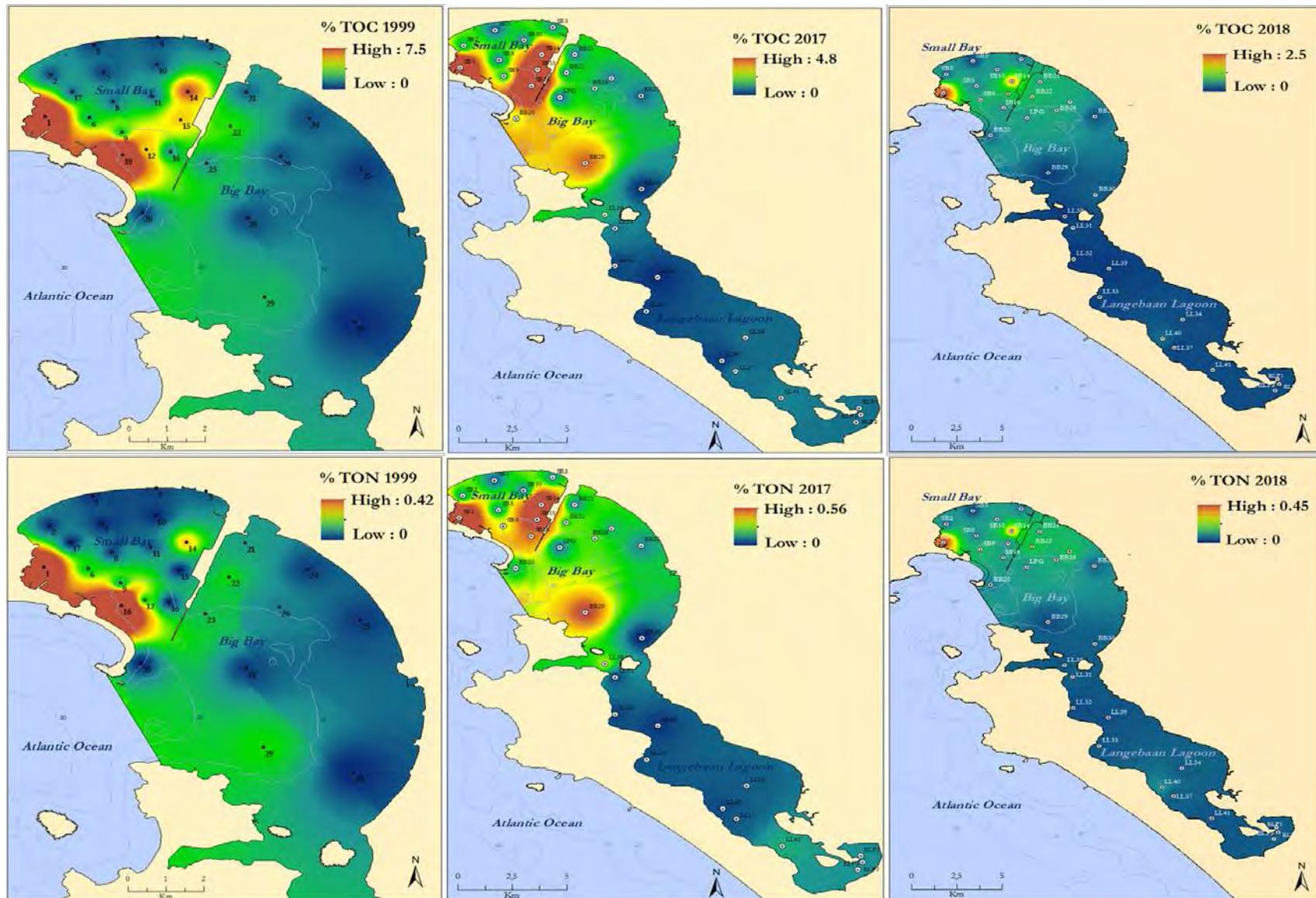


Figure 7.10 Total organic carbon (TOC) and total organic nitrogen (TON) levels in sediments in Saldanha Bay in 1999 (Source: CSIR 1999a), 2017 and 2018.

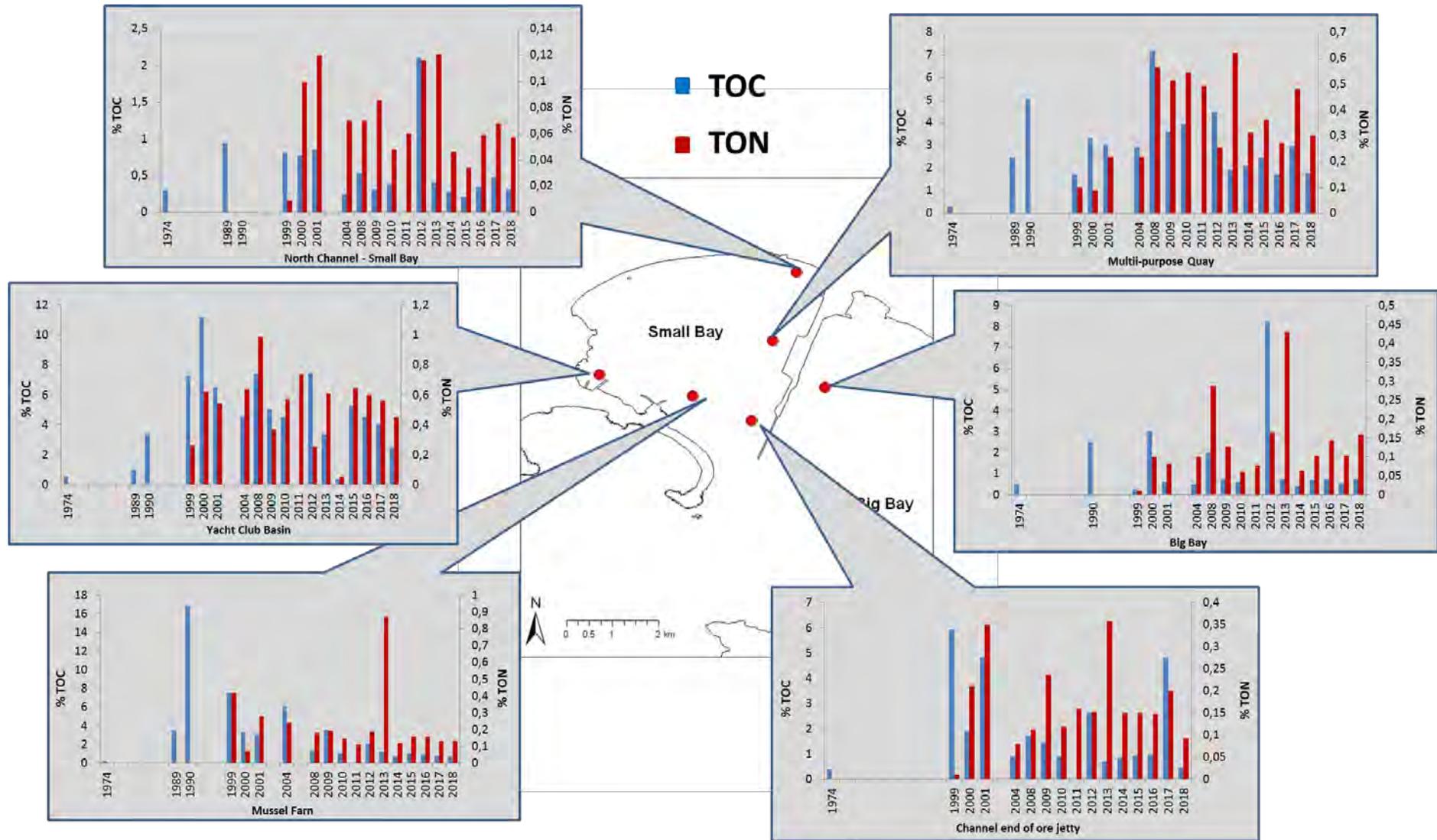


Figure 7.11 Total organic carbon and nitrogen in sediments of Saldanha Bay at six locations between 1974 and 2018. Data sources: 1974: Flemming (1977b), 1899-1990: Jackson & McGibbon (1991), 1999-2018: SBWQFT.

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 2016-2017 were somewhat variable. 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 7.12). 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). In 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. The latest 2018 survey results revealed that only the multipurpose ore terminal was above the expected range, while the majority of the sites within Small Bay were below the range of marine production. The latter pattern was also observed in Big Bay and Langebaan Lagoon (Figure 7.12).

There are two possible reasons for elevated C:N ratios observed in 2017; 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 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 low C:N ratio values recorded in 2018 for the northern sites within Small and Big Bay are most likely due to the shallow water and/or high wave action and current patterns experienced at these sites resulting in a considerable amount of organic carbon being flushed out (Atkinson *et al.* 2006). The other alternative of reduced C:N ratios in 2018 compared to the 2017 survey is related to the low mud content present in the Bay. Much literature has revealed that organic carbon content in terrestrial soils and marine sediments have been positively correlated with mud content (Baptista *et al.* 2000; Falco *et al.* 2004; Leipe *et al.* 2011; Serrano *et al.* 2016). Reduced mud content is most likely attributable to the consistent dredging events occurring in the Bay. Such activities suspend the finer particle grain sizes and local currents/tides remove these types of sediment.

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.

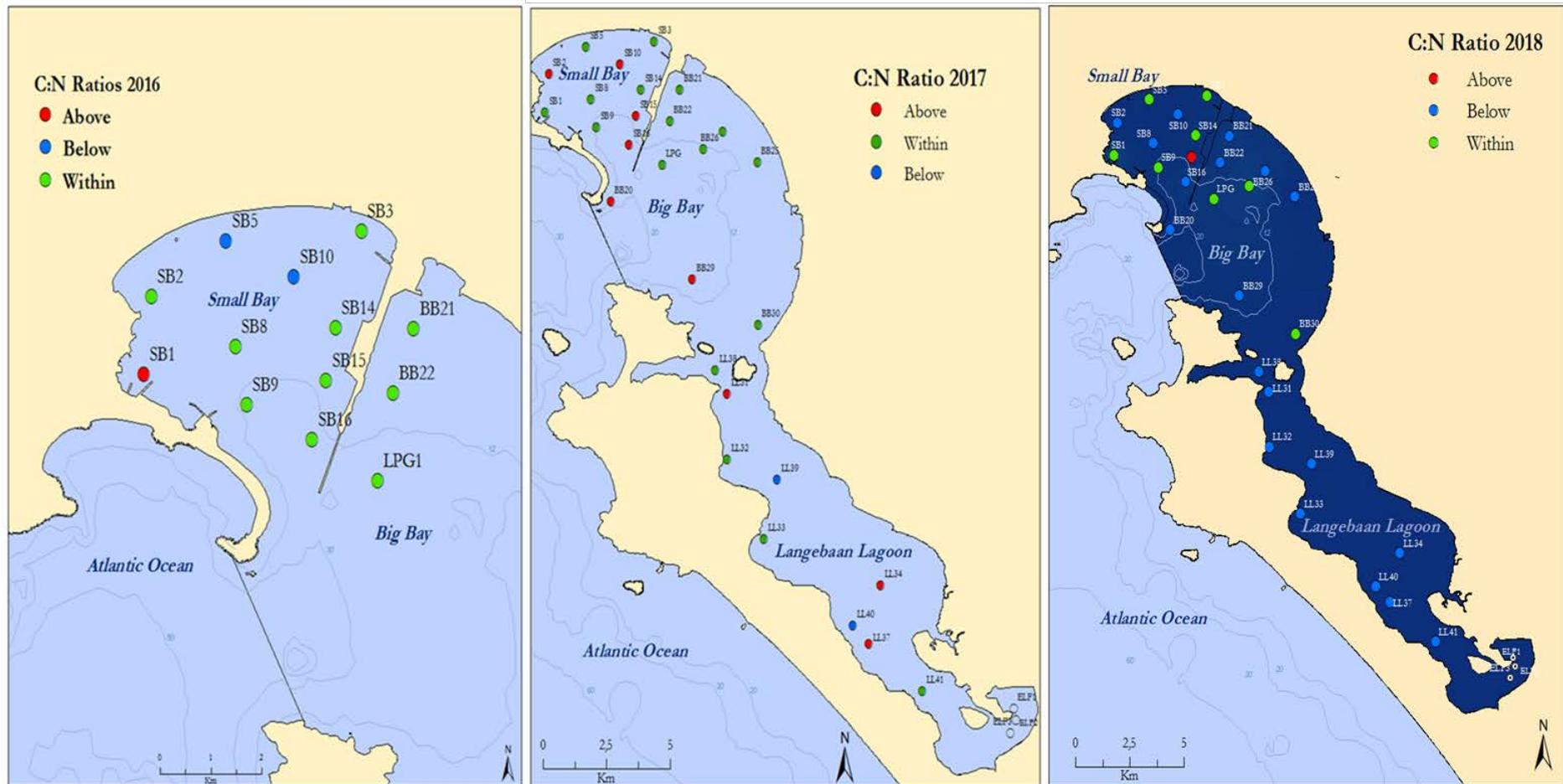


Figure 7.12 C:N ratios at different sites surveyed in Saldanha Bay and Langebaan Lagoon in 2016, 2017 & 2018 (red = exceeds the range expected for marine production, green = within the range expected for marine production and blue = below range expected for marine production).

### 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 the lower 10<sup>th</sup> 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 the lower 50<sup>th</sup> 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, five 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 2018 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<sub>3</sub>) / perchloric acid (HClO<sub>3</sub>)/ hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>)/ 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 the sections dedicated to each of the trace metals below.

**Table 7.3** Concentrations (mg/kg) of metals in sediments collected from Saldanha Bay in 2018. Values that exceed sediment quality guidelines are highlighted in red font. ND indicates no data.

	Sample	Al	Fe	Cd	Cu	Ni	Pb	Mn
<b>*ERL Guideline (mg/kg)</b>		-	-	1.2	34	20.9	46.7	56.50
<b>Small Bay</b>	SB1	8329	10303	2.97	49.11	10.49	28.075	42.43
	SB2	1667	2933	0.42	1.39	2.06	6.036	11.83
	SB3	698	1012	0.09	ND	0.90	ND	3.99
	SB5	1795	2253	0.31	2.52	0.82	17.45	16.76
	SB8	1578	2844	0.38	1.49	1.67	8.60	14.47
	SB9	2628	4511	0.56	2.71	2.50	4.93	19.13
	SB10	915	1688	0.24	0.14	ND	5.14	7.51
	SB14	5047	6386	0.96	15.75	5.74	40.98	34.78
	SB15	2810	3555	0.58	3.58	1.68	13.55	20.28
	SB16	2553	3546	0.64	2.45	1.30	7.00	17.92
<b>Big Bay</b>	BB20	1267	1665	0.48	0.24	0.22	2.47	8.97
	BB21	2320	3110	0.45	2.67	1.76	0.79	15.01
	BB22	2461	4056	0.44	1.83	2.04	7.97	17.59
	LPG	2639	3580	0.65	2.78	2.61	9.02	17.46
	BB24	2217	2756	0.69	1.24	0.92	7.73	13.18
	BB25	874	1194	0.29	ND	0.32	5.18	6.26
	BB26	2613	3258	0.54	1.20	1.53	5.96	15.33
	BB29	1652	2057	0.33	0.42	1.27	2.11	9.99
	BB30	721	860	0.16	ND	ND	3.87	4.64
<b>Langebaan Lagoon</b>	LL31	1354	2441	0.20	ND	0.39	1.89	12.20
	LL32	1034	2900	0.16	ND	1.23	2.41	7.04
	LL33	613	1005	0.12	ND	ND	1.24	3.45
	LL34	1699	1856	0.18	ND	0.94	2.28	7.89
	LL37	694	816	0.09	ND	ND	ND	3.40
	LL38	2883	4398	0.33	1.23	2.89	2.70	19.66
	LL39	680	1441	0.22	ND	ND	0.74	7.91
	LL40	590	784	0.12	ND	ND	0.70	17.22
	LL41	1611	1706	0.20	ND	1.01	1.66	7.54
<b>Elandsfontein</b>	Eland 1	2521	2694	0.27	1.00	1.30	3.51	13.78
	Eland 2	-	-	-	-	-	-	-
	Eland 3	-	-	-	-	-	-	-

In 2018, cadmium and copper concentrations were highest, and exceeded ERL guidelines, in the vicinity of the Yacht Club Basin (Table 7.3). All other metal concentrations had relatively decreased in the vicinity of the Yacht Club Basin and iron ore terminal, with the exception of lead and manganese; but these did not exceed ERL guideline levels. 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. 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 within Small Bay displayed low cadmium concentrations; whereas the area within the vicinity of the Yacht Club Basin revealed the highest concentration of cadmium (Figure 7.13; Table 7.3). Cadmium is a trace metal used in electroplating, in pigment for paints, in dyes and in photographic 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 7.13 & 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 2018 (Table 7.4).

#### 7.3.1.3 Nickel

Nickel values measured in 2018 were elevated at the yacht club and alongside the iron ore terminal within Small Bay (Figure 7.13 & 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 7.14 & 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 (51.2), 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 7.14 Spatial interpolation of Lead (Pb) and Manganese (Mn) values measured in sediments in Saldanha Bay in 2018. & Table 7.3). 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 2018 relative to sediments from 1980.

	Sample	Cd	Cu	Pb
	<b>1980 average</b>	<b>0.075</b>	<b>0.41</b>	<b>0.8</b>
Small Bay	SB1	39.65	119.78	35.09
	SB2	5.61	3.39	7.55
	SB3	1.16	ND	ND
	SB5	4.11	6.14	21.81
	SB8	5.07	3.62	10.75
	SB9	7.51	6.62	6.17
	SB10	3.13	0.33	6.43
	SB14	12.80	38.42	51.22
	SB15	7.68	8.72	16.94
Big Bay	SB16	8.53	5.98	8.75
	BB20	6.45	22.32	3.08
	BB21	5.97	6.52	0.99
	BB22	5.87	4.46	9.96
	LPG1	8.67	6.78	11.28
	BB24	9.20	35.57	9.66
	BB25	3.80	23.25	6.48
	BB26	7.23	39.61	7.45
	BB29	4.44	29.53	2.63
BB30	2.08	13.28	4.84	

Table 7.5 Normalized values for Cadmium, Copper, Nickel, Lead and Manganese in sediments collected from Saldanha Bay and Langebaan Lagoon in 2018.

	Sample	Cd:Al	Cu:Al	Ni:Al	Pb:Al	Mn: Al
Small Bay	SB1	3.57	16.51	12.59	33.71	50.94
	SB2	2.53	3.30	12.36	36.22	70.97
	SB3	1.25	ND	12.89	ND	57.17
	SB5	1.72	8.18	4.55	97.20	93.35
	SB8	2.41	3.91	10.56	54.46	91.66
	SB9	2.14	4.82	9.52	18.78	72.80
	SB10	2.57	0.58	ND	56.18	82.04
	SB14	1.90	16.41	11.36	81.19	68.90
	SB15	2.05	6.21	5.96	48.21	72.15
	SB16	2.51	3.83	5.10	27.41	70.18
Big Bay	BB20	3.82	0.49	1.70	19.46	70.82
	BB21	1.93	5.97	7.59	3.42	64.71
	BB22	1.79	4.16	8.29	32.38	71.48
	LPG	2.46	4.27	9.90	34.20	66.18
	BB24	3.11	1.79	4.14	34.88	59.44
	BB25	3.26	ND	3.68	59.32	71.67
	BB26	2.07	2.22	5.84	22.82	58.68
	BB29	2.02	1.27	7.68	12.75	60.45
	BB30	2.16	ND	ND	53.71	64.31
	Langebaan Lagoon	LL31	1.46	ND	2.85	13.95
LL32		1.52	ND	11.85	23.30	68.06
LL33		1.93	ND	ND	20.29	56.30
LL34		1.07	ND	5.56	13.43	46.47
LL37		1.35	ND	ND	ND	48.98
LL38		1.13	3.79	10.01	9.36	68.20
LL39		3.21	ND	ND	10.88	116.32
LL40		1.95	ND	ND	11.85	292.00
LL41		1.22	ND	6.24	10.30	46.82

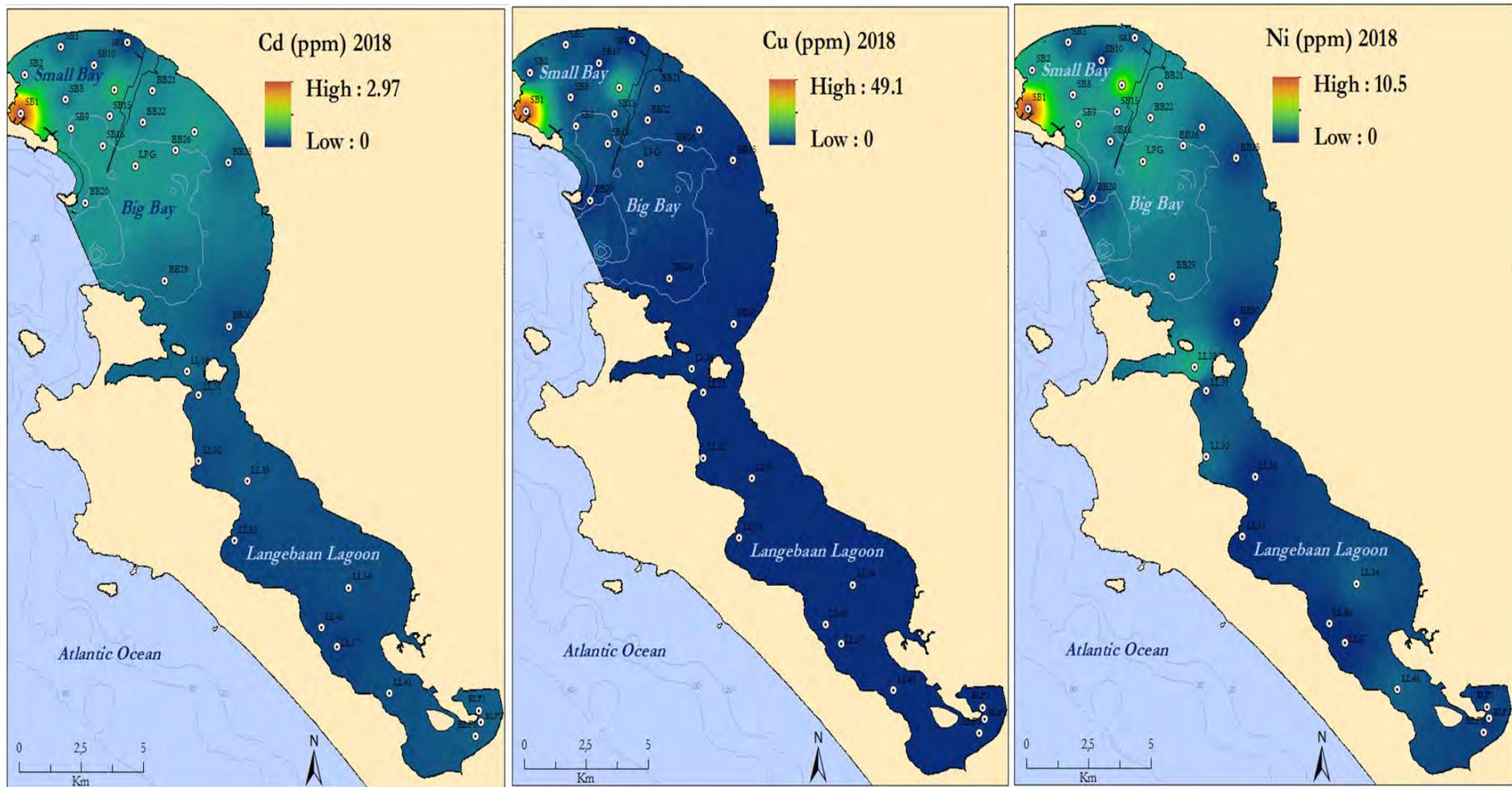


Figure 7.13 Spatial interpolation of cadmium (Cd), copper (Cu) and Nickel (Ni) values measured in sediments in Saldanha Bay in 2018.

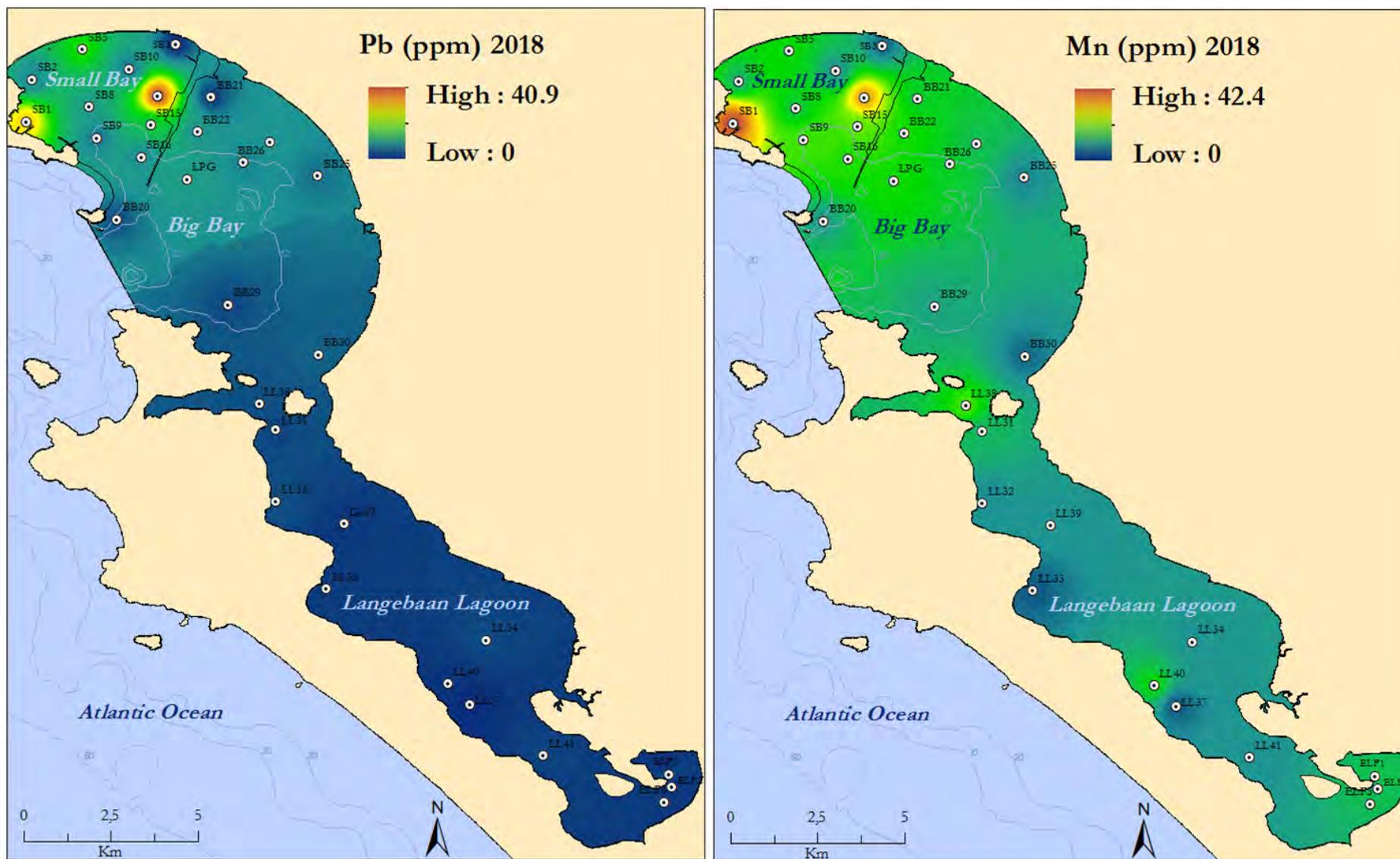


Figure 7.14 Spatial interpolation of Lead (Pb) and Manganese (Mn) values measured in sediments in Saldanha Bay in 2018.

### 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 Saldanha 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 7.15). 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 Multi-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, 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, however have elevated in 2018.

#### 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 7.16). Apart from the low levels recorded in 2014, copper concentrations at the Yacht Club Basin have remained high (above the ERL guideline) over the past eight 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 7.17). 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. From the 2018 survey, all six localities had a decrease in nickel concentration.

#### 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 7.18). 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 16 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 7.19. 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; however the manganese concentrations are elevated in 2018 for two of the three sites within Small Bay. The two sites located along the ore terminal within Big Bay have also shown increases from 2017 to 2018.

### 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 7.20. 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 2018. However, the concentration of iron at SB15 has fluctuated dramatically since 2012, but has shown an overall decrease in the last seven 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.

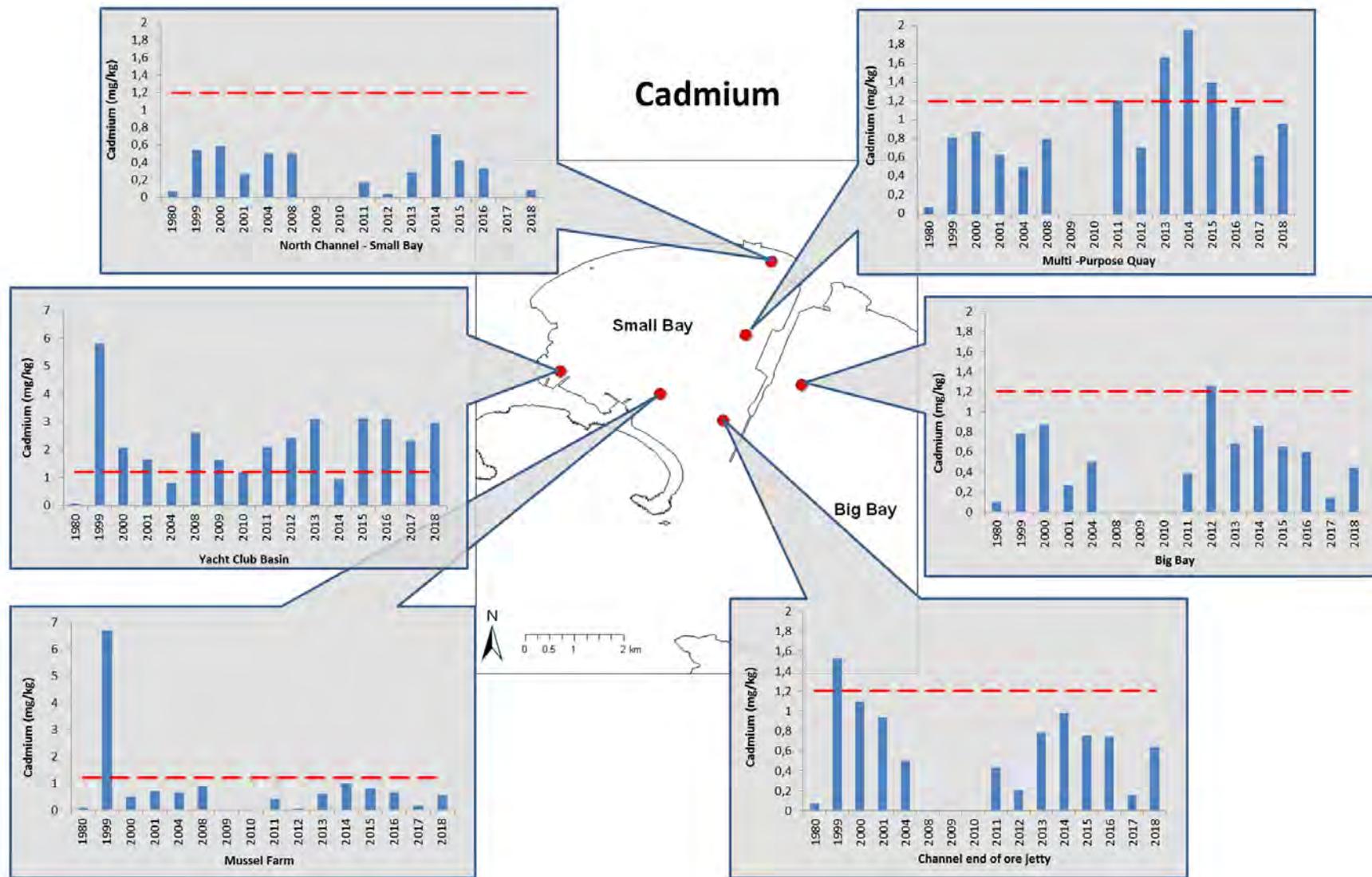


Figure 7.15 Concentrations of Cadmium (Cd) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2018. Dotted lines indicate Effects Range Low values for sediments.

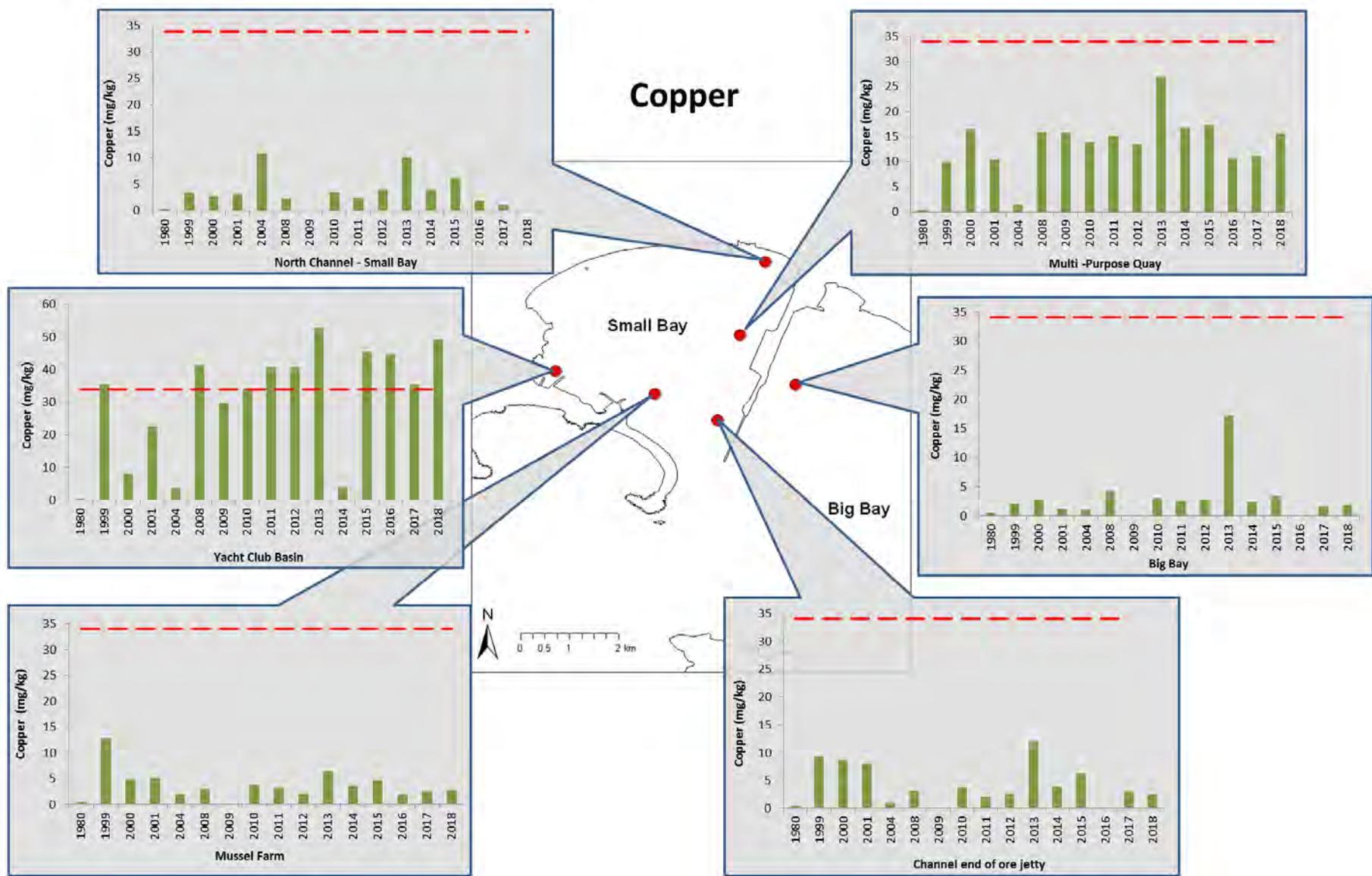


Figure 7.16 Concentrations of Copper (Cu) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2018. Dotted lines indicate Effects Range Low values for sediments.

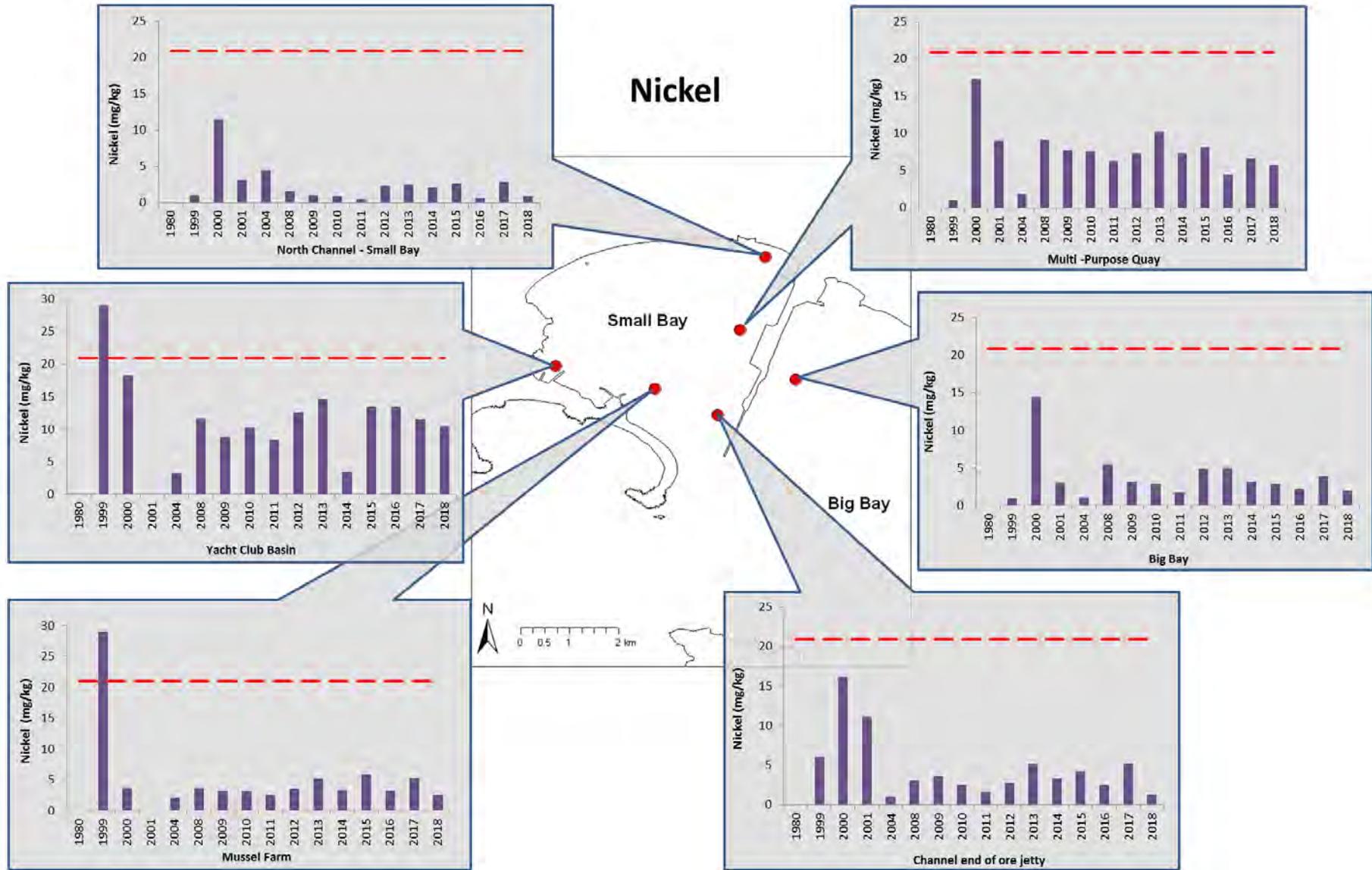


Figure 7.17 Concentrations of Nickel (Ni) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2018. Dotted lines indicate Effects Range Low values for sediments.

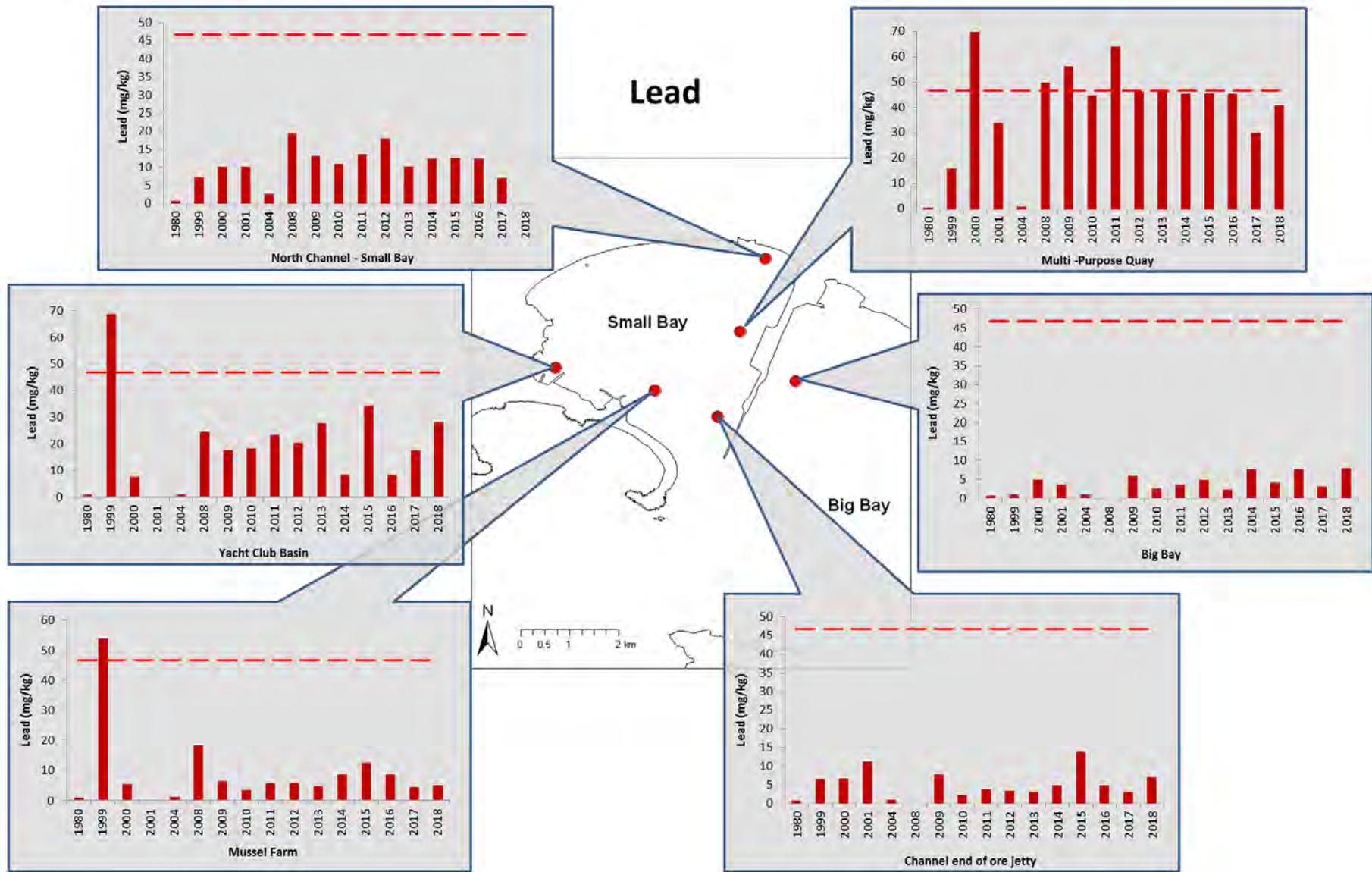


Figure 7.18 Concentrations of Lead (Pb) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2018. Dotted lines indicate Effects Range Low values for sediments.

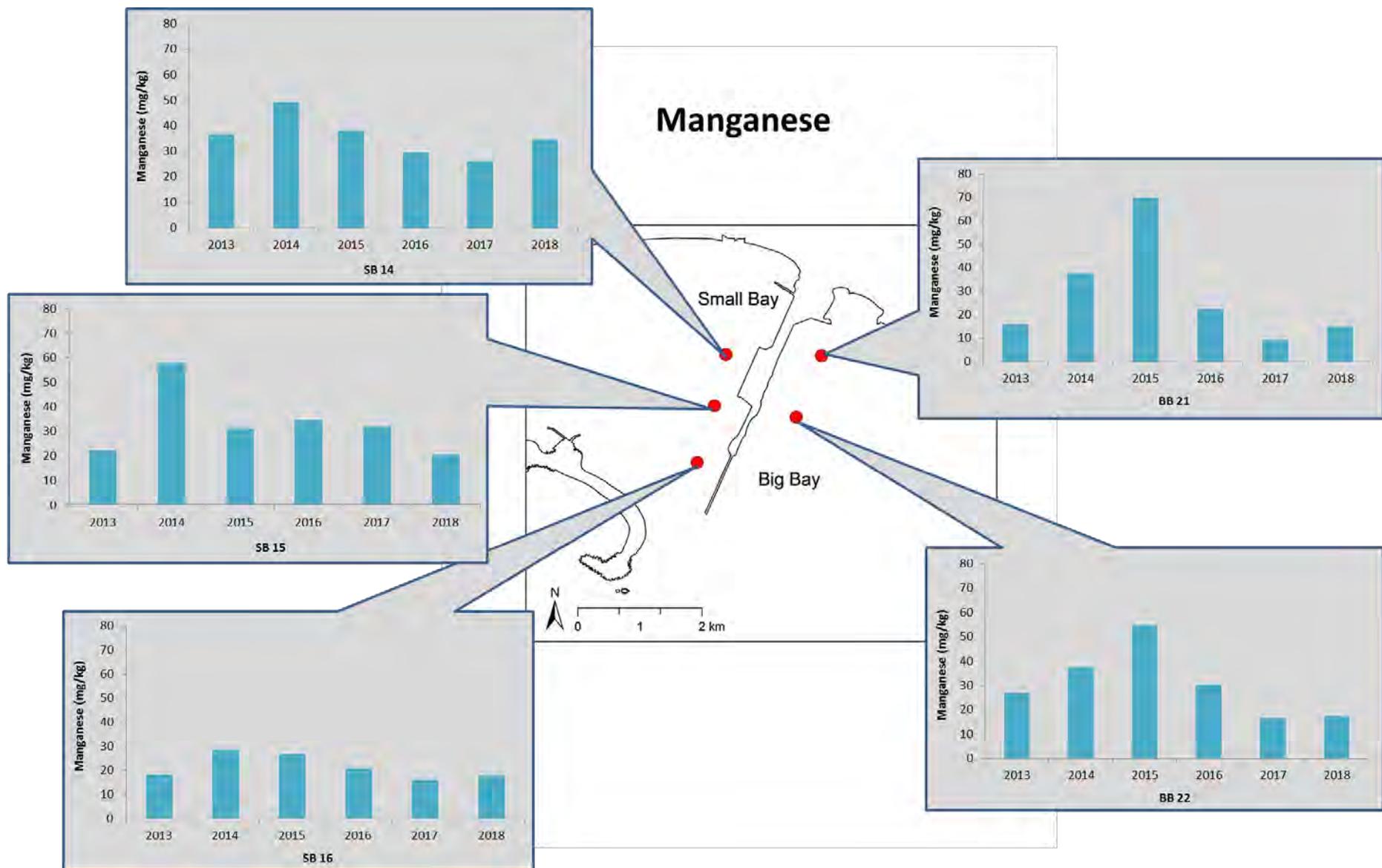


Figure 7.19 Concentration of manganese (Mn) in mg/kg recorded at five sites in Saldanha Bay between 2013 and 2018.

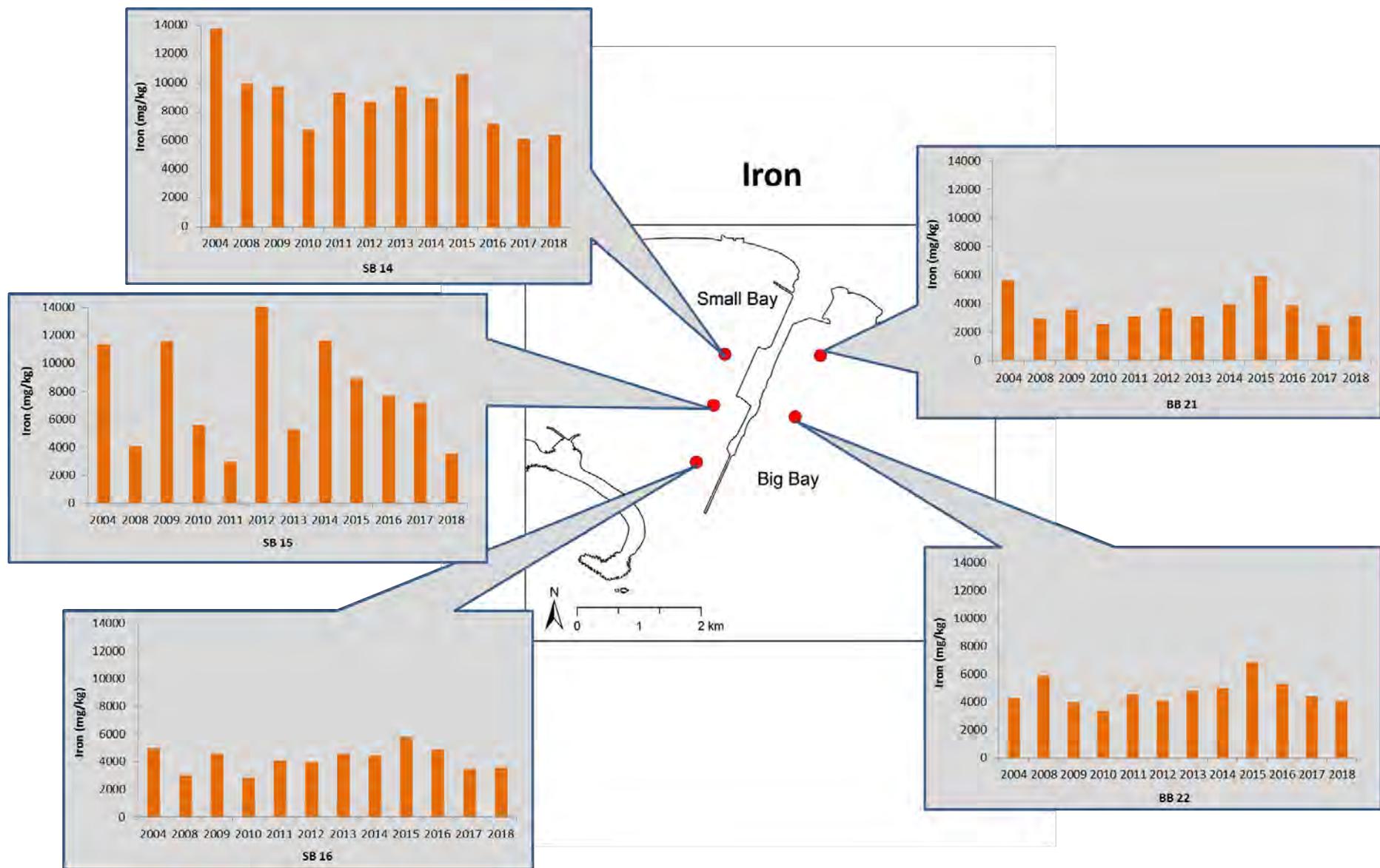


Figure 7.20 Concentrations of Iron (Fe) in mg/kg recorded at five sites in Saldanha Bay between 2004 and 2018.

## 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 2011-2018 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	2018
SB14	<20	34	130	19	<38	<38	<38	<38
SB15	<20	35	ND	53	<38	<38	<38	<38
SB16	<20	24	28	14 649	<38	<38	<38	<38
BB21	<20	20	32	20	<38	<38	<38	<38
BB22	<20	17	27	<0.2	<38	<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 7.6). 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 remained at this level at all five sites to present date.

Sediment samples collected in 2018 had low PAH levels across all sites (Table 7.7). While the TPH and PAH findings 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 2018.**

Hydrocarbon (mg/kg)	ERL*	ERM**	SB14	SB15	SB16	BB21	SB22
Acenaphthene	<b>0.016</b>	<b>0.5</b>	<0.002	<0.002	<0.002	<0.002	<0.002
Acenaphthylene	<b>0.044</b>	<b>0.64</b>	<0.002	<0.002	<0.002	<0.002	<0.002
Anthracene	<b>0.0853</b>	<b>1.1</b>	<0.002	<0.002	<0.002	<0.002	<0.002
Benzo(a) anthracene	<b>0.261</b>	<b>1.6</b>	<0.002	<0.002	<0.002	<0.002	<0.002
Benzo(a) pyrene	<b>0.43</b>	<b>1.6</b>	<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	<b>0.384</b>	<b>2.8</b>	<0.002	<0.002	<0.002	<0.002	<0.002
Dibenzo(a,h) anthracene	<b>0.0634</b>	<b>0.26</b>	<0.1	<0.1	<0.1	<0.1	<0.1
Flouranthene	<b>0.6</b>	<b>5.1</b>	<0.002	0.007	<0.002	<0.002	0.003
Flourene	<b>0.019</b>	<b>0.54</b>	<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	<b>0.16</b>	<b>2.1</b>	<0.002	<0.002	<0.002	<0.002	<0.002
Phenanthrene	<b>0.24</b>	<b>1.5</b>	<0.002	0.008	<0.002	<0.002	0.003
Pyrene	<b>0.665</b>	<b>2.6</b>	<0.002	0.005	<0.002	<0.002	<0.002
Total PAH	<b>4</b>	<b>44.7</b>	-	-	-	-	-

\*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, *Callinassa 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 prawns 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.

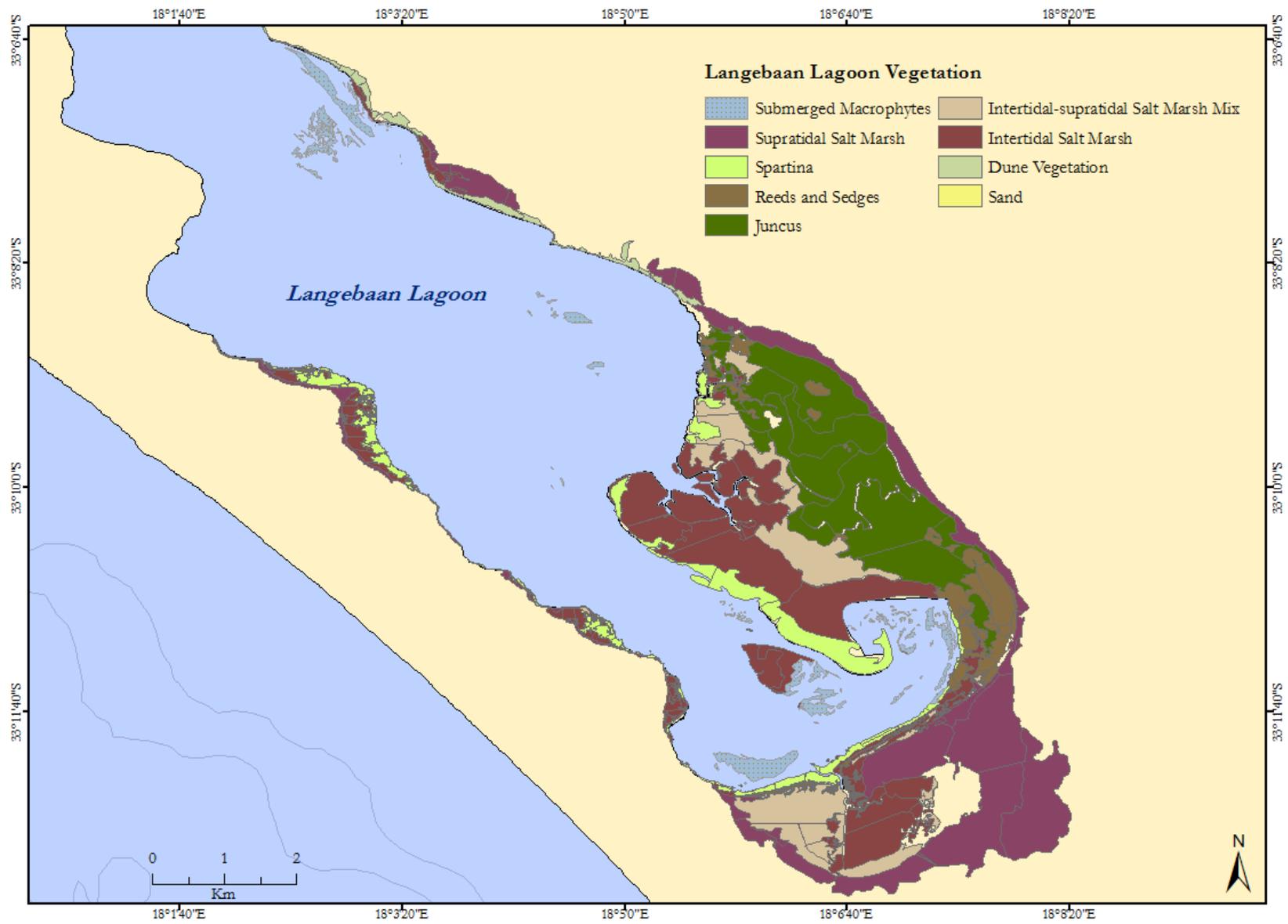


Figure 8.2. Vegetation and habitat structure at Langebaan Lagoon (Source: Shapefiles provided by van der Linden 2013).

## 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 *Assimineia 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<sup>2</sup> 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 *Siphonaria compressa* and *Fisurella mutabilis* and general surface dwellers such as the gastropods *Assimineia 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 occurred. 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.

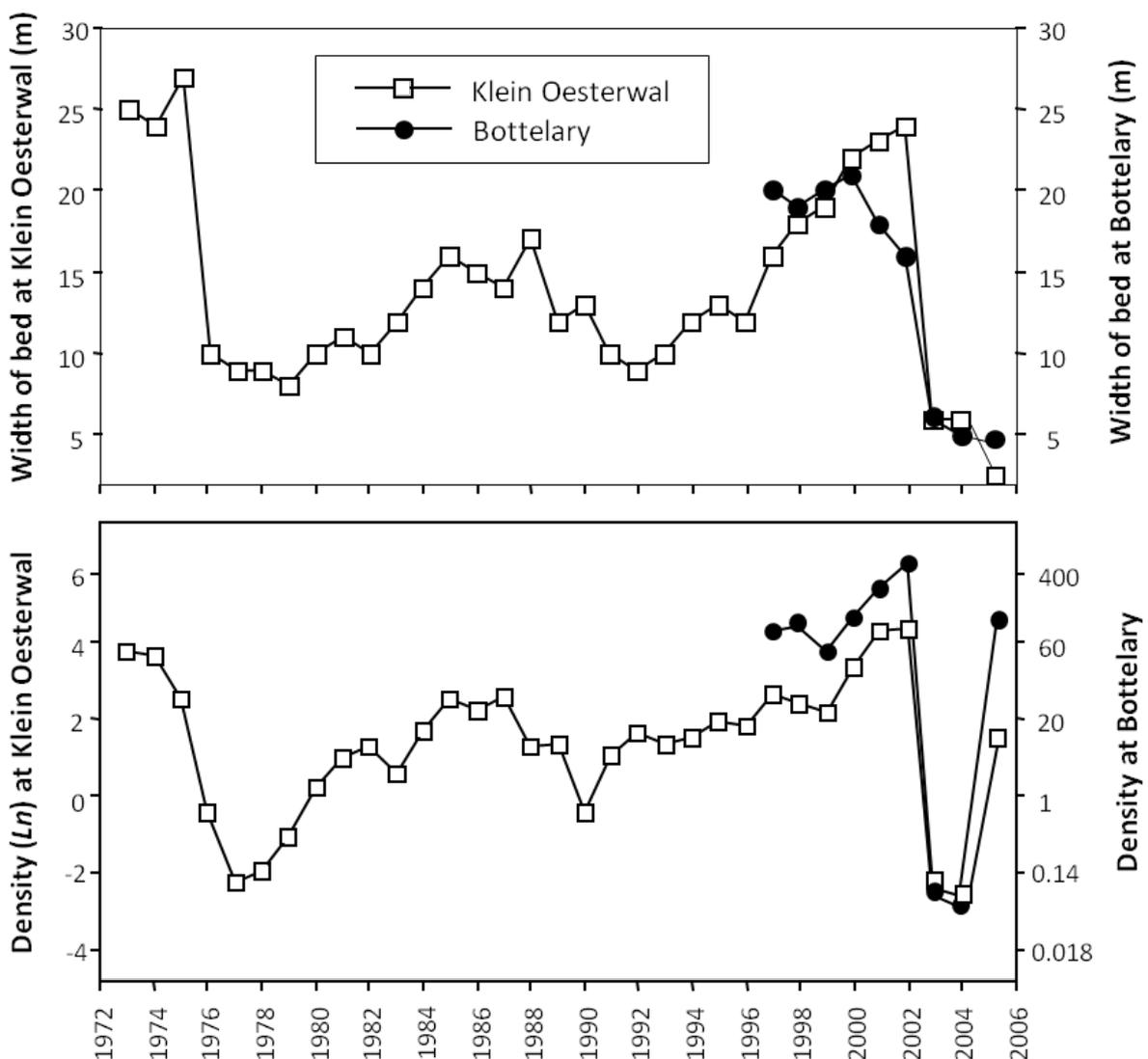


Figure 8.3. Width of the *Zostera* beds and density of *Siphonia* at Klein Oesterwal and Bottelary in Langebaan Lagoon, 1972-2006.

### 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<sup>2</sup> per annum. Total loss during this period was estimated at 325 000 m<sup>2</sup>, 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 Gericke 2008).

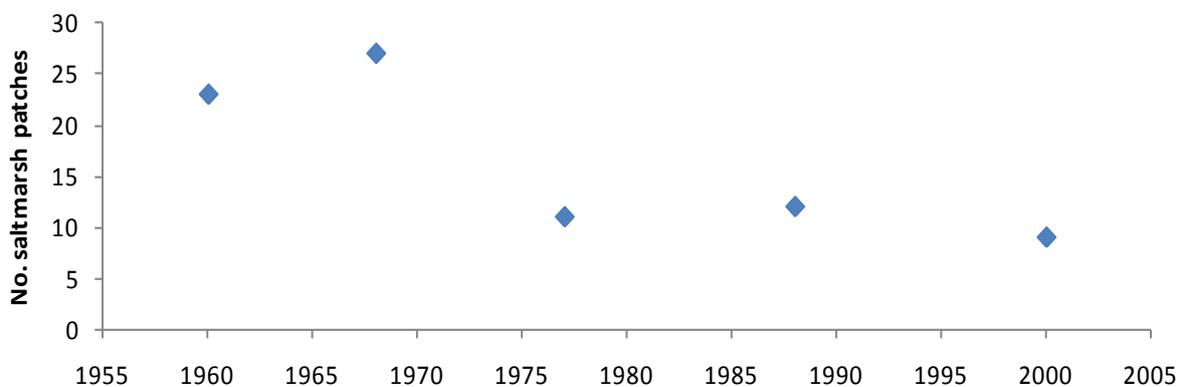


Figure 8.5. Change in the number of discrete saltmarsh patches over time in Langebaan Lagoon. (Data from Gericke 2008).

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 2018 (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 2008-2017 do, however, provide benthic macrofauna data from Saldanha Bay and Langebaan Lagoon that are comparable with those collected in 2018. 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<sup>2</sup> 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<sup>2</sup> to a depth of 30 cm. The former sampling technique (van Veen grab) would be expected to sample a smaller proportion of benthic macrofauna due to its limited ability to penetrate the sediment beyond the surface layers. The suction sampler is effective in penetrating to a depth of 30 cm, which is within range of larger species such as prawns and crabs. The study conducted in 1975 in Langebaan Lagoon (Christie and Moldan 1977), and those conducted by Anchor Environmental Consultants, both made use of a diver-operated suction sampler which sampled an area of 0.24m<sup>2</sup>. 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 the 1999-2017 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 2018

### 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. Since then, 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 2018 sampling sites are illustrated in Chapter 7.

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 third year, are presented in this chapter.

Samples were collected using a diver-operated suction sampler, which sampled an area of 0.08 m<sup>2</sup> 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<sup>2</sup> per site. Three hand-core samples were taken at sites less than 2 m deep, totalling a sampling surface area of 0.08 m<sup>2</sup>. In 2016 and 2017 Elandsfontein samples were collected using a hand-core. This year, in the interest of efficiency, a Van Veen grab was used to collect five replicate samples (each with a sampling surface area of 0.14 m<sup>2</sup>) at each of the Elandsfontein sites. All macrofauna abundance and biomass data were ultimately standardised per unit area (m<sup>2</sup>). 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](http://www.marinespecies.org)). The biomass (blotted wet mass to four decimal places) and abundance of each species was recorded for each sample. Expedient

### 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 2018 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:

$$H' = - \sum p_i (\log p_i) \quad ^{10}$$

The diversity ( $H'$ ) value for each site was plotted geographically and this was used to interpolate values 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 pre-designated locations for past surveys from 1999 to present: Small Bay, Big Bay, Langebaan Lagoon and Elandsfontein.

## 9.4 Benthic macrofauna 2018 survey results

### 9.4.1 Species diversity

Variation in species diversity (represented by the Shannon Weiner Index,  $H'$ ) is presented in

Figure 9.1. Diversity was highest in Langebaan Lagoon (at sites LL 41, LL 34 and LL 37) and was lowest in Big Bay around the iron ore jetty (BB 24 and BB 22) and the LPG site. In Small Bay, the lowest diversity was observed at the yacht basin (SB 1). This 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.

<sup>10</sup> 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.

### 9.4.2 Community structure

An ordination plot, prepared from 2018 macrofaunal abundance data, is presented in Figure 9.2. These data show a very similar pattern as for the diversity data, with the macrofaunal communities present at 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 macrofaunal 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).

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.

The relationship between 2018 macrofaunal abundance data and abiotic data (sediment grain size fractions, TOC, TON and trace metals) was investigated using a Distance Based Linear Model (DistLM) (Anderson *et al.* 2008). A sequential test revealed that a combination of all input variables explained ~45% of the variation in macrofaunal abundance data, with medium sand explaining the greatest amount (~15%) followed by the mud fraction (8%) and gravel (5%).

The full model can be visualised by examining the distance-based redundancy analysis (dbRDA) ordination (Figure 9.3). The first two axes capture 60.8% of the variability in the fitted model, and 27.2% of the total variation in the data cloud. The black lines in the dbRDA plot are category vectors, whereby the length of the vectors is a measure of the strength of the relationship between that category and the axes. The medium sand category clearly separated the Langebaan Lagoon sites from the Big Bay and Small Bay sites. Further separation between sites seems to be driven by mud and gravel.

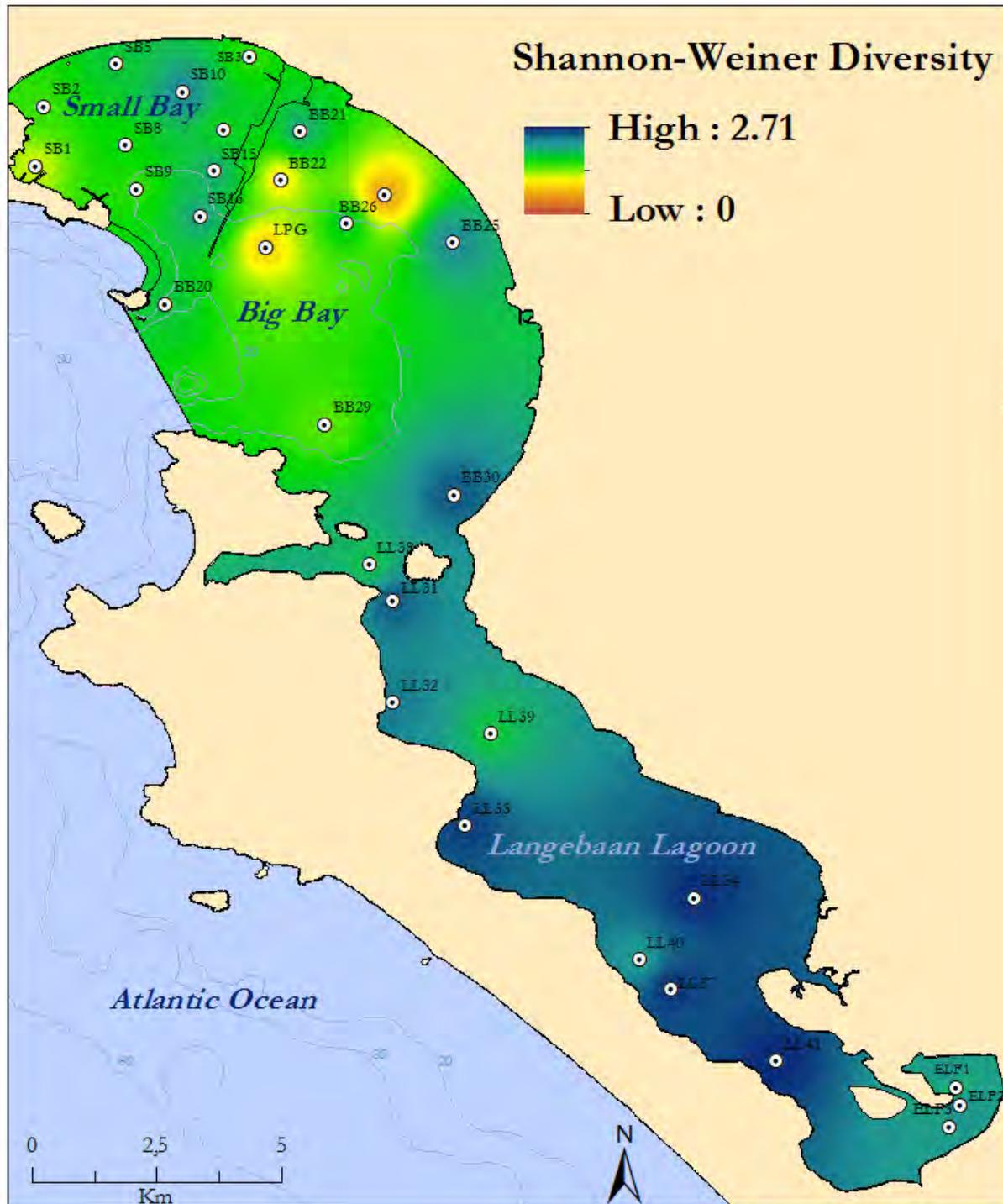


Figure 9.1 Variation in the diversity of the benthic macrofauna in Saldanha Bay and Langebaan Lagoon as indicated by the 2018 survey results ( $H' = 0$  indicates low diversity,  $H' = 3.32$  indicates high diversity).

Species that contributed significantly 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.

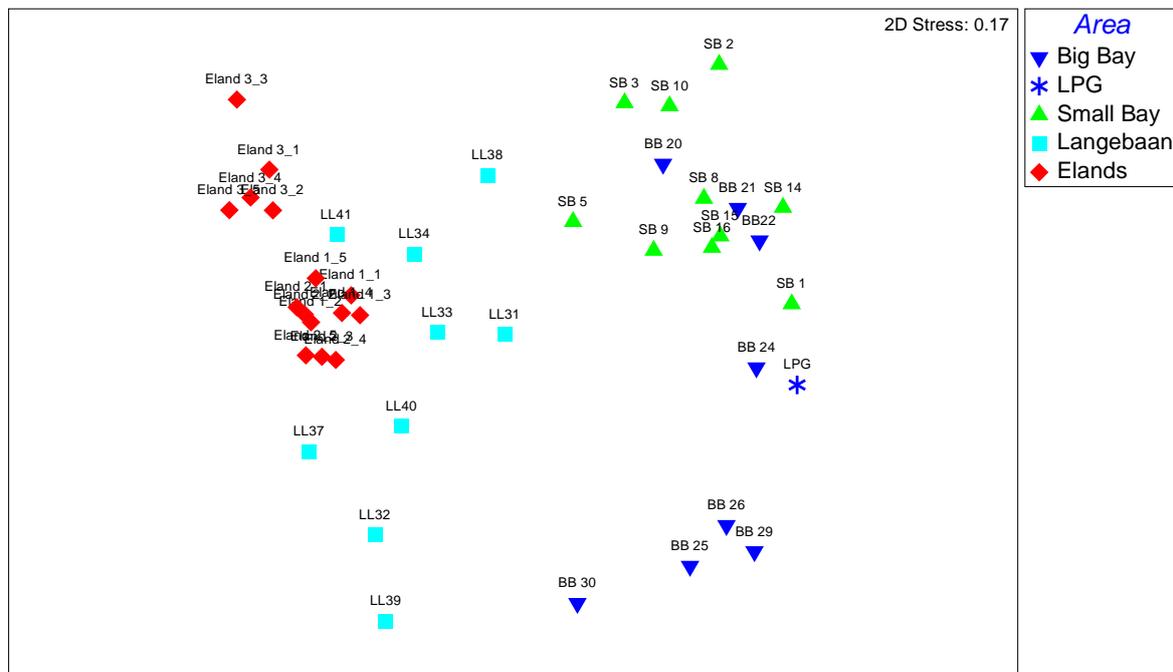
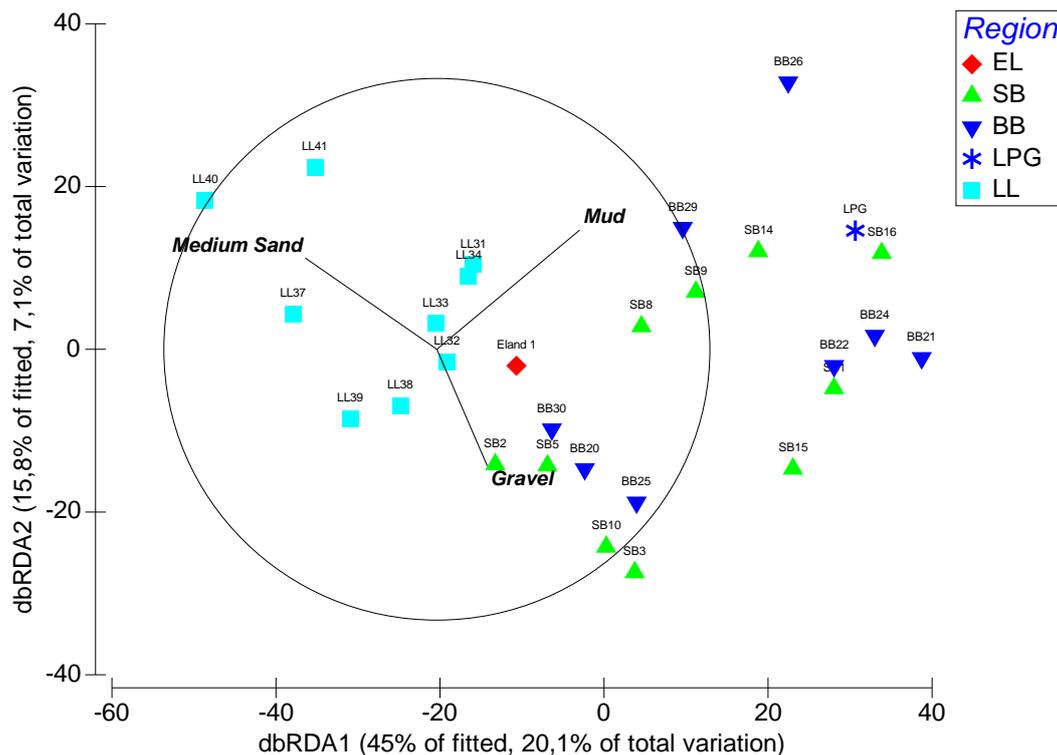


Figure 9.2 Ordination plots showing similarity amongst sample sites based on benthic macrofauna abundance in 2018. Symbols on the ordination plots are as follows: Small Bay (SB), Big Bay (BB), Langebaan Lagoon (LL) and Elandsfontein (Elands).



**Figure 9.3** dbRDA plot of 2018 macrofaunal abundance data. Sediment fractions, TOC, TON, C:N and trace metal concentrations were included as categorical predictors in this design. Sediment fractions were arcsine transformed prior to analysis. The blue lines are category vectors, whereby the length of the vector is a measure of the strength of the relationship between that category and the axes.

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*, the mud prawn, *Upogebia africana*, 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.

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 9.4. 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 9.4). 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 9.4). Detritivores were numerically the most abundant group on the mudflats at Elandsfontein and in Langebaan Lagoon (Figure 9.4). 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 and organic pollution.

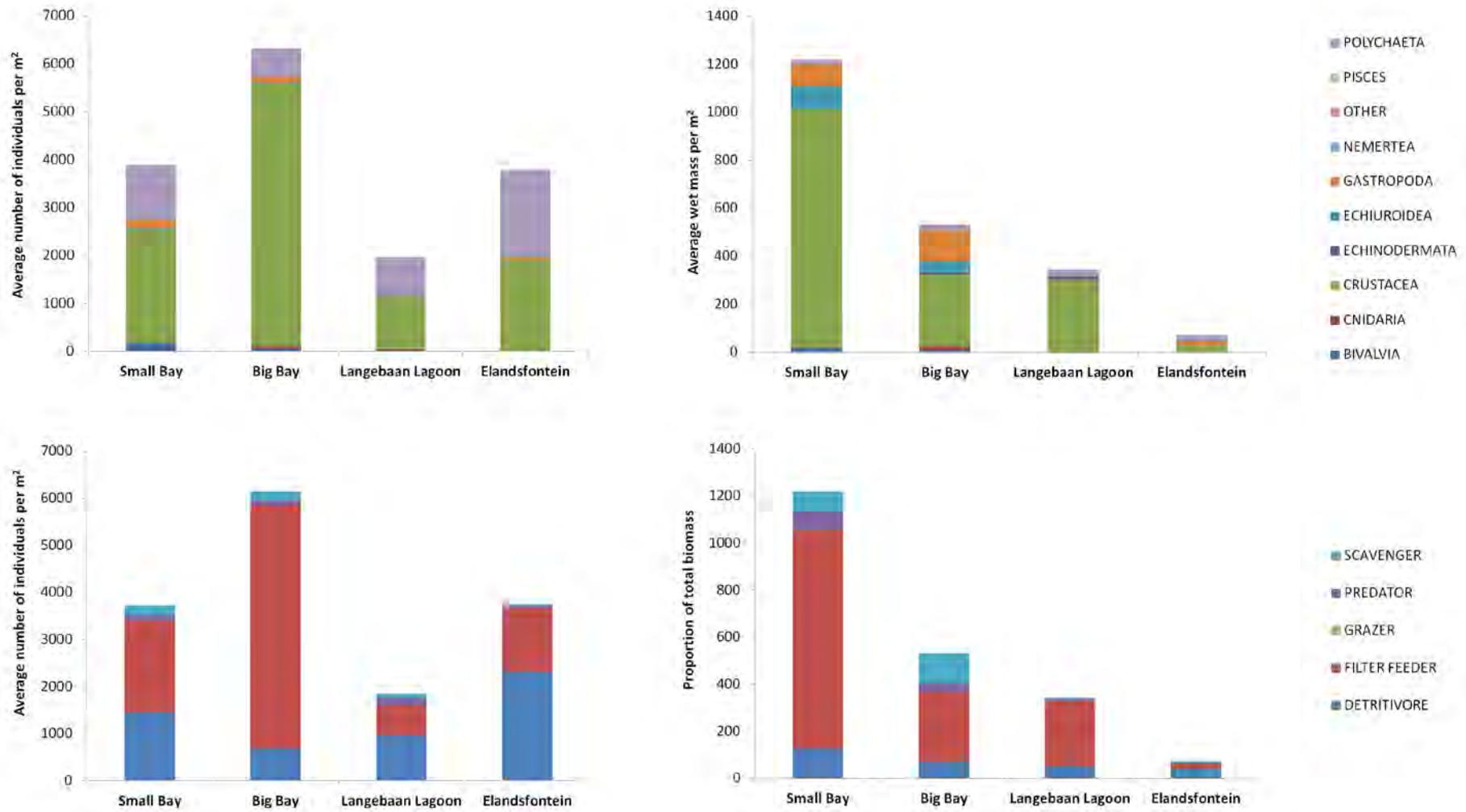


Figure 9.4 Average abundance and biomass ( $g/m^2$ ) of benthic macrofauna by functional and taxonomic group in Big Bay, Small Bay, Langebaan Lagoon and Elandsfontein in 2018.

## 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 2018 is shown in Figure 9.5. 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<sup>3</sup> 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<sup>3</sup> 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<sup>3</sup> 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, 2013-2018).

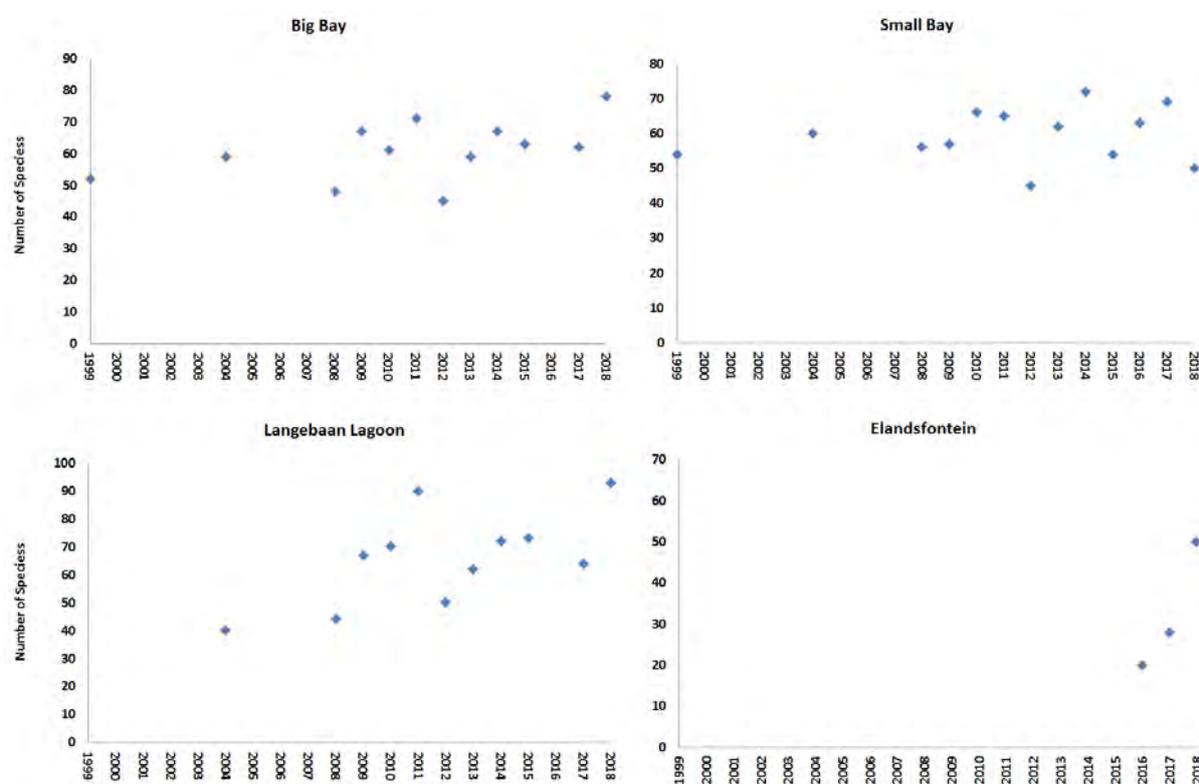


Figure 9.5 Variation in the number of species recorded at Small Bay, Big Bay, Langebaan Lagoon (1999 – 2018) and Elandsfontein (2016 – 2018).

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 third 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 22 species were recorded here in 2018 – this is most likely attributable to the change in sampling gear used (despite the fact that all data were standardised per unit area). The Van Veen grab does appear to be more effective at sampling benthic macrofauna and we recommend this be continued for future monitoring.

## 9.6 Abundance, biomass and community composition

Changes in the abundance and biomass of benthic macrofauna in Small Bay are shown in Figure 9.6. 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<sup>3</sup> of material was removed from the Saldanha Side of the iron ore terminal, but we cannot be certain of this. Since then, both abundance and biomass have increased in Small Bay with no significant change observed in 2018. 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<sup>3</sup> of seabed material was removed from the area of the Mossgas Quay and the Multi-purpose Terminal in 2007/2008.

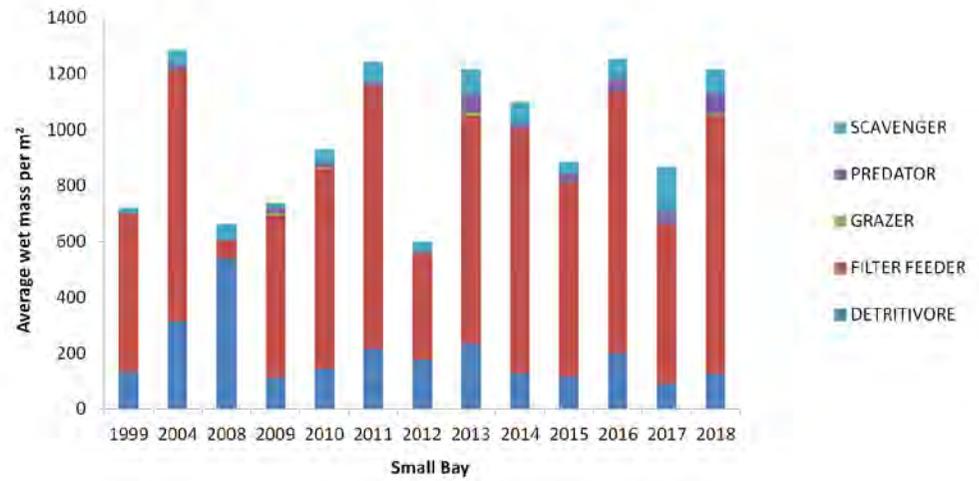
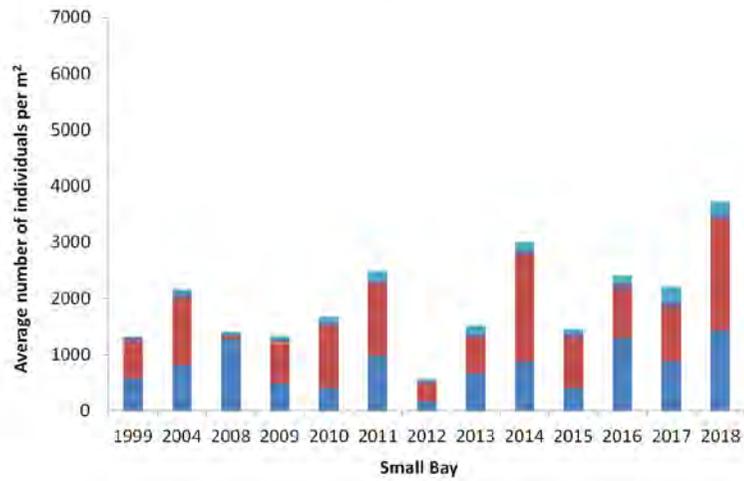
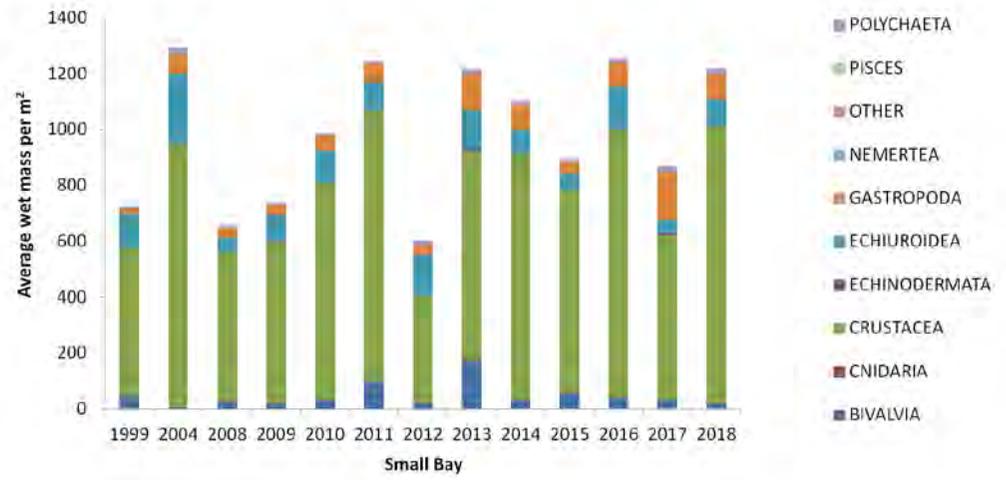
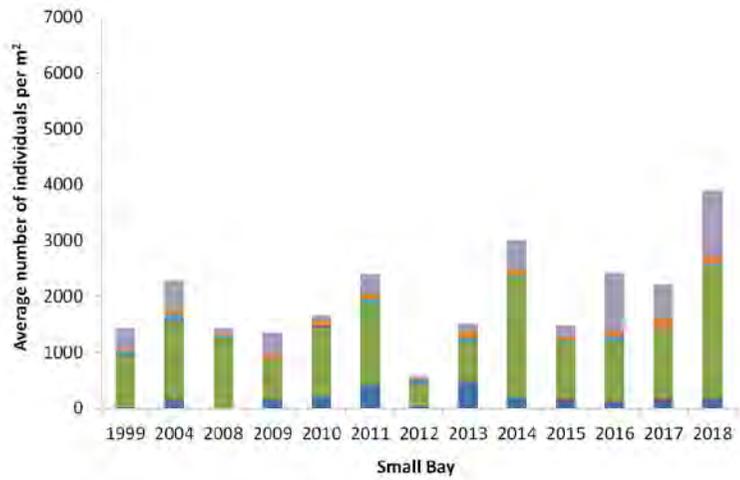


Figure 9.6 Overall trends in the abundance and biomass (g/m<sup>2</sup>) of benthic macrofauna in Small Bay as shown by taxonomic and functional groups.

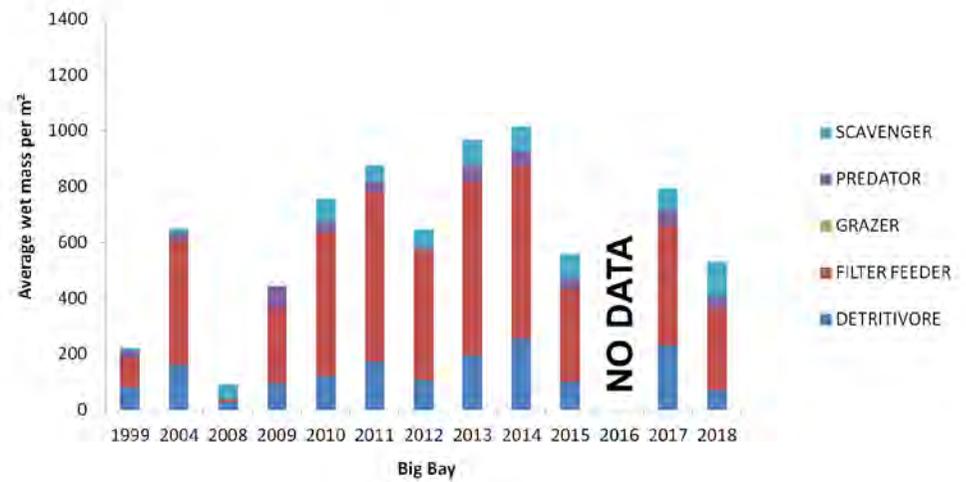
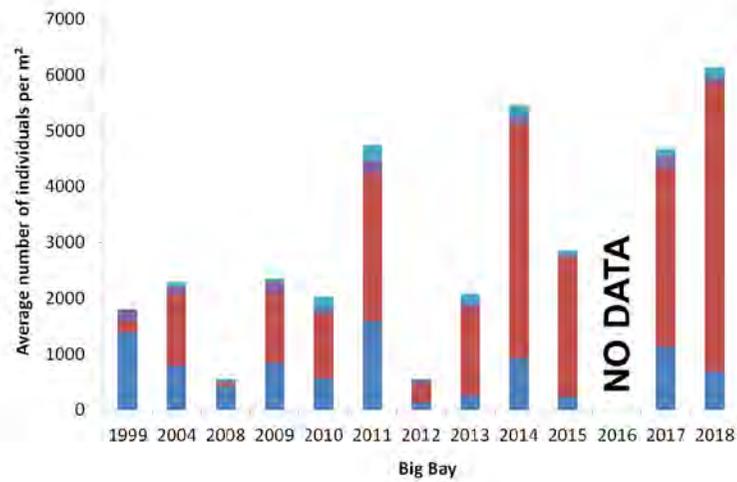
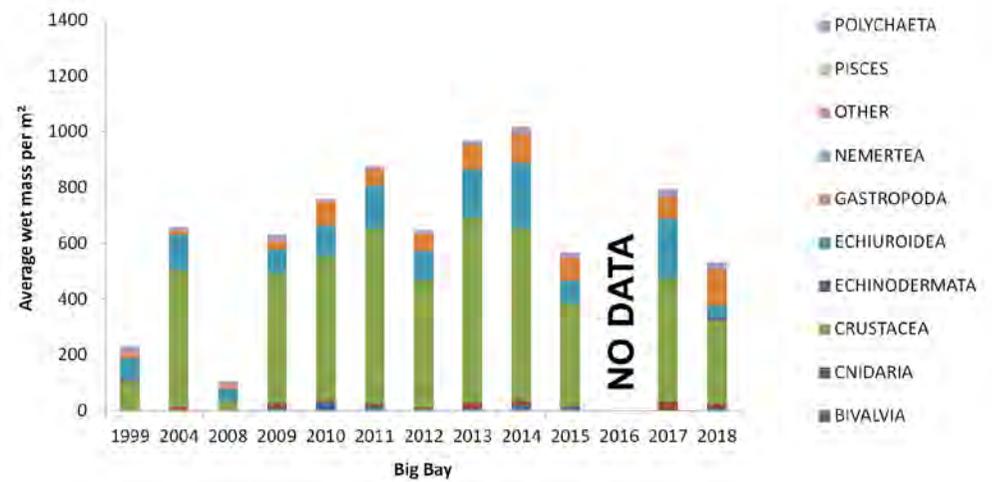
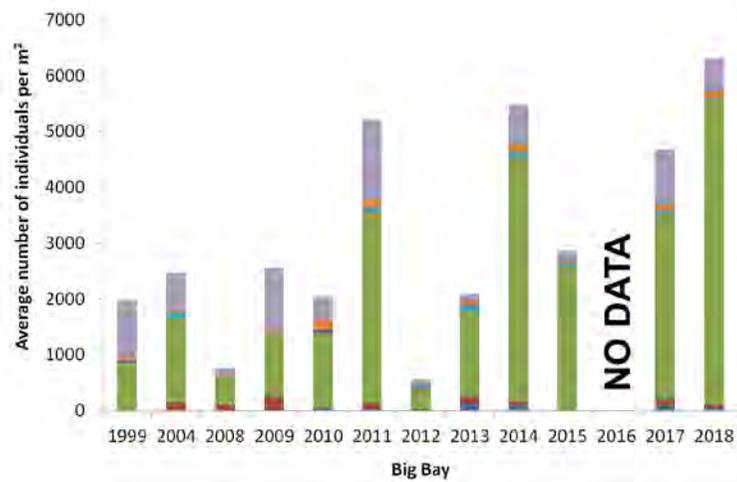


Figure 9.7 Overall trends in the abundance and biomass (g/m<sup>2</sup>) of benthic macrofauna in Big Bay as shown by taxonomic and functional groups.

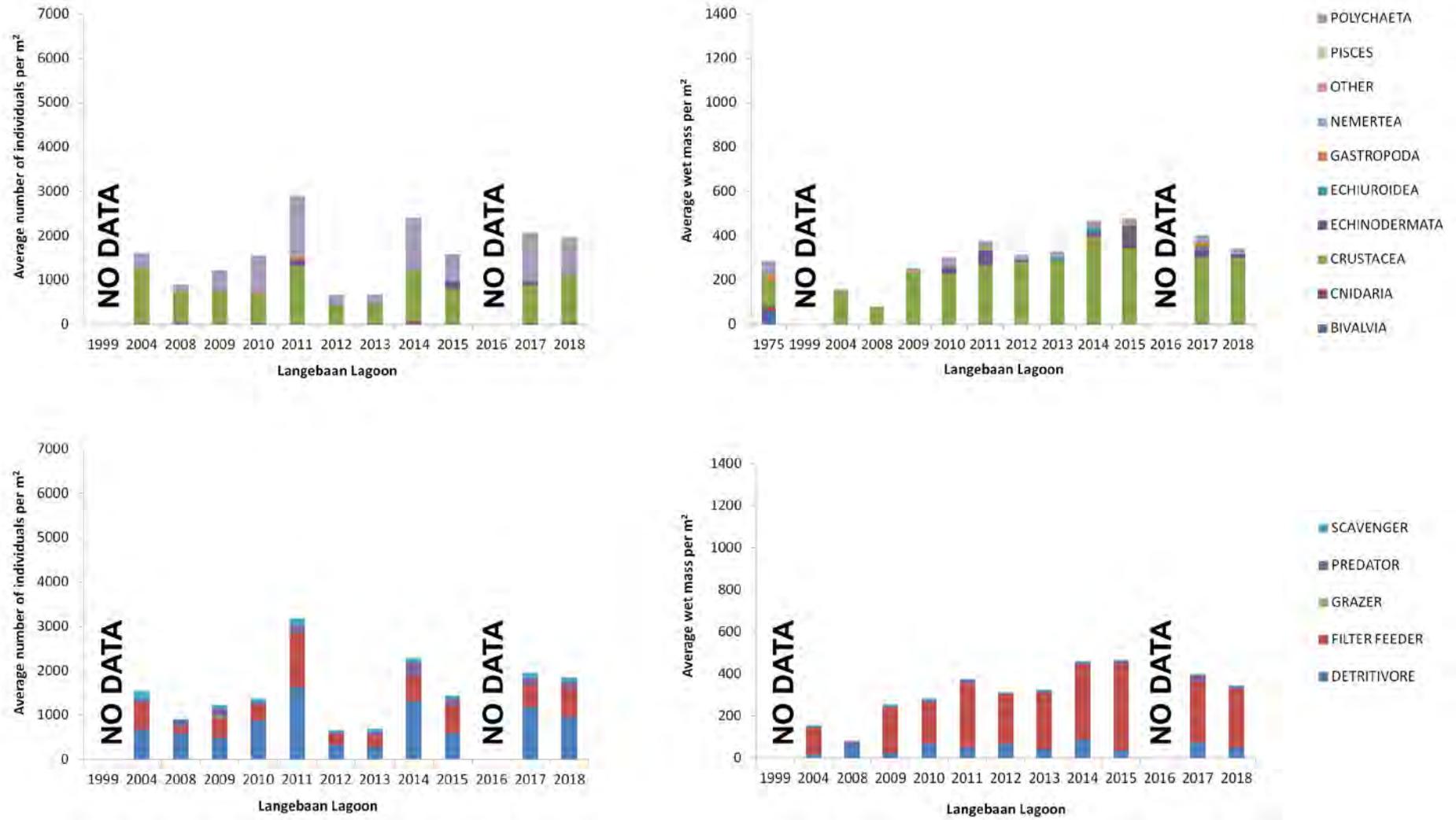


Figure 9.8 Overall trends in the abundance and biomass ( $\text{g}/\text{m}^2$ ) of benthic macrofauna in Langebaan Lagoon as shown by taxonomic and functional groups.

Filter feeders tend to be more sensitive to levels of suspended sediment than 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. These filter feeders 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 9.9). 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 2009-2018 suggests that the smaller 2009 dredging event had a limited impact with little change in macrobenthic community structure over the last ten years.

### 9.7.2 Big Bay

The 2008 Big Bay macrobenthos samples also clustered separately from all other years on the ordination plot indicating that they were dissimilar to the others in some way (Figure 9.9). 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 9.9). Low abundance or absence of filter feeding mud prawns *Upogebia capensis*, the polychaete *Notomastus latericeus* and the isopod *Natanolana 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 2009-2018 suggests that the smaller 2009 dredging event had a limited impact with little change in macrobenthic community structure over the last ten years.

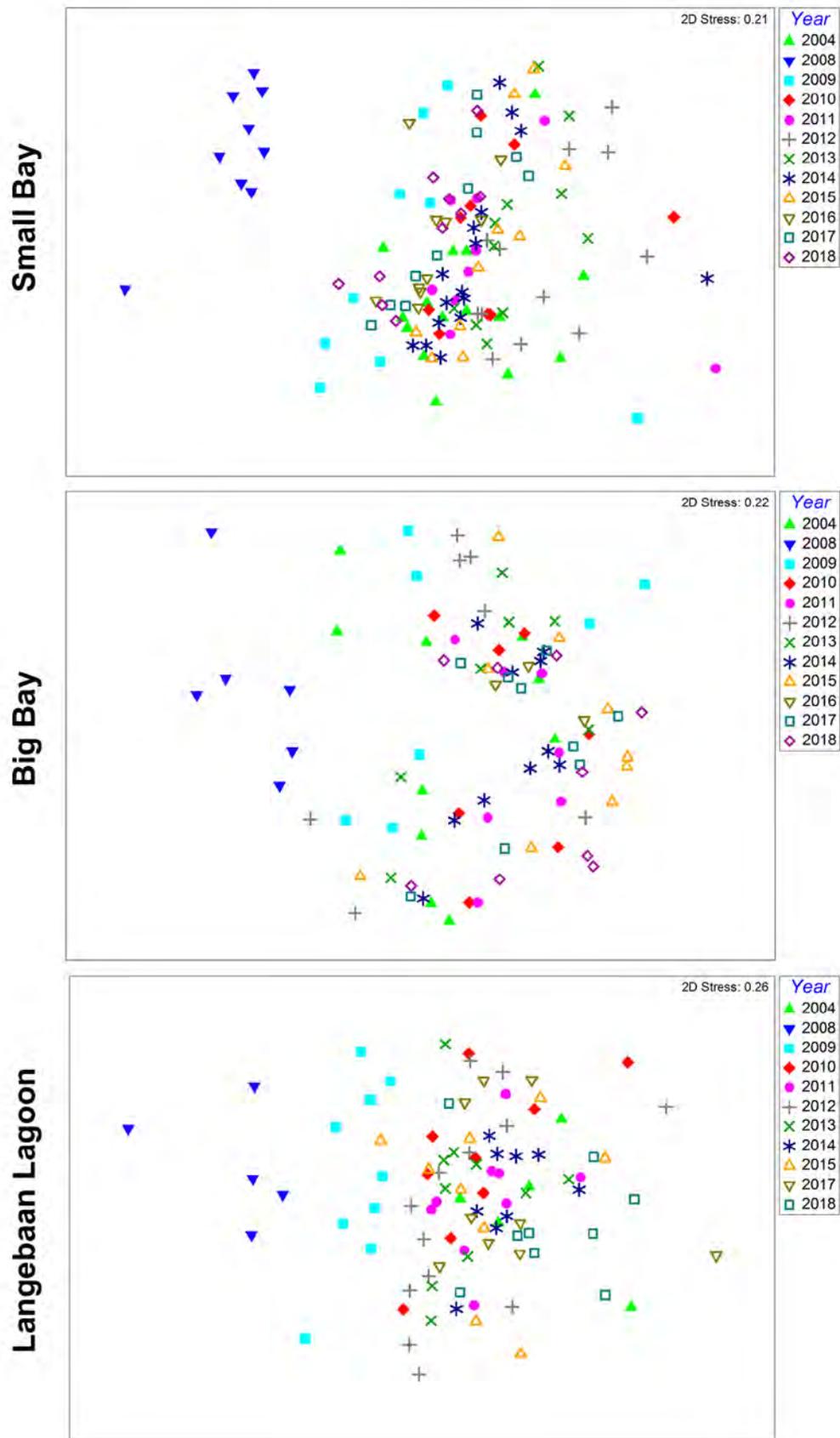


Figure 9.9. MDS plots based on macrofaunal abundance data from samples collected in Small Bay (top), Big Bay (middle) and Langebaan Lagoon (bottom) during the period 2004-2018.

## 9.8 Elandsfontein 2018 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 third set of baseline results are presented here and are assessed in context of the entire Saldanha Bay/Langebaan Lagoon system.

The ordination plot prepared from the 2018 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 (69.4% dissimilarity) and in turn are most dissimilar to those in Small Bay (86.4%) and Big Bay (88.5%). 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, sun-warmed and possibly freshwater/estuarine influenced Elandsfontein habitat.

In total, 50 species (consisting of polychaetes, crustaceans, gastropods, bivalves, a nemertean and a cnidarian - Figure 9.10) were recorded at Elandsfontein, of which six are found nowhere else in the system namely the polychaetes *Ancistrosyllis rigida* and *Scoloplos johnstonei*; the crabs *Danielella edwardsii* and *Paratyloidiplax algoensis*; the gastropod *Nassarius kraussianus*; and an isopod belonging to the Sphaeromatidae.

Macrofaunal abundance and biomass results from 2016 to 2018 (broken down into taxonomic and functional feeding groups) are shown in Figure 9.10. There does not appear to be any significant difference in mean abundance over the years, however, mean biomass has decreased in 2018. On a community composition level, the samples collected in 2018 group separately to those collected in 2016 and 2017 (Figure 9.11). In addition there are further differences in macrofaunal community structure between the different sites at Elandsfontein with sites Eland\_1 and Eland\_2 grouping together and site Eland\_3 forming its own cluster (Figure 9.11). A simpler analysis reveals 66.75% dissimilarity between Eland\_3 and Eland\_1 & 2 with the amphipod, *Urothoe grimaldii*, the prawns *Upogebia africana* and *Callichirus kraussi*, and the polychaetes *Notomastus latericeus*, *Telothelopus 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 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.

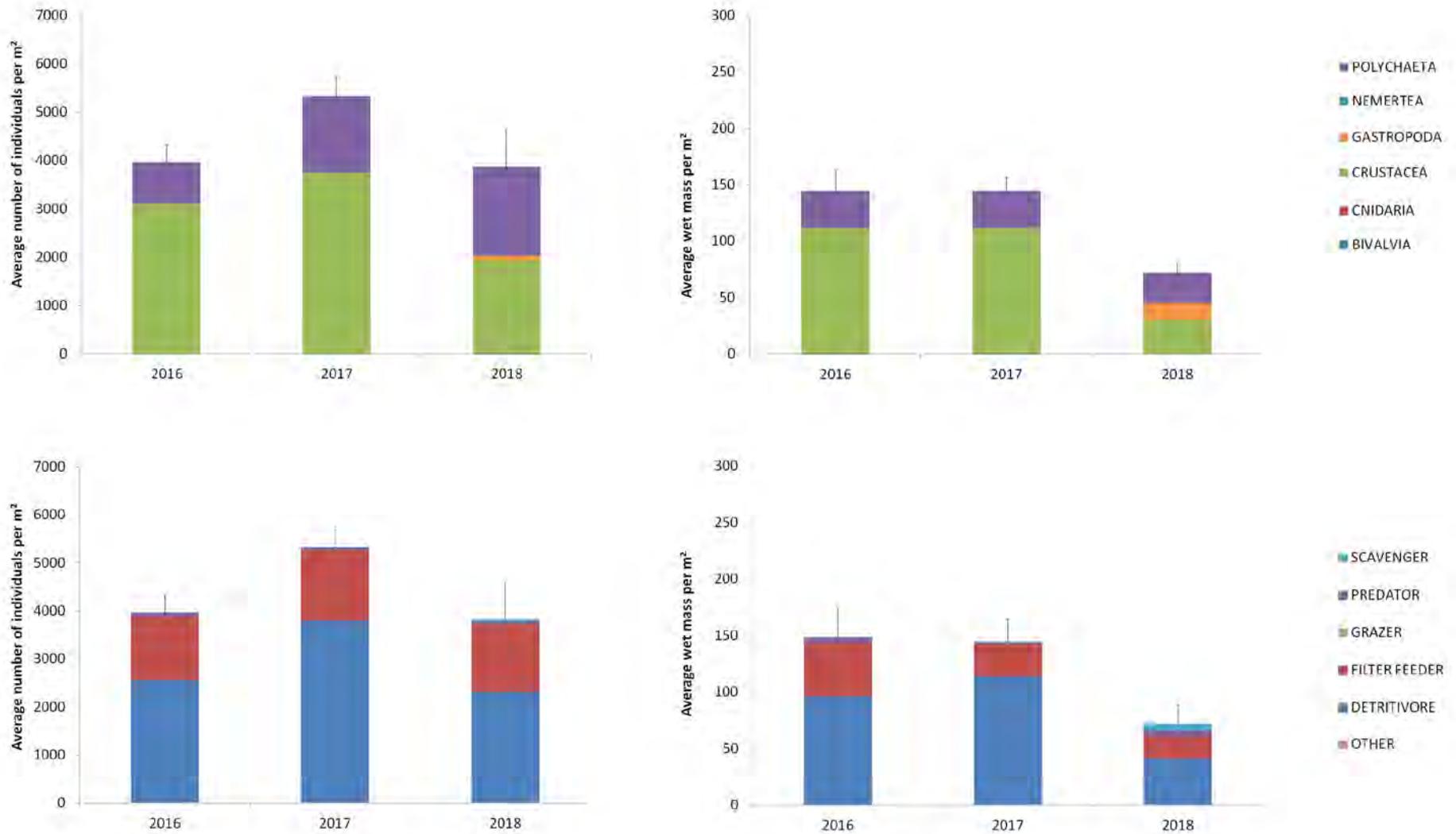
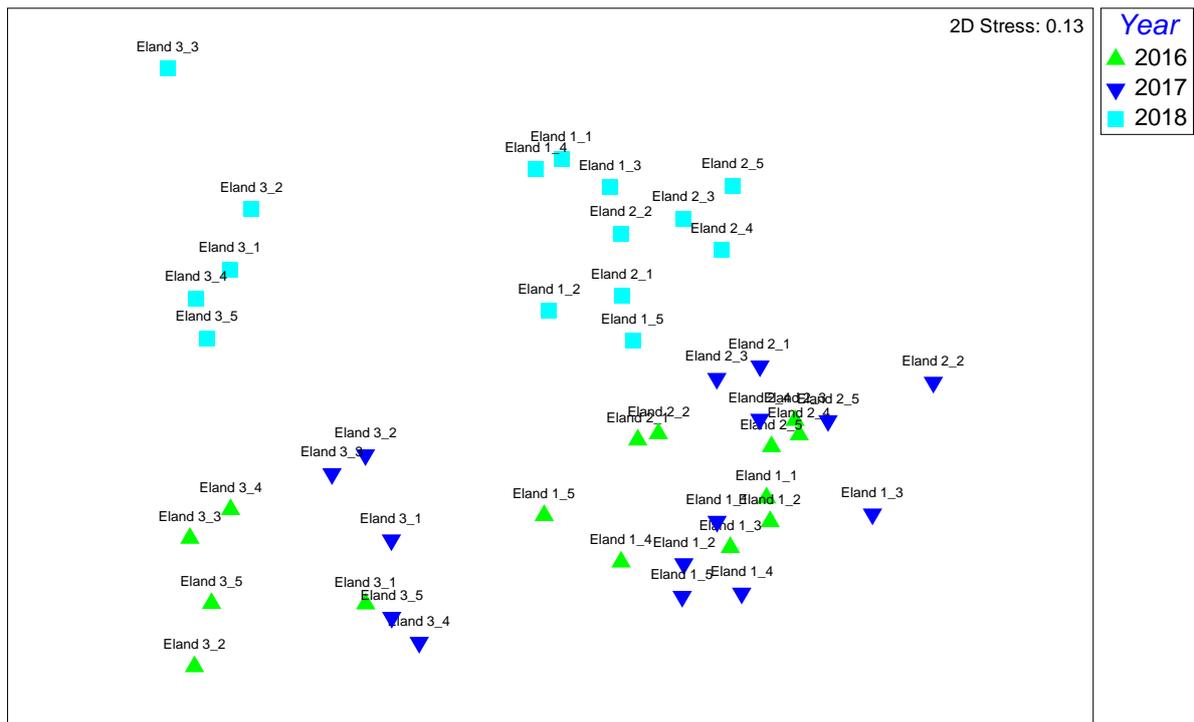


Figure 9.10 Average abundance and biomass (g/m<sup>2</sup>) of benthic macrofauna by functional and taxonomic group from sampling sites at Elandsfontein from 2016 to 2018 - error bars are + 1 Standard Error (n=5).



**Figure 9.11** MDS plot based on macrofaunal abundance data from samples collected at Elandsfontein from 2016 to 2018.

## 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 2018 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 2010-2017) 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 fluctuations observed in abundance and biomass data from 2016 to 2018 are 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 a clear trend in 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 among 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.

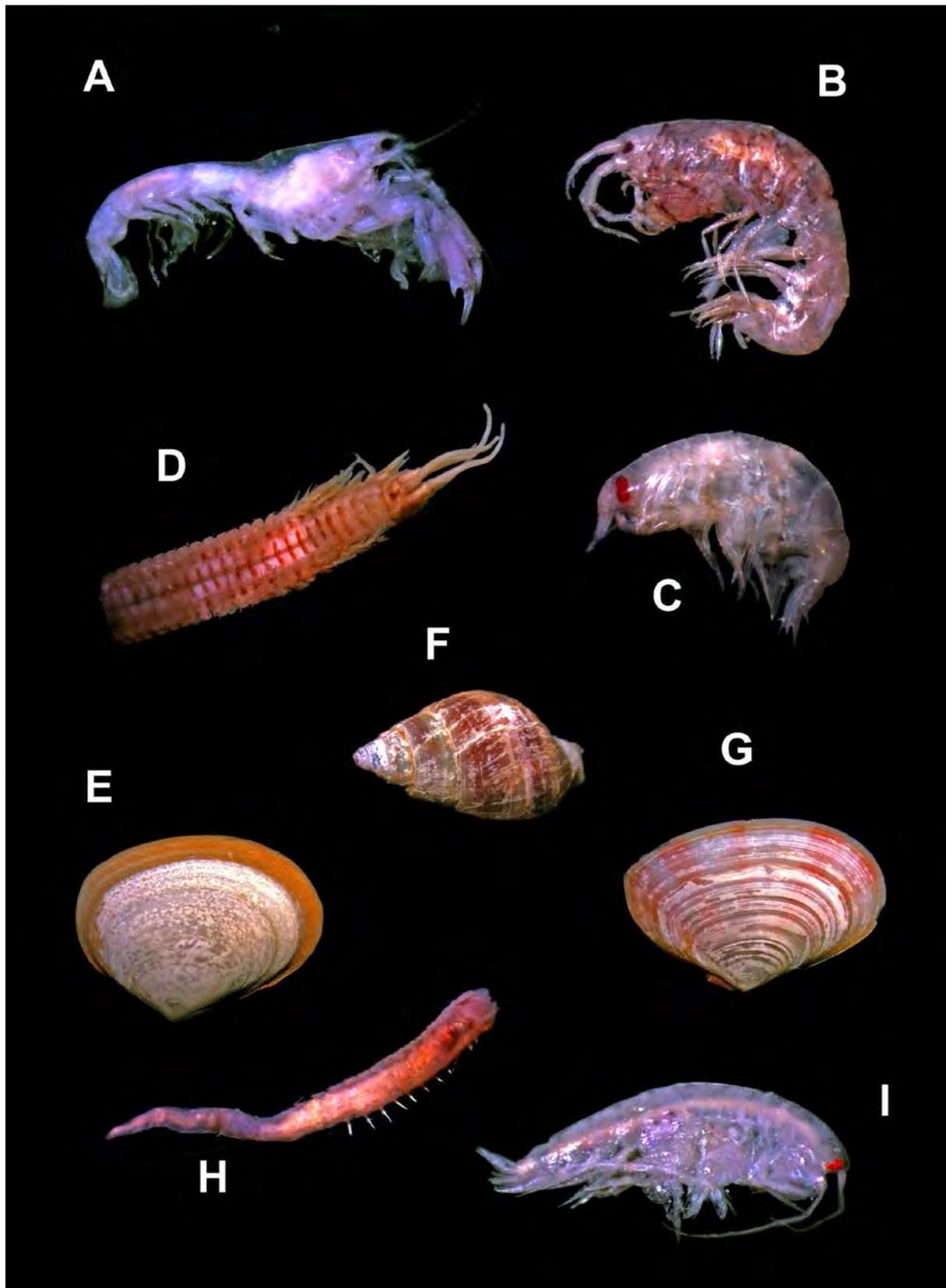


Figure 9.12. Benthic macrofauna species frequently found to occur in Saldanha Bay and Langebaan Lagoon, photographs by: Aiden Biccard. A – *Upogebia capensis*, B – *Idunella lindae*, C – *Hippomedon normalis*, D – *Diopatra monroi*, E – *Macoma c. ordinaria*, F – *Nassarius vinctus*, G – *Tellina gilchristi*, H – *Sabellides luderitzi*, I – *Ampelisca anomola*.

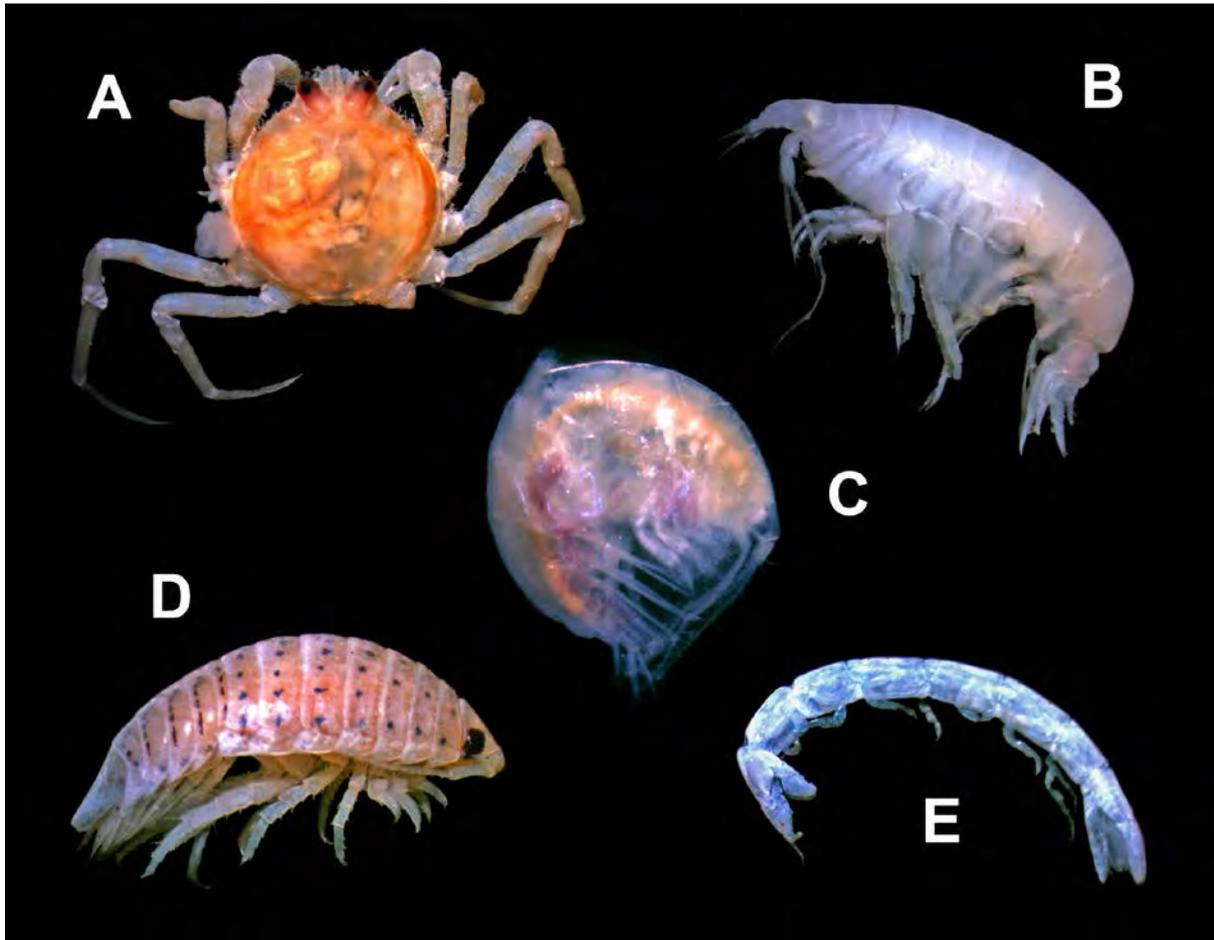


Figure 9.13. Benthic macrofauna species frequently found to occur in Saldanha Bay and Langebaan Lagoon, photographs by: Aiden Biccard. A – *Hymenosoma obiculare*, B – *Socarnes septimus*, C – *Ampelisca palmata*, D – *Eurydice longicornis*, E – *Centrathura caeca*.

## 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* (see Chapter 13).

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 constraints a survey was not conducted in 2016.

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 eleventh annual monitoring survey conducted in April 2018.

## 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 The location of the eight rocky shore study sites in Saldanha Bay are 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.



Dive School - very sheltered



Jetty - very sheltered



Schaapen East - sheltered



Schaapen West - sheltered



Iron Ore Jetty - semi-exposed



Lynch Point - semi-exposed



North Bay - exposed



Marcus Island - exposed

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<sup>2</sup>). 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<sup>th</sup>-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 ( $H'[\log_e]$  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 2018, a total of 99 taxa were recorded from all rocky shore sites, of which 58 taxa were invertebrates (59%) and 41 (41%) algae. The faunal component was represented by 18 filter feeding taxa, 26 grazers, and 14 predators/scavengers. The algal component comprised 27 corticated (foliose) seaweeds, seven 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, 2016, 2017). 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). This is indeed true for all sites over the survey years (Anchor Environmental Consultants 2009, 2010, 2011, 2012b, 2013b, 2014, 2015, 2016, 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 Consultants 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 Consultants 2015). The latter typically accumulated in moist cracks and crevices at Lynch Point, Marcus Island and North Bay.

Field data collected in 2018 showed that Jetty and Dive School were less similar to the other high shore sites due to the presence of the barnacle *Oxystele antoni*. Most quadrats were largely barren with >45% of the similarity attributed to the periwinkle at each site. The alien barnacle *Balanus glandula* occurred in the high shore zone at the Dive School, North Bay and Schaapen West but with a relatively low average coverage (<2%). On average, barren rock accounted for >70% on the high shore, while algal cover was extremely sparse, except at the Schaapen Island sites which had  $\pm 1.5\%$  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 antoni* 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 2018 showed that ephemeral algae *Ulva* spp. and *Porphyra capensis*, the whelk *Burnupena* spp., the cushion starfish *Parvulastra exigua*, the encrusting algal *Hildenbrandia* spp. and the limpet *Siphonaria capensis* 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 most abundant at the semi-exposed site Iron Ore Terminal with an average cover of 3% and 7% in 2018, down from 20% and 26% in 2017. Substantia numbers were also recorded at Marcus Island in 2018. In contrast, neither of these species was present in substantial numbers 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.* 2010b). 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 low in comparison with the exposed sites (North Bay and Marcus Island). Algal cover at sheltered sites was much lower than that at exposed sites, and consisted primarily of the green alga, *Ulva* spp., the encrusting algae *Hildenbrandia* spp. and a variety of encrusting coralline species. At the sheltered Schaapen Island sites, the ground cover was dominated by a diverse array of algal species, with encrusting coralline species 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 worm *Spirobis* spp. *Aulacomya atra* can be found living deep down in *Mytilus* beds, taking advantage of the moisture within the overlying 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 2018 survey, the ribbed mussel contributed <5% to the cover. As these populations cannot be seen without destructive sampling, it is possible that the changes in *A. atra* cover recorded between survey years are at least partly due to the *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 6% compared to 33% on 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 2018 at each site (Figure 10.4). 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. North Bay 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 16% cover at Dive School to 55% 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.

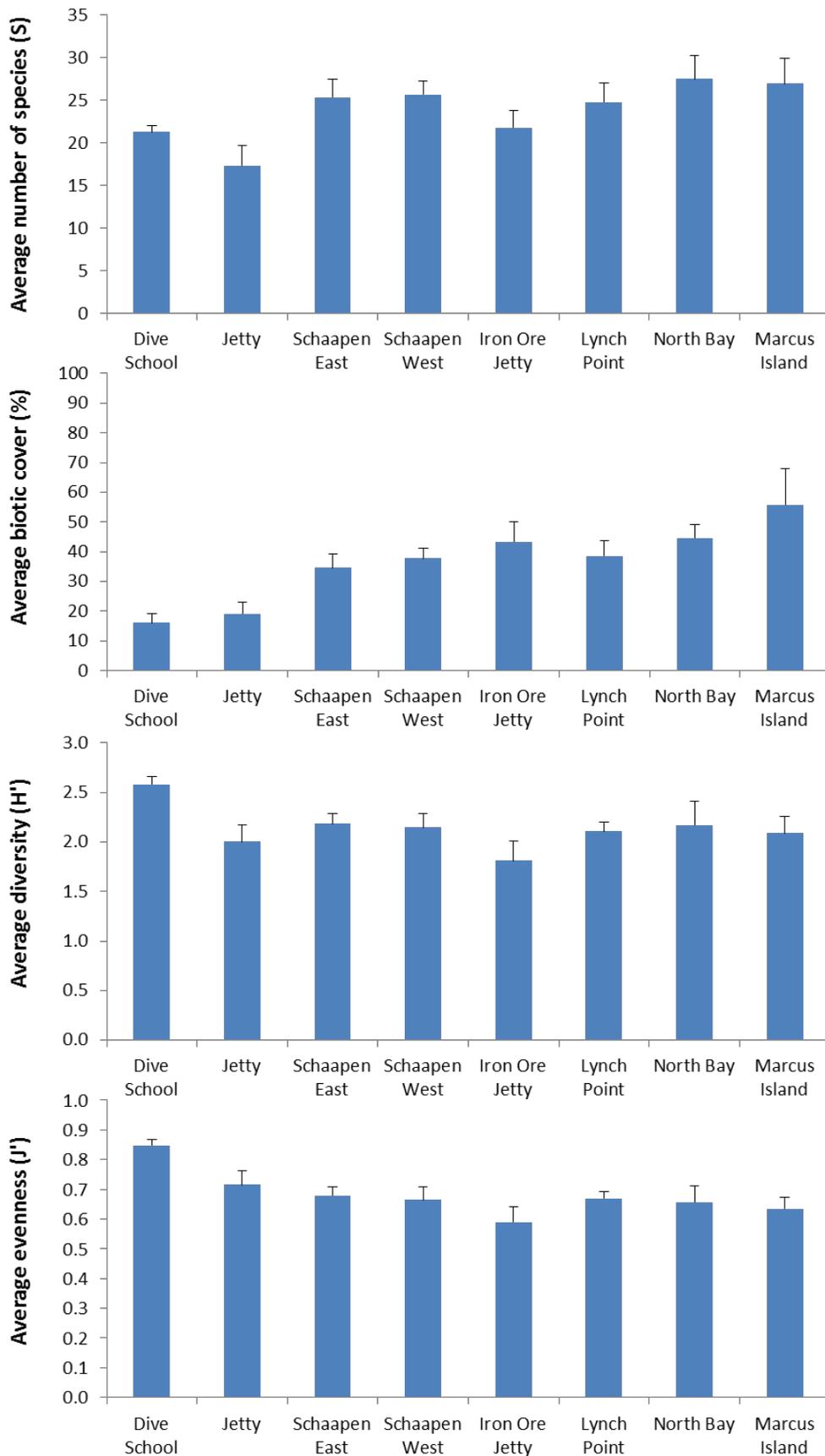


Figure 10.4 Temporal biotic cover data from 2005 – 2018 averaged across years and displayed as biotic indices of ‘species number’ (S), ‘biotic cover’ (N), ‘diversity’ (d) and ‘evenness’ (J’). Error bars indicate standard error.

### **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 10.5). 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 10.5). 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 0.23, 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.

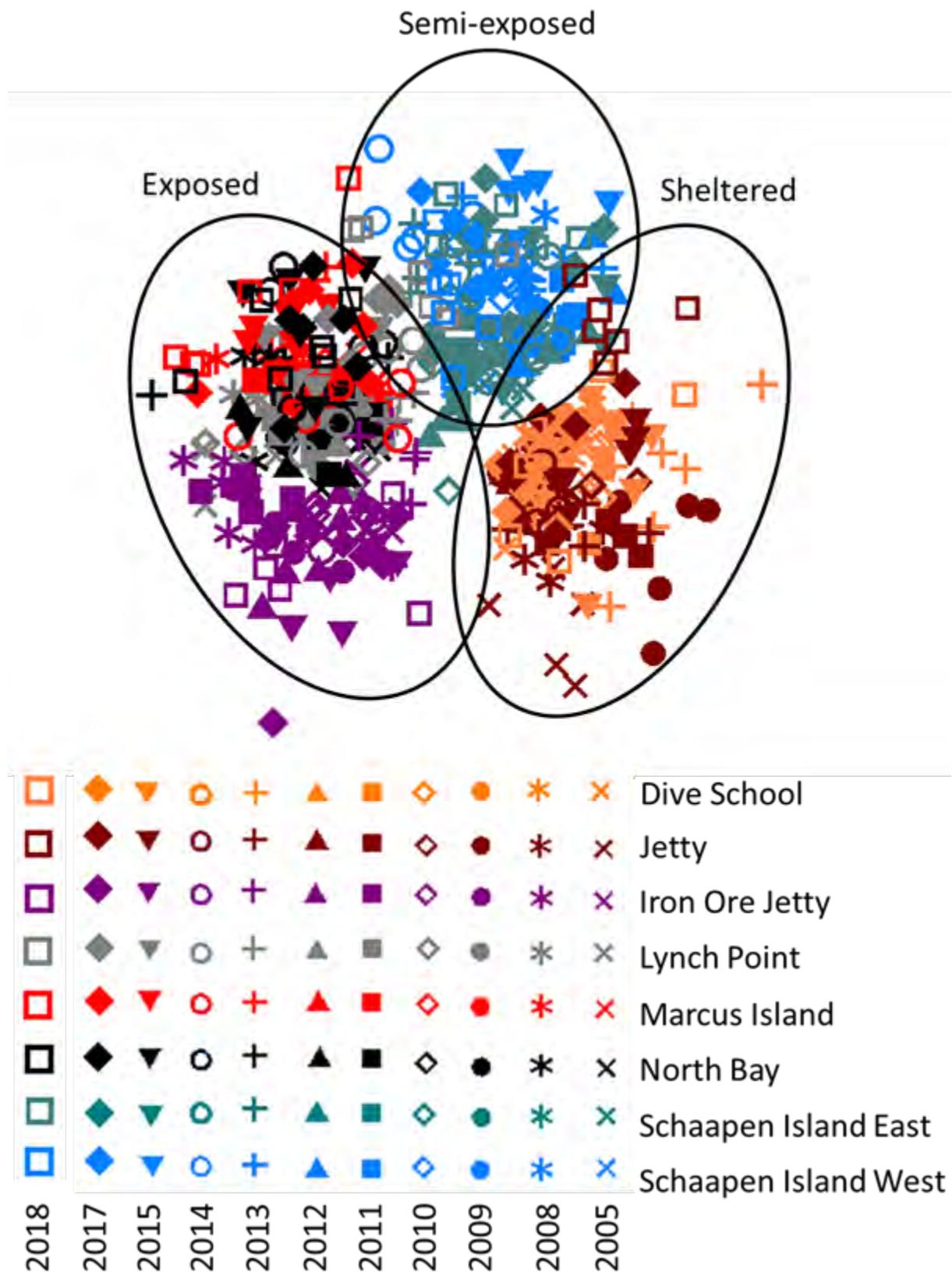


Figure 10.5 Multi-dimensional scaling (MDS) plot of the rocky shore communities at the eight study sites from 2005 to 2018. The circles delineate a 40% similarity level and the plot has with a 2D stress of 0.23.

### 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 2018 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 2018, except for Jetty where four species contributed and the exposed site Lynch Point where no single species contributed >4% (Table 10.1). For the latter site, 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 eight algal species listed, two were ephemeral algae, four were corticated algae, and two were encrusting algae. The only animals listed were two filter-feeding species, the alien barnacle *Balanus glandula* and the introduced mussel *Mytilus galloprovincialis*. Two grazing limpets were also listed, *Scutellastra cochlear* and *Cymbula oculus*. Percentage cover of the alien barnacle *Balanus glandula* increased from 2015 to 2017 at Schaapen West and decreased at North Bay.

The presence of diatoms contributed to differences between the years at the North Bay and Marcus Island rocky shore sites. 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). The decrease in cover of *Gigartina* contributed largely to the difference between the years at Dive School, Jetty and Schaapen East. The appearance of *Cymbula oculus* was largely responsible for changes at the Jetty. At Marcus Island and North Bay, the increase in diatoms contributed to the differences at both sites making them the best indicators of dissimilarity between the years. At the Iron Ore Terminal there was a noticeable increase in *Gigartina* and an absence of red turf.

**Table 10.1** SIMPER results listing the species that contribute >4% to the dissimilarity between 2017 and 2018 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	2017 %cover	2018 %cover	Ave. dissimilarity	% Contribution	Ave. dissimilarity between years
Dive School	<i>Cymbula oculus</i>	0	0.83	2.36	5.11	46.11
	<i>Gigartina polycarpa</i>	0.89	0.27	1.86	4.04	
Jetty	<i>Hildenbrandia spp.</i>	0	1.20	3.54	5.95	59.37
	<i>Gigartina bracteata</i>	0	1.06	3.12	5.26	
	<i>Gigartina polycarpa</i>	1.27	0.23	3.11	5.24	
	<i>Porphyra capensis</i>	0	0.96	2.90	4.89	
Schaapen East	<i>Porphyra capensis</i>	0.1	1.20	2.38	4.30	55.38
	<i>Gigartina polycarpa</i>	1.09	0.09	2.14	3.86	
Schaapen West	Green turf	1.38	0	2.68	5.39	49.67
	<i>Balanus glandula</i>	0.09	0.78	1.40	2.81	
Iron ore terminal	Red turf	1.34	0	3.43	6.21	55.23
	<i>Gigartina bracteata</i>	0	1.02	2.66	4.81	
	<i>Grateloupia longifolia</i>	1.01	0.16	2.42	4.38	
Lynch Point*	Red turf	0.95	0.00	1.87	3.76	49.62
	<i>Scutellastra cochlear</i>	1.00	0.12	1.76	3.55	
North Bay	Diatoms	0.19	2.04	3.92	8.10	53.57
	<i>Balanus glandula</i>	0.81	1.28	1.97	4.07	
Marcus Island	Diatoms	0.18	1.82	4.09	7.41	55.18
	<i>Mytilus galloprovincialis</i>	1.19	1.67	2.28	4.14	

\* 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 one kilometre 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 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, although biotic cover was high at Iron Ore Jetty in 2018 due to an increase in filter feeders. At North Bay, filter feeders increased slightly over time with 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 greater biotic cover overall in 2009. In 2010, ephemerals had somewhat reduced but returned again in 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 but decreased at Schaapen Island West in 2018.

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). No pollution events can be detected in these data and fluctuations of functional groups over the years are likely to be a natural seasonal and inter-annual phenomenon.

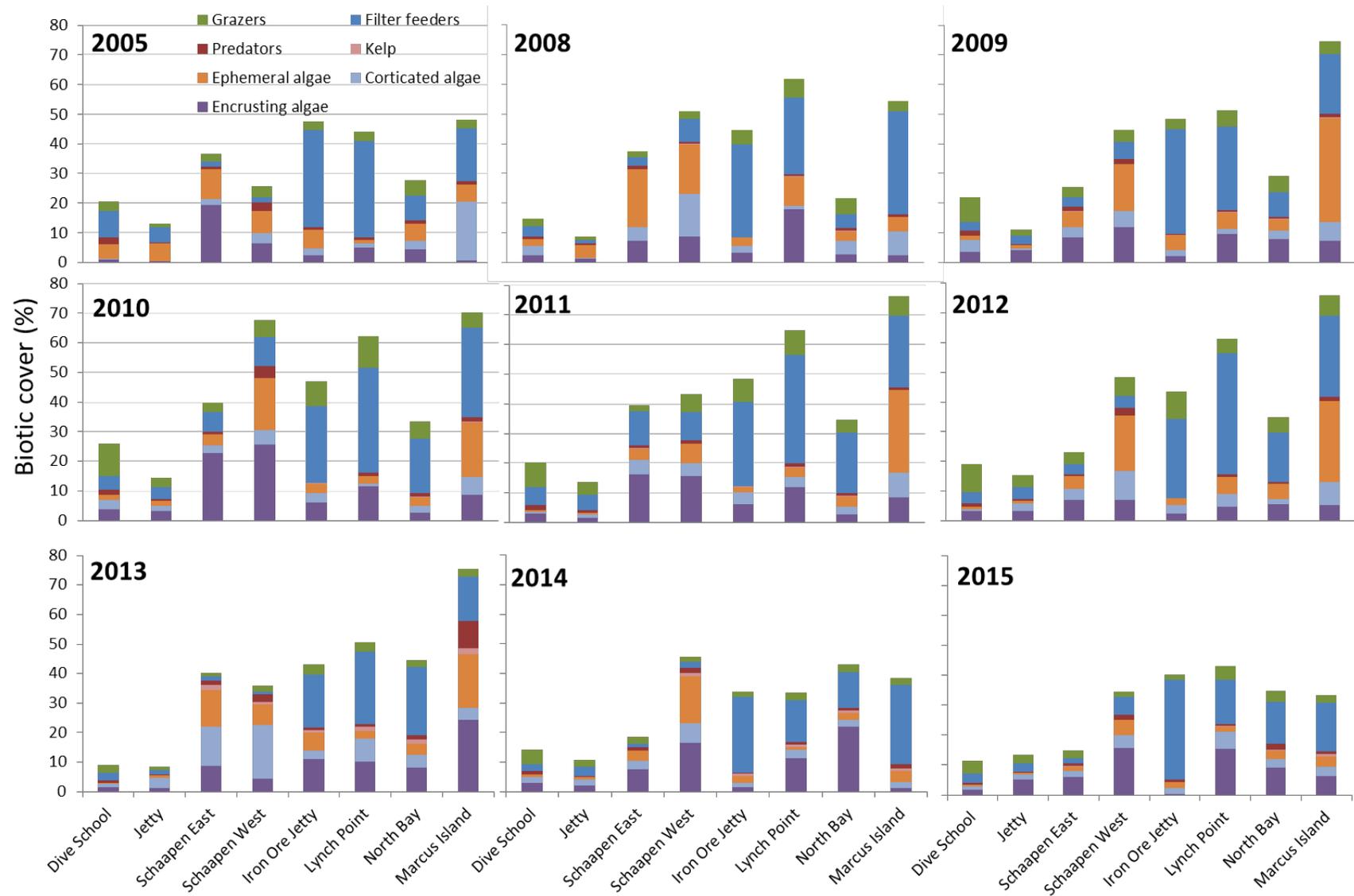


Figure 10.6 Total percentage cover (averaged across the whole shore) of the seven functional groups at the eight study sites from 2005 to 2015.

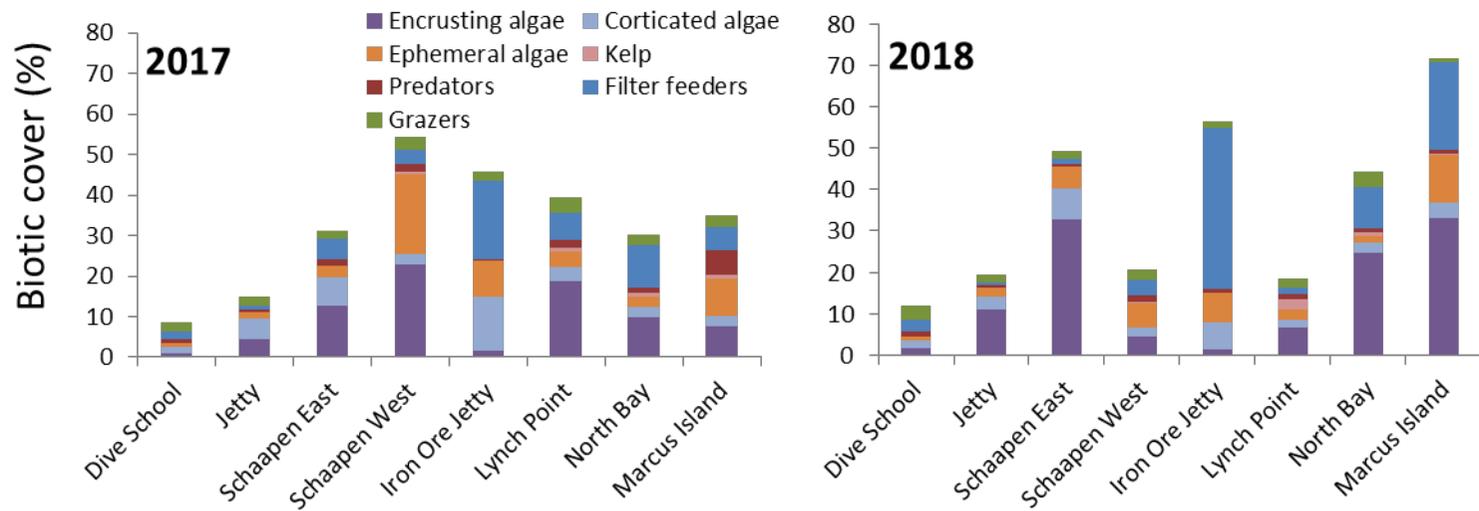


Figure 10.7 Total percentage cover (averaged across the whole shore) of the seven functional groups at the eight study sites from 2017 and 2018.

### 10.3.3 Summary of findings

In 2018, a total of 99 taxa were recorded from the eight study sites, most of which had been found in previous survey years. The faunal component was represented by 18 species of filter-feeders, 26 species of grazers, and 14 species of predators and scavengers combined. The algal component comprised 27 corticated (foliose) seaweeds, seven ephemerals, five species of encrusting algae, and two species of kelp. The species recorded in Saldanha Bay are generally common to the South African West Coast and many are listed by other studies conducted in the Saldanha Bay area including the two alien invasive species, the Mediterranean mussel *Mytilus galloprovincialis*, the North American acorn barnacle *Balanus glandula*, and two alien barnacle species.

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 and Marcus Island. The steep boulder beach at the Iron Ore Terminal has high biotic cover which is most likely due to the complex habitat with many cracks and crevices available for shelter when compared to the more flattish semi-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 13 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*. Most of the catch was 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) is vitally important for protecting white stumpnose stocks during the summer months, which 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 of 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.* (2017) provide an updated analysis of angler survey data, commercial linefish catch returns and the juvenile white stumpnose catch in the seine net surveys, which 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 most recent research on fish of the Saldanha Bay system was an investigation of the age, growth and stock assessment of the harder *Chelon* (previously *Liza richardsonii*) stock (Horton 2018). Preliminary results from this study indicate that the stock has collapsed (the current spawner biomass was estimated at less than 20% of the pristine level). These results are currently being validated by age and growth analysis of additional specimens and a scientific paper is in preparation. A reduction in fishing effort and increase in mesh size are both recommended to help rebuild the stock (Horton 2018).

Anchor Environmental has been undertaking experimental seine-net sampling of near shore fish assemblages at a number of sites throughout the Saldanha-Langebaan system since 2005 at the behest of the Saldanha Bay Water Quality Forum Trust (SBWQFT) as part of the monitoring of ecosystem health “State of the Bay” programme. Seine-net surveys are conducted during late summer to early autumn each year, as this is the timing of peak recruitment of juveniles to the near-shore environment. 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 2018 seine-net survey and investigates trends in the fish communities by comparing this with data from previous seine-net surveys (1986/87, 1994, 2005, 2008-2018) 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 are sub-sampled on site, the size of the sub-sample estimated visually and the remainder of the catch is released alive.

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.

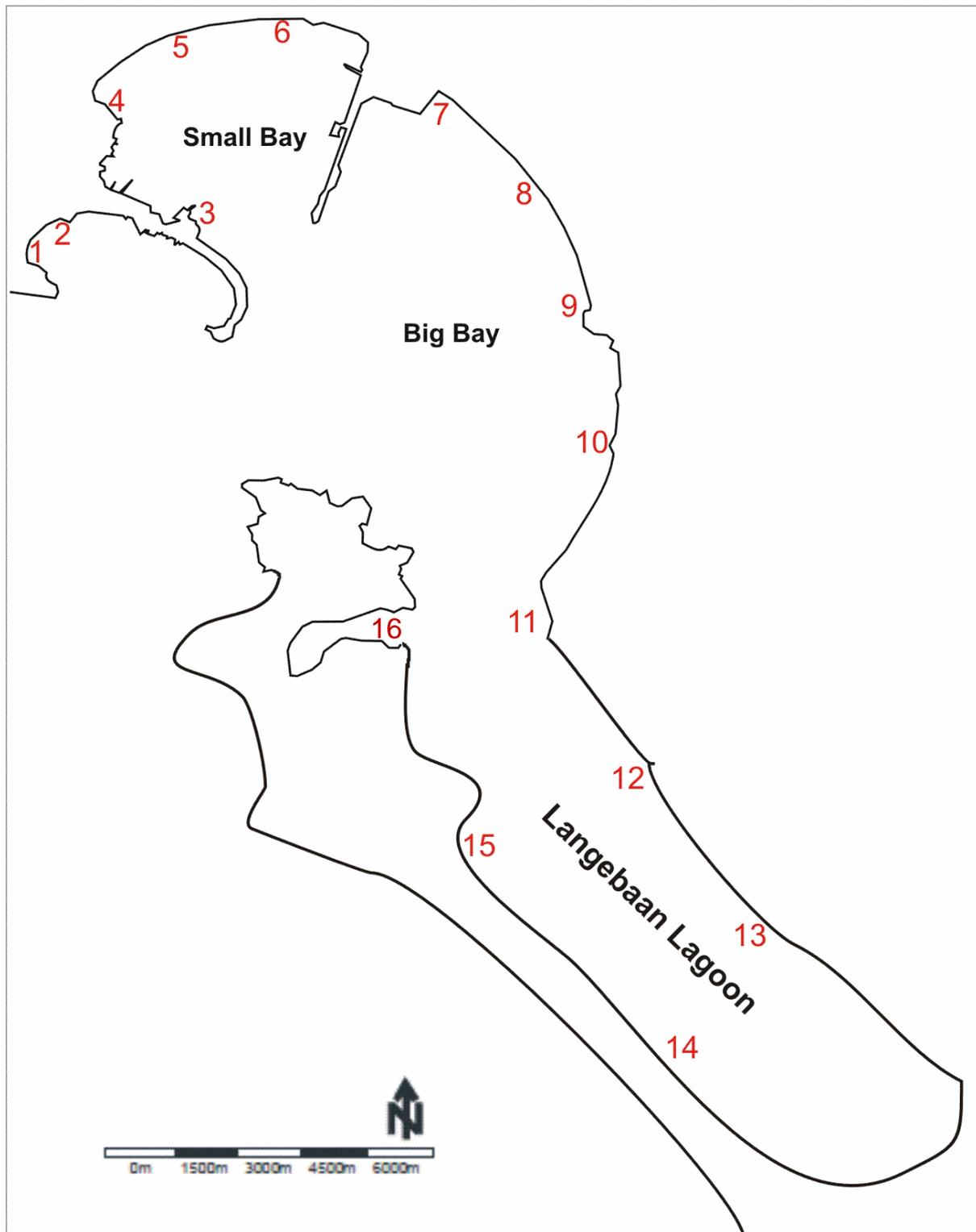


Figure 11.1. Sampling sites within Saldanha Bay and Langebaan lagoon where seine net hauls were conducted during the 2005 and 2007-2018 annual sampling events. 1: North Bay west, 2: North Bay east, 3: Small craft harbour, 4: Hoedjiesbaai, 5: Caravan site, 6: Blue water Bay, 7: Sea farm dam, 8: Spreeuwalle, 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 remains 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. 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 2018 samples fish diversity in Big Bay (10 species) was relatively low, but not unprecedented with only 10 species caught in Big Bay during the 2007 survey. In all three areas, 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.).

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. 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 and was again absent in the 2018.

Four of the 37 species recorded in Big Bay occurred in all surveys (gurnard, Cape sole, harders and white stumpnose). False Bay klipvis are only absent from one survey each (1994), whilst Cape silverside and elf have been absent from two surveys (most recently in 2018). Sand sharks were not caught in Big Bay during the 2014 and 2016 surveys, but have been caught in the last two surveys. 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 15 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.).

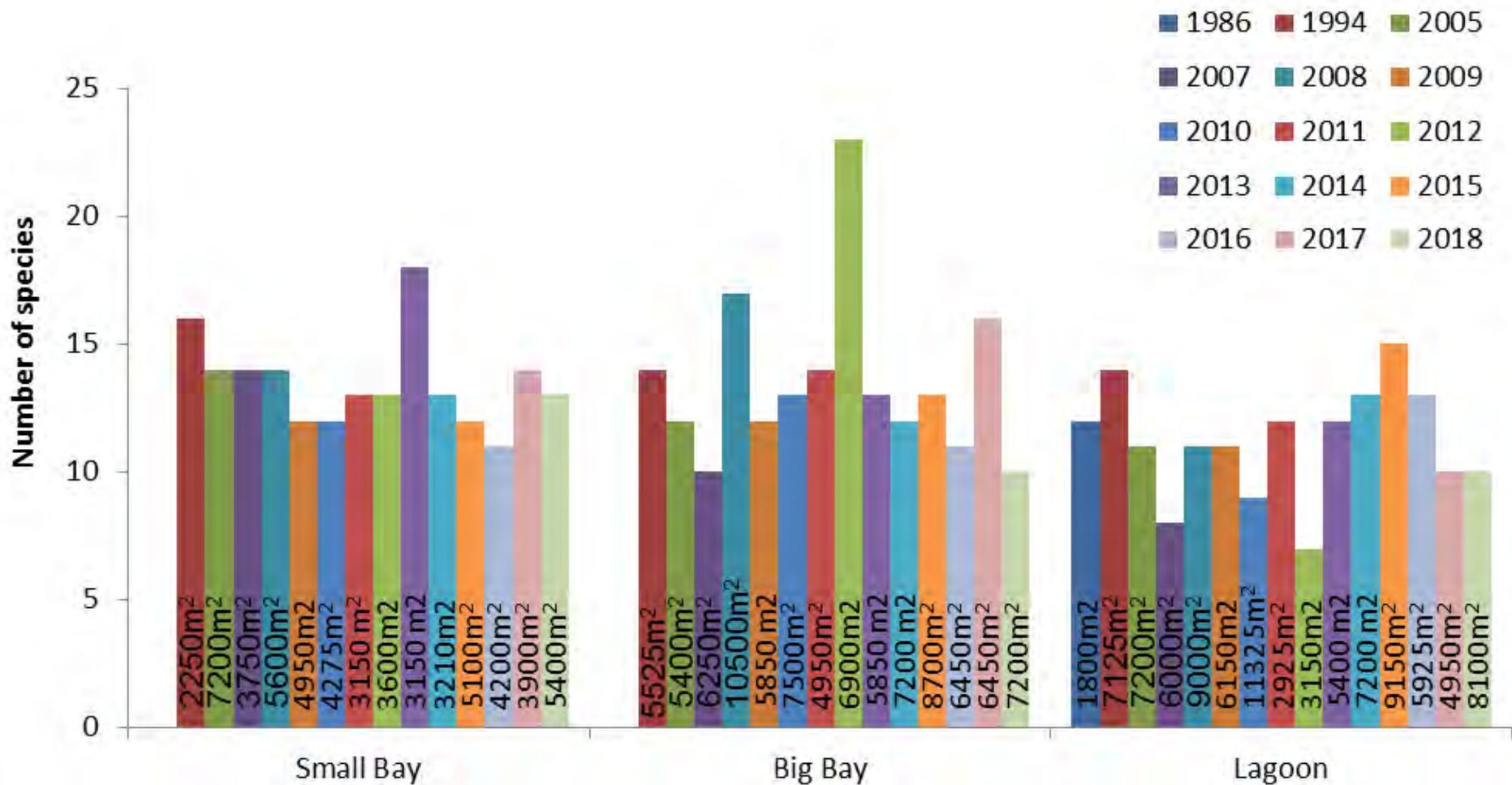
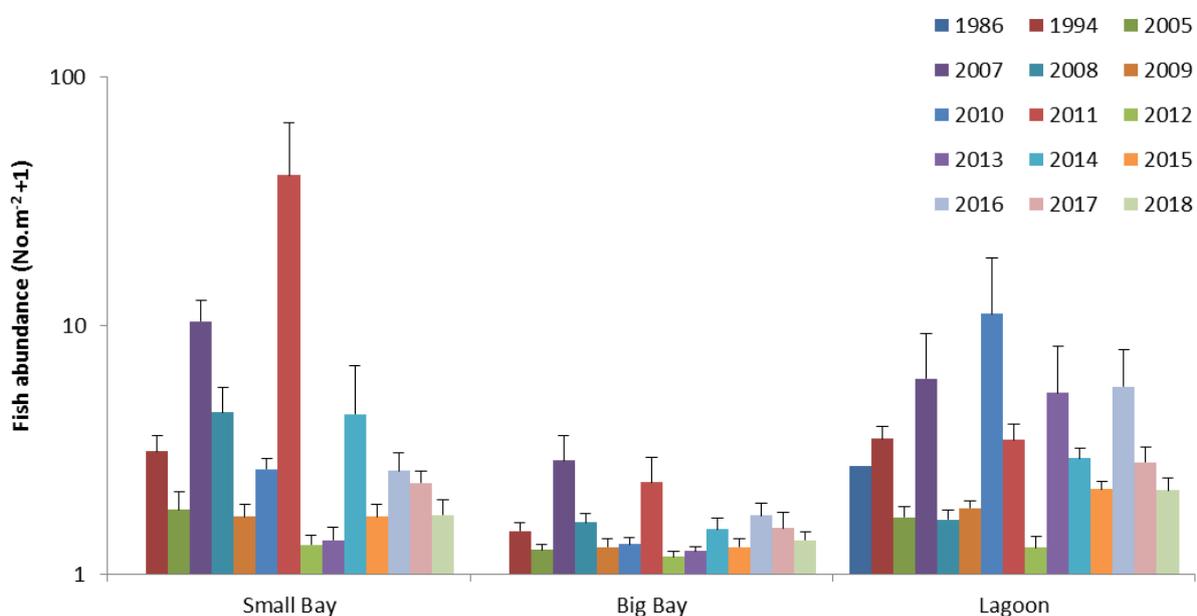


Figure 11.2. Fish species richness during 15 seine-net surveys in Saldanha Bay and Langebaan lagoon conducted over the period 1986-2018. The total area netted in each area and survey is shown. Note: The low species richness for Langebaan lagoon during 2012 is an artefact due to low sampling effort.

### 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 last five years 2014-2018 the overall abundance of fish has compared favourably with earlier surveys (Figure 11.3.).



**Figure 11.3.** Average fish abundance (all species combined) during 15 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 third highest white stumpnose abundance and second highest blacktail abundance was recorded in 2016 samples, however. Unfortunately blacktail juveniles that were entirely absent from Small Bay catches in 2017 remained scarce in 2018 samples with only five individuals caught; and white stumpnose abundance was again significantly down from that recorded during 2016.

Within Big Bay too, average harder density observed during the 2013-2018 sampling was comparable to earlier surveys, but the abundance of white stumpnose remains 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.). The strong elf recruitment in Big Bay evident in the 2016 and 2017 sampling was not repeated in 2018, and for the second time only in the 14 year survey history, juvenile elf were absent from samples. Elf start to become sexually mature at 1 year (Maggs and Mann 2013), but as larger and older fish spawn exponentially more eggs, it will likely be several years before the strong 2016 and 2017 cohorts contribute significantly to the juvenile recruitment in the Bay. Cape silverside were also absent from Big Bay catches for the first time in the sampling history, but this small pelagic species was abundant in Small Bay and Lagoon samples in comparable numbers to earlier surveys and it remains the second most abundant species after harders in the Saldanha Bay system. After a period of relatively poor recruitment for many species spanning 2009-2015, the 2016 and 2017 samples revealed better recruitment of most species to surfzone nursery habitats in all areas of the Bay and Lagoon. The initially encouraging improved white stumpnose and blacktail abundance estimates in Small Bay, however, appears to have not continued through to 2018. With the exception of harders, the estimated abundance of the more common species in Langebaan lagoon during 2018 compared poorly with earlier surveys with substantial declines in gobies, silversides and white stumpnose (Figure 11.4.). The cause behind the observed decline in the abundance of the dominant species in Langebaan Lagoon is not known. Speculatively, it could be linked to the prolonged drought in the Western Cape, with reduced freshwater run-off limiting nutrient input from the terrestrial environment. With the more “normal” rainfall experienced during the 2018 winter, next year’s sampling may will hopefully show and increase in juvenile fish abundance in the Lagoon.

Naturally high variability in recruitment strength is common for marine fish species and it is probably, at least partly natural environmental fluctuations rather than anthropogenic factors that caused the poor recruitment of most species 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 suggested improved environmental conditions that facilitated survival of eggs, larvae and juveniles during the preceding summer. The continued low abundance estimates of juvenile white stumpnose throughout this period however, indicates that the spawning capacity of the adult stock remains compromised.

More concerning is the recent capture of three alien rainbow trout by gill net fishers in Kraalbaai, indicating that fish have escaped from the experimental fish cages in Big Bay, survived and entered the Lagoon. Trout are predators that, like many fish, exhibit a high degree of dietary plasticity. They will therefore consume indigenous invertebrates and small fish. Given the relatively small number of trout that are thought to have escaped (this is an assumption as the fish cage operators have yet to report on the magnitude of the breakout) compared to the abundance of indigenous predatory fish such as elf, it is considered unlikely that escapees from the experimental cages to date, have had a significant impact on juvenile fish abundance in the Lagoon (and elsewhere in Saldanha Bay). Trout, and other salmonids earmarked for fish cage farming in the Saldanha area also require cool, fast flowing mountain streams for successful spawning.

Given the paucity of clear river systems entering the sea along the west coast it is considered a low risk that escaped salmonids will become naturalised (i.e. form self-sustaining natural populations) and invasive. Although the possibility of escapees establishing a spawning population in a South Western Cape River cannot be rejected with absolute certainty, we believe that the probability of this occurring is low.

However, escapes from fish cages moored in the sea are inevitable and should finfish cage farming in Saldanha Bay be expanded to a commercial scale of several thousand tonnes per annum (as proposed in the recent Aquaculture Development Zone EIA), then the impact of ongoing escapees of alien salmonids on indigenous biota (including juvenile fish) are expected to be significant. The environmental impacts caused by the introduction of salmonids into pristine ecosystems with no native salmonid species are severe and interlinked with oftentimes unpredictable knock-on effects at the ecosystem scale. Salmonid invasions present a strong top-down control on community structure and ecosystem functioning by inducing change in individual behaviour, distributions of populations and abundance within functional groups. Given the importance of the nearshore waters of Saldanha Bay and Langebaan lagoon as nursery areas for a number of vulnerable indigenous fishery species, finfish cage farming should be restricted to the outer Bay, and mitigation measures to minimise escapes from cages should be strictly enforced.

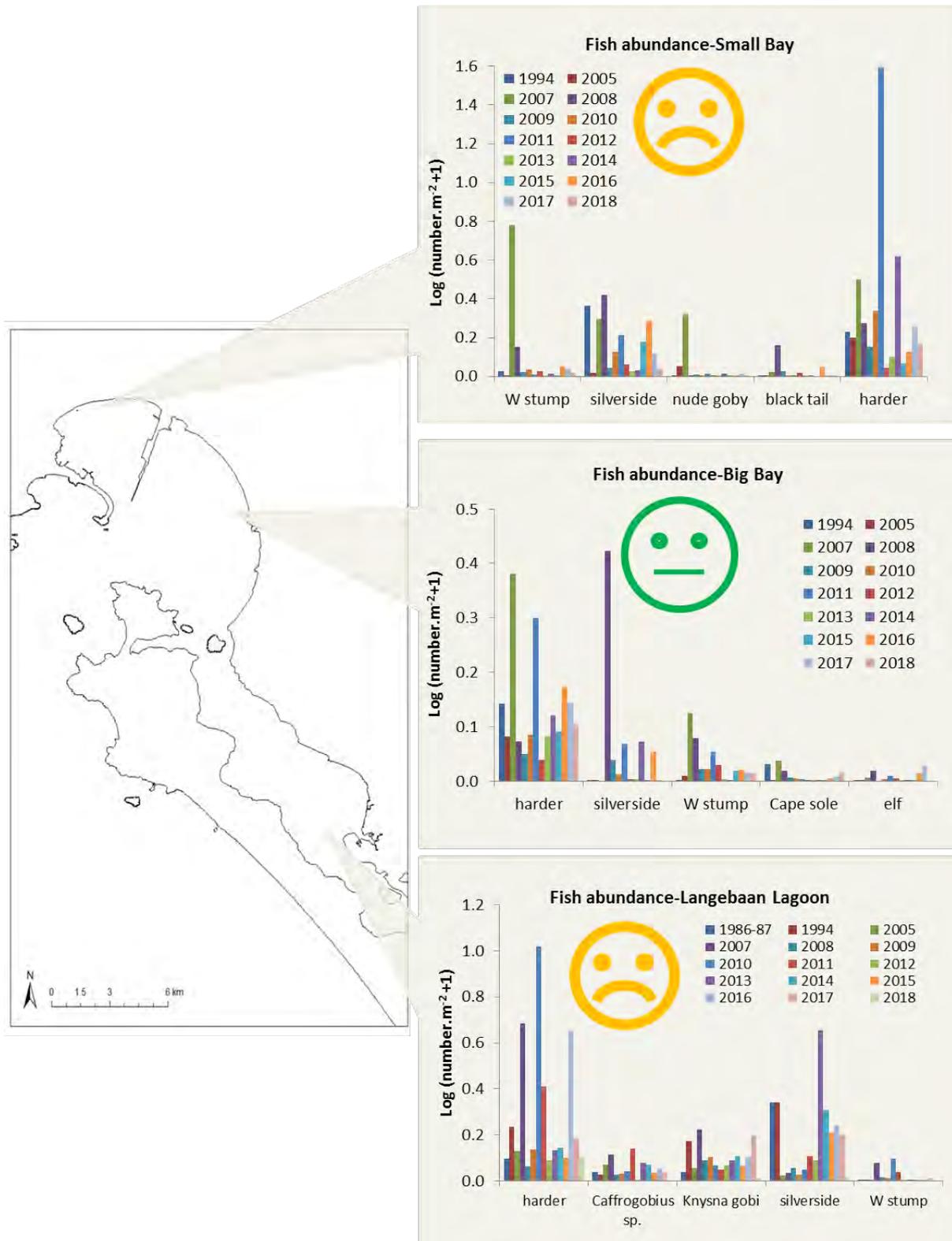


Figure 11.4. Abundance of the most common fish species recorded in annual seine-net surveys within Saldanha Bay and Langebaan Lagoon (1986/87, 1994, 2005 & 2007-2018).

### 11.3.3 Status of fish populations at individual sites sampled in 2018

The average abundance of the four most common species in catches made during all earlier surveys and the most recent 2018 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 all four species at Small Bay sites in the 2018 survey was lower than the long term average recorded in earlier surveys (Figure 11.5.). At all the Big Bay sites, catches of harders during the 2018 survey were similar to the historical average with no clear spatial trend; whilst silversides were absent from all sites (Figure 11.6.). White stumpnose catches at the Big Bay sites in 2018 were similar to, or less than, the long-term average, except at North Bay West when 2018 catches were greater (but not significantly so) than the historical average for this site (Figure 11.6.). Catches of silversides and harders at lagoon sites during 2018 were similar to the long term average; whilst goby and white stumpnose density was significantly lower at four of the sites and greater than the long-term average only at Botlery (Figure 11.7).

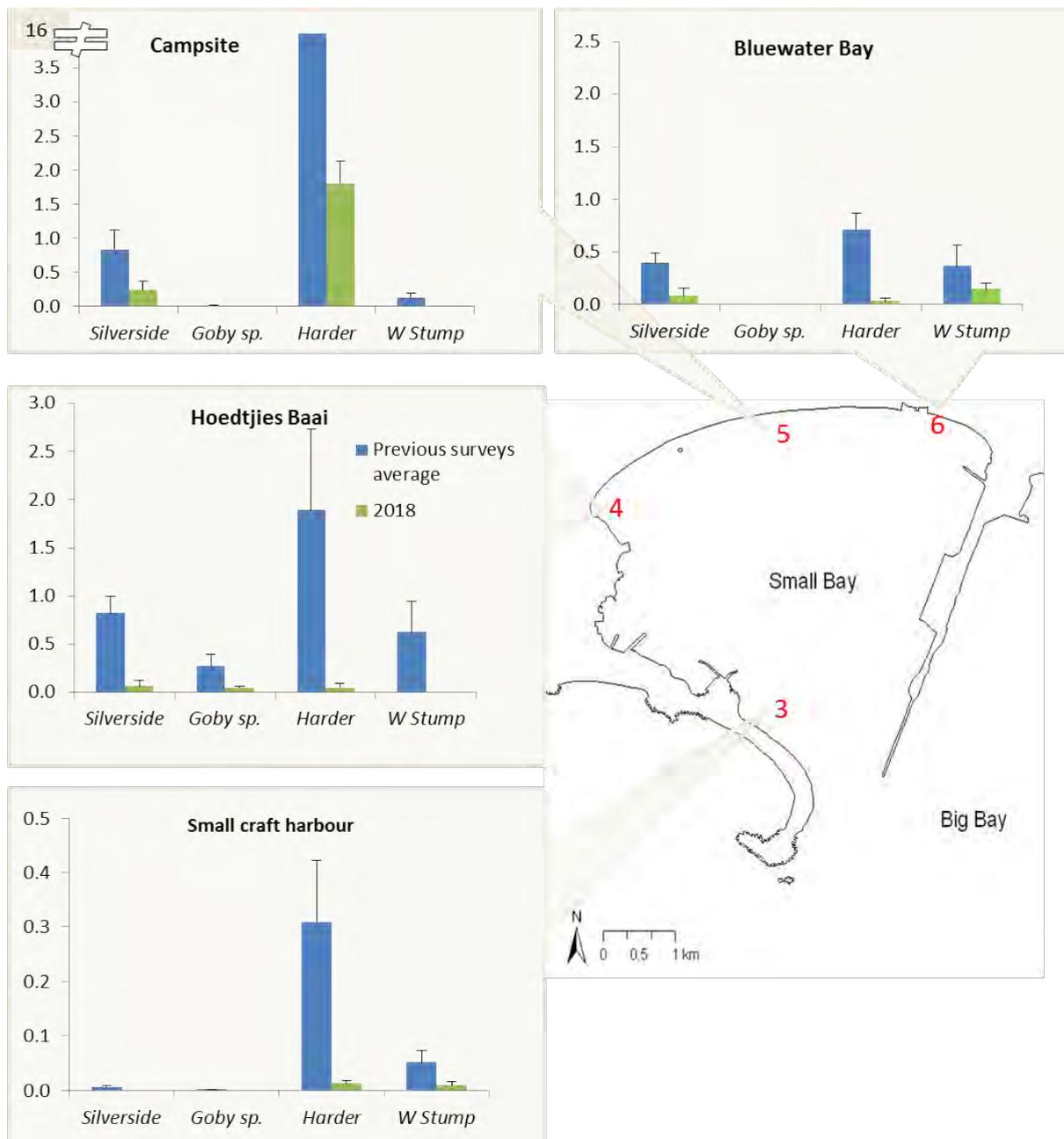


Figure 11.5. Average abundance (No.fish.m<sup>-2</sup>) of the four most common fish species at each of the sites sampled within Small Bay during the earlier surveys (1994, 2005, 2007-2017) and during the 2018 survey. Errors bars show 1 Standard error.

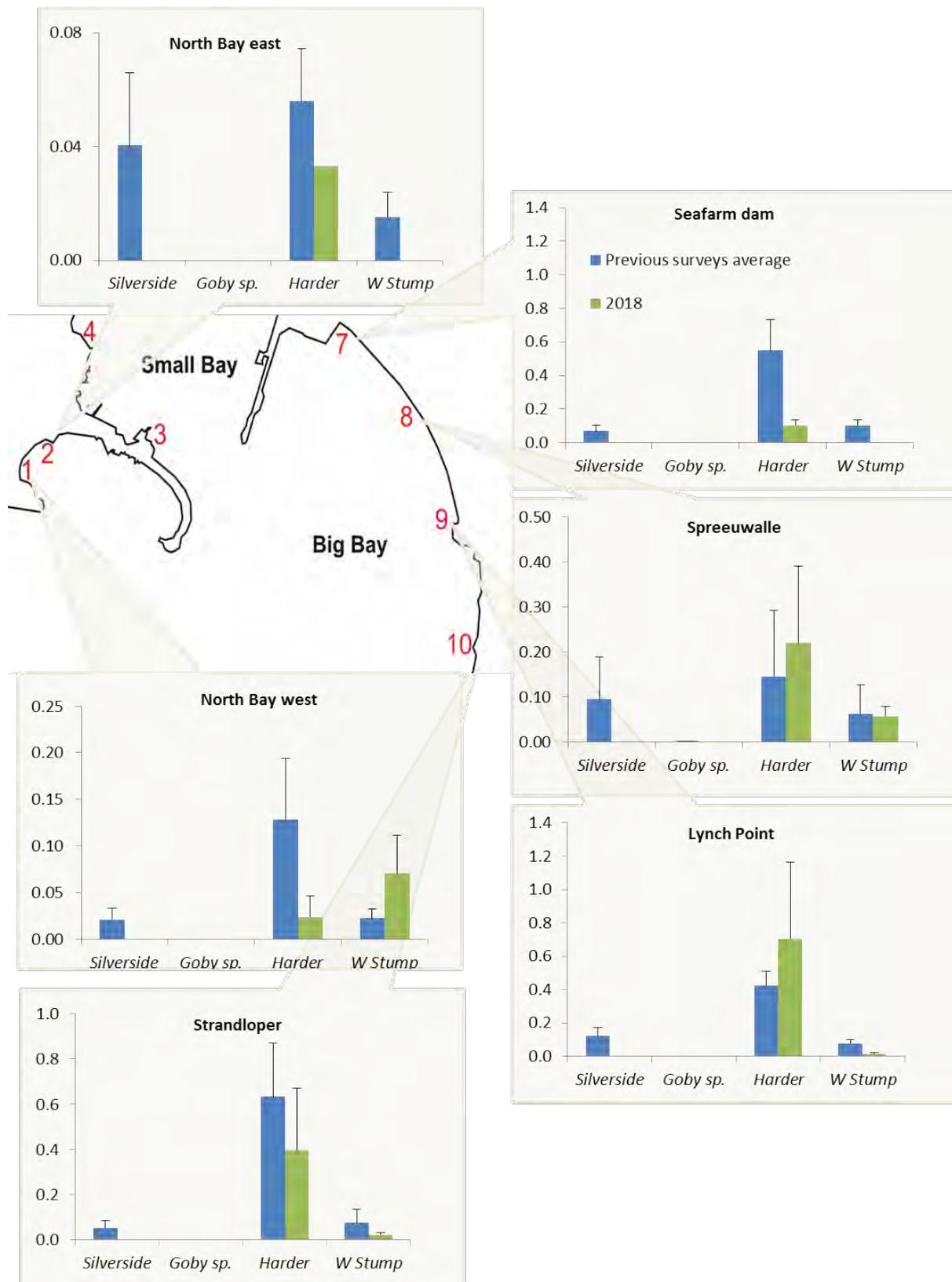


Figure 11.6. Average abundance (#fish.m<sup>-2</sup>) of the four most common fish species at each of the sites sampled within Big Bay during the earlier surveys (1994, 2005, 2007-2017) and during the 2018 survey. Errors bars show plus 1 Standard error.

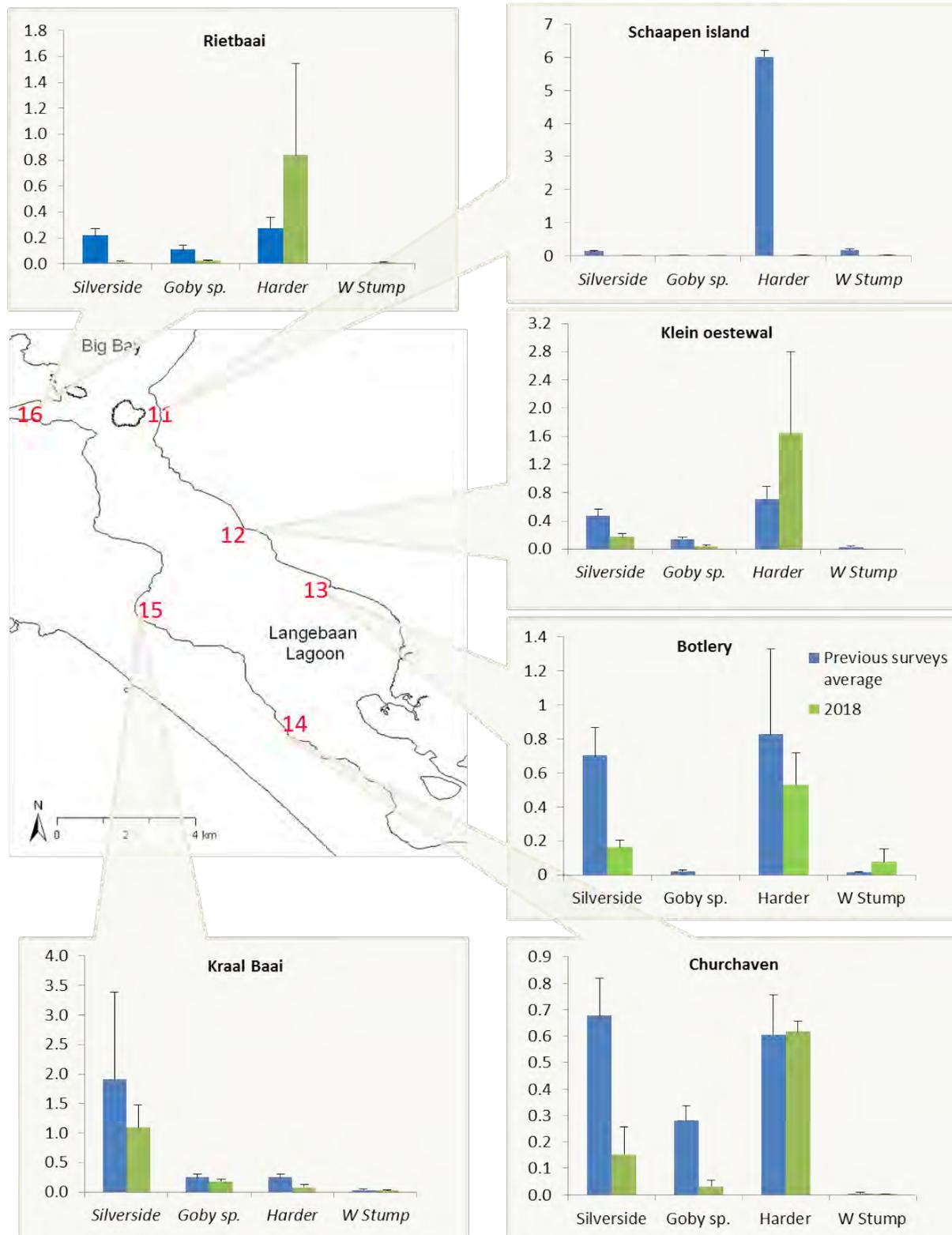


Figure 11.7. Average abundance (#fish.m<sup>-2</sup>) of the four most common fish species at sites sampled within Langebaan lagoon during the earlier surveys (1994, 2005, 2007-2017) and during the 2018 survey. Error bars show plus 1 standard error.

## 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 of 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 and 2018 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) and Horton (2018), 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 11.8, Figure 11.9, Figure 11.10).

The density of blacktail juveniles in sampled habitats was significantly higher in 2008 than in all other years, there was an absence of blacktail recruits in the 2015 and 2017 samples and only five were caught in the 2018 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 2018 hauls was similar to the median but significantly less than that recorded in 2001 and 2010-2011. 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 and 2018 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) which was followed by a zero catch in 2018. 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.

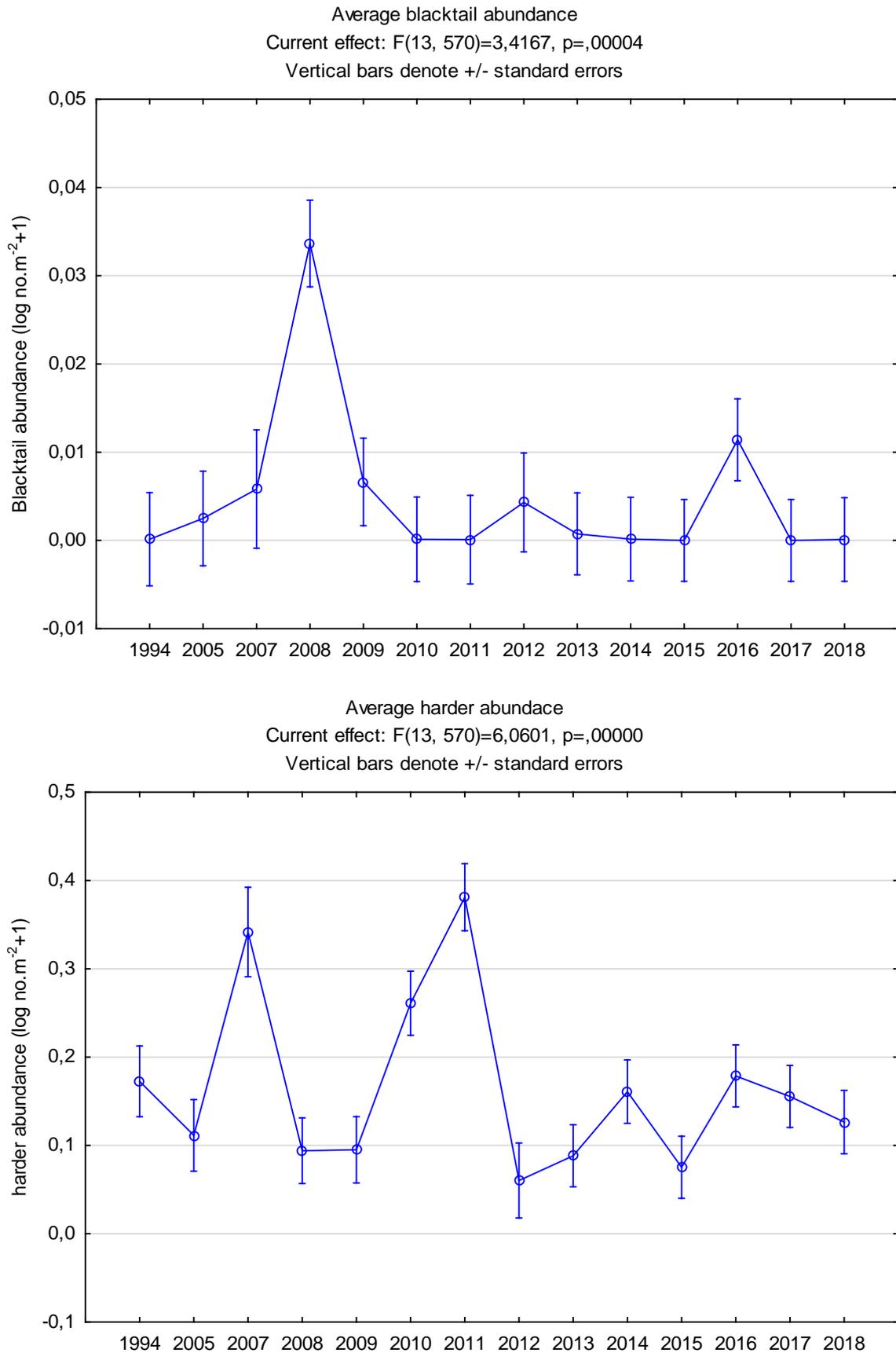


Figure 11.8. ANOVA results comparing the average annual density of blacktail and harders at all sites sampled in all surveys (1994-2018).

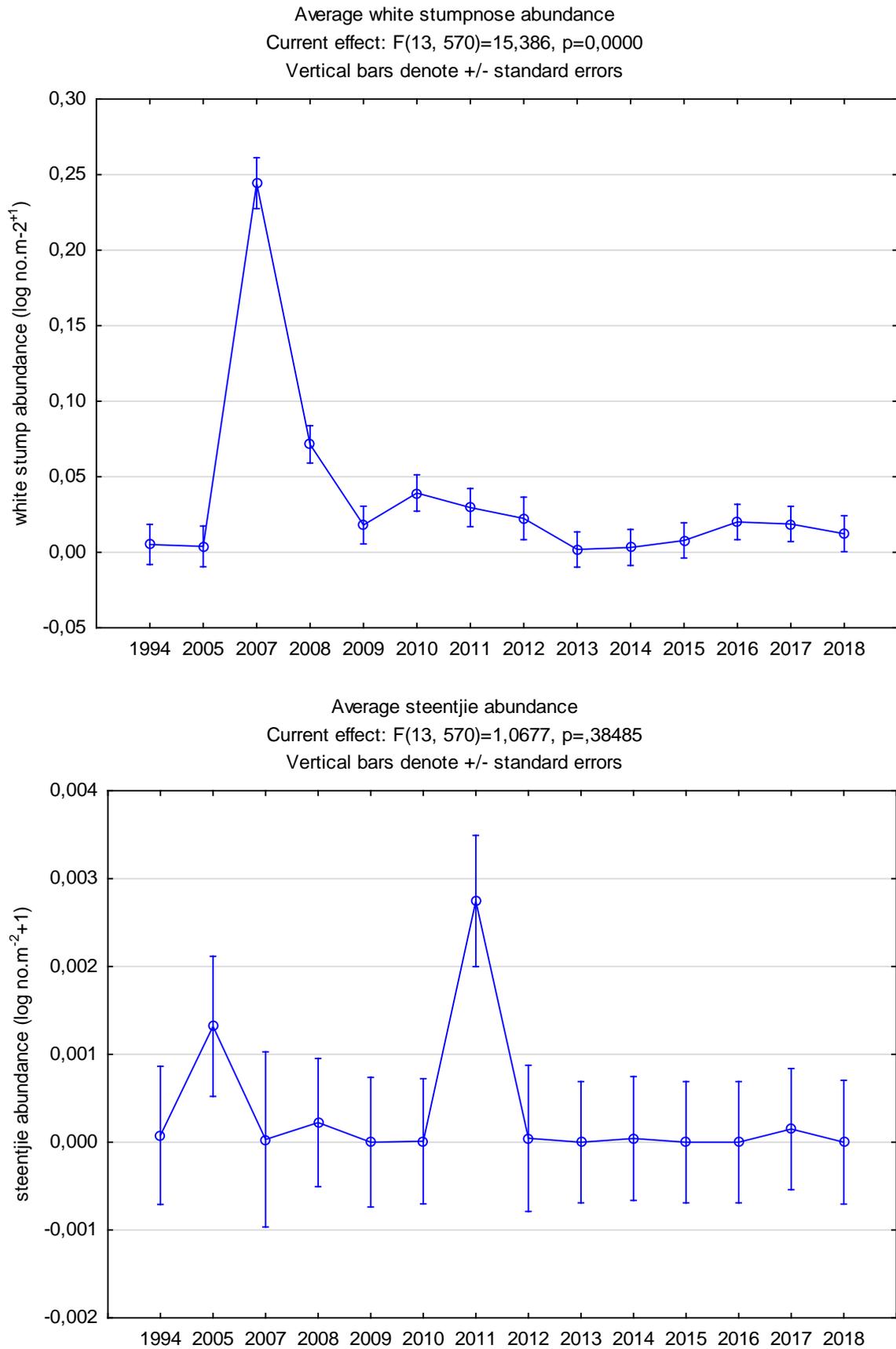


Figure 11.9. ANOVA results comparing the average annual density of white stumpnose and steentjies at all sites sampled in all surveys (1994-2018).

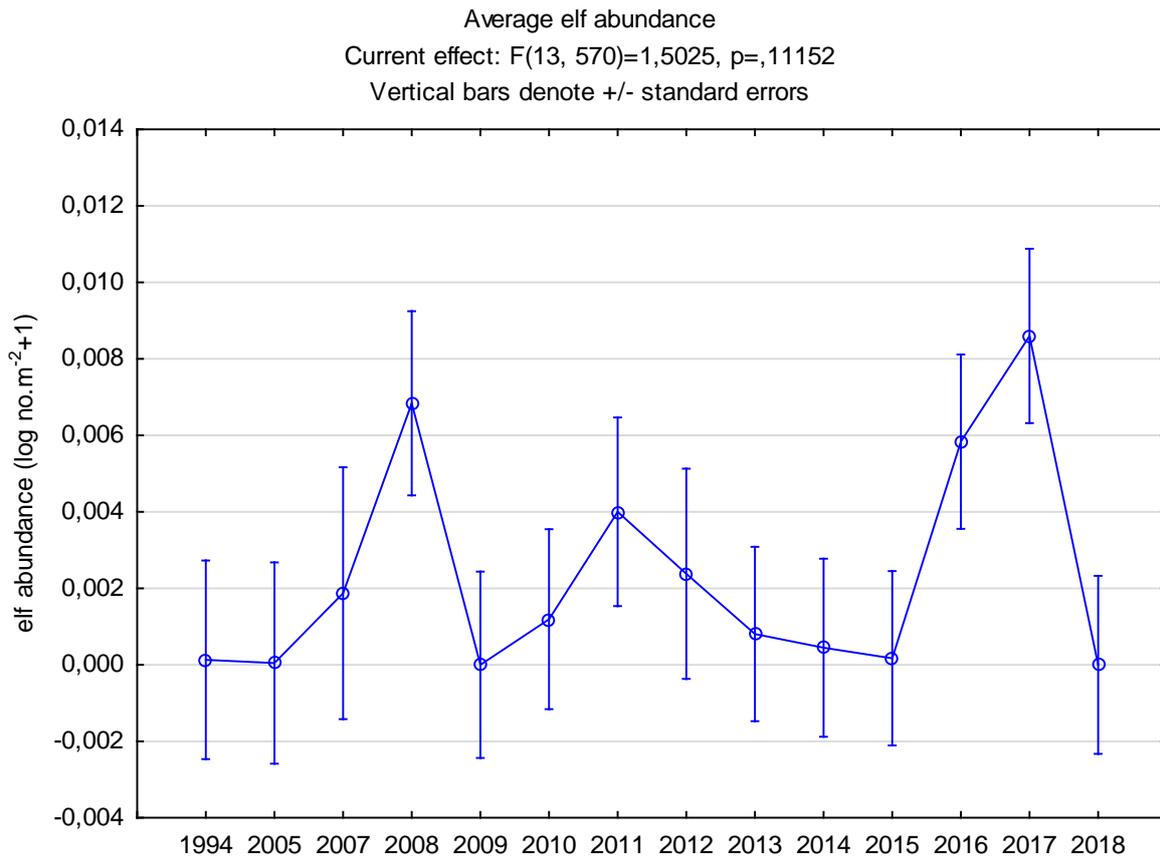


Figure 11.10. ANOVA results comparing the average annual density of elf at all sites sampled in all surveys.

## 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.* 2017). In 2017 report 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) was presented. These data showed 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 2016-2018 surveys, which suggests that recruitment overfishing is not taking place. The observed shift towards a smaller size class of harders in catches did 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. Recent research that included age and growth analysis and per-recruit stock assessment of the Saldanha-Langebaan harder stock confirmed that fishing mortality is too high and the stock is overexploited (Horton 2018).

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 Churchhaven 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 they 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 strongly oppose and attempts to open Zone B to further fishing effort.

## 11.6 Conclusion

The 2018 seine net survey revealed some concerning trends in juvenile fish populations within the Saldanha Bay and Langebaan Lagoon system. The encouraging signs of recovery of white stumpnose and blacktail in Small Bay in 2016 did not continue through to 2017 and 2018, and white stumpnose abundance remains low throughout the system. 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 it must however be acknowledged that overall abundance is dominated by harders, which appear resilient to decreases in water quality. Despite the strong elf recruitment in Big Bay evident in the 2016 and 2017 sampling, none were caught during the 2018 sampling, this suggests that these strong year classes are not yet contributing juveniles to the stock in significant numbers. Silversides were absent in Big Bay in 2018 samples but other species common in Big Bay catches (harders, white stump and Cape sole) were present in comparable numbers to earlier surveys. Harders were present in Langebaan lagoon samples in similar numbers to previous surveys, but catches of all other common species were amongst the lowest recorded to date.

Previously fish abundance at sites within or in close proximity to the Langebaan MPA appeared 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 over the last decade, however, suggest that the protection afforded by the Langebaan MPA is 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 suggests 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.* 2017). Harder recruitment to nearshore nursery areas appears to have not changed significantly over the monitoring period since 1994. A recent stock assessment however, does indicate that the Saldanha-Langebaan harder stock is overexploited and effort reductions and commercial net gear restrictions are recommended to rebuild the stock (Horton 2018).

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 five 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. We also support the recommendation of Horton (2018) for a reduction in harder fishing effort and gear changes (increase in minimum mesh size) to facilitate stock recovery.

The recent discovery of alien rainbow trout in Kraalbaai (almost certainly escapees from the pilot fish cage farming in Big Bay) is another threat to the indigenous fish fauna in the region. These predatory fish will prey on indigenous invertebrates and fish and could cause ecosystem level impacts. These alien fish are highly unlikely to establish self-sustaining populations in the bay and lagoon due to the lack of suitable spawning habitat (cool, clear fresh water rivers) in the region. At the current experimental scale of fish farming, the number of escapees are not expected to be having highly significant impacts on indigenous fauna. However, at the proposed commercial scale finfish cage farming the number of alien salmonids introduced into the Bay and the Lagoon via ongoing escapes will probably have significant negative effects on indigenous fauna. Given the importance of the nearshore waters of Saldanha Bay and Langebaan lagoon as nursery areas for a number of vulnerable indigenous fishery species, finfish cage farming should be restricted to the outer Bay, and mitigation measures to minimise escapes from cages should be strictly enforced.

## 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. Drainage channels also contribute to 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). It was not possible to obtain island bird data for the calendar year 2017 from the Department of Environmental Affairs in time for the publication of the 2018 report due to a change in the procedure governing the release of data. Readers are referred to the 2017 State of the Bay report for information on trends in island bird breeding populations.

## 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.

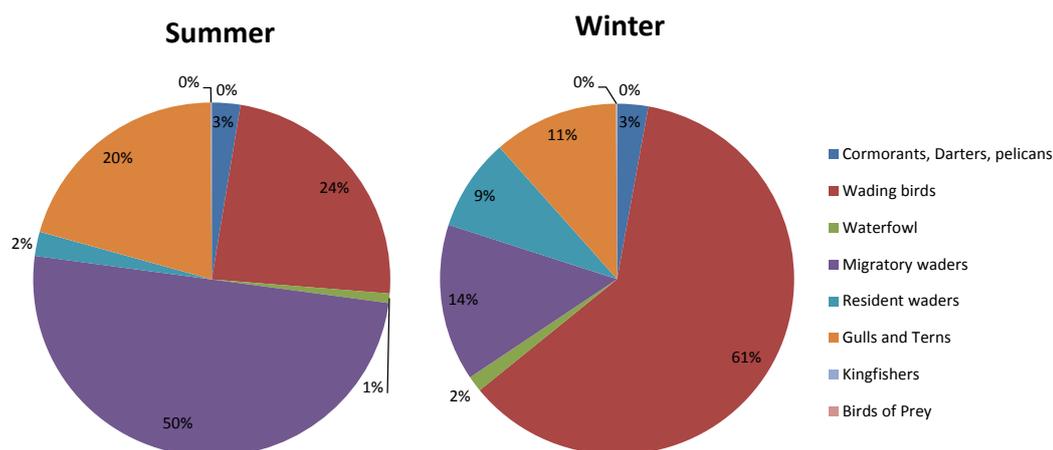
Waterbird numbers on Langebaan Lagoon have, however, declined dramatically since monitoring began in the 1970s. Decreases in both migratory and resident wader numbers are a common trend around the South African coast. Decreases in numbers of migrants can be attributed to loss of breeding habitat and 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 12.1). Currently, waders account for about 52% of the birds in Langebaan Lagoon during summer, nearly all of these being migratory. In winter, the contribution by resident waders increases to around 9%, and numbers of wading birds increase from 24 to 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 synchronously in early April, but the immature birds of many of these species remain behind, accounting 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 over a longer period in spring, with birds beginning to filter in from August, rising rapidly in numbers during September and 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 <i>Anhinga rufa</i> are uncommon, and are more typical of lower salinities and habitats with emergent vegetation which are not common in the study area.
Wading birds	This group comprises the egrets, herons, ibises, flamingos and spoonbills. 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 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 adapt 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 Palearctic 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 12.1** Present average numerical composition of the waterbirds on Langebaan Lagoon during summer (left) and winter (right) and winter (2013-2018) (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 (species recorded more than 20% of the time). 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 12.1). 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 non-passerine 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 12.1). 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 1976-2018 see (Table 12.1).

**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 (Hérons, 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	
<b>Total</b>		<b>62</b>	<b>25</b>

### 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 12.2). In the 1970s and 1980s, migratory waders commonly numbered over 35 000 during summer, and over 10 000 in winter. Summer water bird numbers have since decreased significantly with only 2 352 individuals recorded in 2011. Since 2011, numbers have fluctuated around 6000 individuals (Figure 12.2 and Figure 12.3). Today (since 2011), waders make up only 29-69% of summer water bird numbers (Figure 12.2).

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 5320 birds in summer 2018 is approximately 84% 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 12.4) 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 2 635 birds in 2018. Congruent with the overall temporal pattern described above, Curlew Sandpiper numbers reached a minimum in 2011 with only 413 individuals. 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 12.3). 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). Hunting of migratory waterbirds is a strong tradition in several European countries and is thought to contribute towards global declines in migratory water birds (Bregnballe *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.

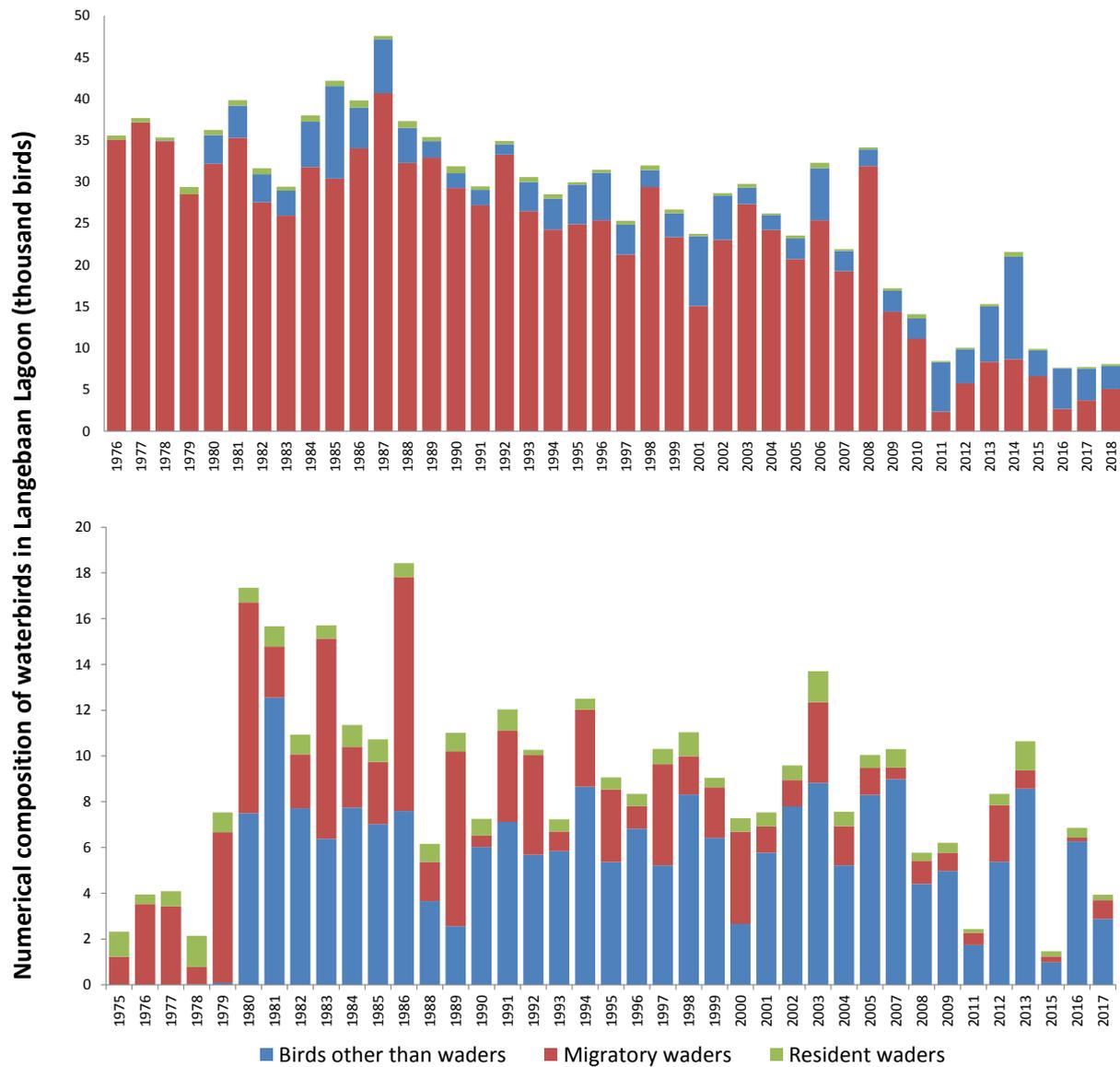


Figure 12.2. Long-term trend in the numerical composition of waterbirds in the Langebaan Lagoon during summer (top) and winter (bottom) (1976-summer 2018). Note that no data was collected in the summer of 1975, as well as in the winter of 1987, 2006, 2010, and 2014 (Data source: Coordinated Waterbird Count data, Animal Demography Unit at the University of Cape Town 2018).

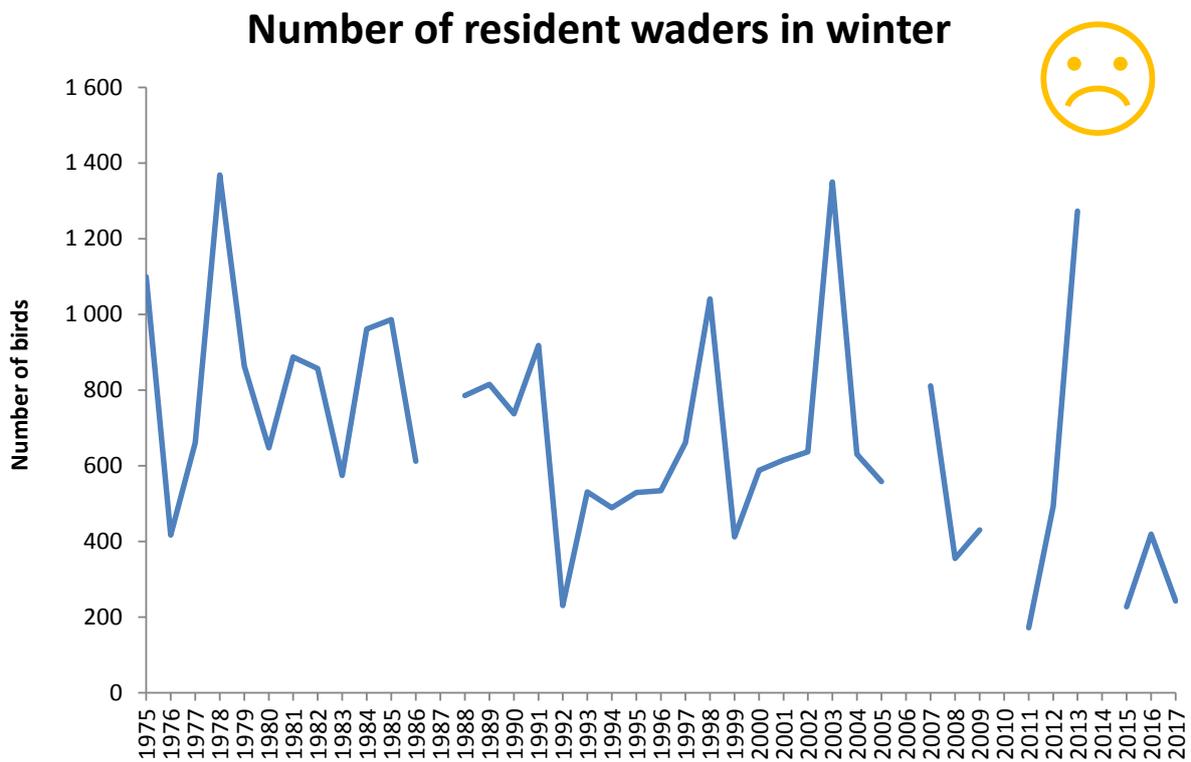
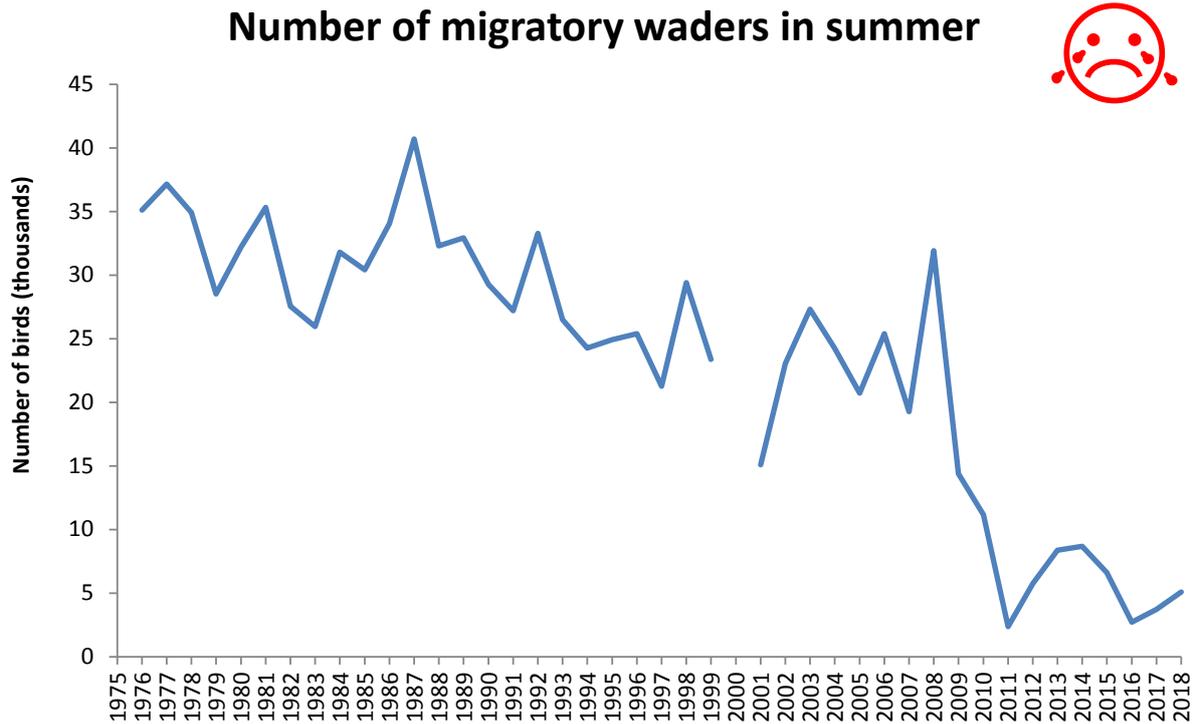
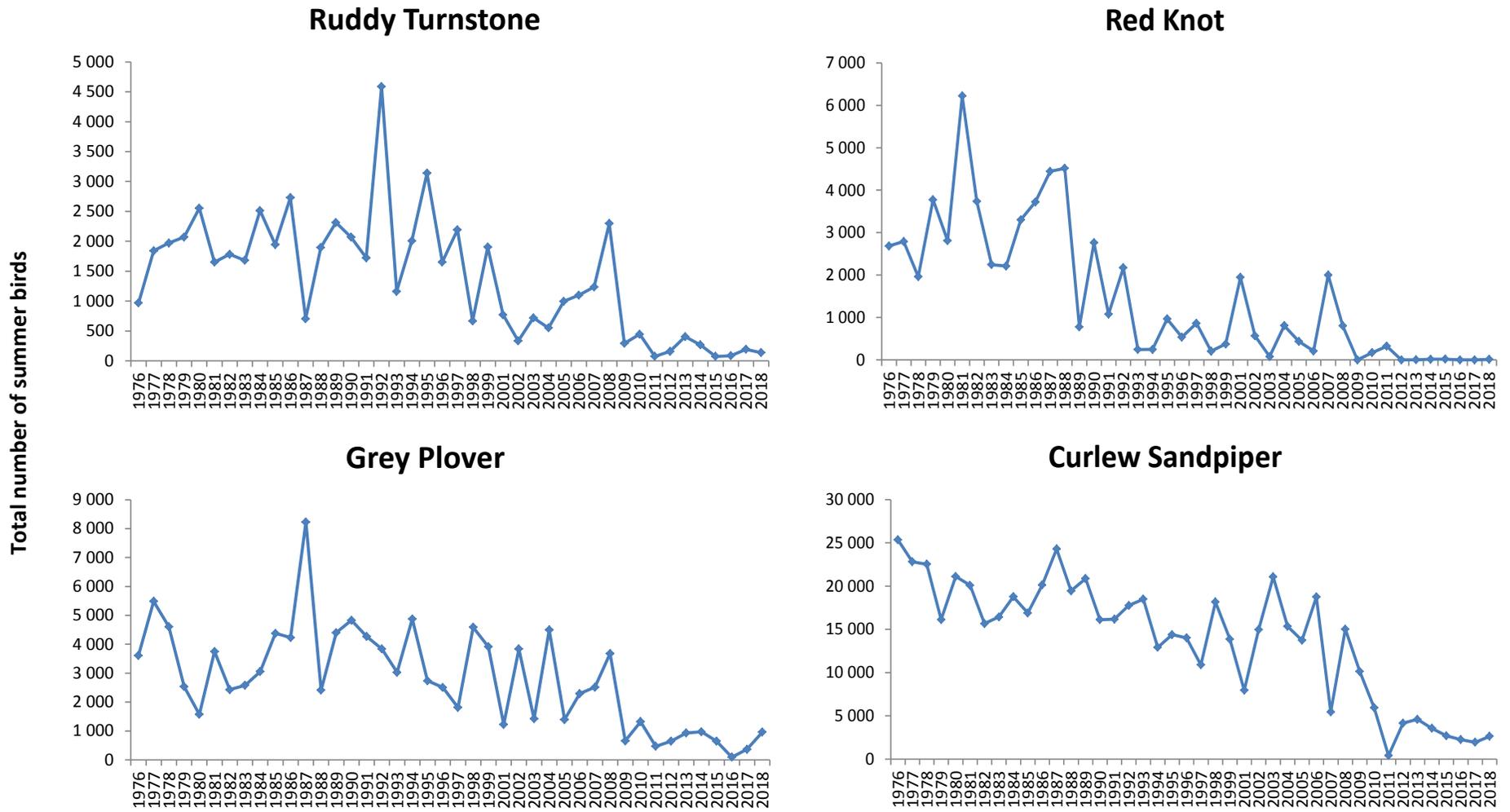


Figure 12.3. Long term trends in the numbers of summer migratory (top) and winter resident (bottom) waders on Langebaan Lagoon for the years 1976–summer 2018 (Data source: Coordinated Waterbird Count data, Animal Demography Unit at the University of Cape Town 2018).



**Figure 12.4** 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 1976-2018. (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 2 635 birds in 2018. 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 maotica*, 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 16.3.). 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 perforatus* (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 16.3.). 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.

An additional 41<sup>11</sup> 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 16.3.). 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. For example, it has been shown that translocated oysters act as vectors of marine alien species all over the world. Oysters attach to rocks, walls and other surfaces and are colonised by fouling organisms, which can be exported into other countries on the oysters. Alien species imported on oyster shells may have significant ecological impacts in areas where they establish (Haupt *et al.* 2010).

Marine scientists have been exploring the link between biological characteristics of invasive species in relation to their observed success. For example, invasive species are often more efficient at utilising resources when compared to native species. Recent research on the invasive *M. galloprovincialis* shows that the success of this species on the west coast of South Africa could be explained at least partially by the species' capability to utilise food resources more efficiently when

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<sup>11</sup> 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.

compared to other mussel species (invasive *Semimytilus algosus* and native *Aulacomya atra*) (Alexander *et al.* 2015). Alexander *et al.* 2015 showed that *M. galloprovincialis* was the most efficient consumer of algal cells at colder temperatures when the resource was presented in both low and high starting densities. These results may explain the observed success of this species on the west coast of South Africa relative to the new invader *S. algosus*, which, based on the results of this study is predicted to become established along the south coast of South Africa. This is due to the finding that algae consumption was more efficient in warmer water. Marine scientists are trying to find new ways to predict the spread of established invasive species to facilitate early detection and to inform focused management interventions.

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 16.3.). 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). The species has recently been reported to have spread east past Cape Point, which was until now thought of as a biogeographical barrier (Robinson *et al.* 2015).



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

Recent research shows that when compared to the indigenous barnacle species *Notomegabalanus algicola*, *B. glandula* more efficiently takes up algae regardless of water temperature or cell concentration. Furthermore, warmer conditions on the south coast enhanced the uptake of algae cells, which could result in *B. glandula* spreading further east than currently observed (Pope *et al.* 2016).

*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.

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. The abundance of this species has been fluctuating over time, most noticeably at the iron ore terminal where it is most abundant. This year, *B. glandula* covered 50% of the mid shore quadrats, representing the dominant species at this site.

*B. glandula* disappeared from Schaapen East and Lynch Point in 2015 and 2017 respectively. Although generally observed in low numbers at the Jetty, it is still important to mention that *B. glandula* was not detected on the midshore in the 2018 survey. It was noticeable that mostly empty shells were found at the site. It remains to be seen whether this species has permanently disappeared from these sites.

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.

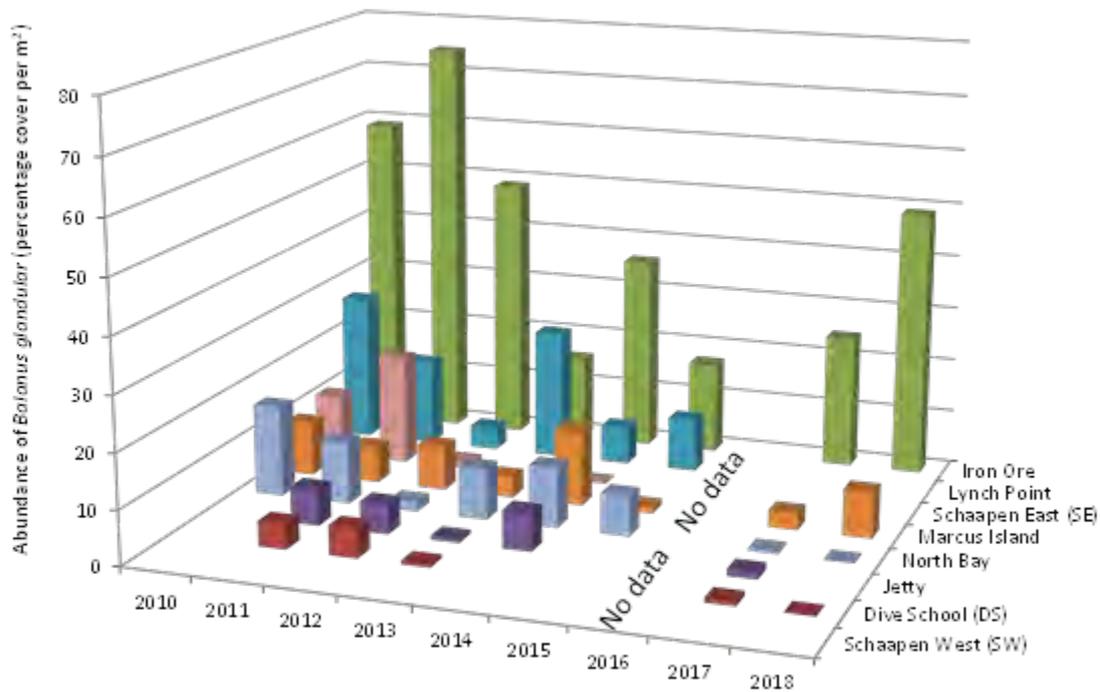


Figure 13.2. Changes in the abundance (% cover) of the acorn barnacle *Balanus glandula* at eight rocky intertidal sites on the mid shore in Saldanha Bay over the period 2010-2018. Data are shown as an average of percentage cover on the mid shore. No samples were collected 2016. Information of the locations 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). The detection rate in both Big and Small Bay has been fluctuating around 40% and 20% respectively, reaching a peak in 2016 and 2017 when the species was found at 67% of the sites sampled in Big Bay (Figure 13.6).

Abundance and biomass in both regions fluctuated 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 bars) (Figure 13.7). *Pinnixa occidentalis* is most prevalent to the east of the iron ore and multi-purpose terminals in Big Bay towards Mykonos (sites LPG, BB26 and BB25 Figure 13.8) as well as to the east of the terminals at the entrance to Small Bay (site SB9 Figure 13.8). *Pinnixa occidentalis* is present in lower numbers in Small Bay at sites close to the terminals (i.e. sites SB16, SB14 Figure 13.8). No recruitment trends of this species can be picked up from the abundance and biomass time series (Figure 13.7).

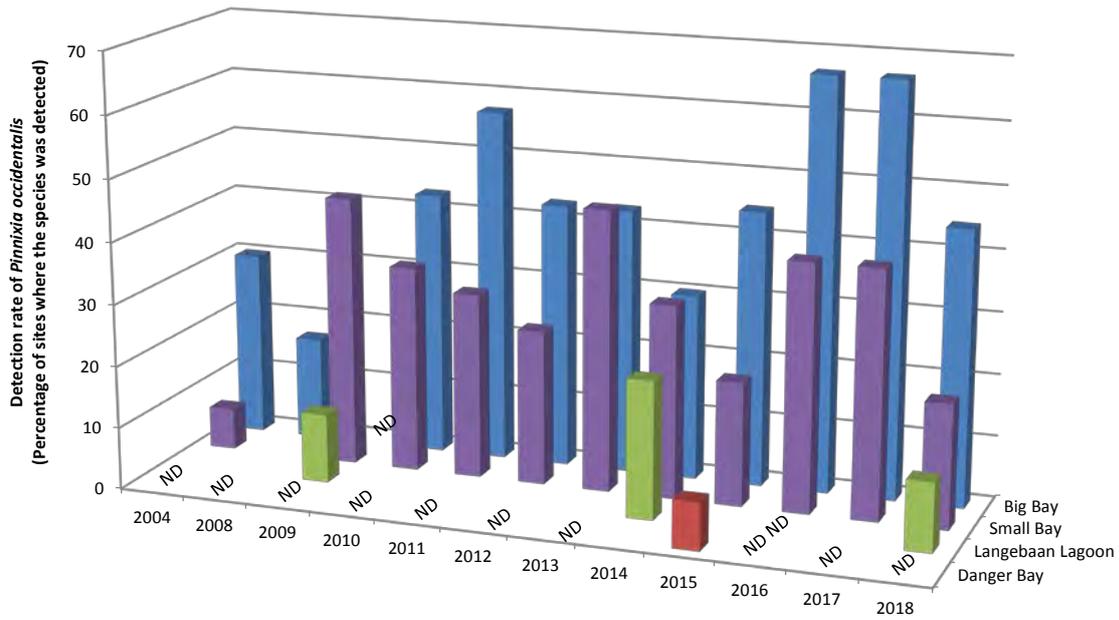
*Pinnixa occidentalis* has been sporadically present in Langebaan Lagoon three sites (LL31, LL33 and LL40) but abundance at these sites was very low with only four individuals per square metre (Figure 13.6). This crab was again found in Langebaan this year, at the same site and density recorded in 2014 (LL31). Currently this species does not appear to be spreading or increasing in density in Langebaan Lagoon.

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.

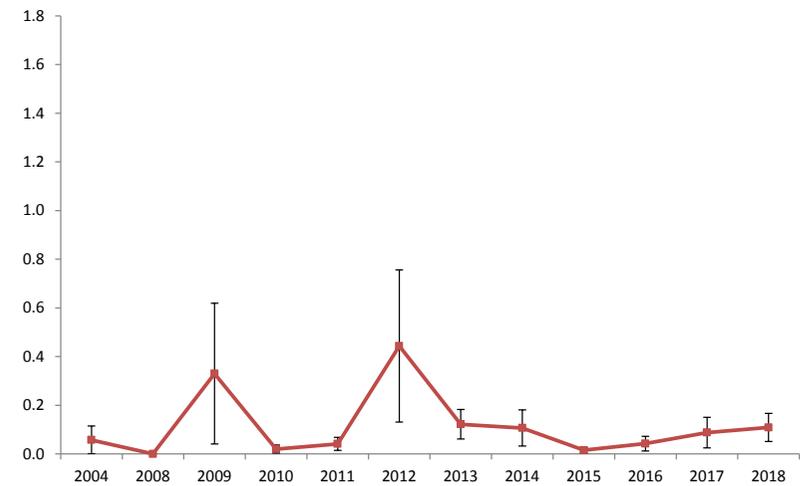
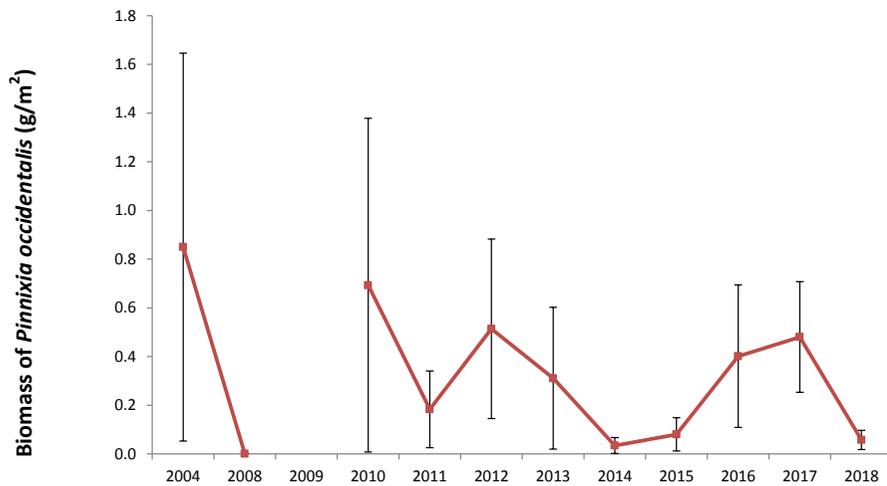
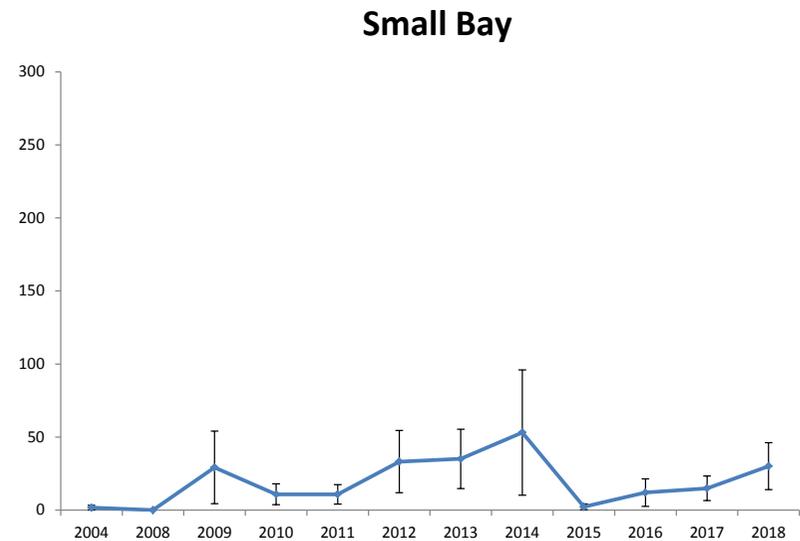
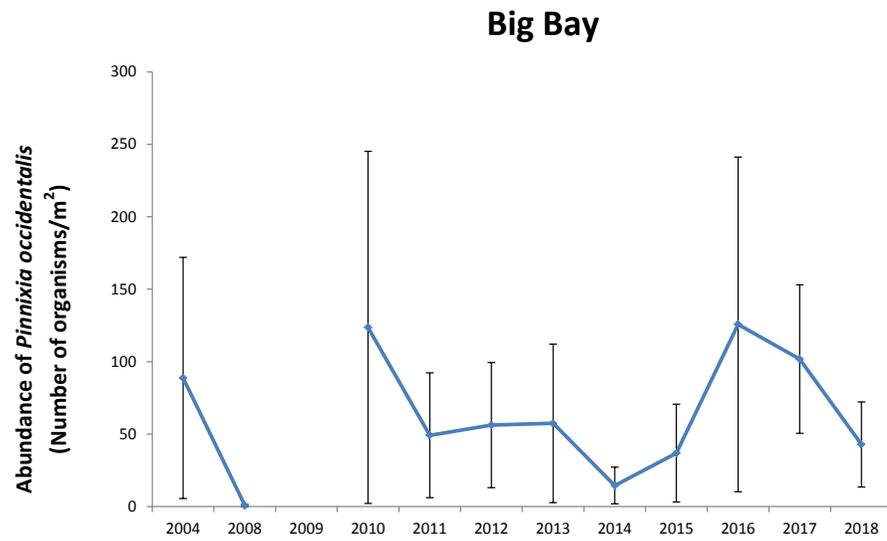
In conclusion, these data suggest that *P. occidentalis* is now well established in Big Bay and Small Bay and may be in the process of expanding into more exposed and deeper habitats outside of the Bay, including Danger Bay.



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 2004-2018. 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 2004-2018. No data were collected in the period 2005-2007.

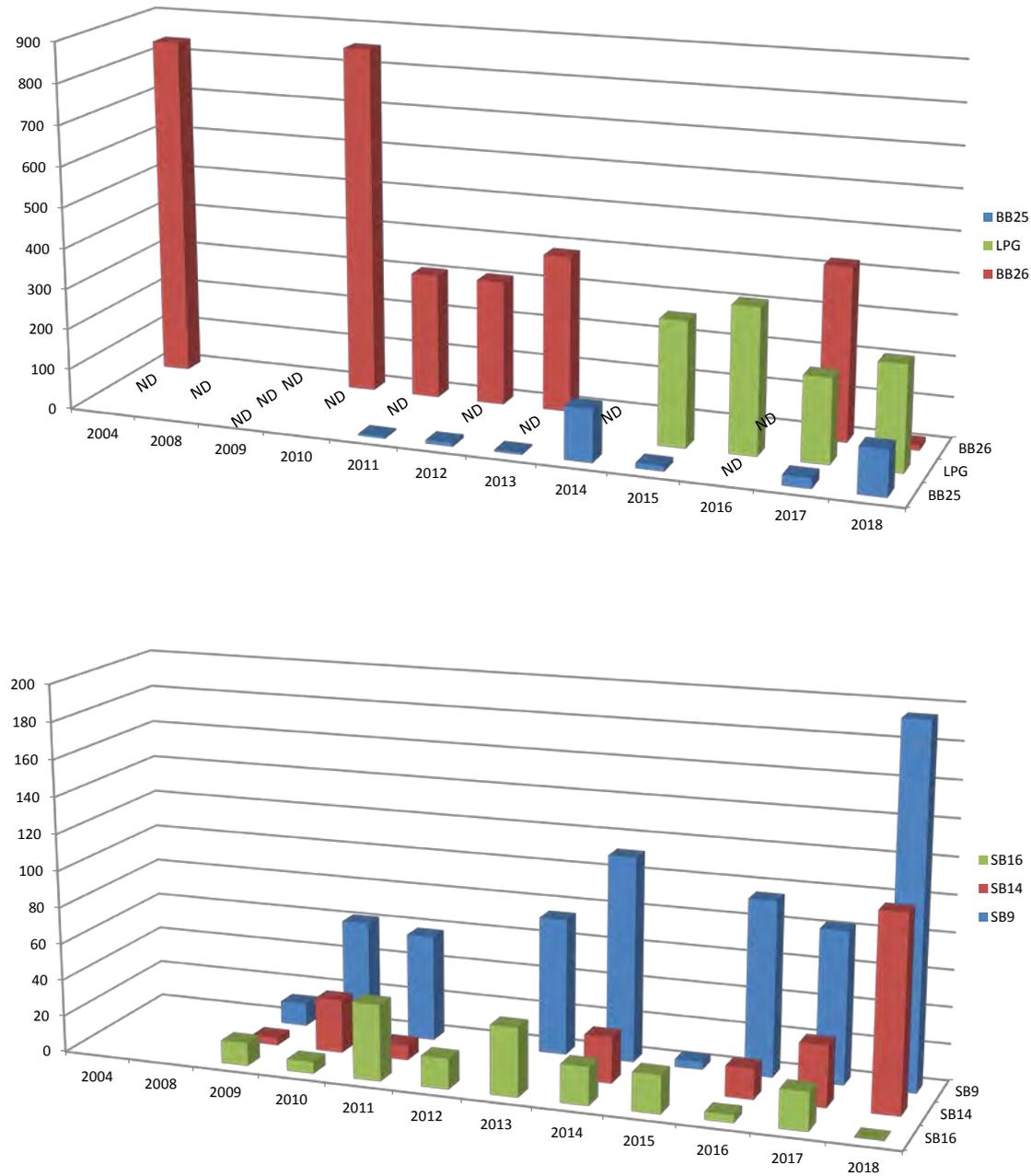


Figure 13.8 Abundance of the Western Pea crab *Pinnixia occidentalis* in Saldanha Bay, at selected sites in Big Bay (top) and Small Bay (bottom) from 2004-2018. No data were collected in the period 2005-2007.

### 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.



### 13.7 Pacific oyster *Crassostrea gigas*

Figure 13.9 Lagoon snail *Littorina saxatilis* (Photo: Prof. C.L. Griffiths)

*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.

Translocated oysters act as vectors of marine alien species all over the world. Oysters attach to rocks, walls and other surfaces and are exposed to colonisation by fouling organisms, which can be transported to other countries. Marine alien species imported on oyster shells may have significant ecological impacts in areas where they establish (Haupt *et al.* 2010) (e.g. Disc lamp shell *Disciniscus tenuis* – Section 13.10).

### 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 13.10). 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).



Figure 13.10 European mussel *Mytilus galloprovincialis*. (Photo: Prof. C.L. Griffiths.)

The population subsequently crashed, decreasing in size by 88% by early 2001 (Hanekom & Nel 2002) and had died off completely by mid-2001, leaving only empty shells and anoxic sand (Robinson *et al.* 2007a). The reason for the die off is still not clear, and impacts on the macrobenthic infauna on the banks was evident for at least six months after most of the dead mussel shells had been removed by SANParks in late 2001.

Data from the State of the Bay surveys suggest that *M. galloprovincialis* 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). 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%). 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.

At Marcus Island, a comparison of intertidal communities pre- and post-invasion of *Mytilus galloprovincialis* (1980 vs 2001), *Semimytilus algosus* and *Balanus glandula* (1980 vs 2012) demonstrated that the indigenous mussels *Choromytilus meridionalis* disappeared by 2012, and *Aulacomya atra* decreased in abundance (Sadchatheeswaran *et al.* 2015). While recruits of the limpet *Scutellastra granularis* initially benefited from the arrival of *M. galloprovincialis*, adults were adversely affected (Sadchatheeswaran *et al.* 2015). Although *M. galloprovincialis* did not alter habitat complexity when replacing *C. meridionalis* on the low shore at Marcus Island, it was responsible for diminishing habitat complexity when replacing *Aulacomya atra* on the mid shore. Here, *M. galloprovincialis* was responsible for a reduction in abundance and diversity of other species (Sadchatheeswaran *et al.* 2015). *Mytilus galloprovincialis* has also been shown to overshadow interannual and seasonal changes of intertidal rocky shore communities on Marcus Island and was found to be the most important factor influencing community composition (Sadchatheeswaran *et al.* 2018). As a result, *M. galloprovincialis* is considered to be an alien ecosystem engineer within the intertidal zone of the South African west coast (Sadchatheeswaran *et al.* 2015).

In more recent years, *M. galloprovincialis* abundance has decreased reaching levels lower than those observed in 2005 at North Bay and Lynch Point. 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. The Stellenbosch Marine Laboratory is currently investigating 'predator naivety' through responses towards a newly invasive prey species (PhD student Lisa Stein supervised by Tamara Robinson). The findings of this study will provide important insights on how the native rocky shore communities respond to mussel invasions (The Robinson Lab 2018).

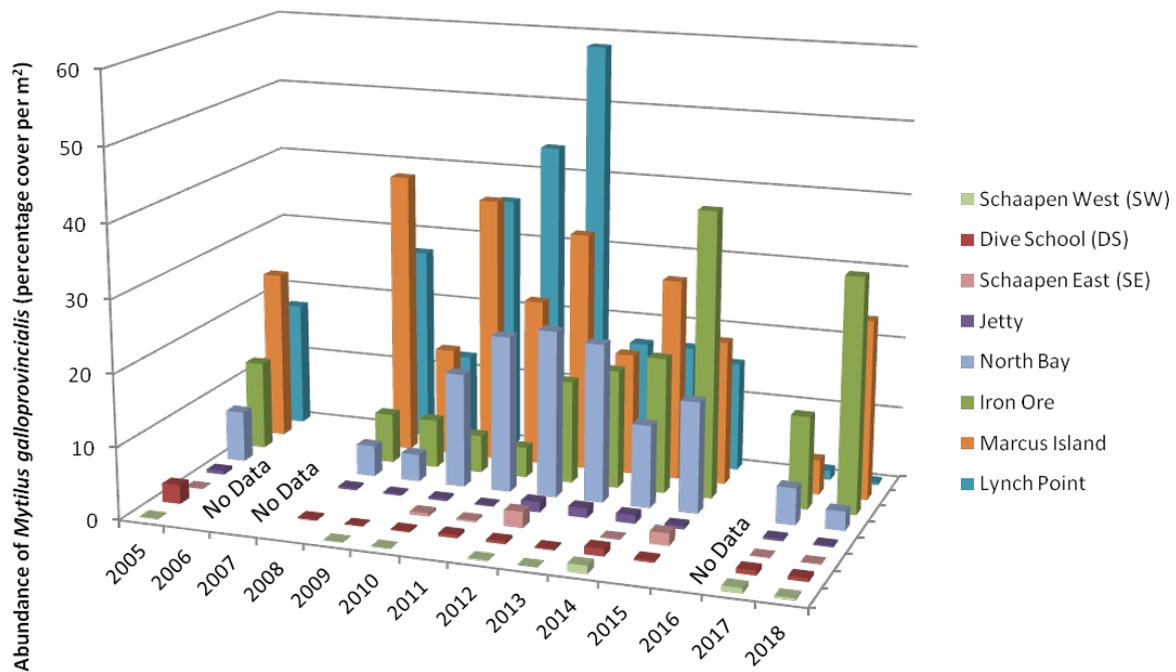


Figure 13.11. Changes in the abundance (% cover) of the Mediterranean mussel *Mytilus galloprovincialis* at eight rocky intertidal sites in Saldanha Bay over the period 2005-2018. Data are shown as an average of percentage cover on the mid and low shore. No samples were collected in 2006, 2007 and 2016. Information of the locations of these sampling stations is provided in Chapter 8.

### 13.9 Pacific South American mussel *Semimytilus algosus*

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).



Figure 13.12 Pacific South American mussel *Semimytilus algosus* (Photo: Prof. C.L. Griffiths)

At exposed sites, this species 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). A recent study addressed the lack of information available on subtidal mussel communities (Skein *et al.* 2018). This study confirmed that *S. algosus* has a strong preference for wave exposed shores and forms dense intertidal beds along the west coast (de Greef *et al.* 2013; Skein *et al.* 2018). However, the subtidal surveys found that *S. algosus* represents the dominant species at sheltered sites on the west coast and forms equally dense beds at exposed sites when compared to the indigenous species (Skein *et al.* 2018). These findings may explain why *S. algosus* has previously been found on mussel farm ropes in Saldanha Bay. A subtidal reef survey to confirm or deny the presence and spread of *S. algosus* could provide more information on adaptability of this species. Furthermore, subtidal specimens were generally found to be considerably larger than those found in the intertidal zone. *Semimytilus algosus* attained maximum sizes larger than 120 mm, in contrast to 54 mm in the intertidal (Skein *et al.* 2018). Mussels smaller than 60 mm are considered to be vulnerable to predators which could potentially have implications for the future spread and success of the species (de Greef *et al.* 2013).

In a laboratory study conducted by Alexander *et al.* (2015) algae consumption exhibited by *S. algosus* was shown to be more efficient in warm water than in cold water, which led to the conclusion that this species may have the potential to establish along the south coast of South Africa (Alexander *et al.* 2015). In conclusion, the establishment of large individuals in the subtidal zone could have important implications for the future invasion of *S. algosus* as large mussels contribute proportionally more to the reproductive output of the population (van Erkom Schurink and Griffiths 1991; Skein *et al.* 2018).

### 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 13.13). 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 its 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 13.13 Disc lamp shell *Discinisca tenuis* (Photo: Prof. C.L. Griffiths)

### 13.11 Dirty sea squirt *Ascidella aspersa*

*Ascidella 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 13.14). 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 13.14 *Ascidella 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 13.15). 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 13.15 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 13.16 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  $426 \pm 81$  to  $508 \pm 218$  individuals per  $m^2$ ).



Figure 13.17 Brooding anemone *Sagartia ornata* (Photo: Prof. C.L. Griffiths)

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 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 13.18).

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 *P. perforatus* appeared for



Figure 13.18 *Perforatus perforatus* (Pilsbry, 1916)  
(Photograph: Dr. Nina Steffani)

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).

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



Figure 13.19 *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



Figure 13.20 European porcelain crab *Porcellana platycheles* (Photo: Prof. C.L. Griffiths).

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 13.20). 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.

## **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 15% 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.

In an effort to reduce potable water consumption in the area, the Saldanha Bay Municipality (SBM) has come to an agreement with various types of water users (construction, irrigation, industry) to re-use treated wastewater. This has dramatically reduced the potable water demand and has had the positive spinoff in that currently only very small volumes of wastewater from the WWTWs enter the marine environment.

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<sup>3</sup> per annum at a maximum daily discharge volume of 1 152 m<sup>3</sup>. 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. Sea Harvest uses a fair amount of potable water for the fish processing activities and has implemented a Reverse Osmosis plant to reclaim freshwater from seawater and wastewater. Sea Harvest commissioned Anchor Environmental Consultants (Pty) Ltd to conduct the compliance monitoring and dispersion modelling study to establish whether the current CWDP conditions are adequate. It was found that the benthic macrofauna community around the outfall differs significantly from the rest of Small Bay, which is due to the changes in sediment characteristics as a result of high TSS content in the effluent. The dispersion modelling study demonstrated that Sea Harvest is required to move their pipeline further offshore to facilitate improved mixing of the effluent in the receiving environment. Sea Harvest is currently engaging with The Department of Public Works to move the discharge to the end of the Government Jetty which would take the discharge point at least 150 m further from the shore and into also into deeper water where potential for dispersal is much greater.

#### 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 currently in the process of establishing a sea-based Aquaculture Development Zone (ADZ) in Saldanha Bay. The ADZ areas comprise four precincts totalling 420 ha of new aquaculture areas in Saldanha Bay for a total ADZ comprising 884 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 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. Although no domestic legislation is currently in place to regulate ballast water discharge, the Transnet National Port Authority in Saldanha Bay has implemented a number of mechanisms to track and control the release of ballast water into the harbour.

### 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 recycling should continue as wastewater production increases in the area.
- 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, promulgated 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 Ground water

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<sup>3</sup> 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. It is recommended that additional monitoring points are established at the head of the lagoon as well as analysis of extent of phragmites coverage by up to date mapping and aerial photographs.

### 14.3 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 need 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 higher along the shore and are above published guidelines for foodstuffs in the case of lead. Concentrations reported for mariculture operations that are located offshore are slightly lower. This may be linked to higher growth rates of farmed mussels, and the fact that the cultured mussels feed on phytoplankton blooms in freshly upwelled, uncontaminated water.

Metal contamination poses a very serious risk to the health of people harvesting mussels from the shore (large quantities of shellfish are harvested and consumed by recreational and subsistence fishers from the shore of the Bay) and concentrations above regulatory limits requires management interventions to address the 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 elevated trace metals 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 West Coast District Municipality (WCDM). The microbial monitoring program provides evidence that three sites deteriorated in water quality, while only one improved. The situation in Small Bay remains a concern, with 40% of the sites exceeding the levels for safe mariculture practices, three sites bordering on minimum requirements for safe recreational activities and one not meeting these minimum requirements in 2017. Faecal coliform counts at three of the four sites in Big Bay were within the 80<sup>th</sup> percentile limits for mariculture in 2017 and 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.

#### 14.4 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 2018, 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 budget allows. 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 2018 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 2018 and present no major concern, however, it is recommended that TPH and PAH monitoring continues on an annual basis as a precautionary measure.

## 14.5 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, and 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.

## 14.6 Benthic macrofauna

Monitoring of benthic macrofaunal communities over the period 1999-2018 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 macrofaunal 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.

## 14.7 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 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 99 taxa were recorded from the eight study sites, most of which had been found in previous survey years. The faunal component was represented by 18 species of filter-feeders, 26 species of grazers, and 14 species of predators and scavengers combined. The algal component comprised 27 corticated (foliose) seaweeds, seven 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.

## 14.8 Fish

Long-term monitoring of juvenile fish assemblages by means of experimental seine-netting in the surf zone has revealed some concerning trends. A significant decline 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<sup>-1</sup> day<sup>-1</sup> 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.

The recent discovery of alien rainbow trout in Kraal Baai (almost certainly escapees from the pilot fish cage farming in Big Bay) is another threat to the indigenous fish fauna in the region. These predatory fish will prey on indigenous invertebrates and fish and ongoing introductions could cause ecosystem level impacts. These alien fish are highly unlikely to establish self-sustaining populations in the bay and lagoon due to the lack of suitable spawning habitat (cool, clear fresh water rivers) in the region. At the current experimental scale of fish farming, the number of escapees are not expected to be having highly significant impacts on indigenous fauna. However, at the proposed commercial scale finfish cage farming the number of alien salmonids introduced into the Bay and the Lagoon via ongoing escapes will probably have significant negative effects on indigenous fauna. Given the importance of the nearshore waters of Saldanha Bay and Langebaan lagoon as nursery areas for a number of vulnerable indigenous fishery species, finfish cage farming should be restricted to the outer Bay, and mitigation measures to minimise escapes from cages should be strictly enforced.

Fish sampling surveys should be conducted annually at the same sites selected during the 2018 study for as long as possible. This sampling should be confined to the same seasonal period each year for comparative purposes.

## **14.9 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 2 635 birds in 2018. 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.

## 14.10 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, overall the abundance of *B. glandula* and *M. galloprovincialis* on rocky shores in Saldanha Bay has been decreasing in the last few years (note that percentage cover fluctuates but a decreasing trend is currently observed). 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 recently detected barnacle *Balanus glandula* and the Pacific mussel *Semimytilus algosus*. The latter was recently shown to occur exclusively subtidally in sheltered areas such as Saldanha Bay (Skein *et al.* 2018). Indeed, *S. algosus* is absent in the intertidal zone in Saldanha Bay but has been previously observed on mussel rafts in the Bay. It is therefore recommended that subtidal surveys are conducted to ascertain whether populations have indeed established in Saldanha Bay.

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.

## 14.11 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
<b>GROUND WATER</b>			
Aquifer and Lagoon: Physical aspects (extraction rates, volumes, recharge rates, volumes, temperature, salinity, tidal height, rainfall)	1984 – 2018 And 2016-2018	Aquifer overextraction can have a detrimental impact as indicated in the past. Especially during times of draught, but more recently, is being monitored and managed closely in order to prevent overextraction. Baseline monitoring of the Lagoon is ongoing at present.	
<b>WATER QUALITY</b>			
Physical aspects (temperature, salinity, dissolved oxygen, nutrients and chlorophyll)	1974-2000, 2010-2011, 2014-2018	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. 2018	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)	1999-2018	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 <i>Enterococci</i> as well.	
Trace metal contaminants in water	1997-2008, 2014-2018	Concentrations of lead in mussel flesh are consistently above the safety guidelines for food stuffs. Any future dredging events should be limited as far as possible owing the likely mobilization of trace metals from sediments.	
<b>SEDIMENTS</b>			
Particle size (mud/sand/gravel)	1974-2018	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)	1974-2018	Elevated levels of TOC at the Yacht Club basin and near the mariculture rafts (negative impacts) are of particular concern.	

Parameter monitored	Time period	Anthropogenic induced impact	Rating
Total organic nitrogen (TON)	1974-2018	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	1980-2018	Cadmium, lead, and copper are currently elevated considerably above historic levels. Concentrations were highest in 1999 following major dredge event. Pb, Cu, Ni elevated in 2008-2016 and Cd and Cu in 2018 at Yacht Club and <i>multi-purpose terminal</i> , which may be related to shipping activities and maintenance dredging.	
<b>AQUATIC MACROPHYTES</b>			
Seagrasses, salt marsh, reeds and sedges	2016-2018	Seagrass ( <i>Zostera capensis</i> ) 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. To date, no monitoring program exists for reeds and sedges.	
<b>BENTHIC MACROFAUNA</b>			
Species abundance, biomass, and diversity	1999-2018	Benthic macrofaunal communities in Saldanha Bay and Langebaan Lagoon Bay are highly sensitive to dredging activities and drop dramatically immediately after each major dredging event. Macrofaunal communities are currently increasing in abundance and biomass since the last major event in 2008.	
<b>ROCKY INTERTIDAL AND INTRODUCED SPECIES</b>			
Impact of alien mussel and barnacle introductions	1980-2018	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.	
<b>FISH</b>			
Community composition and abundance	1986-2018	White stumnose abundance and fishery landings have declined dramatically over the last decade. Abundance of some other species in the Bay and Lagoon (e.g. harders and gobies) have also been declining for several years, and this is of some concern.	
<b>BIRDS</b>			
Population numbers of key species in Saldanha Bay and islands	1977-2016	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	1976-2018	Populations of migrant waders utilising Langebaan Lagoon have decreased dramatically over the last 30	

Parameter monitored	Time period	Anthropogenic induced impact	Rating
		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.	
<b>ALIEN AND INVASIVES</b>			
Total number of alien and invasive species in Saldanha Bay and Langebaan Lagoon	Current 2018	Twenty five of these species have been confirmed from Saldanha Bay and/or Langebaan Lagoon, of which all but one are considered invasive.	
Acorn barnacle <i>Balanus glandula</i>	2010-2018	Decreasing trend in abundance at some sites. Nevertheless, it remains one of the more abundant species on the mid-shore in Saldanha Bay and is still of significant concern.	
European mussel <i>Mytilus galloprovincialis</i>	2005-2018	Decreasing trend in abundance at some sites. Nevertheless, it remains one of the most abundant species on the mid and low shore at exposed sites in Saldanha Bay and is still of significant concern.	
Western pea crab <i>Pinnixia occidentalis</i>	2004-2018	Abundance and biomass in both regions fluctuated over time, showing no apparent upward or downward trend	

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## **16 APPENDIX**

The Chapter contains supplementary information for the Rocky Intertidal, Bird and Alien and Invasive Species Chapters in table format (Table 16.1 - Table 16.3).

**Table 16.1** Percentage cover of each species found on the rocky shores of Saldanha Bay and Langebaan Lagoon in 2018. DS = Dive School; J = Jetty; IO = Iron Ore Terminal; L = Lynch Point; M = Marcus Island; NB = North Bay; SE = Schaapen Island East; SW = Schaapen Island West. Total percentage cover for each feeding guild is shown in bold.

Percentage cover	DS	J	IO	L	M	NB	SE	SW
<b>SUBSTRATE</b>	<b>88.0</b>	<b>80.7</b>	<b>43.6</b>	<b>81.6</b>	<b>28.2</b>	<b>55.6</b>	<b>50.9</b>	<b>79.3</b>
Rock	85.5	68.5	43.2	81.3	28.2	55.6	47.8	78.0
Sand	2.5	0.8	0.3	0.3	0.0	0.0	3.1	1.3
Gravel	0.0	11.3	0.0	0.0	0.0	0.0	0.0	0.0
<b>GRAZERS</b>	<b>3.5</b>	<b>1.7</b>	<b>1.6</b>	<b>2.1</b>	<b>1.2</b>	<b>3.9</b>	<b>1.6</b>	<b>2.5</b>
<i>Acanthochiton garnoti</i>	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Afrolittorina knysnaensis</i>	0.0	0.0	0.7	0.3	0.0	0.3	0.0	0.0
<i>Callochiton dentatus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Chaetopleura papilio</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Chiton nigrovirescens</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cymbula granatina</i>	0.0	0.0	0.0	0.2	0.0	0.3	0.1	0.3
<i>Cymbula miniata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Cymbula oculus</i>	0.5	0.0	0.1	0.0	0.0	0.0	0.1	0.0
<i>Dendrofissurella scutellum</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Fissurella mutabilis</i>	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1
<i>Gibbula</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Gibbula zonata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
<i>Haliotis midae</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Helcion dunkeri</i>	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
<i>Helcion pectunculus</i>	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Helcion pruinus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Ischnochiton oniscus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Scutellastra argenvillei</i>	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
<i>Scutellastra barbara</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Scutellastra cochlear</i>	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
<i>Scutellastra granularis</i>	0.0	0.0	0.3	0.0	0.9	0.7	0.0	0.0
<i>Scutellastra tabularis</i>	0.0	0.2	0.0	0.2	0.0	0.6	0.4	0.1
<i>Siphonaria capensis</i>	0.2	0.0	0.0	0.1	0.1	1.4	0.0	0.8
<i>Siphonaria serrata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
<i>Parechinus angulosus</i>	0.8	0.2	0.0	0.1	0.0	0.0	0.0	0.0
<i>Parvulastra exigua</i>	0.7	0.4	0.3	0.2	0.0	0.1	0.4	0.6
<i>Onchidella maculata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Oxysteles tigrina</i>	0.3	0.3	0.0	0.2	0.0	0.0	0.2	0.4
<i>Oxysteles antoni</i>	0.6	0.4	0.0	0.7	0.0	0.0	0.2	0.0
<i>Tricolia capensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<b>PREDATORS</b>	<b>1.0</b>	<b>0.6</b>	<b>0.9</b>	<b>1.2</b>	<b>1.0</b>	<b>0.9</b>	<b>0.7</b>	<b>1.7</b>
<i>Actinia equina</i>	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1
<i>Anthopleura michaelsoni</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Anthostella stephensoni</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Anthothoe stimpsonii</i>	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.4
<i>Bunodactis reynaudi</i>	0.0	0.0	0.4	0.0	0.8	0.2	0.1	0.2
<i>Bunodosoma capense</i>	0.0	0.0	0.0	0.2	0.0	0.3	0.0	0.1
<i>Burnupena papyracea</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Burnupena</i> spp.	0.3	0.4	0.2	0.4	0.2	0.4	0.1	0.3
<i>Callopatiria granifera</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Clionella sinuata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Conus mozambicus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Percentage cover	DS	J	IO	L	M	NB	SE	SW
<i>Corynactis annulata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
<i>Cyclograpus punctatus</i>	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.0
<i>Doris granulosa</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Doris verrucosa</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Dromidia</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flatworm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Fusinus</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Henricia ornata</i>	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Hermit crab	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Hymenosoma orbiculare</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Marthasterias glacialis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nudibranch	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Nucella dubia</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
<i>Nucella squamosa</i>	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Ophiuroidea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Paguristes gamianus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Philine aperta</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Platydromia spongiosa</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Pseudactinia flagellifera</i>	0.1	0.0	0.0	0.2	0.0	0.0	0.2	0.0
<i>Pseudactinia</i> sp.	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.2
<i>Trochia cingulata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
<i>Volvarina capensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<b>FILTER FEEDERS</b>	<b>2.8</b>	<b>0.9</b>	<b>39.0</b>	<b>1.6</b>	<b>20.9</b>	<b>10.0</b>	<b>1.2</b>	<b>3.6</b>
<i>Amphibalanus amphitrite amphitrite</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Aulacomya atra</i>	0.3	0.2	0.8	0.2	1.2	1.0	0.0	0.6
<i>Austromegabalanus cylindricus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Balanus glandula</i>	0.9	0.0	16.4	0.2	2.8	6.4	0.0	1.1
<i>Choromytilus meridionalis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Chthamalus dentatus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Colonial ascidian	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.2
<i>Crepidula porcellana</i>	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.1
<i>Dendropoma corallinaceum</i>	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
<i>Dodecaceria capensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Encrusting Bryozoa	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Fanworm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Gunnarea gaimardi</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydroids	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Menesiniella regalis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Mytilus galloprovincialis</i>	0.3	0.1	21.7	0.2	16.6	2.0	0.0	0.2
<i>Notomegabalanus algicola</i>	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.2
<i>Octomeris angulosa</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Pentacta doliolum</i>	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0
<i>Perforatus perforatus</i>	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0
<i>Pseudocnella insolens</i>	0.1	0.0	0.0	0.0	0.3	0.0	0.0	0.4
<i>Pyura stolonifera</i>	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
<i>Roweia frauenfeldi</i>	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1
<i>Spirorbis</i> spp.	0.1	0.1	0.0	0.2	0.0	0.1	0.1	0.2
Sponge	0.3	0.1	0.0	0.1	0.0	0.2	0.8	0.4
<i>Tetraclita serrata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Thyone aurea</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Percentage cover	DS	J	IO	L	M	NB	SE	SW
Tubeworm	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
<b>CRUSTOSE</b>	<b>1.6</b>	<b>11.2</b>	<b>1.5</b>	<b>6.5</b>	<b>33.0</b>	<b>24.8</b>	<b>32.8</b>	<b>4.4</b>
Coralline (crustose)	0.4	7.2	0.2	3.0	11.5	1.8	9.3	2.1
Coralline (upright)	0.0	0.0	0.0	0.4	0.1	0.1	0.1	0.1
Diatoms	0.2	0.1	0.3	1.6	20.9	22.1	0.0	1.6
<i>Hildenbrandia</i> spp.	0.7	3.3	1.0	1.4	0.5	0.2	22.2	0.3
<i>Ralfsia verrucosa</i>	0.2	0.6	0.0	0.1	0.0	0.6	1.2	0.2
<b>EPHEMERALS</b>	<b>1.2</b>	<b>2.1</b>	<b>7.2</b>	<b>2.6</b>	<b>11.8</b>	<b>1.7</b>	<b>5.3</b>	<b>6.0</b>
<i>Callithamnion collabens</i>	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
<i>Centroceras clavulatum</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Ceramium</i> spp	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.1
<i>Cladophora</i> spp.	0.0	0.1	0.0	0.3	0.2	0.0	0.2	0.7
Green turf	0.0	0.2	0.0	0.0	2.6	0.0	0.0	0.0
<i>Porphyra capensis</i>	0.0	1.1	0.0	1.7	1.8	1.1	2.3	1.7
<i>Pachymenia orbitosa</i>	0.2	0.0	0.0	0.0	0.0	0.1	0.2	0.2
<i>Ulva</i> spp.	1.0	0.7	6.3	0.6	7.2	0.5	2.5	3.4
<b>CORTICATED</b>	<b>1.8</b>	<b>2.9</b>	<b>6.4</b>	<b>1.9</b>	<b>3.7</b>	<b>2.3</b>	<b>7.4</b>	<b>2.4</b>
<i>Ahnfeltiopsis complicata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Ahnfeltiopsis glomerata</i>	0.0	0.0	0.5	0.0	0.2	0.0	0.5	0.0
<i>Ahnfeltiopsis polyclada</i>	0.0	0.1	0.6	0.0	0.0	0.0	0.1	0.0
<i>Aristophamnion collabens</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Botryocarpa prolifera</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Botryocladia paucivesicaria</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Botryoglossum platycarpum</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Bryopsis myosurioides</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Carpoblepharis flaccida</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Caulacanthus ustulatus</i>	0.0	0.0	0.9	0.3	0.2	0.4	0.4	0.1
<i>Champia compressa</i>	0.0	0.0	0.1	0.0	0.5	0.0	0.0	0.0
<i>Champia lumbricalis</i>	0.0	0.0	0.0	0.0	0.3	0.6	0.0	0.0
<i>Chondria capensis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Chordariopsis capensis</i>	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Cochlear Garden	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Codium fragile fragile</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
<i>Codium lucasii</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Codium stephensiae</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Colpomenia sinuosa</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Gelidium pristoides</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
<i>Gelidium pteridifolium</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Gelidium vittatum</i>	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0
<i>Gigartina bracteata</i>	0.4	2.2	1.2	0.0	1.3	0.1	1.9	0.0
<i>Gigartina polycarpa</i>	0.1	0.1	0.4	0.5	0.0	0.7	0.0	1.6
<i>Grateloupia belangeri</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Grateloupia filicina</i>	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
<i>Grateloupia longifolia</i>	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
<i>Gymnogongrus dilatatus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Halopteris funicularis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Hypnea ecklonii</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Hypnea spicifera</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Laurencia glomerata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Leathesia marina</i>	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Percentage cover	DS	J	IO	L	M	NB	SE	SW
<i>Mazzaella capensis</i>	0.0	0.0	0.0	0.1	0.1	0.3	0.0	0.1
<i>Neuroglossum binderianum</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Nothogenia erinacea</i>	0.0	0.0	2.3	0.7	0.0	0.0	0.1	0.3
<i>Nothogenia ovalis</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Plocamium corallorhiza</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Plocamium</i> spp.	0.0	0.0	0.2	0.1	0.8	0.0	0.2	0.1
<i>Polyopes constrictus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Portieria hornemanii</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Pterosiphonia cloiophylla</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red turf	0.9	0.2	0.0	0.0	0.0	0.0	3.4	0.0
<i>Rhodophyllis reptans</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Rhodymenia pseudopalmata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Rhodymenia</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Sarcothalia radula</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Sarcothalia scutellata</i>	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
<i>Sarcothalia stiriata</i>	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0
<i>Schizymenia apoda</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Splachnidium rugosum</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
<i>Tayloriella tenebrosa</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Tsengia lanceolata</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<b>KELP</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>2.4</b>	<b>0.2</b>	<b>0.8</b>	<b>0.0</b>	<b>0.1</b>
<i>Ecklonia maxima</i>	0.0	0.0	0.0	1.4	0.1	0.5	0.0	0.1
<i>Laminaria pallida</i>	0.0	0.0	0.0	1.1	0.1	0.2	0.0	0.0

**Table 16.2** 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	<i>Haematopus moquini</i>	19	163
African Darter	<i>Anhinga rufa</i>	2	3
African Fish-Eagle	<i>Haliaeetus vocifer</i>	1	2
African Marsh-Harrier	<i>Circus ranivorus</i>	2	9
African Purple Gallinule	<i>Porphyrio madagascariensis</i>	2	2
African Rail	<i>Rallus caerulescens</i>	2	3
African Sacred Ibis	<i>Threskiornis aethiopicus</i>	112	720
African Snipe	<i>Gallinago nigripennis</i>	4	19
African Spoonbill	<i>Platalea alba</i>	24	137
Arctic Tern	<i>Sterna paradisaea</i>	35	35
Bank Cormorant	<i>Phalacrocorax neglectus</i>	10	29
Bar-tailed Godwit	<i>Limosa lapponica</i>	227	3000
Black Crake	<i>Zapornia flavirostra</i>	2	2
Black-crowned Night-Heron	<i>Nycticorax nycticorax</i>	3	6
Black-headed Heron	<i>Ardea melanocephala</i>	3	29
Black-necked grebe	<i>Podiceps nigricollis</i>	1	1
Blacksmith Lapwing	<i>Vanellus armatus</i>	20	78
Black-tailed Godwit	<i>Limosa limosa</i>	1	1
Black-winged Stilt	<i>Himantopus himantopus</i>	37	180
Cape Cormorant	<i>Phalacrocorax capensis</i>	88	2289
Cape Shoveler	<i>Anas smithii</i>	13	70
Cape Teal	<i>Anas capensis</i>	23	154
Caspian Tern	<i>Sterna caspia</i>	8	53
Cattle Egret	<i>Bubulcus ibis</i>	8	45
Chestnut-banded Plover	<i>Charadrius pallidus</i>	57	581
Common Greenshank	<i>Tringa nebularia</i>	119	1175
Common Moorhen	<i>Gallinula chloropus</i>	2	5
Common Redshank	<i>Tringa totanus</i>	14	76
Common Ringed Plover	<i>Charadrius hiaticula</i>	102	548
Common Sandpiper	<i>Actitis hypoleucos</i>	4	34
Common Tern	<i>Sterna hirundo</i>	528	9658
Common Whimbrel	<i>Numenius phaeopus</i>	168	2000
Crowned Cormorant	<i>Phalacrocorax coronatus</i>	31	142
Crowned Plover	<i>Vanellus coronatus</i>	4	8
Curlew Sandpiper	<i>Calidris ferruginea</i>	3377	25347
Egyptian Goose	<i>Alopochen aegyptiaca</i>	16	433
Eurasian Curlew	<i>Numenius arquata</i>	83	1373
Giant kingfisher	<i>Megaceryle maximus</i>	1	1
Glossy Ibis	<i>Plegadis falcinellus</i>	15	54
Goliath Heron	<i>Ardea goliath</i>	3	3

Common name	Scientific name	Average count	Maximum count
Great Crested Grebe	<i>Podiceps cristatus</i>	2	2
Great White Egret	<i>Egretta alba</i>	2	3
Great White Pelican	<i>Pelecanus onocrotalus</i>	28	262
Greater Flamingo	<i>Phoenicopterus roseus</i>	899	8724
Greater Sand Plover	<i>Charadrius leschenaultii</i>	7	35
Grey Heron	<i>Ardea cinerea</i>	8	83
Grey plover	<i>Pluvialis squatarola</i>	733	8228
Grey-headed Gull	<i>Larus cirrocephalus</i>	5	19
Hartlaub's Gull	<i>Larus hartlaubii</i>	228	1881
Kelp Gull	<i>Larus dominicanus</i>	155	2445
Kittlitz's Plover	<i>Charadrius pecuarius</i>	55	545
Lesser Flamingo	<i>Phoeniconaias minor</i>	213	1606
Lesser Sand Plover	<i>Charadrius mongolus</i>	7	19
Little Egret	<i>Egretta garzetta</i>	24	126
Little Grebe	<i>Tachybaptus ruficollis</i>	12	21
Little Stint	<i>Calidris minuta</i>	143	858
Little Tern	<i>Sterna albifrons</i>	9	64
Malachite Kingfisher	<i>Alcedo cristata</i>	1	2
Marsh Owl	<i>Asio capensis</i>	2	5
Marsh Sandpiper	<i>Tringa stagnatilis</i>	10	55
Osprey	<i>Pandion haliaetus</i>	2	5
Pied Avocet	<i>Recurvirostra avosetta</i>	53	521
Pied Kingfisher	<i>Ceryle rudis</i>	5	16
Pink-backed Pelican	<i>Pelecanus rufescens</i>	26	26
Purple Heron	<i>Ardea purpurea</i>	1	3
Red Knot	<i>Calidris canutus</i>	977	6219
Red-billed Teal (Duck)	<i>Anas erythrorhyncha</i>	5	22
Red-knobbed Coot	<i>Fulica cristata</i>	34	277
Reed Cormorant	<i>Phalacrocorax africanus</i>	22	277
Ruddy Turnstone	<i>Arenaria interpres</i>	559	4587
Ruff	<i>Philomachus pugnax</i>	25	237
Sanderling	<i>Calidris alba</i>	594	4950
Sandwich Tern	<i>Thalasseus sandvicensis</i>	34	1474
South African Shelduck	<i>Tadorna cana</i>	14	131
Southern Pochard	<i>Netta erythrophthalma</i>	4	4
Spur-winged Goose	<i>Plectropterus gambensis</i>	7	71
Swift Tern	<i>Thalasseus bergii</i>	38	1538
Terek Sandpiper	<i>Xenus cinereus</i>	43	266
Three-banded Plover	<i>Charadrius tricollaris</i>	6	38
Water Thick-knee	<i>Burhinus vermiculatus</i>	2	3
White-breasted Cormorant	<i>Phalacrocorax lucidus</i>	12	89
White-fronted Plover	<i>Charadrius marginatus</i>	86	473
White-winged Tern	<i>Chlidonias leucopterus</i>	4	17
Wood Sandpiper	<i>Tringa glareola</i>	3	9

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Common name	Scientific name	Average count	Maximum count
Yellow-billed Duck	<i>Anas undulata</i>	49	335
Yellow-billed Egret	<i>Ardea intermedia</i>	4	31

**Table 16.3.** 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
<u>PROTOCTISTA</u>					
<i>Mirofolliculina limnoriae</i>	Likely	Alien	Unknown	SB	Mead et al. 2011
<u>DINOFLAGELLATA</u>					
<i>Alexandrium minutum</i>	Likely	Alien	Europe	BW	Mead et al. 2011
<i>Alexandrium tamarense-complex</i>	Likely	Alien	N Atlantic/N Pacific	BW	Mead et al. 2011
<i>Dinophysis acuminata</i>	Likely	Alien	Europe	BW	Mead et al. 2011
<u>PORIFERA</u>					
<i>Suberites ficus</i>	Likely	Invasive	Europe	SF	Samaai and Giboons 2005
<u>CNIDARIA</u>					
ANTHOZOA					
<i>Metridium senile</i>	Likely	Alien	N Atlantic/N Pacific	SF/OR	Mead et al. 2011
<i>Sagartia ornata</i>	Confirmed	Naturalised	Europe	SF/BW	Robinson and Swart 2015
HYDROZOA					
<i>Coryne eximia</i>	Confirmed	Invasive	N Atlantic/N Pacific	SF/BW	Mead et al. 2011
<i>Gonothyrea loveni</i>	Likely	Alien	North Atlantic	SF/BW	Mead et al. 2011
<i>Laomedea calceolifera</i>	Likely	Alien	North Atlantic	SF/BW	Mead et al. 2011
<i>Obelia bidentata</i>	Likely	Naturalised	Unknown	SF/BW	Mead et al. 2011
<i>Obelia dichotoma</i>	Likely	Naturalised	Unknown	SF/BW	Mead et al. 2011
<i>Obelia geniculata</i>	Likely	Naturalised	Unknown	SF/BW	Mead et al. 2011
<i>Pachycordyle navis</i>	Likely	Alien	Europe	SF/BW	Mead et al. 2011
<i>Pinauay larynx</i>	Likely	Naturalised	North Atlantic	SF/BW	Mead et al. 2011

Taxon	Occurrence in Saldanha/Langebaan	Status	Origin	Vector	Reference
<i>Pinauay ralphi</i>	Likely	Alien	North Atlantic	SF/BW	Mead et al. 2011
<u>ANNELIDA</u>					
POLYCHAETA					
<i>Boccardia proboscidea</i>	Confirmed	Invasive	Eastern Pacific	M	David and Simon 2014; CAS unpublished data
<i>Capitella sp.</i>	Likely	Cryptogenic	Unknown	SF/BW	Mead et al. 2011
<i>Dodecaceria fewkesi</i>	Likely	Naturalised	North American Pacific	SF/BW	Peters et al. 2014
<i>Ficopomatus enigmaticus</i>	Likely	Invasive	Australia	SF	McQuaid and Griffiths 2014
<i>Janua pagenstecheri</i>	Likely	Alien	Europe	SF/BW	Mead et al. 2011
<i>Neodexiospira brasiliensis</i>	Confirmed	Invasive	Indo-Pacific	SF/BW	Mead et al. 2011
<i>Simplicaria pseudomilitaris</i>	Likely	Alien	Unknown	SF/BW	Mead et al. 2011
<i>Polydora hoplura</i>	Confirmed	Invasive	Europe	SF/BW	Simon 2011; David and Simon 2014
<i>Polydora cf. websteri</i>	Likely	Alien, in potentially open facility	Unknown	M	Simon 2015; Williams 2015
<i>Hydroides elegans</i>	Likely	Cryptogenic	Unknown	SF/BW	Robinson et al. 2016
<u>CRUSTACEA</u>					
CIRRIPEDIA					
<i>Amphibalanus amphitrite amphitrite</i>	Confirmed (AEC 2014)	Cryptogenic	Unknown	SF/BW	Mead et al. 2011
<i>Amphibalanus venustus</i>	Likely	Invasive	North Atlantic	SF	Mead et al. 2011
<i>Balanus glandula</i>	Confirmed	Invasive	North American Pacific	SF/BW	Robinson et al. 2015
<i>Perforatus perforatus</i>	Confirmed	To be confirmed	North American Pacific	SF/BW	Biccard and Griffiths ( <i>Pers Comm. 2017</i> )
COPEPOD					
<i>Acartia (Odontacartia) spinicauda</i>	Likely	Alien	Western North Pacific	BW	Mead et al. 2011

Taxon	Occurrence in Saldanha/Langebaan	Status	Origin	Vector	Reference
ISOPODA					
<i>Dynamene bidentata</i>	Likely	Invasive	Europe	SF/BW	Mead et al. 2011
<i>Ligia exotica</i>	Likely	Cryptogenic	Unknown	SB	Mead et al. 2011
<i>Limnoria quadripunctata</i>	Likely	Alien	Unknown	SB	Mead et al. 2011
<i>Limnoria tripunctata</i>	Likely	Alien	Unknown	SB	Mead et al. 2011
<i>Paracerceis sculpta</i>	Likely	Alien	Northeast Pacific	SF/BW	Mead et al. 2011
<i>Synidotea hirtipes</i>	Confirmed	Cryptogenic	Indian Ocean	SF/BW	Mead et al. 2011
<i>Synidotea variegata</i>	Confirmed	Cryptogenic	Indo-Pacific	SF/BW	Mead et al. 2011
AMPHIPODA					
<i>Caprella equilibra</i>	Likely	Cryptogenic	Unknown	SF/BW	Mead et al. 2011
<i>Caprella mutica</i>	Likely	Alien	North-east Asia	SF	Peters and Robinson 2017
<i>Caprella penantis</i>	Likely	Cryptogenic	Unknown	SF/BW	Mead et al. 2011
<i>Chelura terebrans</i>	Confirmed	Invasive	Pacific Ocean	SF/SB	Mead et al. 2011
<i>Cerapus tubularis</i>	Confirmed	Invasive	North American Atlantic	BS	Mead et al. 2011
<i>Cymadusa filosa</i>	Likely	Cryptogenic	Unknown	BS	Mead et al. 2011
<i>Erichthonius brasiliensis</i>	Likely	Invasive	North Atlantic	SF/BW	Mead et al. 2011
<i>Erichthonius difformis</i>	Likely	Alien	Unknown, northern hemisphere	SF	Peters <i>et al.</i> 2014
<i>Ischyrocerus anguipes</i>	Likely	Invasive	North Atlantic	SF/BW	Mead et al. 2011
<i>Jassa marmorata</i>	Likely	Naturalised	North Atlantic	SF/BW	Conlan 1990; Mead et al. 2011
<i>Jassa morinoi</i>	Likely	Invasive	Eastern North Pacific	SF/BW	Conlan 1990; Mead et al. 2011
<i>Jassa slatteryi</i>	Confirmed	Invasive	North Pacific	SF/BW	Conlan 1990; Mead et al. 2011
<i>Paracaprella pusilla</i>	Likely	Cryptogenic	Unknown	SF/BW	Mead et al. 2011

Taxon	Occurrence in Saldanha/Langebaan	Status	Origin	Vector	Reference
<i>Orchestia gammarella</i>	Confirmed	Invasive	Europe	BS	Mead et al. 2011
DECAPODA					
<i>Carcinus maenas</i>	Confirmed (G. Branch pers. comm.)	Invasive	Europe	SF/BW/OR	Robinson et al. 2005
<i>Pinnixa occidentalis</i>	Confirmed (Anchor 2011)	Invasive	North American Pacific	BW	Clark and Griffiths 2012
<i>Porcellana platycheles</i>	Confirmed (Branch and Griffiths pers. comm. 2015)	To be confirmed	Mediterranean	BW	Unpublished
<i>Xantho incicus</i>	Likely	Alien	France	M	Haupt et al. 2010
<u>INSECTA</u>					
COLEOPTERA					
<i>Cafius xantholoma</i>	Likely	Invasive	Europe	BS	Mead et al. 2011
<u>MOLLUSCA</u>					
GASTROPODA					
<i>Catriona columbiana</i>	Likely	Alien	North Pacific	SF/BW	Mead et al. 2011
<i>Littorina saxatilis</i>	Confirmed	Invasive	Europe	BS	Mead et al. 2011
<i>Tritonia nilsodhneri</i>	Likely	To be confirmed	Europe	SF/BW	Zsilavec 2007
<i>Kaloplocamus ramosus</i>	Likely	To be confirmed	Unknown	SF/BW	Zsilavec 2007
<i>Thecacera pennigera</i>	Likely	Cryptogenic	Unknown	SF/BW	Mead et al. 2011
<i>Anteaeolidiella indica</i>	Confirmed	Cryptogenic	Unknown	SF/BW	Mead et al. 2011
BIVALVIA					
<i>Bankia carinata</i>	Likely	Cryptogenic	Unknown	SB	Mead et al. 2011
<i>Bankia martensi</i>	Likely	Cryptogenic	Unknown	SB	Mead et al. 2011
<i>Crassostera gigas</i>	Confirmed	Invasive	Japan	M	Haupt et al. 2010; Keightley et al. 2015
<i>Dicyathifer manni</i>	Likely	Cryptogenic	Unknown	SB	Mead et al. 2011

Taxon	Occurrence in Saldanha/Langebaan	Status	Origin	Vector	Reference
<i>Lyrodus pedicellatus</i>	Likely	Alien	Unknown	SB	Mead et al. 2011
<i>Mytilus galloprovincialis</i>	Confirmed	Invasive	Europe	SF/BW	Robinson et al. 2005
<i>Semimytilus algosus</i>	Confirmed	Invasive	South Pacific	SF/BW	de Greef <i>et al.</i> 2013
<i>Teredo navalis</i>	Likely	Invasive	Europe	SB	Mead et al. 2011
<i>Teredo somersi</i>	Likely	Cryptogenic	Unknown	SB	Mead et al. 2011
<u>BRACHIOPODA</u>					
<i>Discinisca tenuis</i>	Confirmed	Invasive	Namibia	M	Haupt <i>et al.</i> 2010; Peters <i>et al.</i> 2014
<u>BRYOZOA</u>					
<i>Bugula flabellata</i>	Likely	Invasive	Unknown	SF	Florence et al. 2007
<i>Bugula neritina</i>	Likely	Invasive	Unknown	SF	Florence et al. 2007
<i>Conopeum seurati</i>	Confirmed	Invasive	Europe	SF	McQuaid and Griffiths 2014
<i>Cryptosula pallasiana</i>	Confirmed	Invasive	Europe	SF	Mead et al. 2011
<i>Watersipora subtorquata</i>	Confirmed	Invasive	Caribbean	SF	Florence et al. 2007; Mead et al. 2011
<u>CHORDATA</u>					
ASCIDIACEA					
<i>Ascidia sydneiensis</i>	Likely	Invasive	Pacific Ocean	SF	Mead et al. 2011; Rius et al. 2014
<i>Asciella aspersa</i>	Likely	Invasive	Europe	SF	Mead et al. 2011; Peters <i>et al.</i> 2014; Rius et al. 2014
<i>Botryllus schlosseri</i>	Likely	Invasive	Unknown	SF	Mead et al. 2011; Peters <i>et al.</i> 2014; Rius et al. 2014
<i>Ciona robusta</i> (formally known as <i>Ciona intestinalis</i> )	Confirmed (Picker & Griffiths 2011)	Invasive	Unknown	SF	Mead et al. 2011; Rius et al. 2014; Brunetti et al. 2015
<i>Clavelina lepadiformis</i>	Confirmed (Picker & Griffiths 2011)	Invasive	Europe	SF	Mead et al. 2011; Rius et al. 2014
<i>Cnemidocarpa humilis</i>	Likely	Invasive	Unknown	SF	Mead et al. 2011
<i>Corella eumyota</i>	Confirmed	Cryptogenic	Unknown	SF	Mead et al. 2011

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<i>Diplosoma listerianum</i>	Confirmed	Invasive	Europe	SF	Mead et al. 2011; Rius et al. 2014
<i>Microcosmus squamiger</i>	Likely	Invasive	Australia	SF	Mead et al. 2011; Rius et al. 2014
<i>Trididemnum cerebriforme</i>	Confirmed	Cryptogenic	Unknown	SF	Mead et al. 2011
<u>PISCES</u>					
<i>Cyprinus carpio</i>	Likely	Invasive	Central Asia to Europe	I	Mead et al. 2011
<u>RHODOPHYTA</u>					
<i>Antithamnionella spirographidis</i>	Confirmed	Invasive	North Pacific	SF/BW	Mead et al. 2011
<i>Antithamnionella ternifolia</i>	Likely	Cryptogenic	Australia	SF/BW	Mead et al. 2011
<i>Asparagopsis armata</i>	Likely	Invasive	Australia	Unknown	Bolton et al. 2011
<i>Schimmelmannia elegans</i>	Likely	Alien	Tristan da Cunha	BW	De Clerck et al. 2002
<u>CHLOROPHYTA</u>					
<i>Codium fragile fragile</i>	Confirmed	Invasive	Japan	SF/BW	Mead et al. 2011



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