SBWQFT
Saldanha Bay Water Quality Forum Trust

THE STATE OF SALDANHA BAY AND LANGEBAAN LAGOON 2023

2023

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Report prepared for:

Saldanha Bay Water Quality Forum Trust
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FOREWORD

In an era of rapid urbanisation, industrial expansion, and climate uncertainty, protecting our natural environment cannot be overstated. In recognition of the undeniable significance of the Saldanha Bay and Langebaan Lagoon ecosystem, the Saldanha Bay Water Quality Forum Trust (SBWQFT) embarked upon a mission guided by responsibility, awareness, and a dedicated commitment to preserving the treasures that lie beneath the waves. The vision of the SBWQFT is to maintain a sustainable marine ecosystem via the active involvement and collaboration of all relevant stakeholders. Only if the requirements of stakeholders and the environment are in harmony can this vision be sustained.

For the past 24 years, the SBWQFT has been an embodiment of hope—an alliance between science, policy, industry, and society with a shared vision of a world where marine life flourishes and the area's resources endure for the future. Establishing this trust has been a journey of collaboration, foresight, and shared responsibility. It is a product of the concerns voiced by scientists, industry, policymakers, environmentalists, and citizens alike, all of whom recognised the urgent need for a dedicated entity to ensure the marine ecosystem's protection, preservation, and restoration. This trust is not just an institution; it embodies a promise to current and future generations that we are taking concrete steps to guarantee a viable ecosystem. Striking a balance between short-term gains and long-term well-being is essential for creating a sustainable environment for our future.

The SBWQFT is not limited to mere scientific assessment; it embodies the ideals of transparency, accountability, and inclusivity. Its efforts are underpinned by the latest monitoring methodologies, and an unwavering commitment to encourage responsible water management practices. As we all move forward, let us remain steadfast in our dedication to the principles enshrined within this trust. Let us strive to ensure that every drop of water entering our bay, lagoon, and aquifers meets the highest standards of quality. Let us embrace innovation in the face of emerging contaminants and changing climatic patterns. Let us empower local government, industry and communities with the knowledge and tools they need to be guardians of our marine ecosystem. This report again illustrates the work that the SBWQFT performs to attain these goals.

Jacques Bezuidenhout

Chairperson Saldanha Bay Water Quality Forum Trust

Figure 1.1. The 2023 Trustees. Front (Left to Right) – Jacques Bezuidenhout (Chairman), Adele Groenewald (TPT), Elmien de Bruyn (DSP), Nazeema Duarte (SBM), Ethel Coetzee (TNPA). Back (Left to Right) – Christo van Wyk (Metsep), Pierre Nel (SANP), Cliffton Rajgopaul (Sea Harvest).

EXECUTIVE SUMMARY

Introduction

Regular, long-term environmental monitoring is essential to identify and to enable adaptive management and 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 biodiversity, 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 total organic nitrogen TON)) 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 non-governmental organisations (NGOs)).

In this 2023 State of the Bay report, available data on a variety of physical and biological topics are covered, including activities and discharges affecting the health of the Bay (e.g., residential and industrial development, dredging, coastal erosion, shipping, mariculture, fishing and fish processing, 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, TOC and TON), and ecological indicators (benthic macrofauna, rocky intertidal macrofauna, fish, birds and seals and aquatic macrophytes). 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

Major developments in the Bay itself over the last 50 years include the development of the Port of Saldanha (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 include 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 affected 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 (IDZ), a process that was initiated in 2013.

Human settlements surrounding Saldanha Bay and Langebaan Lagoon have expanded tremendously in recent years. As of 2022, 26% of the West Coast District Municipality's (WCDM) population resides within the bounds of the Saldanha Bay municipal area. The population was at 125 687 individuals in 2022, and is projected to reach 136 611 by 2026, indicating an average annual growth rate of 2.1% during this period. Tourist numbers for those visiting the West Coast National Park (WCNP) increased steadily leading up to 2016/17 (~12% per annum since 2005), but visitor numbers have subsequently declined steadily each year. The limitations implemented due to COVID-19 restrictions resulted in lower visitor numbers for the period 2019/20. However, overall visitor numbers have continued to drop in the subsequent years and although international visitor numbers have almost returned to pre-COVID-19 numbers, 2022/23 overall visitor numbers were the lowest they have been since 2008/2009. It is possible that the decline in visitors relates to the economic climate This rapid population growth and seasonal tourism influxes translate to corresponding increases in the amount of infrastructure required to house and accommodate these people, and in the amount of waste and wastewater that is produced which must 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. Iron ore exports from the Bay average 55 million tonnes in the last 10 years, with the total export for the 2022/2023 fiscal year slightly lower than this average at 53.1 million tonnes. South Africa accounts for approximately 78% of the world's identified manganese resources. Manganese exports from the Saldanha Port increased rapidly from 95 thousand tonnes in 2013/14 to 4.3 million tonnes in 2017/18, export volumes have fluctuated since then. In 2022/23, manganese exports increased by 23%, reaching the highest ever total of 5.76 million tonnes. While lead and copper exports from the Multi-purpose terminal (MPT) have remained fairly constant in the last 5 years, averaging 57.2 and 23.3 thousand tonnes, respectively, zinc exports increased dramatically in the last four rolling years, peaking at 595.2 thousand tonnes in 2022/23. This is a result of the opening of a new Gamsberg opencast zinc mine, from which exports are exported to reach 1 million tonnes per annum at the conclusion of phase two of the mines development (2023).

Dredging in Saldanha Bay has had tremendous immediate impact on benthic micro and macrofauna, as extensive dredging has been conducted in the bay in the past, and particles suspended in the water column during dredging can kill suspension feeding taxa including zooplankton, benthic macrofauna, and in severe cases fish. It also limits the penetration of sunlight in the water column and can cause die offs of seaweeds 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 size composition of the settled material is likely to be different, ecological functioning as well as major species groups generally return in time. The most recent dredging, undertaken between November 2022 and March 2023 was dredged for the upkeep and maintenance of the OSSB Berth and resulted in the removal of 6491.09 m^3 of sediment

Ballast water discharge volumes are increasing over time as shipping traffic and the overall size of ships visiting Saldanha Bay increases. The total number of ships entering the Port of Saldanha has increased substantially over the years from 262 ships in 1994/5 to peak at 616 in 2018/19 rolling year, before dropping steadily to 531 ships in 2021/22. The full year's worth of data were not available for the 2022/23 rolling year. However, based on available data the average number of ships entering the port per month was 51.0 which is just below the peak of 51.3 vessels per month reached in 2018/19. As a result, the volume of ballast water discharged more than tripled between 1994 and 2017/18, from 8.2 to 25.1 million m^3, despite the slight drop in ship numbers, 2021/22 saw that highest volume of ballast water discharge to date, 25.9 million m^3. Conversely, despite the increase in monthly average vessel numbers in 2022/23 the volume of ballast water discharged dropped significantly. Ballast water can and often does include 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 Ballast Water Management Bill remains in draft format), the Transnet National Port Authority (TNPA) in Saldanha Bay have a well-recognised management plan in place and have implemented several mechanisms to track and control the release of ballast water into the harbour.

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 significant 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 Saldanha Bay Municipality (SBM) has, however, made several improvements both to existing wastewater treatment facilities and in the management of the effluent discharged from the plants. Most of the wastewater is now being used for irrigation. However, after the closure of ArcelorMittal Steel Works the Saldanha plant no longer receives industrial effluent from the plant and no longer supplies treated effluent to the ArcelorMittal Reverse Osmosis (RO) plant. Therefore, the balance of treated effluent from Saldanha Bay Wastewater Treatment Works (WWTW) that is not used for irrigation is currently discharged into the Bok river and ultimately ends up in the ocean. It is reported that no effluent from the Langebaan WWTW is entering the Bay, with all treated effluent used for irrigation. Additionally, effluent quality has generally improved over the last few years.

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. In January 2018 the then Department of Agriculture, Forestry and Fisheries (DAFF, now the Department of Forestry, Fisheries and Environment (DFFE)) was granted Environmental Authorisation (EA) to establish a sea-based Aquaculture Development Zone (ADZ) in Saldanha Bay and expand the total area available for aquaculture in the Bay to 884 ha, which is located within four precincts (Small Bay, Big Bay North, Outer Bay North and South). As of September 2023, 30 entities have been granted marine aquaculture rights in the ADZ in terms of section 18 of the Marine Living Resources Act of 1998 (MLRA). Twenty-four of these right holders are currently operational, with two of these entities having more than one right allocated to them. The area of the ADZ actively being utilised changes frequently as new leases are being granted, new farms start, current lease holders expand their areas, or alternatively shrink in size, based on economic factors.

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 Branch Fisheries Management of DFFE in conjunction with others are continuously monitoring the ADZ precincts, conducting ongoing research to ensure that any negative impacts of the aquaculture are identified early, and appropriate action is taken. A substantial body of work has been undertaken in compliance with the stipulations in the EA and the Environmental Management Plan (EMP) for the Saldanha Bay ADZ and work conducted by independent specialists includes, dispersion modelling, baseline macrofauna and physicochemical surveys (2020), a benthic macrofauna monitoring survey (2021) and annual benthic chemical surveys (2021–2023), a survey of the hard substrate/reef structure in Big Bay (2022), data collection for dispersion model validation and a report on the first qualitative sampling of fouling organisms (2022).

Additionally, reports have been issued to the DFFE on the scientific recommendations for the management and expansion of the ADZ along with updates to the Sampling Plan, based on the results of monitoring work completed to date.

Management and Policy

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, Marine Protected Areas (MPAs) and National Parks) are immediately adjacent to one another. Furthermore, the Saldanha Bay environment supports conflicting uses including industry, fisheries, mariculture, recreation, and the natural environment itself. This situation necessitates sustainable development that is steered towards transformed or 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 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 are used or have been proposed for the Greater Saldanha Bay Area, including (1) an Integrated Development Plan, (2) a Coastal Management Programme, (3) a generic Environmental Management Programme (EMPr), (4) an Environmental Management Framework (EMF), (5) a Strategic Environmental Assessment (SEA), and (6) 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 effectively implemented, we are confident that measures for the conservation alongside rapid development of the Saldanha Bay area will be addressed more effectively. To better understand management practices within Saldanha Bay, it is important to understand the legislation governing the area under consideration. This chapter provides a concise overview of the predominant legislation that governs the area under consideration. Additionally, various plans, guidelines, and policies have recently been released or have undergone updates. Given the evolving nature of legislation, it's important to monitor and review updates.

Ground Water

Within the Greater Saldanha Bay (GSB) area on the Cape West Coast, groundwater is a critical component of the natural capital within the area. It plays a crucial role in sustaining critical and unique ecosystems. It is a backup resource (and possible future primary resource in times of drought) of water supply to the municipality and provides support to the agricultural sector.

The geological setting is complex and highly variable within the GSB area. For this reason, the groundwater is also highly variable across the study area regarding flow rates, volumes and quality. Many hydrogeological studies have been completed in the area, dating back to the late 1970s. There has also been a lot of recent and ongoing hydrogeological work in the area, especially regarding natural and artificial recharge, as well as management systems and numerical models. Recent work in the region contributes to knowledge of the aquifer dimensions, groundwater flow and recharge characteristics for which there has been some uncertainty.

In 2022, in collaboration with GEOSS and Ramboll, Saldanha Bay Local Municipality (SBLM) established a groundwater monitoring network consisting of twelve (12), which would be monitored monthly (for water levels and basic water chemistry). Over the past year, the municipality ensured that continued groundwater monitoring took place at the selected twelve monitoring sites. The monitoring data are included in this report section. Currently, all monitored groundwater in the area (water levels, abstraction volumes and groundwater quality) remain stable, and no significant nett abstraction is occurring within the region.

Comprehensive groundwater monitoring and an associated database within the entire region are essential for the long-term management and preservation of the aquifers and freshwater inflows into the Langebaan Lagoon. A local database has been established for the local monitoring network and a regional database using Aquabase is currently being set up by GEOSS that integrates all the groundwater information (from the Department of Water and Sanitation (DWS) and private authorised users) to provide a regional overview of the groundwater status within the area. The public can access the regional database and register via a link provided in this report.

Over the next year, the SBM plans to establish a numerical flow model for the two wellfields contained in the area — the Langebaan Road Wellfield and Hopefield Wellfield. These models will predict different scenarios, allowing for better planning and management of groundwater resources in the area, especially during drought conditions.

Water Quality

Aspects of water quality (temperature, salinity, dissolved oxygen, nutrients) are currently, or have in the past been studied in Saldanha Bay, to better understand changes in the health of the environment. Regional oceanographic processes appear to be driving much of the variation in water temperature, salinity, dissolved oxygen and nutrients 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, and also reflect a changing climate. 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 alongside unnatural obstacles (i.e., enhanced boundary flow, for example alongside the ore terminal). 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. Furthermore, the wave energy climate (significant wave heights) in the coastal region of Saldanha Bay has increased over time (1960 to present day), supporting well-documented observations of changing weather and climate around Southern Africa. This should be considered when assessing, and forecasting, changes in oceanographically driven aspects of water quality.

The frequency of hypoxic events (periods of low dissolved oxygen <2 ml/l) in Small Bay associated with major harbour development in the 1970s, does not appear to have changed much, with more recent continuous dissolved oxygen measurement data collected in the period 2020–2023 showing similar patterns. These new data show that hypoxic and intermittent near anoxic conditions in the lower part of the water column are frequent occurrences during the summer-autumn season in Big and Small Bay (pointing to an external upwelled source of low oxygen water); while in Small Bay, anthropogenic organic loading appears to exacerbate the situation with decreased dissolved oxygen measured at sites under mariculture farms compared to control sites, suggesting this decrease in oxygen availability is associated with organic pollution and poor circulation.

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 SBWQFT in 1999 and has continued with the assistance of the WCDM. These data indicate that chronic faecal coliform pollution was present in the early parts of the record but that conditions have improved considerably since then. However, the 2023 *Escherichia coli* count data indicate that only 9 of the 20 sampled stations were categorized as having 'Excellent' water quality and with two rated as 'Poor' water quality and six rated as fair over the past 12 months. This represents a substantial change from the 2022 results where 17 sites were rated as 'Excellent'. The Seafarm TNPS site was the only site to have shown an improvement in *E. coli* counts between 2022 and 2023, while 8 other sites have been downgraded. Alarmingly, Langebaan Main Beach, a popular bathing water, fell from 'Excellent' to 'Fair' (marginally close to being rated as 'poor') over the last 12 months. Other popular swimming and water sport sites close to Langebaan (i.e., Mykonos Beach) also declined. The general consensus has been that reuse of the majority of treated wastewater, historically discharged via the Bok River Mouth, was having a positive effect on water quality in Saldanha Bay. However, 2023 represents one of the most significant declines in recreational water quality since monitoring began, particularly at sites that historically have always had low levels of *E. coli*, and is a major concern. Although this poor water quality could be related to once off or isolated events, immediate action is warranted to reverse this trend.

Faecal coliform counts in Big Bay were all below concentration limits for mariculture in 2023. This is an improvement for the Small Quay at Pepper Bay in Small Bay, which was not compliant for the previous two years, and also for Big Quay at Pepper Bay (also in Small Bay) which only recently became compliant. Coliform levels at the remaining three sites within Small Bay (northern beach sites), however, continue to exceed the mariculture guidelines (i.e., Hoedjies Bay Beach, the beach at Caravan Park and the Bok River Mouth). Areas of particular concern have always been at Hoedjies Bay and the Bok River Mouth, and in 2023 the Bok River Mouth exceeded the guideline by an order of magnitude (290 colony-forming units (cfu)/100 ml), the worst concentration recorded since 2012. The Bok River Mouth also failed to meet *E. coli* concentration limits in 2023. Although a sustained improvement in levels of compliance with mariculture water quality guidelines (WGQ) has occurred since the 1999–2005 period at most Small Bay sites, continued monitoring indicates that there remains a serious issue of water quality with respect to mariculture operations within areas of Small Bay, particularly in light of the proposed additional mariculture development in the area. If allowed to continue, 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 any land-based mariculture facilities wishing to develop within the IDZ.

Concentrations of trace metals in marine organisms (mostly mussels and oysters) in Saldanha Bay have historically been monitored by the DFFE and by mariculture farm owners. DFFE discontinued their Mussel Watch Programme in Saldanha Bay in 2007, but this has now been incorporated into the annual State of the Bay surveys. In 2023 concentrations of trace metals were above prescribed limits along the north eastern shore of Small Bay (particularly cadmium but also arsenic). No regulatory limits exist for manganese in mollusc flesh as elevated levels have not been shown to have an adverse effect on marine life. Despite this, in 2023 all five sites samples as part of the Mussel Watch program showed dramatic increases manganese concentrations compared to previous years. This was worst at the Portnet site, where level was similar to those recorded in 2022, while levels recorded at other sites were either the highest recorded or above the 90th percentile for all previous concentrations since monitoring of this kind began. Manganese export volumes have been steadily increasing from 95 000 tonnes in 2013/2014 to just over 4.5 million tonnes in 2017/2018. There seems to be a link therefor, between increased manganese exports and manganese concentrations in the Bay. Transnet Port Terminals (TPT) has applied to increase the annual throughput of manganese to 8 million tonnes so measures to better manage storage and handling of manganese ore in the port are clearly warranted.

Lead concentrations in bivalves collected were lower in 2023 than 2022, with recorded concentrations all below the guideline limit which suggests conditions in the Bay have improved. Lead levels in bivalves (mussels and oysters) from mariculture farms remain lower than those from shore-based samples, and in nearly all cases, are within the limits of the relevant food safety guideline. Lead and cadmium levels in mussels and oysters collected from the shoreline have regularly exceeded the guideline limit in previous years at various locations in the Bay since the monitoring started. Research samples collected from the Iron Ore jetty did exceed the guideline limit for cadmium concentration in 2023 (the first time since 2006 at this site) and should be carefully monitored. Generally, though, cadmium concentrations have are within guideline limits but remain close to the prescribed acceptable limit, and this is a concern.

Historically, arsenic concentrations had regularly exceeded food safety guidelines from both shore based and farmed bivalves, and this is the case with the most recent data. Levels recorded in mussel watch research samples in 2023 exceeded the acceptable limit of 1.0 ppm. For this past year, arsenic levels above revised limits were recorded in all sites, with an average of 1.81 ppm (guideline 1 ppm). Worryingly, three of the four samples collected from oyster farms in 2022/2023, and the one sample taken from mussel farms in 2022/2023 exceeded arsenic concentration limits. This, in combination with shore-based research mussels showing elevated concentrations above recommended limits, is a concern and needs to be addressed. Mercury concentrations in both mussels and oysters have remained well below the food safety limits in almost all cases throughout the monitoring campaign.

Infrastructure within the Saldanha Bay has significantly changed the physico-chemical properties of the water. Data from 2023 indicates that this has been a particularly bad year in terms of microbial concentrations (when considering the past 10–15 years of monitoring). Levels of certain trace metal levels (e.g., manganese and arsenic) have also increased. This reiterates the need for continued monitoring and continued improvement in ore handling and wastewater discharge management when it comes to maintaining healthy waters in Saldanha Bay for both recreational and commercial users.

Sediments

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 most 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 has resulted in increased deposition of finer sediment (mud) in the Bay. Large-scale disturbances of sediments (e.g., dredging) also re-suspends fine particles that were historically buried beneath the sand and gravel and these later settle in areas where water movement is reduced. Contaminants (trace metals and toxic pollutants) associate with fine sediment (silt and mud) 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 fine material (silt and mud) in the sediments of Saldanha Bay was very low. High mud content is concerning as it is associated with decreased ecological health (particularly of benthic macrofaunal communities) as well as being associated with the accumulation of contaminants such as trace metals. Furthermore, since Saldanha is a naturally sandy system, muddy sediments result in changes to benthic community structure. Reduced water circulation in the Bay and dredging activities have resulted in an overall increase in fine material in sediments in the Bay. The most significant increases have been observed following dredging events. Historical studies and data collected as part of the State of the Bay surveys since 1999 has shown that mud content peaked in the system in around 1999, and has subsequently declined (despite dredging events that have temporarily spiked levels) till approximately 2009, thereafter these levels have been fluctuating without significant change till present. Subsequent dredging has resulted in visible spikes in mud content in specific areas of the system, however, the changes are generally localised to the dredge site in question. Many areas in the system now appear to have a mud content close to those seen in 1974.

Despite these overall encouraging trends, the sediment at several deeper or more sheltered sites within Small and Big Bay still have elevated mud fractions, without any clear patterns of improvement or deterioration. Areas most significantly affected in this way are all located in the vicinity of the iron ore terminal, the mussel rafts and the Yacht Club Basin.

Levels of TOC and TON are also elevated in the more sheltered and deeper areas of the bay, notably near the Yacht Club Basin, mariculture rafts and Iron Ore Terminal. Phytoplankton production is still considered to be the dominant natural source of organic matter in sediments in the Bay but has almost certainly been 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) with negative impacts on benthic communities (e.g., the Saldanha Yacht Club and under the mussel rafts). 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 (particularly in the shipping channels) and in Small Bay (reaching levels up to17%). Data from subsequent surveys (2000, 2001, 2004) and those undertaken between 2008 and 2013 suggest that TOC levels have remained high throughout this period. Levels of TOC began to decline following this and have continued on a downward trajectory, which has largely persisted till present. This is a very encouraging sign and may be linked with a reduction in the volumes of wastewater discharged into the Bay over the same period.

Levels of TON were first recorded in 1999 and were low (≤0.2%) at most sites in the Bay 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 (up to 1.2%). Results from the State of the Bay surveys conducted between 2008 and 2013 suggest that, similar to the TOC results, levels remained high for a while but have since shown a declining trend extending right through to the present day. Again, this is seen as a positive development and may well be linked to reduction of wastewater discharged into Small Bay.

Another noteworthy finding in this year's assessment is the reduction in the Carbon to Nitrogen Redfield ratios for sediments in the Bay, which suggest that there is relatively more nitrogen in the system than carbon when compared with previous years. It appears likely that this shift is occurring as a result of natural conditions, and not anthropogenic forcing, and it is interesting to consider that this may be linked with the global shift from a La Niña to an El Niño phase in the Pacific. This phenomenon can influence the rainfall and oceanography along the west coast of South Africa, and could potentially have some influence on the carbon: nitrogen balance, although this cannot be confirmed.

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 which does, for example, contribute to high cadmium (Cd) concentrations, or due to impacts of human activities (e.g., lead (Pb), copper (Cu), manganese (Mn) and nickel (Ni)) which are more likely to be associated with ore exports and ship repair operations. While trace metals are generally biologically inactive when buried in the sediment, they can become toxic to biota 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 lowest (mostly below detection limits) in Langebaan Lagoon. Following a 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. After this time, there have been numerous 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 except for a few sites in Small Bay, where thresholds have been exceeded on a number of occasions between 2016 and 2023. Key areas of concern regarding trace metal pollution within Small Bay include the Yacht Club Basin, where Cd and Cu have exceeded recommended thresholds for eight years in a row as well as adjacent to the MPT where levels of Cd and Pb are highly enriched relative to historic levels but remain below internationally accepted guidelines. The MPT is also the only site where Mn concentrations exceed guideline concentrations. Spatially, average Cu concentrations increased in both Small Bay and Big Bay. Average Mn concentrations increased in all areas except Small Bay, with the greatest increases evident in Langebaan Lagoon. These observed increases in Mn level is concerning, and ongoing monitoring will indicate if the trend continues. On a positive note, average Ni concentrations appear to have decreased substantially since 2022 in all domains, suggesting a lessening of Ni contamination. Finally, Pb concentrations have also declined in the system, with the greatest declines occurring in Langebaan Lagoon and Big Bay. Another relevant result in this years' survey is the system-wide increase in Iron concentrations relative to 2022 which will need to be monitored in following years to see if it represents a trend or simply relates to the conditions prior to the April 2023 sampling.

Enrichment Factor (EF) analysis revealed that SB5, located in the North of Small Bay, was of concern in this survey, with very high EF values, with copper (Cu) having "Extremely High" enrichment, followed by Pb and Ni, with "Very High" and "Significant" enrichment respectively. The most persistent pollutant in the system seems to be Pb, with enrichment factor results for Small Bay indicating that the area has at least "Significant" enrichment, with three sites having "Very High" enrichment. Spatially, trace metal enrichment remains most intense in Small Bay, with areas of Big Bay, particularly those close to the iron ore terminal, also having relatively high amounts of trace metal enrichment. Conversely, Langebaan Lagoon and Elandsfontein have very little trace metal enrichment besides some notable lead enrichment at LL32 (located to the south of Schaapen Island).

Poly-aromatic hydrocarbon (PAH) contamination measured in the sediments of Saldanha Bay since 1999 have always been well below internationally accepted risk levels 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 2023 remain unchanged since 2022 and as such 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.

Aquatic Macrophytes

Three distinct intertidal habitats exist within Langebaan Lagoon: seagrass beds, such as those of the eelgrass *Zostera capensis* (a type of seagrass); salt marsh dominated by cordgrass *Spartina maritima* and *Sarcocornia perennis* and the dune slack rush *Juncus kraussi*; and unvegetated sandflats dominated by the sand prawn, *Kraussillichirus 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 common reed *Phragmites australis*. Eelgrass and salt marsh 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 salt marsh 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.

As part of the 2020 State of the Bay assessment, change in reed and sedge communities surrounding the head of Langebaan Lagoon was assessed using Landsat 5,7 and 8 and Sentinel-2 satellite imagery covering the period 1989 to 2020 and the open-source geospatial platform Google Earth Engine (GEE). Results of this analysis indicated that variation in reed cover over time was relatively modest and that this has remained more or less constant over the last 31 years (1989 v 2020). The biggest perturbations in reed cover correspond with the two largest droughts that have been experienced in the region in this period (a 1:20 year event that occurred in the period 2002–2003) and an even bigger drought that occurred recently (a 1:100-year event in the period 2015–2017).

The 2020 assessment made use of an unsupervised classification approach within areas of previously mapped “reeds and sedges”. This provided a useful, relatively rapid approach to understanding the potential change in the area of common reed. This year, the aim was to expand on the approach taken in 2021 by adding the supervised classification results from 2022 and 2023. To aid the classification process, training polygons were used from the previous supervised classification in 2021 as well as the ground-truthing exercise undertaken in June 2021. This approach has been used further refine the unsupervised methodology undertaken in 2020 where direct observation points were used to train supervised classification and was applied to the non-validated first iteration supervised classification effort for seagrass beds and salt marsh.

Results from these analyses suggest that the area of common reed and saltmarsh habitat in the lagoon are slowly expanding (apart from a minor setback in reed area following the drought of 2015–2017), while seagrass is generally declining. The reasons for these changes is not clear at this stage but certainly warrant further investigation.

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. These species are mostly short lived and, consequently, their community composition responds rapidly to environmental changes. Monitoring of benthic macrofaunal communities over the period 1999–2023 has revealed a pattern of decreased abundance and biomass in response to dredging events (2008, 2012, 2015 and 2017) followed by rapid recovery. During these perturbations a general decrease in filter feeders and an increase in shorter lived opportunistic detritivores was recorded. Aside from these Bay-wide effects, localised improvements in health have been detected at sites in the Yacht Club Basin and at Salamander Bay following construction of the boat dock. At one point (2008) benthic fauna had been almost eliminated from the Yacht Club Basin in Small Bay, owing to very high levels of trace metals and organic contaminants at this site (TOC, Cu, Cd and Ni). A similar scenario was evident in 2017 (high organic loading from discharge of fish waste) at Sea Harvest nearby. Macrofaunal communities in this area have, however, recovered steadily year-on-year since this time and are now almost on a par with other sites in Small Bay. Other notable changes 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 *Listriolobus capensis*, and several gastropods. Indeed, there has been a significant increasing trend in biomass recorded in Langebaan Lagoon since the early 2000s which would suggest recovery of infaunal communities since the invasion and subsequent die-off of the Mediterranean mussel, *Mytilus galloprovincialis* on intertidal mudflats near the mouth of the lagoon. 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. Further to this, disturbance at the Liquid Petroleum Gas (LPG) site in Big Bay following installation of the Single Point Mooring (SPM) had resulted in reduced indices of abundance, biomass, and diversity in this area. The latest results from this location do, however, indicate some improvement — further monitoring is required to determine whether full recovery has been achieved or not.

Given the identification of reef in the Big Bay precinct during previous surveys it is recommended that further studies be conducted to provide a quantitative assessment of the epifaunal reef communities present. Additionally, the extent of the reef in Big Bay is yet to be determined and a detailed bathymetry survey should be undertaken.

Rocky Shores

As a component of the ongoing State of the Bay assessment, monitoring of rocky intertidal communities in Saldanha Bay was initiated in 2005. Eight rocky shore sites, spanning a wave exposure gradient from very sheltered to exposed, are sampled in Small Bay, Big Bay and Outer Bay each year. These surveys have been repeated annually from 2008 to 2023, with the exclusion of 2016. This chapter presents results from the sixteenth annual monitoring survey conducted in March 2023.

In 2023, a total of 111 species were recorded across all rocky shore sites, representing typical species found on the South African west coast. Since the start of the surveys in 2005, the cumulative count of recorded species has now surpassed 200. Furthermore, the overall count of taxa recorded in Saldanha Bay has remained relatively consistent over the years. Of the 111 species, 39 (representing 35%) were algae, while 72 (comprising 65%) were invertebrate animals. These species spanned diverse taxonomic groups, including Chlorophyta (green algae), Rhodophyta (red algae), and Ochrophyta (brown algae), as well as porifera (sea sponges), gastropods (sea snails and limpets), bivalves (mussels), echinoderms (sea urchins, sea cucumbers, feather stars, and sea stars), ascidians (sea squirts like redbait), Cnidarians (sea anemones, soft corals, and hydroids), polychaetes (bristle worms), arachnids (sea spiders), and crustaceans (barnacles and crabs). Amongst these species, seven were identified as alien species. These included the Mediterranean mussel *Mytilus galloprovincialis,* bisexual mussel *Semimytilus patagonicus,* blue mussel *M. edulis* and bay mussel *M. trossulus* (all collectively referred to as the mytilid mussel species complex), the acorn barnacle *Balanus glandula*, the North West African porcelain crab *Porcellana africana* and the red-rust bryozoan *Watersipora subtorquata*. This marks the first record of *M. edulis* and *M. trossulus* in South Africa. Additionally, *W. subtorquata* is recorded for the first time as part of a rocky shore survey, with its presence noted at several sites. However, its presence in Saldanha Bay was noted in 1935. Notably, there have been fewer records of the alien porcelain crab with its absence at the Dive School but its first-time appearance at the Iron Ore Jetty (see Chapter 13: Aliens and Invasives for more information). *M. galloprovincialis* and *S. patagonicus* (previously *S. algosus*) were believed to be the only alien mussels present in Saldanha Bay (and were collectively referred to as *Mytilus* spp. in previous reports). However, recent DNA (Deoxyribonucleic acid) analysis suggests the potential presence of two other morphologically similar species, the blue mussel *M. edulis* and the bay mussel *M. trossulus*. Detailed information on this discovery is presented in Chapter 13. Given the difficulty in reliably distinguishing these species based on morphological characteristics, they are collectively referred to as the mytilid species complex. Nonetheless, it's important to note that *M. galloprovincialis* is still considered the dominant mussel species, as inferred from DNA barcoding analysis and supported by previous studies.

The overall biotic cover within a site typically varied, with an increase observed from the high shore to the low shore, averaging between 40% to 60% cover. The high shore was typically characterised by barren rock. Algal cover was notably sparse in this zone, with occasional occurrences of certain algae in more exposed sites. Mobile species were also scarce but included various gastropod grazers and the occasional predatory crab. The periwinkle *Afrolittorina knysnaensis* was a common sight on the more exposed high shores where they were often found in crevices, or between the indigenous toothed barnacle *Chthamalus dentatus* and the alien barnacle *B. glandula*. This alien was prominently found across various sites, although the extent of coverage varied. Within sheltered sites, the mid shore was relatively barren, while the more exposed sites with higher wave action supported more biotic cover. Grazers (limpets, chitons and topshells) and filter feeders (mussels and barnacles) were particularly common in this zone, especially since algal cover was higher than in the high shore. A common sight on exposed mid shores were the alien mytilid mussel species complex and *B. glandula,* as well as the indigenous ribbed mussel *Aulacomya atra* and barnacle *Tetraclita serrata*. The low shore exhibited the highest biotic diversity and percentage cover, and was mainly dominated by algae, specifically crustose coralline. It was also the most diverse in terms of its faunal composition. At very sheltered sites both faunal and algal cover was notably lower compared to exposed sites. The most dominant species in these sheltered areas included indigenous and alien mytilid mussels, pear limpets *Scutellastra cochlear*, and the cape sea urchin *Parechinus angulosus*. While the indigenous mussel used to be the dominant mussel on the shore, recent surveys indicate that mytilids have consistently outnumbered this local mussel in most locations over the past few years.

The biotic cover also exhibited variations among different sites with the primary factor being exposure to wave action, and, to a lesser extent, shoreline topography. Sheltered sites tended to have lower biotic cover compared to exposed sites. Moreover, there was a noticeable increase in species coverage as wave exposure increased, primarily driven by a rise in filter-feeding organisms and encrusting algae. In exposed sites, both flora and fauna were equally present, with filter-feeders being the dominant faunal group. Conversely, in fully sheltered areas, various functional groups contributed roughly equally to the overall biotic cover. The community structure of rocky shorelines was also influenced by the topography and substratum type of the shoreline. Sites characterised by large rocky boulders displayed a higher percentage cover of faunal species compared to smoother flatter profiles. These latter sites displayed a more substantial encrusting algae coverage compared to sites with smaller boulders and rougher surfaces. The islands exhibited a higher presence of ephemeral and corticated algae. Islands are sheltered sites are home to numerous birds, thereby receiving substantial nutrient input from seabird guano, promoting algal growth. Additionally, Schaapen Island's location in the transition zone between Saldanha Bay and Langebaan Lagoon results in differences in water quality, such as temperature, which further influences biological communities.

Over the years, rocky intertidal areas in Saldanha Bay have experienced fluctuations in the percentage cover and composition of biota. Understanding these changes is important as they often signal shifts in biodiversity due to environmental stress. These can include a loss of certain species and an increase in others. The percentage cover and composition of biota have shown fluctuation at all sites since the start of the surveys in 2005. Among these sites, Marcus Island has shown the most stability, although the types of organisms recorded have changed. One significant observation has been the notable increase in encrusting algae across most sites, particularly over the last three to five years, and a decline in filter feeders at some locations.

Historically, alien mussels and barnacles dominated these shores, outcompeting native species. Their spread throughout the Bay has significantly altered natural community structure in the mid and lower intertidal, particularly in wave exposed areas. However, recent surveys show a decline in these aliens, most notably at the Iron Ore Terminal and at Lynch Point. Consequently, there has been a noticeable reduction in the abundance of filter feeders at many of the sites once dominated by these aliens, particularly over the last four years. The decline in filter feeders, along with several other species, may have created an ecological niche for encrusting algae, facilitating their colonisation of available rock space and potentially accounting for their substantial increase in abundance. Encrusting coralline algae typically act as the initial colonisers of rock surfaces devoid of biota and are renowned for their ability to occupy substantial areas in rocky intertidal systems.

Despite changes and declines in community and functional group composition, none of the sites demonstrated a temporal change in their rocky shore communities that would suggest a dramatic alteration such as the arrival or loss of a key species. Furthermore, no major pollution events or point sources of pollution are apparent in these data. Instead, the fluctuations of functional groups over the years are considered a natural seasonal and inter-annual phenomenon. While shifts may be attributed to natural variability, anthropogenic events and climate changes as possible contributors should be explored.

Fish

No clear long-term trends are evident in overall fish diversity and abundance in the Bay, but there is some evidence of declines in abundance in Small Bay. It must be acknowledged, though, that overall abundance is dominated by harders, which appear resilient to changes in water quality. The abundance of most of the other common species in Small Bay (white stumpnose, gobies and blacktail) remain low in 2023 relative to earlier surveys, although the gobies do show some sign of recovery. The fish community health in Small Bay in 2023 is considered to be in a poor state compared to historical levels. Fish diversity in Big Bay was up in 2023, and due to an increase in abundance of white stumpnose, elf, and Cape sole, it is considered to be in good condition. Langebaan Lagoon had an average level of diversity and high abundances of Knysna sandgobies and *Caffrogobius* gobies, but lower than average abundance of white stumpnose, so is also considered to be in average health overall.

This finding is consistent with most of the seine net survey history, where fish abundance at sites within or near the Langebaan MPA appear largely stable with some 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 additional commercial gill net permit holders access to the Lagoon 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 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.

Recent seine net surveys have recently revealed some concerning declines in elf recruitment to surf zone nurseries, and it is recommended that this should also be carefully monitored in the future, despite the slight increase in juvenile elf abundance in the 2023 survey. Interpretation of the recruitment signal of exploited fish species would be greatly enhanced if there was ongoing monitoring of recreational catch and effort in the system. Only commercial linefishers are required to submit catch returns and as most of the white stumpnose and elf fishing effort is recreational, there is a substantial gap with respect to catch-per-unit-effort data for this sector. Such data would provide another direct line of evidence as to the status of exploited fish stocks in the Saldanha Bay-Langebaan lagoon system.

The significant declines in juvenile white stumpnose abundance that occurred throughout the system over the period 2007–2020 suggested that the protection afforded by the Langebaan MPA has not been enough to sustain the fishery at the historical high effort levels. Arendse (2011) found the adult stock to be overexploited using data collected during 2006–2008 already, and the evidence from the seine net surveys conducted since then certainly suggested that recruitment overfishing has occurred. The annual seine net surveys did act as an early warning system that detected poor recruitment and should have allowed for timeous adjustments in fishing regulations to reduce fishing mortality on weak cohorts and preserve sufficient spawner biomass. Unfortunately, despite repeatedly expressing concern about the collapse of white stumpnose recruitment in State of the Bay Reports since at least 2013 and supporting the implementation of the harvest control measures recommended by Arendse (2011); namely a reduction in bag limit from 10 to 5 fish per person per day and an increase in size limit from 25 cm TL to 30 cm TL, the warning calls have not been heeded. A statistically comprehensive analysis of fishery dependent and survey data confirmed the collapse of the Saldanha-Langebaan white stumpnose stock and the fishery yield in recent years is a fraction of its historical peak or potential (Parker et al. 2017). The 2021 seine net survey revealed an encouraging increase in juvenile white stumpnose in Big Bay and Langebaan Lagoon, with estimated overall abundance similar to levels last seen during the 2008–2011 period. This recovery did not carry forward into the 2023 seine net surveys, with total predicted biomass of juvenile white stumpnose back down to below average levels, although still higher than it has been in the last ten years. Ongoing monitoring is still necessary, along with lobbying for increased harvest control measures for this important fishery.

Extending the seine net monitoring record will 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. As fishing effort continues to increase, fishing mortality will need to be contained, if the fisheries are to remain sustainable. Although recruitment overfishing appears to have been taking place for several years now, the white stumpnose 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. Indeed, there is circumstantial evidence that a reduction in fishing mortality occurred in response to poor catch rates and this possibly contributed to the improved white stumpnose recruitment observed in the 2021 seine net survey. We also support the recommendation of Horton *et al*. (2019) for a reduction in harder fishing effort and gear changes (increase in minimum mesh size) to facilitate stock recovery. Short term reductions in fishing mortality will have an economic cost but will yield substantially greater socio-economic benefits for fishers in the medium to longer term as the sustainable catch from an optimally exploited fish stock greatly exceeds that from a collapsed stock.

The economic value of the recreational fishery in Saldanha-Langebaan should not be regarded as regionally insignificant as a lot of the expenditure associated with recreational angling is taking place within Langebaan and Saldanha itself. Furthermore, the historically popular white stumpnose fishery used to be a major draw card to the area and has probably contributed significantly to the growth in the residential property market the region has experienced. These benefits should be quantified by an economic study of the recreational fisheries. The value of Small Bay as a fish nursery and the economic value of the resultant fisheries could then be quantitatively considered when the environmental impacts of the proposed future industrial developments within Small Bay are assessed. The monitoring record from the annual seine net surveys will prove increasingly valuable in assessing and mitigating the impacts of future developments on the region's ichthyofauna.

Birds and Seals

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 and seals. 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 and seals, 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 species they support. At least 56 non-passerine waterbird species commonly use the area for feeding or breeding, and eleven species 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, four species of marine cormorant, and important populations of the endemic African 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 (DFFE: Oceans and Coasts), and bi-annually (summer and winter) in Langebaan Lagoon (Avian Demography Unit of the University of Cape Town).

Except for bank cormorants, the populations of the seabirds breeding 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 Oystercatcher, the increase in mussel biomass as a result of the spread of the Mediterranean mussel.

On the islands of Saldanha Bay, populations African Oystercatcher, Cape Cormorants, Caspian Terns Swift Terns and Hartlaubs gulls have been variable, but without any obvious trends since the turn of the century, but populations of some other species then started to decline, particularly, the penguins, crowned cormorants and kelp gulls, which have declined to 5.8%, 33% and 39% respectively, of their populations at the turn of the century. The Bank Cormorant population has been declining for three decades and is currently at just 3% of the 1990 peak. Declines in the numbers of seabirds breeding on the Saldanha Bay Islands can be attributed to several 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 15 years, (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 Bank Cormorants feed. The recent extension for 10 years of the September 2022 closure of a 20 km radius around important seabird breeding islands to small pelagic purse seine fishing was largely in response to continuing declines of endangered African penguins. Time will tell if the closure around Dassen Island, (which lies within the foraging range of several species) brings any benefits to penguins and other seabirds inhabiting the Saldanha Bay Islands.

Because seabird populations are so depressed, conditions at the islands in Saldanha, particularly predation by Cape Fur Seals, Pelicans and Kelp Gulls, have now become major factors in driving current population decreases for many seabird species. Direct amelioration actions to decrease these impacts at the islands (Pelican Watch, problem seal culling) 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. Increasing volumes of shipping traffic and associated underwater noise pose a further threat as it may negatively impact the feeding behaviour and hence survival of some sea bird species.

Decreasing numbers of migrant waders utilising Langebaan Lagoon reflects a global trend, which can be attributed to loss or modification of habitat, climate change, predation, pollution, hunting and other forms of human disturbance. The fact that numbers of resident waders have also declined, however, suggests that unfavourable conditions persisting in Langebaan Lagoon as a result of anthropogenic disturbance may be partly to blame. Resident wader numbers in the winter of 2019 dropped to the lowest recorded in the 40–year count record and the post subsequent winter counts showed no recovery with a new low of just 142 recorded in August 2022. This is a continuation of the declining trend over the last two decades. Migratory wader counts in summer appeared to stabilize at around 3 000–6 000 birds over the period 2015–2023, with the exception of 2021 during the global COVID-19 lockdowns when nearly 13 000 were counted. In Langebaan Lagoon, drastic population declines in four species of migratory waders, including the Ruddy Turnstone, Red Knot, Grey Plover and Curlew Sandpiper have signified this downward trend in summer migratory bird numbers. Despite notable increases in 2021, the 2022 and 2023 summer counts of migratory waders were unfortunately much lower and revealed that the observed "recovery" was a once-off anomaly associated with the extraordinary global COVID-19 pandemic. It is highly recommended that the status of coastal and wading bird species continues to be monitored and that these data are used to inform and assesses the efficacy of management interventions aimed at halting the observed declines and supporting recovery of the region's birds.

Cape Fur Seals are amongst the largest marine top predators found in and around Saldanha Bay. They are opportunistic, generalist feeders that have been shown to benefit from human activities including utilisation of discards from fishing boats or taking fish directly from fisherman. In addition, seals compete with seabirds, such as penguins and gannets, as well as with commercial fisheries, for small pelagic fish which form a key part of their diets. It has been suggested that the increasing numbers of seals on Vondeling island may lead to increased pressure to cull seals both from a fisheries perspective as well as to protect important seabird species on which seals are known to prey. Concerns have also been raised that, with the increased number of seals along the shores surrounding Saldanha Bay and with the addition of finfish aquaculture in the Bay, seal numbers within the Bay will likely increase, along with the occurrence of problem seals. Although seals are likely attracted to the aquaculture infrastructure within Saldanha Bay that provides floating resting sites, it is unlikely that their numbers will continue to increase significantly as the animals in the bay are comprised mostly of sub-adult males. Additionally, the carrying capacity of Vondeling Island appears to have been reached and the overall population within Southern Africa has remained stable over the last 30 years.

Aliens and Invasive species

Human induced biological invasions have become a major cause for concern worldwide. 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 South Africa have been documented from sheltered areas such as harbours and are believed to have been introduced through shipping activities, either by ballast water or hull-fouling. These findings highlight the need for implementing more efficient protocols to prevent the introduction of and to monitor the spread of alien species. A precautionary approach to prevent biological invasions is often considered the most efficient method of management and can include identifying and managing important pathways of introduction. However, if species are already present, regular monitoring and management protocols should be implemented to reduce the impacts of these invaders on the receiving environment and biota as far as possible. The most recent review of marine alien species in South Africa identified a total of 95 alien marine species in South African waters, with 56 classified as invasive. With new introductions and discoveries every year, and the changing status of species as more information becomes available, the list of alien species in South Africa remains dynamic.

This chapter provides an updated account of alien and invasive species identified in the last 12 months, based on the findings from the State of the Bay surveys (which include the benthic macrofauna and rocky shore), and those reported by other researchers. This report further presents quantitative data on changes in the abundance and biomass of three invasive species for which sufficient data spanning several years have been compiled. These include the Pacific barnacle *Balanus glandula*, the mytilid species complex, and the western pea crab *Rathbunixa occidentalis*. This year, additional qualitative data were included from two biofouling studies conducted by Anchor Environmental Consultants (Anchor) in the Saldanha Bay ADZ (Aquaculture Development Zone) during 2021 and 2022, as well as the first DNA-based survey undertaken in 2022. The latter included the environmental DNA (eDNA) metabarcoding and analysis of ballast water, sea water, sediment, and wall scrape samples.

No alien species were found in ballast water (taken directly from vessels in the Port of Saldanha) or sea water samples collected from the Bay, while both morphology-based taxonomy and eDNA metabarcoding detected two and 17 alien species from the sediment and wall scrape samples, respectively. Overall, the DNA-based survey detected more non-native taxa than the other long-term monitoring surveys, with 18 alien species identified. Most of these species had been previously detected in Saldanha Bay through State of the Bay collections or previous research surveys. However, five species were identified from Saldanha Bay, or as part of the State of the Bay survey, for the first time as part of this survey.

In total, 37 alien and invasive species have been recorded from Saldanha Bay and Langebaan Lagoon to date, with nine new alien species added to the State of the Bay list since the 2022 report (Table 1.1). These include the tuberculate pear crab *Pyromaia tuberculata,* skeleton shrimp *Caprella mutica*, pitted barnacle *Balanus trigonus*, fat-feeler amphipod *Monocorophium acherusicum*, pink-mouthed hydroid *Ectopleura crocea,* thin-walled obelia *Obelia dichotoma,* amphipod *Ericthonius brasiliensis,* blue mussel *Mytilus edulis* and the bay mussel *M. trossulus.*

Table 1.1 Alien species identified in Saldanha Bay and Langebaan Lagoon from various surveys, including Benthic Macrofauna, Rocky Shore, ADZ biofouling, and eDNA-based surveys, as well as previous research. An asterisk (*) indicates species that were detected from the DNA-based survey. SA = South Africa; SOB = State of the Bay.

Species	Common Name	Status	Taxa	Class	Update
*Mytilus edulis**	Blue mussel	Invasive	Mollusca	Bivalvia	New to SA
*Mytilus trossulus**	Bay mussel	Invasive	Mollusca	Bivalvia	New to SA
*Mytilus galloprovincialis**	Mediterranean mussel	Invasive	Mollusca	Bivalvia	Important update
*Semimytilus patagonicus**	Bisexual mussel	Invasive	Mollusca	Bivalvia	Important update
*Pyromaia tuberculata**	Tuberculate pear crab	Invasive	Crustacea	Decapoda	New to Saldanha
*Caprella mutica**	Japanese skeleton shrimp	Invasive	Crustacea	Amphipoda	New to Saldanha
*Balanus trigonus**	Pitted/ triangle barnacle	Invasive	Crustacea	Cirripedia	New to Saldanha
*Monocorophium acherusicum**	Fat-feeler amphipod	Alien	Crustacea	Amphipoda	New to Saldanha
*Ectopleura crocea**	Pink-mouthed hydroid	Alien	Cnidaria	Hydrozoa	New to Saldanha
*Obelia dichotoma**	Thin-walled obelia	Alien	Cnidaria	Hydrozoa	New to SOB
Ericthonius brasiliensis	Amphipod	Invasive	Crustacea	Amphipoda	New to SOB
*Watersipora subtorquata**	Red-rust bryozoan	Invasive	Bryozoa	Gymnolaemata	New to SOB
*Balanus glandula**	Pacific barnacle	Invasive	Crustacea	Cirripedia	Important update
Rathbunixa occidentalis	Western pea crab	Invasive	Crustacea	Decapoda	Important update
*Porcellana africana**	Porcelain crab	Invasive	Crustacea	Decapoda	Important update
*Perforatus perforatus**	Perforated barnacle	Alien	Crustacea	Cirripedia	Important update
*Ciona robusta**	Sea vase	Invasive	Chordata	Ascidiacea	Important update
*Clavelina lepadiformis**	Light-bulb sea squirt	Invasive	Chordata	Ascidiacea	New to SOB
*Discinisca tenuis**	Disc lamp shell	Invasive	Brachiopoda	Lingulata	Important update
*Polydora hoplura**	Shell-boring spionid	Invasive	Annelida	Polychaeta	New to SOB
Codium fragile subsp. fragile	Fragile upright codium	Invasive	Chlorophyta	Ulvophyceae	Important update
Cylista ornata	Brooding anemone	Alien	Cnidaria	Anthozoa	Important update
Magallana gigas	Pacific oyster	Invasive	Mollusca	Bivalvia	No updates
Boccardia proboscidea	Shell worm	Invasive	Annelida	Polychaeta	No updates
Jassa slatteryi	Hitchhiker amphipod	Invasive	Crustacea	Amphipoda	No updates
Littorina saxatilis	Lagoon snail	Invasive	Mollusca	Gastropoda	No updates
Diplosoma listerianum	Jelly crust tunicate	Invasive	Chordata	Ascidiacea	No updates
Coryne eximia	Hydroid	Invasive	Cnidaria	Hydrozoa	No updates
Cerapus tubularis	Tubular amphipod	Invasive	Crustacea	Amphipoda	No updates
Chelura terebrans	Wood-boring amphipod	Invasive	Crustacea	Amphipoda	No updates
Conopeum seurati	Encrusting bryozoan	Invasive	Bryozoa	Gymnolaemata	No updates
Cryptosula pallasiana	Red crust bryozoan	Invasive	Bryozoa	Gymnolaemata	No updates
Antithamnionella spirographidis	Red Algae	Invasive	Rhodophyta	Florideophyceae	No updates
Orchestia gammarellus	Beach hopper	Invasive	Crustacea	Amphipoda	No updates

Species	Common Name	Status	Taxa	Class	Update
Heliaster helianthus	South American sunstar	Alien	Echinodermata	Asteroidea	No updates
Homalaspis plana	Chilean stone crab	Alien	Crustacea	Decapoda	No updates
Carcinus maenas	European shore-crab	Invasive	Crustacea	Decapoda	No updates

The alien species from Saldanha Bay largely comprise crustaceans (40%), molluscs (16%) and cnidarians (11%). Certain species are routinely recorded during the surveys, including *M. galloprovincialis*, the bisexual mussel *S. patagonicus* (previously S. *algosus*), *B. glandula*, the perforated barnacle *P. perforatus*, the fragile upright codium *C. fragile* spp., the porcelain crab *P. africana* and *R. occidentalis*. Some species, although known from South Africa, were recorded for the first time in Saldanha Bay, indicating a range expansion (i.e., *P. tuberculata, C. mutica*, *B. trigonus, M. acherusicum* and *E. crocea*). Other species, despite previous records in Saldanha Bay, are reported for the first time in the State of the Bay survey (e.g., *W. subtorquata, C. lepadiformis, O. dichotoma* and *P. hoplura*). Most notably, two mytilid mussel species, the blue mussel *M. edulis* and the bay mussel *M. trossulus,* are documented for the first time in South Africa, challenging previous assumptions about the identity and current understanding of mytilids in the country. Prior to the eDNA-based survey, *M. galloprovincialis* and *S. patagonicus* were believed to be the only alien mussels present in Saldanha Bay. Given the difficulty in reliably distinguishing these species based on morphological characteristics, they are collectively referred to as the mytilid species complex. Nonetheless, *M. galloprovincialis* still remains the dominant mussel species on the shore. Surveys indicate that mytilids were more predominant at exposed rocky shore sites, reaching higher densities when compared to the more sheltered sites. These invasive mussels are the most dominant faunal species on the rocky shore, reaching greatest density on the lower shore, in areas exposed to high wave action. Recent surveys suggest that populations have declined at these exposed sites. Mytilids are considerably less abundant in the years post-2016 compared to pre-2016, with some sites lacking mussels altogether. The reason for this decline remains unclear, although similar trends have been observed in the past. This could be due to a range of factors, although the most probable cause is severe weather events and wave action. Despite the overall lower abundances, there has been a trend of increasing mytilid abundance at Lynch Point, Marcus Island, and North Bay over the past four years.

Data suggests that *B. glandula* predominantly occupies the mid shore and is most abundant at semi-exposed rocky shore sites. When initially detected over a decade ago, it was relatively abundant across monitoring sites. However, post-2016, this barnacle has declined in abundance, with the lowest total percentage cover recorded in the 2023 survey. Fluctuating densities may be due to competition with other species, like limpets, for space on the mid shore. Limpets are known to dislodge newly settled barnacles, potentially influencing population sizes. The percentage cover of *B. glandula* is expected to continue to fluctuate in the future. Although this species competes for space with other intertidal species, it is not believed to have significant impacts on rocky shore communities in Saldanha Bay, particularly where population sizes are small. The western pea crab *Rathbunixa occidentalis* has a higher abundance in Big Bay than Small Bay, and there is a potential population in Langebaan Lagoon, although annual fluctuations in average abundance occur. The current status of this pea crab in Danger Bay is unknown. The data indicates a preference of this species for deeper water habitats. Despite the significant numbers recorded in Big Bay, Small Bay, and Langebaan Lagoon in 2022, no specimens were detected in the 2023 survey. The absence of detection in 2023 raises questions about the population status, emphasising the need for continuous monitoring to establish conclusive trends. The impact and role of this crab in the benthic community of Saldanha Bay remains undetermined, underscoring the necessity for more comprehensive studies. The North-West African porcelain crab *Porcellana africana* is believed to be well-established and abundant on the northern, eastern, and western shores of

Saldanha Bay where it inhabits the intertidal zone under boulders, loose rocks, mussels and kelp holdfasts. It was initially discovered on Schaapen Island in 2012 and first recorded in a State of the Bay Survey in 2021, albeit at low densities. In 2022, dozens of individuals were documented at multiple sites. However, in 2023, this crab was observed in significantly lower densities, present at only two sites. The ecological impact of this alien crab has not yet been fully determined, although no serious impacts are anticipated. Nonetheless, it is recommended that populations be monitored.

In summary, nine new alien species have been recorded from Saldanha Bay in the last 12 months, bringing the total number to 37. Including the two newly identified alien mussel species, and the recently reported pear crab, the total number of known alien species in South Africa is now believed to stand at 98. It's important to note that the identity of some new species, particularly those identified through eDNA metabarcoding, requires verification through morphological, taxonomic and DNA studies.

The detection of nine new alien species is of concern and highlights the need for management action. Management actions should firstly focus on invasive species already present in Saldanha Bay. Dedicated sampling effort targeting these species should be implemented to better understand their abundance, distribution and potential impacts in Saldanha Bay and Langebaan Lagoon. For some species, there may be a need to explore control or eradication programs for effective management. Secondly, efforts should be focused on preventing further invasions. Watchlists have been identified as a useful preventative measure, and are created based on selecting species with an invasion history, pathways to the area of concern, occurrence in similar climatic regions or those with biological traits that could predispose them to becoming successful invaders. Another vital aspect includes identifying and managing important pathways of introduction. This should be done in combination with TNPA to monitor vessels entering harbours with mandatory treatment of hulls and ballast water before port entry, and the regular monitoring of harbours. All these efforts require in-depth research. Such research will not only contribute towards our understanding of the drivers and traits governing successful invasions, but also give insight into associated impacts. This, in turn, could be used to support directed management actions for successfully controlling invasions and mitigating impacts. However, the knowledge gained from this research needs to be shared with stakeholders and policy makers to implement appropriate management strategies and inform action.

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 stumpnose) and many bird species in Saldanha Bay and Langebaan Lagoon are of particular concern. These most likely reflect long term changes in exploitation levels (fish) and habitat quality (sediment and water quality and increasing levels of disturbance) and 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 maintaining 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, particularly in the face of increased development in the Bay.

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GLOSSARY

Abundance: Refers to the number of individuals of a specific species.

Alga: A seaweed. These can be green (Chlorophyta), brown (Ochrophyta) or red algae (Rhodophyta) and comprise corticated algae, ephemeral algae, foliose algae and kelps.

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).

Anthropogenic: relating to or resulting from the influence of human beings on nature.

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.

Articulated coralline algae: Branching, tree-like plants which are attached to the substratum by crustose or calcified, root-like holdfasts.

Ascidians: Sea squirts like redbait.

Baseline: Information gathered at the beginning of a study which describes the environment prior to development of a project, and against which predicted changes (impacts) are measured.

Bedrock: Solid rock that lies under loose material within the crust of Earth.

Benthic: Pertaining to the environment inhabited by organisms on or in the bottom of a body of water such as the ocean. Organisms living in this zone are collectively referred to as the "benthos", e.g., the benthic invertebrate community, including crustaceans and polychaetes.

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.

Biofouling: The undesirable accumulation of microorganisms, plants and/or animals on wet surfaces that have a mechanical function, causing structural or other functional deficiencies (synonyms: biological fouling).

Biological Traits: Characteristics of an organism that affect how it interacts with its environment.

Biomass: The mass of living biological organisms in an area or ecosystem.

Bioregion: A region defined by characteristics of the natural environment rather than by man-made divisions. See 'ecoregion'.

Biota/ biotic: All the plant and animal life of a particular region.

Bivalves: A class of marine and freshwater molluscs that have laterally compressed bodies enclosed by a shell consisting of two hinged parts. Includes oysters, mussels, and scallops.

Brachiopod: Lamps shells, which have a chalky shell, distinguished by having dorsal (upper) and ventral (lower) shell-valves and a fleshy stalk. Valves are hinged at the rear end, while the front can be opened for feeding or closed for protection.

Branchiae: The gills of invertebrates.

Bryozoan: Moss Animals. Builds colonies of tiny individuals, each enclosed in a tiny skeleton and crowned filter feeding tentacles.

Chlorophyta: Green algae.

Cnidarians: A phylum that includes jellyfish, hydroids, sea anemone and corals.

Coliform: Bacteria that are always present in the digestive tracts of animals.

Colony-forming unit: A unit which estimates the number of microbial cells in a sample that are viable or able to multiply via binary fission under the controlled conditions.

Community structure: The number of species in a community and the relative number of individuals per species.

Community: Any group of organisms belonging to a number of different species that co-occur in the same habitat or area.

Conductivity: A measure of the ability of water to pass an electrical current. Because dissolved salts and other inorganic chemicals conduct electrical current, conductivity increases as salinity increases.

Contaminants: Biological or chemical substances or entities, not normally present in a system, capable of producing an adverse effect in a biological system, seriously injuring structure or function.

Coralline algae: Also known as crustose coralline algae or encrusting coralline. An encrusting red alga in the Family Corallinaceae of the order Corallinales characterised by a thallus that is hard because of calcareous deposits contained within the cell walls. Typically, pink, or reddish, but can be purple, yellow, blue, white, or grey-green. See encrusting algae and crustose algae.

Corticated (foliose) algae: An alga consisting of multiple cell layers, most regularly an outer pigmented layer and an inner unpigmented layer. Usually relatively large and long-lived.

Cosmopolitan: Occurs all over the world.

Coxa: The proximal segment and functional base of the leg.

Critical Biodiversity Area (Natural): Areas in a natural/near-natural ecological condition. Together with MPAs, CBAs are required to meet biodiversity targets so that a representative sample of coastal and marine biodiversity can persist. Management objectives include maintaining in natural or near natural ecological condition.

Critical Biodiversity Area (Restore): Areas in a degraded or secondary condition and which should be restored. Management objectives include improving ecological condition, and, in the long-term, restoring to a natural or near-natural condition or as close to that as possible. As a minimum in CBA Restore sites, further deterioration in ecological condition must be avoided, and options for future restoration must be maintained. Only low-impact, biodiversity-sensitive land-uses are appropriate.

Critical Biodiversity Area 1 (Irreplaceable): Areas in a natural condition that are required to meet biodiversity targets, for species, ecosystems or ecological processes and infrastructure. The management objective for these areas is to maintain in a natural or near-natural state, with no further loss of natural habitat. Degraded areas should be rehabilitated. Only low-impact, biodiversity-sensitive land uses are appropriate.

Crustacean: Generally different from other arthropods in having two pairs of appendages (antennules and antennae) in front of the mouth and paired appendages near the mouth that function as jaws. E.g., barnacles and crabs.

Crustose algae: Also see encrusting algae and coralline algae. An alga exhibiting a crust-like morphology that tightly adheres to the substratum and can be fleshy or calcified. They have a thallus that is hard because of calcareous deposits contained within the cell walls. Usually a red alga in the order Corallinales. This alga is typically pink, or reddish. Some species can be purple, yellow, blue, white, or grey-green.

Cryptogenic: Species of unknown origin.

Cumulative impacts: Direct and indirect impacts that act together with current or future potential impacts of other activities or proposed activities in the area/region that affect the same resources and/or receptors.

Densities of species: The abundance or number of individuals of a particular species within a given area or habitat.

Detritus: Waste or debris of any kind.

Diatoms: Single-celled algae.

Dissolved oxygen: A measure of the amount of oxygen dissolved in the water. The amount of oxygen available to living aquatic organisms.

Diversity: The number of different species and relative abundance of each of those species present in an ecosystem or in a community. Also see species diversity.

DNA barcoding (sequencing): A method of species identification using short segment of DNA from a specific gene. Every species has its own barcode. These DNA barcodes can be compared to a reference library to provide an ID (Synonyms: metabarcoding).

DNA: Deoxyribonucleic acid is the molecule that carries genetic information for the development and functioning of an organism.

Dredging: The act of removing silt and other material from the bottom of bodies of water.

Echinoderms: The adults are usually characterised by their radial symmetry (usually five-point) and incudes sea urchins, sea cucumbers, feather stars, and sea stars.

Ecological Support Areas (ESA): Areas not essential for meeting biodiversity targets, but that play an important role in supporting the functioning of Protected Areas and CBAs and are often vital for delivering ecosystem services. The management objective is to maintain these sites in a functional, near-natural state. Some habitat loss is acceptable. Marine ESAs include all portions of EBSAs that are not already within MPAs or CBAs, and a 5 km buffer area around all MPAs (where these areas are not already CBAs or ESAs).

Ecologically or Biologically Significant Marine Areas (EBSAs): Defined by the Convention on Biological Diversity (CBD) as "geographically or oceanographically discrete areas that provide important services to one or more species/populations of an ecosystem or to the ecosystem as a whole, compared to other surrounding areas or areas of similar ecological characteristics, or otherwise meet the [EBSA] criteria".

Ecosystem Threat Status: Developed by SANBI (2018) is an indicator of how threatened ecosystems are, specifically the degree to which ecosystems are still intact or alternatively losing vital aspects of their structure, function, or composition (SANBI 2019). See National Biodiversity Assessment.

Ecosystem: A biological community of interacting organisms and their physical environment — a complex network or interconnected system.

eDNA: Environmental DNA is organismal DNA that can be found in the environment. It originates from cellular material shed by organisms (via skin, excrement, etc.) into aquatic or terrestrial environments that can be sampled and monitored using new molecular methods.

El Niño: The periodic fluctuation in the thermal functioning of the Pacific Ocean.

Encrusting algae: Also see crustose algae and coralline algae. An alga exhibiting a crust-like morphology that tightly adheres to the substratum and can be fleshy or calcified. They have a thallus that is hard because of calcareous deposits contained within the cell walls. Usually a red alga in the order Corallinales. This alga is typically pink, or reddish. Some species can be purple, yellow, blue, white, or grey-green.

End of pipe effluent limits: The specific regulatory or permitted limits set for the quality of wastewater or pollutants that are discharged from a facility or process at the final stage of treatment, typically at the point where it is released into the environment, such as a water body or a sewer system. These limits ensure that the discharged effluent meets certain environmental and health standards to minimise its impact on the receiving environment.

Enrichment Factor: A widely used metric for determining how much the presence of an element in a sampling media has increased relative to average natural abundance because of human activity.

Environment: The external circumstances, conditions and objects that affect the existence of an individual, organism or group. These circumstances include biophysical, social, economic, historical and cultural aspects.

Environmental Authorisation: Permission granted by the competent authority for the applicant to undertake listed activities in terms of the NEMA EIA Regulations, 2014.

Environmental Impact Assessment: A process of evaluating the environmental and socio-economic consequences of a proposed course of action or project.

Ephemeral algae: Opportunistic algae with a short life cycle that are usually the first settlers on a rocky shore.

Epifauna: Organisms living on or just above the bottom sediments of a body of water.

Eukaryotes: Organisms whose cells have a membrane-bound nucleus. All animals, plants, fungi, and many unicellular organisms are eukaryotes.

Fauna: General term for all the animals found in a particular location.

Filter-feeders: Animals that feed by straining suspended matter and food particles from water.

Flora: General term for all the plant life found in a particular location.

Foliose algae: Leaf-like, broad and flat; having the texture or shape of a leaf.

Fouling Communities: Communities of organisms found on artificial surfaces like the sides of docks, marinas, harbours, and boats, essentially fouling these structures.

Functional group: A collection of organisms of specific morphological, physiological, and/or behavioural properties.

Gastropods: A large and diverse class of molluscs that belong to the phylum Mollusca. They are characterised by their distinctive spiral shells, though some species have reduced or absent shells. These organisms have a muscular foot located at the ventral side of their body that is used for movement.

Genus (singular)/ genera (plural): A taxonomic rank referring to a group of closely related species that share common ancestry and exhibit similar characteristics. Organisms within the same genus have more similarities than those in different genera but are still distinct species.

Gnathopods: Nippers.

Government Gazette (GG): An official Government publication used to publish acts and bills, regulations and notices in terms of acts, changes of names, company registrations and deregistrations, financial statements, land restitution notices, liquor licence applications and transport permits.

Government Notice (GN): A Notice published in a Government Gazette.

Government Notice Regulation (GNR): Regulations published as a Government Notice in a Government Gazette.

Grain size (or particle size): The diameter of individual grains of sediment, including mud, sand and gravel.

Gravel: Sediment with a grain size ranging between 2 mm and 64 mm.

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.

Guano: The excrement of seabirds and bats. Can be used as fertiliser.

Hybridisation: The mating of genetically differentiated individuals or groups, forming a hybrid organisms genetically distinct from either parent.

Hydrodynamic forces: Referring to forces acting on or exerted by water.

Hydrogeology: The study of groundwater. Sometimes referred to as geohydrology or groundwater hydrology.

Image classification: The process of assigning land cover classes to image pixel values.

Indigenous: Species within the limits of their native range (Synonyms: native).

Infauna: Organisms living within bottom sediments of a body of water, e.g., polychaetes, amphipods, isopods.

Intertidal: Also known as the littoral zone, is the area of shoreline that is exposed to the air during low tide and underwater during high tide. It is the region where land and sea meet, and it experiences regular fluctuations in water level and exposure to air.

Introduced species: Non-native species that have been intentionally or unintentionally brought into a region with the help of humans.

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: Large algae or seaweeds from the family Laminaria of the order Laminariales, the more massive brown algae.

Late successional species: Plant/ algal species that can grow with limited resources. Typically establish themselves long after a disturbance has occurred.

Macrobenthos/macrofauna: Those animals retained by a 1.0-mm-mesh sieve. Macrobenthic invertebrates are defined as organisms that live on or inside the deposit at the bottom of a water body.

Macrophyte: An aquatic plant large enough to be seen by the naked eye.

Marine Protected Areas (MPA): Areas formally protected in terms of the Protected Areas Act. The Management objective is defined by the management plan of each MPA.

Mesozooplankton: Zooplankton ranging in size 0.2–20 mm. Examples include copepods or the larvae of different animals.

Metabarcoding: A technique of plant and animal identification based on DNA-based identification and rapid DNA sequencing. The barcoding of DNA/RNA in a manner that allows for the simultaneous identification of many taxa within the same sample (Synonyms: DNA barcoding/ sequencing).

Micro-topography: Surface features of the earth of small dimensions, commonly less than 15 m.

Monitoring: The process of collecting information about a state of the environment of species.

Morphological characteristics: The appearance, form or structure of an organism.

Mud: Sediment with a grain size <62.5 µm.

Mytilid mussels: Any bivalve mollusc of the order Mytilida.

Mytilid species complex: Any bivalve mollusc of the order Mytilida. In this case *Mytilus galloprovincialis*, *M. edulis*, *M. trossulus* and *Semimytilus patagonicus*.

National Biodiversity Assessment (NBA): The threat status and sensitivity of different habitat types based on biodiversity (richness, uniqueness, spatial extent of the habitat type) and exposure levels to natural disturbance or environmental perturbations. Ecosystem types are categorised as "Critically Endangered", "Endangered", "Vulnerable", "Near Threatened" or "Least Concern", based on the proportion of the original extent of each ecosystem type that remains in good ecological condition relative to a series of biodiversity thresholds. See Ecosystem Threat Status.

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.

Non-Native: 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, exotic).

Ochrophyta: Brown algae.

Operational Taxonomic Unit: The Basic Unit Used In Numerical Taxonomy.

Operculum (Scutum): A structure that closes or covers an opening.

Opportunistic: Capable of rapidly occupying newly available space.

Organic matter: Matter composed of organic compounds that have come from the faeces and remains of organisms such as plants and animals. Example total organic carbon (TON) and total organic nitrogen (TON).

Other Natural Areas: Areas not currently identified as a priority, but retain most of their natural character and perform a range of biodiversity and ecological infrastructure functions. The management objective includes minimising habitat and species loss and ensure ecosystem functionality through strategic landscape planning.

Pathways: The processes that lead to the movement of alien taxa from one geographical location to another, e.g., shipping.

pH: Potential hydrogen. A measure of the acidity or alkalinity of a solution equal to the common logarithm of the reciprocal of the concentration of hydrogen ions in moles per cubic decimetre of solution. Pure water has a pH of 7, acid solutions have a pH less than 7, and alkaline solutions a pH greater than 7.

Phylum (singular)/ phyla (plural): One of the major hierarchical levels used to group and categorise living organisms based on their shared characteristics and evolutionary relationships. It is based on the concept of body plans and major structural features that define the members of a particular group.

Phytoplankton: Ocean dwelling microalgae that contain chlorophyll and require sunlight in order to live and grow.

Polychaetes: Segmented marine worms commonly called bristle worms due to each segment bearing a collection of bristles.

Polychromatic: Having various or changing colours; multicoloured.

Porifera: Sea sponges.

Prostomium: Head of the organism.

Protists: Any eukaryotic organism that is not an animal, plant, or fungus, e.g., amoebas.

Pygidium: Tail end of the organism.

Quadrats: A frame, traditionally square/ rectangular, used to study a standard unit of area in a larger area.

Qualitative data: Descriptive data.

Quantitative data: Numbers-based, countable, or measurable.

Ramsar site: A wetland site designated to be of international importance under the Ramsar Convention, also known as "The Convention on Wetlands of International Importance". This is an international environmental treaty signed on 2 February 1971 in Ramsar, Iran, under the auspices of UNESCO (See abbreviations). South Africa is a signatory to the Ramsar Convention. Langebaan Lagoon is recognised as an internationally important site under the Ramsar Convention.

Raster: A matrix of cells (or pixels) organized into rows and columns (i.e., a grid) where each cell contains a value representing information, such as land class. Rasters are digital aerial photographs, imagery from satellites, digital pictures, or even scanned maps.

Redox (Reduction Potential): The tendency of a chemical species to either be reduced by accepting electrons or oxidized by donating electrons.

Rhodophyta: Red algae.

Rocky shore community: A group of interdependent organisms inhabiting the same rocky shore region and interacting with each other.

Sand: Sediment with a grain size ranging between 63 μm and 2000 μm.

Scavenger: An animal that eats already dead or decaying animals.

Seabirds: Birds that are adapted to life within the marine environment.

Semigration: short for semi-emigration, the act of moving to another location within your home country.

Sentinel-1x/2x: European optical imaging satellite providing global coverage 20 m resolution imagery. 1A launched in 2014, 1B in 2016. 2A launched in 2015, 2B in 2017, and 2C proposed launch date in 2024.

Siphon: Tube-like structures in which water or air flows.

Species complex: A group of closely related organisms too similar in appearance to reliably distinguish based on morphological characteristics, e.g., mytilid species complex.

Species diversity: The number of different species and relative abundance of each of those species present in an ecosystem.

Species richness: The number of different species represented in an ecological community. It is simply a count of species and does not take into account the abundance of species.

Species: A category of biological classification ranking immediately below the genus, grouping related organisms. A species is identified by a two-part name; the name of the genus followed by a Latin or Latinised un-capitalised noun.

Spectral signature: A unique combination of values under different light wavelengths for a particular pixel in a remotely sensed image.

Substratum: The surface or underlying layer.

Subtidal: The marine habitat that lies below the level of mean low water for spring tides.

Supervised image classification: A procedure for identifying spectrally similar areas on an image by identifying training sites of known targets and then extrapolating those spectral signatures to other areas of unknown targets.

Suspension feeder: An aquatic animal which feeds on particles of organic matter suspended in the water, especially a filter feeder.

Taxon (singular)/ taxa (plural): Also referred to as a taxonomic group. Refers to any unit used in the science of biological classification, or taxonomy.

Ternary diagrams: Triangular representations of data.

Thallus: Vegetative tissue of a plant.

Thermocline: An abrupt temperature gradient in a body of water, marked by a layer, above and below which the water is at different temperatures).

Tides: The rise and fall of sea level, usually twice a day, due to gravitational forces by the moon. Spring tides have higher high tides and lower low tides, whereas neap tides have lower high tides and higher low tides. Spring and neap tides each occur twice a month, the former occurring just after every full and new moon, when the sun, moon and earth are in line. During a spring low tide, the water level drops lower than during an average low tide.

Topography: The relief features or surface configuration of an area.

Trace metals: Elements such as chromium, cobalt, copper, iron, magnesium, selenium, and zinc that normally occur at very low levels in the environment. Living things need very small amounts of some trace metals, but high levels of these same metals can be toxic.

Training sample: Location information (either points or polygons) within or encompassing a known associated land cover class. An image classification algorithm uses the training samples, saved as a feature class, to identify the land cover classes in the entire image.

Unsupervised image classification: A process by which each pixel value in a dataset or image is identified to be a member of one of the inherent categories present in the image collection, without the use of labelled training samples.

Vectors: The specific means of introduction within a pathway. For example, if a species has been introduced via the shipping pathway, the vector of introduction can be hull-fouling or ballast water.

Vertebrates: Animals with bony or cartilaginous axial endoskeleton — known as the vertebral column, spine or backbone.

Waders: Birds of the order Charadriiformes commonly found wading along shorelines and mudflats in order to forage for food crawling or burrowing in the mud and sand, usually small arthropods such as aquatic insects or crustaceans.

WGS84: World Geodetic System 1984. Since the 1st January 1999, the official co-ordinate system for South Africa.

Zooids: An animal arising from another by budding or division. Specifically, a single organism that is part of a colonial organism.

LIST OF ABBREVIATIONS

°C	Degrees Celsius
µC/mL	microcoulomb per millilitre
µg	microgram
µg/L	microgram per millilitre
µm	micrometre
ADZ	Aquaculture Development Zone
Anchor	Anchor Environmental Consultants
ANOVA	Analysis of variance (statistical test)
BAR	Basic Assessment Report
BCLME	Benguela Current Large Marine Ecosystem
BSP	Biodiversity Spatial Plan
C	Carbon
C:N	Carbon to Nitrogen
CBA	Critical Biodiversity Area
CBD	Convention on Biological Diversity
Cd	Cadmium
Cfu	colony-forming unit
CML	Coastal management line
CMP	Coastal Management Programme
COD	Chemical Oxygen Demand
CSIR	Council for Scientific and Industrial Research
CSL	Coastal Setback Line
Cu	Copper
CWAC	Co-ordinated Waterbird Counts
CWDP	Coastal Water Discharge Permit
DAFF	Department of Agriculture, Forestry and Fisheries (Together with the national DEA forms the DFFE)
DD	Data Deficient IUCN category
DD	Decimal Degrees
DEA	Department of Environmental Affairs (Together with DAFF forms the DFFE)
DEA&DP	Western Cape Department of Environmental Affairs & Development Planning
DEA: O&C	Department of Environmental Affairs: Oceans and Coasts (former name)
DFFE	Department of Forestry, Fisheries and the Environment (previously DEA)
DFFE:O&C	Department of Forestry, Fisheries and the Environment: Oceans and Coasts (new name)
DNA	Deoxyribonucleic acid
DS	Dive School
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry (Est. 1994 up until May 2009)
DWS	Department of Water and Sanitation (DWS was established in May 2009 and was previously DWAF. DWS is the current custodian of water resources)
EA	Environmental Authorisation
EAS	Elandsfontein Aquifer System
EBSA	Ecologically or Biologically Significant Marine Area
EC	Electrical Conductivity

ECO	Environmental Control Officer
eDNA	environmental DNA
EEM	Elandsfontein Exploration and Mining (Pty) Ltd
EF	Enrichment Factor
EIA	Environmental Impact Assessment
EIAr	Environmental Impact Assessment report
EICAT	The Environmental Impact Classification for Alien Taxa
EMF	Environmental Management Framework
EMPr	Environmental Management Programme
En	Endangered
ERL	Effects Range Low
ERM	Effects Range Median
ERP	Emergency Response Plan
ESA	Ecological Support Area
ET	Evapotranspiration
Fe	Iron
FPP	Floating Power Plant
GA	General Authorisation
GDA	General Discharge Authorisation (promulgated in 2022 in the Government Gazette No. 47019, 15 July 2022)
GEE	Google Earth Engine
GG	Government Gazette
GIS	Geographical Information System
GN	Government Notice
GNR	Government Notice Regulation
GSB	Greater Saldanha Bay
H_2O_2	Hydrogen peroxide
H_2S	Hydrogen sulphide
ha	Hectare
$HClO_3$	Perchloric acid
Hg	Mercury
HNO_3	Nitric acid
ICMA	National Environmental Management: Integrated Coastal Management Act (No. 24 of 2008)
IDZ	Industrial Development Zone
IGTT	Intergovernmental Task Team
IO	Iron Ore Terminal
IUCN	International Union for Conservation of Nature
J	Jetty
km	kilometre
km^2	square kilometre
L	Lynch Point
L/hr	litres per hour
L/s	litres per second
LNG	Liquefied Natural Gas
LPG	Liquid Petroleum Gas
LRAS	Langebaan Road Aquifer System

M	Marcus Island
m	metres
m^2	square metres
m^3	Cubic metre
m^3/a	metres cubed per annum
MAP	Mean Annual Precipitation
MAR	Mean Annual Run-off
max	Maximum
MDS	Multidimensional Scaling
mg	milligram
Mg/kg	Milligrams per kilogram
mg/L	milligram per millilitre
min	Minimum
mL	millilitre
MLRA	Marine Living Resources Act (No. 18 of 1998)
mm	millimetre
mm/a	millimetres per annum
Mm^3/a	Million cubic metres per annum
Mn	Manganese
MPA	Marine Protected Area
MPT	Multi-purpose Terminal
mS/m	milliSiemens per meter
MSPA	Marine Spatial Planning Act
Mtpa	Million tons per annum
N	Nitrogen
NB	North Bay
NBA	National Biodiversity Assessment
NE	Not Evaluated
NEMA	National Environmental Management Act (No. 107 of 1998)
NEMBA	National Environmental Management: Biodiversity Act (No. 10 of 2004)
NEMPAA	National Environmental Management: Protected Areas Act (Act No. 57 of 2003)
NGA	National Groundwater Archive
NGO	Non-Governmental Organisations
NHRA	National Heritage Resources Act (Act 25 of 1999)
Ni	Nickel
NOAA	National Oceanic and Atmospheric Administration
NWA	National Water Act (No. 36 of 1998)
OTU	Operational taxonomic unit
PAH	Poly-aromatic hydrocarbon
Pb	Lead
PERMANOVA	Permutational multivariate analysis of variance (statistical test)
pH	Potential hydrogen
POC	Particulate Organic Carbon
Ppm	parts per million
PSU	Practical Salinity Unit. Same as parts per thousand (ppt)
Q	Discharge/Yield
RWQ	Receiving Water Quality

S^{2-}	Sulphide
SANBI	South African National Biodiversity Institute
SANParks	South African National Parks
SB	Small Bay
SBLM	Saldanha Bay Local Municipality
SBM	Saldanha Bay Municipality
SBWQFT	Saldanha Bay Water Quality Forum Trust
SE	Schaapen Island East
SEA	Strategic Environmental Assessment
SIMPER	Similarity Percentages
SO_4^{2-}	Sulphate
SOB	State of the Bay
sp	species
SPLUMA	Spatial Planning and Land Use Management Act (Act 16 of 2013)
SW	Schaapen Island West
SWH	Significant Wave Height
TNPA	Transnet National Ports Authority
TOC	Total organic carbon
TON	Total organic nitrogen
TPH	Total petroleum hydrocarbon
TPT	Transnet Port Terminals
TSS	Total Suspended Solids
UES	Uniform Effluent Standard
UGEP	Utilisable Groundwater Exploitation Potential
VRF	Vessel Repair Facility
Vu	Vulnerable
WC	Western Cape
WCDM	West Coast District Municipality
WCNP	West Coast National Park
WGS84	World Geodetic System 1984
WL	water level
WoRMS	World Register of Marine Species
WQBEL	Water Quality-Based Effluent Limits
WQG	Water Quality Guidelines
WSMS	Water Supply Management System
WUL	Water Use Licence
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 (MPAs) have been proclaimed in and around the Bay, while Langebaan Lagoon and much of the surrounding land falls within the West Coast National Park (WCNP) (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).

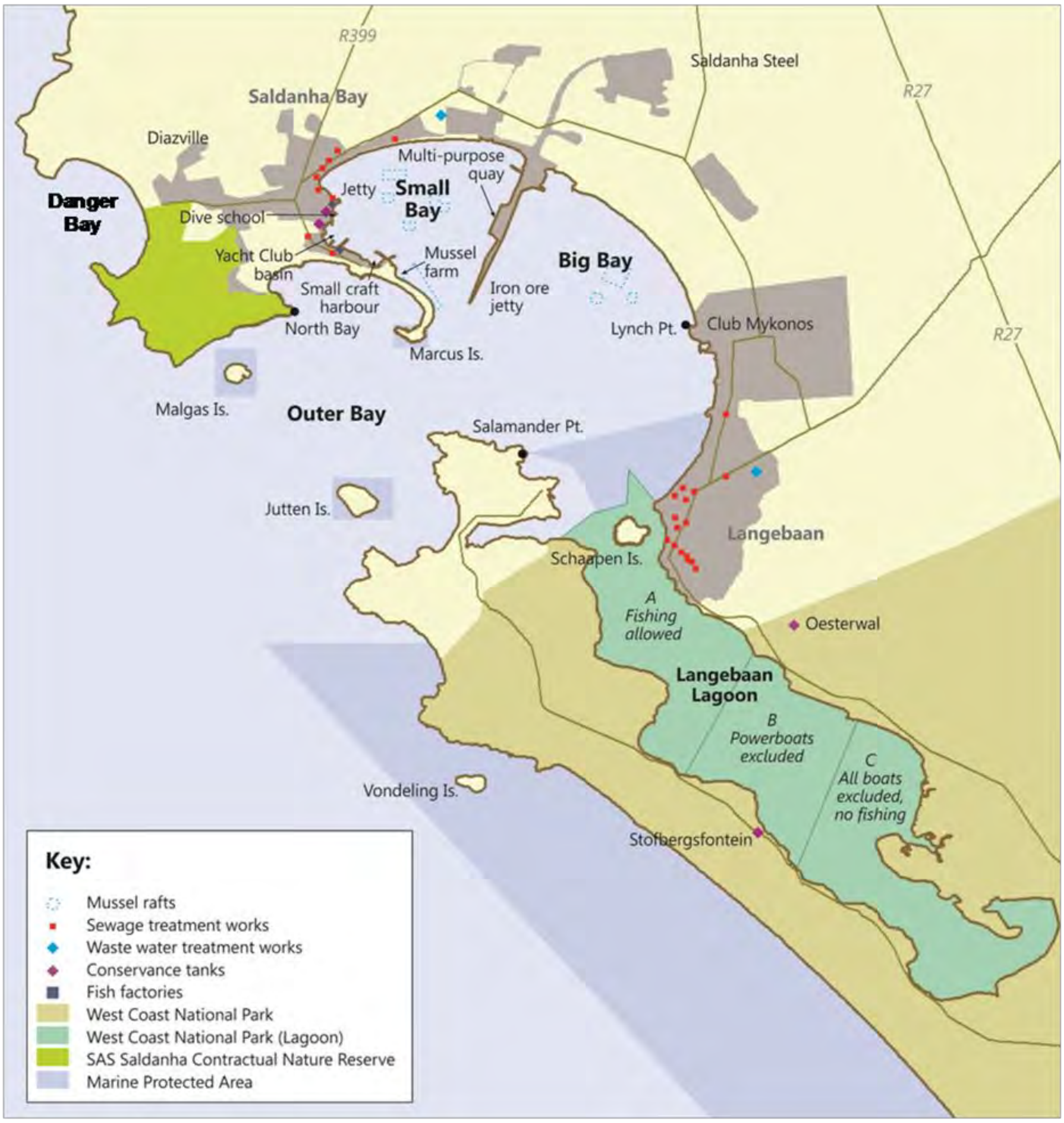


Figure 1.1. Regional map of Saldanha Bay and Langebaan Lagoon and Danger Bay showing development (grey shading) and conservation areas.

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.

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 Total organic nitrogen TON)) 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. Despite 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 (Anchor) 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 (2023) report is the 16th 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 (2022). It includes information on trends in all of the parameters reported on in the previous reports (2006, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021 and 2022).

This edition also incorporates several 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).

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 fourteen 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 provides a comprehensive overview of the predominant legislation that governs the area under consideration. It also 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 Industrial Development Zone (IDZ) and associated 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 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 in Saldanha Bay, Langebaan Lagoon, and Elandsfontein. The chapter centrally focusses on changes in sediment composition (particle size distribution) and quality (trace metal, organic carbon and nitrogen content) over time and/or related to dredging events.

Chapter Eight presents data on the current status and historical changes in aquatic vegetation communities (macrophytes) associated with Langebaan Lagoon and Saldanha Bay and also highlights the importance of groundwater discharge to the Bay and Lagoon for these communities.

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

Chapter Ten addresses changes that have occurred in the rocky intertidal zones in and around Saldanha Bay over the past 20 years. It presents results from rocky intertidal monitoring surveys initiated in 2005. It assesses differences in biotic community composition within sites, among sites in Saldanha Bay and over time. Furthermore, this chapter seeks to establish links between the observed changes and determine whether they arise from natural processes or human-induced factors.

Chapter Eleven 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 Twelve 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. Additionally, a brief summary of the current status of the Saldanha Bay seal population is provided.

Chapter Thirteen summarises available information on marine alien species known to be present in Saldanha Bay and Langebaan Lagoon, as well as trends in their distribution and abundance.

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

1.3 WHAT'S NEW IN THE 2023 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 twelve months, 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 therefore 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 (2022) 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 2022 for more details. Additional and updated information included in the sections of this chapter are listed below:

- Numbers of visitors to the WCNP;
- Metal exports from the Saldanha Bay Multi-purpose and iron ore terminals;

- Information on new and existing development proposals for Saldanha (The refurbishment of the Saldanha Bay harbour development);
- Shipping traffic and ballast water discharges;
- Effluent discharges into Saldanha Bay:
  - the volumes and quality of wastewater discharged into the Bay from the Saldanha and Langebaan Water Treatment Works, including the details on the effort of the Saldanha Bay Municipality (SBM) to reclaim freshwater from treated wastewater.
- Mariculture industry in Saldanha, including a summary of the most recent 2023 Chemical survey results.

Chapter 4: Coastal and environmental policy and management

This chapter now provides an overview of the predominant legislation that governs the area under consideration. Additionally, various plans, guidelines, and policies have recently been released or have undergone updates. Examples include the Draft Marine Biodiversity Sector Plan (2023), prepared to facilitate the formulation of Marine Area Plans in conjunction with the Marine Spatial Planning process, and the National Biodiversity Offset Guideline that was published on 23 June 2023. Given the evolving nature of legislation, it's important to monitor and review updates.

Chapter 5: Groundwater

In 2022, in collaboration with GEOSS and Ramboll, Saldanha Bay Local Municipality established a groundwater monitoring network consisting of twelve monitoring sites, which would be monitored monthly. Over the past year, the municipality ensured that continued groundwater monitoring took place at the selected twelve monitoring sites. The monitoring data is included in this report section. Currently, all monitored groundwater in the area (water levels, abstraction volumes and groundwater quality) remain stable, and no significant nett abstraction is occurring within the region. A local database has been established for the local monitoring network and a regional database using Aquabase is currently being set up by GEOSS that integrates all the groundwater information (from DWS and private authorised users) to provide a regional overview of the groundwater status within the area. The public can access the regional database and register via a link provided in this report. Over the next year, the Saldanha Bay Municipality plans to establish a numerical flow model for the two wellfields contained in the area — the Langebaan Road Wellfield and Hopefield Wellfield.

Chapter 6: Water quality

This chapter presents new information on variations in temperature, salinity, dissolved oxygen, and dissolved inorganic nitrogen at various locations in the Bay and at the head of the Lagoon, microbial indicators relating to bathing safety, as well as trace metals in mussels on the shoreline and offshore mariculture facilities. The 2023 results continued the trend of 2022 with elevated manganese in all shore-based mussel tissue sampled. This expands from two to five sites now showing dramatic increases in manganese concentrations. Arsenic from shore base and farm-based bivalves were above guideline limits for almost all samples collected in 2023, which is a concern. Lead concentrations dropped in 2023 compared to 2022 which is encouraging. Microbial indicators have revealed a worrying decline in safety at many sites, particularly *E. coli*, with faecal coliforms remaining high at many sites in Small Bay. Water quality monitoring activities that were initiated as part of the Environmental Monitoring Programme for the Aquaculture Development Zone (ADZ) are providing valuable new insights into oxygen dynamics in the bay and have again highlighted the impacts of reduced water circulation and organic loading in Small Bay.

Chapter 7: Sediments

The chapter presents new information on grain size composition and health of benthic sediment in Saldanha Bay (TOC, TON, trace metals and hydrocarbons). The historical background of sediments composition and quality has been shortened substantially as they are covered in previous State of the Bay reports. Additions to this chapter include a thorough analysis of sediment particle size changes through time, detailed discussion on changes relating to the interactions between carbon and nitrogen, and refinements to the methodology used to assess trace metal contamination in sediments.

Chapter 8: Aquatic Macrophytes

The new additions to this chapter provide updated supervised classification results for the years 2022 and 2023, adding to the spatio-temporal analysis conducted for three broad classes of aquatic macrophytes (common reed, sea grasses, and salt marshes). Low-resolution (30 m) unsupervised image classification results derived from the Landsat imagery collection are available for the years 1989–2020, while high-resolution (10 m) supervised classification results are available for the years 2016–2023.

Chapter 9: Benthic Macrofauna

Monitoring over the period 1999–2023 has revealed a pattern of decreased abundance and biomass in response to dredging events, followed by rapid recovery. During these perturbations, a general decrease in filter feeders and an increase in shorter lived opportunistic detritivores was recorded. However, localised improvements in health and a steady recovery of macrofaunal communities have recently been detected at some sites in the Bay. Other notable changes 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 *Listriolobus capensis*, and several gastropods. Certain areas of Small Bay still have impoverished macrofauna communities due to reduced water circulation and the accumulation of fine sediment, organic material and trace metals. Disturbances had resulted in reduced indices of abundance, biomass, and diversity at some sites in Big Bay. However, the latest results indicate some improvement.

Chapter 10: Rocky shores (intertidal invertebrates)

Since the start of the surveys in 2005, the cumulative count of recorded species has now surpassed 200. Several of the species documented during these surveys have been identified as alien. These include the mytilid mussel species complex (*M. galloprovincialis*, *S. patagonicus, M. edulis* and *M. trossulus*), the acorn barnacle *Balanus glandula*, the North West African porcelain *Porcellana africana* and the red-rust bryozoan *Watersipora subtorquata*. *M. galloprovincialis* is still considered the dominant mussel species amongst those in the mytilid species complex, as inferred from DNA barcoding analysis and supported by previous studies. This further marks the first record of *M. edulis* and *M. trossulus* in South Africa and of *W. subtorquata* in a rocky shore survey. One significant observation has been the notable increase in encrusting algae across most sites and a decline in filter feeders at some locations. This decline in filter feeders is most likely due to the decline in alien mussels and barnacles, as has been observed during recent surveys. This has most likely created an ecological niche for encrusting algae, facilitating their colonisation of available rock space and potentially accounting for their substantial increase in abundance.

Chapter 11: Fish

This chapter presents new information on species composition, abundance, biomass and health of fish communities in Saldanha Bay and Langebaan Lagoon and provides updates on the current population status of key line-fish, net-fish and angling species in the Bay. In 2023, species diversity was up in Small Bay and Big Bay, and stable in Langebaan Lagoon. White stumpnose recruitment remains lower than average.

Chapter 12: Birds and seals

This chapter provides an update on the species threat status, and presents new data on the composition, abundance and health of birds breeding and feeding in Langebaan Lagoon and on the Islands in Saldanha Bay. It also presents data on trends in the biomass of small pelagic fish (sardines and anchovies) that are the most important prey species for endangered sea birds that breed on the Saldanha Bay Islands. It is still to be seen if the recent extension, (for 10 years) of a ban on small pelagic purse seine fishing around Dassen Island will yield benefits for bird populations breeding on the Saldanha Bay Islands.

Chapter 13: Alien invasive species

This year, additional qualitative data were included from two biofouling studies conducted by Anchor Environmental Consultants (Anchor) in the Saldanha Bay ADZ during 2021 and 2022, as well as the first DNA-based survey undertaken in 2022. The latter included the environmental DNA (eDNA) metabarcoding and analysis of ballast water, sea water, sediment, and wall scrape samples. In total, 37 alien and invasive species have been confirmed from Saldanha Bay and Langebaan Lagoon to date, while nine new alien species have been added to the State of the Bay list since the 2022 report. These include the tuberculate pear crab *Pyromaia tuberculata,* skeleton shrimp *Caprella mutica*, pitted barnacle *Balanus trigonus*, fat-feeler amphipod *Monocorophium acherusicum*, pink-mouthed hydroid *Ectopleura crocea,* thin-walled obelia *Obelia dichotoma,* amphipod *Ericthonius brasiliensis,* blue mussel *Mytilus edulis* and the bay mussel *M. trossulus.* Three species, although previously known from South Africa, are recorded for the first time in Saldanha Bay, indicating a range expansion (i.e., *P. tuberculata, C. mutica* and *B. trigonus*). Most notably, the two mytilid mussel species *M. edulis* and *M. trossulus*, are documented for the first time in South Africa, challenging previous assumptions about the identity and current understanding of mytilids in South Africa. This report further presents updated quantitative data on the abundance and biomass of the Pacific barnacle *B. glandula*, the mytilid species complex and the western pea crab *Rathbunixa occidentalis*. Including the two newly identified alien mussel species, and the recently reported pear crab, the total number of known alien and invasive species in South Africa is now believed to stand at 98.

Chapter 14: Management and monitoring recommendations

This chapter provides an updated summary of the key changes detected in each parameter covered in this report and assigns a health status rank to each. It also includes updated recommendations on management actions that need to be implemented to mitigate key threats highlighted in the previous chapters.

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 several sources, the major one being sewage, industrial effluent, and agricultural runoff. They are of concern owing to the vast quantities discharged to the environment each year which has the propensity to cause eutrophication of coastal and inland waters. Eutrophication in turn can result in proliferation of algae, phytoplankton (red tide) blooms, and deoxygenation of the water (black tides).

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

2.2 MECHANISMS FOR MONITORING CONTAMINANTS AND THEIR EFFECTS ON THE ENVIRONMENT

The effects of pollutants on the environment can be detected in a variety of ways as can the concentrations of the pollutants themselves in the environment. Three principal ways exists for assessing the concentration of pollutants in aquatic ecosystems - through the analysis of pollutant concentrations in the water itself, in sediments or in living organisms. Each has their advantages and disadvantages. For example, the analysis of pollutant concentrations in water samples is often problematic owing to the fact that even at concentrations lethal to living organisms, they are difficult to detect without highly sophisticated sampling and analytical techniques. Pollutant concentrations in natural waters may vary with factors such as season, state of the tide, currents, extent of freshwater runoff, sampling depth, and the intermittent flow of industrial effluents, which complicates matters even further. To accurately elucidate the degree of contamination of a particular environment, many 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 therefore 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 and Rainbow 1993). 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 integrate 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.

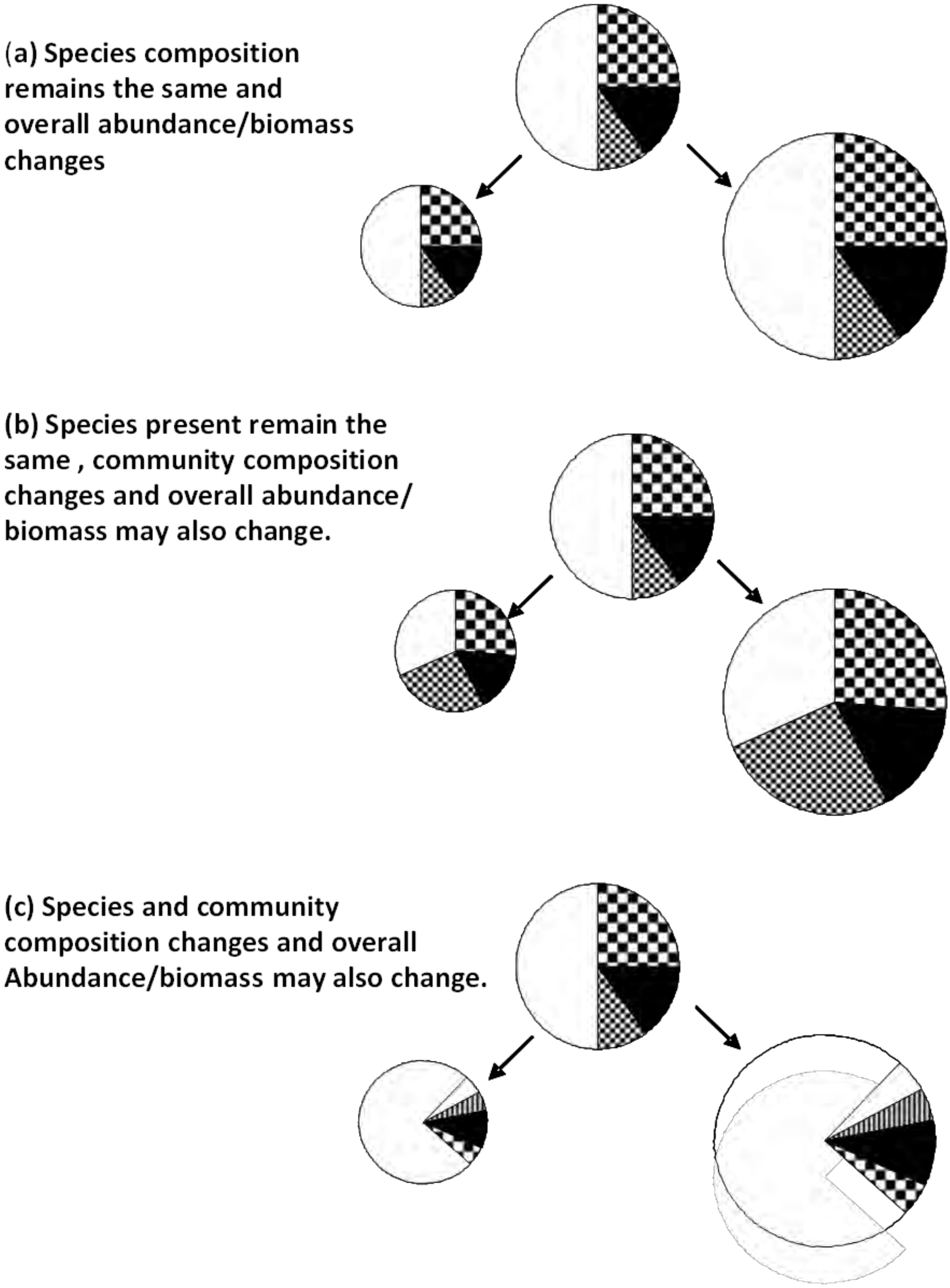


Figure 2.1. Possible alterations in abundance/biomass and community composition. Overall abundance/biomass is represented by the size of the circles and community composition by the various types of shading. After Hellawell (1986).

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.

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 also able to integrate changes over short periods of time (weeks to months) and are thus good indicators or short to very short-term changes in environmental health.

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

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

Macrophytes: Estuarine macrophytes are good indicators of ecological health and condition due to their temperature and salinity tolerance range, sensitivity to nutrient loads and extent in response to anthropogenic and climatic changes. They can be monitored relatively infrequently (1x per year) as well as at low costs once the initial ground truthing assessment has been captured. With advancements in remote sensing and spatial analytics a long-term monitoring framework can be easily maintained.

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: South Africa has at least 95 confirmed alien species, most of which are considered invasive. With new introductions and discoveries every year, this list remains dynamic with several additions underway. Most alien 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. As ballast water tends to be loaded in harbours, alien species often originate from these sheltered habitats. Although they have difficulty adapting to the more exposed coastline, they easily gain a foothold in sheltered bays such as Saldanha Bay.

3 ACTIVITIES AND DISCHARGES AFFECTING THE HEALTH OF THE BAY

3.1 Introduction

Industrial development of Saldanha Bay dates back to the early 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 (IOT). 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 IOT with berths for three ore carriers, an oil jetty, a Multi-purpose Terminal (MPT), 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 (IDZ), 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 (TPT) have thus far been unsuccessful in obtaining a variation to their existing Air Emission License (AEL) applicable to the IOT 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. During the 2017/18 drought in the Western Cape, however, industry and local municipalities came 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. A significant portion of the wastewater is being used for irrigation, and current water users receiving treated effluent include: the Weskus School, Saldanha Sports Ground (Stadium and practise field), Blue Bay Lodge and Arcelor Mittal (intermittently). It is reported that no effluent from The Langebaan Wastewater Treatment Works (WWTW) is entering the Bay. In contrast, the balance of treated effluent from Saldanha WWTW not used for irrigation is currently discharged into the Bok River and ultimately ends up in the ocean, however, effluent quality for all but one of the limits presented in the General Discharge Authorisation were compliant. It is worth noting that the exact quantity of effluent entering the Bok is unknown, and although it has been indicated previously that a flow gauge will be installed no results from this have been made available.

Ballast water discharges are by far the highest in terms of volume and have been increasing year on year due to constant and increasing shipping traffic. Ballast water often includes high levels of contaminants such as trace metals and hydrocarbons, and, along with the vessels that carry the ballast water, serves to transport alien species from other parts of the world into Saldanha Bay. Ballast water discharges can, however, be effectively managed and the remit of the International Maritime Organisation (IMO) is to reduce the risks posed by ballast water to a minimum through the direct treatment of the water while on board the ship, as well as by regulating the way in which ballast water is managed while the ship is at sea. Although no domestic legislation is currently in place to regulate ballast water discharge, the Transnet National Port Authority (TNPA) 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 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 464 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 established 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. Previously allocated areas have been incorporated into the ADZ which now comprised a total area of 884 ha set aside for mariculture.

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 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: Management and Policy Development for more details on this). 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 IOT and a causeway, built in 1975, that linked Marcus Island to the mainland, providing shelter for ore-carriers. The construction of the IOT 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 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 IOT 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. More recently, Henrico & Bezuidenhout (2020) illustrate how the construction of the harbour altered the bathymetry within the Bay leading to an increased water depth of roughly 1.4 m, steeper surf zone slopes (as a result of erosion of the north eastern edge of the Bay) and a generally smoother, steeper bottom profile in the Bay (Chapter 7: Sediments).

Aerial photographs taken in 1960 (Figure 3.1), 1989 (Figure 3.2) 2007 (Figure 3.3) and 2023 (Figure 3.4) clearly show the extent of development that has taken place within Saldanha By over the last 50 years. The current layout of the Port of Saldanha is shown in Figure 3.5. Future plans, including short term (2032) and long-term (Beyond 2052) goals for the development of the Bay are shown in Figure 3.6 and Figure 3.7, these were taken from the Port Development Framework 2022 update (Transnet National Ports Authority (TNPA) 2022).

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; and
4. Marine protection services and ocean governance.

In line with this development, Transnet and 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 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. Aerial photo of Saldanha Bay and Langebaan Lagoon taken in 2023 (Source Google Earth). Note expansion in residential settlements particularly around the town of Langebaan and between Langebaan and the Iron Ore Terminal.

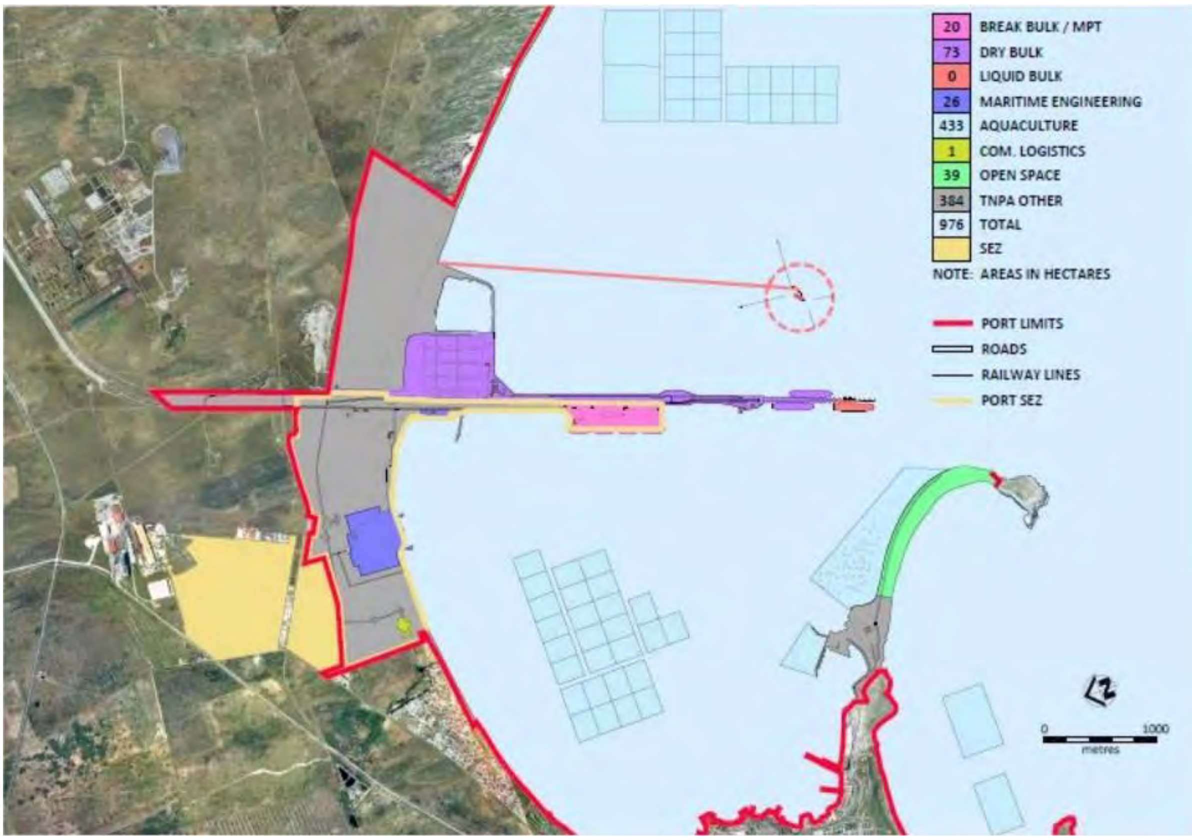


Figure 3.5. Current layout of Transnet Saldanha Bay Port (Source: Transnet National Port Authority 2022, Port Development Framework 2022 update).

Figure 3.6. Short term layout (2032) of Transnet Saldanha Bay Port (Source: Transnet National Port Authority 2022, Port Development Framework 2022 update).

From the current (Figure 3.5) to short-term layout (Figure 3.6), the following changes are envisaged (Transnet National Ports Authority (TNPA) 2022):

1. Amendment of Port Limits to include newly acquired land in compliance with the Terminal Operator Agreement;
2. Land earmarked for ship repairs at small craft harbour;
3. Environmental sensitive area;
4. Widening of causeway;
5. Land earmarked for energy, liquid bulk, and gas storage;
6. New berth 100 to increase handling capacity to 67 Million tons per annum (mtpa);
7. Increase Dry Bulk storage (stockpile) land area handling capacity (iron Ore);
8. Reconfiguration of Oil Jetty, Berth 104, handling of white fuels;
9. Relocation of Haul Road Port Entrance;
10. Maritime Engineering; and
11. Berth 205, Potential Maritime Engineering, and other Bulk cargo.

The following changes are envisaged from the short-term to the medium-term port layout (image not shown) (Transnet National Ports Authority (TNPA) 2022):

1. Increase the footprints of the liquid bulk storage, energy and Liquefied Natural Gas (LNG) (extension of land in Dunes area);
2. Maritime engineering: additional berth facilities as per increased demand in the Mossgas quay;
3. Berth 200 to accommodate increased MPT demand and changes in vessel forecast;
4. Infilling of land adjacent to Oyster dam to increase liquid bulk storage land area; and
5. LNG jetty for liquid bulk.

Changes which are envisioned for the long-term layout are as follow (Transnet National Ports Authority (TNPA) 2022):

1. Additional berths or handling liquid bulk and LNG and other energy products;
2. Berth 199, 198 to accommodate increased demand and vessel size forecast; and
3. Maritime engineering (alignment to OSSB masterplans).

Figure 3.7. Long-term layout (Beyond 2052) of Transnet Saldanha Bay Port (Source: Transnet National Port Authority 2022, Port Development Framework 2022 update).

3.2.1 Socio-economics

Data are derived mainly from Statistics South Africa and the Western Cape Government 2022. The population of Saldanha increased from 16 820 in 1996 to 21 636 in 2001 and to 28 135 in 2011 (Statistics South Africa 2012). The Langebaan population increased from 2 735 to 3 428 between 1996 and 2001, and rapidly from there up to 8 294 in 2011 (Statistics South Africa 2011). The population in Saldanha Bay, particularly that in Langebaan Village, is expanding rapidly, which has been attributed to the immigration of people from surrounding municipalities in search of real or perceived jobs (Saldanha Bay Municipality (SBM) 2011). In 2022, 26% of the West Coast District Municipality's (WCDM) population resides within the bounds of the Saldanha Bay municipal area. The population here stands at 125 687 individuals in 2022, projected to reach 136,611 by 2026, indicating an average annual growth rate of 2.1% during this period. This growth rate is 0.4 percentage points higher than the WCDMs estimated average annual population growth rate of 1.7% (Western Cape Government 2022). Data shows that as of 2022, there are slightly more females than males in the Saldanha Bay municipal area, with a ratio of 50.2% females to 49.8% males (Western Cape Government 2022). The age distribution gives the proportion of the population within different age cohorts. These groupings reveal the dependency ratio, indicating the working-age population (15–64 years) and those dependent on them (children or senior citizens). The 65+ age category experienced the highest population growth of 2.8% between 2022 and 2026, potentially indicating improvements in life expectancy or a growing attraction of Saldanha Bay as a retirement destination (Western Cape Government 2022).

In 2020, Saldanha Bay's economy was valued at R10.9 billion, providing employment to 48,438 individuals. Between 2016 and 2020, the municipal area exhibited an average annual growth rate of -0.2%, influenced by factors like the 2020 recession, load shedding, and provincial drought. However, 2021 witnessed a significant recovery (6.0%) from COVID-19 restrictions, driven by sectors like community services, agriculture, trade, and manufacturing. Despite this growth, the economy lost around 1,570 jobs, primarily in wholesale & retail, manufacturing, and agriculture sectors, indicating a lag in employment creation compared to the improved GDP (Western Cape Government 2022).

The three largest sectors (as a % of Gross Domestic Product) in the broader Saldanha Bay Local Municipality (SBLM) in 2022 were agriculture, forestry and fisheries (20.4%), followed by manufacturing (19%), and finance, insurance, real estate & business services (18.1%) (Western Cape Government 2022).

Urban development around Langebaan Lagoon has encroached right up to the coastal margin, leaving little or no coastal buffer zone (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).

Figure 3.8. Satellite image of Saldanha (Small Bay, left) showing little or no set-back zone between the town and the Bay, and of Langebaan (Right) showing absence of development set-back zone between the town and the lagoon. Source: Google Earth.

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 (WCNP), 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 (2005–2023) on numbers of visitors to the WCNP indicate strong seasonal trends in numbers of people entering the park, peaking in the summer months and December holiday period, and during the flower season in August and September (Figure 3.9). Paying day guests (excluding international visitors) contribute the most to this seasonal pattern, followed by free guests[1] which peak in September due to the Annual South African National Parks (SANParks) Week during which entries into the park are free for all. Wild Card holders (memberships) similarly peak in the flower season in September. Conversely, international guests and overnight guest numbers are relatively constant throughout the year and are considerably lower than the other visitor categories (Figure 3.9).

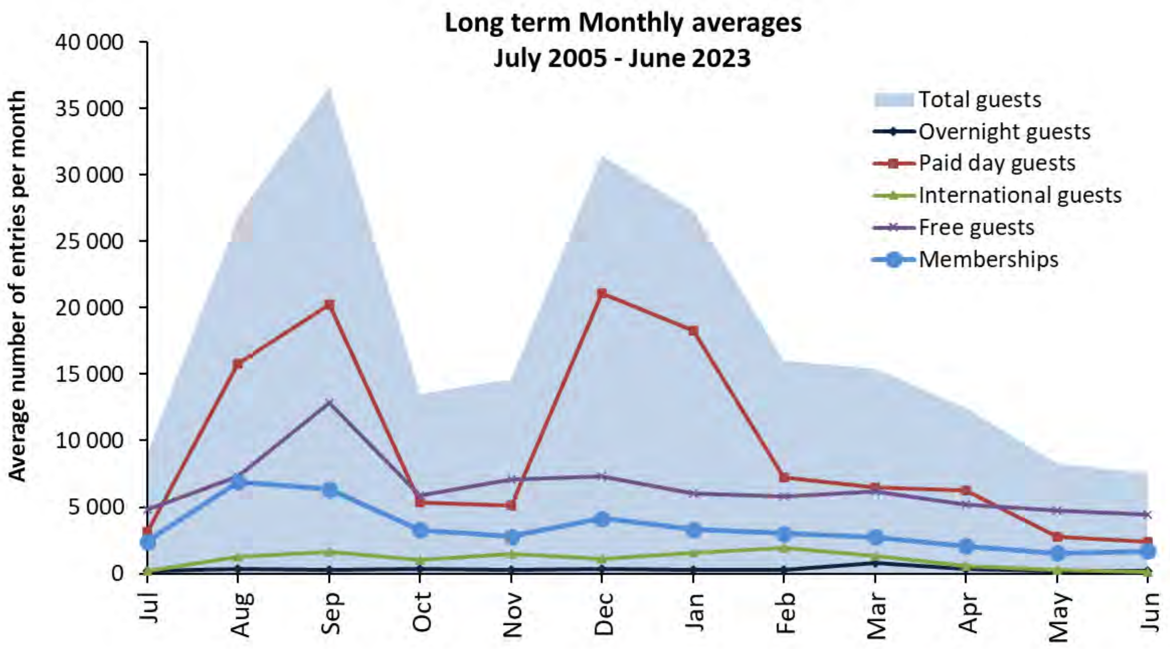


Figure 3.9. Monthly average numbers of entries into the West Coast National Park between July 2005 and June 2023. Paid day guests include all South African visitors (adults and children), while Overnight guests refer to those staying in SANParks accommodation. International guests include all SADC and non-African day visitors (adults and children) while the category 'Free guests' includes residents, staff, military, school visits. Memberships = Wild Card holders. Note that SANParks tourism data are now managed by national head office and the reporting structure has changed. (Source: Pierre Nel, WCNP).

The number of free guests has been increasing steadily over time and is now similar to the proportion of day guests, however, the recent data format shows that this category is likely made up of equal parts complimentary guests and guests with memberships, such as Wild Card holders (Figure 3.10). The popularity or overnight stays inside the park decreased substantially after 2009, reaching an all-time low in the 2020/2021 rolling year with only 12 overnight guests on record. In the 2021/2022 rolling year, 57 guests overnighted in the park and this number increased dramatically in 2022/2023, with 550 overnight guests recorded. Total number of guests and Wild Card holder numbers were only available for 2018/19. It should be noted that SANParks tourism data are now managed by national head office and the reporting structure has been standardised across all national parks.

1 These include school groups, military personnel, official visits, SANParks and Concessionaire staff, residents and service provider entries.

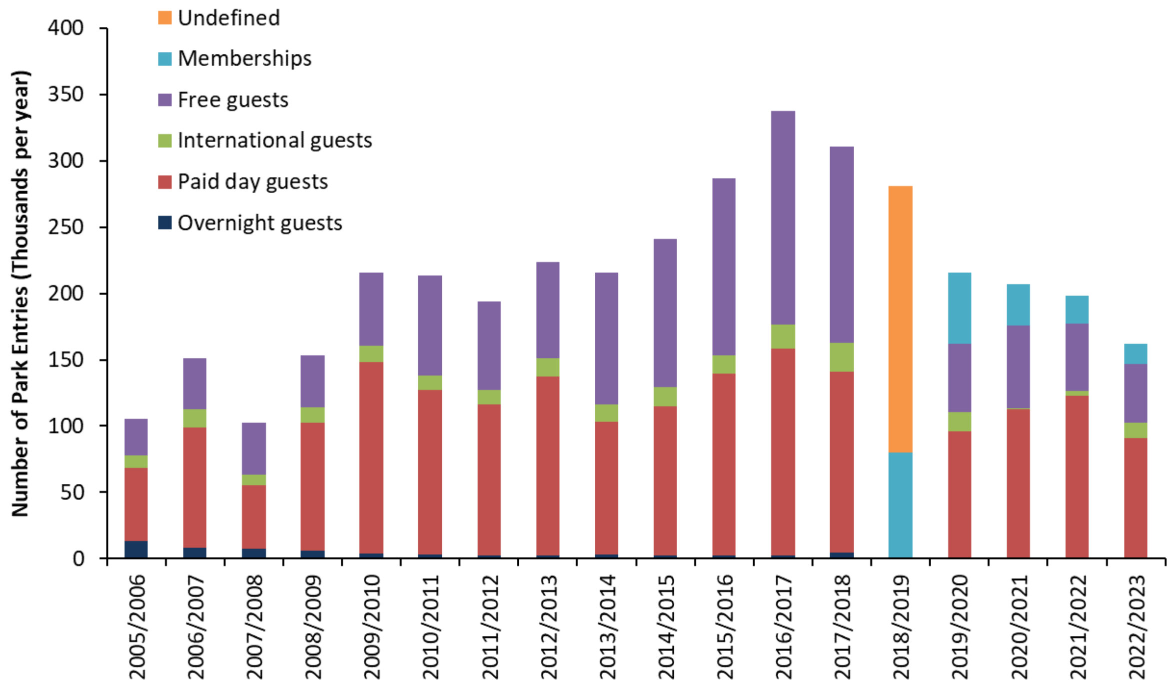


Figure 3.10. Numbers of entries into the West Coast National Park in a rolling 12-month periods from July 2005 until June 2023. Paid day guests include all South African visitors (adults and children) while Overnight guests refer to those staying in SANParks accommodation. International guests include all SADC and non-African day visitors (adults and children) while the category 'Free guests' originally included residents, staff, military, school visits and wild cards. In 2018/2019 only total number of guests and wild card holders (Memberships) were recorded, however, this has changed with recent data again being categorised. The 2019–2021 'Free guests' are now divided into 'Complimentary' and 'Memberships' (Wild Cards) (Source: Pierre Nel, WCNP).

Visitor numbers increased at an average rate of 13% per annum[2] from 2005/06 until 2016/2017 when over 338 thousand visitors entered the park. Since then, the total number of visitors decreased steadily until 2018/2019 and then dropped by 27% to just under 207 000 visitors in 2020/21 (Figure 3.10). This drop in visitor numbers over the last four years is likely due to the COVID-19 Pandemic, patterns of which can be clearly seen when comparing the historical average monthly entries data to that of the 2019/2020 and 2020/2021 rolling years (Figure 3.11). South African underwent varying degrees of lock-down and travel restrictions during from 27th March 2020, with hard lockdown and the closure of all national parks extending through April and May of 2020, causing visitor numbers to drop to zero in these months (Figure 3.11). The second wave of COVID-19 infections within South Africa occurred over the December 2020 holidays, causing numbers at this time to drop to almost half that of the historical values for this period.

2 The average annual growth rate was calculated from the data reflecting the total numbers of tourists entering the West Coast National park in a rolling 12-month period.

Interestingly, visitor numbers during the 2020 spring flower season (August – September 2020/2021) were significantly higher than both historical values and those of the preceding year. It is likely due to the fact that national parks, provincial borders and tourism had only recently been re-opened and many people took the opportunity to escape the confines of lockdown.

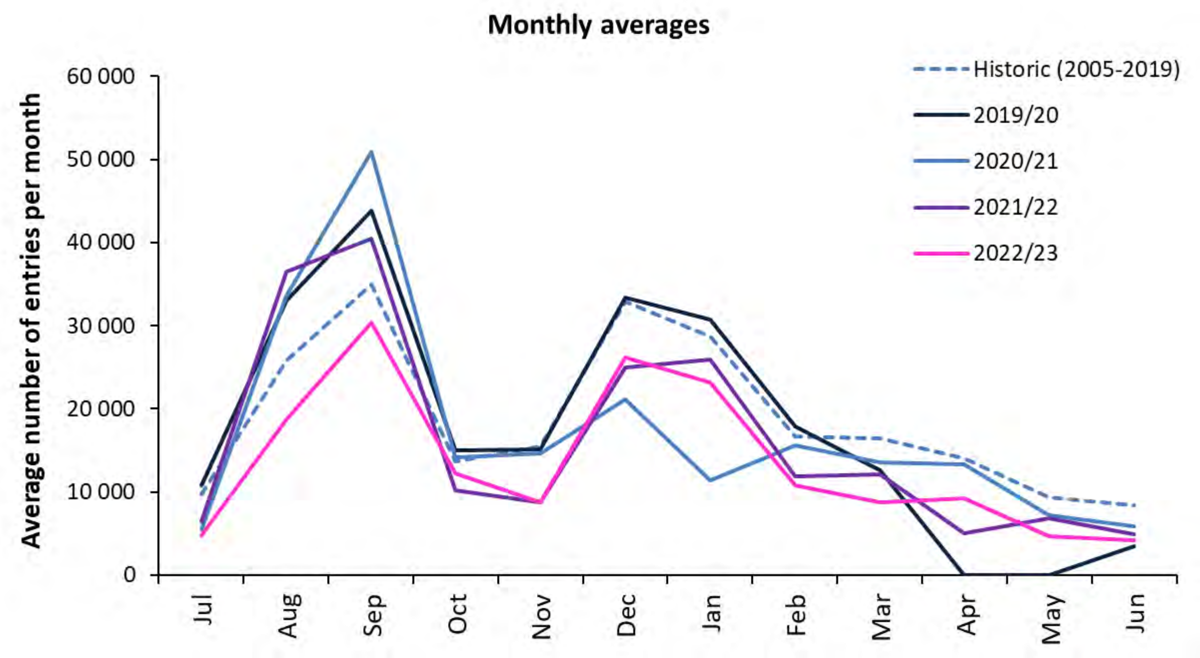


Figure 3.11. Monthly average numbers of entries into the West Coast National Park for the months July to June: historically (2005 – June 2019) and for the last four rolling years 2019–2023 (Source: Pierre Nel, WCNP).

The annual total of international visitors to the park dropped to an all-time low in 2020/2021 as the COVID-19 restrictions strongly influenced international travel, however, in 2022/2023 international visitor numbers to the WCNP have returned back to almost pre-COVID-19 visitor numbers (Figure 3.10). This is supported by overall numbers of international visitors to South Africa, which declined significantly in 2020 and 2021, and then increased again more than three-fold in 2022, with a similar jump back to pre-COVID-19 numbers likely to have occurred this year (2023) (Figure 3.12).

Interestingly, although the basic trend of the proportions of specific groups contributing to entries in 2022/2023 appears to have returned to match that of historical trends, the overall visitor numbers are significantly lower than historical and previous years (Figure 3.10 and Figure 3.11). The number of membership entries has also dropped in 2022/2023 (Figure 3.10) suggesting that with the increasing cost of living, South Africans may be 'tightening their belts' and no longer purchasing annual Wild Card memberships or spending on a visit to our national parks.

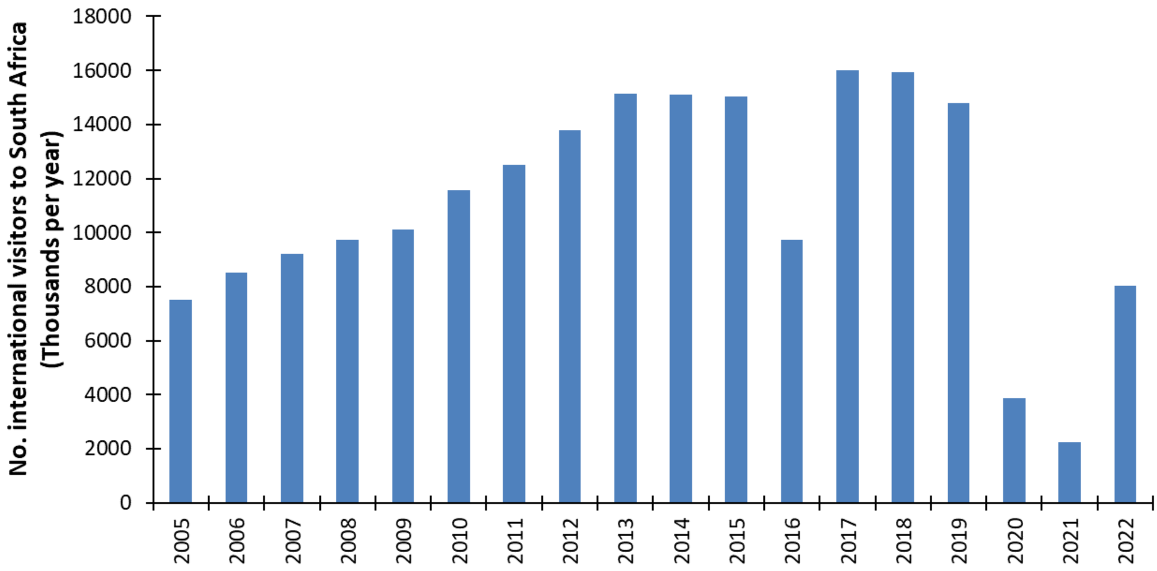


Figure 3.12. Total annual numbers of international guests visiting South Africa.

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 is the 5th Generation IDP published in April 2023 that covers the period 2012–2027 (Saldanha Bay Municipality (SBM) 2023). The latest SDF for the SBM was produced in May 2019 and is available on the municipality website (https://sbm.gov.za/spatial-development-framework/). This document advocates a holistic approach to the development of the municipality and compliance with the Spatial Planning and Land Use Management Act (SPLUMA), ensuring social justice, spatial sustainability, efficiency, spatial resilience and good administration. The Spatial Development Framework 2020 of the WCDM was adopted at a Council meeting held on 27 May 2020.

A study by van der Merwe *et al.*, (2004) 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 2019 SDF estimated that the total housing requirements to 2021 in all sectors of the entire municipality was 21 579 (Saldanha Bay Municipality (SBM) 2019). This has likely increased even further given the high amount of semigration into the Western Cape Province and as work from home jobs become more common and people choose to live away from main city centres.

3.2.2 GREEN HYDROGEN HUB

"Green hydrogen" is a clean energy source that has the potential to play a crucial role in decarbonizing such sectors by replacing the use of fossil fuels. Hydrogen gas (H_2) is generated via the process of electrolysis and involves splitting water molecules into H_2 (or simply referred to as hydrogen) and oxygen (O_2). Unlike traditional methods of hydrogen production that rely on fossil fuels, green hydrogen is produced using electricity from renewable sources (such as solar or wind power) and does not emit greenhouse gases during its production. This makes green hydrogen a 'clean' and sustainable energy source. As the production of hydrogen requires freshwater, this process might prove challenging for a water scarce country like South Africa. Therefore, Reverse Osmosis (RO) seawater desalination has been proposed as a solution for green hydrogen projects in the country and any Green Hydrogen plant in SA will also require the construction of a desalination plant.

In October 2022 the Saldanha Bay Industrial Development Zone signed a memorandum of understanding (MOU) with Sasol South Africa (Sasol) to facilitate a green hydrogen hub in Saldanha Bay and research is underway to investigate the economic, technical, legal, environmental, and social suitability of desalination plants as a water source for green hydrogen projects in South Africa.

Any proposed development of a renewable energy desalination plant project that triggers listed activities in accordance with the amended EIA regulations, of the National Environmental Management Act (NEMA) 107 of 1998 will require the completion of a Scoping & EIA (S&EIA).

3.2.3 REFURBISHED SALDANHA BAY HARBOUR DEVELOPMENT

In June 2022, Deputy Minister Noxolo Kiviet and Media Liaison Zara Nicholson visited the Saldanha Bay harbour to inspect infrastructure upgrades to the Saldanha Harbour undertaken as part of a major refurbishment programme to the 13 Proclaimed Fishing Harbours in the Western Cape, completed by the Department of Public Works and Infrastructure (DPWI).

The repairs completed at Saldanha and Pepper Bay Harbours, aimed at boosting local economy, fisherman and surrounding communities with approximately R27 million was paid to contractors from locally appointed Small, Medium and Micro Enterprises (SMMEs), with a total of 145 local residents benefitting from added work opportunities.

Work undertaken at harbours included work on the slipway infrastructure at Saldanha harbour, reassembling the cradle and the motor in the winch room, as well as building refurbishments. New electrical infrastructure was installed in operations buildings and ablution facilities, coupled with improvements to security in the form of automated access control and the upgrading of CCTV, security cameras and street lighting. Civil works included the removal of old asbestos buildings and roofs, as well as upgrades to the existing buildings, ablution facilities and offices as well as the harbour winch rooms at Saldanha and Pepper Bay harbours.

These activities have resulted in the increased capacity of the slipway from 600 tonnes to 1 200 tonnes which is anticipated to improve and increase the commercial use of the harbour.

3.2.4 FRONTIER POWER SA GAS TO POWER FACILITY

The Risk Mitigation Independent Power Producer Procurement Program (RMIPPPP) was designed by the Department of Mineral Resources and Energy DMRE in order to fulfil the Minister's directive to procure 2 000 MW of new generation capacity from a range of energy source technologies. In response to the Request for Proposals under the RMIPPPP sent on 23 August 2020, Frontier Power SA (RF)(Pty) Ltd (Frontier Power) submitted a bid for a Gas to Power facility on 22 December 2020. They proposed to construct and operate a circa (export capacity no greater than) 315 MW Gas to Power Facility located in the Saldanha Bay IDZ. The Facility will utilise gas engine technology, with Liquid Petroleum Gas (LPG) as the fuel source and was proposed to be located on an historical quarry site on Farm 1238 (now Erf 16001), Saldanha Bay, with an LPG pipeline running from the adjacent existing Sunrise Energy LPG Storage Facility located on Farm 1237 (Erf 16000) to the power plant.

On 9 November 2021, the Department of Forestry, Fisheries and the Environment (DFFE), issued a Provisional Atmospheric Emission Licence (PAEL) to Frontier Power in terms of Section 41 (1) of the National Environmental Management: Air Quality Act, 2004, (Act No. 39 of 2004) (NEM: AQA) (DFFE Ref: PAEL/WCP/FPSA/15/12/2020).

3.2.5 KARPOWERSHIP

In response to the Request for Proposals under the RMIPPPP sent on 23 August 2020, Karpowership SA (Pty) Ltd (Karpowership) was selected to provide electricity through three floating power stations in the ports of Richards Bay, Ngqura and Saldanha Bay. This would entail the generation of electricity from a floating mobile Powership moored in each Port and proposed two ships berthing in the Port of Saldanha Bay during the project lifespan, a Floating Storage Regasification Unit (FSRU) and one Powership, a Liquefied Natural Gas Carrier (LNGC).

Prior to the commencement of activities at the Port of Saldanha Bay, Karpowership applied for Environmental Authorisation (EA) and an atmospheric emission licence (AEL), with the final reports, required in terms of the National Environmental Management Act, Act no, 107 of 1998, as amended and the EIA regulations, submitted to the department for decision-making on 26 April 2021.

The Competent Authority for the project, the DFFE issued a Record of Refusal refusing EA for the project on 23 June 2021. Reasons for refusing EA are outlined in the Record of Refusal issued by the DFFE dated 23 June 2021 (DFFE Reference: 14/12/16/3/3/2/2006), and include the fact that the applicant did not meet the minimum requirements relating to public consultation and information gathering set out in the NEMA and the EIA Regulations of 2014, that certain specialist studies (specifically a noise modelling study) recommended by specialists on the project had not been completed, and that all potential and actual impacts on the environment had not been fully evaluated.

Karpowership SA (Pty) Ltd appealed this decision, but the appeal was also rejected by the Minister DFFE on 5 of August 2022. Reasons for the rejection are set out in a letter issued by the minister on 1 August 2022 (Ref: LSA207023). In refusing the Appeal, the Minister noted that there were gaps in information and procedural defects in relation to the process followed for the EIA that could not be corrected during the appeal process and made the decision, and in accordance with her powers under NEMA, elected to remit the KSA EA to the Competent Authority in the DFFE, to enable the applicant to address the perceived gaps and procedural defects, and to resubmit the application to the Department.

Following the advice of the Minister, Karpowership SA (Pty) Ltd elected to revise and resubmit an application for EA to the competent Authority for consideration. Additional studies, such as a Saldanha Bay site specific noise study were undertaken and previous impact assessments were revised and resubmitted in January 2023. The application was suspended after allegations that the views of small-scale fisheries were misrepresented. On 26 April the department informed Karpowership that 'no evidence could be found to support the claims and the suspension was duly lifted". Karpwership then withdrew the EIA report (EIAr) and the Legal team submitted a letter to DFFE to request a condemnation for missing EIA regulation deadlines - application to be submitted 106 days after acceptance of the scoping report and to include an EIAr, specialist reports and an EMPr. The April 2023 letter also included a request for a time extension in respect of their application for EA to submit the required genetic EMPr and make minor amendments to the Final EIAr. In a letter signed on 23 May 2023, the DFFE informed the Karpowership legal team that their request for extra time to comply with the required application process had been refused. The legal team appealed this decision on the grounds that they had complied with legal timeframes and were now requesting a 60–day extension in order to undertake minor amendment to the EIA prior to resubmission. This appeal was upheld by Minister Creecy on 22 July 2023 and a period of sixty (60) days from the date of the decision letter was allowed. The Final EIAr was submitted on 19 September 2023 and is available on Triplo4's website along with the required generic EMPr.

3.2.6 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 IDZ in October 2013. The Saldanha Bay IDZ is the first Special Economic Zone (SEZ) to be located within a port and is the only sector specific SEZ in South Africa catering specifically to the oil and gas, maritime fabrication and repair industries and related support services (SLR 2019). The Saldanha Bay IDZ is managed by the Saldanha Bay IDZ Licensing Company (LiCo). The Saldanha Bay IDZ LiCo is the holder of an EA for the development of an oil and gas offshore service complex (EA was granted on 16 November 2015). More information on the on the Saldanha Bay IDZ can be found in previous versions of the State of Saldanha Bay and Langebaan Lagoon report (Clark et al. 2018).

At the time of the initial application for EA, it was not known which future operations and specific industries would be established within the Saldanha Bay IDZ. It was for this reason not possible to account for all possible activities in terms of the NEMA EIA Regulations that might be triggered by future developments or operations within the Saldanha Bay IDZ (SLR 2019). Recently, EA for the storage of dangerous goods/hazardous substances within the IDZ was granted on 2 August 2019. The appeal period was concluded on 26 August 2019.

The Saldanha Bay IDZ has the potential to impact on the marine environment in Saldanha Bay in numerous ways, including increased vessel traffic, which cumulatively contributes to underwater noise and invasive alien species transfer (via ballast water release); increased pollution of the Saldanha Bay through maintenance and repair activities, and storm water runoff. Although a detailed marine ecological specialist study was not conducted as part of the EIA process, mitigation measures for these direct and indirect marine ecological impacts were included in the Final Environmental Impact Report (SLR 2016). Potential impacts that may occur as a result of the construction and operation of marine infrastructure associated with the Offshore Service Complex (OSC) is to be investigated in a separate EIA process undertaken by the TNPA at a later stage.

3.2.7 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 2013) (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 é 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 Clark et al. (2014) for more information on this project).

Transnet recently increased the length of the manganese ore train from 312 to 375 carriages, thereby increasing the volume of manganese transported during individual trips from roughly 19.5 thousand tonnes to roughly 23.5 thousand tonnes. 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 to transport this product globally.

3.2.8 Development of liquid petroleum gas facilities in Saldanha Bay

LPG is a fuel mix of propane and butane which is in a gaseous form at ambient temperature but is liquefied under increased pressure or by a temperature decrease. 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 ecosystems in Saldanha Bay.

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 Department of Environmental Affairs & Development Planning (DEA&DP, refer to Clark et al. (2014) for more information). The Draft EMPr for the project required 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 (SBWQFT) monitoring program, and this is currently underway. The bulk earthworks and construction commenced in January 2014, and installation of the marine infrastructure commenced in September 2017 (Sunrise Energy (Pty) Ltd, Janet Barker, pers. comm. 2015).

Delays in this project have occurred due to unforeseen difficulties and legal issues with competitors Avedia Energy.

Avedia Energy developed a land based liquid petroleum gas storage facility on Portion 13 of Farm Yzervarkensrug No. 127 in Saldanha. The storage facility was designed to 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 Clark et al. (2014) for more information). Avedia Energy completed construction of their LPG storage facility in 2017 and upgraded the facilities to support an additional 6000 tonnes of LPG monthly in the second half of 2018.

3.2.9 Liquefied Natural Gas Import Facilities

The LNG Import Facilities aim to secure gas supplies to supplement land-based gas power plants, other industrial users and Floating Power Plants (FPPs) (Environmental Resources Management (ERM) 2015). 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 3.2.10) (Environmental Resources Management (ERM) 2015). ERM provided stakeholders with a Background Information Document in October 2015 of which excerpts and illustrations are provided in previous AEC reports (Environmental Resources Management (ERM) 2015). 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 land-based regasification technologies are currently considered for this project (refer to AEC 2017 and 2018 for more information on the infrastructure). A feasibility study for the Integrated Liquefied Natural Gas Importation and Gas-to-Power Project was completed in 2019 which demonstrated that there is a demand for natural gas for industrial processes as well as a likelihood of the development of new industries in Saldanha that would require natural gas (Delphos International 2019).

3.2.10 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 LNG power supply project to the Saldanha Steel Plant (Environmental Resources Management (ERM) 2016). LNG will be supplied by ship to the Port of Saldanha, where it will be re-gased 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 EA from the National Department of Environmental Affairs (DEA) under the NEMA through a S&EIA process on 24 February 2017.

It is anticipated that this project will connect to the Department of Energy's planned LNG import terminal in the Port of Saldanha (Section 3.2.9). Should this not occur, a separate EIA will be undertaken to permit the marine component of the import of LNG. Given the closure of the ArcelorMittal Steel Plant the marine component of the LNG import facility will likely require a separate EIA.

3.2.11 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, are in the process of constructing 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).

3.2.12 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 Elandsfontein 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 Elandsfontein Formation and represent preferred groundwater flow paths that feed into Langebaan Lagoon and Saldanha Bay, respectively (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 EA process for the proposed Elandsfontein Phosphate project. The EA was granted in February 2015 and a WUL 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 WUL (Furlong 2017). An environmental non-governmental organisation, the West Coast Environmental Protection Association (WCEPA), lodged an appeal with the Water Tribunal, which found in November 2017 that there was a "prima facie basis" to challenge the licence. In addition, the tribunal found that temporary permission granted by the Department of Water and Sanitation in December 2017 was "questionable". The temporary permission referred to by Kropz as having been granted by the responsible authority appears to be questionable as only a WUL or General Authorisation (GA) allows a person to use water according to the National Water Act (NWA). The hearing was set for September 2019 and there is still question around the validity of the WUL as well as direct opposition, by local activists, environmental lawyers and the community, to the sustainability of the water use in a water-poor area.

In December 2021, the Elandsfontein phosphate processing plant received its first input of ore aimed at initiating the processes required for the production of the first concentrate. Commissioning activities were expected to transition into full scale ramp-up of the mining and beneficiation plant before the end of 2022. Transnet provided Kropz Elandsfontein with a draft port access agreement to support the long-term export of the company's phosphate rock through the port of Saldanha. The first phosphate rock ore exports were expected to commence in the March quarter of 2022, however, export data for the 2021/22 fiscal year (ending in March 2022) did not report any Phosphate exports see Section 3.

Kropz Elandsfontein has adopted a precautionary approach and is carefully monitoring any potential impacts on Langebaan Lagoon in association with the SBWQFT. The State of the Bay monitoring activities undertaken by the SBWQFT have therefore 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 Chapter 5: Groundwater and Chapter 9: Benthic Macrofauna. Additionally, research into the impacts on groundwater are still underway by local hydrology experts, geohydrologists, the Council for Scientific and Industrial Research (CSIR), independent researchers and consultants.

3.2.13 Manganese storage expansion

The Port of Saldanha is under the authority of TPT. The terminals comprise the IOT and the MPT and are positioned on a constructed jetty of approximately 4 km long that separates Big and Small Bay. Their main purpose of the IOT is the handling, storage, and export of iron ore and several other heavy minerals, metals and commodities. A maximum of 90 000 tonnes of manganese is currently being stored in two sheds at the MPT, with current annual throughput at around 400 000 t/a. Due to the global increased demand of manganese in addition to the fact that the MPT is currently being underutilised, TPT decided to expand its operations and increase the storage of manganese in dedicated storage areas at the terminal to 450 000 tonnes. This will increase annual throughput to 8 million tonnes. This expansion is intended to supply in the global demand of manganese and in doing so provide major socio-economic benefits to the Western Cape and South Africa.

The proposed development triggered several listed activities under Listing Notice 2 in the EIA Regulations promulgated in terms of the National Environmental Management Act. The proposed activity therefore required a S&EIA and EA from the competent environmental authority. The scoping report was released for public review in December 2021 and the final Scoping report was accepted in March 2022. The EIA report was made available for public review in May 2022 and then final report submitted to DFFE in July 2022. The DFFE granted the EA to increase the manganese storage and handling capacity at the MPT on the 13th of October 2022. A total of 21 appeals were received by the DFFE in November 2022, to which the lead consultants (SRK Consulting) and the Acting Chief Director: Integrated Environmental Authorisations responded to in December 2022. Environmental Impact Management Services (Pty) Ltd were appointed as independent experts to provide the department with expert recommendations and a report on the appeals received. This report was completed in March 2023 and in the appeals decision letter (LSA 223883) dated 3 July 2023 Miniter Creecy published her decision to dismiss the appeals and uphold the approval of the EA granted on 13 October 2022.

3.2.14 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 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.

These three projects are described in more detail in Section 3.2 of the 2022 State of the Bay report. The potential impacts on the marine environment associated with the VRF and the Mossgas Jetty are also summarised in Section 3.2.13. The development of Berth 205 and the Mossgas Jetty will require extensive dredging operations to allow large oil and gas vessels access to new berthing infrastructure. The total dredge area during construction for the long-term development scenarios for the Mossgas Jetty and Berth 205 was estimated by TNPA at approximately 2.6 million m^3. This equates to the second largest dredge event in the history of Small Bay and is comparable to the dredging which commenced in 1996 for the construction of the MPT (Refer Section 3.4 for more information about dredging in Saldanha Bay).

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 IOT (Figure 3.13), although small volumes have also been exported from the MPT at times (Figure 3.14). 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 3.2.7). Iron ore exports increased steadily from 20.7 to 53.7 million tonnes between 2003/04 and 2012/13, after which the rate of increase slowed and values fluctuated around 55 million, peaking at 57.2 million tonnes in 2018/19. The drop to 53.2 million tonnes in 2020/21 was assumed to be the result of COVID-19 as export volumes increased again to 55.2 million tonnes in the 2021/22 fiscal year, however, overall iron exports in 2022/23 were also at 53.2 million tonnes (Figure 3.13, note that annual metal export is calculated based on the fiscal year, i.e., April – March).

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, with no iron export data available for the MPT in the last two rolling years (Figure 3.14). 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 South Africa 2017). Manganese exports from the Saldanha Port started in the 2013/14 fiscal year with a mass of 95 thousand tonnes (roughly 17.3% of the total MPT exports for that year), export masses increased substantially (by more than one third of the previous year) until 2017/18 after which they stabilised, averaging roughly 4.3 million tonnes, and peaking just below 4.7 million tonnes in the 2021/22 rolling year (Figure 3.14). In 2022/23, Manganese exports increased by 23%, reaching the highest ever total of 5.76 million tonnes.

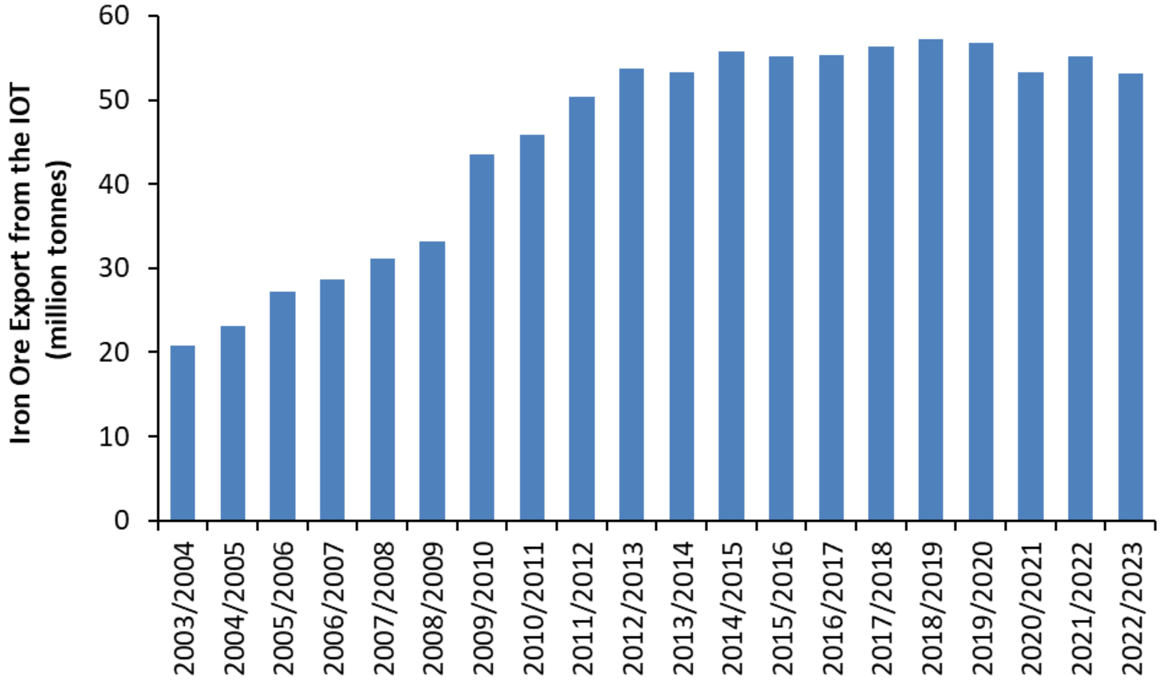


Figure 3.13. Annual exports of iron ore from the Iron Ore Terminal at the Port of Saldanha between April 2003 and March 2022 (Data provided by Transnet National Ports Authority 2023).

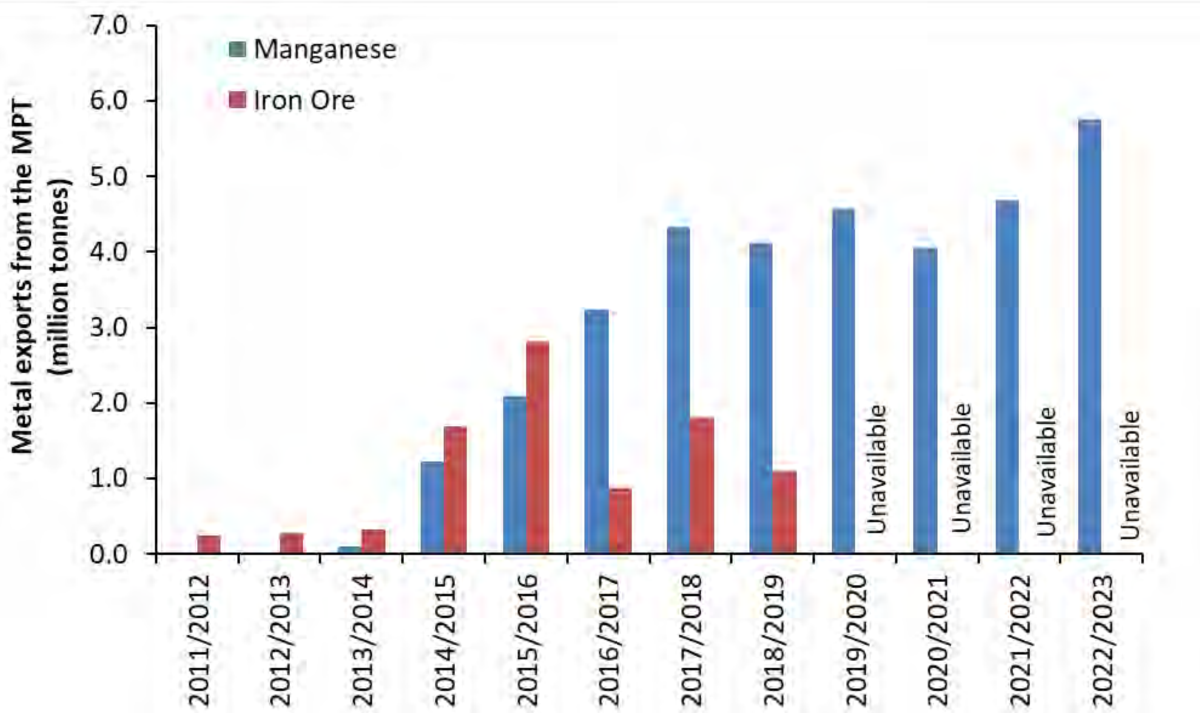


Figure 3.14. Annual exports (April 2011 – March 2023) of manganese and iron ore from the Multi-Purpose Terminal at the Port of Saldanha Bay (Data provided by Transnet National Ports Authority 2023).

Lead, copper and zinc metal exports from the MPT increased steadily from 2007/8, peaking in 2012/13 before stabilising at an average of roughly 138.1 million tonnes between 2013/14 and 2018/19. In the 2019/20 fiscal year the copper and lead exports appear similar to previous years, however, the mass of zinc exported increased dramatically to roughly 4.2 times that of previous years and has continued to increase (Figure 3.15). In 2020/2021, the mass of copper and lead exports dropped to approximately 80 and 57% of the previous year, respectively, while zinc exports increased to 127% of the previous year's export value. In 2021/22 export densities of all three metals increased. While in 2022/23 lead exports increased by 40% and zinc by a further 29%. In contrast, copper exports dropped by 16% in the latest fiscal year. The increase in zinc exports is due to the fact that Vedanta Resources Limited, a natural resources company, opened a new Gamsberg opencast zinc mine in conjunction with the old underground mine. As a result, the volume of zinc export is expected to increase further until 2023, once phase two of the project is complete, pushing the zinc export volumes, from this site alone, to roughly 1 million tonnes per annum (pers. comm. Pieter Venter, September 2021).

Initially only lead, copper and zinc were exported from the MPT, with lead and zinc exported in similar quantities, and copper the smallest proportion of the exported material until in 2019/20 when the zinc export proportion increased dramatically (Figure 3.15). The export of combined lead, copper and zinc increased from 74 thousand tonnes in 2007/8 to 183 thousand tonnes in March 2013, after which it fluctuated around 141 thousand tonnes until the inclusion of the opencast zinc concentrated in 2019/2020 (Figure 3.15). Individual annual export volumes for lead, copper and zinc are only available since 2010/11 (Figure 3.15). Lead exports remained stable around 80 thousand tonnes between 2010 and 2013 before dropping by nearly half between 2014–2016. Lead exports then recovered to approximately 60 thousand tonnes per annum by March 2020, however, dropped significantly in the 2020/21 fiscal year to only 36 thousand tonnes but have increased to 74 thousand tonnes in 2022/23. Copper is exported in small quantities compared to other metal ores with exports averaging 23.2 thousand tonnes in the last 5 years.

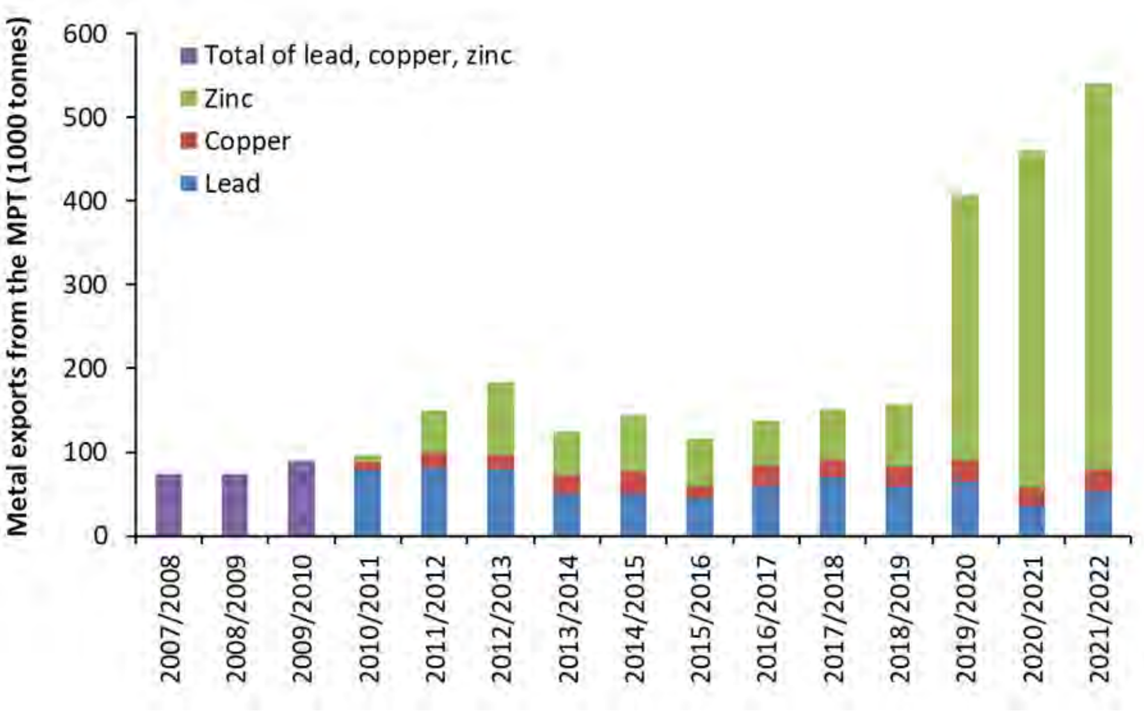


Figure 3.15. Annual exports (April 2007 – March 2023) of lead, copper, and zinc from the Multi-Purpose Terminal at the Port of Saldanha Bay. Note that separate data for these commodities was only available for April 2010 – March 2021 (Data provided by Transnet National Ports Authority 2023).

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 WCDM 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 WCDM. Since the promulgation of NEM: AQA on 01 April 2010 the majority of atmospheric emission licences were issued within the SBM.

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 IOT and the TPT currently holds a license for the storage and handling of 60 million tonnes of iron ore per annum which was issued on 5 February 2016. 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 tonnes 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 for a number of 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^2 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.

A PAEL for the storage and handling of ore and coal, specifically manganese (Mn), at the MPT was issued by the air quality officer of the Department of Environmental Affairs on 26 September 2018 (Reference: AEL/WCP/TPT/26/06/2018-2387). The air quality impact assessment for the MPT conducted by WSP in December 2017 indicated that the annual average and 99th percentile of PM10 (coarse particles smaller than 10 micrometres in diameter) and PM25 concentrations associated with the storage of manganese were 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 PAEL was appealed in November 2018 by 15 appellants, the main concern being the "Harmful and health effects of manganese to people, water, aqua farms, tourism and businesses including the efforts to develop Saldanha Bay as a Green City and that an EIA should have been conducted". In her appeal decision, dated January 2020 (Reference LSA 177442), the Minister of Environment, Forestry and Fisheries (Ms BD Creecy) decided that the appeal should be upheld and therefore the PAEL for the storage of manganese ore should be set aside. Ms Creecy indicated that the activities required for the storage of manganese in the port, specifically the need for the expansion of current storage facilities, should have triggered an EIA prior to the issuing of the PAEL. Given this, the quantity of manganese being stored at the MPT has been significantly reduced.

The establishment of several small operations not requiring an Atmospheric Emissions License in the SBM 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 consumers 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) 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 to avoid the spread of particulate matter:

- **Transportation**: Material transported by rail or road must be suitably covered to prevent the spread of windblown dust. The use of alternative methods to effectively contain material whilst in transit may be considered, on condition that the transporter provides documentation confirming that the alternative method ensures reliable and equivalent containment of the material to prevent windblown dust. In many instances existing transport corridors i.e., railway lines run through residential developments with the effect that the environment and human health and wellbeing are impacted on. The transportation of material through these corridors must be discouraged and if unavoidable, more stringent conditions such as containerisation should be considered. A suitably designed road vehicle washing facility to effectively remove particulate matter from wheels, wheel arches, mud flaps and undercarriages must be provided on the storage and handling site. Effluent from washing facility must be drained to a sump for re-use or safe disposal;

- **Storage**: Manganese and other potentially hazardous ores, and concentrates must be stored within an enclosed building on a hard, impervious surface graded and drained to a sump from where the effluent will be re-used or safely disposed of;

- **Handling**: Loading and offloading of materials can also be a significant source of dust emissions. Materials can be reclaimed by underfeed conveyor, grab crane or front-end loader with totally enclosed conveyors used to transport dust-forming material. Transfer by pneumatic, dense phase systems may also be used. The loading and offloading of material must as far as practically possible be done inside the enclosed storage facility. In instances where this is not practically possible, material must be offloaded into containers or onto trucks for direct transportation into the enclosed storage facility. The double handling of material must be avoided. The storage of potentially hazardous material (concentrates e.g., manganese and zinc) in open air stockpiles is not allowed. Approved dust suppression methods that result in zero visible emissions must be applied and the area used for this purpose must be provided with a suitably drained, hard and impervious surface such as concrete. Material spillages must be removed immediately and contained for re-use or safe disposal. Emergency spillage incidents must be reported to the relevant authorities in terms of section 30 of the National Environmental Management Act, 1998 (Act 107 of 1998). Excess contaminated water used for dust suppression must be drained to a sump from where it is collected for re-use or safe disposal.

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

The draft guideline was presented on 5 April 2017 and stakeholders were given until the 18th April 2017 to provide written comment. The WCDM intends to 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. The 2nd generation WCDM air quality management plan was published in June 2019 and is available on their website.

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 and Robin Lewis 2006) and has therefore 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;

- o Transport of fine sediments to adjacent areas, and hence transport of pollutants; and
- o 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 & Robin Lewis, 2006).

Saldanha Bay is South Africa's largest and deepest natural port and as a result has undergone extensive harbour development and has been subjected to several bouts of dredging and marine blasting as listed below (refer to AEC 2014 for more detailed information on the dredging events):

- 1974–1976: 25 million m^3 of sediment was dredged during the establishment of the ore terminal.
- 1996–1997: 2 million m^3 of sediment removed for the expansion of the MPT.
- 2005–2007: 380 000 m^3 sediment removed from Big Bay for the nourishment of Langebaan Beach.
- 2007–2008: 50 000 m^3 of sediment removed for maintenance of the Mossgas quay and MPT.
- 2009–2010: 7300 m^3 of sediment removed to allow for the establishment of a new ore-loading berth.
- 2009–2010: Maintenance dredging (unknown quantity) conducted by the South African National Defence Force (SANDF) at the Salamander Bay boatyard.
- 2015–2016: 25 000 m^3 Expansion of the General Maintenance Quay.
- 2019: 14 265 m^3 of sediment removed for maintenance of the OSSB quay.
- 2019–2020: 6 403 m^3 of sediment removed for maintenance of the Mossgas channel; and
- 2020: 13 433 m^3 of sediment removed for maintenance of the OSSB channel.
- June to September 2022 — 3 228 m^3 removed for maintenance of the OSSB Berth and 15 170.67 m^3 for maintanence of the Mossgas Berth.
- November 2022 to March 2023 — 6491.09 m^3 sediment removed for maintenance of the OSSB Berth.

The most recent dredging, undertaken between November 2022 and March 2023, removed 6491.09 m^3 of sediment and was for the upkeep and maintenance of the OSSB Berth.

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 more than 500 ships per annum. The Port is comprised of an IOT for export of iron ore, an oil terminal for import of crude oil, a MPT dedicated mostly for export of lead, copper, zinc and manganese concentrates, and the Sea Harvest/Cold Store terminal that is dedicated to frozen fish products (Figure 3.5). There are also facilities for small vessels within the Port of Saldanha including the Government jetty used mostly by fishing vessels, the TNPA small boat harbour used mainly for the berthing and maintenance of TNPA workboats and tugs, and the Mossgas quay. Discharge of ballast by vessels visiting the IOT 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 caused a new wave of marine invasions, as species with a larval or planktonic phase in their life cycle were now able to be transported long distances between ports on board ships. Furthermore, because ballast water is usually loaded in shallow and often turbid port areas, sediment is also loaded along with the water and this can support a host of infaunal species (Hewitt et al. 2009). The global nature of the shipping industry makes it inevitable that many ships must load ballast water in one area and discharge it in another, which has an increasing potential to transport non-indigenous species to new areas. It has been estimated that major cargo vessels annually transport nearly 10 billion tonnes of ballast water worldwide, indicating the global dimension of the problem (Gollasch et al. 2002). It is estimated that on average, 3 000–4 000 species are transported between continents by ships each day (Carlton and Geller 1993). Once released into ports, these non-indigenous species have the potential to establish in a new environment which is potentially free of predators, parasites and diseases, and thereby 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 Oligochaeta and Polychaeta, Crustacea, Brachyura and molluscan bivalves, and fish (Carlton and 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. 2004). In addition, it has been emphasised that the link between marine alien species and harbours (just over half of the alien species in South African marine waters are located in harbours) highlights the role of shipping as a method by which these alien species are introduced (Robinson et al. 2020).

The latest review of marine alien species in South Africa identified a total of 95 such species, with 56 considered invasive, i.e., population are expanding and are consequently displacing indigenous species (Robinson et al. 2020). The West Coast of South Africa is the most invaded region, hosting 67 recorded alien species. Recent surveys, including the State of the Bay reports and other research over the past 12 months, revealed a total of 37 alien and invasive species in Saldanha Bay and Langebaan Lagoon. Notably, nine new alien species have been added to the State of the Bay list since the 2022 report. These include the tuberculate pear crab *Pyromaia tuberculata,* skeleton shrimp *Caprella mutica*, pitted barnacle *Balanus trigonus*, fat-feeler amphipod *Monocorophium acherusicum*, pink-mouthed hydroid *Ectopleura crocea,* thin-walled obelia *Obelia dichotoma,* amphipod *Ericthonius brasiliensis,* blue mussel *Mytilus edulis* and the bay mussel *M. trossulus.* With the inclusion of the two newly identified mussel species and the recently reported pear crab, the total number of known alien species in South Africa is now believed to be 98.

In addition, it has been 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. 2004). More detail on alien invasive species in Saldanha Bay is provided in Chapter 13: Aliens and Invasives.

Other potential 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. All parameters measured in 1996 exceeded the current South African Water Quality Guidelines (WQG) for the Marine Environment (DEA 2018) (Table 3.1). 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: Water Quality).

Table 3.1. Mean trace metal concentrations in ballast water (µg/L) and ballast tank sediments from ships deballasting in Saldanha Bay (Source: Carter, 1996) and SA Water Quality Guideline limits (DEA 2018). Those measurements in red denote exceedance of these guidelines.

	Water (µg/L)	SA WQ Guideline limit (µg/L)	Sediment	ERL Guideline (mg/kg)
Cadmium	5	0.12	0.040	1.2
Copper	5	3	0.057	34
Zinc	130	20	0.800	150
Lead	15	2	0.003	46.7
Chromium	25	2	0.056	-
Nickel	10	5	0.160	20.9

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 public comments period for the bill was extended in February 2017 (Notice 111 of 2017), however, the Draft Bill has as of October 2023 still not yet been promulgated. The Department of Transport is the authority responsible for administration of this Act. The Draft Bill can be found on the South African government website (www.gov.za). A study examining the status of ballast water management in South African ports discovered that there was a lack of publicly accessible documentation which detailed the requirements for ballast water management in numerous South African ports with the exception of Saldanha Bay (Calitz 2012). This documentation was prepared for the Port of Saldanha during a 2002 pilot study called GloBallast (Global Ballast Water Management Programme, Calitz, 2012).

In the absence of domestic legislation regulating ballast water discharge, the TNPA in Saldanha Bay implemented certain measures to control the release of alien species into the harbour. For example, the following procedures need to be followed 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. 2004). 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 nearly doubled between 1994 and 2011 from 261 to 487 vessels, after which ship numbers remained fairly constant until 2017/18 when numbers increased by 25% from 474 to 591 vessels per annum (Figure 3.16). Vessel numbers peaked in 2018/19 at 616. The total number of ships dropped slightly to ~570 vessels in 2019/20 and 2020/21, respectively, dropping further to 531 vessels in 2021/22. Only 10–month of data were available for the 2022/23 rolling year, with data from May and June 2023 unavailable at the time of printing this report. This must be considered when interpreting the 2022/23 data. Therefore, to better understand how vessel traffic entering the port in 2022/23 compared to previous years we look at the average number of vessels entering the port monthly (Figure 3.17). Based on this we can actually see that vessel traffic has increased relative to preceding years and has nearly reached the peak observed in 2018/19 (Figure 3.17).

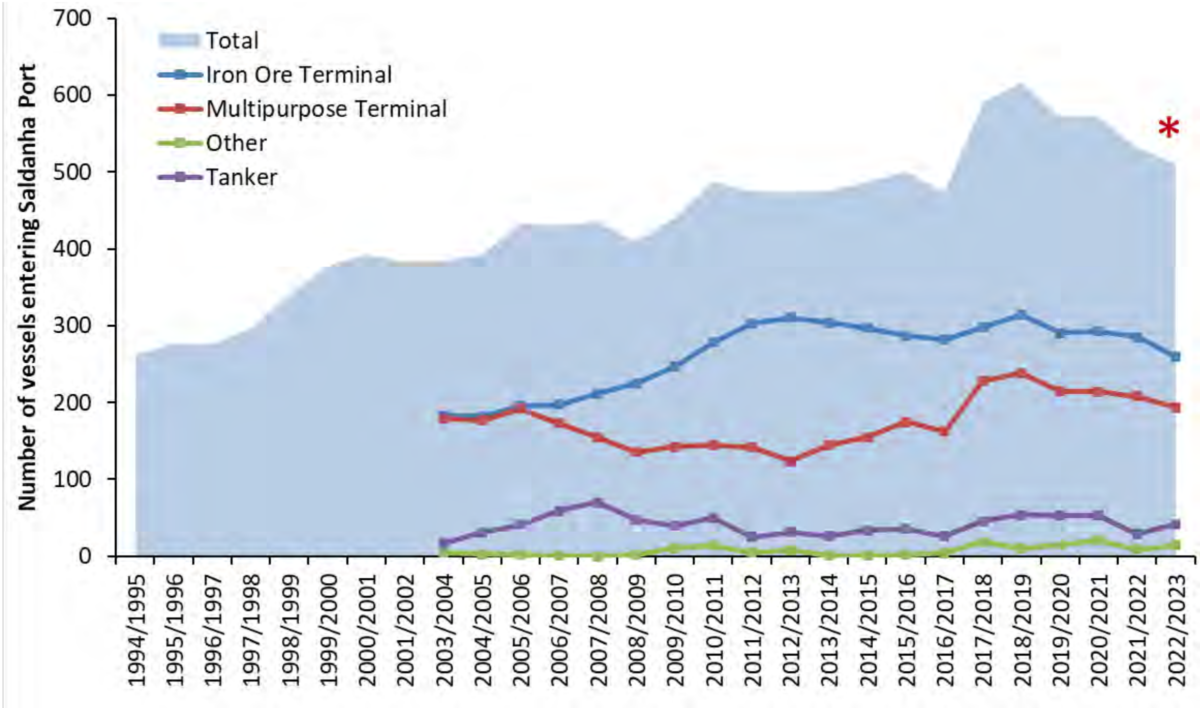


Figure 3.16. The numbers and types of vessels entering Saldanha Port per year. The total number of vessels entering Saldanha Port between July 1994 and April 2023 is shown as the blue area (*only 10 months of data available for 22/23 rolling year). The numbers of vessels docking at the Iron Ore Terminal, 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.*, 2004), TNPA unpublished data 2003–2023).

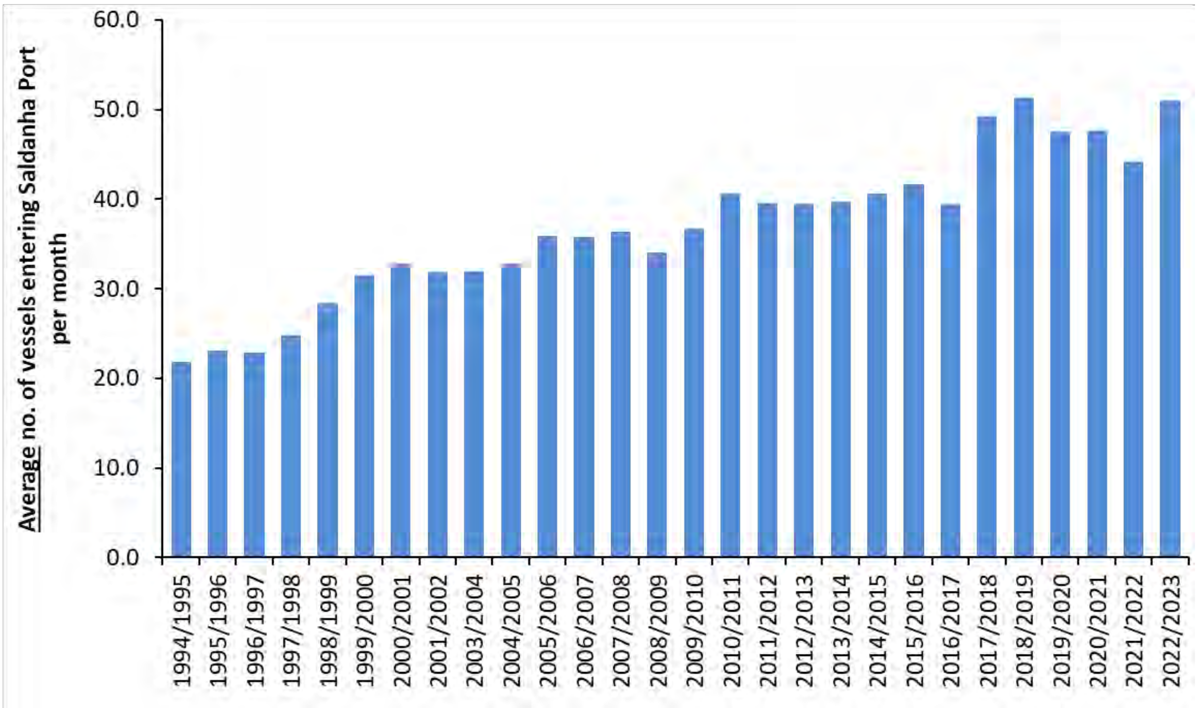


Figure 3.17. The average number of vessels entering Saldanha Port every month. TNPA unpublished data 2003–2023).

Generally, iron ore tankers contributed a little over 50% to the observed vessel traffic and 91% to the total water discharged between July 2018 and June 2019 (specific vessel discharge volumes are not available for 2019/20 and beyond, see Figure 3.16 and Figure 3.18). This is to be expected given that iron ore tankers are large vessels and hold the highest quantities of ballast water.

Average vessel size increased over the years and as a result, the volume of ballast water discharged annually almost tripled between 1994/5 and 2010/11 from 8.2 to 21.1 million m³ (Figure 3.18). Since 2011, ballast water discharge has remained fairly stable averaging around 23 million tonnes per annum, peaking in 2017/18 (25.1 million m³) and then declining in the two subsequent years to 24.2 million m³ in 2019/20 (Figure 3.18). The 2021/22 rolling year saw the highest ever recorded ballast water discharge at 25.9 million m³. While this appears to drop in 2022/23 this is likely the result of the data not including a full years' worth of discharge volumes.

Data provided by Transnet indicate that the total volume of Ballast water in the 2020/21 rolling year dropped to 9.8 million m³, or to 40% of the previous year's total volume of Ballast discharged. This value was queried, given that the number of vessels did not change significantly between the two years (Figure 3.16). However, it is reported that there has been no change in the 2020/21 discharge process (pers. comm. Deidre Isaacs, Marine Safety Specialist, TNPA), leading us to believe that this value is erroneous.

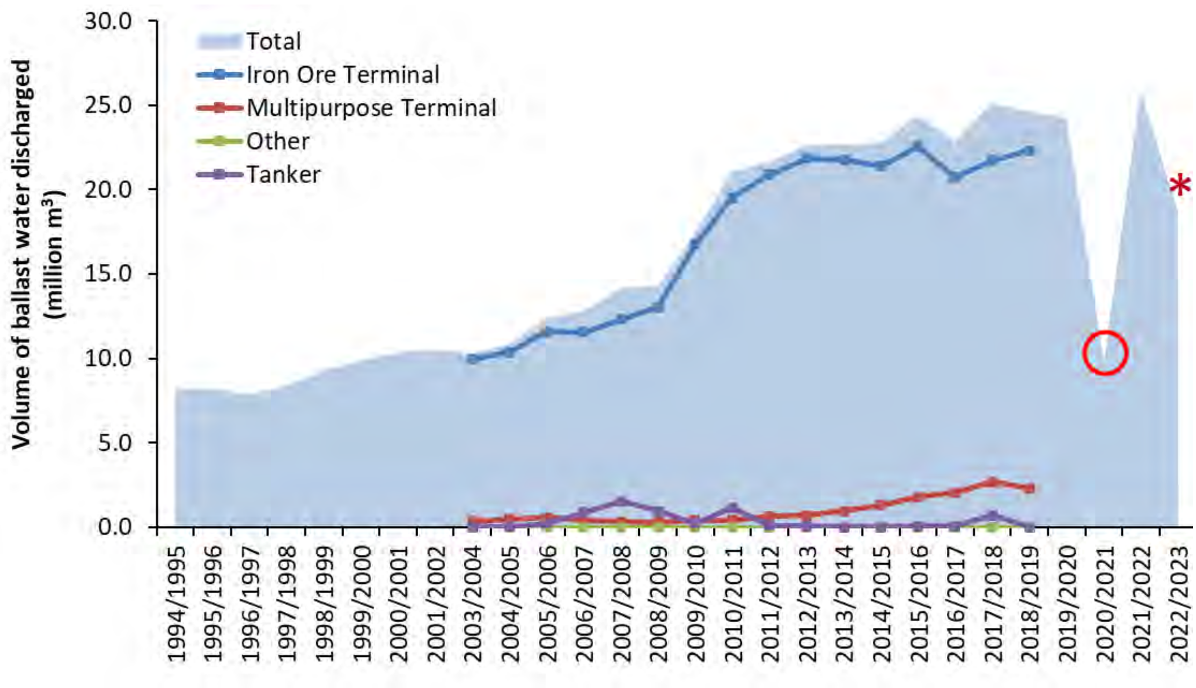


Figure 3.18. Volumes of ballast water discharged into Saldanha Port per rolling year. The total amount of ballast water discharged in Saldanha Port between the years 1994 and April 2023 is shown as the blue area (*only 10 months of data available for 22/23 rolling year). Ballast water discharged by vessels 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 to June 2019 (Sources: Marangoni, 1998; Awad *et al.*, 2004), TNPA unpublished data 2003–2023).

Vessels docking at the IOT have a higher average volume of ballast water discharge than other vessel types, with volumes increasing from 54.4 thousand m^3 per vessel in 2003/4, peaking at 78.6 thousand m^3 in 2015/16 and dropped to 71.2 thousand m^3 in 2018/19 (Figure 3.19). While discharge volumes for Tankers fluctuates irregularly ranging between zero and 21.8 thousand m^3, vessels docking at the MPT showed low average ballast discharge volumes between 2003/4 and 2010/11 (less than three thousand tonnes) before increasing in size until 2016/2017 (12.6 thousand m^3) and dropped in the two subsequent years to 9.6 thousand m^3 in 2018/19 (Figure 3.19). Only total ballast water volumes for the entire port were available from 2019/20 onwards. When comparing the average discharge for all vessels combined in 2019/20 and 2021/22 to similar data for the period 1994/5 to 2001/2, we see that volumes have increased by more than one third of historic volumes. Values in 2020/21 are questionable due to the possibly erroneously low overall ballast water volume for this period (Figure 3.19). In addition, it is interesting to note that the average ballast water volumes per vessel have decreased in 2022/2023 by 24% relative to 2021/22, despite the fact that the average number of vessels per month has increased from 44 in 2021/22 to 51 vessels per month in 2022/23. Additionally, the overall cumulative weight of all minerals exported from the port has only dropped by 2% in 2022/2023 relative to 2021/22. The volume of ballast water discharged should change proportionally to the weight of minerals exported again suggesting a possible error in ballast water data.

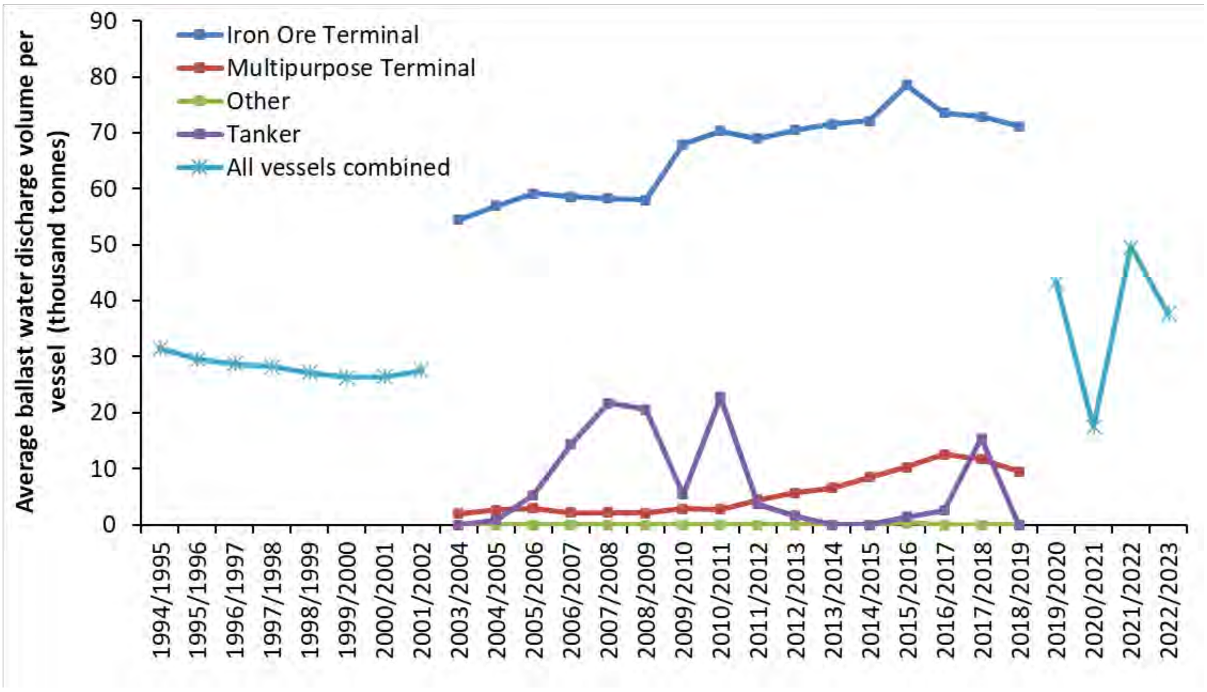


Figure 3.19. Average ballast water volumes discharged per vessel into Saldanha Port per year. The average total volume of ballast water discharged in Saldanha Port between the years 1994 and June 2002, and for 2019–2023 is shown as the blue line. Average Ballast water discharged by vessels docking at 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 to 2019, (Sources: Marangoni, 1998; Awad *et al.*, 2004, TNPA unpublished data 2003–2023).

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 TNPA 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 (TNPA) 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 FPPs (Section 3.2.10) will increase the risk of oil spills (frequency and magnitude) unless the Environmental Management Programme contains effective mitigation measures and implementation is ensured.

POLLUTION INCIDENT AT GOVERNMENT JETTY SLIPWAY REPORTED BY SEA HARVEST

In early July of 2020 it was reported that a pollution incident had occurred on the Government jetty slipway. According to reports, high tidal intrusion caused an over-full bin (located adjacent to the ship repair facility) to be knocked over. As a result, the contents of the bin which included pieces of sponge and domestic waste were observed floating in the adjacent water. In addition, an oily-fatty solution coated the slipway, and was seen running down into the water of the Bay and forming an oily slick on the water surface towards the quay side of the Sea Harvest Operations plant. Although the harbour master sent out a small boat to retrieve the sponges and domestic waste, the presence of the oily slick on the water surface reduces water quality and can prevent the abstraction of water from the Bay for use in the Sea Harvest Desalination plant.

Incidents such as this are not uncommon and poor operational management practices at the ship repair facility (based on the slipway next to Sea Harvest) have previously been reported. The facility appears to lack appropriate structures or procedures to contain waste and other materials (fouling material, paint, oil etc.) generated during ship maintenance operations. This is of great concern as continuous or repetitive pollution input at the slipway could threaten the quality of the oysters and mussels in adjacent aquaculture farms as well as having negative impacts for the Sea Harvest desalination plant. Therefore, it is strongly suggested that this matter be investigated, and that the facility is better managed in future. Potential mitigation measures include: 1) the retention and storage of oily/contaminated runoff from the vessels on the slipway in steel drums in an appropriate storage facility with retaining bund walls and 2) the installation of separate bins for domestic waste located at a suitable distance from the water to prevent tidal disruption and with lids to prevent the distribution of waste via wind.

POLLUTION INCIDENT AT STRATEGIC FUEL FUND (SFF) OIL TERMINAL

On Tuesday, 1 February 2022, the occurrence of an oil leak from the crude oil pipeline under maintenance at the Strategic Fuel Fund (SFF) Oil Terminal was reported to the TNPA. The leak resulted in a minor Pill into the bay estimated at 400 L. Clean up operations were quickly undertaken and TNPA confirmed that all oil had be recovered from the water by within 24 hrs of the original spill event. All recovery operations were complete by close of business on 2 February 2022.

POLLUTION INCIDENT AT SMALL BAY HARBOUR

On the 17 October 2023, the Harbour Master for Small Bay Harbour was informed that the Paraclete vessel had partially sunken (still buoyant) (Incident Report Sep 23-01). The vessel had broken loose from its moorings and the stern drifted away from the Government Jetty, Saldanha Bay fishing harbour. The vessel was carrying ±300 L of hydraulic oil and an unknown amount of engine oil. This triggered an Emergency Response Plan (ERP) and relevant affected persons and stakeholders were informed including SAMSA, TNPA, Chief Compliance Inspector, Sea Harvest and the ADZ ECO. On the same day, the ADZ Environmental Control Officer (ECO) informed the farm operators of this incident. Ocean and Coast pollution unit was contacted with no success. DFFE harbour personnel launched a dinghy loaded with peat absorbent and sausage booms. Unfortunately, sausage booms were not enough to cover the entire vessel, the staff ended up applying peat absorbent. Later, Spill Tech inflated booms were deployed around the partially sunken vessel to prevent the oil spill from remobilising and impacting other parts of the Bay. Guerrini Marine Construction (GMC) has submitted a methodology to re-float the vessel not later than the 20 October 2023.

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 and Hastings 2009) as well as noise produced by shipping vessels which is characterised in wide spread and prolonged low frequency noise (Slabbekoorn et al. 2010).

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 (1994) described the 'auditory scene' of fishes which provides information from great distances or information at night for navigation, predator avoidance and prey detection. Consequences of a disturbance in the 'auditory scene' of fishes have been shown in captive three-spined sticklebacks (*Gasterosteus aculeatusl*) (Purser and 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 and 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 (Abbott 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 and Bing-Sawyer 2002, Bellmann and 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 include 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 (Anchor Environmental Consultants 2015) and it appears that most countries have adopted this framework and have developed WQG 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 WQG 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 WQG 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 WQG/standards is to determine site-specific effluent limits which are calculated based on the WQG/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 (Anchor Environmental Consultants 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 (Anchor Environmental Consultants 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 WQG 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). Revised WQG for the Natural Environment and Mariculture Use were recently published by the former Department of Environmental Affairs: Oceans and Coasts (DEA:O&C, now the DFFE:O&C)(DEA 2018), replacing Volumes 1 (Natural Environment) and 4 (Mariculture) of the 1995 Guidelines.

The 2018 WQG 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 seawater properties (temperature, salinity, dissolved oxygen etc.) and constituents (nutrients, toxic substances, pathogens). 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 WQG should be applicable (refer to Chapter 6 for more details on this).

Effluent discharges into the coastal waters were previously regulated in terms of the NWA (Act No 36 of 1998). 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[3]), responsibility for regulating land-derived effluent discharges into coastal waters was transferred to the Department of Environmental Affairs (DEA). In terms of Section 69 of ICMA, no person is permitted to discharge effluent originating from a source on land into coastal waters except in terms of a General Discharge Authorisation (GDA) or a Coastal Waters Discharge Permit (CWDP) (note that regulations pertaining to the GDA were promulgated in 2022 in the Government Gazette No. 47019, 15 July 2022). Exemptions were issued to proponents who, at the time of promulgation, were discharging effluent into coastal waters in terms of permits issued under the NWA, provided that the effluent was treated to meet the General and Special Standard (Government Gazette No. 20526, 8 October 1999[4]), and required that they applied for a CWDP within three years of promulgation of the ICMA. In practice though, not all operations that discharge wastewater into the Bay have applied for a CWDPs even though many years have 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 WQG 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 (Anchor Environmental Consultants 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 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 an 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 2019 the DEA:O&C published the Coastal Waters Discharge Permit Regulations (Government Notice Regulation (GNR). 382, Government Gazette 42304). The new regulations seek to provide an administrative framework to implement Section 69 of the ICMA and stipulate timeframes, renewal application processes, applicable fees and information to be

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

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

submitted as part of an application for a CWDP. The DEA:O&C are still in the process of finalising regulations for General Discharge Authorisations discussed above.

To date, six CWDPs have been issued to companies discharging effluent into Saldanha Bay and two applications are currently pending. A list of these and other relevant information has been included in Table 3.2.

The regulations pertaining to the GDA for coastal discharges were promulgated in 2022 in the Government Gazette No. 47019 15 July 2022. As per Condition 3, a GDA is applicable to a neutrally or positively buoyant effluent that meets the end of pipe General or Special Limits stipulated for either coastal or offshore[5] discharge, and dependent on the discharge volumes (Table 3.3 and Table 3.4).

Table 3.2. Pending applications for Coastal Waters Discharge Permit and issued permits for effluent discharges into Saldanha Bay (Source: Rueben Molale, DFFE 2023).

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	Quarterly monitoring
Sea Harvest Corporation (Pty) Ltd	Permit granted	Fish processing effluent and brine	Medium	Quarterly monitoring
Transnet State Owned Company (SOC) Ltd	Permit granted	Desalination (brine)	Medium	Quarterly monitoring
Transnet Port Terminals	Permit granted	Industrial Storm Water	Medium	Quarterly monitoring
Sunrise Energy (Pty) Ltd	Permit lapsed	Once off discharge	Low	Monitoring occurred after discharge
Facilities operating under the General Discharge Authorisations (GDAs - Gazette No. 47019, July 2022)				
Saldanha Lobster	GDA	Unknown (processing/holding facility?)	Unknown	Discharge < 2000 m^3 per day
Saldanha Oyster	GDA	Holding facility	Low	Discharge < 2000 m^3 per day

5 As per Government Gazette No. 47019 15 July 2022, "offshore" means the area in coastal waters (a) starting from the 10 m isobath; or (b) starting at 500 m in distance from the low-water mark, whichever is further in distance from the low-water mark.

Table 3.3. General and Special effluent limits for organic and inorganic constituents in effluent. Note that the value 0 means that the consistent in question is not present in the effluent at all.

Parameter	Unit	General Limit (Offshore discharges; volume of discharge < 10 000 m³ per day)	Special Limit (Coastal discharges; volume of discharge < 2 000 m³ per day)
Ammonia (ionised and un-ionised) as N	mg/l	10	2
Arsenic	mg/l	0.8	0.04
Cadmium	mg/l	0.02	0.001
Total Chlorine Residual	mg/l	0.2	0.01
Chromium (VI)	mg/l	0.2	0.01
Copper	mg/l	0.3	0.015
Cyanide	mg/l	0.1	0.005
Fluoride	mg/l	150	7.5
Lead	mg/l	0.2	0.01
Mercury	µg/L	1.6	0.08
Nickel	mg/l	0.5	0.025
Nitrate as Nitrogen	mg/l	20	3.5
Nitrogen (Total Kjeldahl Nitrogen)	mg/l	100	10
Polychlorenated Biphenyls (PCBs)	µg/L	0	0
Chlorophenols	µg/L	0	0
Ortho-Phosphate as Phosphorus	mg/l	20	1
Radioactivity	µC/mL	0	0
Pesticides (Dieldrin, Endrin, DDT)	µg/L	0	0
Soap, oil or grease	mg/l	20	10
Hydrogen sulphide	mg/l	0.2	0.01
Total Suspended Solids (TSS)	mg/l	50	10
Tributyltin	µg/L	0	0
Zinc	mg/l	2	0.1

Table 3.4. General and Special effluent limits for physico-chemical properties of the effluent.

Parameter	Unit	General Limit (Offshore discharges; volume of discharge > 10 000 m³ per day)	Special Limit (Coastal discharges; volume of discharge > 2 000 m³ per day)
Biological Oxygen Demand (BOD)	mg/l	50	10
Chemical Oxygen Demand (COD)	mg/l	250	75
Dissolved oxygen	mg/l	50% saturation	75% saturation
pH	pH	7.1–8.3	7.3–8.2
Temperature	°C	±3 of ambient	±2 of ambient
Salinity	PSU	37	36

3.6.2 Reverse osmosis plants

RO 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. RO involves forcing water through a semi-permeable membrane under high pressure, leaving the dissolved salts and other solutes behind on the surface of the membrane. Water is relatively scarce in the WCDM and the rapidly developing industry in Saldanha Bay requires vast quantities of potable water for their operations. Construction of RO 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 dibromonitrilopropionamide in the effluent;
- The effects of co-discharged wastewater constituents, including possible tainting effects affecting both mariculture activities and fish factory processing in the Bay;
- The effect of the discharged effluent having a higher temperature than the receiving environment;
- Direct changes in dissolved oxygen content due to the difference between the ambient dissolved oxygen concentrations and those in the discharged effluent; and
- Indirect changes in dissolved oxygen content of the water column and sediments due to changes in phytoplankton production as a result of altered nutrient dynamics (both in terms of changes in nutrient inflows and vertical mixing of nutrients) and altered remineralisation rates (with related changes in nutrient concentrations in near bottom waters) associated with near bottom changes in seawater temperature due to the brine discharge plume.

TRANSNET NPA DESALINATION PLANT

TNPA 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 WUL from the Department of Water Affairs (DWA) and subsequent performance tests in 2012 (Membrane Technology 2013) (refer to Clark et al. (2014) for more details on the project design and EIA). The RO plant was granted a CWDP in terms of ICMA in 2017 (DEA: O&C, pers. comm., 2017).

A marine baseline monitoring study was conducted by Environmental Consultants (Anchor) 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 WUL 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 was being conducted by the 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) Cellozyme Environmental were appointed to undertake the monitoring in 2018 but all monitoring ceased shortly after this.

WEST COAST DISTRICT MUNICIPALITY DESALINATION PLANT

The WCDM has proposed the construction of an additional RO plant in the Saldanha Bay area, intended as a long-term sustainable alternative water source. The WCDM has limited water resources (semi-arid climate) and yet is required to supply 22 towns and 876 farms across the region with potable water. Currently water is supplied by the Voëlvlei and Misverstand dams on the Berg River, and the Langebaan Road aquifer, however, the volume allocated from these sources for this is close to the maximum possible. In the financial year 2012/2013, abstractions for the WCDM exceeded allocation by 3.6 million m^3 (DWA 2013). A feasibility study conducted in 2007 to assess the most viable solution to the water scarcity issue in the WCDM identified the following potential additional water resources:

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

The most cost-effective solution was identified as a 25 500 m^3/day sea water desalination plant. EA was granted on 13 August 2013 for the preferred location for the RO plant, which will be situated on the farm Klipdrift at Danger Bay on a portion of municipal owned land (Please refer to the 2013/2014 State of Saldanha Bay and Langebaan Lagoon Report for 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 as they did not receive Grant funding for the construction of the desalination plant and therefore the project has been put on hold (SBM, David Wright, pers. comm. 2020). 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, an application for additional allocation of water sourced from the Berg River was submitted by the WCDM. In October 2017, SBM received an increased allocation of 20 427 000 m^3 per annum from the WCWSS which equates to 56 ML/day and in higher than the current water demand. This in conjunction with the Langebaan Road Well field and Hopefield Well field development has reduced the need for the Desalination plant at this stage, however, SMB with retain the project in their future augmentation projects planning (SBM, David Wright, pers. comm. 2020).

ARCELORMITTAL RO PLANT

ArcelorMittal was 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. It was announced in November 2019 that due to financial losses the plant would be closed, with the immediate winding down of operations and ultimate closure of the plant in the first quarter of 2020. Prior to this, ArcelorMittal Saldanha operations required approximately 6 500 m^3/day of freshwater to operate, which represented approximately 25% of SBMs potable water total usage. ArcelorMittal Saldanha modified its water treatment infrastructure to partially replace its fresh water supply with treated municipal sewage wastewater (from the Saldanha WWTW). Please refer to AEC 2019 for details on the initiation of the RO plant). Since the closure of the ArcelorMittal Saldanha Works in 2020, all operations have stopped which include the operations of the RO plant and therefore no industrial effluent is sent to the Saldanha WWTW and no treated effluent is being pumped from Saldanha WWTW to ArcelorMittal for use in the RO Plant.

3.6.3 SEWAGE AND ASSOCIATED WASTEWATERS

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 slaughterhouses);
- Brewing and distillery wastes;
- Paper pulp mill wastes;
- Chemical industry wastes; and
- 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 and Duarte 2008, Howarth et al. 2011). Vaquer-Sunyer & Duarte (2008) propose a precautionary limit for oxygen concentrations at 4.6 mg O2/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 and Moore 1983). Furthermore, there are several studies documenting the effects that shifts in natural marine concentrations and ratios of nitrates, phosphates and elements such ammonia and silica, have on marine organisms (Herman et al. 1996, Hodgkiss and Ho 1997, Van Katwijk et al. 1997, Howarth et al. 2011). For instance, the depletion of dissolved Silica in coastal systems, as a result of nutrient enrichment, water management and the building of dams, is believed to be linked to worldwide increases in flagellate/ dinoflagellate species which are associated with harmful algal blooms, and are toxic to other biota (Hodgkiss and Ho 1997, Howarth et al. 2011). The toxic effect that elevated concentrations of ammonia have on plants has been documented for Zostera marina and shows that plants held for two weeks in concentrations as low as 125 µmol start to become necrotic and die (Van Katwijk et al. 1997).

The effects of organic enrichment, on benthic macrofauna in Saldanha Bay, have been well documented (Jackson and McGibbon 1991, 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 IOT 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 and 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 at the end of pipe terms of the revised General and Special Standard (Government Notice No. 36820 — 6 September 2013) promulgated under the NWA

(Table 3.5). 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 and Von Gunten 2011).

MANAGEMENT OF TREATED EFFLUENT IN SALDANHA BAY AND LANGEBAAN

There are two 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 (Figure 3.20). To prevent raw sewage being released directly into Saldanha Bay due to malfunction or during power failures, 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 was made available on the 2016–2017 Capital Budget for the implementation of various interventions that prevent overflow of raw sewage that were completed in 2017 (SBM, Gavin Williams, pers. comm. 2016) (Figure 3.21). 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).

Table 3.5. General Limit as specified in the revised General Authorisation (GA) (6 September 2013) in terms of Section 39 of the National Water Act (No. 36 of 1998) (Government Gazette No. 36820, 6 September 2013).

Substance/parameter	General limit as specified in the revised GA
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

Substance/parameter	General limit as specified in the revised GA
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.

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).

Figure 3.21. Emergency generators that have been installed at various pump stations in Saldanha Bay and Langebaan Lagoon (Source: SBM, Gavin Williams 2016).

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 WWTWs are provided in Section 3.6.3, which present data on monthly trends in the effluent produced by the WWTWs. Data were 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; and
- “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 3.5). As the global climate pattern termed El Niño Southern Oscillation[6] weakens, most of the country has been able to recover from the worst drought since 1904. The Western Cape, however, continued to struggle to meet water demands in the province. Water shortages will

6 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.

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. As of 14 September 2020 the overall dam water levels for the Western Cape Water Supply System (WCWSS) were at 96.4%, while this is significantly higher than at the same time during the peak of the drought (roughly 37.4% in September 2017), it is still less than the > 100% seen in winter of 2012–2014 despite a drop in average water use within the province of over 30% (https://www.capetown.gov.za). 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 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^3/day), the Blouwaterbaai Lodge (60 m^3 per day), and Saldanha Sports Grounds (300 m^3 per day). Due to a very wet winter and some severe late winter storms as of 22 September 2023 dam levels in the western Cape were at 101.8% (https://www.capetown.gov.za).

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 RO 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 Clark et al. (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.

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;
- Hoedjiesbaai Hotel;
- Protea Hotel;
- Bongolethu Fishing Enterprises;
- SA Lobster;
- Transnet Port Authority;
- Arcelor Mittal (until its closure in the first quarter of 2020);
- Abattoir; and
- 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 must treat their effluent before it is directed into municipal WWTW. New by-laws have been put in place, which require 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 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. The plant now requires an updated 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^3 per year and that the water quality of the treated effluent is compliant with the General Discharge Limits of the revised General and Special Standard (Government Notice No. 36820 — 6 September 2013) promulgated under the NWA (Table 3.5). The SBM has applied for a new WUL for the upgrades required to accommodate the Industrial Development Zone. A decision is pending as a delineation study by the Department of Water and Sanitation (DWS) is still outstanding (Quintin Williams, SBM, pers. comm. 2020). 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 ten years prior to ~2017. Then, in response to the severe drought that the Western Cape experienced 2014–2018, the SBM made the treated wastewater available for irrigation, dust suppression, water features, and industrial cooling processes.

Before 2008, the average daily volume discharged never exceeded the average daily limit of 2625 m^3, but volumes of effluent released increased steadily over time (Figure 3.22).

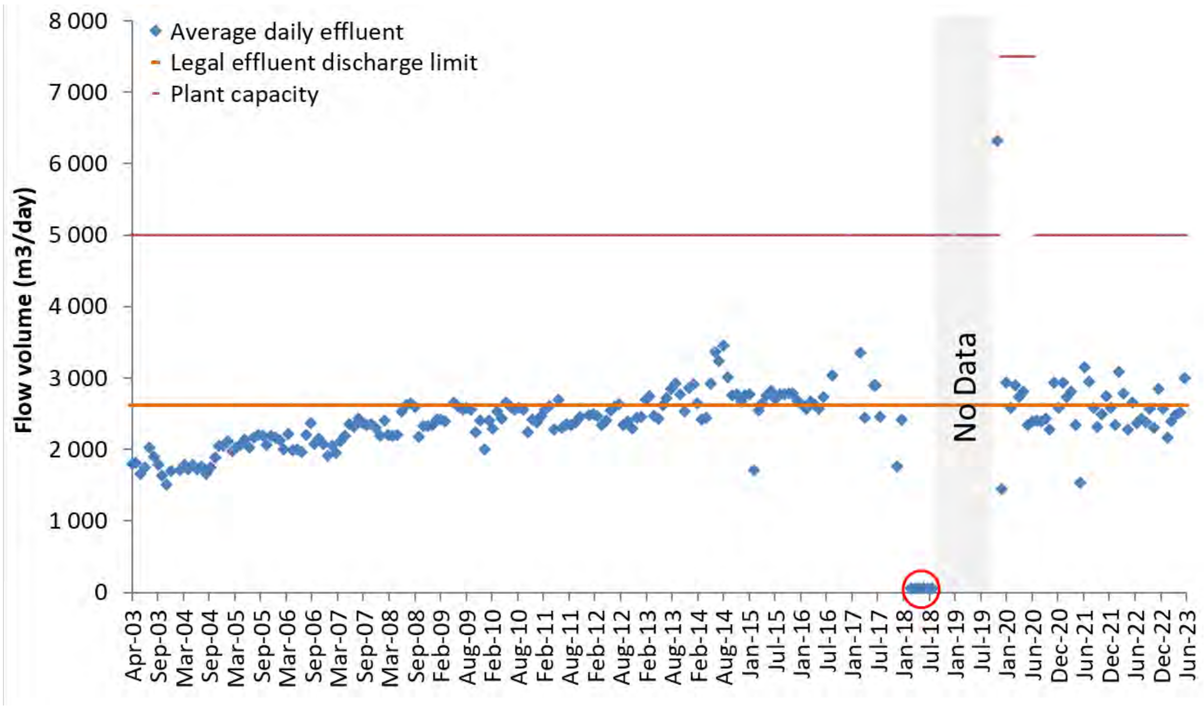


Figure 3.22. Trend in average daily effluent (m3/month) released from the Saldanha Wastewater Treatment Works, April 2003 – June 2023. Allowable discharge limits in terms of the exemption issued by DWS under the National Water Act (No. 36 of 1998, amended in 2022) are represented by the dashed orange line and the design capacity of the plant by the red line. The data points circled in red represent the estimated effluent discharged into the Bok River (60 m3 per day) (pers. comm. Gavin Williams 2018).

Between the years 2008–2012, the Saldanha WWTW was non-compliant only during the winter months and only once a year. Between January 2013 and June 2023 however, the average daily limit was exceeded 56% of the time, reaching unprecedented levels of 6317 m^3 effluent in November 2019. It is important to note though that the WWTW plant capacity was 5000 m^3 or above (for a short period), which means that the effluent quality was not compromised despite regular exceedances of the legal limit. Additionally, during this time frame the plant capacity limit was only exceeded twice. Finally, wastewater volumes treated at the Saldanha Bay WWTW decreased in 2017/2018 due to the water restrictions implemented by the SBM, however, these have increased with the lessoning on restrictions. Despite this, the flow volumes in the last three rolling years, since July 2020, average less than the legal effluent discharge limit and only exceed the limit 33% of the time.

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, SBM allocates treated effluent to multiple different users for re-use, thereby reducing the amount of effluent that is discharged into the otherwise dry Bok River. Since the closure of the ArcelorMittal Saldanha Steel Works and subsequent cessation of the RO plant operations, no treated effluent is being pumped from Saldanha WWTW to ArcelorMittal. However, the closure of all Steel Works operations also means that the Saldanha WWTW no longer receives any industrial effluent from ArcelorMittal.

The current water users receiving treated effluent from the WWTW include: the Weskus School (200 m^3/day), Saldanha Sports Ground (Stadium and practise field/350 m^3/day), Blue Bay Lodge (~70 m^3/day however, they tend to abstract more due to instream retention ponds) and small intermittent amounts used by Arcelor Mittal - only as required for dust suppression (Quintin Williams, SBM, pers. comm. 2023). The balance of treated effluent not used is currently discharged into the Bok River and ultimately ends up in the ocean. A flow meter has reportedly been installed at the Bok River discharge point; although, it is not known whether the discharge volume is recorded. It is strongly recommended that in order to ensure continued compliance with the General Discharge Authorisation's 2000 m^3/day discharge limit, this flow gauge must be installed/monitored to keep a continuous record of effluent volumes entering the Bay.

The Bok River had been dry for over a decade prior to the 2017–2018 drought and as a result any effluent discharged would reach the shore undiluted. However, more recently winter rainfall has been more regular, and it is likely that some level of dilution occurs during the winter months. With the new wastewater management scheme, approximately 670 m^3/day of the treated effluent is used by other water users making the calculated average daily discharge entering the Bok approximately 1800 m^3/day, which falls within the allowable volumes (< 2000 m^3/day) as per the new GDA regulations (promulgated in 2022 in the Government Gazette No. 47019, 15 July 2022). The changes implemented by the SBM are therefore significantly positive and future interpretation of water quality results must continue to consider the volume of effluent entering the marine environment via the Bok River.

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. All data were provided by the SBM. Concentrations of faecal coliforms in the effluent from the Saldanha WWTW exceeded the allowable limit of 1000 org/100 ml on 44 occasions since 2003 (18% of the time) (Figure 3.23). 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 26 occasions since January 2013, frequently reaching the maximum detectable limit (the maximum detectable limit = 2419 org/100 ml, which is multiplied by a safety factor of three = 7257 org/100 ml). A strong improvement is visible from Dec 2018 after which point the faecal coliform counts only exceeded the limit once (Dec 2022). Making the compliance in the last four years 98%, an improvement from 2018/19 where compliance was 60% (Figure 3.23).

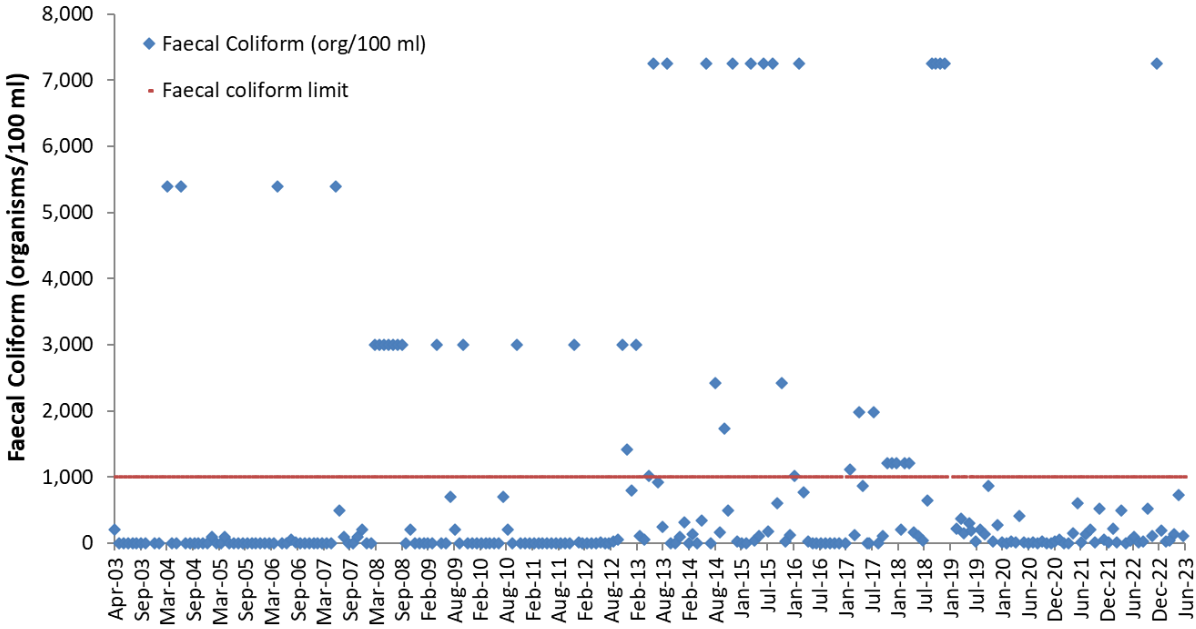


Figure 3.23. Monthly trend in Faecal Coliforms (org/100 ml) in effluent released from the Saldanha Wastewater Treatment Works, April 2003 – June 2023. Allowable limits in terms of a GA under the National Water Act (No. 36 of 1998, amended in 2022) are represented by the dashed red line.

Allowable limits for total suspended solids (TSS) have been exceeded 16% of the time since April 2003 (Figure 3.24, limit was 25 mg/l then increased to 50 mg/l under the 2022 GDA). While compliance clearly improved between 2008 and 2014, the allowable limit was exceeded 45% of the time between December 2014 and April 2019. However, since May 2019, it is positive to note that TSS has only exceeded the limit once (35 mg/l in May 2021), which shows a significant improvement to previous years. In 2022/23, compliance for TSS was 100%.

Chemical oxygen demand (COD) in filtered effluent exceeded the allowable limit of 75 mg/l 21% of the time since April 2003 (Figure 3.25). 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 COD was consistently above the legal limit between November 2017 and May 2019, achieving only 17% compliance. These observations are congruent with high ammonia nitrogen, faecal coliform and free chlorine levels during the same period. It is therefore positive to note that the COD limit was only exceeded four times in the last four years, increasing compliance to 92%, with 100% compliance in the 2022/2023 rolling year.

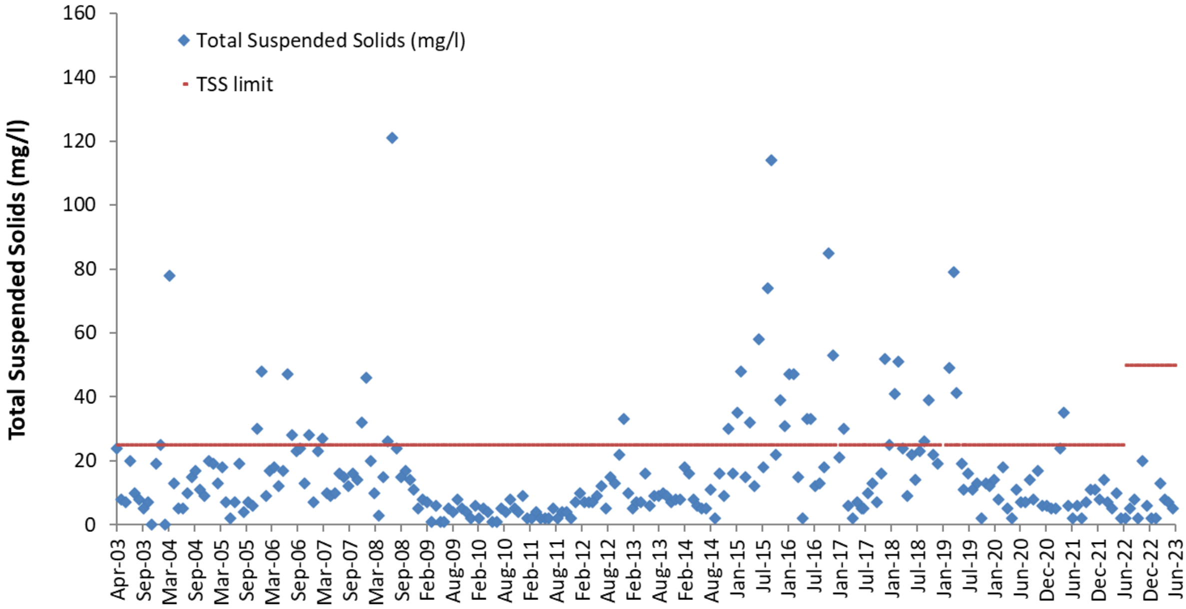


Figure 3.24. Monthly trend in total suspended solids (mg/l) in effluent released from the Saldanha Wastewater Treatment Works, April 2003 – June 2023. Allowable limits as specified in terms of a GA under the National Water Act (No. 36 of 1998, amended in 2022) are represented by the dashed red line.

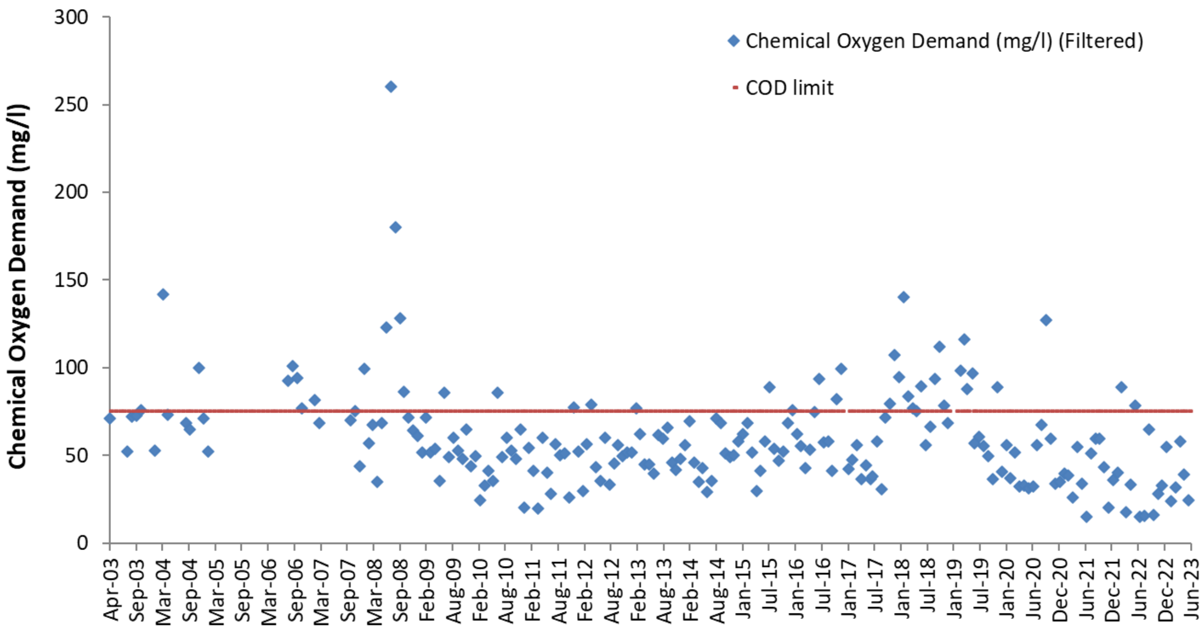


Figure 3.25. Monthly trends in chemical oxygen demand (mg/l filtered) in effluent released from the Saldanha Wastewater Treatment Works, April 2003 – June 2023. Allowable limits in terms of a GA under the National Water Act (No. 36 of 1998, amended in 2022) are represented by the dashed red line.

Levels of Ammonia-Nitrogen (mg/l as N) are of great concern in the treated wastewater of the Saldanha WWTW as readings have exceed the allowable limit (6 mg/l, becoming 10 mg/l in 2022 GDA), 73% of the time since April 2003 (Figure 3.26). Ammonia levels in the effluent measured 91.5 mg/l in October 2018, the highest concentration ever recorded. Ammonia is toxic to aquatic organisms and such high concentrations should not be permitted to be released into the Bok River. However, ammonia levels have improved significantly in recent years as while the average concentration during the period June 2018 to June 2019 was 58.2 ± 28.4 mg/l, concentrations have markedly dropped in the last three rolling years, with an average of 4.1 ± 2.8 mg/l between July 2022 and June 2023.

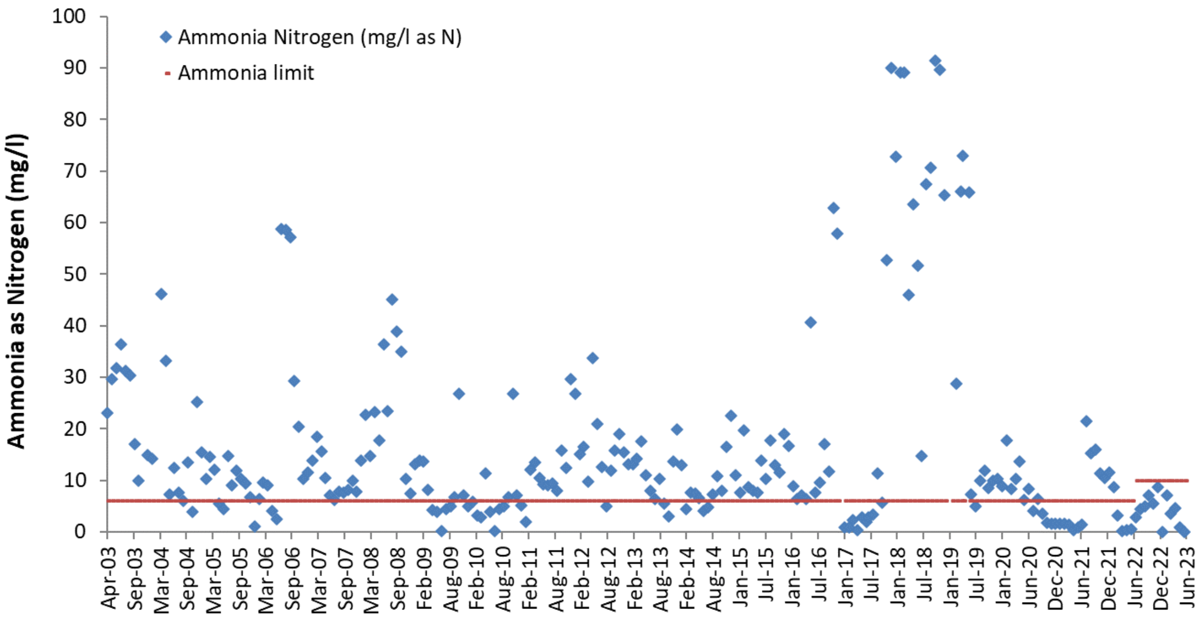


Figure 3.26. Monthly trends in Ammonia Nitrogen (mg/l as N) in effluent released from the Saldanha Wastewater Treatment Works April 2003 – June 2023. Allowable limits in terms of a GA under the National Water Act (No. 36 of 1998, amended in 2022) are represented by the dashed red line.

The Nitrate-nitrogen limit (15 mg/l, becoming 20 mg/l in 2022 GDA) has been exceeded 13% 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 and 2021 (Figure 3.27). 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 (< 0.3 mg/l) between November 2017 and April 2019 complement extremely high levels of ammonia nitrogen indicating the lack of bacterial treatment. Although nitrate-nitrogen levels have increased in the last two years relative to the 2018–2020 period, there have still only been two incidences of exceedances from January 2018 to June 2022. With the limit increasing from 15 to 20 mg/l in 2022 GDA Nitrate Nitrogen was 100% compliant.

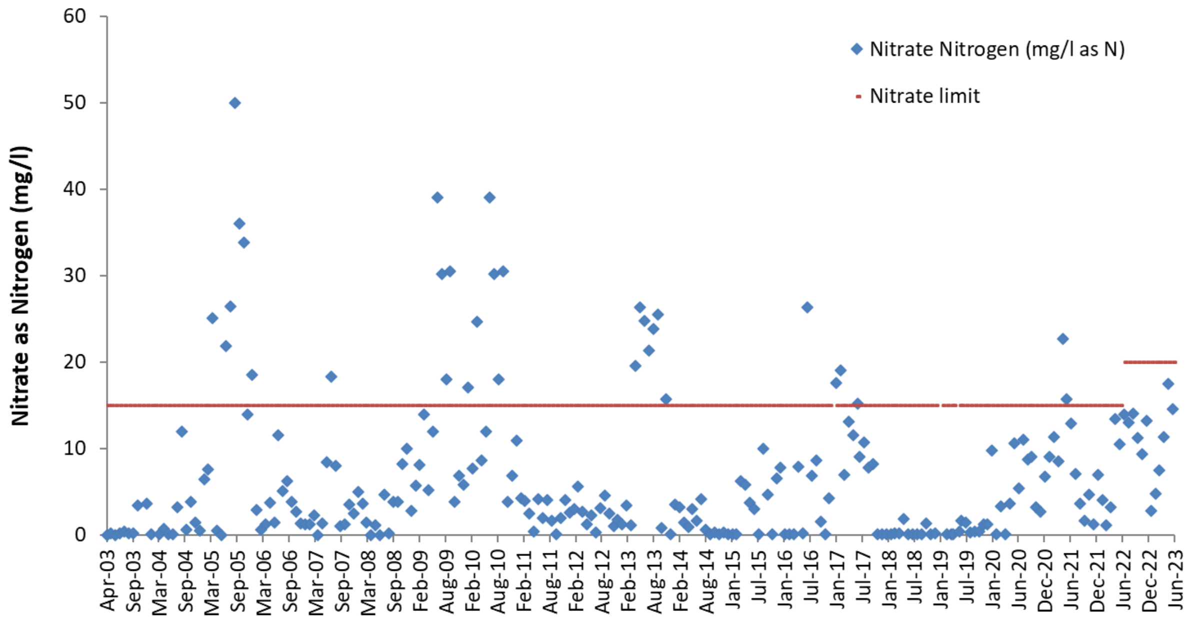


Figure 3.27. Monthly trends in Nitrate Nitrogen (mg/l as N) in effluent released from the Saldanha Wastewater Treatment Works April 2003 – June 2023. Allowable limits in terms of a GA under the National Water Act (No. 36 of 1998, amended in 2022) are represented by the dashed red line.

The concentration of orthophosphate in the effluent has only been measured since October 2007 with a level of exceedance of 23%. Orthophosphate levels remained below the limit between July 2013 and October 2016 however, since then the limit has been exceeded on 23 occasions, 5 of which were in the 2021/22 rolling year. The average orthophosphate was 8.9 ± 3.8 mg/l (Stdev) in the 2021/22 rolling year. The highest reading on record to date (18.9 mg/l) occurred in February 2021 (Figure 3.28). The average orthophosphate was 9.7 ± 1.1 mg/l (Stdev) in the 2022/23 rolling year. However, with the limit increasing from 10 to 20 mg/l in the 2022 GDA, orthophosphate concentrations were 100% compliant in 2022/2023.

Permissible chlorine levels of 0.25 mg/l have been exceeded 60% of the time (Figure 3.29) since 2003. In 2018/2019, chlorine levels improved dramatically compared to previous years, with legal limits only exceeded on three occasions (70% compliance) and concentrations were generally low with an average of 0.25 ± 0.4 mg/l (Figure 3.29). However, since July 2019, compliance dropped to only 37.5% with an average of 0.47 ± 0.44 mg/l. The 2022/23 rolling year saw the limit exceeded in 8 of the 12 readings, with the average value being above the limit at 0.42 ± 0.25 mg/l. The updated GDA regulations do not provide values for free or total chlorine, the only chlorine limit provided is for total chlorine residual (0.2 mg/l) which is combined with free chlorine to provide total chlorine. Residual chlorine is not a value currently testing and it may be worth altering the tests to include this parameter.

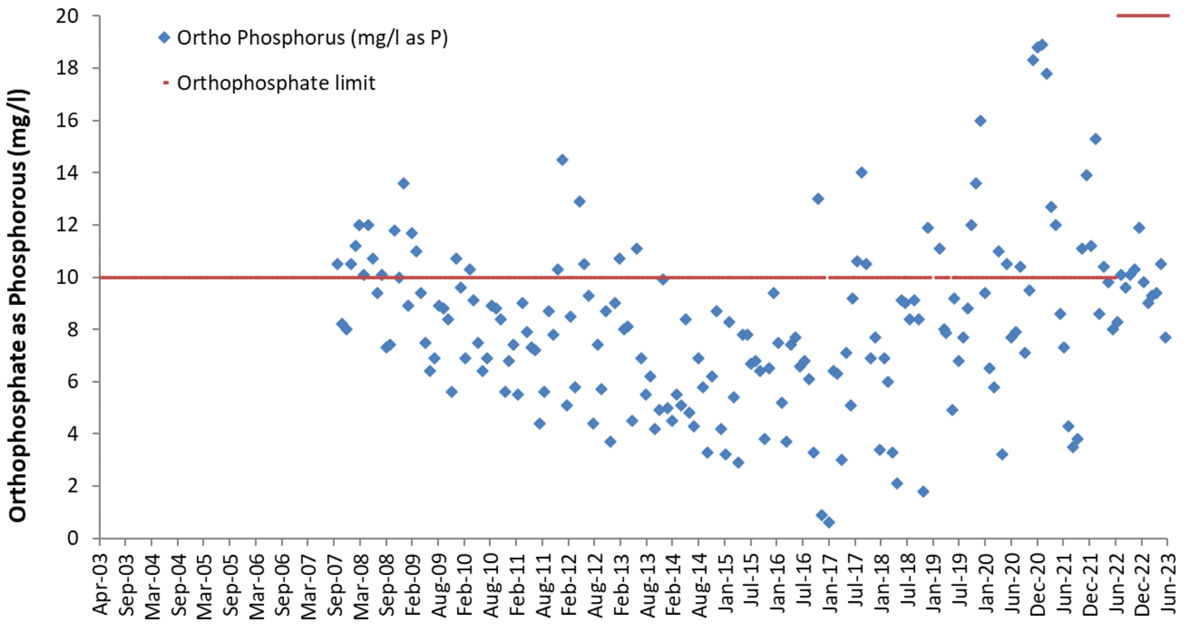


Figure 3.28. Monthly trends in Orthophosphate (mg/l as P) in effluent released from the Saldanha Wastewater Treatment Works April 2003 – June 2023. Allowable limits in terms of a GA under the National Water Act (No. 36 of 1998, amended in 2022) are represented by the dashed red line.

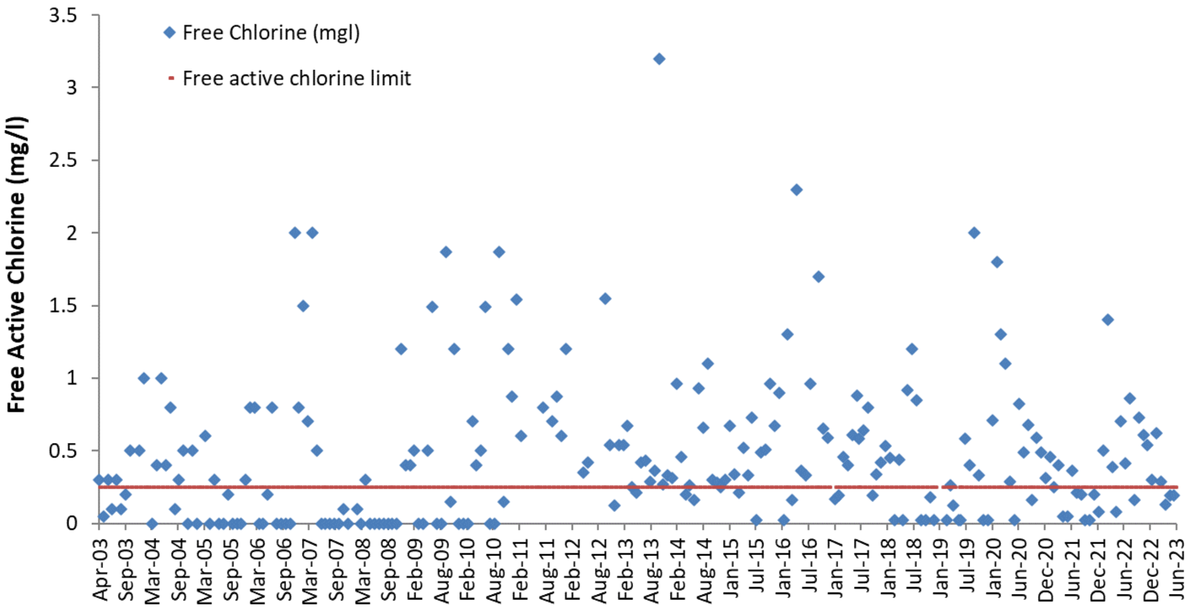


Figure 3.29. Monthly trends in Free Active Chlorine (mg/l) in effluent released from the Saldanha Wastewater Treatment Works April 2003 – June 2023. Allowable limits in terms of a GA under the National Water Act (No. 36 of 1998, amended in 2022) are represented by the dashed red line. An outlier of 12 mg/l measured for January 2008 was removed to show the trend more clearly.

LANGEBAAN WASTEWATER TREATMENT WORKS

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 DWS to use a maximum of 200 m^3 for the irrigation of lawn on the WWTW premises as well as the flower beds along Oostewal Road 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 MPA. However, with the implementation of water restrictions, wastewater produced by the Langebaan WWTW has been decreasing considerably, which means that only very small quantities of wastewater overflowed into the MPA during the winter months in 2018 (SBM, pers. comm. 2018). In addition, SBM has undergone an agreement with Langebaan Country estate to irrigate effluent within its boundaries during the Winter months. Subsequently, it is believed that through this agreement all discharge of effluent into the MPA has been eliminated (Quintin Williams, SBM, pers. comm. 2020).

The overflow from the storage dams was noticed by the former 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) (NEMPAA).

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 RO. 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 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 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^3 (daily maximum of 200 m^3 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^3 (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 GA 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^3 but less than 500 m^3 per day.

The applicable limits are shown in Table 3.6. The GA 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 runoff 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 GA 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 GA 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.

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 3.6 are applicable (the wastewater is not discharged into a water resource and those limits are therefore not applicable in terms of the GA).

Table 3.6. 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 or more than 9 pH units
Electrical conductivity	Not exceed 200 milliSiemens per metre (mS/m)
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 of the GA 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 runoff 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 —
   a) Guidelines for the Utilisation and Disposal of Wastewater Sludge, Volumes1–5, Water Research Commission Reports TT 261/06, 262/06, 349/09, 350/09, 351/09, as amended from time to time; and
   b) "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) and have been ongoing in the form of a phased approach. 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 2017/18 financial year. These upgrades increased the plant capacity to 3.5 ML and included an additional aeration basin, a new clarifier and drying beds as well as new inlet works and screens with a total budget of R17 million (SBM, Gavin Williams, pers. comm. 2019). The ongoing phased approach and installation of new infrastructure will increase the capacity of the plant to 5–7 ML. Phase 2 of these upgrades is in the final stages and is set to be completed by the end of September 2020 and the tender processes for phase 3 was undertaken in 2021. This phase will include the refurbishment of the old bio reactor, mechanical dewatering facility and power supply to the works (SBM, Quintin Williams, pers. comm. 2020). An aerial view of the Langebaan WWTW is shown in Figure 3.30.

Figure 3.30. Construction activities for the upgrade of the Langebaan Wastewater Treatment Plant to increase treatment capacity and improve treatment processes.

Over time more effluent than currently absorbed by the Langebaan Country Club will be produced. The SBM intends to appoint a consultant to design proposals on how to use or discharge excess effluent (SBM, Gavin Williams, pers. comm. 2019). For example, 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.

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 although, according to SBM no effluent has entered the MPA in several years, the actual water quality of the treated wastewater that could enter 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 2023 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 3.6. These parameters include pH, electrical conductivity, Chemical Oxygen Demand, and Faecal Coliforms. No data are currently available for Sodium Adsorption Ratio (SAR).

In addition to the above, due to possible overflow and 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 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 were 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. As of July 2022, the gazetted GDA special limits have been used for reference.

Long-term trends in water quality are shown in Figure 3.31 – 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 consider 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^3 treated effluent per day, which was exceeded 92% of the time between 2009 and December 2017 (Figure 3.31). Overall, effluent volumes peaked over the December holidays when plant capacity was often reached or exceeded (e.g., December 2016, average daily effluent volumes were 2 840 m^3). The legal limit for effluent production increased to 4 485 m^3/day in January 2018 when the SBM was issued with a new GA permission. Shortly thereafter, plant capacity was increased to 3 500 m^3.

Since then, the Langebaan WWTW has been compliant in terms of the legal effluent volume limit. Hydraulic design capacity (3 500 m^3) was exceeded in February 2019 with an average daily flow of 4 167 m^3 per day (i.e., 119% capacity) and marginally in March 2020 (3529 m^3 per day or 100.8%); along with no evidence of exceedance between November 2020 and June 2023.

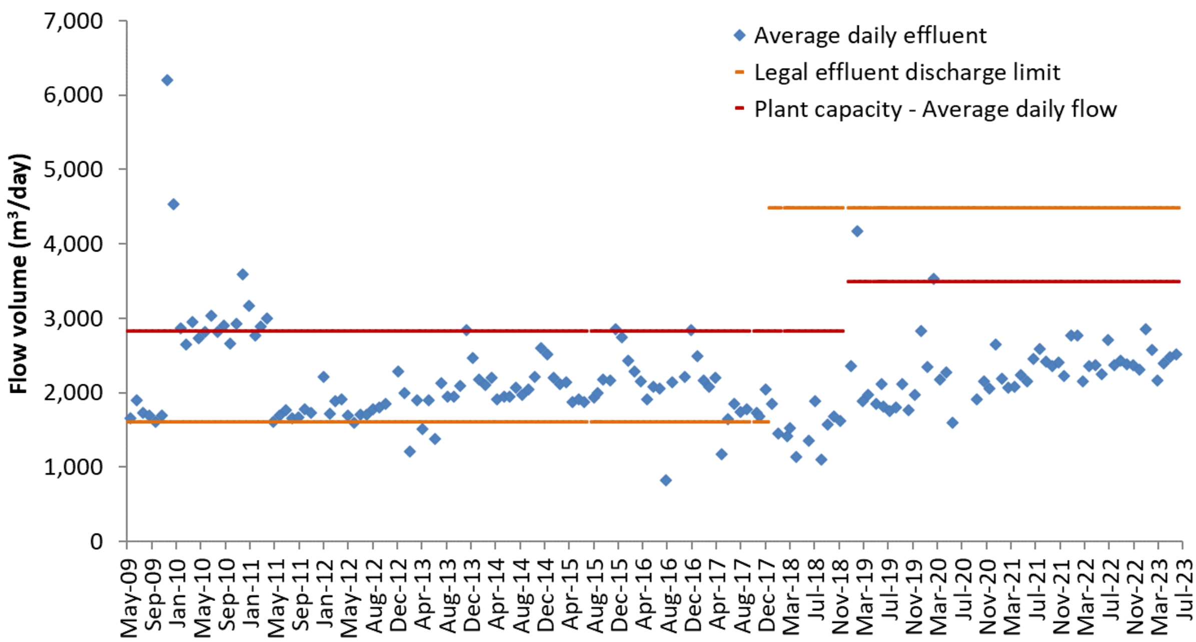


Figure 3.31. Trends in average daily effluent volume (m^3/month) released from the Langebaan Wastewater Treatment Works, June 2009 – June 2023. Allowable discharge limits in terms of the exemption issued by DWAF under the National Water Act (No. 36 of 1998, amended in 2022) are represented by the dashed orange line and the design capacity of the plant by the red line.

The pH 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 m³ wastewater (i.e., between pH of 6 and 9, Figure 3.32). Values of pH recommended for the protection of the inshore marine environment range between 7.3 and 8.2 (2022 GDA). Since 2009 the pH of the wastewater effluent has fallen outside of these limits 39% of the time, with more basic (pH > 8.2) values recorded four times and more acidic (pH < 7.3) values recorded on 62 occasions. In the 2022/23 rolling year pH was 100% compliant with the GDA special limits.

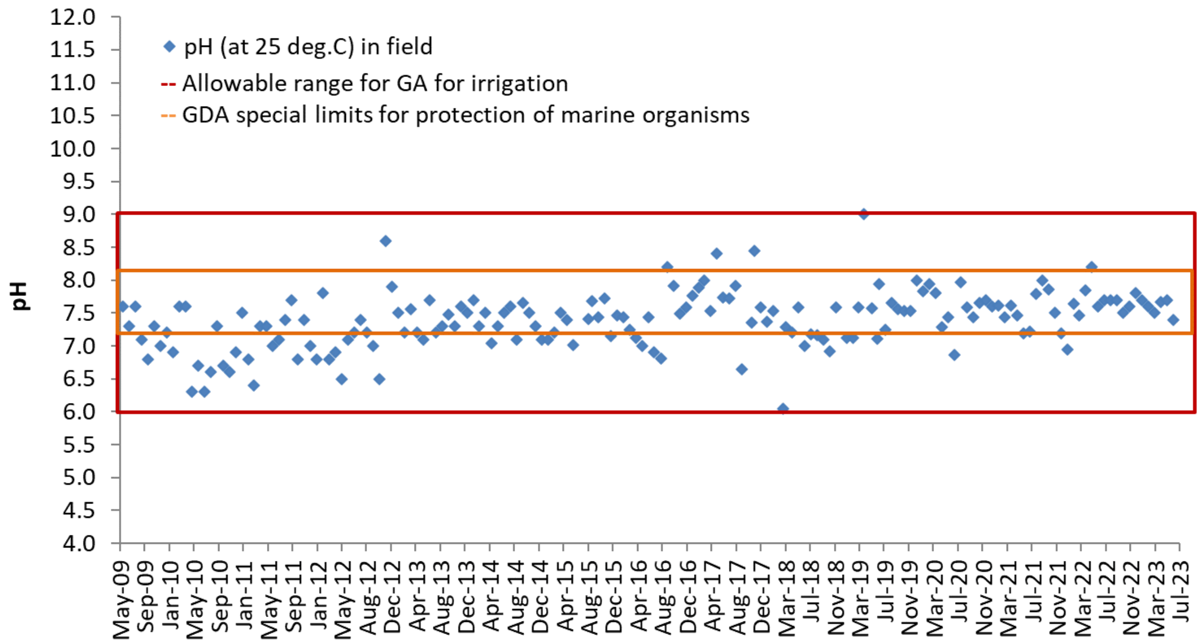


Figure 3.32. Monthly trends in pH of effluent from the Langebaan Wastewater Treatment Works, June 2009 – June 2023. The allowable range in terms of the GA for irrigation purposes under the National Water Act (No. 36 of 1998) is 6–9 and is depicted by the red square. The recommended range to protect marine inshore environments is 7.3–8.2 and is depicted by the orange square (GDA special limits 2022).

In the 14 years since electrical conductivity (in mS/m) was first recorded at Langebaan WWTW, conductivity has been declining steadily (Figure 3.33). With a peak reading of 625 mS/m recorded in September 2011 and the lowest recording occurring in April 2020 (22 mS/m). Values have been fluctuating around the prescribed limit (200 mS/m) since December 2014, however, since February 2022, the conductivity has continuously fallen below the limit.

COD in filtered effluent exceeded the allowable limit for the protection of marine organisms of 75 mg/l 27% of the time since June 2009, reaching an all-time maximum of 235 mg/l in January 2018 (Figure 3.34). However, in the last five rolling years, July 2018 – June 2022 COD has been 85% compliant, in regard to the limits for the protection of marine organisms, exceeding the limit only once in the 2022/2023 rolling year (157 mg/l in Jan 2023). In terms of the limit imposed by the GA applicable for irrigation, the SBM is 100% compliant as COD is always lower than 400 mg/l (Figure 3.34).

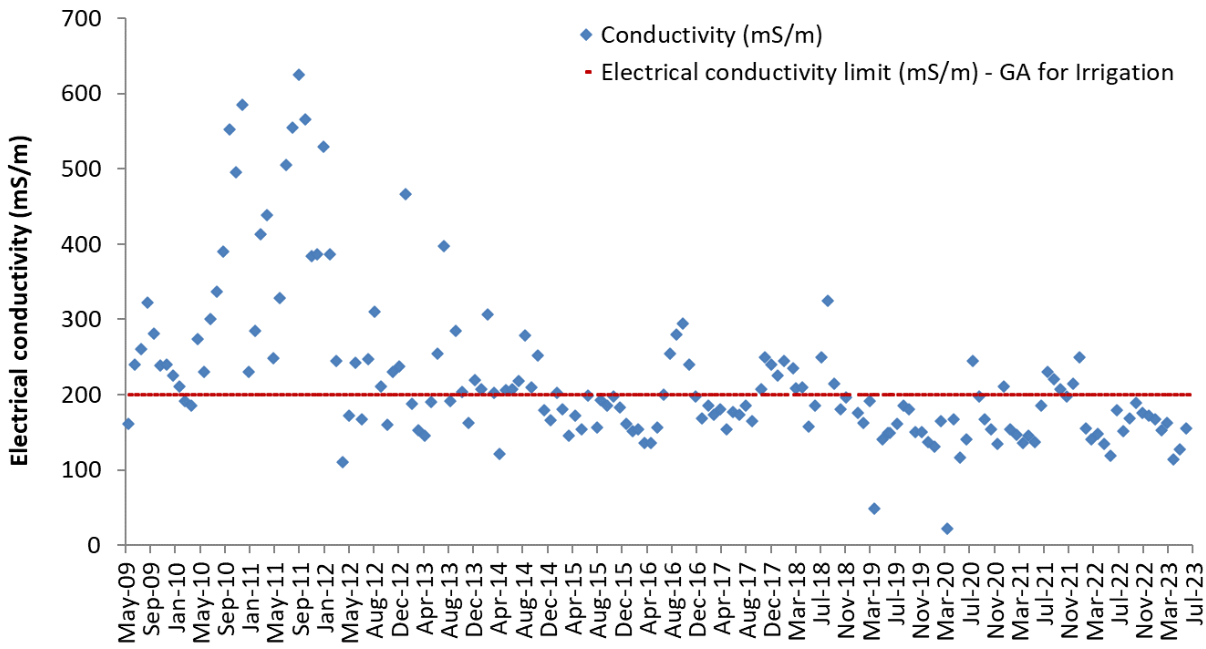


Figure 3.33. Monthly trends in conductivity of effluent from the Langebaan Wastewater Treatment Works, June 2009 – June 2023. The allowable limit in terms of the GA for irrigation purposes under the National Water Act (No. 36 of 1998) is 200 mS/m and is depicted by the red line.

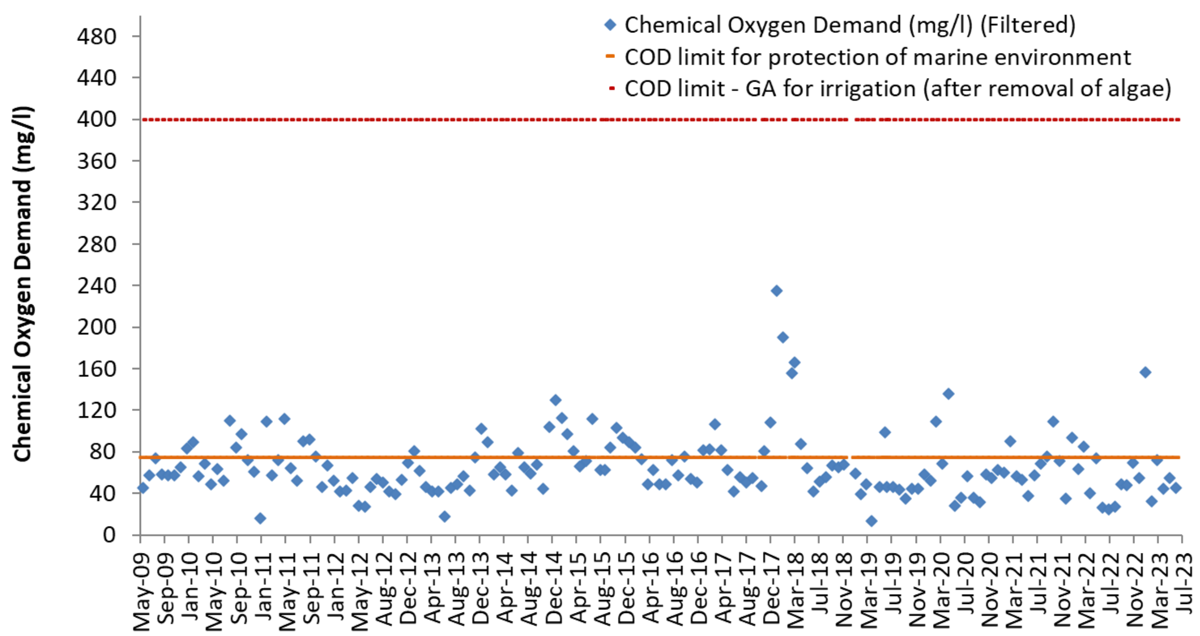


Figure 3.34. Monthly trends in chemical oxygen demand (mg/l filtered) in effluent released from the Langebaan Wastewater Treatment Works, June 2009 – June 2022. Allowable limits as specified in terms of a GA under the National Water Act (No. 36 of 1998, amended in 2022) are represented by the dashed red line. The recommended limit to protect marine inshore environments is shown by the orange dashed line (GDA special limits 2022).

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 unacceptable. The wastewater has stayed well below this limit however, the frequency of readings greater than the detection limit, and therefore multiplied by three to reach the conservative maximum value of 7257 org/100 ml, has increased in the last few years. In 2019/20 as many as eight of the 12 readings recorded were greater than the detection limit. However, in the 2020/21 and 2021/22 only two and one reading were above the detection limit, respectively. Furthermore, nine of the 11 readings taken in 2021/22 were below the desirable faecal coliform readings of 1 000 org/100 ml as prescribed in the GA applicable to the discharge of wastewater into freshwater resources.

In situation in 2022/23, was unfavourable for recreational use with eight of the 12 readings above the detection limit, however, it is important to remember that presently no overflow should be reaching the bay and values are compliant for irrigation purposes.

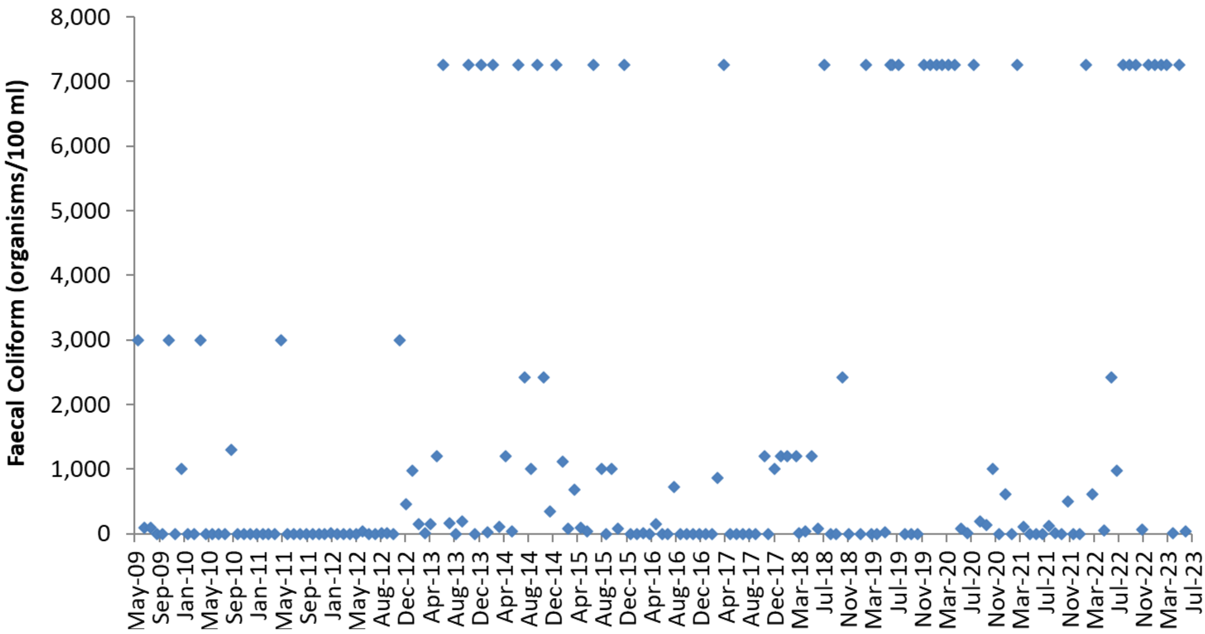


Figure 3.35. Monthly trends in Faecal Coliforms (org/100 ml) in effluent released from the Langebaan Wastewater Treatment Works, June 2009 – June 2023. The allowable limit in terms of a GA for irrigation purposes under the National Water Act (No. 36 of 1998) is 100 000 organisms per 100 ml.

No 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. Therefore, the SBM will be required to remove TSS prior to the irrigation of their own premises and the flower beds on Oostewal 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 110 occasions since 2009 (65% of the time) (Figure 3.36). The maximum TSS value of 198 mg/l occurred in March 2015. Similarly, annual peaks in the concentration occur at the end of the summer or early autumn each year. In 2022/23, all but one reading exceeded the 10 mg/l limit.

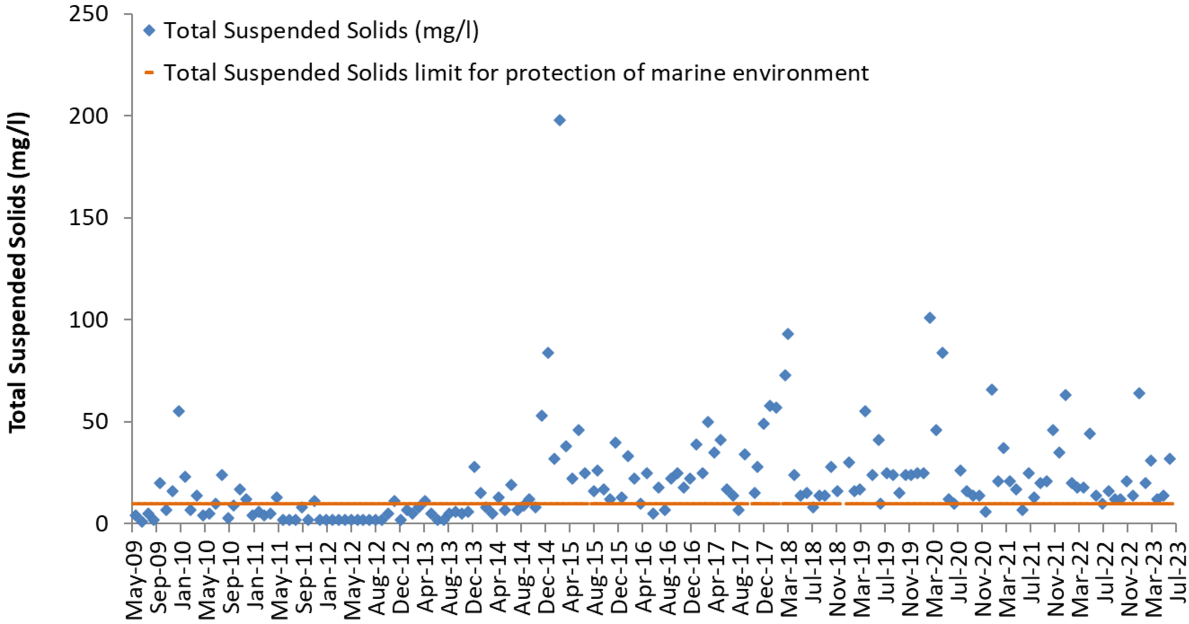


Figure 3.36. Monthly trends in total suspended solids (mg/l) in effluent released from the Langebaan Wastewater Treatment Works, June 2009 – June 2023. The recommended limit to protect marine inshore environments is shown by the orange dashed line (GDA special limits 2022).

No ammonia nitrogen limit is prescribed by the GA applicable to irrigation of wastewater, however, ammonia is very toxic to marine life as it acts as a biocide. The recommended ammonia nitrogen limit for the protection of the inshore marine environment was 3 mg/l in the AEC 2015 and has dropped to 2 mg/l in the 2022 GDA special limits (Figure 3.37).

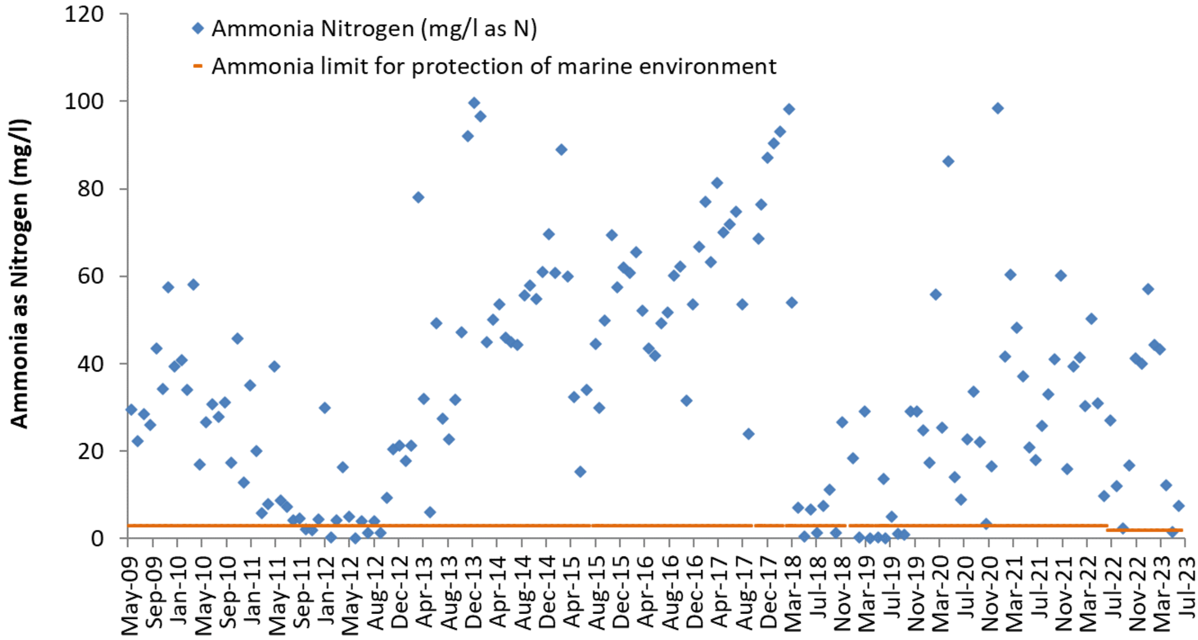


Figure 3.37. Monthly trends in Ammonia Nitrogen (mg/l as N) in effluent released from the Langebaan Wastewater Treatment Works June 2009 – June 2023. The recommended limit to protect marine inshore environments is shown by the orange dashed line (GDA special limits 2022).

The WQG for the coastal environment specify a target of 0.6 mg/l to prevent chronic toxicity. Ammonia levels increased steeply between November 2012 and March 2018 from < 10 mg/l to nearly 100 mg/l. Subsequent to that, the ammonia nitrogen concentrations dropped significantly but were, however, still grossly exceeding the recommended limit for the protection of the marine environment (2 mg/l). Readings have again started to increase with all readings measuring above the limit in 2021/22, and only one reading below the limit in 2022/23. 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 its surrounds. No nitrate-nitrogen limit is prescribed by the GA applicable to irrigation of wastewater. The recommended nitrate-nitrogen limit for the inshore marine environment was 1.5 mg/l, however, has increased to 3.5 mg/l in the 2022 GDA special limits. The limit has been exceeded on 68 occasions since June 2009 (40% of the time), (Figure 3.38).

Lower concentrations were recorded between April 2016 and March 2018 with all values less than the limit. In 2020/21, only four readings were below the limit, however there was an improvement in 2021/22, with 10 of the 12 readings being below the limit, while the new limit of 3.5 mg/l was only exceeded once in the 2022/23 rolling year.

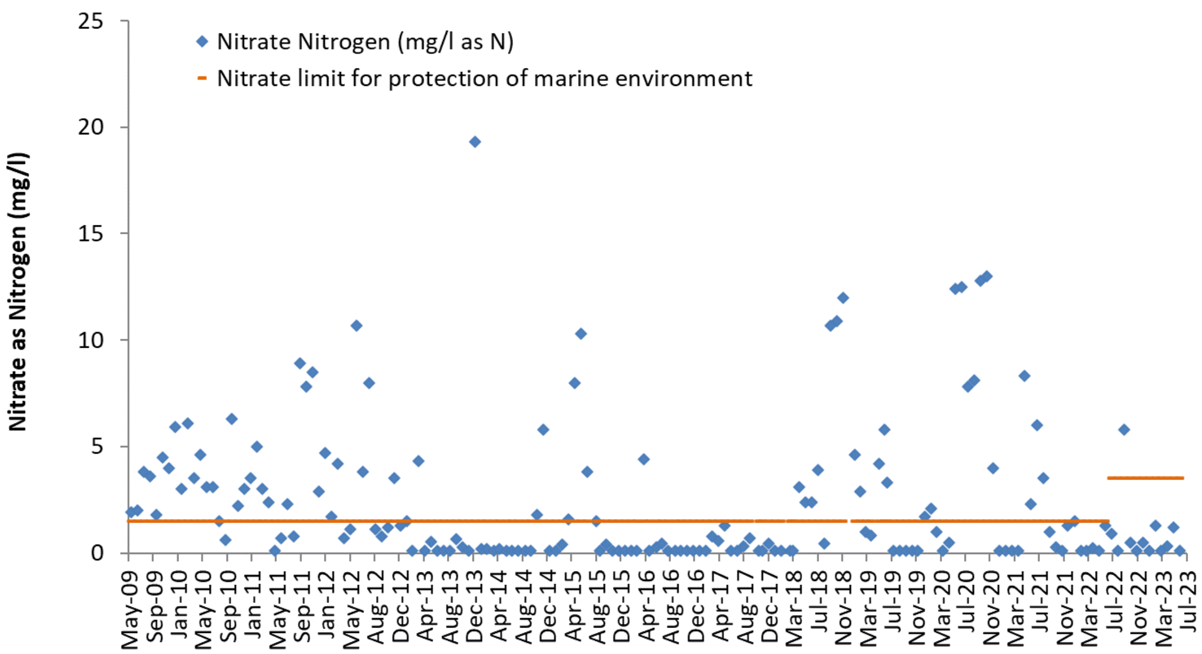


Figure 3.38. Monthly trends in Nitrate Nitrogen (mg/l as N) in effluent released from the Langebaan Wastewater Treatment Works June 2009 – June 2023. The recommended limit to protect marine inshore environments is shown by the orange dashed line (GDA special limits 2022).

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 levels fluctuate widely throughout the year, with the highest value recorded to date at 51.1 mg/l in January 2021 (Figure 3.39). Overall, the orthophosphate concentration in the Langebaan WWTW effluent is considerably higher than 1 mg/l (81% exceedance). However, as observed with several other effluent parameters, orthophosphate levels improved significantly since November 2018, (except for exorbitant reading in January 2021) with an average of 4.3 ± 8.3 mg/l (Stdev, 59% of readings < 1 mg/l), the 2022/23 rolling year improved further with an average of 1.4 ± 1.3 mg/l.

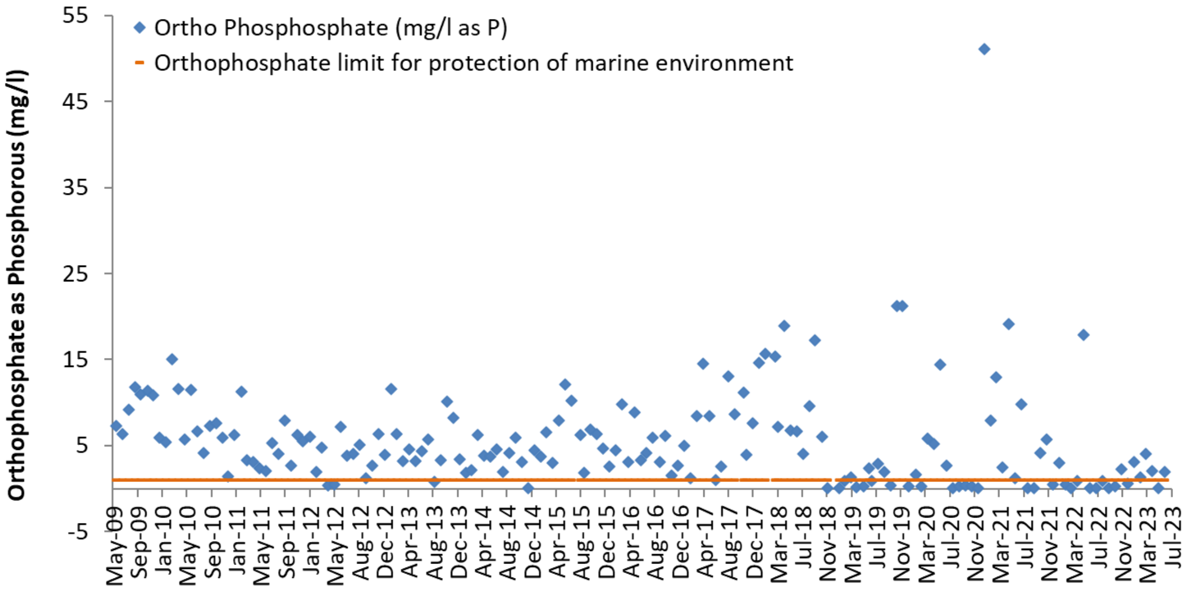


Figure 3.39. Monthly trends in Orthophosphate (mg/l as P) in effluent released from the Langebaan Wastewater Treatment Works June 2009 – June 2023. The recommended limit to protect marine inshore environments is shown by the orange line (GDA special limits 2022).

No free active chlorine limit is prescribed by the GA applicable to irrigation of wastewater, however, free active chlorine is highly toxic to marine life as it acts as a biocide. The recommended limit to protect the inshore marine environment is 0.5 mg/l (Figure 3.40). Monthly values for 2019/20 appeared to improve with most values below 1.2 mg/l and six of the 12 readings not exceeding the limit, however, two high exceptions exist, recorded in February and March 2020, where both readings are above the measurable detection limit. This pattern has persisted, with three readings in both 2020/21 and 2021/22 exceeding the detection limit; along with only four readings below desirable limit in both years. In 2022/23 no values exceeded the laboratory detection limit, but half the readings were above the recommended limit for the safely of marine organisms. These levels are significantly higher than what would be considered acceptable if discharged into the nearshore environment and more careful dosing of chlorine should be implemented.

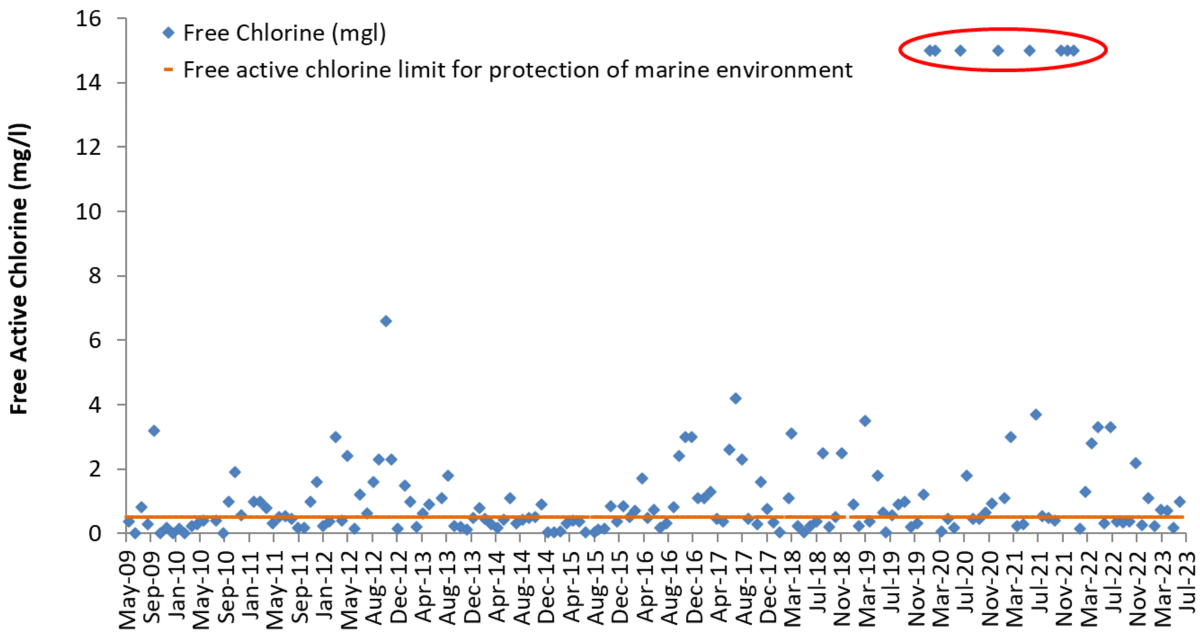


Figure 3.40. Monthly trends in Free Active Chlorine (mg/l) in effluent released from the Langebaan Wastewater Treatment Works June 2009 – June 2023. The recommended limit to protect marine inshore environments is shown by the orange line (AEC 2015).

SUMMARY

The 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. Therefore, very small volumes of effluent have entered the marine environment from the Langebaan 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 volume is reaching the marine environment from Langebaan WWTW and that the Saldanha Bay WWTW is still below the allowable limit as per the General Discharge Authorization limits and impacts are likely to be limited (over time, extent and magnitude).

Overall, the data shows that the majority of Saldanha Bay WWTW water quality parameters have shown a high percentage compliance with limits and conditions as set out in the 2022 GDA. In 2022/23 the plant capacity, TSS, and COD concentrations all showed 100% compliance with the limits. Similarly, with the new GDA limits being slightly higher than the 2013 GA limits, Ammonia Nitrate, Nitrate nitrogen and levels were also 100% compliant. However, it is worth noticing that the 2022/23 rolling years average values for Orthophosphate and Nitrate nitrogen were higher than those in the 2021/22 rolling year, while the average value for Ammonia Nitrate was lower than previous rolling years (8.4 ± 7.1 mg/l in 2021/22 and 4.1 ± 2.8 mg/l in 2022/23). The Faecal Coliforms only exceeded the limit on a single occasion with the daily effluent discharge volume exceeding the limit in two months of this rolling year. In contrast, the chlorine readings exceeded the permissible limit 67% of the time in 2022/23. Therefore, while most of the parameters showed an improvement and were compliant with the GDA limits, there are still some that need to be better managed, especially because since the closure of ArcelorMittal a significant portion of effluent is being discharged into the Bok which ultimately exits into the Bay.

Improved effluent quality was recorded at the Langebaan WWTW for some parameters. The legal effluent discharge limit, the plant capacity, and conductivity were all 100% compliant in 2022/23. pH levels were consistently within the limits for irrigation and were also 100% compliant with the reduced limits for the protection of marine organisms (improving from only 75% compliance in 2021/2022. In terms of the limit imposed by the GA applicable for irrigation, the SBM is 100% compliant as COD is always lower than 400 mg/l and, with the exception of one reading in January 2023, was also below the limit for the protection of marine organisms. Similarly, the level of Nitrates within the treated effluent only exceeded the revised GDA limit once in September 2022 with the average value lower in 2022/23 than in 2021/22. Orthophosphate levels have improved significantly since November 2018 and in 2022/23 50% of readings were below the recommended limit and the average value was substantially lower than that of the previous year (1.4 ± 1.3 mg/l in 2022/23 compared to 3.6 ± 5.4 mg/l in 2021/22).

Constituents of concern that warrant observation should any effluent over top the ponds and be discharged into the lagoon include TSS levels which exceeded the recommended limit for the protection of marine environments 92% of the rolling year, and ammonia Nitrogen levels which exceeded the limit for the protection of marine environments 100% of the time in 2021/22 and 92% of the time in 2022/23. Similarly faecal coliforms were above the laboratory detection limits in eight of the 12 months sampled and free chlorine exceeded the limit 50% of the time. Despite this, it is important to remember that according to SBM no effluent is reaching the marine environment as it is all been allocated for reuse.

The data shows that the Saldanha WWTW is receiving close to, if not slightly greater, volumes of effluent for treatment than permitted, despite the cessation of industrial effluent from ArcelorMittal. However, it should be noted that the SBM is currently in the process of amending their WUL and that effluent volumes rarely exceed the plant capacity (nearly double that of the legal limit). It is also important to note that discharge into the Bok has likely increased in recent years and that following the diversion of some effluent for irrigation and alternate uses the approximate average daily discharge is still below the required limit for the GDA (2000 m^3/day). The Langebaan WWTW was recently upgraded to 3 500 m^3 and was issued permission to store 4 485 m^3 in January 2018. The legal limit has not been exceeded since, and plant capacity has only been exceeded twice.

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 and Jackson 1997, Bay et al. 2003).

Typical concentrations of various storm water constituents (metals, nutrients, bacteriological) for industrial and residential storm water from South Africa and elsewhere were extracted from the literature by the CSIR in 2002 (Table 3.7).

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

Parameter	Residential	Industrial	Water Quality Guidelines
Total suspended solids (TSS) (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**

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 WQG 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.

On 7 August 2022, there was an incident during which raw sewage flowed into Hoedjiesbaai Saldanha, reportedly due to vandalism in the area. The spill was contained, and infrastructure attended to by close of business on the same day.

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 (Table 3.8 and Figure 3.41). Runoff coefficients used to calculate storm water runoff from rainfall data were 0.3 for residential areas and 0.45 for industrial areas (CSIR 2002). Note that runoff from the Port of Saldanha and ore terminal have been excluded from these calculations. Storm water runoff is highly seasonal and peaks in the wet months of May to August. Due to the rapid pace of holiday and retail development in the area, Langebaan residential area produces the greatest volumes of storm water runoff, followed by the industrial areas, with lower volumes arising from the Saldanha residential area. The actual load of pollutants entering the Bay and Lagoon via this storm water can only be accurately estimated when measurements of storm water contaminants in the storm water systems of these areas are made.

Table 3.8. Monthly rainfall data (mm) for Saldanha Bay over the period 1895–1999 (source Visser et al. 2007). MAP = mean annual precipitation.

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

Figure 3.41. 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.

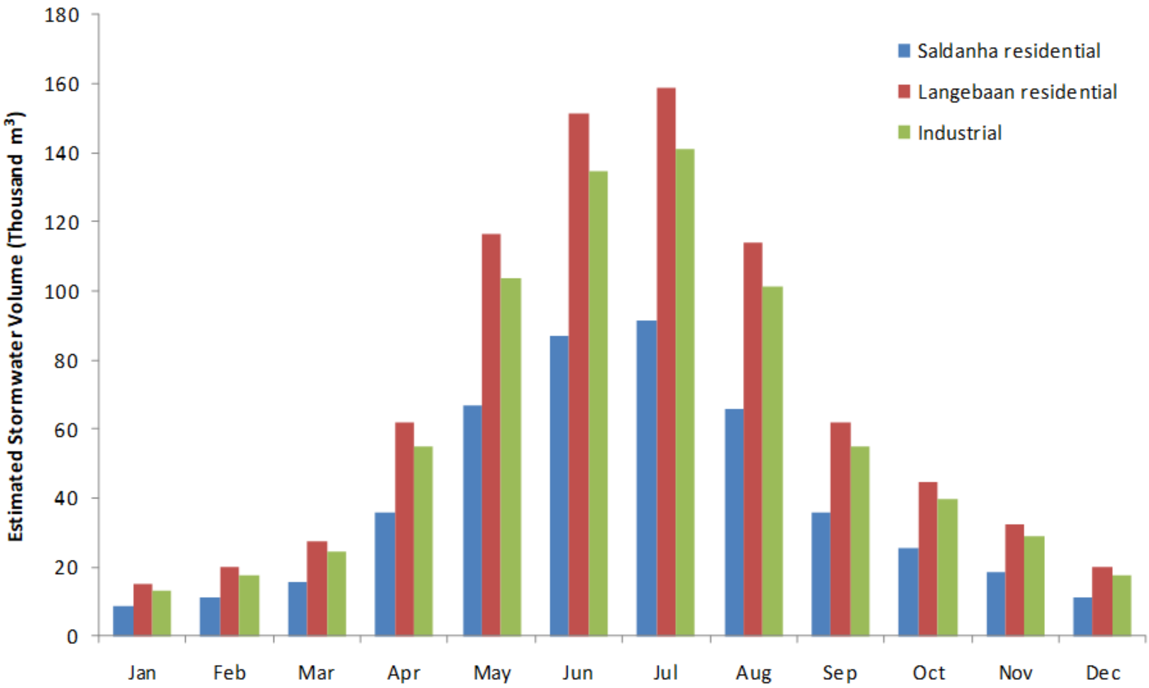


Figure 3.42. Monthly estimated storm water volume (m^3) for Saldanha and Langebaan residential areas and industrial area. Note that runoff from the Port of Saldanha and ore terminal have been excluded as this is now reportedly all diverted to storm water evaporation ponds.

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 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 wastewater treatment facility;
- Upgrade of the storm water management infrastructure as well as maintenance of existing ones; and
- Associated activities.

These upgrades require EA from the Western Cape Department of Environmental Affairs and Development Planning and the SBM commissioned NSOVO Environmental Consulting to conduct the Basic Assessment Process (NSOVO Environmental Consulting 2017). The draft Basic Assessment Report (BAR) was published in January 2019 and the process is still ongoing.

Despite the efforts by the iron ore industry to reduce dust emission (refer to Section 3.3.1) and to divert and storm 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 in 2012 (Anchor Environmental Consultants 2012). 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 and Wilkinson 2007) and reduce fitness of intertidal organisms by changing the rate of heat absorption and reflective properties of their shells (Erasmus and 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. 2010). 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).

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 (SBM) 2014). Furthermore, the following concerns have been registered by the SBM:

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

As a result of these concerns, a Stormwater Management Master Plan was drafted and is amended as new issues arise (living document) (Saldanha Bay Municipality (SBM) 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.

Stormwater litter traps

A collaboration between Sea Harvest and SBM saw the installation of a pilot stormwater litter trap in Saldanha Bay. This net, attached to the end of a stormwater outlet, traps any litter and debris suspended in the stormwater thereby preventing it from entering and polluting the Bay. The example shown in Figure 3.44 was the first installation of its type in within the Bay and unfortunately due to COVID-19 restrictions the project has not yet been expanded although, Sea Harvest and SBM hope to resume the initiative in the future (Sea Harvest Group Sustainability Manager, Kirshni Naidoo, pers. comm. 2020).

Figure 3.44. A stormwater litter trap installed in Saldanha Bay to prevent litter entering the Bay (Source: SADSTIA annual report 2019).

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 3.45. Premier Fishing is currently in the process of re-commissioning and upgrading their fish processing plant.

SA Lobster Exporters (Oceana Lobster Saldanha) discharges seawater from their operations into Pepper Bay. The average monthly effluent volumes range from 40 to 60 000 m^3, and this water cycles through tanks where live lobsters are kept prior to packing (CSIR 2002). It was not possible to obtain more updated information or data for effluent volume and quality. No CWDP has been issued (Source: DEA:OC) and it is unknown whether this organisation is compliant with the revised General Discharge Limit.

Live Fish Tanks (West Coast)-Lusitania take up and release wash water from Pepper Bay. Neither discharge volume nor 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.

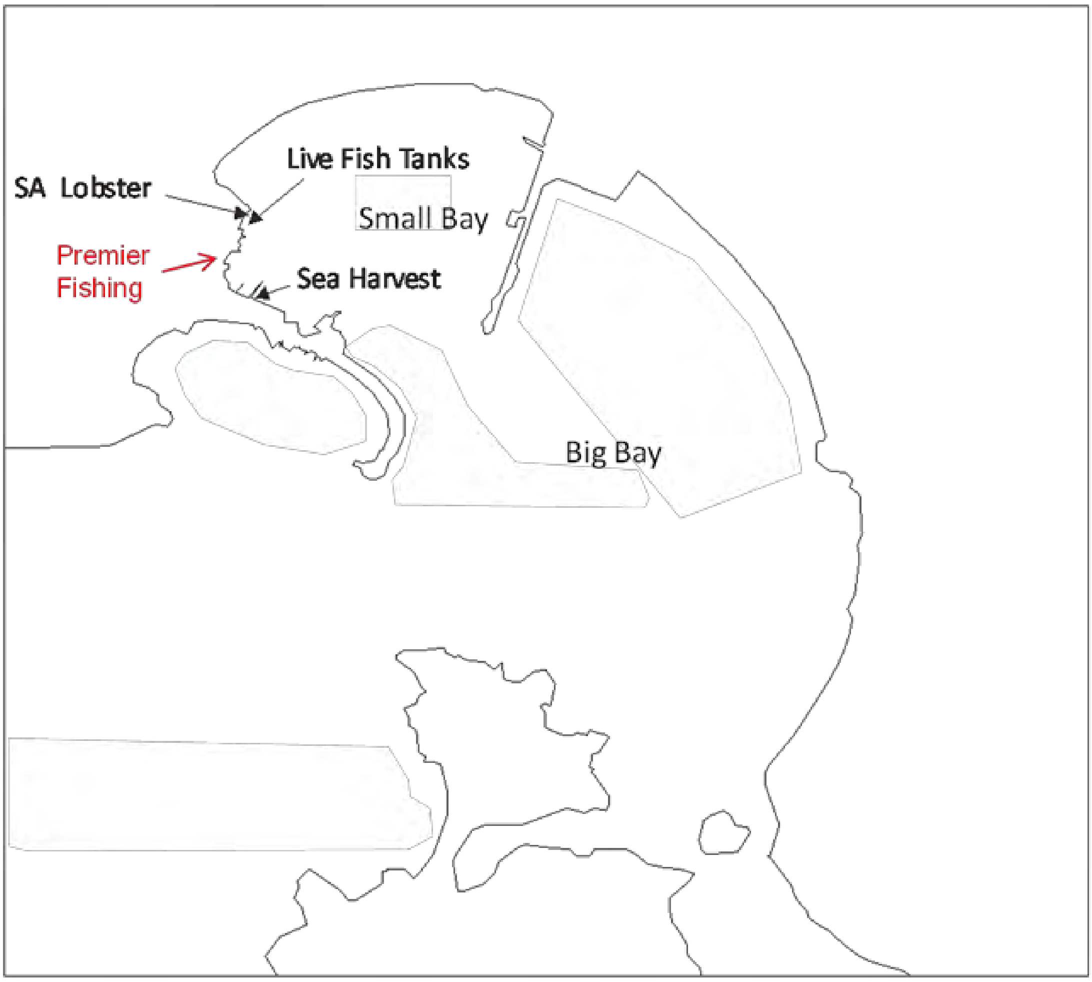


Figure 3.45. Location of seawater intakes and discharges for current and proposed seafood processing factories in Saldanha Bay. Current factories are indicated in black while the proposed Premier Fishing Fish Processing Plant is indicated in red.

SEA HARVEST FISH PROCESSING PLANT

Sea Harvest is a predominantly demersal trawl fishing company which was established in 1964. The fish processing factory is situated near the base of the causeway to Marcus Island in Saldanha Bay and processes mostly hake (*Merlucius paradoxus* and *M. capensis*) into a variety of primary fish products including fillets, cutlets, steaks and loins.

Sea Harvest discharges large volumes of treated effluent from the fish processing plant (FFP) into the sea. This includes seawater that has been used as wash-water as well as freshwater effluent originating from the fish processing and related activities such as cleaning.

Sea Harvest requires high volumes of potable water for the processing of fish. With the implementation of water restrictions in 2017, Sea Harvest implemented a RO plant (commissioned in April 2018) for the reclamation of potable water from seawater for daily operational consumption. This enabled the plant to reduce its fresh water consumption by 90% since 2016. The abstracted sea water is first treated at the Sea Water Treatment Plant before being pumped into a settling tank, which controls water levels. The sea water is then pumped to the RO Plant, Jetty and the Fresh Fish factory production floor. The effluent consisting of RO brine, Fresh Fish Processing (FFP) factory effluent (i.e., process seawater is used for cleaning processes to save potable water,.) and treated Added Value factory effluent are pumped through a Glass media filtration system for the removal of solids and diluted with sea water before being discharged.

Coastal Waters Discharge Permit

Sea Harvest Corporation (Pty) Ltd was issued with a CWDP in terms of Section 69 of the ICMA 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.

Anchor Environmental Consultants Pty (Ltd) was appointed by Sea Harvest to undertake scientific assessments required to meet the requirements of the permit conditions in 2018. 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 (n = 8) plus two control stations 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; and
6. Provision of recommendations on an effluent improvement plan to reduce the impacts of effluent in the marine environment.

From the dispersion modelling study completed by Anchor Environmental Consultants (Pty), the outcomes included (but were not limited to) the recommendation that the effluent outfall be moved further offshore along the Government Jetty to facilitate effective mixing of the effluent (Figure 3.46). The Department of Public Works authorised Sea Harvest to proceed with the installation of the new outfall pipeline on the Government Jetty, which was completed by January 2020. Sea Harvest received a draft Permit from the DEA in respect of the amendment applications made in 2018 on 16 August 2019 and the final amended permit was granted on 7 November 2019.

Figure 3.46. Outfall position at the end of the Government Jetty (33° 1'17.00"S; 17°57'6.76"E) for effluent originating at the fish processing plant, the reverse osmosis plant and the added value factory of Sea Harvest in Saldanha Bay.

With the intention to save municipal water and to improve effluent quality Sea Harvest reclaims potable water by means of a RO plant. As of the end of July 2022, it is reported that 99.8% of all water consumed at the Saldanha Operations is sourced from the Desalination Plant. Sea Harvest is committed to meeting effluent quality thresholds and environmental monitoring requirements as stipulated in the CWDP and continuous investigations are conducted in order to improve effluent quality. This is evidenced by the generally increasing overall annual compliance of the Sea Harvest effluent over the last 5 years.

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 (former 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).

The White stumpnose stock in the bay suffered severely as a result of recruitment overfishing over the last two decades (too many fish being caught before they had a chance to spawn) but reduction in fishing effort during the COVID-19 pandemic seems to have allowed some fish to spawn successfully, evidenced by an increase in the numbers of new recruits in the bay in 2022. This recovery is likely to be short-lived though unless levels of fishing mortality are reduced through the implementation of more conservative catch limits (reduced bag limits and increased minimum size limits). The reported annual catch of harders declined from around 130 tonnes per year over the period 2008–2012 to about 90 tonnes per year over the period 2013–2016, whilst effort remained fairly constant (Horton et al. 2019) (Figure 3.47). Data on fishing effort in recent years is lacking unfortunately (See Chapter 11: Fish).

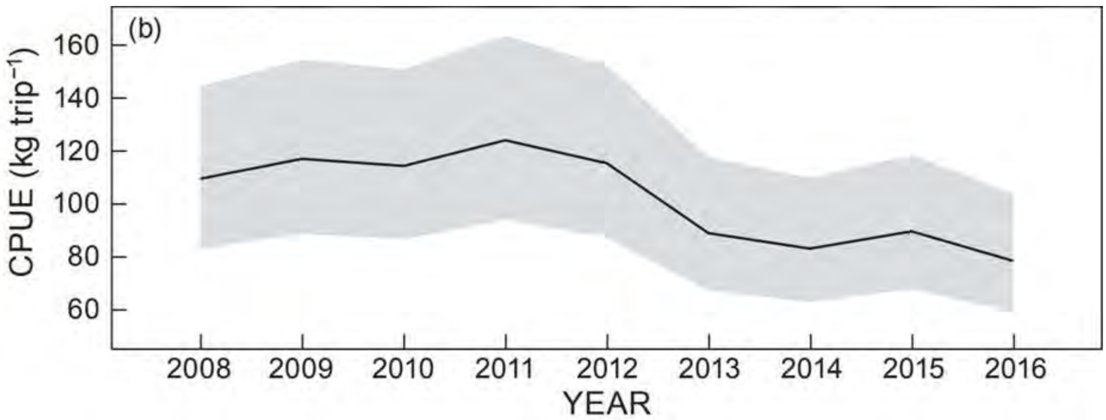


Figure 3.47. The standardised catch-per-unit-effort (CPUE) estimates for harders (with 95% confidence intervals, grey area) derived from mandatory catch records kept between 2008 and 2016 (Source: Horton et al 2019).

3.8 MARINE AQUACULTURE

The DFFE is driving sustainable development of the aquaculture sector in South Africa with the aim to create jobs for marginalised coastal communities and to contribute towards food security and national income. The development of the aquacultures sector is considered an important opportunity that can 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 since the 1980s. In January 2018 the then Department of Agriculture, Forestry and Fisheries (DAFF) was granted EA to establish a sea-based ADZ in Saldanha Bay and expand the total area available for aquaculture in the Bay to a maximum area of 884 ha from 464 ha allocated area, which is located within four precincts (Small Bay, Big Bay, Outer Bay North and Outer Bay South) (Figure 3.48). In 2018, it was reported that of the new established area, 151 ha was being actively farmed. In March 2020, 28 companies within the Saldanha Bay ADZ were registered on the Marine Aquaculture Right Register, of which only 15 companies were actively operational. More recently, as of September 2023, 30 entities have been granted marine aquaculture rights in the ADZ in terms of section 18 of the Marine Living Resources Act of 1998 (MLRA). Twenty-four of these right holders are currently operational, with two of these entities having more than one right allocated to them. The area of the ADZ actively being utilised is changing as new leases are being granted, new farms start, current lease holders expand their areas, or alternatively shrink in size, based on economic factors.

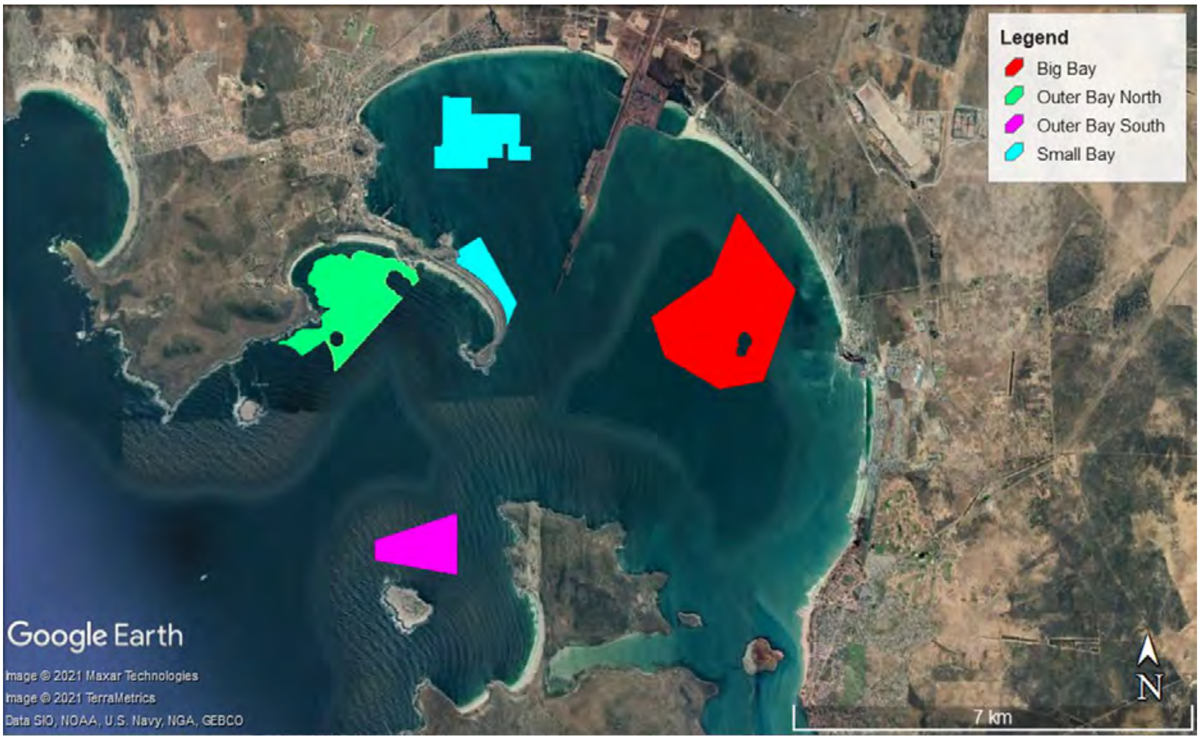


Figure 3.48. The four precincts that make up the entire ADZ area (884 ha).

3.8.1 Saldanha Bay Aquaculture Development Zone

The aim of establishing the ADZ is to (a) encourage investor and consumer confidence (b) create incentives for industry development (c) provide marine aquaculture services, (d) manage the risks associated with aquaculture; and to provide skills development and employment for coastal communities.

The ADZ project triggered activities listed in terms of Listing Notice 1 of the EIA Regulations, 2014, required a Basic Assessment which was undertaken in 2017. SRK Consulting (Pty) Ltd. (SRK) was appointed by the Branch Fisheries Management as the independent consultant to develop a framework for the Saldanha Bay ADZ and undertake the Basic Assessment. The competent authority (the then DEA) granted three separate Environmental Authorisations (EAs) for aquaculture in the Bay, these were issued to the then DAFF: Fisheries Management Branch, Southern Cross Salmon Farm (combined application with DAFF but separated into two EAs) and the Molapong Aquaculture farm on 8 January 2018. Four appeals to the EA were received from interested and affected parties and the Appeal Decision was issued by the then DEA, on 7 June 2018 which dismissed the appeals, and the EA was upheld. Subsequently, the Branch Fisheries Management within the newly formed DFFE appointed an Environmental Control Officer (ECO) to oversee the construction and operational phase of the ADZ and set up two committees: (1) a Consultative Forum (public and industry forum), which includes 125 members (as of October 2022) and meets every three months, and (2) the Aquaculture Management Committee (AMC) (government committee) which meets every two months, to ensure that the implementation of the ADZ is in line with the requirements specified in the EA and EMPr.

Branch Fisheries Management published a "Guideline for Bivalve Production Estimates for the Saldanha Bay Aquaculture Development Zone". The guideline serves to manage the ADZ through a precautionary approach with regards to instillation of new infrastructure for bivalve operators to ensure that the initial production threshold of 10 000 tons per annum (graded production) for the first two years is maintained, as specified in the EA, is upheld by the ADZ operators. Coupled with environmental monitoring, adherence to the authorised tonnages should facilitate adaptive environmental management in the ADZ as a whole. To this end, the Branch Fisheries Management appointed an independent specialist to compile a Sampling Plan for the ADZ which was reviewed by local and international stakeholders and experts (DAFF 2018), as well as a dispersion model for the finfish farming (more details on these two studies are provided in the 2019 and 2020 State of the Bay Report). Further work conducted for the ADZ by independent specialists includes, baseline macrofauna survey sampling undertaken by Capricorn Fisheries Monitoring in 2018, of which the macrofauna and physicochemical properties of the sediment were analysed by Steffani Marine Environmental Consultant and CSIR, respectively.

In 2020, the Branch Fisheries Management appointed Anchor to compile the ADZ baseline data collected in 2018 into a Benthic survey report (Mostert et al. 2020b) and to conduct the 2020 Annual redox survey and compile the resulting report (Mostert et al. 2020a). Additionally, the WWF South Africa through its Fish for Good initiative is currently implementing a Fisheries Improvement Project with the Saldanha Bay mussel sector (which is designated as a “catch and grow” fishery by the Marine Stewardship Council). WWF (SA) appointed Anchor to undertake the 2021 Benthic monitoring survey (Dawson et al. 2021) and conduct the Annual benthic chemical surveys for the Saldanha Bay ADZ for 2021 (Gihwala et al. 2021), 2022 (Gihwala et al. 2022), and 2023 (Dawson et al. 2023) in an effort to support the development of the ADZ by fulfilling the requirements as per the Sampling Plan. A summary of the 2021 reports is provided in the State of the Bay 2021 report while a summary of the 2022 chemical survey is provided in State of the Bay 2022 and the 2023 summary is provided below (Dawson et al. 2023). Furthermore, work is underway to complete multiple tasks including, but not limited to, the ongoing maintenance of continuous monitoring sensors within the Bay, a survey of the hard substrate/reef structure in Big Bay (Dawson et al. 2022, summarised in section 3.8.1.2 of State of the Bay 2022), data collection for dispersion model validation and a report on the first qualitative sampling of fouling organisms (the latter has not yet been released to the public and is therefore not summarised here). Additionally, reports have been issued to the DFFE on the scientific recommendations for the management and expansion of the ADZ along with updates to the Sampling Plan, based on the results of monitoring work completed to date.

Various guidelines and protocols have been developed for managing the ADZ, these include an ADZ Entanglement Guideline (May 2020), Compliance Strategy (June 2020) and Incident and Emergency Response Protocol (March 2021) and an Operational and Management guideline (Nov 2020). Additionally, DFFE has engaged with the SBWQFT to combine sampling efforts. The ADZ has had a three external Compliance audits of the EA and EMPr conditions, which have resulted in no significant non compliances. The ADZ is also audited monthly by the ADZ ECO to manage the compliance of the operators at a farm level as well as an ADZ level. The mussel industry is in the process of undertaking a Fisheries Improvement programme to improve overall fishing practices in the Rope Grown Mussel Industry, enhance the management of the fishery, establish critical partnerships, generate community support to inspire change in other fisheries in South Africa, and improve the accessibility of the Marine Stewardship Council standard in South Africa and other countries in the global South Africa. This initiative also includes a farmer awareness training programme on Endangered Threatened and Protected Species as well as training on the EA and EMPr conditions.

2023 ANNUAL BENTHIC CHEMICAL SURVEY

Monitoring of benthic impacts below mariculture installations is international best practice and is being undertaken in Saldanha Bay by DFFE to validate dispersion model predictions of minimal impact. Organic deposition and the subsequent decomposition by sediment bacteria increases oxygen demand which can lead to anaerobic (without air) conditions in the seabed beneath both finfish and shellfish farms. Ammonification and sulphate reduction to sulphides occur as typical responses to lowering of the oxygen reduction (Redox) potential. Sediment organic carbon, redox potential (Eh) and total sulphides (S^{2-}) have effectively been used in describing adverse impacts below finfish aquaculture and can be used to classify sediments associated with fish farming into five organic enrichment groups: two oxic (oxygen present), two hypoxic (oxygen deprived), and one anoxic (without oxygen) group. The Aquaculture Stewardship Council (Aquaculture Stewardship Council 2017) provides threshold limits directly below the aquaculture structures, as well as at the edge of the Acceptable Zone of Effect (AZE), a prescribed distance from the aquaculture structures — defined as 30 m from a fish cage array or shellfish longlines. Failure to meet the prescribed thresholds at the AZE limit or at finfish cages or directly below shellfish longlines will require management intervention and/or additional sampling (DAFF 2018). Non-compliance is dependent on the farm or AZE station being significantly greater than levels measured at the reference/control stations.

The 2023 annual redox survey of the Saldanha Bay ADZ was conducted during the annual Saldanha State of the Bay survey (4–9 April 2022) (Gihwala et al. 2022). Sediment samples for the measurement of redox potential and sulphide (S^{2-}) were collected at 27 stations in Big Bay, Small Bay and Outer Bay North (Figure 3.49). Scientific divers collected triplicate sediment samples at each of the 18 stations where macrofauna were sampled in Big Bay and Outer Bay North. Additionally, triplicate samples were collected at control and impact sites in Small Bay as was previously done in the 2020 rapid synoptic survey (Mostert et al. 2020b). In the finfish precinct in Big Bay, three sediment samples were collected at 0 m, 30 m and 60 m along a transect from the edge of the proposed finfish cage location.

Figure 3.49. Stations sampled during the annual redox survey of the Saldanha ADZ, control sites are indicated with blue arrows while impact sites are indicated with red arrows, yellow arrows indicate sites in Finfish area (controls) and green markers indicated locations of continuous environmental sensors.

The 2021–2023 surveys implemented some improvements to the sampling protocol, namely collection by divers rather than grab samples which reduced exposure to air and the risk of oxidation of sediment sample; the use of the methylene blue method rather than the ion-selective electrode protocol along with revised sediment Ecological Quality Standards (EQS) developed by Cranford et al. (2020). Results for the chemical surveys are available for the period 2019–2023.

For most sites in the five surveys, redox values fell within -100 mV redox threshold as stipulated by the Sampling Plan (Figure 3.50). In instances where thresholds were exceeded, redox measurements were not consistently, significantly different from those measured at control sites. Notably the redox values at all of the Small Bay sites (impact and control sites) were observed to be lower/more negative than all previous year's results in Small Bay (Figure 3.50). However, all Sulphide values within Small Bay were low and fell within the 'High'/Oxic A category (Figure 3.50). The lowest redox values in the 2023 survey tended to be at the control sites. In the 2023 surveys, sulphide measurements at nearly all impact sites did not exceed the moderate EQS thresholds (>250 µM) and only two sites (one impact site and one control site in North Bay) exceeded the threshold of 500 µM equivalent to a poor EQS (Figure 3.50). However, these values were outliers, with all other replicates being below or very close to the laboratory detection limit and the high variance as a result of these outlier values means that these sites did not differ significantly from the prescribed threshold value. Average sulphide values within North Bay fell within the High/Oxic A EQS, with the 2023 average very similar to that of 2022 (453 and 464 µM respectively) and both below the Threshold.

The Big Bay site, B4, previously flagged as being of concern due to high Sulphide and Redox values in 2021 and 2022, had significantly lower values in 2023 than in previous years and fell within the Moderate to Good categories. Suggesting that previous high results may have been the result of temporary and variable sediment and organic matter deposition. And no further management action is required. Despite this, it is still advised that previously recommended increased monitoring at two new sites (B 9 and B 10) should still be sampled in the next annual benthic chemical survey to address the spatial gap in sampling sites downwind of mariculture infrastructure. This can help ascertain if the previously poor sediment quality at site B4 was due to the bathymetry or if there were wider spatial scale benthic impacts occurring downwind of the bivalve infrastructure. Average redox concentrations for Small Bay were notably higher than those measured in sediments collected from Big Bay or Outer Bay North (Figure 3.50).

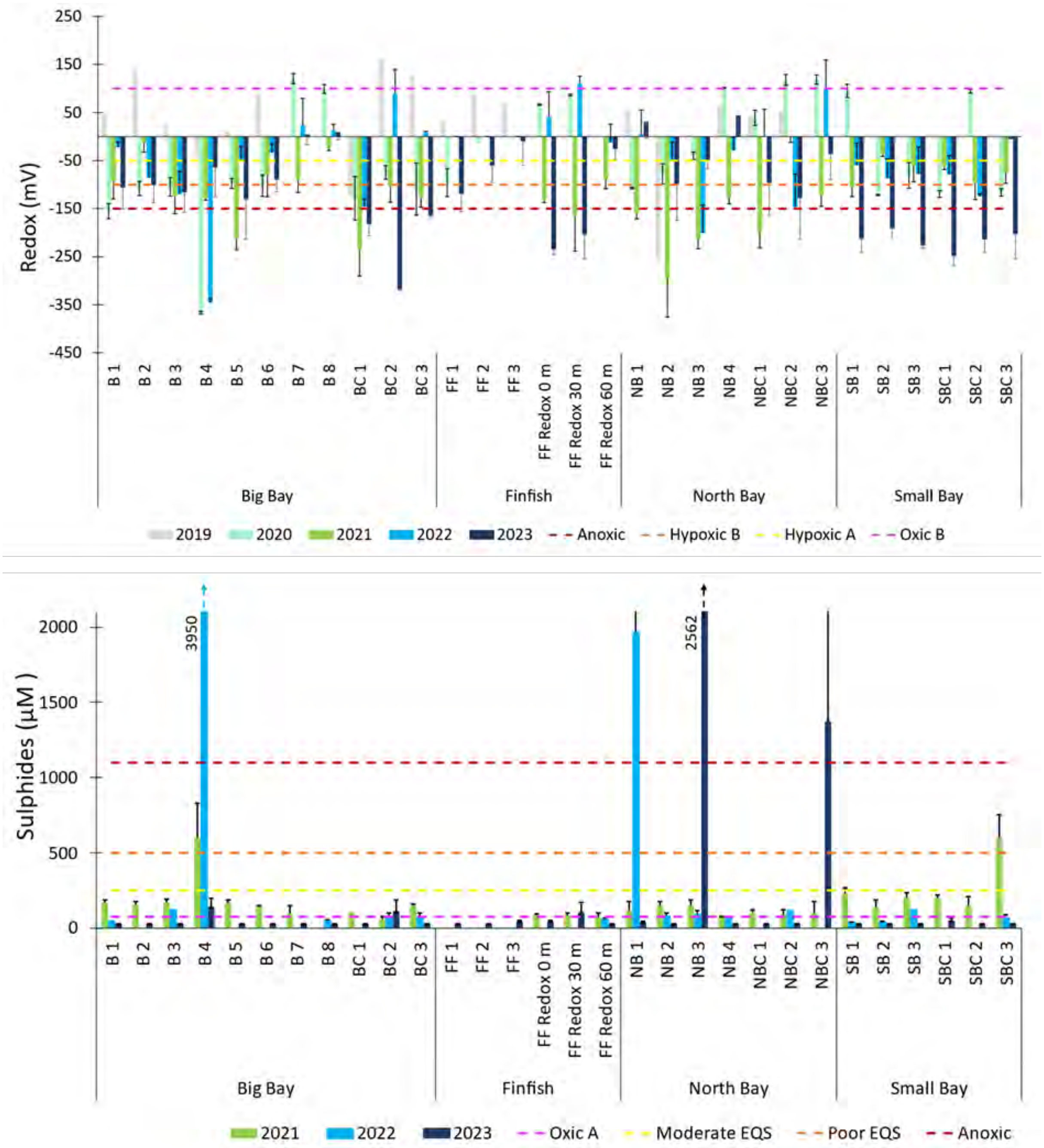


Figure 3.50. Redox (mV) and sulphide (µM) measurements recorded during the annual 2023 ADZ monitoring survey (bars ± standard error). Included are redox values sampled during the 2019–2022 surveys, and Sulphide values from 2021 & 2022 (Source: Dawson et al. 2023).

This is attributed to both the regular, seasonal hypoxia of near bottom water due to upwelling linked water movements, organic loading and relatively high retention times; as well as anthropogenic carbon and nitrogen inputs including fish factory wastes, biogenic waste from mussel and oyster culture and sewage effluent (Clark et al. 2021).

Outcome/take home message: The annual 2019–2021 and 2023 chemical surveys did not reveal sulphide concentrations or redox values that trigger management action in terms of the sampling plan. Any threshold exceedances that did occur were not significantly difference between farmed and reference sites, thus suggesting natural or bay wide impacts as opposed to specific ADZ related impacts. The single site highlighted as being of concern in the 2022 report (B4) had significantly lower values in 2023 than in previous years and fell within the Moderate to Good categories. On balance, the annual chemical survey data suggests that current levels of mariculture production within the ADZ are not having significant negative impacts on sediment (and sediment water interchange) quality. It must be noted that the impact sampling sites are located in between aquaculture infrastructure and are not directly under bivalve longlines and rafts. These results do not, therefore, contradict the earlier studies where a localised impact directly beneath the rafts was detected. Small Bay is identified as the area with the highest average sediment sulphide concentrations which is attributed to both hydrodynamic process, natural and anthropogenic inputs (including mariculture).

3.8.2 AQUACULTURE SUB-SECTORS

Most established operators hold rights to farm mussels (*M. galloprovincialis* and *Choromytilus meridionalis*) and the pacific oyster *Crassostrea gigas*, while finfish rights (*Salmo salar* and *Oncorhynchus mykiss*) have only been issued to two farms since 2014. 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). Most of the farming occurs in Small Bay, however, operations have expanded in Big Bay to include oysters and mussels, and mussels are being grown on lines in Outer Bay North. 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 Branch Fisheries Management therefore included alien trout species in their application for EA. Consequently, the EA issued to for the ADZ includes the following alien finfish:

- Atlantic salmon (*S. salar*);
- Coho salmon (*O. kisutch*);
- King/Chinook salmon (*O. tshawytscha*);
- Rainbow trout (*O. mykiss*); and
- Brown trout (*S. 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*).

SHELLFISH MARINE AQUACULTURE

Raft culture of mussels has taken place in Saldanha Bay since 1985 (Stenton-Dozey et al. 2001). Larvae of the mussels *M. galloprovincialis* and *C. meridionalis* attach themselves to ropes hanging from rafts and are harvested when mature. Mussels are graded, washed and harvested on board a boat. In 2015, the mussel sub-sector (based in Saldanha Bay) contributed 48.83% to the total mariculture production and was the highest contributor to the overall mariculture productivity for the country (DAFF 2016). Mussel production was fairly consistent between 2007 and 2011, after which it showed a steady increase, more than tripling from 2012 to 2019 when it peaked at 3 053 tonnes (Figure 3.51).

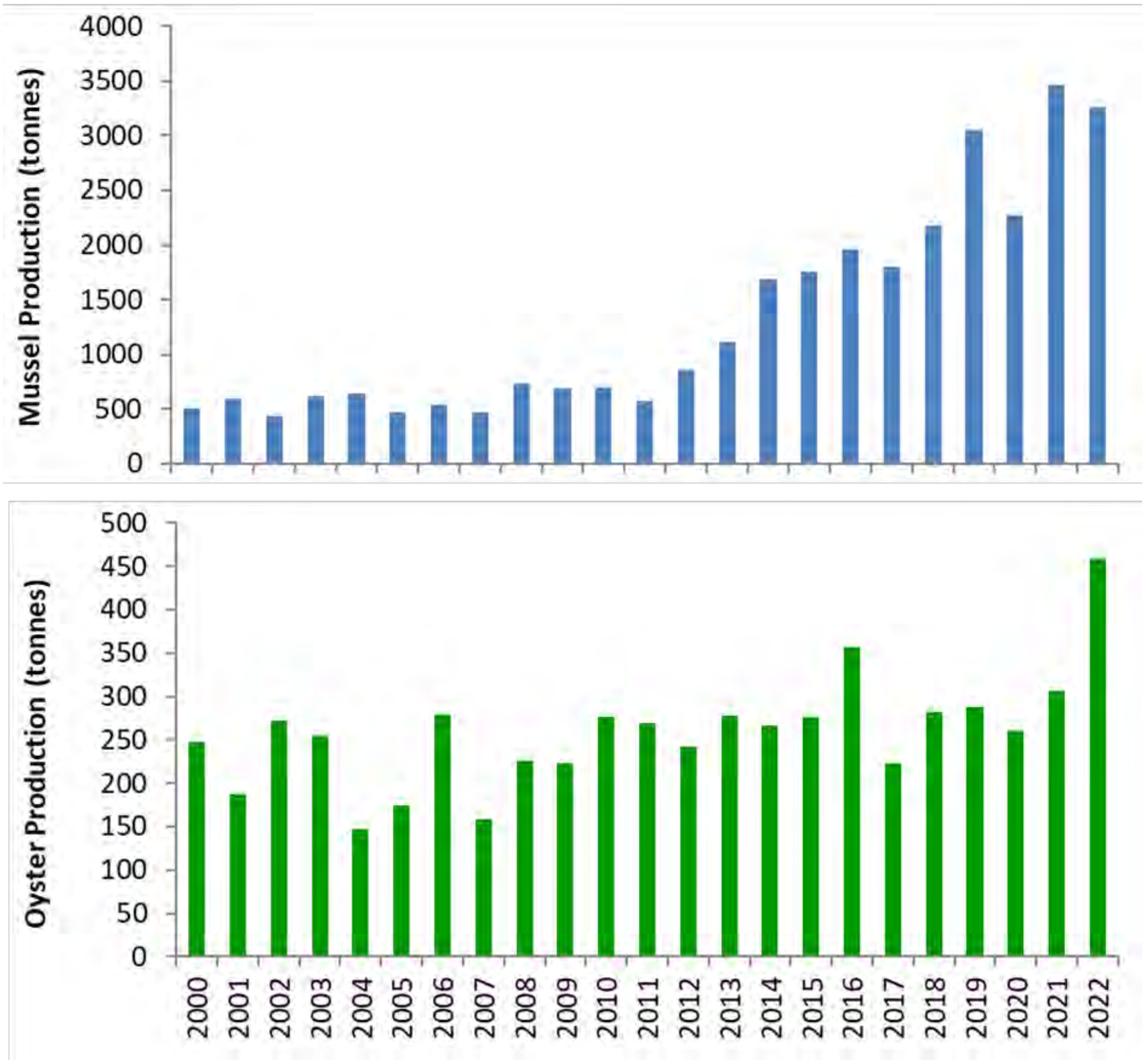


Figure 3.51. Annual mussel (top) and oyster (bottom) production (tonnes) in Saldanha Bay between 2000 and 2022 (source: Department of Forestry, Fisheries and the Environment 2022 unpublished data, which may be subject to change). Data represent production from January to December of each year.

In 2020, mussel production dropped by roughly 25% to 2 276 tonnes, it is possible that the COVID-19 pandemic influenced the production, as the highest production values on record were reported in 2021 (3 459 tonnes) with the 2022 production dropping slightly to 3 262 tonnes (Figure 3.51). Oyster production fluctuated around an average of 240 ± 45 tonnes per annum between 2000 and 2015. Oyster production peaked in 2016 at 357 tonnes per annum before decreasing again with the 2017 to 2021 average production being at 271 ± 32 tonnes of oysters were produced (Figure 3.51). In 2022, the production reached an all time record high of 458.9 tonnes.

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 pseudofaeces, 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).

A 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 2 500 jobs for the region without compromising the environment.

Benthic macrofauna and sediment quality monitoring undertaken in Big Bay and Outer Bay in terms of the sampling plan has not detected significant impacts from mariculture activities on soft sediment habitats at Impact sampling sites located within the precincts i.e., any impacts that may exist, do not extend beyond the area immediately below mariculture infrastructure and the sediment quality and macrofaunal communities are not significantly different from samples collected from Control sites outside of the ADZ precincts. Bivalve production levels in these two precincts remain well below those from Small Bay and the deeper, naturally better flushed benthic habitat is less susceptible to accumulation of organic matter.

In 2023, a paper was published which extended knowledge of the effects of mussels farming on benthic biogeochemistry and macrofaunal communities, and provided first time records for the effects of oyster farming in Saldanha Bay (Probyn et al. 2023). Results showed that species diversity was significantly lower in the farmed sites relative to control sites. Variations in community structure between Small Bay and Big Bay was partially related to physical aspects such as sediment particle size distribution and wave energy. Biogeochemical fluxes showed insignificant differences in sediment oxygen demand between the farm and control sites (Probyn et al. 2023). Other biogeochemical factors varied with Ammonium regeneration greater at farm sites than controls, and fluxes of oxidised Nitrogen less at farmed sites than at controls. Finally, a measure of community disturbance, the Warwick statistic, showed that the greatest level of disturbance occurred at the mussel farm site that has been operating for the longest time (established in 1984), relative to the newer mussel farm site (established in 2008) and oyster farm site (operating for approximately 10 years at the time of sample collection). This suggests that the longer a farm is in place the more the community may start to diverge/change to withstand disturbance, with suspension feeders the more important discriminating species for control sites, and detritivores and scavengers for farm sites; although, exceptions were common (Probyn et al. 2023).

FINFISH CAGE FARMING

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). Finfish cage culture has been pioneered in Saldanha Bay and was largely focused on the farming of salmonid species, including Atlantic salmon (*S. salar*) and rainbow trout (O. mykiss). Both species are non-native to South Africa; however, O. mykiss is farmed in many parts of the country in ponds and raceways, but this has been severely impacted by the drought and is limited in terms of seasonality of rain and temperatures. Molapong Aquaculture (Pty) Ltd (Molapong) piloted under 50 tonnes of finfish per annum in Big Bay within Saldanha Bay. This experimental phase was successful and Molapong appointed Ecosense CC to conduct a Basic Assessment process to obtain EA for the phased installation of sea cages on 40 ha in Big Bay and 15 ha near Jutten Island for the production of finfish, mussels and seaweed in Saldanha Bay up to a total of 2000 tonnes per year over both lease areas. The EA was issued on 8 January 2018. The pilot phase within the bay concluded in 2021/22 and all finfish cages were removed from the bay. Therefore, there is presently no active finfish mariculture in the Saldanha Bay ADZ and none planned for the foreseeable future. This is likely due to the fact that it has been determined that the majority of the sea floor below the designated Finfish area is covered by reef (~79.9%) and therefore development of the finfish area within Big Bay is not advised. More information on the marine ecological impacts of finfish farming can be found in previous versions of this monitoring report.

KELP CULTIVATION

In June 2022, the final report of a Pre-feasibility study investigating the potential for commercial kelp cultivation along the West Coast was published (CSIR 2022). The project, which was a collaborative effort between the aquaculture industry, government, research institutions and academic institutions, aimed to review and summarise available biological, environmental, and economic information on kelp culturing and to set up facilities for conducting pilot experiments on kelp seeding. This, to investigate the available sea space, financial viability and appetite of the industry for such an enterprise, and to determine if it would be worthwhile to proceed to the feasibility study stage. The project focused on three west coast kelp species, sea bamboo *Ecklonia maxima*, bladder kelp *Macrocystis pyrifera* and split fan kelp *Laminaria pallida*. Given that South Africa already has an existing industry for kelp, based on the harvesting of natural populations and the collection of drift kelp washed up on the shoreline, it was determined that the successful commercial cultivation of these three kelp species would provide access to the global market.

Research showed that kelp cultivation is possible at ten offshore areas, and inshore areas in the Saldanha Bay ADZ. A rope raft for the cultivation of kelp in the ADZ was designed and a pilot experiment will be run in the bay whereby this raft will be seeded using sporophytes produced during laboratory trials (conditional on the receipt of further funding). An additional, potentially viable, option included the installation of 4 ha of kelp longlines within the bay, to be harvested twice annually.

The report includes specialist insights by Emeritus Professor John J Bolton; market, technical and financial insights; as well as providing information regarding the fit of kelp mariculture in a local context. Overall, it was recommended that investigations proceed to the techno-economic feasibility stage to facilitate the collection of further data and information to support a decision to invest in kelp production mariculture.

4 MANAGEMENT AND POLICY DEVELOPMENT

4.1 Introduction

Continuously accelerating urban and industrial development poses a significant threat in the form of fragmentation, loss of natural habitat and loss of ecological integrity of remaining marine and coastal habitats in Saldanha Bay and Langebaan Lagoon. While many developments are ostensibly "land-based", several rely on ships to transport raw material and/or processed products to and from them. While the increase in vessel traffic associated with each of these individual developments may be minor, collectively they contribute to the ever-increasing number of vessels visiting the Bay each year as well as to the 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 into 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 Industrial Development Zone (IDZ) and associated industrial development) and conservation areas (Ramsar Site, Marine Protected Areas (MPAs) and National Parks) are immediately adjacent to one another. Furthermore, the Saldanha Bay environment is utilised by a variety of potentially conflicting activities including industry, fishery, mariculture, recreation and the natural environment itself. This situation necessitates sustainable development that is steered towards transformed or environmentally resilient locations and away from sensitive areas (Thérivel et al. 1999). To better understand management practices within Saldanha Bay, it is important to understand the legislation governing the area under consideration. This chapter provides a brief overview of some of the most important legislation pertaining to the area:

4.2 Legislative Context

4.2.1 National Environmental Management Act (Act 107 of 1998)

The National Environmental Management Act (NEMA) establishes principles for decision making on matters that affect the environment, to provide for cooperative environmental governance. Activities that have the potential to impact on— (a) the environment; (b) socio-economic conditions: and (c) the cultural heritage, need to be identified and must be considered, investigated and assessed prior to their implementation and reported to the organ of state charged by law with authorizing, permitting, or otherwise allowing the implementation of such an activity.

4.2.2 Environmental Impact Assessment Regulations 2014

The Environmental Impact Assessment (EIA) regulations promulgated in terms of Chapter 5 of NEMA control certain listed activities. These activities are prohibited until Environmental Authorisation (EA) has been granted by the competent authority.

4.2.3 National Environmental Management: Integrated Coastal Management Act (Act 24 of 2008)

The National Environmental Management: Integrated Coastal Management Act (No. 24 of 2008) (ICMA) is responsible for the integration and coordination of various coastal and marine management efforts. Chapter 8 Section 69(1) of ICMA controls marine and coastal pollution and provides that no person may discharge effluent originating from a land source into coastal waters without a General Authorisation (GA) or Coastal Waters Discharge Permit (CWDP), depending on the effluent quality and volume. Any discharges of effluent must be compliant with waste standards or water management practices prescribed under ICMA and the National Water Act (NWA). The CWDP Regulations (Government Notice Regulation (GNR). 382, Government Gazette 42304, March 2019) seek to provide an administrative framework to implement Section 69 of the ICMA and stipulate timeframes, renewal application processes, applicable fees and information to be submitted as part of an application for a CWDP. The Department of Forestry, Fisheries and the Environment: Oceans and Coasts (DFFE:O&C) are still in the process of finalising regulations for General Discharge Authorisations.

COASTAL POLLUTION CONTROL IN SOUTH AFRICA

Coastal water management aims to maintain or improve the quality of water in order to make it suitable for various uses. This is called the Receiving Water Quality (RWQ) framework and led to the development of Water Quality Guidelines (WQGs). In South Africa, WQGs are legislated and include appropriate contaminant limits that must be met by every user/outfall in the receiving environment, restrictions on certain types of discharges in specific areas, bans on certain substances, and even financial incentives to reduce pollution at its source. South Africa uses two methods to implement the RWQ framework: water quality-based effluent limits (WQBEL) and the Uniform Effluent Standard (UES) approach. Guidelines for water quality have been published for different uses in both inland and marine waters, encompassing activities like human consumption, aquaculture, recreation, and industrial use, as well as protecting biodiversity and ecosystems (DWAF 1995a, 1995b). The 1995 WQG for Coastal Marine Waters provide details about various properties and constituents of water along with their guideline values and background information (DWAF 1995a, 1995b). In 2018, the Department of Environmental Affairs (DEA) released updated WQG for Coastal Marine Waters: Natural Environment and Mariculture, but these have not yet been promulgated (DEA 2018). Similarly, the Department of Environmental Affairs (DEA) published guidelines for recreational use of coastal waters in 2012. Although these guidelines are not yet legally binding, they set standards for water quality suitable for recreational and mariculture activities based on aesthetic, safety, and hygiene considerations (DEA 2012).

4.2.4 The National Water Act (Act 36 of 1998)

The NWA 36 of 1998 makes provision for the conservation and development of water resources in South Africa. Under this act, certain water uses and activities in or near a watercourse would necessitate a Water Use Licence (WUL) before it may commence.

4.2.5 National Environmental Management: Protected Areas Act (Act 57 of 2003)

The National Environmental Management: Protected Areas Act (NEMPAA) primarily provides for the protection and conservation of ecologically sensitive areas and those which are representative of the Republic's biological diversity. Chapter 2 states that MPAs declared in terms of section 43 of the Marine Living Resources Act (MLRA) 1998 (Act No. 18 of 1998), and which exists when the NEMPAA Amendment Act, 2014, takes effect, must be regarded as such. Chapter 3 of the Act empowers the Minister to declare an area to be a MPA where various activities are prohibited.

4.2.6 National Environmental Management: Biodiversity Act (Act 10 of 2004)

The National Environmental Management: Biodiversity Act (NEMBA) provides legal protection and management of South Africa's biodiversity within the framework of NEMA and the sustainable use of biological resources, with the aim to manage and conserve South Africa's biodiversity. The Act seeks to protect species and ecosystems that require national-level safeguarding. It promotes the sustainable utilisation of indigenous biological resources and emphasises the fair and equitable sharing of benefits derived from activities involving such resources. The legislation also establishes the South African National Biodiversity Institute (SANBI), defining its roles and functions.

4.2.7 Biodiversity Offset Guidelines

South Africa introduced its first National Biodiversity Offset Guideline, published under NEMA in Government Notice 3569 of Government Gazette 48841 on 23 June 2023. This guideline addresses the decline of biodiversity and ecosystem degradation highlighted in the National Biodiversity Assessment 2018. Its purpose is to counterbalance biodiversity loss due to unsustainable development. Biodiversity offsetting, a novel practice in the country, is outlined in the guideline, aiming for consistent and evidence-based implementation. The guideline applies to terrestrial and freshwater areas, offering direction on offsetting requirements and binding responsibilities. It doesn't replace existing regulations but complements them. The biodiversity offset process requires assessing potential impacts of the project on specific biodiversity assets. Where residual negative impacts (impacts post mitigation) are assessed to be of medium or high significance, a biodiversity offset would be required. When an activity will have a very high residual impacts, including when it will result in the loss of irreplaceable biodiversity, such as Critical Biodiversity Area 1 (Irreplaceable), biodiversity offsets would not be appropriate and the project cannot be approved in that area.

4.2.8 The Marine Living Resources Act (Act 18 of 1998)

The objectives and principles of the MLRA deal with the management of marine living resources, the need to protect whole ecosystems, preserve marine biodiversity and minimize marine pollution, as well as to comply with international law and agreements. Chapter 4 of the Act empowers the Minister to declare an area to be a MPA where various activities are prohibited.

4.2.9 Sea Birds and Seals Protection Act (Act 46 of 1973)

This legislation explicitly prohibits the harassment or unnecessary disturbance of seabirds and also bans the killing, capture, or deliberate disturbance of these birds. The South African Policy on the Management of Seals, Seabirds, and Shorebirds (2007) commits the government to developing action plans aimed at reducing incidental mortality of seabirds, seals, and shorebirds caused by fishing operations. A Biodiversity Management Plan was implemented in 2013 with revisions in 2019 and 2022 (See Chapter 12: Birds and Seals) specifically for the African Penguin, with the goal of ensuring its long-term survival.

4.2.10 Convention on Biological Diversity 1992

The Convention on Biological Diversity (CBD) serves as the international legal framework aimed at safeguarding biological diversity, promoting the sustainable utilisation of its components, and ensuring the just and equitable sharing of benefits derived from genetic resources. The Convention addresses biodiversity across various levels, including ecosystems, species, and genetic resources. South Africa became a signatory to the CBD on 4 June 1993 and has been a member state of the Convention since 2 November 1995.

4.2.11 National Heritage Resources Act (Act 25 of 1999)

The National Heritage Resources Act (NHRA) provides the legal framework for the management of cultural and heritage resources in South Africa. In terms of Section 38 of the Act, it is required that a heritage assessment be undertaken before development or other activity which will change the character of a site, and for the responsible heritage resources authority be informed and granted the opportunity to provide feedback.

Coastal Protection Zone

The coastal protection zone consists of land falling within an area declared as a sensitive coastal area in terms of the Environment Conservation Act (Act No. 73 of 1989) (repealed by the NHRA). Under ICMA, this zone extends 100 m inland of the coastal and estuarine high-water mark in urban areas which are presently zoned for residential, commercial, industrial or multiple-use purposes, and 1 000 m inland for all areas zoned as agricultural or undetermined use and that are not part of a lawfully established township, urban area or other human settlement. A Coastal management line (CML) and Coastal Setback Line (CSL) have also been established to protect the coastal protection zone. Any future development seawards of the coastal management/setback lines will automatically be subject to an EIA, and would have to be compatible with the vision and objectives defined in the Coastal Management Programme (DEA&DP 2014).

4.2.12 World Heritage Convention Act (Act 49 of 1999)

This legislation enables the integration of the World Heritage Convention into the legal framework of South Africa. It encompasses the enforcement and execution of the World Heritage Convention within the country and addresses the development of comprehensive management plans for World Heritage Sites.

4.2.13 Spatial Planning

Several laws and regulations play a role in shaping and guiding spatial planning. These include, amongst others, the NEMBA, the Spatial Planning and Land Use Management Act 16 of 2013 (SPLUMA) and the Marine Spatial Planning Act (MSPA).

Spatial Planning and Land Use Management Act

SPLUMAs purpose is to establish a new framework for managing planning permissions and approvals, setting guidelines for new developments, and defining legal land uses in South Africa. It functions as a foundational law, outlining general principles for provincial laws that will manage planning. Additionally, SPLUMA clarifies how planning law interacts with other legal regulations and policies.

THE MARINE SPATIAL PLANNING ACT

The MSPA establishes the necessary framework for implementing marine spatial planning within South Africa. It aims to develop and execute a systematic approach for effectively managing the ever-changing marine environment while ensuring access for all sectors. It seeks to promote sustainable economic opportunities within the realm of the ocean economy, while concurrently conserving marine resources for the benefit of both current and future generations. The act also underscores the importance of comprehensive documentation, mapping, and understanding of the various physical, chemical, and biological processes occurring within the ocean, including identifying opportunities and potential threats. Lastly, the MSPA serves to ensure that South Africa meets its international obligations related to marine management and conservation.

The Draft Marine Biodiversity Sector Plan (2023) has been drafted to support the development of Marine Area Plans. Marine Sector Plans specify the overall developmental objectives and priorities of each sector from a national point of view and the extent of its spatial presence and interests. The published draft Marine Sector Plans are therefore not the integrated Marine Area Plans but are critical inputs for the next step of developing integrated cross-sectoral Marine Area Plans and as such, they serve as the sectors' proposals that will need to be considered during the development of Marine Area Plans (Harris et al. 2022b, 2022a).

MARINE CRITICAL BIODIVERSITY AREAS

The Western Cape Biodiversity Spatial Plan (BSP) identifies priority areas for biodiversity conservation, encompassing diverse ecosystems, species, and ecological processes. It includes Critical Biodiversity Areas (CBA), Ecological Support Areas (ESA) and Protected Areas (Pool-Stanvliet et al. 2017, Harris et al. 2022b). BSPs have been developed for both the coastal marine and the terrestrial environment (including aquatic).

The Management objectives of MPAs are defined by the management plan of each MPA. Marine CBA Natural areas are areas in a natural/near-natural ecological condition and should be maintained in this state. Together with MPAs, CBAs are required to meet biodiversity targets. Marine CBA Restore areas, are areas that are no longer in a natural ecological condition and which should be restored. Marine ESAs are areas important primarily for ecological processes and ecosystem services. The majority of Saldanha Bay is composed of ESA, while there are localized regions of CBA Restore near the mouth of the Bay the Lagoon. Additionally, the Langebaan Lagoon and all islands throughout the system are an MPA (Figure 4.1).

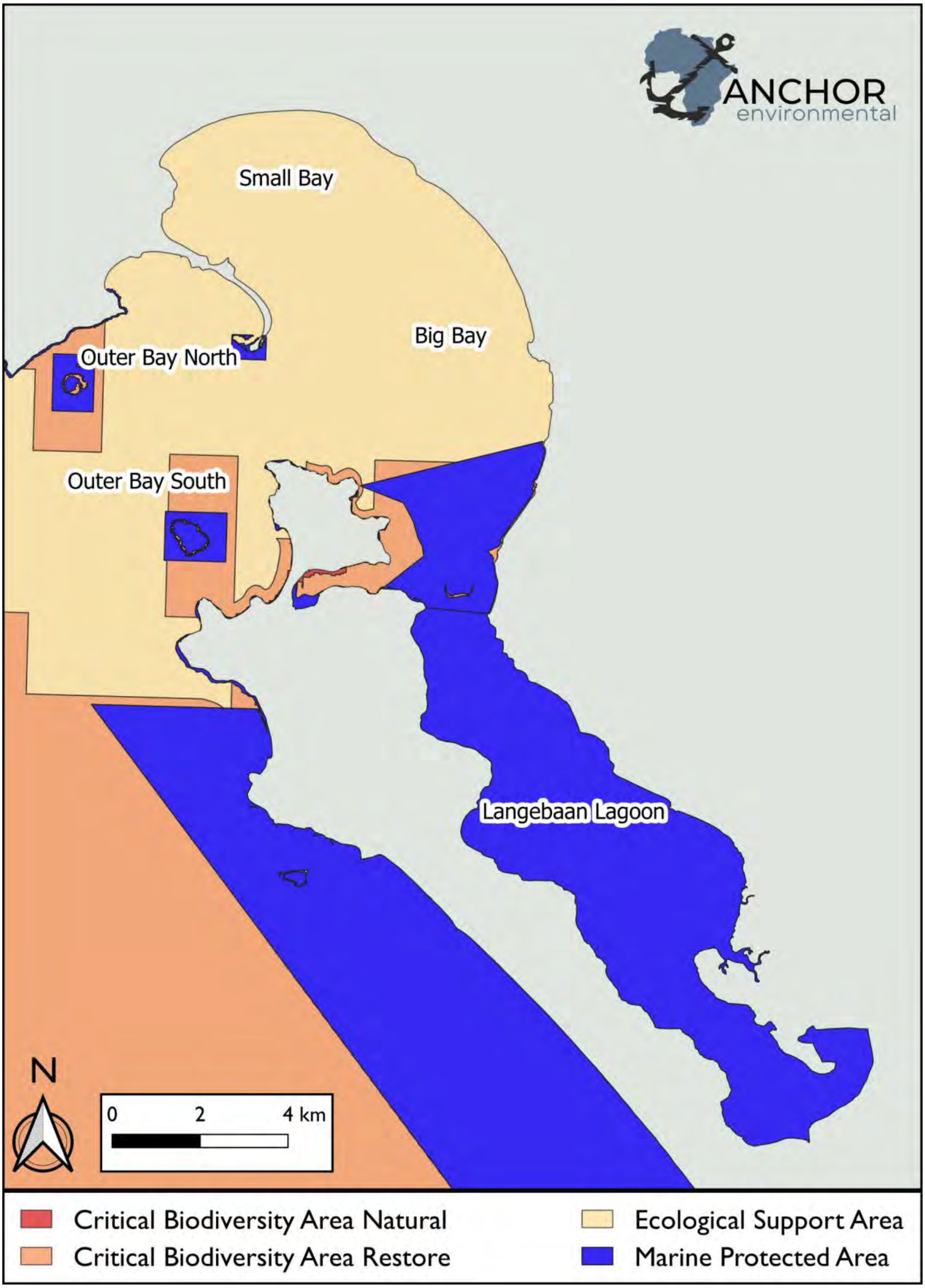


Figure 4.1. Marine Critical Biodiversity Areas, Ecological Support Areas and Protected Areas in the Saldanha study site. Data source: Harris et al. (2022b). Map by Anchor 2023.

TERRESTRIAL CRITICAL BIODIVERSITY AREAS

Terrestrial CBA 1 (Irreplaceable) are areas in a natural condition, while CBA 2 (Restore) areas are degraded or in secondary condition. CBAs should be maintained in a natural or near-natural state, with no further loss of habitat, while degraded areas should be rehabilitated. Only low-impact, biodiversity-sensitive land-uses are appropriate. Terrestrial ESA 1 and ESA 2 areas are not essential for meeting biodiversity targets, but are important in supporting the functioning of Protected Areas or CBAs. These areas should be maintained in a functional, near-natural state or be restored and/or managed. Some habitat loss is acceptable. Other Natural Areas are not currently identified as a priority, but retain most of their natural character. Habitat and species loss should be minimised to ensure ecosystem functionality through strategic landscape planning. The terrestrial environment along the Saldanha coastline area consists of a mosaic of CBA and ESA areas, with the greatest portion consisting of CBA 1, indicating that the area is largely in a natural or near-natural state (Figure 4.2).

PROTECTED AREAS

Protected Areas include Forest Nature Reserves, Forest Wilderness Areas, MPAs, Mountain Catchments, National Parks, Nature Reserves, Protected Environments, Special Nature Reserves, and World Heritage Sites. As per Section 50(5) of the NEMPAA, no development, construction, or farming may be permitted in a National Park, Nature Reserve or World Heritage Site without the prior written approval of the management authority. Saldanha Bay includes several MPAs (see Figure 4.1) which fall under the West Coast National Park (WCNP) MPA (Figure 4.2). The surrounding terrestrial environment in Saldanha has several protected areas, with the largest being the WCNP to the south, and four nature reserves on the West Coast North of the Saldanha Bay.

ECOSYSTEM THREAT STATUS

The 2018 National Biodiversity Assessment (NBA) Ecosystem Threat Status assesses the status and sensitivity of different habitat types based on biodiversity (richness, uniqueness, spatial extent of the habitat type), exposure levels to natural disturbance or environmental perturbations and the degree to which ecosystems are still intact or losing vital aspects of their structure, function, or composition (SANBI 2019). The threat status assessment and categories are based on the International Union for Conservation of Nature (IUCN) Red List of Species and Red List of Ecosystems assessment frameworks. Ecosystem types are categorised as “Critically Endangered”, “Endangered”, “Vulnerable”, “Near Threatened” or “Least Concern”. The coastal region of Saldanha Bay and its surroundings exhibit a diverse range of coastal ecosystems (Harris et al. 2019b) with several being classified as “Endangered”. Sheltered marine bays and lagoons are a rare habitat type in South Africa and due the existing and planned future development, the majority of the Saldanha Bay coastal and marine area is classified as “Endangered” (Figure 4.3).

The threat status of Saldanha terrestrial ecosystem heavily relies on the local vegetation and exhibits significant variation (Skowno et al. 2019)(Figure 4.4). The region is predominantly categorised as "Endangered" due to the prevalence of Saldanha Flats Strandveld.

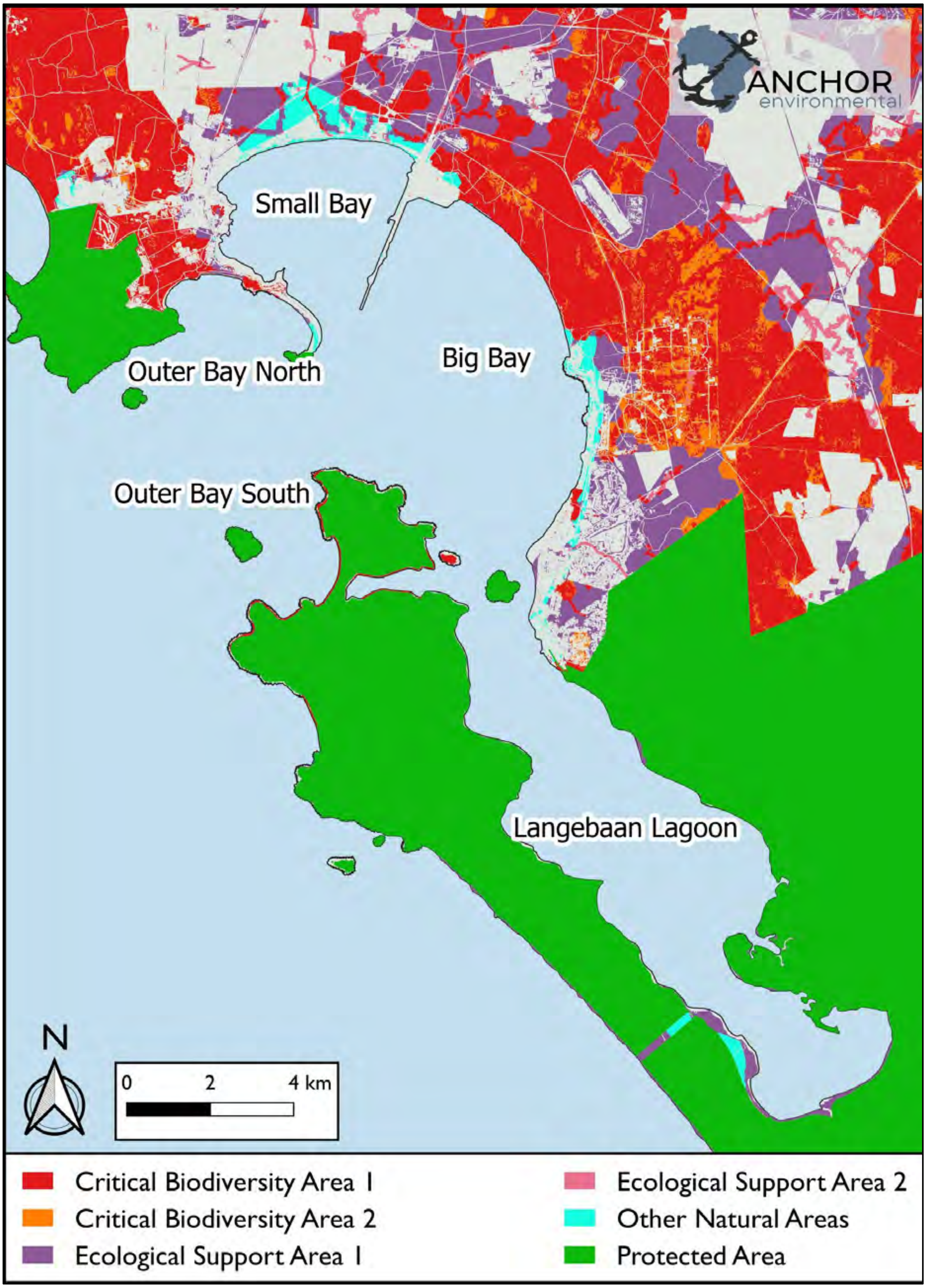


Figure 4.2. Terrestrial Critical Biodiversity Areas in the Saldanha area. Data source: (CapeNature 2017, DFFE 2023). Map by Anchor 2023.

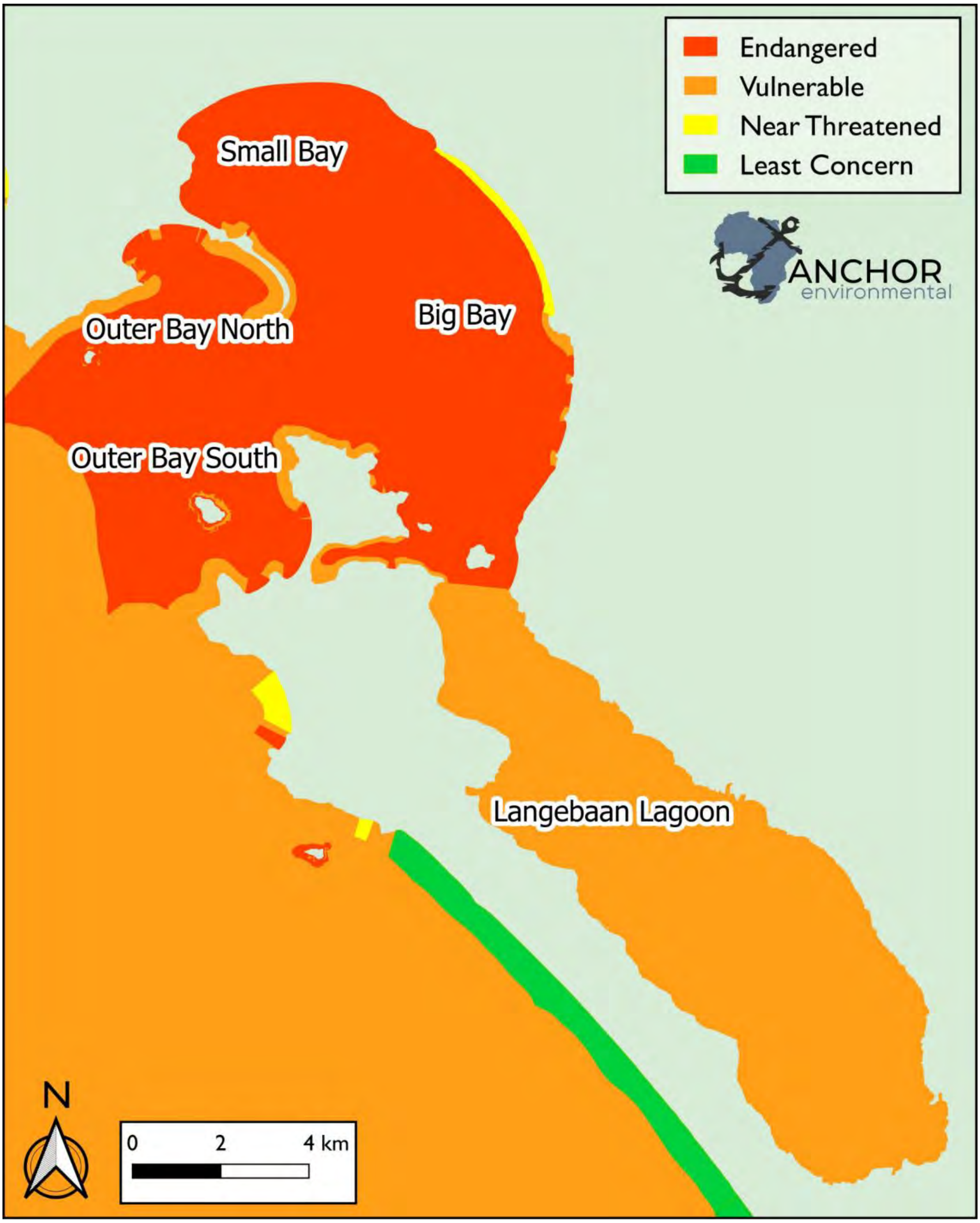


Figure 4.3. Marine Ecosystem Threat Status of ecosystems in the Saldanha study site as per the 2018 NBA. Data Source: (Harris et al. 2019b, Sink et al. 2019).

Figure 4.4. Terrestrial ecosystem type and threat status. Data sources: (Harris et al. 2019a, Skowno et al. 2019). LC = Least Concern; EN = Endangered; CR = Critically Endangered; VU = Vulnerable.

ECOLOGICALLY OR BIOLOGICALLY SIGNIFICANT MARINE AREAS

Ecologically or Biologically Significant Marine Areas (EBSAs) are defined by the Convention on Biological Diversity (CBD) as "geographically or oceanographically discrete areas that provide important services to one or more species/populations of an ecosystem or to the ecosystem as a whole, compared to other surrounding areas or areas of similar ecological characteristics, or otherwise meet the [EBSA] criteria" (CBD 2009). Saldanha Bay falls entirely within the Cape Canyon and Associated Islands, Bays and Lagoon EBSA. This area was identified as a priority area through a national plan to identify areas for offshore protection and by a systematic biodiversity plan for the west coast (Sink et al. 2012, Majiedt et al. 2013). It was also identified as an important area for pelagic ecosystems and species (Grantham et al. 2011).

4.3 Management Tools

In reference to the above, several environmental management tools are considered in developing the Saldanha Bay region. These include the:

1. Integrated Development Plan (Municipal Systems Act)
2. Coastal Management Programme (ICMA)
3. Strategic Environmental Assessment (NEMA)
4. Environmental Management Framework (NEMA)
5. Environmental Management Programme (NEMA)
6. Establishment of a Special Management Area (ICMA)

These management tools are described in more detail below.

4.3.1 Integrated Development Plan

The Integrated Development Plan (IDP) is the main strategic planning instrument which guides and informs all planning, budgeting and development undertaken by a municipality. The Saldanha Bay Municipality (SBM) Council adopted the 2023/24 Amended 5th Generation IDP on 26 April 2023. It serves as a strategic planning framework, aligning with constitutional mandates to provide citizens access to essential services, safety, viable municipal operations, and economic prospects. The IDP, is integral to municipal development and steers the SBM towards community growth, poverty reduction, economic enhancement, and environmental preservation. This document is designed to be easily comprehensible and serves as a cornerstone for the municipality's strategic decision-making and developmental progress.

4.3.2 Coastal Management Programme

The ICMA mandates all three spheres of Government (local, provincial and national) to develop and implement Coastal Management Programmes (CMPs). CMPs contain principles and objectives to guide decisions and successful coastal management. These policy tools consist of three core components: 1) a situational analysis or status quo assessment; 2) a vision, priority and objectives setting component; and, 3) a five-year implementation programme, which includes specific coastal management objectives and implementation strategies for each identified priority area.

The SBM compiled its first CMP in 2013, which was recently reviewed and updated (SBLM 2019). Ten objectives for coastal management have been identified in this updated CMP, which will be implemented by defined coastal management strategies. Objectives relevant to this monitoring report have been extracted from the CMP 2019–2024 document (SBLM 2019). The implementation of this five-year plan will be monitored, and implementation success will be measured by indicators identified in the CMP (Table 4.1).

Table 4.1. Selected objectives of the Second Generation Saldanha Bay Local Municipality Coastal Management Programme.

Coastal Management Objective	Coastal Management Strategy
1. Improve cooperative governance and clarify institutional arrangements	Clarification of institutional arrangements for coastal management and the facilitation of the generation of capacity. The continued implementation and update of the Coastal Management Programme. The promotion of cooperative governance through engagement with all relevant coastal stakeholders.
3. To ensure that coastal planning and development is conducted in a manner that ensures the protection and rehabilitation of the coastal zone.	Incorporation of biodiversity, environmental and climate change policies into town planning processes. Addressing Coastal Erosion within the coastal zone. To address the high percentage of vacant plots and the low occupancy levels of residential dwellings.
4. To enhance compliance monitoring and enforcement efforts in the district	Developing Local Authority Environmental Management Inspectorate and Honorary Marine Conservation Capacity. Facilitating and encouraging public reporting of illegal activities. Facilitating the development and enforcement of Municipal by-laws. Addressing the increase in illegal Off-Road Vehicle activity.
5. To ensure effective management of estuarine resources in the West Coast District Municipality (WCDM)	Facilitating the designation of Responsible Managing Authorities. Supporting the development of Estuarine Management Plans for smaller estuaries in the West WCDM. Facilitating the implementation of Estuarine Management Plans in the District.
6. The protection, management and sustainable use of natural resources	The effective control of invasive alien plants. Cooperative management of Protected Areas. Monitoring mining activities in the coastal zone. Facilitating the coordinated management of Marine Living Resources.
8. The effective management and control of pollution in the coastal zone	Managing the discharge of effluent, stormwater and other industrial-based pollutants into coastal waters. Continue to plan, install, alter, operate, maintain, repair, replace, protect and monitor municipal Wastewater Treatment Works (WWTWs) in coastal towns. To promote the effective management of Air Quality. To ensure the effective management of solid waste in the coastal zone. Encouraging the Reinstatement of the Blue Flag Beach Programme.
9. Ensuring the socio-economic development of coastal communities	Promotion of the Small Harbours: Spatial and Economic Development Framework. Development of marine aquaculture within the District. Supporting the Small-Scale Fisheries Industry. The facilitation of coastal tourism development. Preparing for the growth of the renewable energy sector.

4.3.3 STRATEGIC ENVIRONMENTAL ASSESSMENTS FOR THE GREATER SALDANHA BAY AREA

Shortcomings that limit the role project-level EIAs as a tool for achieving sustainable development are widely documented. These are often linked to the reactive and piecemeal focus of project level EIAs which have limited capacity for anticipating and assessing changes to affected ecosystems beyond property boundaries. Project level EIAs are also not effective in addressing cumulative impacts from multiple developments or activities (Brown and Hill 1995, Thérivel et al. 1999, Dalal-Clayton and Sadler 2005, Glasson and Therivel 2019). Inefficiencies arising from fragmented, activity-based EIA procedures can be countered by means of a strategic environmental management approach, which places a proposed activity within the environmental context of a particular geographical area. Accordingly, NEMA Section 24(3) provides that:

The Minister, or an Member of the Executive Council with the concurrence of the Minister, may compile information and maps that specify the attributes of the environment in particular geographical areas, including the sensitivity, extent, interrelationship and significance of such attributes which must be taken into account by every competent authority.

A task team has been set up by the Department of Environmental Affairs and Development Planning (DEA&DP) with the objective to conduct a Strategic Environmental Assessment (SEA) for the Greater Saldanha Bay Area. SEAs are effective environmental management instruments that are designed to ensure that environmental and other sustainability aspects are considered effectively and holistically in policy, plan and programme making within an area such as Saldanha Bay. The development of a SEA typically involves formulating a desired environmental state for the area under consideration and the identification and evaluation of limiting environmental attributes against a set of thresholds beyond which the realisation of the desired environmental state would be compromised. Any proposed development can then be evaluated against the SEA to ascertain whether the activities are congruent with the desired environmental state. To date, the SEA process has completed a risk and resilience assessment of natural capital in the greater SBM (DEA&DP 2019). This assessment considered marine aquatic biodiversity and systems in the greater Sadhana Bay area to be approaching thresholds where ecosystem service delivery is compromised. Main drivers and impacts were considered to be physical habitat alteration and loss as well as current and proposed heavy/hazardous industry development, e.g., oil and gas (DEA&DP 2019).

4.3.4 ENVIRONMENTAL MANAGEMENT FRAMEWORK

Environmental Management Frameworks (EMFs) are one of several prescribed environmental management instruments that give effect to NEMA Section 24(3) through the Environmental Management Framework Regulations of 2010. These regulations take cognisance of the fact that important natural resources must be retained to provide for the needs and ensure the health and well-being of citizens in a particular area in the long-term. The EMF Regulations of 2010 state that an EMF should aim to promote sustainability, secure environmental protection and promote cooperative governance and may be adopted by the competent authority. If adopted by the competent authority, EMFs must be considered in all EIAs and must be considered by every competent authority during the decision-making process. The burden of proof to demonstrate that a proposed development is aligned to the EMF lies with the project proponent. The EMF provides applicants with a preliminary indication of the areas in which it would be potentially inappropriate to undertake an activity listed in terms of the NEMA EIA regulations by:

1. Specifying the sensitivity or conservation status of environmental attributes in a particular area;
2. Stating the environmental management priorities of the area; and
3. Indicating which activities would be compatible or incompatible with the specified area.

Chand Environmental Consultants were appointed in 2010 by the DEA&DP to compile a Draft EMF in 2013 for Saldanha Bay (for more information on the original EMF refer to (Clark et al. 2016). The original Draft EMF was recently reviewed as part of the Greater Saldanha Regional Spatial Implementation Framework (DEA&DP 2018). The original extent of the Saldanha Bay EMF was expanded to include the Berg River and its estuary (Figure 4.5). A draft EMF was completed in April 2017 and a revision was published for public comment in March 2021 (DEA&DP 2017). No final EMF is available, and it is unknown whether the EMF has been adopted yet.

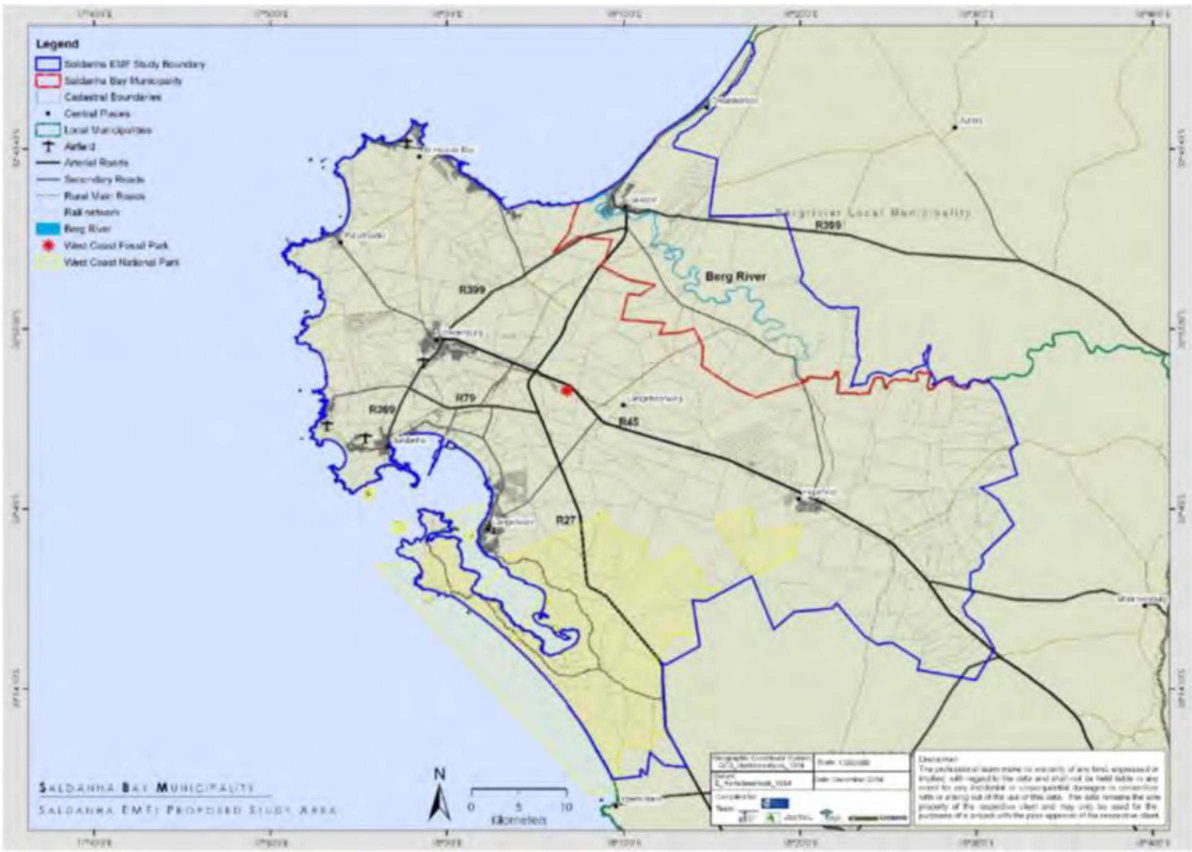


Figure 4.5 Study Area for the Greater Saldanha Bay Environmental Management Framework (DEA&DP 2017).

4.3.5 Generic Environmental Management Programme

DEA&DP compiled an Environmental Management Programme (EMPr) 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 (SBWQFT) (DEA&DP 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 in 2019 and allows government officials involved in the EA 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.

4.3.6 Special Management Area

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))

5 GROUNDWATER

5.1 Introduction

The Greater Saldanha Bay (GSB) region is experiencing significant growth from many sectors as it is close to a port; is well suited for industrial development, has good infrastructure, and is particularly scenic in places and within a unique natural setting. These attributes have resulted in the region's rapid growth and thus need to be managed strategically with a long-term perspective to satisfy as many role players as possible. The geographical extent of the project area is the administrative boundary of the Saldanha Bay Municipality (SBM) with the addition of a marine component comprising 12 nautical miles from the High-Water Mark, Langebaan Lagoon, including the islands in the bay (Schaapen and Marcus) and just outside of the bay (Malgas, Jutten and Vondeling). Groundwater is a key component of the natural capital within the area. It plays a crucial role in sustaining critical and unique ecosystems and is also partly a source of water supply to the municipality as well as providing support to the agricultural sector. The geological setting is highly variable within the GSB area and for this reason, the groundwater is also highly variable across the study area in terms of flow rates, volumes and quality. This variability has meant that a lot of geohydrological work has been completed in the area, dating back to the late 1970s. There has also been a lot of recent and ongoing geohydrological work in the area, especially regarding natural and artificial recharge. Recent work done in the area contributes to knowledge of the aquifer dimensions and recharge characteristics for which there has previously been some uncertainty. This chapter provides an update on the geohydrology of the area with a little more detail on the areas of actual and planned groundwater abstraction. It highlights the areas where crucial ecosystem support is received from groundwater as well as updated groundwater and quality monitoring data that has been collected over the past year. The background and contextual information pertinent to the hydrogeology in the area remain the same. While this background and contextual information is important, it can be a little tedious for those who have seen it before in previous versions of the Saldanha Bay Water Quality Forum Trust (SBWQFT) report. This chapter thus highlights the new data and information to make it easier for those readers to hone in on the material that is of greatest interest to them. Background information on the aquifers contained in the area has been addressed in great detail in previous versions of the State of the Bay Report. The 2021 SBWQFT report (Clark et al. 2021) should be consulted for a more comprehensive hydrogeological background of the area. The updates of this report focus on the updated data collected from the monitoring boreholes in the area and provide details of the aquifer structure and flow paths. The G10M quaternary catchment within the GSB is the main area of concern. Figure 5.1 displays the location of the study area within a regional context. Saldanha Bay's current water supply system is primarily based on surface water being transported in a pipeline from surface water dams in the mountains around Franschhoek, west of Cape Town. To increase drought resilience, more groundwater is planned to be implemented in the bulk water supply by two wellfields to augment water supply to Saldanha Bay and the surrounding towns. Within the area are two municipal wellfields, namely the Langebaan Road Wellfield and Hopefield Wellfield. These wellfields were established to augment the water supply to the towns in and around Saldanha Bay. The wellfields were also drilled for backup water supply should a drought occur again in future. The spatial extent of the two wellfields along with the monitoring borehole network in the area is displayed in Figure 5.2. Further details on the monitoring network are provided in below.

Figure 5.1. Location of the study area (Greater Saldanha Bay) within a regional setting.

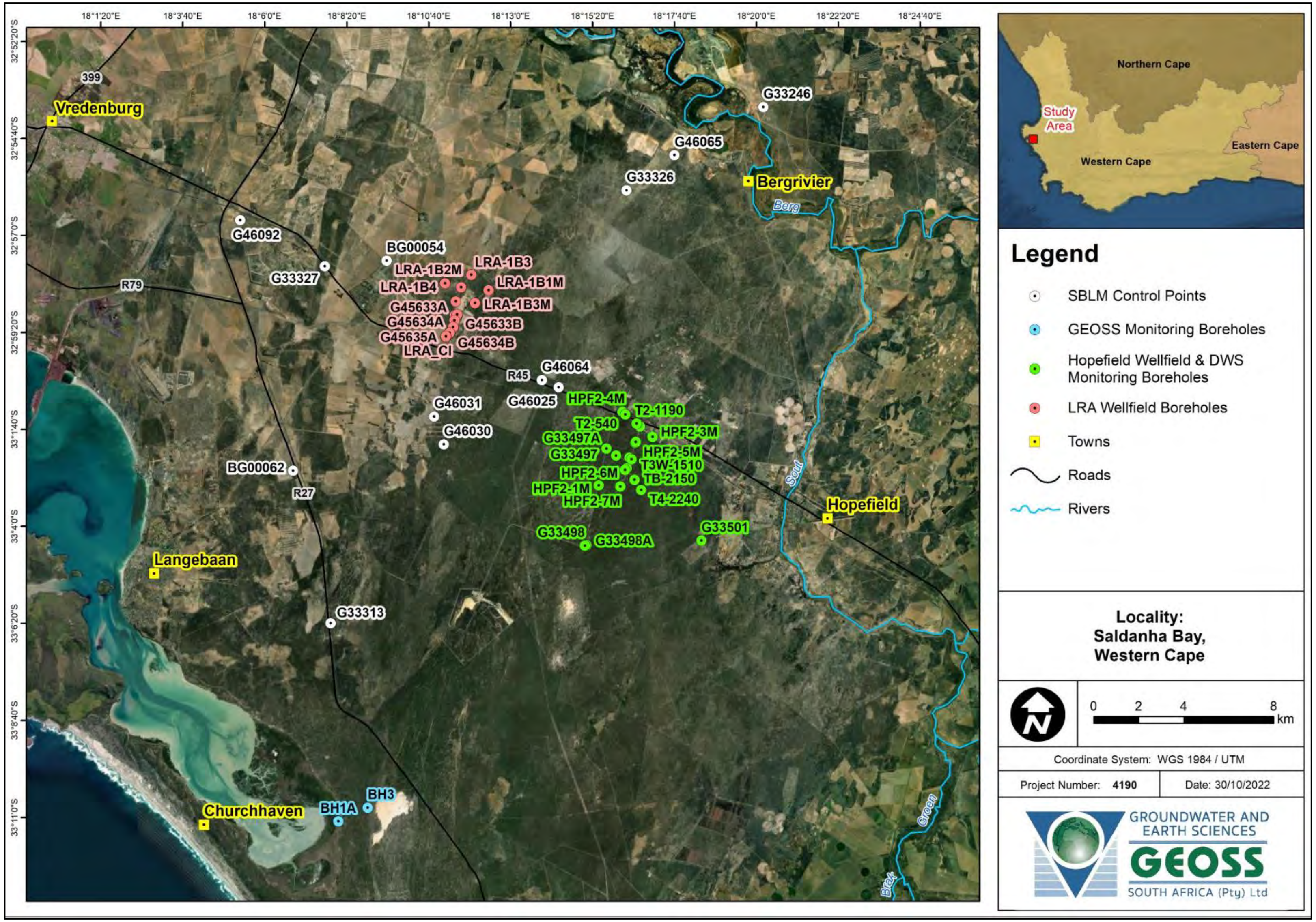


Figure 5.2. Spatial view of the locations of the selected monitoring boreholes across Saldanha Bay.

Annual rainfall data for the period 2017 to 2023 (year to date) is displayed in Figure 5.3. Rainfall data are obtained from the Elandsfontein Phosphate Mine's weather station which is situated in the centre of the study area. The rainfall volume is observed to increase year on year since 2017 as the area comes out of the 2015–2019 drought. Over the past four years, the yearly rainfall has been above average, A total of 523.50 mm of rainfall has been recorded over the January – September 2023 period, 109.50 mm more than the annual 2022 volume and 208.3 mm above the annual average volume (~315 mm) for the area. The current year-to-date volume is the highest recorded over the 7-year period.

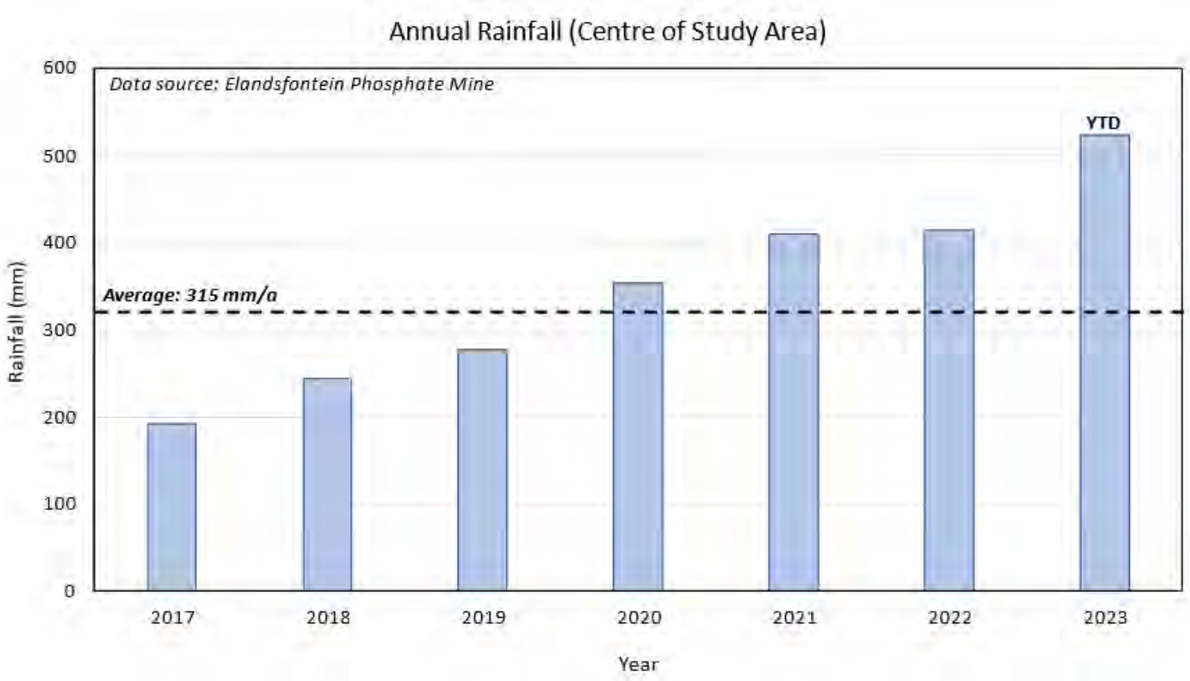


Figure 5.3. Annual rainfall (2017–present) from data collected at a rainfall station in the centre of the study area (data provided by Elandsfontein Phosphate Mine).

5.2 Groundwater monitoring Update

To better manage groundwater in the area, SBM, in collaboration with GEOSS and Ramboll, established a groundwater monitoring network for Saldanha Bay. The network consists of twelve (12) monitoring boreholes across the Saldanha Bay area and is spatially displayed in Figure 5.2. It should be noted that in addition to these selected sites, the Department of Water and Sanitation (DWS) also conducts groundwater monitoring in the area. The spatial distribution of the DWS sites is displayed in Figure 5.4. The monitoring data on these boreholes are generally made available by DWS on request. These selected twelve (12) monitoring boreholes were required to surround specific control points, discussed in the Water Supply Management System (WSMS) Workshop (Block II) held in Saldanha Bay on 16 November 2021. The workshop was a knowledge exchange/transfer between Danish consultants and South African consultants and water operators. The purpose of the workshop was to go through selected control points and design criteria based on the local water resources, challenges, and threats. The selected control points included were:

- The Berg River
- Langebaan Road Airforce Base (potential point of pollution)

- Langebaan Lagoon
- Neighbouring boreholes (between the Berg River, Langebaan Road Wellfield, Hopefield Wellfield, the Elandsfontein Phosphate Mine and the Langebaan Lagoon).

The following steps were followed when selecting the boreholes for the monitoring network:

1. **Availability of data:** to evaluate groundwater trends over the long term, long-term water level and water quality (electrical conductivity) data needed to be available for the selected sites. The DWS and persons who had previously worked in the area were consulted for this step of the selection process.

2. **Current Monitoring:** DWS were consulted to determine which sites are currently being monitored and plans to monitor moving forward. It would benefit the impact assessment if DWS were currently monitoring the site to ensure that site monitoring would occur more frequently.

3. **Accessibility:** due to boreholes in the area being quite far away and not always easy to access, for the ease and effectiveness of monitoring — sites were selected based on whether they were easily accessible to ensure that all boreholes were visited when a monitoring trip takes place.

4. **Control Points:** The boreholes were required to surround the control points discussed during the WSMS Workshop to evaluate impacts on groundwater in Saldanha Bay properly. During the selection process, it was ensured that the final boreholes were near these points.

5. **Aquifer:** To monitor the impacts on the different aquifers within Saldanha Bay (Upper, Lower and Bedrock), boreholes were selected in the area that tapped into the different aquifers.

The boreholes that form part of the monitoring network are tabulated below:

Table 5.1. Selected monitoring boreholes for the Saldanha Bay area. DD = Decimal Degree; WGS84 = World Geodetic System 1984. This is the official co-ordinate system for South Africa.

	BH ID	Latitude (DD, WGS84)	Longitude (DD, WGS84)	Aquifer
1	G46064	-33.00985	18.23050	Lower
2	G46031	-33.024110	18.179020	Unknown
3	G46092	-32.944730	18.087620	Lower
4	G33327	-32.963480	18.127610	Unknown
5	BG00054	-32.961460	18.157050	Unknown
6	G46065	-32.933970	18.271270	Lower
7	G46025	-33.012720	18.238470	Upper
8	G33313	-33.106630	18.128970	Upper
9	G46030	-33.035270	18.183600	Bedrock (shale)
10	BG00062	-33.045360	18.111760	Bedrock (granite)
11	G33246	-32.901000	18.336530	Upper
12	G33326	-32.933970	18.271270	Upper

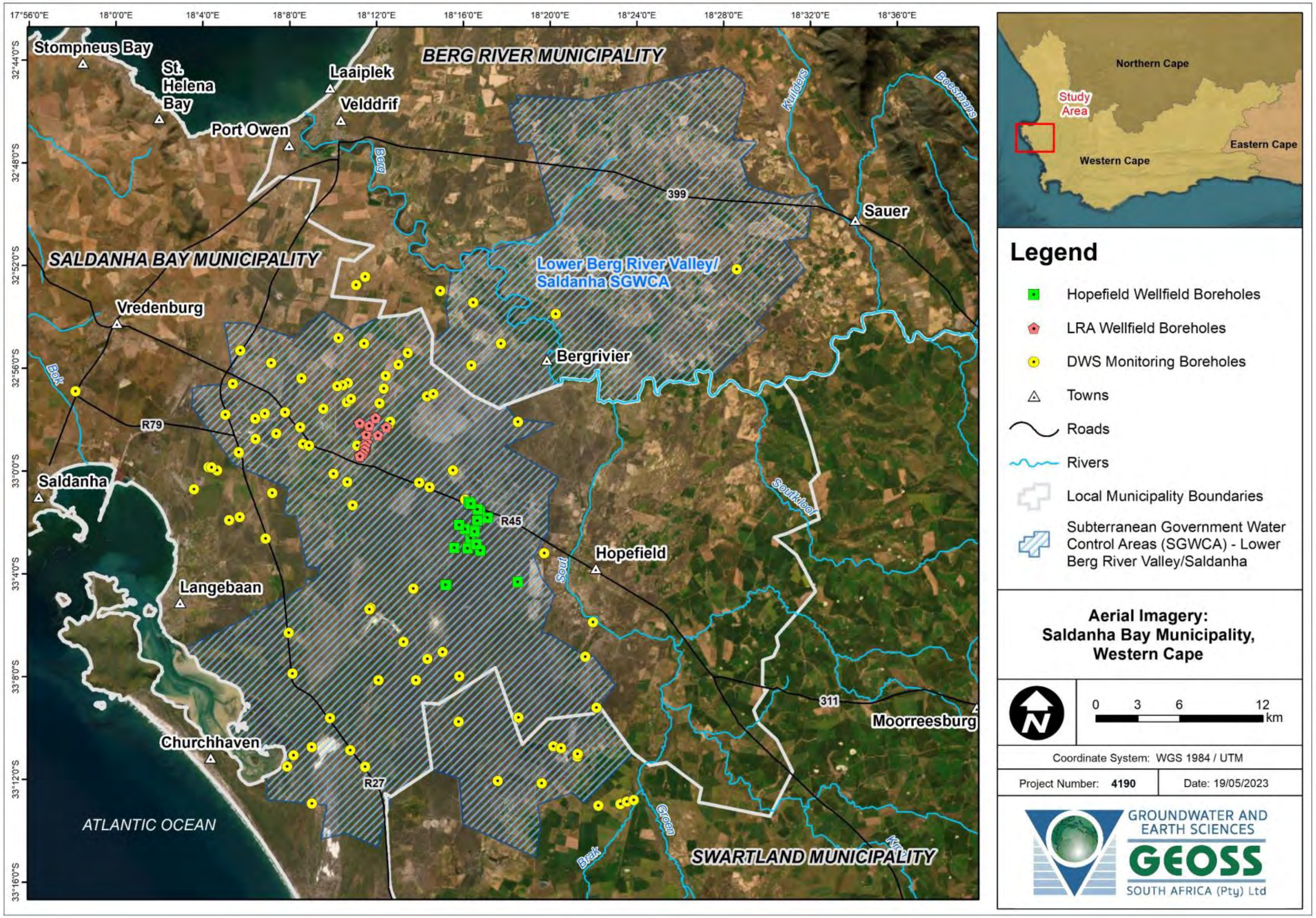


Figure 5.4. Spatial overview of the DWS monitoring boreholes within the larger area.

These boreholes will be the designated monitoring boreholes for Saldanha Bay moving forward. Groundwater levels and basic chemistry parameters (electrical conductivity and pH) occur on a monthly basis. Information on these boreholes provides an indication of the regional status of groundwater within the SBM area.

Groundwater levels across the abovementioned monitoring network boreholes are relatively stable over the long term with no concerning trends in water level or general water quality (represented by electrical conductivity) being observed. In some areas, the upper aquifer boreholes display a marginal decline in water levels, which can be attributed to increased groundwater usage by local farmers in the area. The lower aquifer boreholes display fluctuations in water levels due to wellfield abstraction. Groundwater levels of boreholes drilled into bedrock are stable over the long term, with no response to abstraction taking place in the area. Overall the upper aquifer is characterised by higher electrical conductivities (115–500 mS/m), whereas the water quality in the lower aquifer, with the exception of G46092 as it is outside of the groundwater flow path in the area, ranges between 50 mS/m and 110 mS/m. The electrical conductivity in the bedrock aquifer is variable with EC ranges between 60 mS/m – 800 mS/m.

Long-term groundwater level data (updated until June 2023) of the control points and analysis thereof can be found in Appendix 1: Long-term water level and electrical conductivity graphs for the SBM control points (Section 16.1).

5.3 AQUIFER CHARACTERISTICS

As part of a collaboration project between the SBM and Danish consulting company, Ramboll, two models (geological model and hydrological model) were generated in 2021 to better predict and manage groundwater resources in the area. The models prove the basis for establishing flow direction in the area and aquifer extent and layers. It also serves as a predictive tool to plan for extreme events such as a drought.

An important data source for updating the geological interpretation is data from the geophysical survey (SkyTEM) carried out in the area in 2020 (reported in the 2021 SBWQFT report). A dense geophysical dataset covering a large area and providing a high spatial resolution has thus been made available, which has been valuable, particularly in understanding the bedrock topography and aquifer extent (Eltved and Højberg 2022, Kürstein and Højberg 2022).

The bedrock topography was interpreted from the contact between the sand and the bedrock in each layer and then combined to form a single data set. The bedrock depth was then combined with the topography to provide a bedrock elevation map (Figure 5.5). The bedrock elevation map allowed for the delineation of the paleochannels in the area. The paleochannels are the deepest parts of the aquifer where preferred groundwater flow takes place.

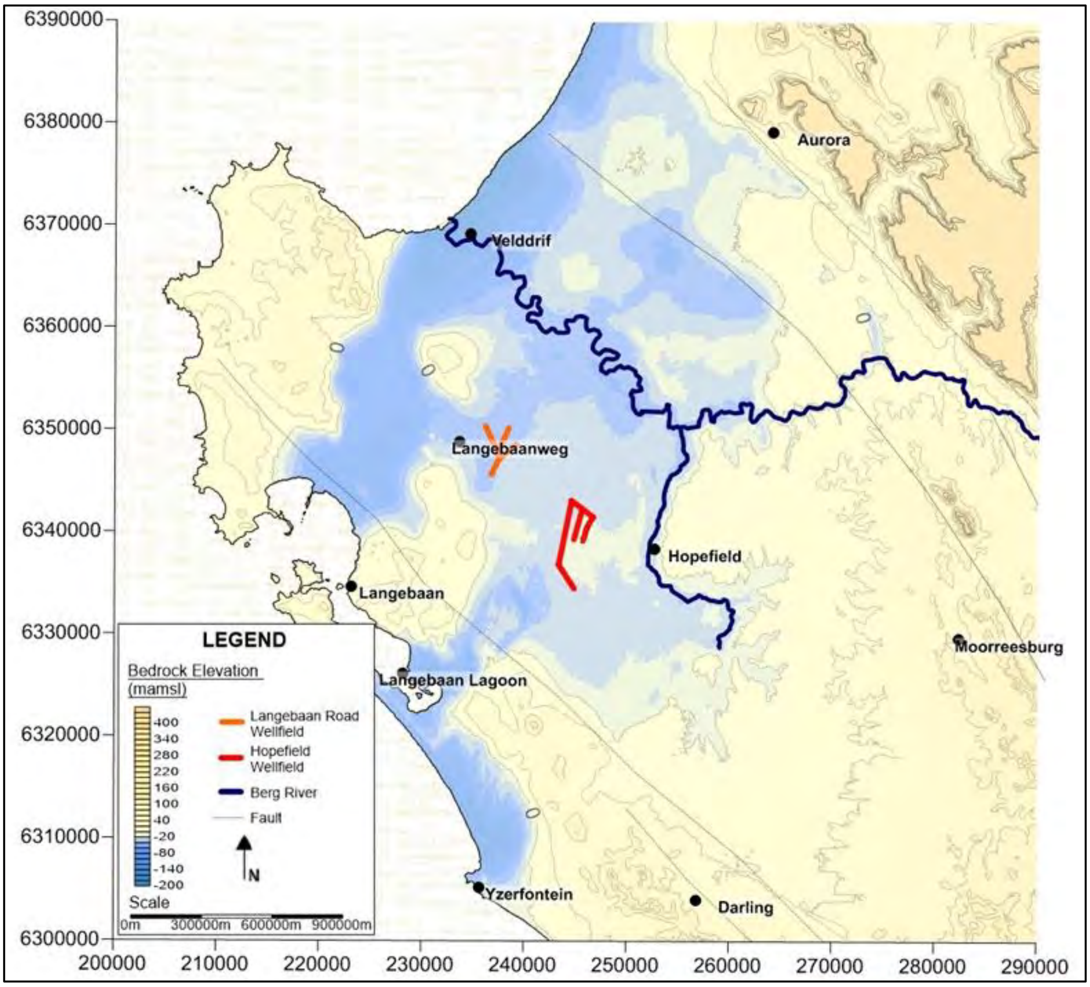


Figure 5.5. Bedrock elevation for the GSB area displaying the deepest part of the aquifer as well as the paleochannels in the area.

The yellow colour shown on Figure 5.5 depicts the higher elevated areas such as the mountains at Aurora, Moorreesburg and the granite hills along the western and coastal areas of the Saldanha Bay area. The blue colour illustrates the deeper parts of the bedrock, indicating areas of available groundwater. The deepest bedrock elevations (dark blue) occur in the southwestern part of the Elandsfontein aquifer towards the Lagoon, south towards Yzerfontein and in the north western side where a paleo channel is located in a north easterly to south westerly direction along the coast towards Saldanha Bay town. These bedrock depths (dark blue) are approximately 100 m below sea level. There are also some deep bedrock patches found in the Langebaan Road wellfield vicinity and between the Berg River and Aurora with depths up to 60 m below sea level. Overall, the blue-coloured area is where sands were deposited over time and make up the aquifer structure.

The bedrock depths at the Hopefield wellfield range between 10 m and 30 m below sea level, this slightly higher bedrock elevation suggests local groundwater flow from the Hopefield wellfield towards the Lagoon in a south westerly direction.

In addition to the geological model, Ramboll also developed a hydrological model for the same area Data sources for the model included: topography, climate, land use and vegetation, geological maps, borehole logs, groundwater chemistry, groundwater abstraction, groundwater level measurements, pump test data and aquifer yields, river data (types of streams and river discharge measurements) as well as publications on research carried out in the area. The main aim of the model was to determine groundwater flow and recharge in the area, which would allow for the prediction of the response of the aquifers, should recharge amounts/precipitation either increase or decrease.

The model was calibrated from 2010 to 2020 using a timestep of one day. The period contains both wet and dry years. It is worth mentioning that the period contained the three dry years (2015–2017) responsible for the 2018 drought and water crisis in the area. The model outputs showed that the flow pattern in the upper aquifer is very much controlled by the topography with different flow directions within the area but with a dominant flow direction towards the northwest (Figure 5.6).

Based on the modelled results, which were influenced by the 2020 geophysical survey and a recharge study conducted in the area between 2019 to 2020 (Parker 2022, Tomlinson 2022), groundwater flow within the lower/deep aquifer system could be delineated (Figure 5.7). The data indicated that the main flow direction seems to be from the Aurora-Piketberg Mountain range towards the Berg River and from the Moorreesburg area to Hopefield. Some of the flow moves from the Hopefield Wellfield to the Langebaan Road Wellfield. Groundwater also flows from Hopefield to the Langebaan Lagoon discharge area. The groundwater flowing from the Hopefield area to the Langebaan Road area discharges into the Berg River.

The hydrological modelled assisted with the estimation of recharge amounts for the area (Figure 5.8). In general, the recharge to the groundwater is highest in more flat areas with alluvial deposits or sand dunes around the wellfields. The groundwater recharge is generally lower in more elevated areas with surface near bedrock and steeper topography, increasing overland flow. Around the rivers, upward groundwater flow is generally dominating.

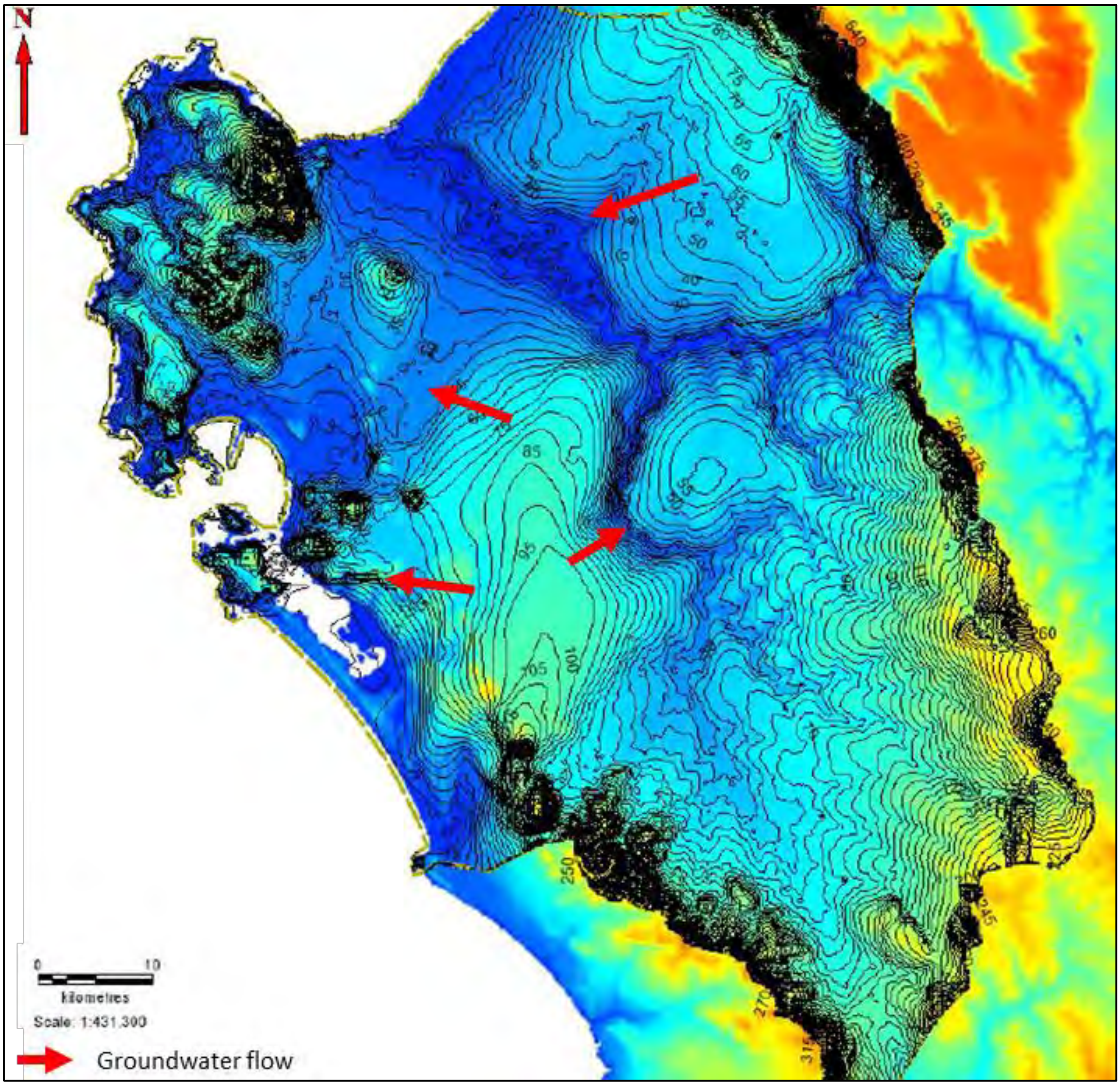


Figure 5.6. Simulated groundwater level map in the upper aquifer (average 2015–2020) in meters and general groundwater flow direction (modified from Kürstein and Højberg 2022).

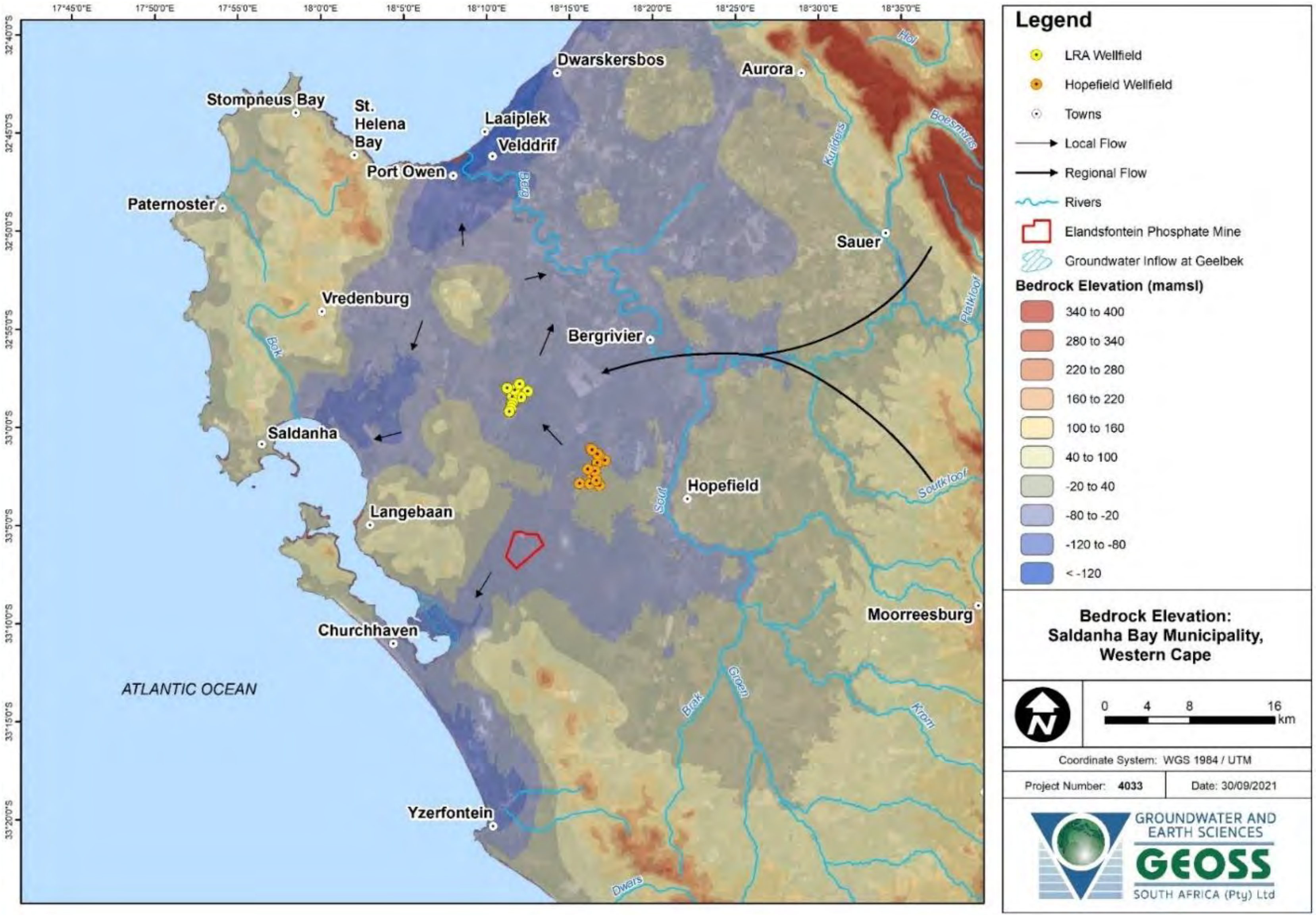


Figure 5.7. Deep groundwater flow for the lower aquifer systems in the study area.

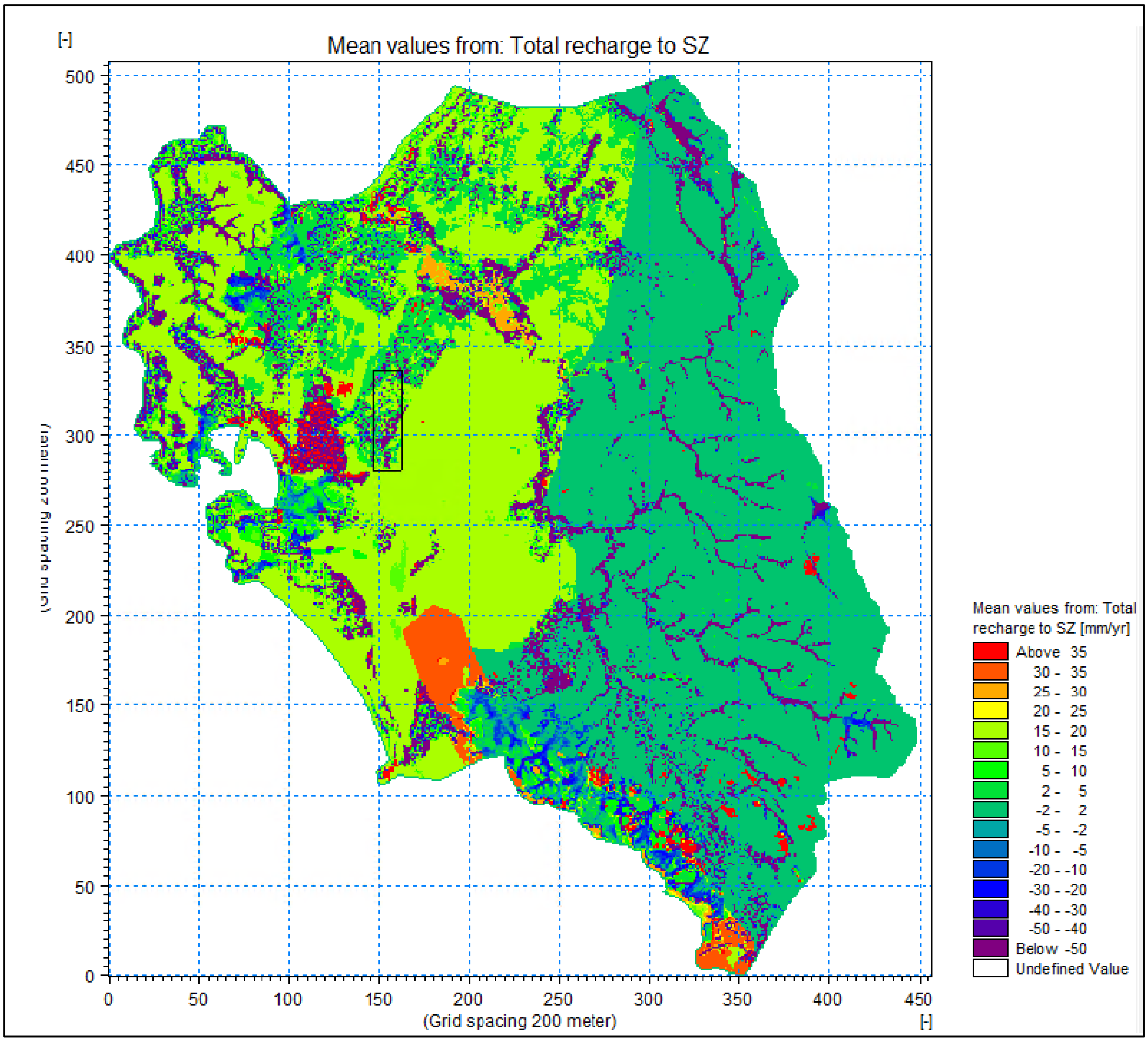


Figure 5.8. Modelled mean annual recharge to the groundwater for the period 2015–2020 (Kürstein and Højberg 2022).

5.4 Regional Database Status

The Saldanha Bay/Langebaan area groundwater database is part of the larger Western Cape (WC) Province groundwater database, which was established from various data sources with the Aquabase Water Resources Management software:

1. National Groundwater Archive (NGA) of the DWS, forming the basis of the WC database.
2. Groundwater chemistry for the Water Management System of DWS Hydrogeology.
3. Groundwater data from the Water Business Continuity Project of the Western Cape Government.
4. Elandsfontein Phosphate mine groundwater monitoring data (water levels end chemistry).

The database continues to be updated regularly with groundwater data available in the area. These data must be downloaded from the NGA on a monthly to quarterly basis and imported into the WC database to create a general overview of the groundwater levels in the area. Monitoring of the twelve 'control points' in the area are also included.

The Elandsfontein Phosphate Mine, south of the Hopefield Wellfield, has a comprehensive groundwater level and chemistry monitoring network around the mine and "downstream" of the mine, towards the Geelbek area at the southern tip of the Langebaan Lagoon. The WC database is updated with incoming data from the mine on a monthly basis. To display these data, an online map has been produced and can be accessed via https://www.groundwaterinfo.africa. Access to the map requires a login, which can be requested through the proper channels.

This website also has some maps accessible to the general public, which present an overview of the groundwater properties in the area. The public can register to view the database by clicking on the following link: https://elandsfontein.groundwaterinfo.africa/. The images below (Figure 5.9 – Figure 5.12) provide an example of the data available within the database.

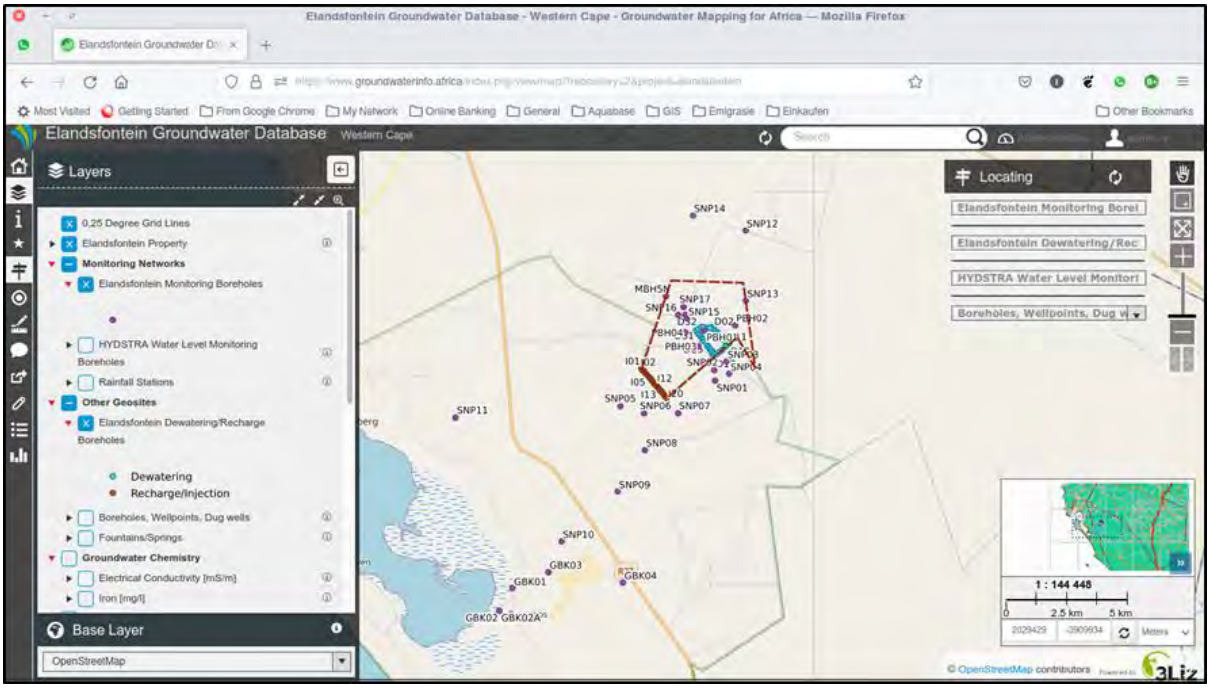


Figure 5.9. Regional database at Elandsfontein Phosphate Mine.

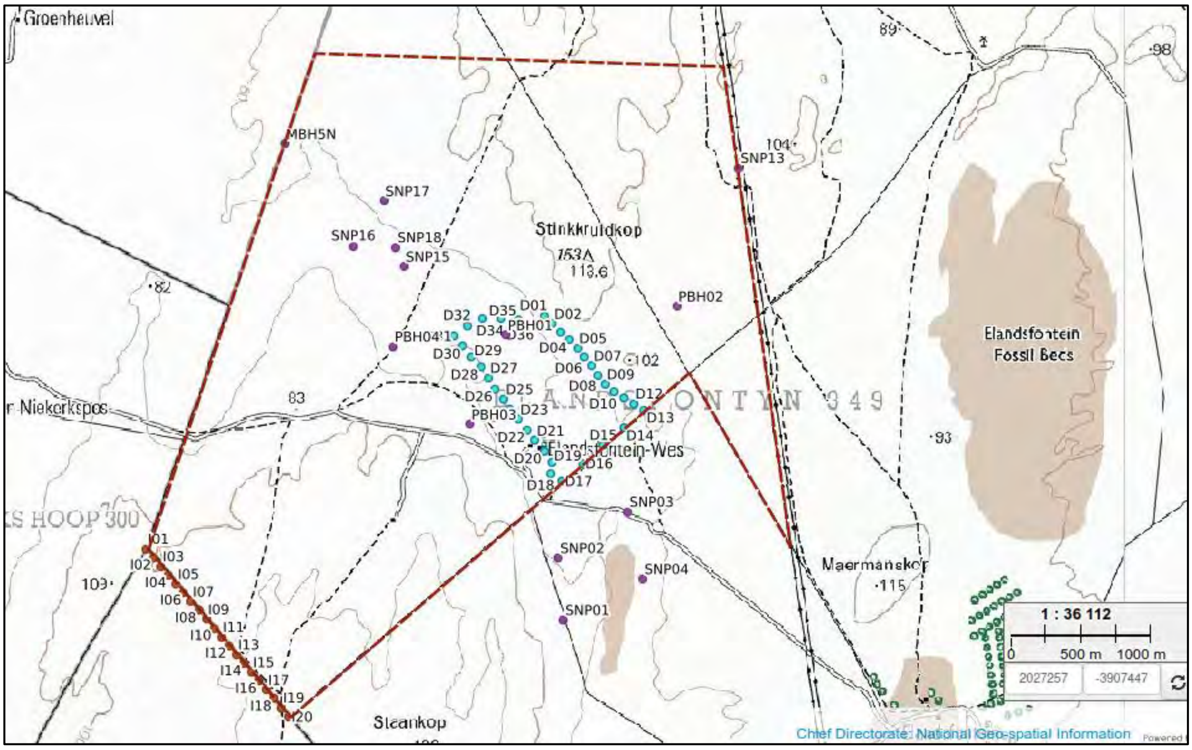


Figure 5.10 Regional database at Elandsfontein Phosphate Mine

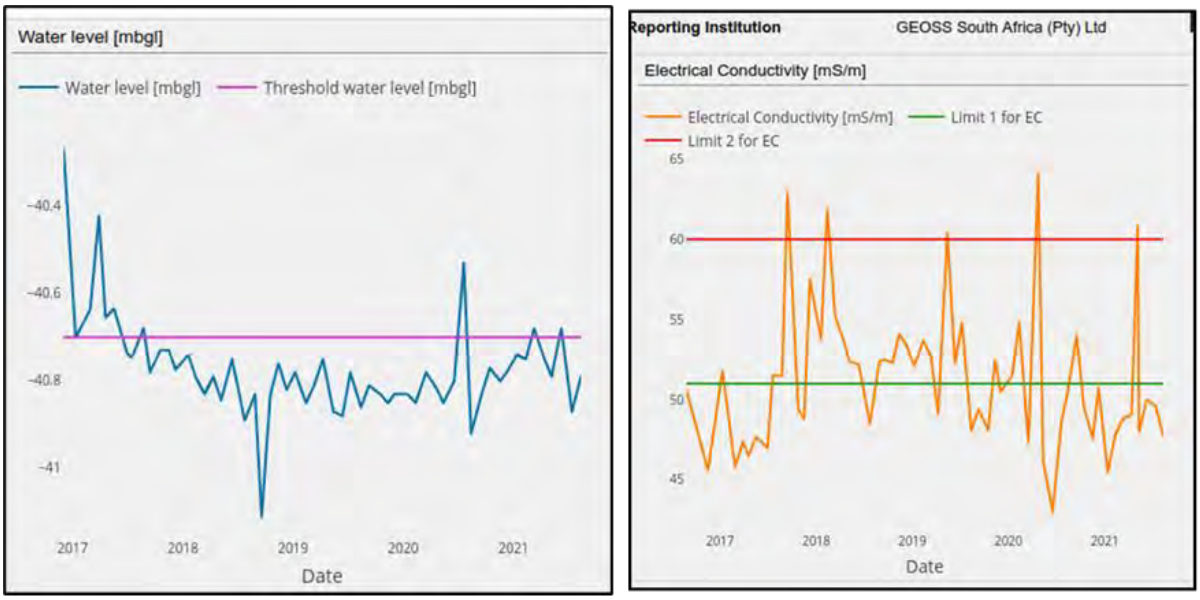


Figure 5.11. Examples of long-term electrical conductivity and water level trends available currently on the regional database for Elandsfontein boreholes. 7

7 Note: the water level graphs relate to the Elandsfontein mine's licensed dewatering programme and are not representative of regional conditions.

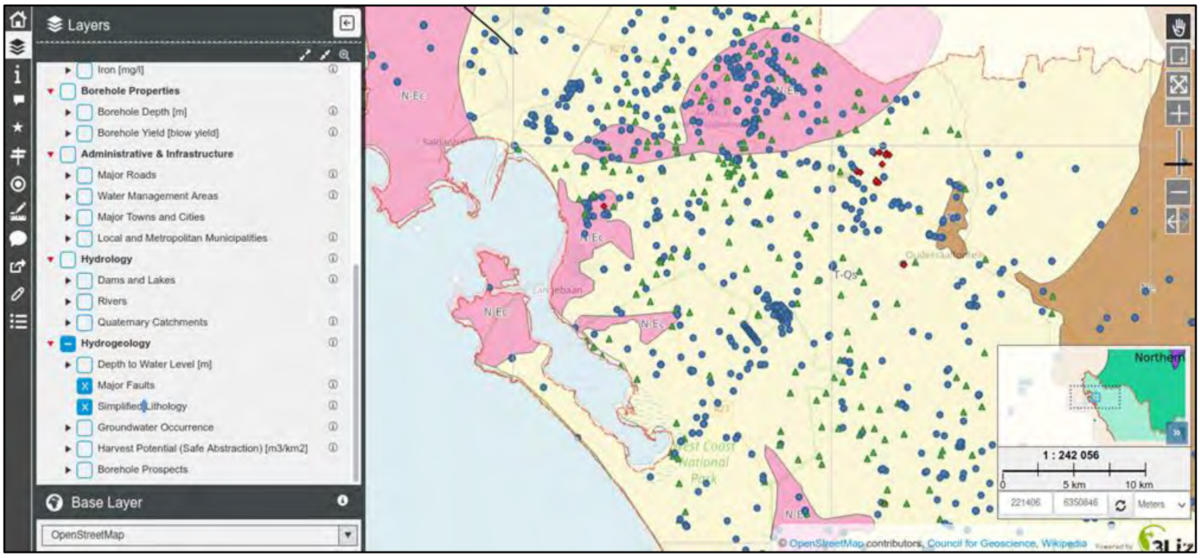


Figure 5.12. Snapshot of all the boreholes for which groundwater information will be available once the regional database has been completed.

5.5 Summary of findings

Over the past year, the SBM has ensured continued groundwater monitoring in the area, from both the wellfields and the twelve critical monitoring boreholes. The local database has also been updated continually with new data that was collected. The regional database is updated on a quarterly basis. The monitoring network, previously developed models and databases will assist relevant authorities in better managing the resource.

The monitoring data collected over the 2023 period indicates that groundwater levels across the monitoring network are relatively stable over the long term with no concerning trends in water level or general water quality (represented by electrical conductivity) being observed. The long-term monitoring trends indicate insignificant groundwater level drawdowns. Overall, groundwater levels in the area have recovered well over the past year due to above average rainfall experienced in the area.

In some areas, the upper aquifer boreholes display a marginal decline in water levels, which can be attributed to increased groundwater usage by local farmers in the area. The lower aquifer boreholes display fluctuations in water levels due to wellfield abstraction. Groundwater levels of boreholes drilled into bedrock are stable over the long term, with no response to abstraction taking place in the area. Overall, the upper aquifer is characterised by higher electrical conductivities, whereas the water quality in the lower aquifer is considered good. The water quality in the bedrock aquifer is variable in different parts of the area.

The models and databases are continually being improved. This, along with ongoing groundwater research in the area and continued groundwater monitoring, will assist in maintaining this important resource so that it is available for years to come.

Over the next year, the SBM plans to establish a numerical flow model for the two wellfields contained in the area — the Langebaan Road Wellfield and Hopefield Wellfield. These models will enable different scenarios to be predicted, allowing for better planning and management of groundwater resources in the area, especially during drought conditions.

6 WATER QUALITY

6.1 Introduction

The temperature, salinity (salt content) and dissolved oxygen concentration in marine waters are the variables most frequently measured by oceanographers 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 1974–2023. A thermistor string comprising four underwater temperature recorders (UTRs), 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 (Anchor) on behalf of the Saldanha Bay Water Quality Forum Trust (SBWQFT). This array is retrieved and maintained during the annual field survey and data up until April 2023 are included in this report. Data on ocean currents 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. Recently, from the 24 April 2020, the Department of Forestry, Fisheries and Environment (DFFE) initiated dissolved oxygen monitoring at Aquaculture Development Zone Precincts in Small Bay and Big Bay with instruments moored 0.5 m from the sea floor at Farm (within the Aquaculture Development Zone (ADZ) precincts) and Control stations (Figure 6.1). Data are recorded hourly, and the instruments are being serviced every 6–8 weeks. Data for the period April 2020 – April 2023 are presented below, but this monitoring is scheduled to be ongoing and should reveal interesting seasonal and long-term trends in the Bay's water quality.

Figure 6.1. Saldanha ADZ precincts (red border), Marine Protected Area (MPA) (white border) and location of moored oxygen sensors.

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, funded by the Elandsfontein Phosphate Mine (Kropz). The Star ODDI was subsequently replaced with an Aqua TROLL 200 data logger (August 2019) which has been yielding better and more useful data. Variations in temperature, salinity and depth are recorded every 20 minutes, and data for the entire monitoring period to date (September 2016 to December 2022) are presented in this chapter.

Furthermore, long term trends in microbial contaminants (introduced to the Bay through wastewater discharges) and trace metals (from natural and anthropogenic sources) found in bivalve tissue are presented below. Data on other physico-chemical parameters from the Bay including turbidity and bromide can be found in previous State of the Bay reports by Anchor.

6.2 Circulation, currents and climate

The currents and circulation of Saldanha Bay have previously been described by (Weeks et al. 1991a). They authors 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. The authors also 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 (IOT) (Figure 6.2).

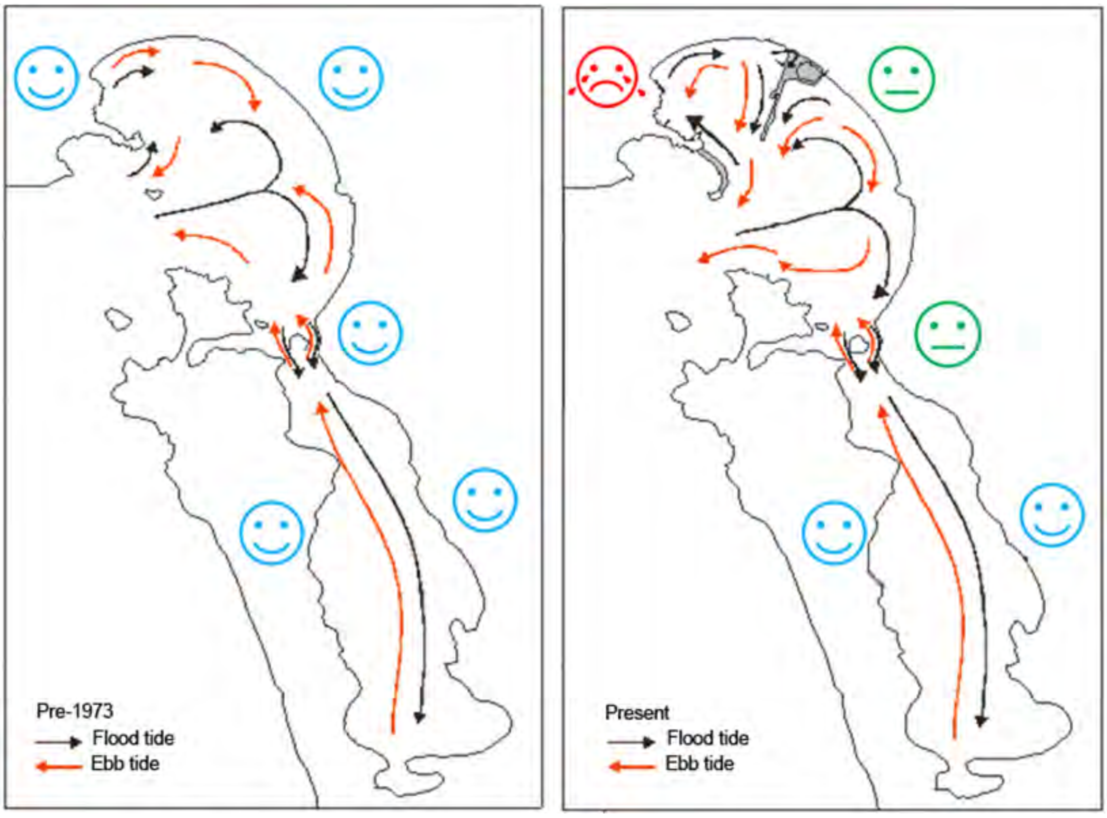


Figure 6.2. Schematic representation of the surface currents and circulation of Saldanha Bay prior to harbour development (pre-1973) and after construction of the causeway and Iron Ore Terminal (present) (Adapted from: (Shannon and Stander 1977, Weeks et al. 1991a)

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, during both ebb and flood tides. The importance of wind as the dominant forcing factor of bottom, as well as surface, waters was further confirmed by (Monteiro and Largier 1999) who described the density driven inflow-outflow of cold bottom water into Saldanha Bay during summer conditions when prevailing SSW winds cause regional scale upwelling.

Construction of the IOT and the Marcus Island causeway had a major impact on the distribution of wave energy in Saldanha Bay, particularly in Small Bay. Prior to port development in Saldanha Bay, (Flemming 1977a) 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 6.3 left). The IOT essentially divided the Bay into two parts, eliminating much, if not all, the semi-exposed area in Small Bay, greatly increasing the extent and degree of shelter in the north-western part of Small Bay, and subtly altering wave exposure patterns in Big Bay (Figure 6.3 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).

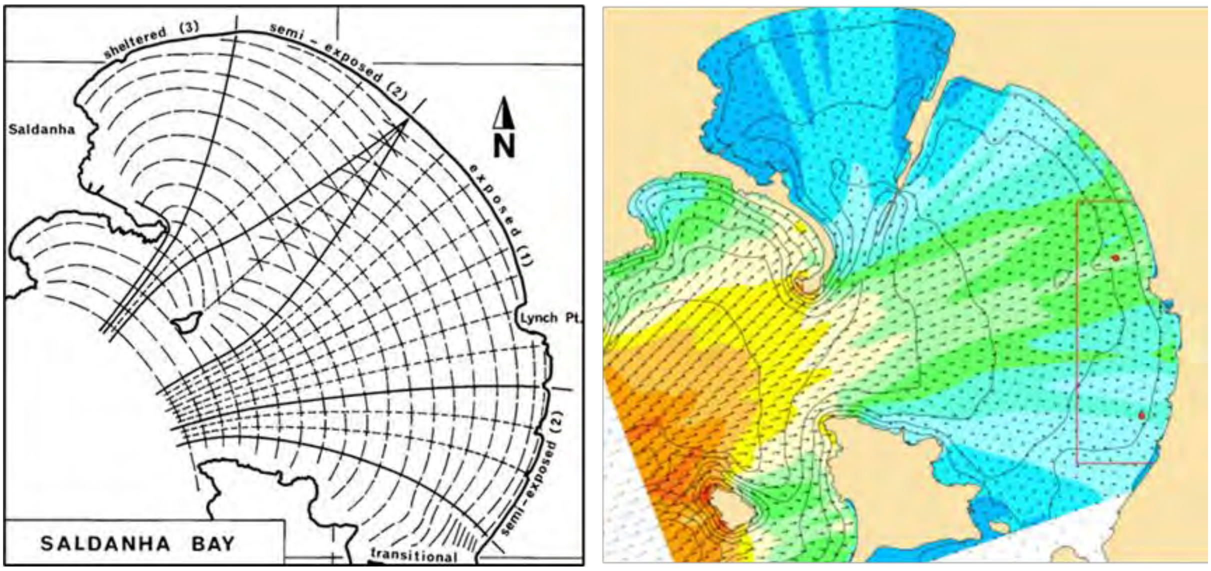


Figure 6.3. Predicted wave fields in Saldanha Bay showing wave height and direction prior to (left) and post (right) harbour development. Orange shading indicates wave heights >1.4 m, while blue shading indicates wave heights of <0.6 m (Sources: Flemming, 1977a; WSP Africa Coastal Engineers, 2010).

In 2022 daily significant wave height (SWH, combined wind and swell) and mean wave direction of ocean/sea surface waves data were accessed for Jan 1959 – Dec 2021 (ERA data from Hersbach et al. 2023). Mean wave direction at these sites, including the frequency occurrence of each wave height (0–9 m), was averaged for two localities closest to Saldanha Bay and data are expressed in Figure 6.4. It is evident that over this period dominant wave direction is approximately Southeast, with wave heights largely between 0–3 metres (Mean height= 2.34 m).

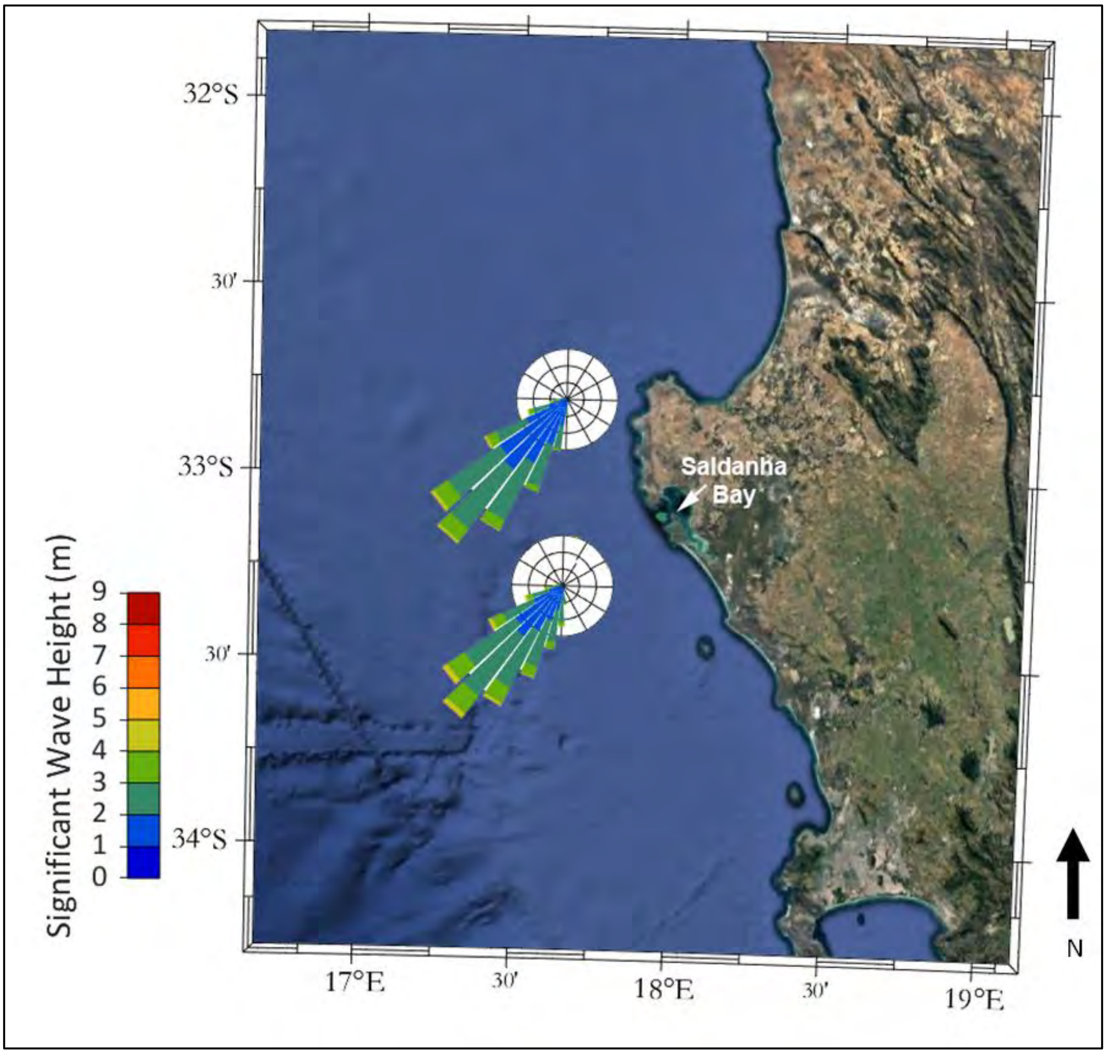


Figure 6.4. Compass roses (average direction x frequency of observed wave height) for daily ERA5 data (12:00 PM each day) from January 1959 to December 2021 for two locations nearest to Saldanha Bay (Hersbach et al. 2023).

SWH is the average height of the highest third of surface ocean/sea waves generated by wind and swell (Hersbach et al. 2023). Daily SWH data for two locations near Saldanha Bay were averaged and data were then aggregated by decade (latest data = 2022). The frequency distribution (Weibull probability density function (PDF)) of SWHs for each decade are presented (Figure 6.5). The Weibull PDF is a statistical distribution used to model the distribution of continuous random variables (Weibull 1951). The data shows a marginal shift over time towards higher SWHs occurring more frequently, from the 1960s – 2022, with the 1980s showing particularly greater frequencies of higher SWHs (Figure 6.5). Maximum SWH observed within each decade also showed a general increase over time, with the highest observed SWH occurring on the 13 July 2020 (Table 6.1). These data supports published literature that the wave climate is becoming more extreme around South Africa and that this, coupled with increasing sea levels and more extreme temperatures, is indicative of a shifting climate (Mather 2012, DEA 2014, Muis et al. 2016, Allison et al. 2022).

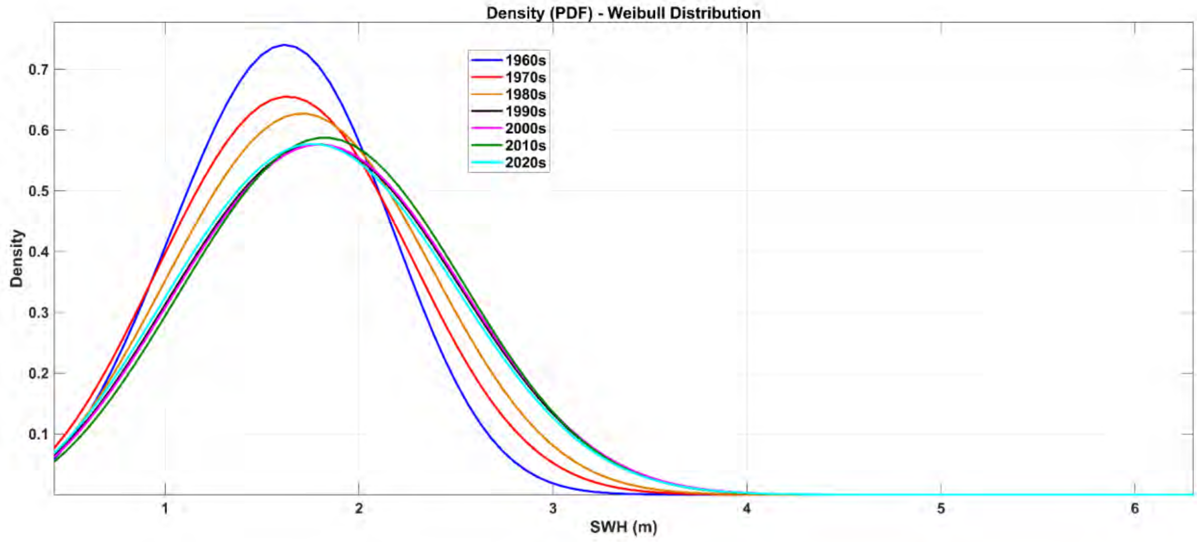


Figure 6.5. Frequency distribution (Weibull PDF) of significant wave heights (SWH), in meters, for aggregated locations close to Saldanha Bay (daily data from 1959–2022), plotted by decade.

Table 6.1. Maximum Significant Wave Height (SWH) observed within each decade.

Decade	Maximum SWH (m)
1960s	4.18
1970s	5.02
1980s	5.96
1990s	5.43
2000s	5.85
2010s	6.10
2020–2022	6.24

6.3 Water temperature

Monitoring of water temperature within Saldanha Bay has been undertaken by various organisations as part of a range of surveys conducted over the past 50 years. Detailed descriptions of these surveys can be found in previous State of the Bay reports and relevant papers (Monteiro and Brundrit 1990, Monteiro et al. 1999).

In summary, temperature of the surface waters of Saldanha Bay fluctuate seasonally, with surface sun warming occurring in summer, followed by cooling in winter, while the temperature of deeper (10 m depth) water shows a smaller magnitude, non-seasonal variation, with recorded summer and winter temperatures being similar (Shannon and Stander 1977, Monteiro and Brundrit 1990, Luger et al. 1999). In most years, a strong thermocline (an abrupt temperature gradient in a body of water, marked by a layer, above and below which the water is at different temperatures) separating the sun warmed surface layer from the cooler deeper water is typically present during the summer months at between 5–10 m depth. During the winter months, the thermocline often breaks down due to surface cooling and increased turbulent mixing, and the water column becomes nearly isothermal (surface and deeper water similar in temperature (Monteiro and Brundrit 1990, Monteiro and Largier 1999). 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 is reflected in the high salinity and low nitrate and chlorophyll concentration (a measure of phytoplankton production) observation by the same authors (Weeks et al. 1991a).

More intensive monitoring in 1997 revealed the summer thermocline is not a long-term feature but has a six to eight-day cycle (Monteiro et al. 1997). Cold water, being denser than warmer water, flows 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 between Saldanha Bay and coastal waters is estimated to be capable of flushing the Bay within six to eight days. 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 visually clear.

With a view to continuing the long-term temperature data set within Saldanha Bay, Anchor deployed five underwater temperature recorders (UTRs), programmed to record temperature every hour at 2 m, 4.5 m, 7 m, 9.5 m and 12 m depth on 12 April 2014. These thermistors have been retrieved and serviced annually since this time, and average daily temperature data for the period April 2014 to April 2023 are displayed on Figure 6.6. It should be noted that during this period of time, UTRs have periodically suffered battery failures and exhaustion, or data were periodically lost due to technical errors. Therefore, during various short periods of time, some data from certain depths is missing (Figure 6.6). In 2022, data were not retrieved for the 12.5 depth so to supplement bottom water temperatures, data from a temperature logger located near (<100 m) the Small Bay control site were provided by DFFE. This temperature logger was located at 14 m and was included in the 2022 data set for 'bottom' water temperature (comparisons showed values were fairly consistent between each of the two loggers despite different depths and locations in Small Bay (Figure 6.7). Data from DFFE were therefore included in the long-term temperature dataset for 2022 (Figure 6.6). Unfortunately, these data were acquired for 2023. The temperature data from 1 April 2014 to 9 April 2023 (winter 2022 data missing) 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 in most years (Figure 6.6). 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. The seasonal presence of water column stratification during summer, and absence thereof in winter, is clearly seen in a plot of the difference between the average daily water temperature measured at 2 m depth and that at 12 m depth (April 2014 – March 2021 only, as 2 m / 12 m data were not available thereafter)(Figure 6.8).

Although some stratification is evident in the spring of 2017, a complete breakdown of the thermocline occurred for an extended period during January 2018, when cool (approximately 12°C) water persists throughout the water column. This stands in marked contrast to historical data when thermocline breakdown typically occurred only during winter, or when it did occur in summer, it was associated with a "warm water" event. Winter water temperatures during the drought (2016–2017) were low (average for the period June to August was 12°C on the bottom) compared to the winters before (2014) and after, (2018–2020) when the average on the bottom was 13.4°C. This inter annual variation is not unusual and may be linked with El Nino-La Nina climatic cycles. The anomalous data collected over the period December 2016 to February 2017 during the drought is almost certainly linked to the dominance of the South Atlantic High-Pressure system during this period. Persistent southerly winds throughout most of the year would have promoted coastal upwelling, resulting in reduced summer water maxima and causing cooler than average winter water temperatures. The monthly average bottom (11–13°C) or surface (13–18°C) water temperatures for most years were, however, similar to those recorded in earlier monitoring (since 1974).

In 2021, stratification broke down around November, but returned by December the same year, likely a result of inclement weather mixing the water column. The summer data from 2022/2023 shows the water column remained stratified (Figure 6.6) with a thermocline being detected at 9.5 m in the most recent data.

There appears to be no clear trend of seawater warming or cooling over time, but rather some anomalies creeping into the normal seasonal scale events. Continuous, high temporal resolution water temperature monitoring is valuable for 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, health and ecosystem service provision.

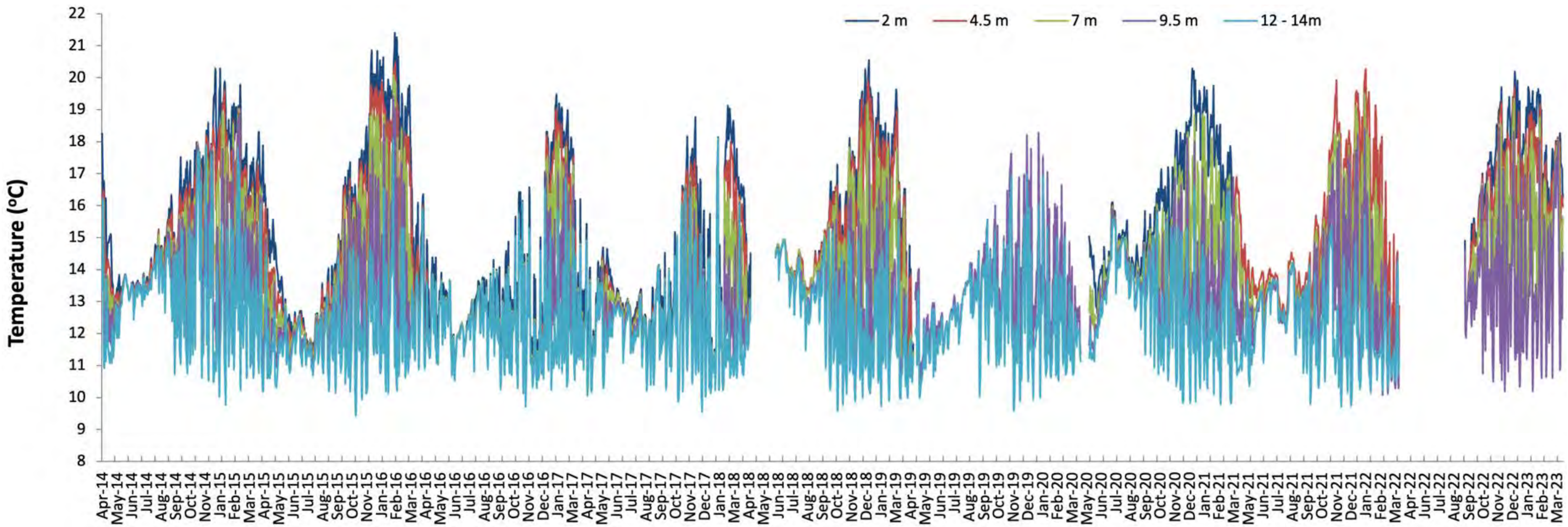


Figure 6.6. North buoy temperature time series for the period 12 April 2014 – 9 April 2023. Temperature was recorded every hour and the average daily temperature is shown here. Note that only the bottom two sensors provided data over the period April 2019 – April 2020, September 2022 – March 2023, the 4.5 m depth was not sampled during May 2020 – March 2021, the 2 m depth logger was not working from March 2021 – Aug 2022 and the 12.5 m depth is missing in 2023.

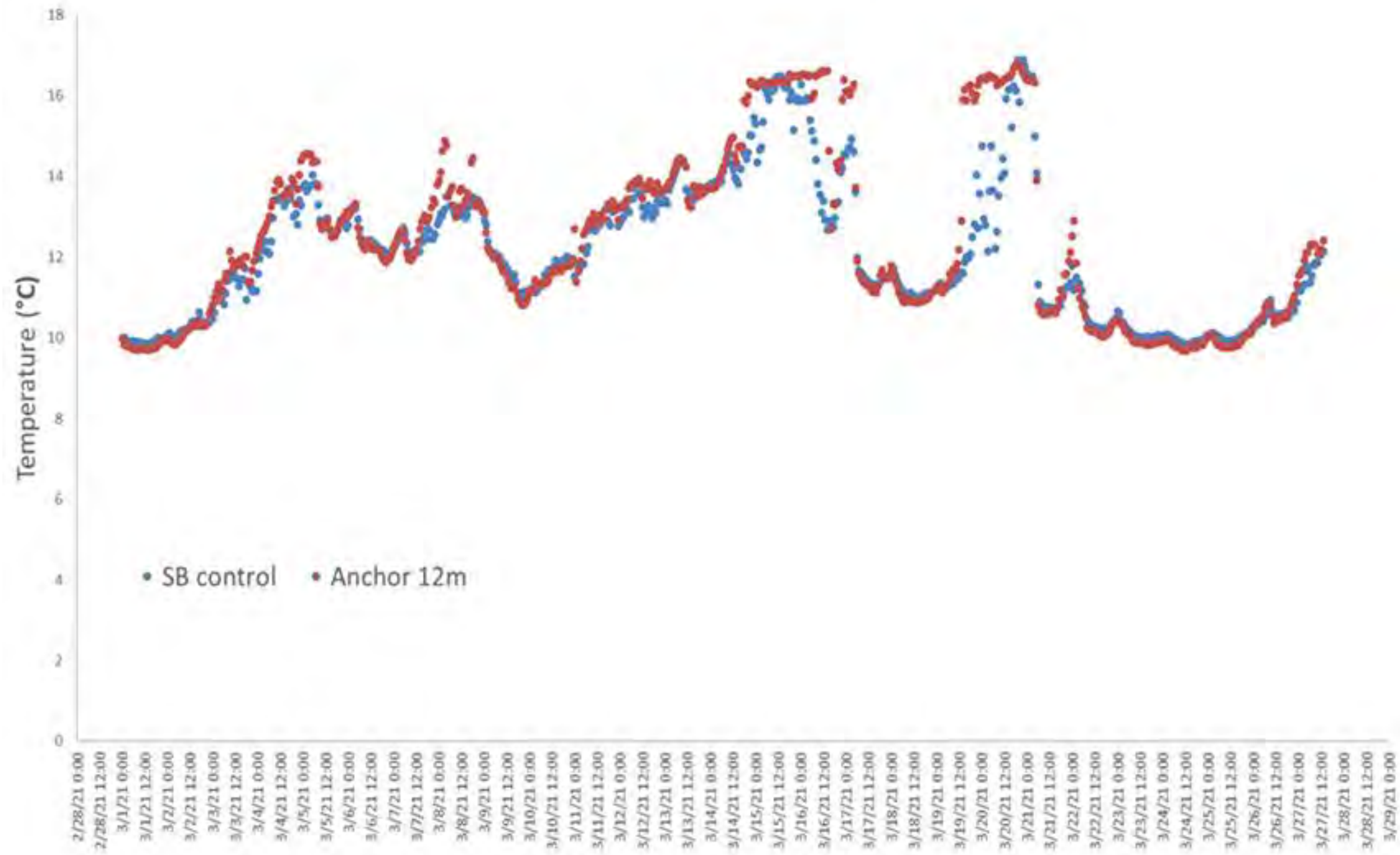


Figure 6.7. Validation comparison of overlapping (28th February – 29th March 2021) temperature data collected from North Buoy 12 m site and Small Bay control data collected from nearby and at 14 m (14 m data provided by DFFE) to justify inclusion of 14 m data in the long-term temperature dataset presented in section 6.3.

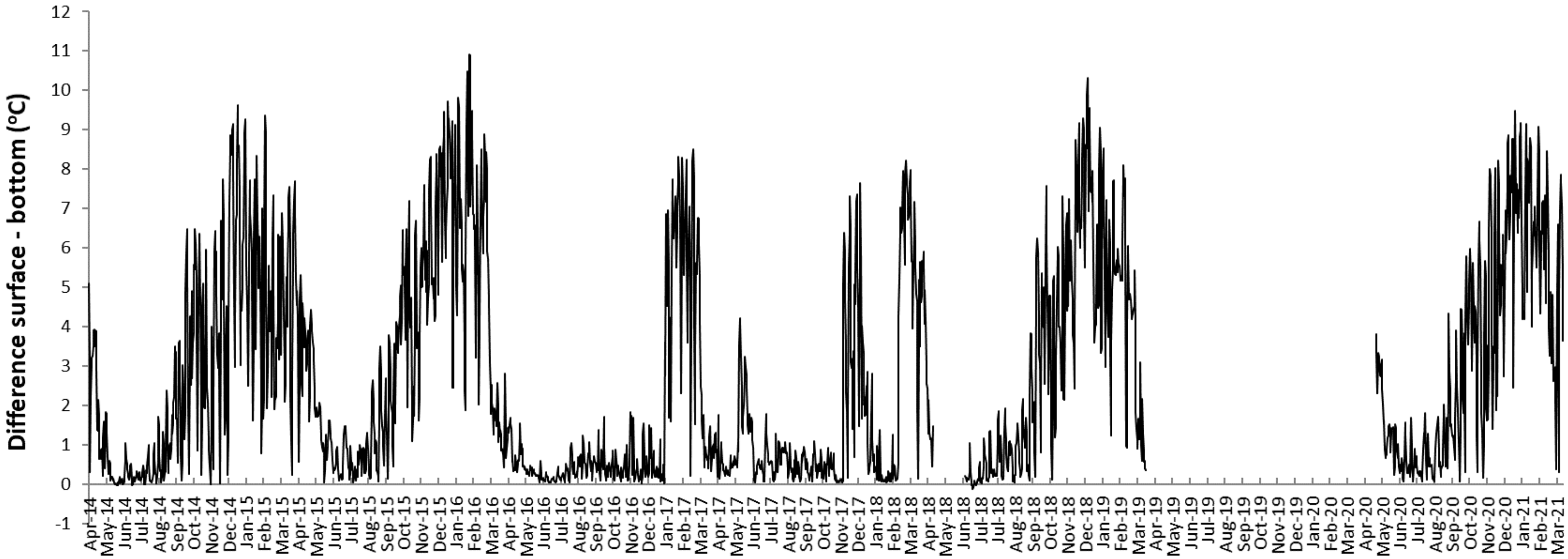


Figure 6.8. Difference in the average daily water temperature measured at 2 m and 12 m depth at North Buoy in Small Bay for the period 12 April 2014 – 27 March 2021. A large positive difference depicts strong water column stratification.

6.4 SALINITY

6.4.1 SALDANHA BAY

Salinities of the inshore waters along the West Coast of South Africa typically vary between 34.6 and 34.9 Practical Salinity Units (PSU) (Shannon and Nelson 1996), 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 for Saldanha Bay covers much of the same period as that for water temperature. Salinity data at 10 m depth were extracted from the studies of Shannon and Stander (1977), Monteiro and Brundrit (1990), Weeks et al. (1991b), Luger et al. (1999) and are presented in Figure 6.9. These data show 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 reflect those of the source water. 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 (Figure 6.10). 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 (Luger et al. 1999).

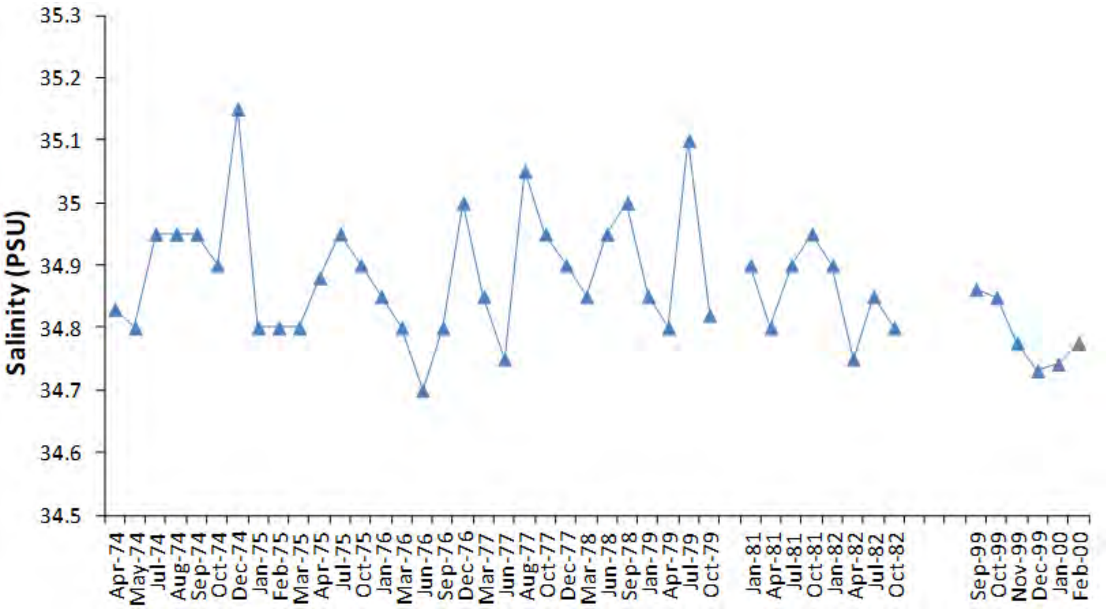


Figure 6.9. Time series of salinity records for Saldanha Bay. Data sources: (Shannon and Stander 1977, Monteiro and Brundrit 1990, Monteiro and Largier 1999).

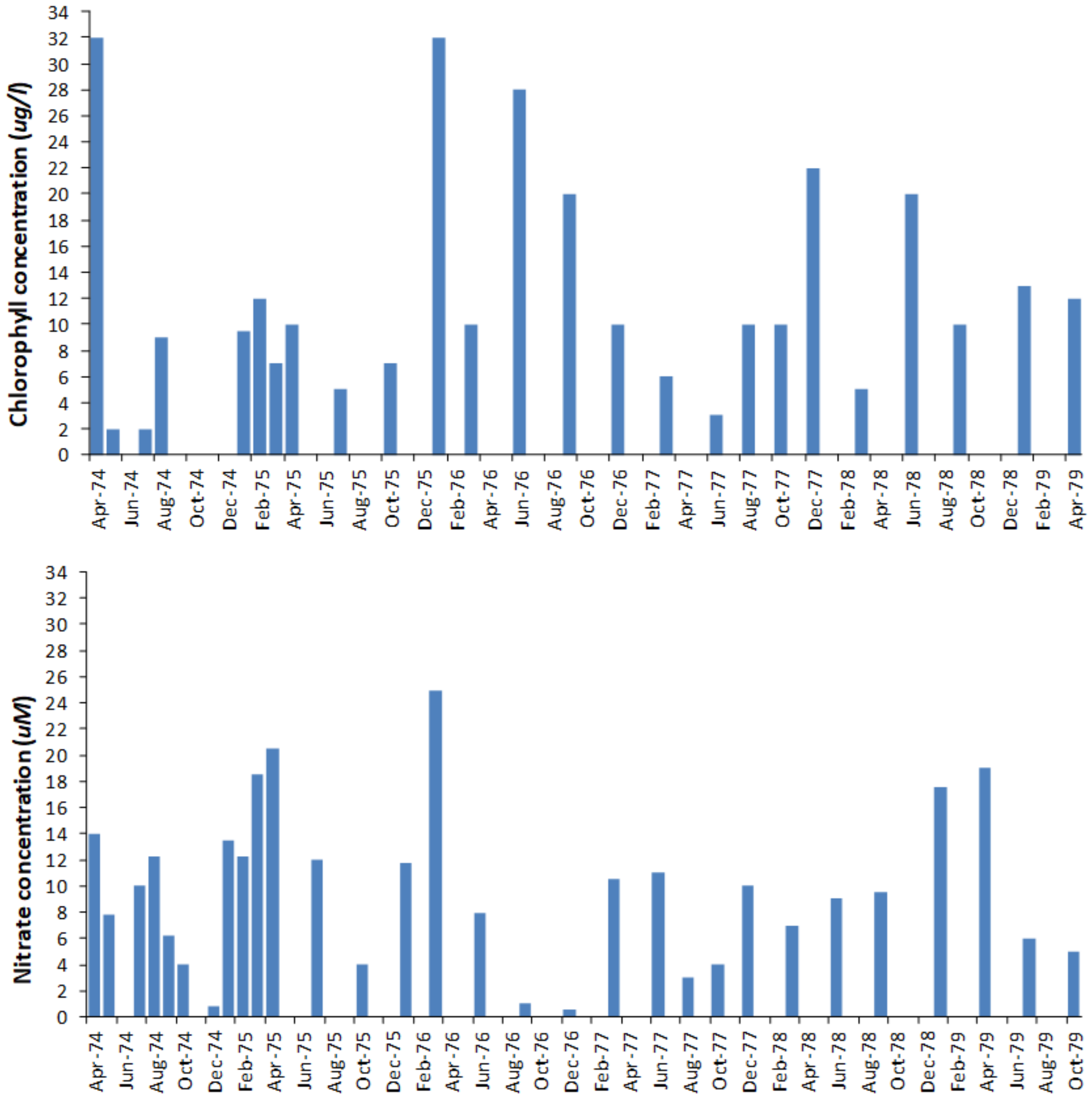


Figure 6.10. Time series of chlorophyll and nitrate concentration measurements for Saldanha Bay. (Data source: Monteiro and Brundrit (1990).

6.4.2 Langebaan Lagoon

Given the sensitivity of the Langebaan Lagoon, and in spite of confidence expressed by a range of specialists that groundwater use by Elandsfontein mine is unlikely to impact on the lagoon, Kropz Elandsfontein in conjunction with the SBWQFT have been monitoring a range of biological and physico-chemical variables associated with Langebaan Lagoon to establish an appropriate baseline against which any potential future changes in the Lagoon can be benchmarked. This includes monitoring of temperature and salinity (see below) and biota (see Chapter 9) as well as macrophytes (see Chapter 8) around the top end of the lagoon.

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. Data records from this period up until the end of 2018 have been presented in previous State of the Bay reports and are not repeated here. The Star ODDI was replaced with an Aqua TROLL 200 data logger at the end of August 2018 and quality of data collected has improved dramatically since then. The instrument was unfortunately removed (stolen) at some point between January and April 2020 (theft was discovered when we went to service the instrument in April 2020) but was replaced, with the new instrument having been deployed in August 2020 (the delay in securing a new instrument being related to the global COVID-19 pandemic). Data collected over the period August 2019 to September 2023 are presented on Figure 6.11 and Figure 6.12 below, along with measured water level.

The data recorded for the entire period shows a clear seasonal trend, with water temperature being much higher in summer (Dec – Feb, maximum 28°C) than in winter (Jun – Aug, minimum 10°C). Clear day to day oscillations in temperature, and salinity and water level are also evident in the data set. The diurnal fluctuations in temperature are similar across all seasons, with temperatures increasing over the course of the day, peaking in the early afternoon, then declining through the afternoon and night, reaching a minimum at the time of sunrise each day. The trend in salinity is more interesting though, exhibiting a similar diurnal oscillation to that for temperature, but this oscillation is linked to the state of the tide (rather than the time of day) and changes through the year. In winter, salinity oscillates between that of normal seawater (around 35.0 PSU) at high tide and a slightly fresher state (between 32.0 and 34.0 PSU) at low tide. Salinity appears to drop as the tide recedes and is most likely linked with outflow of freshwater from the aquifer at this time. This combination led to large drop in salinity at the end of June 2022 which saw salinity drop and measured depth increase simultaneously. In summer, the pattern reverses with salinity increasing from that of normal seawater (35.0 PSU) at the peak of the high tide, becoming hyper-saline (39-40 PSU) as the tide recedes.

It is likely that this is a function of increased evaporation at this time of year (linked to higher prevailing air temperatures) and that the water emerging from the marshes at the head of the lagoon becomes severely hypersaline as a result, and even though it is diluted by freshwater flowing out of the aquifer, this is not sufficient to bring the level below that of normal seawater. It is likely that this effect (development of hypersaline conditions) is quite localised at present (i.e., restricted to the extreme upper reaches of the lagoon only) but could become much more pervasive if freshwater outflow from the aquifer were to drop in future. Also, of interest in these data, there appears to be no link between rainfall and salinity levels in the lagoon which strongly suggests that variations in salinity in the lagoon are linked with groundwater inflow as opposed to surface water inflow, which is consistent with observations made by others (Nel 2018, Conrad and Naicker 2019).

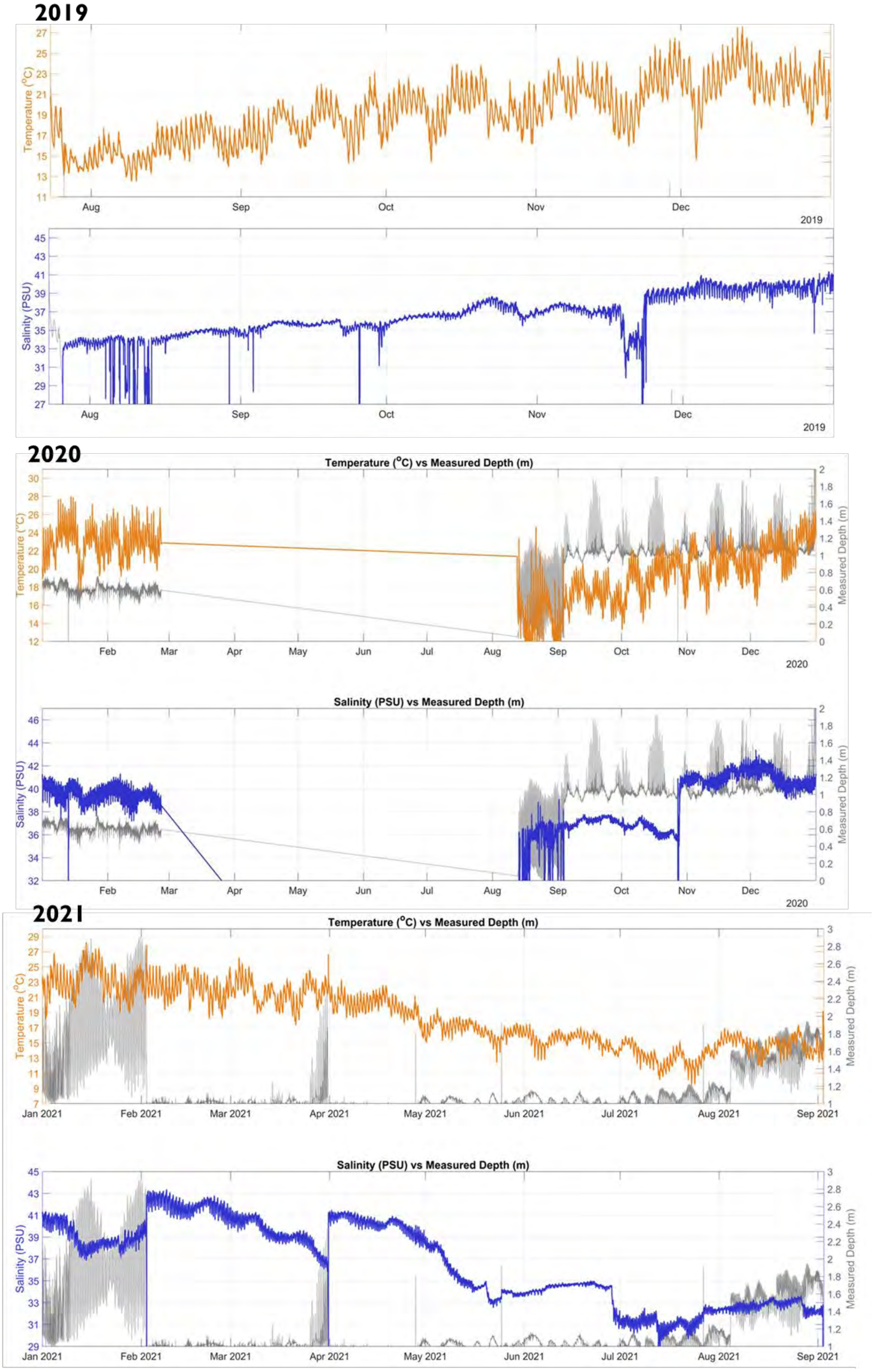


Figure 6.11. Variations in temperature (°C, top, orange) and salinity (PSU, bottom, blue) in the period 2019–2021. Data taken from Anchor's Aqua TROLL 200 moored at the head of the lagoon.

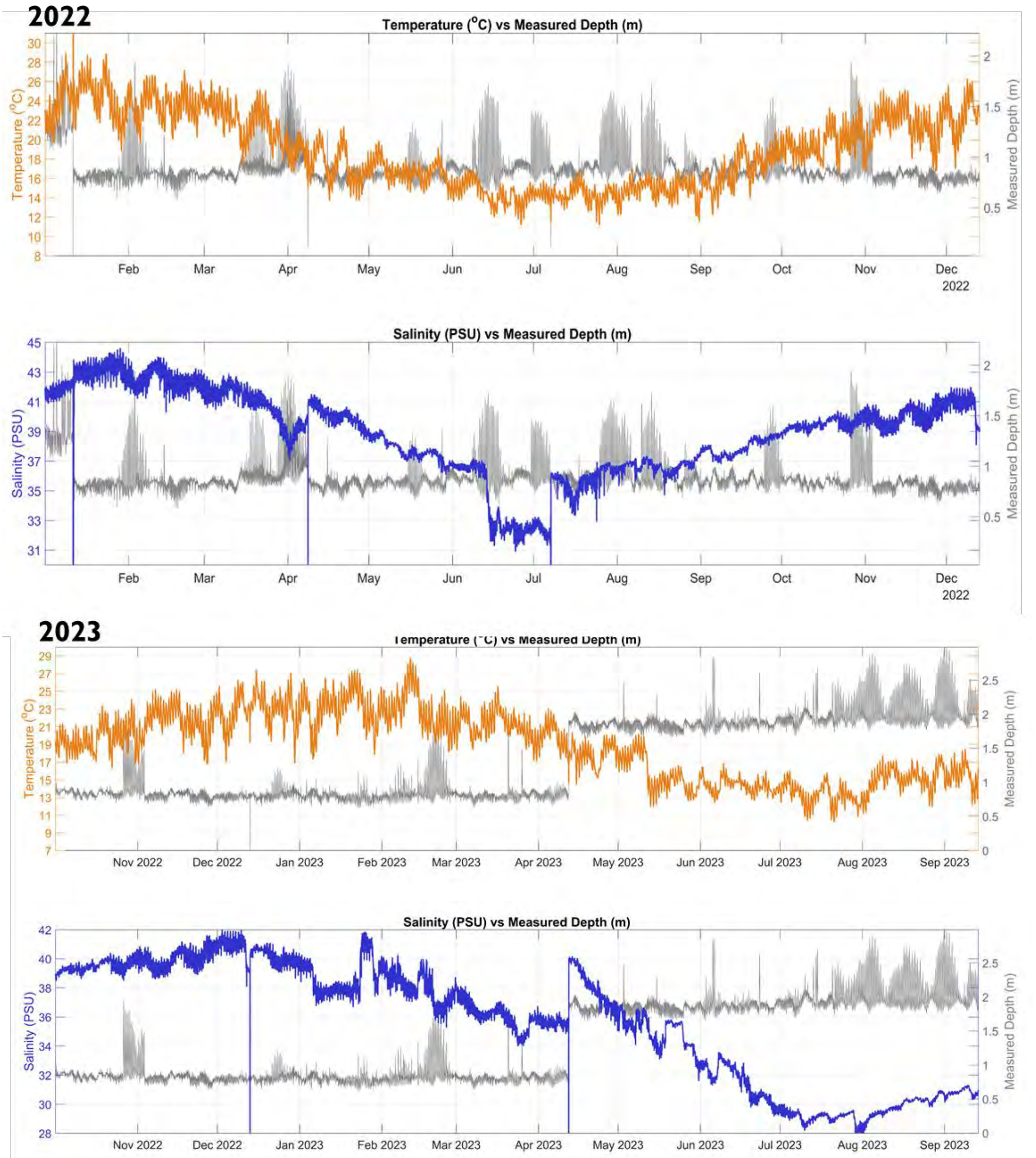


Figure 6.12. Variations in temperature (°C, top, orange) and salinity (PSU, bottom, blue) in the period 2022–2023. Data taken from Anchor's Aqua TROLL 200 moored at the head of the lagoon.

6.5 DISSOLVED OXYGEN

Sufficient dissolved oxygen (DO) 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 (from for example, fish factory waste or municipal sewage) as microbial breakdown of this excessive organic matter depletes oxygen in the water. The well-known "black tides" and associated mass mortalities of 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.

Small Bay does experience a fairly regular oxygen deficit during the winter months, while Big Bay experiences less frequent and lower magnitude oxygen deficits (Weeks et al. 1991a). Weeks et al. (1991a) 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. 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 i.e., increase in oxygen deficit during summer; 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. For detailed descriptions of historical trends observed in previous surveys of DO levels within Saldanha Bay, please see the State of the Bay report 2021.

The most recent DO measurements come from ongoing deployments of instruments at mariculture Farm and Control sites in both Small Bay and Big Bay by DFFE. These data show that these frequently hypoxic conditions (<2 ml/l) continue later, through until autumn (late May/early June) which, as described above, relates to the decline in upwelling and turbulent mixing of the water column with the onset of winter leading to higher DO levels in the bottom waters. It is also clear that there have not been major changes in DO levels in Small Bay over the last two decades, with regular hypoxic and even anoxic events recorded during summer and autumn in both data sets. The major increase in the frequency of Small Bay hypoxic events occurred after the major harbour development in the 1970s and the situation does not appear to have changed much since (Figure 6.13).

There is high spatial variability in near bottom DO concentration throughout Saldanha Bay, largely due to variation in hydrodynamic process and anthropogenic organic inputs. The 2023 data support historic observations that indicate that Big Bay experiences regular hypoxic events during autumn, reflecting the external source of low oxygen upwelled water (Figure 6.13). The absence of any anoxic events, however, is attributed to better mixing of the water column in Big Bay, lower retention times (enhanced flushing) and lower organic loading from anthropogenic sources (e.g., mariculture, fish factory effluent, Wastewater Treatment Works (WWTW)). Note that there is currently no mariculture activity on the Big Bay Farm site that is earmarked for future fin fish cage farming.

Within Small Bay, oxygen concentrations at the Farm site were distinctly lower than the Control site, despite being substantially shallower (DO typically decreases with depth so the deeper control site is expected to have lower DO levels under natural conditions) (Figure 6.13). The more pronounced and frequent hypoxia at the Small Bay farm sites is considered to be a result of organic loading and higher microbial respiration, i.e., a consequence of bivalve mariculture. Hypoxic and intermittent near anoxic conditions in the lower part of the water column are frequent occurrences during summer-autumn seasons in Small Bay and anthropogenic organic loading appears to exacerbate the situation. Conditions very close to anoxia are observed on the Small Bay Farm site, while Control site DO concentrations, although also hypoxic, remained consistently higher (Figure 6.13). Conditions at the Small Bay farm site are more variable, especially throughout summer, but even through periods of hypoxia (Figure 6.13).

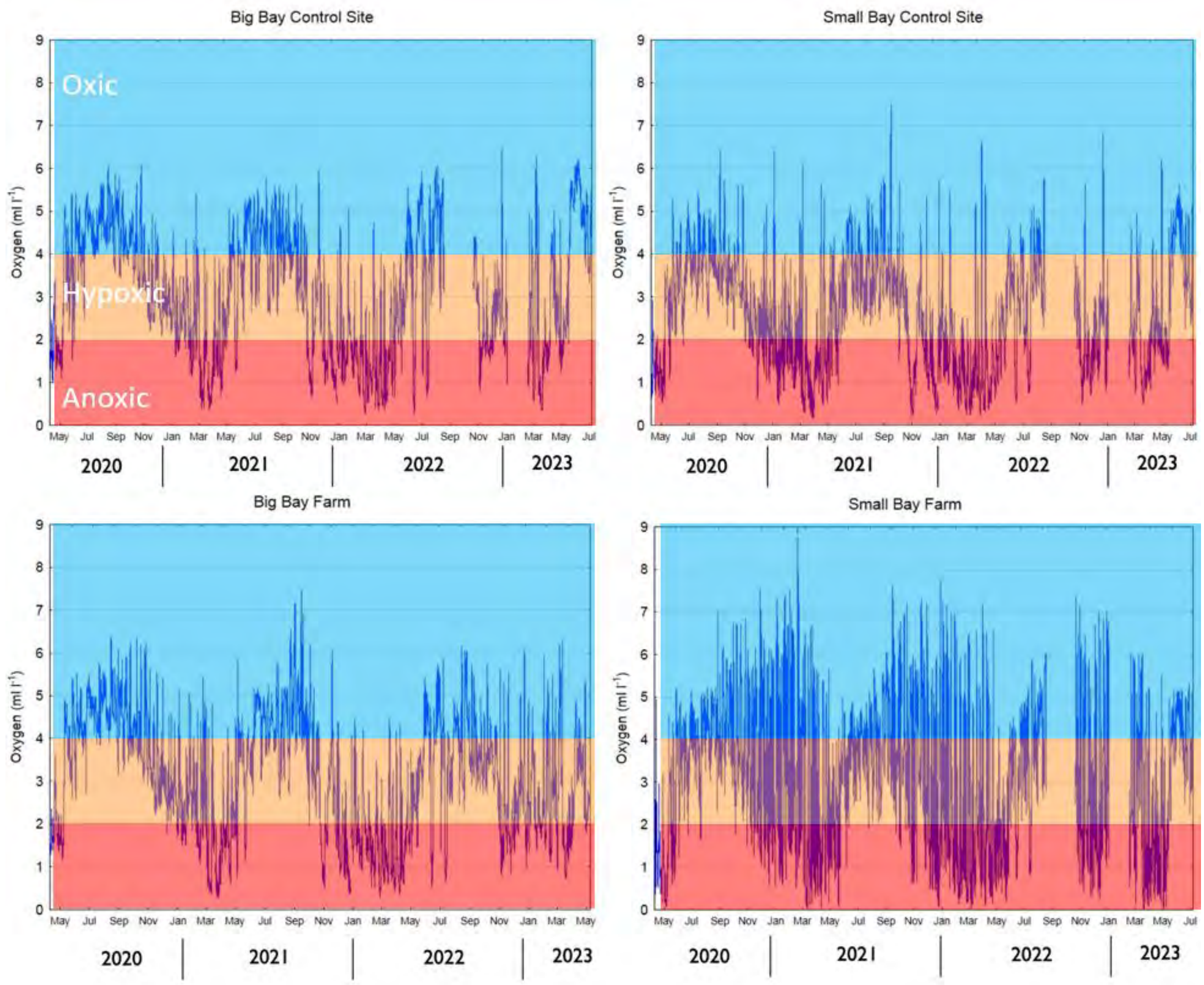


Figure 6.13. Comparison of Dissolved Oxygen concentration at mariculture Farm and Control sites in Small Bay, from Jul 2020 – Jul 2023 (bottom). 2020–23 graphs courtesy of DFFE (D:SAM).

6.6 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 and Largier 1999, Carr and Rickwood 2008). 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).

6.6.1 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, Water Quality Guidelines (WQGs) for the natural environment, industrial use, and mariculture operations were used to assess water bodies not designated as recreational areas (DWAF 1995a), 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.

RECREATIONAL USE

In the past, the Department of Water Affairs and Forestry (DWAF) (1995b) 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 WQG 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. Analyses should be completed by an accredited laboratory, preferably one with ISO 17025 accreditation.

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 (McNeill 2019). In order to calculate 95th percentiles, a minimum of ten data points is required, while the calculation of the 90th 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 globally to determine compliance in meeting stringent water quality targets within specified time frames (Carr and Rickwood 2008). Compliance data are usually grouped into broad categories, indicating the relative acceptability of different levels of compliance. For example, a low count of bacteria would be 'Excellent', while a 'Poor' rating would indicate high levels of bacteria. 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)**	***E. coli.* (count/100 ml)**
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)

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 1995a), 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 80th and 95th 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 1995a)

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

6.6.2 MICROBIAL MONITORING IN SALDANHA BAY AND LANGEBAAN LAGOON

In 1998 the CSIR were contracted by the 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, except for the 80th percentile guideline for mariculture being exceeded at one station (Paradise Beach). All other stations ranged within the guidelines for mariculture and recreational use.

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 August 2023 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 – TNPA), 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. In previous State of the

Bay reports, data were presented cover a complete calendar year to account for seasonal differences. The 2019–2023 reports, however, include data up until end May/June which therefore includes both summer and winter data. Compliance with mariculture guidelines were assessed by comparing faecal coliform counts to the DWAF 1995 guidelines (DWAF 1995a), whilst recreational use compliance was assessed by comparing *E. coli* count data to the revised recreational guidelines (DEA 2012).

6.6.3 WATER QUALITY FOR RECREATIONAL USE

Recreational water quality rankings for all sampled sites throughout Saldanha Bay and Langebaan Lagoon are shown in Table 6.5, while Figure 6.14 and Figure 6.15 graphically depict these data for Langebaan Lagoon. Data from the microbial monitoring programme suggest that generally nearshore coastal waters in the system have improved considerably for recreational use since 2005 (Table 6.5). However, based on the 2023 *E. coli* count data, only 9 of the 20 sampled stations were categorized as having 'Excellent' water quality and with three rated as 'Poor' water quality and six rated as 'Fair'. This is quite a substantial change from the 2022 results where 17 sites were rated as 'Excellent'. The Seafarm TNPS site (11) was the only site to have improved its *E. coli* counts between 2022 and 2023 (Table 6.5), with 8 sites have deteriorating. Alarmingly, Langebaan main beach, a popular bathing water, fell from 'Excellent' to 'Fair' (only marginally avoiding 'poor' rating) in one year. Other popular swimming and water sport sites close to Langebaan (i.e., Mykonos Beach) also declined. All sites towards the mouth of lagoon showed large drops in water quality. The Bok River Beach Site that had previously had poor water quality for most of the monitoring record again has remained 'Poor' in 2023, as it had in both 2021 and 2022. Water quality at the Hoedjies Bay site has remained 'Poor' for the last six years. Water quality at Pepper Bay (Site 5) was ranked as 'Poor' in 2020 but has since increased back up to 'Excellent' again in 2022 and has remained as such in 2023 (Table 6.5).

The general consensus was that reuse of the majority of treated wastewater from the Langebaan and Saldanha WWTW for other uses (including industrial, construction and irrigation) that was historically discharged into the Langebaan Marine Protected Area (MPA) was having a positive effect. However, 2023 represents one of the most extreme declines in recreational water quality since monitoring began and is a major concern. Contamination may not be related to discharges of wastewater and may be from other sources (e.g., storm water, sewage leaks etc.). A closer look at the data show that December 2022 and February 2023 were the worst offending months in terms of *E. coli* counts at these sites.

The Saldanha Bay Municipality (SBM) is in the process of upgrading Oostewal Road, which is one of the main thorough fairs through Langebaan. Citizens of Langebaan are concerned with actions taken by the municipality to divert stormwater from Oostewal Road into the Lagoon as they believe that this will result in negative environmental impacts on the Lagoon. The area around Langebaan main beach (Sites 14–17,Table 6.5) is in close proximity to the Oostewal Road upgrade site and so sites sampled here, as part of the State Of the Bay microbial monitoring, may capture localised changes in water quality which could be related to the road upgrade. Stormwater runoff is widely recognised as one of the major non-point sources of pollution in Langebaan Lagoon (CSIR 2002). Sealed surfaces, such as streets and pavements, prevent rainwater from soaking into the ground and runoff typically flows directly into rivers, estuaries, or coastal waters. Stormwater running over these surfaces accumulates debris and chemical contaminants, which then enters water bodies untreated and may eventually lead to environmental degradation. The road upgrade work has been underway throughout

2022/2023 and is close to its completion. In order to provide a more detailed understanding of potential impacts of this development on water quality, *E. coli* count data were assessed over varying time periods between 2021 and 2023 for key sites around Langebaan main beach to pinpoint a more specific point in time where changes in water quality may occur (Table 6.4). Results show a clear degradation in *E. coli* counts around December 2021 – February 2023. Prior to this water quality was rated to be 'Excellent' and this moved to 'Poor' in terms of acceptable count limits for *E. coli*. This could be related to the Oostewal road development and resulting increases in stormwater runoff.

Table 6.4. Sampling site compliance for recreational use based on E. coli counts for sites around Langebaan main beach in 2021–2023. Ratings are calculated using Hazen percentiles with the 90th and 95th percentile results grouped together to give an overall rating per data period as defined in the table to identify ≈ monthly changes in rating. 'Ex.' indicates excellent water quality.

Site	Assessment data range							
	Sep 21-Sep 22	Oct 21 - Oct 22	Dec 21 - Dec 22	Jan 22-Jan 23	Feb 22-Feb 23	Apr 22 - Apr 23	May 22-May 23	Aug 22 - Aug 23
14. Leentjiesklip	Ex.	Ex.	Ex.	Ex.	Poor	Poor	Poor	Poor
15. Langebaan North - Leentjiesklip	Ex.	Ex.	Ex.	Ex.	Poor	Poor	Poor	Poor
16. Langebaan - Main Beach	Ex.	Ex.	Poor	Poor	Poor	Poor	Poor	Poor
17. Langebaan Yacht Club	Ex.	Ex.	Ex.	Poor	Poor	Poor	Poor	Poor

Furthermore, Hoedjies Bay and Bok River sites have previously been some of the worst sites with highest *E. coli* counts. The rating provided in Table 6.5 is based on percentiles, and the counts at these sites were the >1500 colony-forming units (cfu)/100 ml suggesting actual counts could be much higher for these sites. Although this poor water quality could be related to once off or isolated events, immediate action should be taken to ensure an improvement is achieved.

Table 6.5. 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 (1999–2023). Ratings are calculated using Hazen percentiles with the 90th and 95th percentile results grouped together to give an overall rating per annum. 'ND' indicates that there was insufficient data for the calculation of Hazen percentiles 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	2018	2019	2020	2021	2022	2023
Small Bay	1. Beach at Mussel Rafts	Fair	Fair	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Fair	ND	Ex.	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.	Ex.	Ex.	Fair	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.	Fair	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.
	4. Saldanha Yacht Club	Poor	Poor	Poor	Fair	Poor	Poor	Poor	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Fair	Ex.	Ex.
	5. Pepper Bay - Big Quay	Poor	Fair	Poor	Fair	Fair	Fair	Fair	Poor	Ex.	Ex.	Fair	Ex.	Ex.	Good	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Poor	Good	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.	ND	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	Poor	Poor	Poor	Poor	Poor	Poor
	8. Beach at Caravan Park	Fair	Fair	Fair	Poor	Ex.	Fair	Poor	Ex.	Good	Poor	Fair	Fair	Fair	Poor	Good	Fair	Ex.	Fair	Fair	Fair	Fair	Fair	Ex.	Good	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	Fair	Fair	Good	Poor	Poor	Poor
	10. General Cargo Quay - TNPA	Ex.	Fair	Ex.	Ex.	Ex.	Ex.	Good	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Fair
Big Bay	11. Seafarm - TNPA	Ex.	Fair	Ex.	Ex.	ND	ND	Ex.	Ex.	Ex.	ND	Ex.	ND	ND	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Good	Ex.
	12. Mykonos - Paradise Beach	Ex.	Fair	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Fair	Ex.	Ex.	Good
	13. Mykonos - Harbour	Fair	Fair	Ex.	Ex.	Fair	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Fair	Ex.	Ex.	Good	Fair	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Fair
	14. Leentjiesklip	ND	ND	Good	Fair	Good	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Fair	Ex.	Good	Ex.	Ex.	Ex.	ND	Ex.	Ex.	Ex.	Ex.	Fair
Langebaan Lagoon	15. Langebaan North - Leentjiesklip	Ex.	Fair	Good	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Poor	Good	Ex.	Good	Ex.	Good	Ex.	Ex.	Fair	Ex.	Ex.	Fair
	16. Langebaan - Main Beach	ND	ND	Fair	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Good	Ex.	Ex.	Ex.	Ex.	Ex.	Fair	Ex.	Ex.	ND	Ex.	Good	Ex.	Ex.	Fair
	17. Langebaan Yacht Club	ND	ND	ND	ND	ND	Poor	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Good	Ex.	Ex.	Fair	Good	ND	Ex.	Ex.	Ex.	Ex.	Fair
	18. Tooth Rock	ND	ND	ND	ND	ND	Fair	Ex.	Ex.	Ex.	Ex.	Fair	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	ND	Ex.	Ex.	Ex.	Ex.	Good
	19. Kraalbaai North	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	ND	Fair	Ex.	Ex.	Ex.	Ex.
	20. Kraalbaai South	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	Ex.	Ex.	Ex.	Ex.	Ex.	Ex.	ND	Ex.	Fair	Ex.	Ex.	Ex.

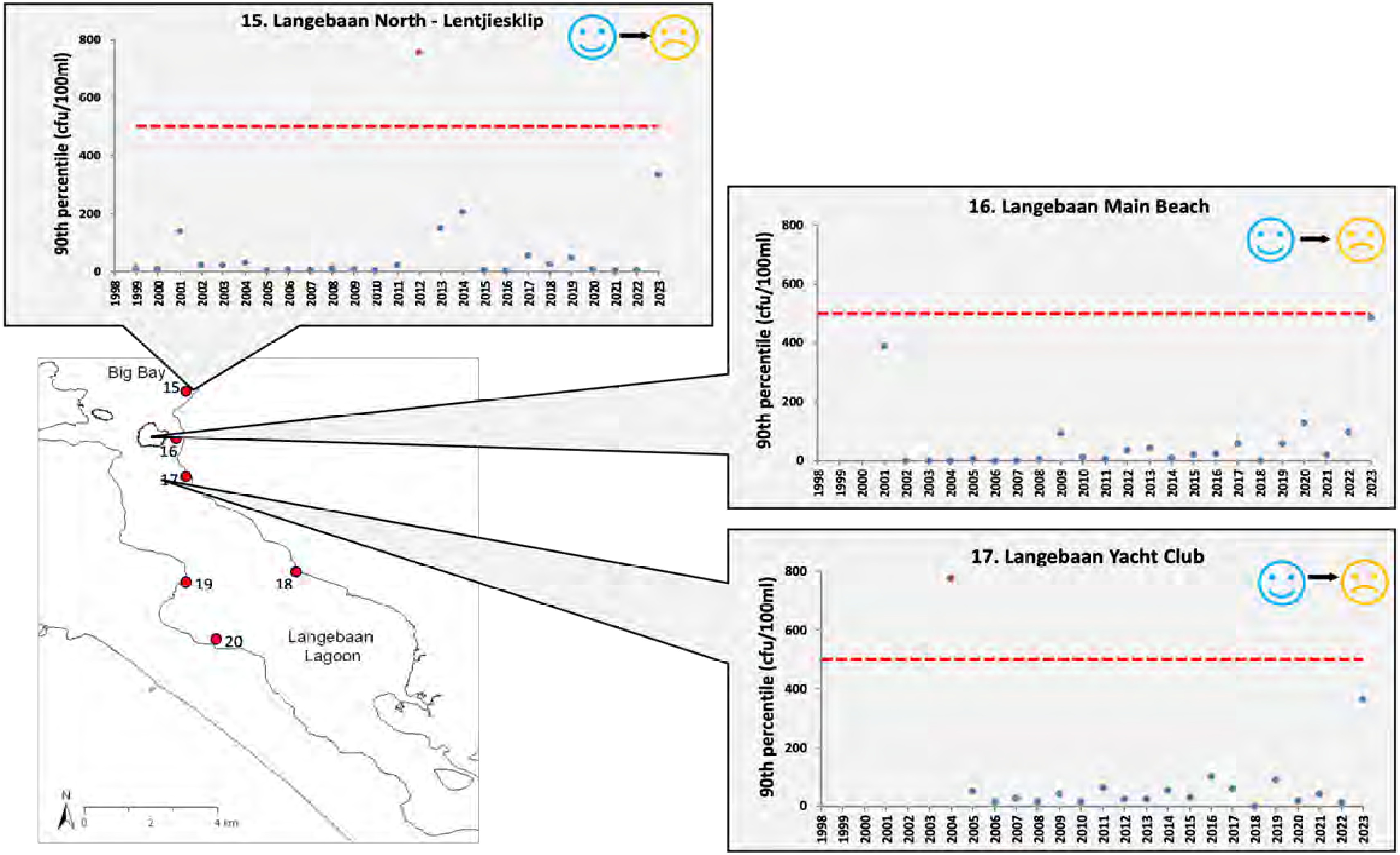


Figure 6.14. Hazen method 90th percentile values of *E. coli* counts at three of the six sampling stations within Langebaan Lagoon (Feb 1999 – Jul 2023). The red line indicates the Hazen method 90th percentile contact recreation limit of *E. coli* counts (500 colony-forming units/100 ml) above which water quality is ranked as 'Poor/Unacceptable'. Red data points indicate 90th percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The faces correspond to changes water quality over time.

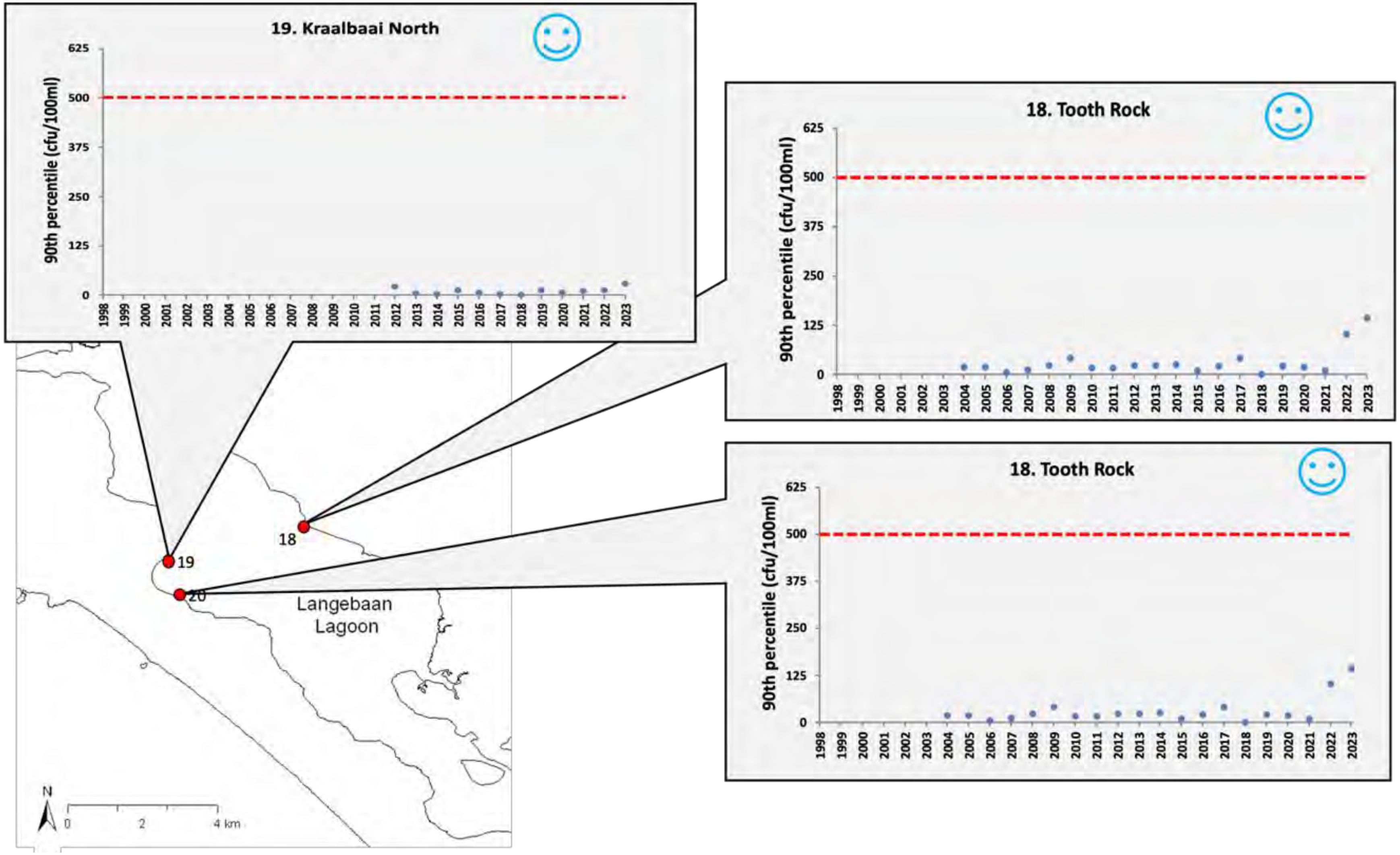


Figure 6.15. Hazen method 90th percentile values of *E. coli* counts at three of the six sampling stations within Langebaan Lagoon (Feb 1999 – Jul 2023). The red line indicates the Hazen method 90th percentile contact recreation limit of *E. coli* counts (500 colony-forming units/100 ml) above which water quality is ranked as 'Poor/Unacceptable'. The faces correspond to water quality over time

6.6.4 WATER QUALITY FOR MARICULTURE USE

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 80th percentile mariculture guideline limits for faecal coliforms (Figure 6.16, Figure 6.17, Figure 6.18). There has been considerable improvement over time, particularly at sites near the entrance to Small Bay (the beach at the Mussel Rafts, the Small Craft Harbour) that have met standards every year since 2000. The Saldanha Bay Yacht Club has also shown considerable improvement since 2005 and met concentration guidelines in all years apart from 2021.

More recent improvement was seen at the small quay at Pepper Bay across the years 2017–2020 but faecal coliforms were above the limit for 2021 and 2022, but in 2023 concentrations of faecal coliforms were below the limit which is an improvement (Figure 6.17). In 2022, the big quay at Pepper Bay met current guidelines for the first time in three years and this has continued into 2023 (Figure 6.17). In 2019, the General Cargo Quay didn't meet the mariculture standard for the first time in the 20-year sampling history but was again compliant in 2020 and continues to be compliant through to 2023. The remaining three sites within Small Bay, however, continue to exceed the mariculture guidelines (i.e., Hoedjies Bay Beach, the beach at Caravan Park and the Bok River Mouth) (Figure 6.17 and Figure 6.18). The areas of particular concern have always been at Hoedjies Bay and the Bok River Mouth. In 2023 the Bok River mouth exceeded the guideline by an order of magnitude (290 cfu/100 ml), the worst concentration since 2012 (guideline limit = 20 cfu/100 ml). The Bok River mouth also fails to meet *E. coli* concentration limits as described in the previous section. Although a sustained improvement in levels of compliance with mariculture WQGs has occurred since the 1999–2005 period at most Small Bay sites (Figure 6.16, Figure 6.17, Figure 6.18), these data indicate that there remains a serious issue of water quality with respect to mariculture operations within areas of 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 any land-based mariculture facilities wishing to develop within the Industrial Development Zone (IDZ).

Faecal coliform counts at all four sites sampled within Big Bay in 2023 were within the 80th percentile limit for mariculture (Figure 6.19). The water quality in Big Bay has largely met mariculture guidelines nearly every year since 2004, with the exception of the Mykonos Harbour site where levels fluctuate and guidelines were marginally exceeded in some of the previous years, most recently in 2021 (Figure 6.19).

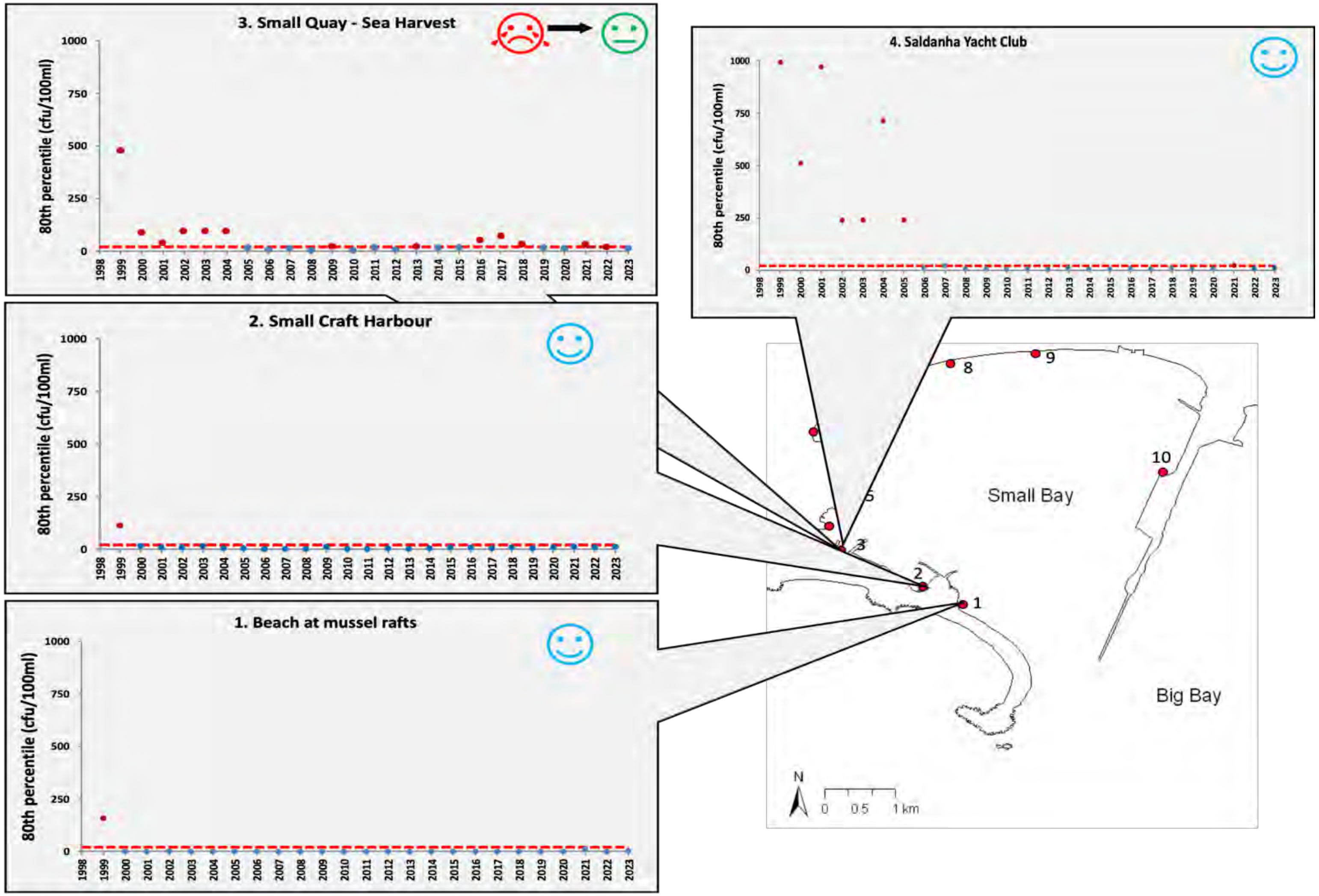


Figure 6.16. 80th percentile values of faecal coliform counts at four of the 10 sampling stations within Small Bay (Feb 1999 – Aug 2023). The red line indicates the 80th percentile mariculture limit of faecal coliforms (20 colony-forming units/100 ml). Red data points indicate 80th percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The faces correspond to changes in water quality over time.

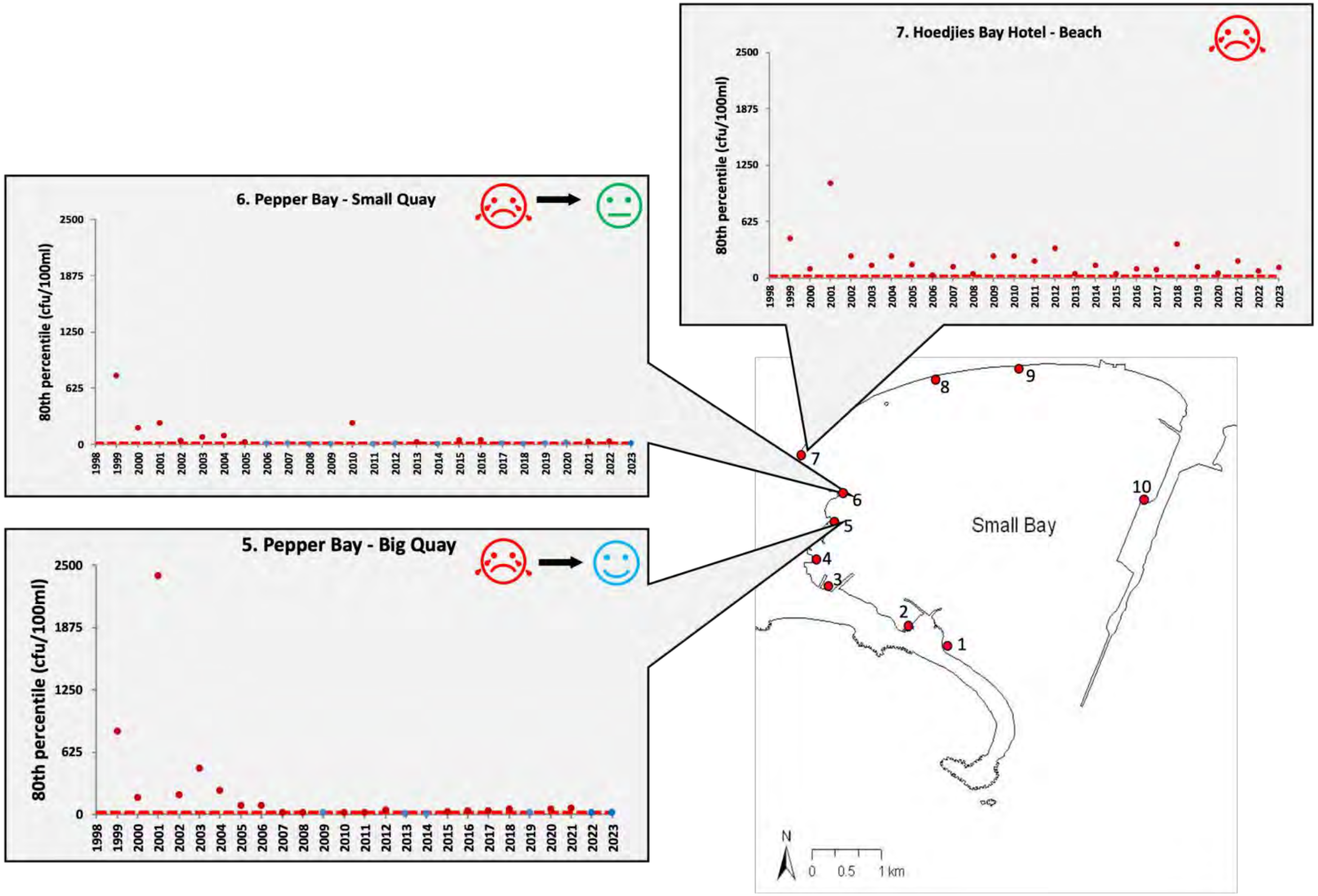


Figure 6.17. 80th percentile values of faecal coliform counts at three of the 10 sampling stations within Small Bay (Feb 1999 – Aug 2023). The red line indicates the 80th percentile mariculture limit of faecal coliforms (20 colony-forming units/100 ml). Red data points indicate 80th percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The faces correspond to changes in water quality over time.

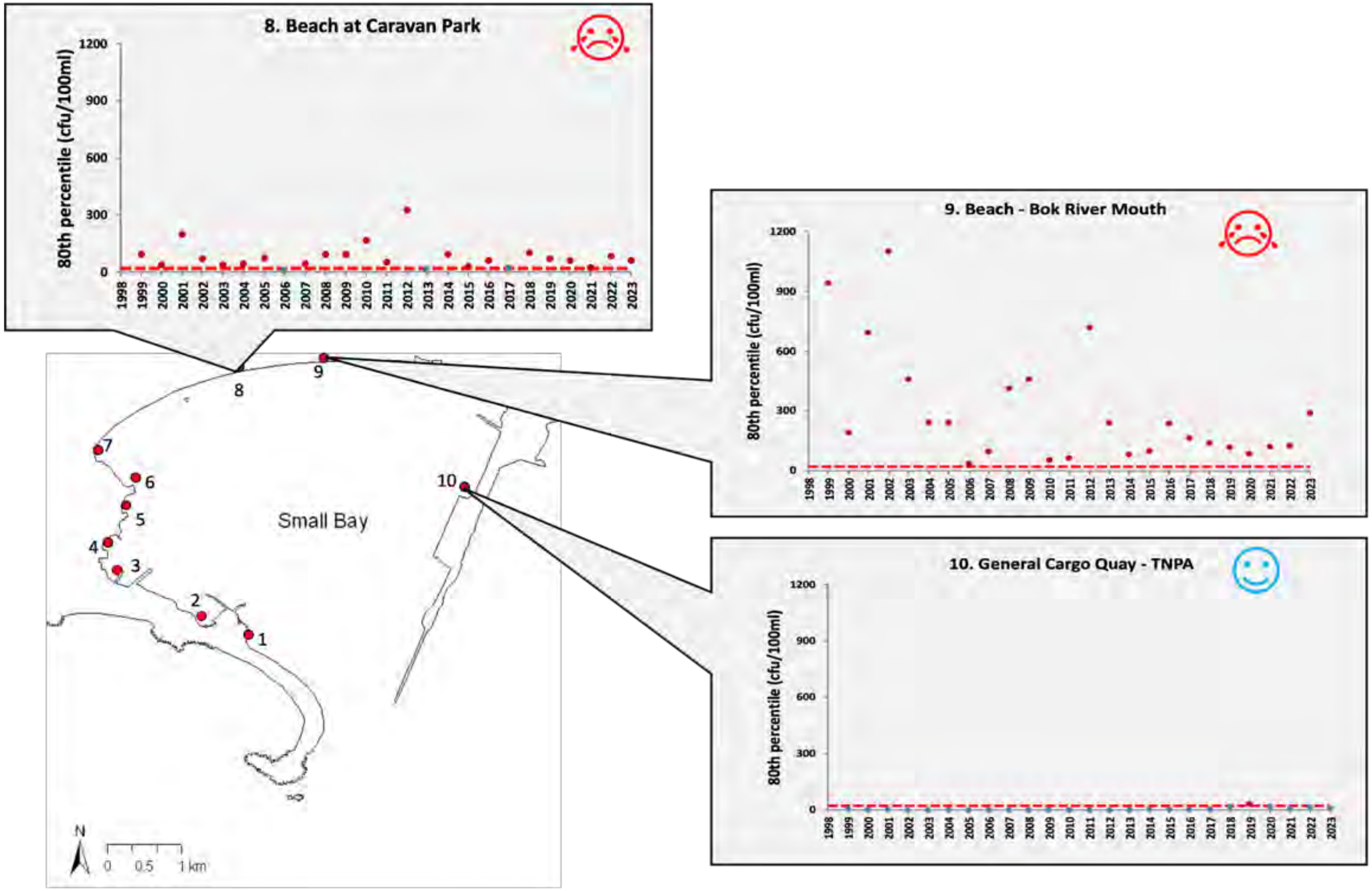


Figure 6.18. 80th percentile values of faecal coliform counts at three of the 10 sampling stations within Small Bay (Feb 1999 – Aug 2023). The red line indicates the 80th percentile mariculture limit of faecal coliforms (20 colony-forming units/100 ml). Red data points indicate 80th percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The faces correspond to changes in water quality over time.

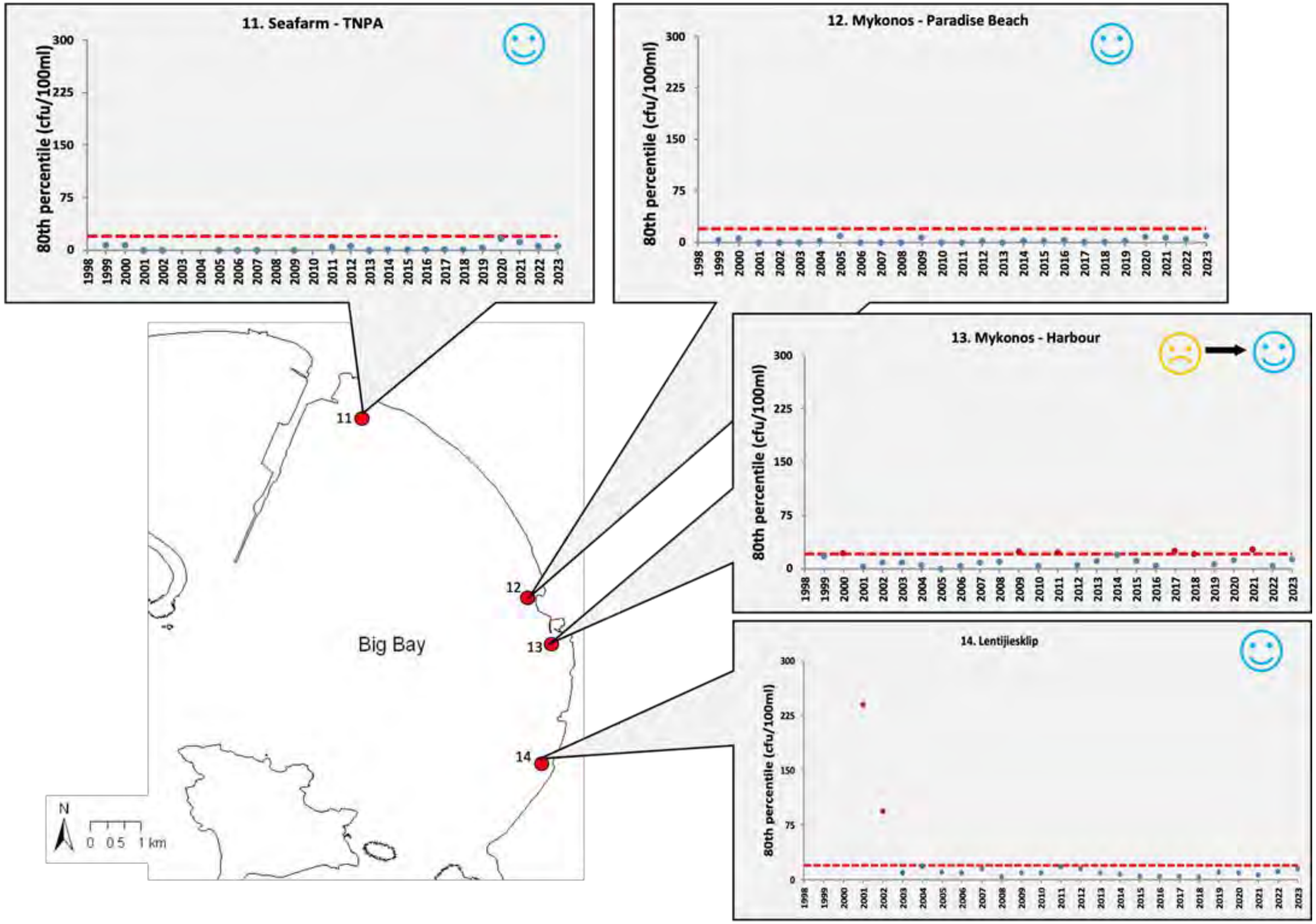


Figure 6.19. 80th percentile values of faecal coliform counts at the four sampling stations within Big Bay (Feb 1999 – Aug 2023). The red line indicates the 80th percentile mariculture limit of faecal coliforms (20 colony-forming units/100 ml). Red data points indicate 80th percentile values exceeding the guideline, whilst blue data points fall within the recommended guideline. The faces correspond to changes in water quality over time.

6.7 HEAVY METAL CONTAMINANTS IN THE WATER COLUMN

It is common practice 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. Sessile bivalves (e.g., mussels and oysters) are good indicator species for monitoring water quality as these filter feeding organisms tend to accumulate trace metals, hydrocarbons and pesticides in their flesh. These sessile molluscs (anchored in one place for their entire life) are affected by both short-term and long-term trends in water quality. Monitoring contaminant levels in mussels or oysters can provide an early warning of poor water quality and detect 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 these metals have the potential to be toxic to living organisms at elevated concentrations (Rainbow 1995). High levels of cadmium, for example, reduces 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 1995a).

Human activities greatly increase the rates of mobilisation 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 1980). 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 (Kljakovic-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 1995, Desideri et al. 2009, Kljakovic-Gašpić et al. 2010).

6.7.1 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* 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 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 May 2023 and analysed for the metals lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), iron (Fe), manganese (Mn) and mercury (Hg) and the metalloid arsenic (As). Data from the Mussel Watch Programme and from the annual 'State of the Bay' field trips are represented in Figure 6.20 to Figure 6.30.

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.

The regulations pertaining to the maximum legal limits of metal contaminants in shellfish (including mussels but excluding oysters) for human consumption in South Africa are published under the Foodstuffs, Cosmetics and Disinfectants Act, Act 54 of 1972. Until 2018, the limits for metals in shellfish as published under regulation R.500 of 2004 were applied to any bivalve samples collected as part of this study. Maximum limits were, however, only specified for cadmium and mercury. In 2018, new South African regulations were published (Regulation R.588 of 2018 in Government Gazette No. 41704) and included amendments to those of 2004. Specifically, it included a reduction of the acceptable concentration of cadmium in marine bivalve mussels from 3 to 2 ppm and the exclusion of mercury from the list, rendering cadmium the only metal for which a legal limit had been stipulated in the South African regulations. For the metals with no specified limits, limits as specified for fish and fish products (in the case of arsenic and lead) or those adopted by other countries (in the case of copper and zinc) were applied. These are indicated in green bolded text in Table 6.6 and with a green line on the graphs. All limits refer to concentrations of contaminants analysed relative to the wet weight of the flesh of the organism. In 2021, international regulations pertaining to metals in foodstuff were again reviewed to set guideline limits for metals in bivalve flesh collected as part of the State of the Bay monitoring programme going forward. Where more than one value was listed per metal, the median value was used. In the case of arsenic, where only two values were available, the most conservative value was used (Table 6.7). These limits will be referred to as the median guideline limits and are indicated in red bolded text in the table and with a dashed red line on each series of graphs.

Table 6.6. Historical maximum levels for metals in mussels in different countries and in South Africa for different years. Values in bold and green were applied to the State of the Bay mussel samples collected up to 2018 for cadmium and December 2020 for copper, lead, zinc, arsenic and mercury.

Country	Cu (ppm)	Pb (ppm)	Zn (ppm)	As (ppm)	Cd (ppm)	Hg (ppm)
South Africa[1]		0.5 up to 2018 (fish products)		3.0 until 2018 (fish products)	3.0[1] until 2018 2.0[11] since 2018	0.5 up to 2018
Canada[2]	70.0	2.5	150.0	1.0	2.0	
Australia & NZ[3]		2.0			2.0	0.5
European Union[4]		1.5			1.0	0.5
Japan[5]		10.0			2.0	0.2
Switzerland[2]		1.0			0.6	0.5
Russia[6]		10.0			2.0	
USA[7, 8]		1.7			4.0	
China[9]					2.0	
Historical guideline limits	**70.0**	**0.5**	**150.0**	**3.0**	**3.0** until 2018 **2.0** since 2018	**0.5**

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)

Table 6.7. Regulations relating to the maximum levels for metals in mussels (wet weight) in different countries and in South Africa. Values indicated in bold and red are the revised median guideline limits that have been applied to the State of the Bay samples collected since January 2021.

Country	Cu (ppm)	Pb (ppm)	Zn (ppm)	As (ppm)	Cd (ppm)	Hg (ppm)
South Africa[1]					2.0	
Canada[2]					2.0	
Australia & NZ[3]		2.0		1	2.0	0.5
European Commission[4]		1.5			1.0	0.5
China [5]		1.5		0.5	2.0	0.5
Revised median guideline limits	**None**	**1.5**	**None**	**1**	**2**	**0.5**

1. Regulation No. 588 of 2018 (Government Gazette No. 41704) published under the Foodstuffs, Cosmetics and Disinfectants Act, 1972 (Act 54 of 1972)
2. Codex. (2019). Codex Standard 193-1995 the general standard for contaminants and toxins in food and feed. Codex Alimentarius Commission. www.codexalimentarius.org
3. Australia New Zealand Food Standards Code — Schedule 19 — Maximum levels of contaminants and natural toxicants. 2021. legislatioin.gov.au.
4. European Commission 2006. Commission Regulation (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs. Off J Eur Union, 364(365–324).
5. FAS Beijing Staff. Food and Agricultural Import Regulations and Standards Country Report. 2020. Peoples Republic of China. Network, United States Department of Agriculture Foreign Agriculture Service and Global Agriculture Information Network. FAIRS Annual Country Report. Report Number: CH2019-0198.

To facilitate comparison with food quality guidelines, trace metal levels in bivalves in the 'State of the Bay' are presented relative to wet weights of bivalve tissue. Mercury concentrations within mussel tissues were measured for the first time in 2016 when they peaked at around 0.2 ppm. To date, values have not exceeded the safe limit of 0.5 ppm (Figure 6.20). With the recent revision of the maximum concentrations of lead permitted in foodstuff by several countries, the median guideline limit has now increased threefold to 1.5 ppm. Mussels samples from Saldanha Bay North have experienced lead concentrations in exceedance of this level between 2016 and 2021 but in 2023 concentrations of lead at this site were the lowest observed in recent years, but this could be part of a fluctuating pattern over time (Figure 6.20). Portnet saw a reduction in the levels of lead from 2022 to 2023. Mussels collected at the Portnet site have historically had high concentrations of lead in their tissue and although values in the last seven years have not been as high as historical peaks (Figure 6.21). The mussel raft and Iron Ore and Fish Factory sites all experienced very low levels of lead in 2023, presumably due to better flushing when compared to sites further north in Small Bay. The high levels of lead are almost certainly linked to the export of lead ore from the multi-purpose quay, which is situated near the Portnet site. The average concentration of lead in the tissues of mussels collected at the five sites within Small Bay has fluctuated from 0.9 ppm to 1.7 ppm over the last seven years with an average of 0.46 ppm in 2023. The lead pollution situation in Small Bay is considered to be improving and recorded concentrations in 2023 support this but 2022 had high levels recorded so close monitoring of lead concentrations at all sites should continue.

The high level of lead in bivalve flesh remains a human health concern in Small Bay but 2023 was improved for all sites, which is encouraging considering wild mussels harvested from the shore do appear to accumulate higher levels of trace metals than farmed mussels. Lead concentrations in excess of the previous South African guideline (0.5 ppm) have been previously detected but all levels from 2023 from mussel watch research samples were below the 1.5 ppm guideline. It is noted that this level is set for "fish", and not specifically for bivalves. The European Commission has set a higher limit (1 ppm) and Australia an even higher limit (2 ppm) for bivalves which implies that farmed mussels from Saldanha Bay are in most cases actually safe for human consumption. Firth et al. (2019) do, however, recommend that it is "imperative to better control and regulate sources of lead pollution within Saldanha Bay". Signboards warning of the health risks of consuming coastal mussels in this area and discouraging their collection are still advised to be posted in areas where these bivalves are easily accessible (e.g., Hoedjies Bay).

Cadmium concentrations were previously very low in all sites, well below the 2.0 ppm median guideline limit (Figure 6.20). Cadmium levels in mussels from all sites over the period 2015–2022 ranged between 0.16 and 3.73 ppm and have decreased steadily from an average of 1.27 ppm in 2018 to 0.74 ppm in 2022. However, all sites apart from Portnet experienced an increase in cadmium concentrations from 2022 to 2023. Despite cadmium concentrations rarely ever exceeding the maximum limit of 2.0 ppm, cadmium concentrations exceed this limit in 2023 at the Iron Ore Jetty, the first exceedance in general since 2018 and the first exceedance at this site since 2006 (Figure 6.22).

Average zinc concentrations recorded in 2023, and historically at nearly all sites, were much lower than the 150 ppm regulatory limit previously listed by the Canadian Authorities (Figure 6.20 and Figure 6.23). This metal only rose above this limit once at the Saldanha Bay North site (165 ppm in 2016), which was also elevated in 2019 & 2020 at this site, albeit not above the regulatory limit. The recent revision of the maximum concentrations of metals permitted in foodstuff have, however, recently excluded zinc from this list, meaning there is now no longer a maximum specified limit.

Historically, the maximum legal limit of copper in food was listed as 70 ppm in Canada. These limits have since been removed, mainly as copper naturally occurs in high concentrations in certain foodstuff. Regardless, copper concentrations have never exceeded 5 ppm at any of the sites over the entire sampling period. In 2023, the samples from the Fish Factory site had the highest copper concentration recorded since 1997, but the level was still below the 5 ppm limit. There appears to be no spatial or temporal trend in level of copper in mussel samples (Figure 6.20 and Figure 6.24).

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 (Brand et al. 1983, Sunda 1989). Historically concentrations were highest at the Portnet site, and this was again the case in 2022 and 2023. 2022 saw a peak in concentration at 5.82 ppm, and concentration recorded in 2023 remained high at 4.54 ppm. These are highest on record and over double the concentrations recorded in all other sites since 1997 (Figure 6.20 and Figure 6.25). Furthermore, concentrations of manganese for samples collected at all other sites were either the highest recorded at that site (Mussel Raft, Iron Ore Jetty, Fish Factory) or in above the 90th percentile (Portnet, Saldanha Bay North) since data have been collected.

Manganese export volume has been steadily increasing from 95 000 tonnes in 2013/2014 to just over 4.5 million tonnes annually 2017–2022, although annual fluctuations in export volumes are common. Manganese concentrations were higher in Portnet compared to that recorded in mussels at the other sites. Concentrations recorded at Portnet seem to coincide with the export volumes of manganese.

South Africa accounts for approximately 78% of the world's identified manganese resources. 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 South Africa 2017) and export masses increased substantially (by more than one third of the previous year) until 2017/18 after which they stabilised, averaging roughly 4270 thousand tonnes over the past 4 years.

The Port of Saldanha is under the authority of Transnet Port Terminals (TPT). The terminals comprise the IOT and the Multi-purpose Terminal (MPT) and are positioned on a constructed jetty of approximately 4 km long that separates Big and Small Bay. The MPT is dedicated mostly for export of lead, copper, zinc and manganese concentrates, and the Sea Harvest/Cold Store terminal that is dedicated to frozen fish products. Although the manganese loading terminal is midway between the MPT at the base of the iron ore jetty and the IOT, currents and onshore winds will cause manganese dust to move towards the base of the jetty and accumulate in this area.

A Provisional Air Emissions Licence (PAEL) for the storage and handling of ore and coal, specifically manganese (Mn), at the MPT was issued by the air quality officer of the Department of Environmental Affairs on 26 September 2018 (Reference: AEL/WCP/TPT/26/06/2018-2387). The PAEL was appealed in November 2018 by 15 appellants, the main concern being the "Harmful and health effects of manganese to people, water, aqua farms, tourism and businesses including the efforts to develop Saldanha Bay as a Green City and that an

Environmental Impact Assessment (EIA) should have been conducted." The Minister of Environment, Forestry and Fisheries (Ms BD Creecy) upheld the appeal and given this, the quantity of manganese being stored at the MPT has been significantly reduced. A maximum of 90 000 tonnes of manganese is currently being stored in two sheds at the MPT. Due to the global increased demand of manganese in addition to the fact that the MPT is currently being underutilised, TPT has decided to expand its operations and increase the storage of manganese in dedicated storage areas at the terminal to 450 000 tonnes. This will increase annual throughput to 8 million tonnes. An additional storage shed that can store 200 000 tonnes of manganese is to be developed and will therefore reduce the volume of manganese stored outside. The proposed development triggers a listed activity under Listing Notice 2 in the EIA Regulations promulgated in terms of the National Environmental Management Act. This EIA is currently still being assessed.

The EIA stipulates that an increase in manganese storage, handling and ship loading activities could result in an increase in accidental spillage or dispersion of manganese ore and ore dust within the area. Manganese ore spreads across surfaces and terminal platforms where it ends up in stormwater runoff or in effluent during cleaning activities whereafter it can enter the marine environment. In the event that manganese enters the marine environment, there is concern that high levels could be toxic to marine organisms. However, bioaccumulation of trace metals in marine organisms as a direct result of manganese spillage is very unlikely as trace metals usually comprise a very small percentage of manganese ore. With the anticipated increased in manganese storage and handling, and especially considering the high concentrations seen in Portnet in 2022 and 2023, measures should be put in place to prevent excessive amounts of manganese dust from entering the Bay.

Iron concentrations in mussel tissue have always fluctuated, although average concentrations appear to be higher over the period 2014–2023 (30.7 ppm) compared to concentrations over the 1997–2007 period (19 ppm) (Figure 6.20). This trend may reflect increases in iron ore export volumes, despite dust mitigation measures implemented over time. Iron concentrations are typically highest at Portnet and Saldanha Bay North sites and lowest at the Mussel Raft site, which probably reflects the effects of the prevailing southerly wind and the more retentive (less flushed) nature of the former sites (Figure 6.26). In 2020, a historical high of 87 ppm was recorded in the tissue of mussels collected at the Saldanha Bay north site (Figure 6.26). 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. Large volumes of iron ore are shipped from Saldanha Bay and iron ore residue is apparent on all structures downwind of the ore jetty and in the vicinity of the Saldanha Steel processing plant, it is therefore recommended that the concentration of this metal in the flesh of bivalves continue to be monitored.

Arsenic and mercury concentrations within mussel tissues were measured for the first time in 2015 and 2016, respectively. To date, mercury concentrations in mussels have not exceeded 0.2 ppm which is well below the median guideline limit of 0.5 ppm. Mussels collected during the 2023 survey had some of the lowest mercury concentrations, with values not exceeding 0.017 ppm (Figure 6.27). Since it was first recorded, arsenic concentrations at the five sites have fluctuated between 0.5 and 2.3. When considering the historical guideline limit of 3.0 ppm, arsenic levels were always well below this threshold. When applying the revised limit, however, levels recorded in 2023 exceeded the acceptable limit of 1.0 ppm. In 2023, arsenic levels above revised limits were recorded in all sites with an average of 1.81 ppm (Figure 6.20 and Figure 6.28).

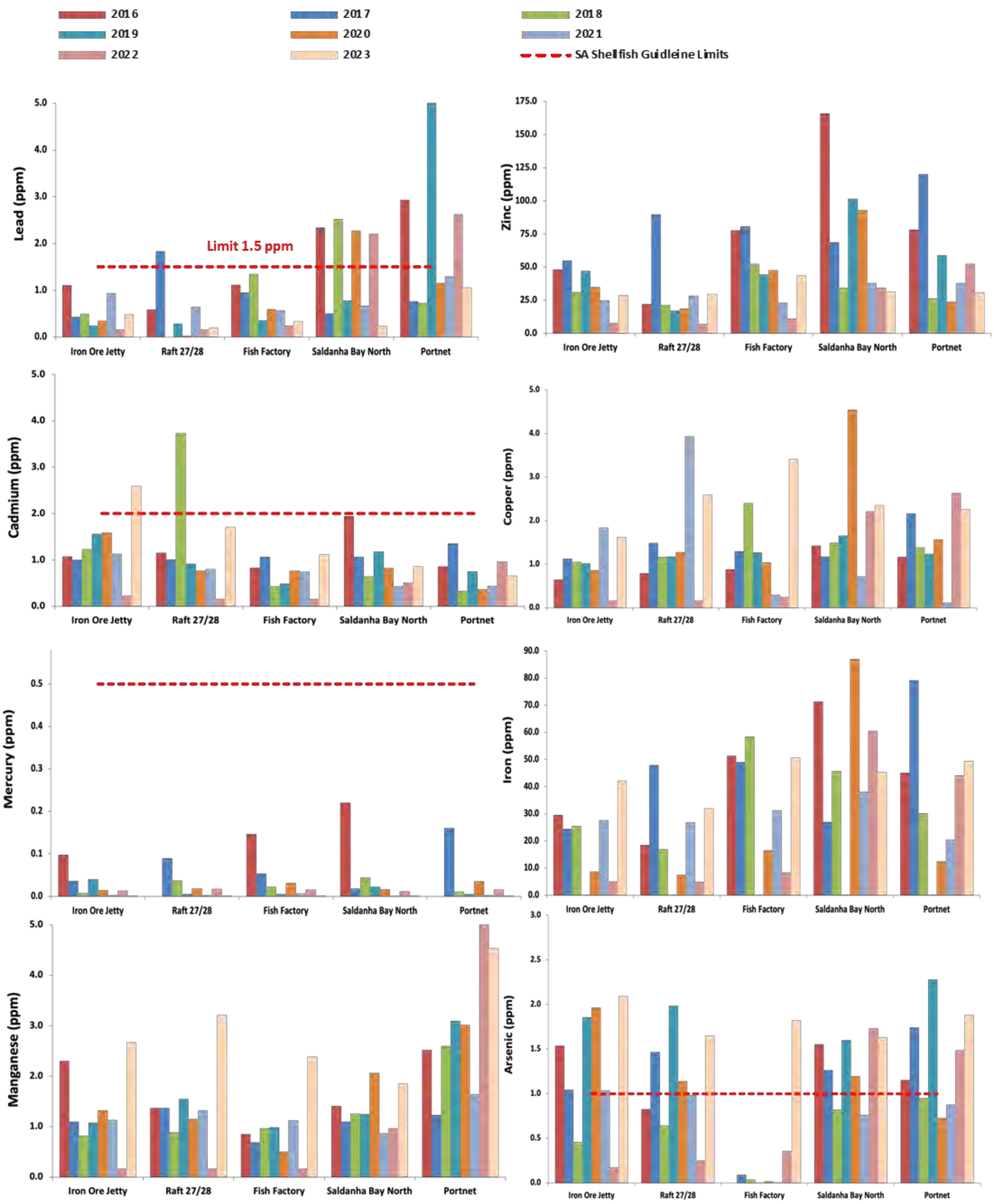


Figure 6.20. Lead, zinc, cadmium, copper, mercury, iron, manganese and arsenic concentrations in wet mussel flesh collected by Anchor from five sites in Saldanha Bay in autumn 2016 to 2023. The recommended maximum limits or maximum guideline limits for the respective metals are shown as dotted red lines.

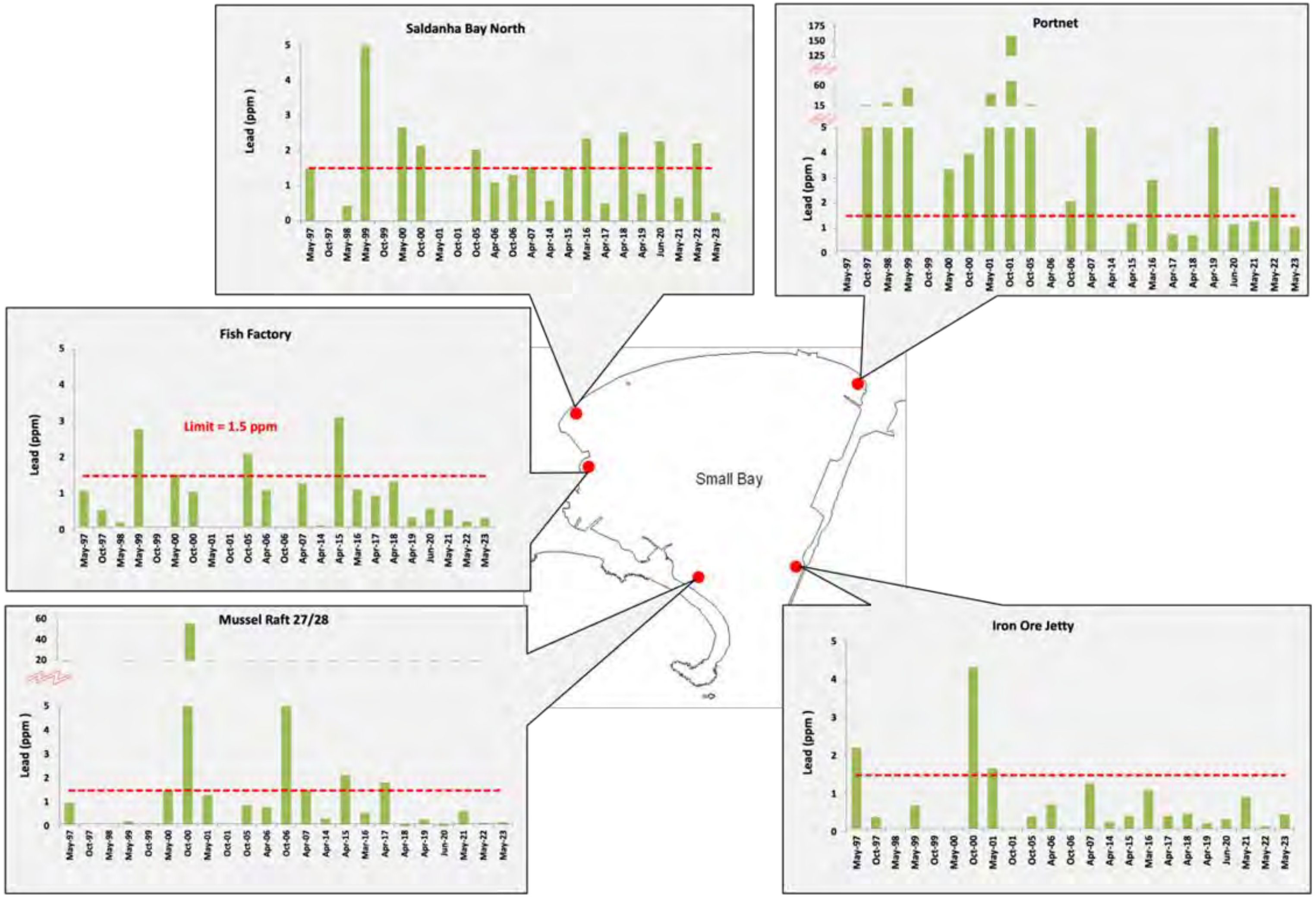


Figure 6.21. Lead concentrations in mussels (wet weight) collected from five sites in Saldanha Bay from 1997–2007 as part of the Mussel Watch Programme (Source: G. Kiviets, Department of Environmental Affairs) and by Anchor from 2014 to 2023. The recommended maximum limit for lead in seafood (0.5 ppm) is shown as a dotted red line.

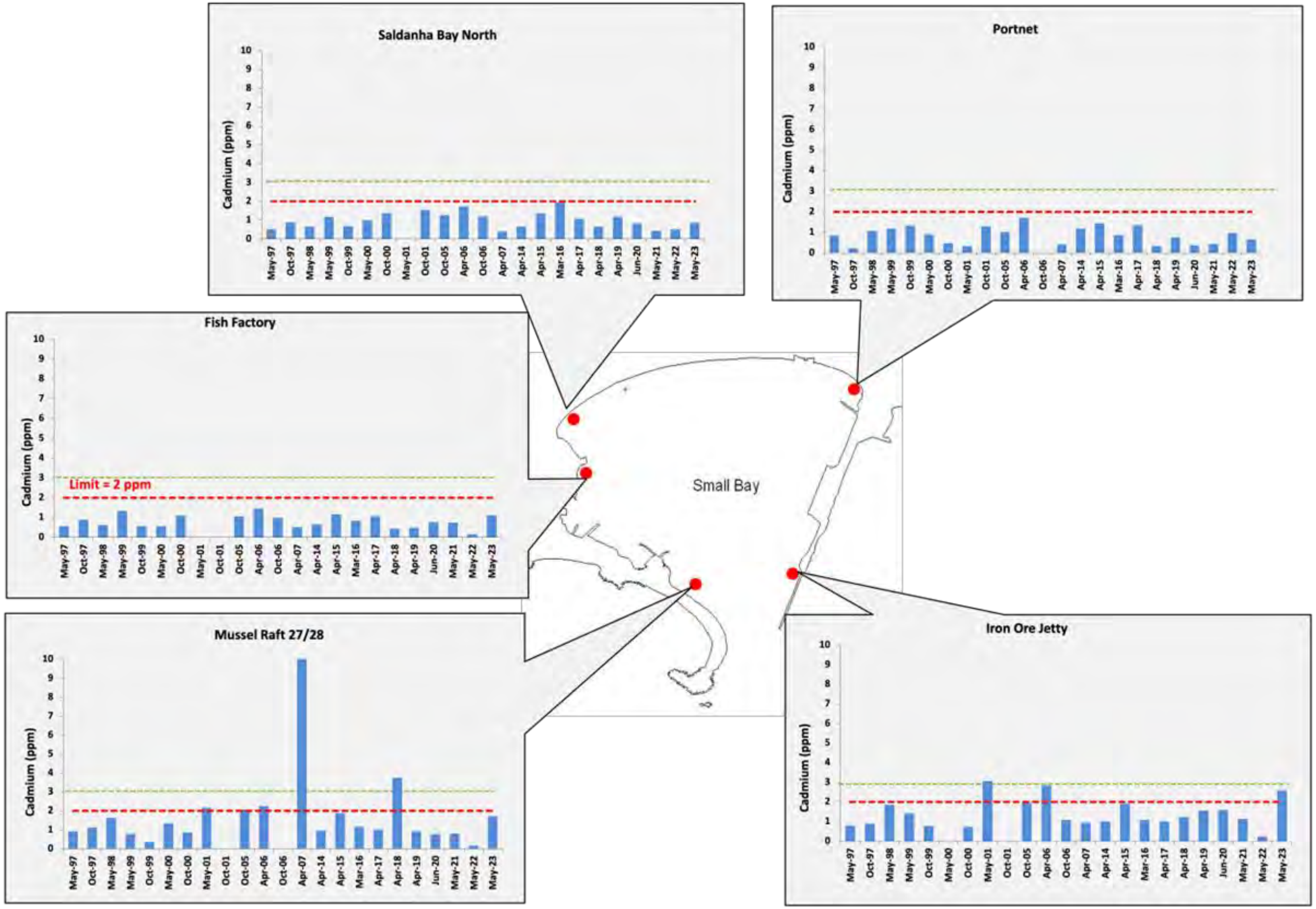


Figure 6.22. Cadmium concentrations in mussels (wet weight) collected from five sites in Saldanha Bay from 1997–2007 as part of the Mussel Watch Programme (Source: G. Kiviets, DEA) and by Anchor from 2014 to 2023. The recommended maximum limit for cadmium in seafood was reduced to 2 ppm (dotted red line) in 2018. Historical maximum levels are shown by the green dotted line.

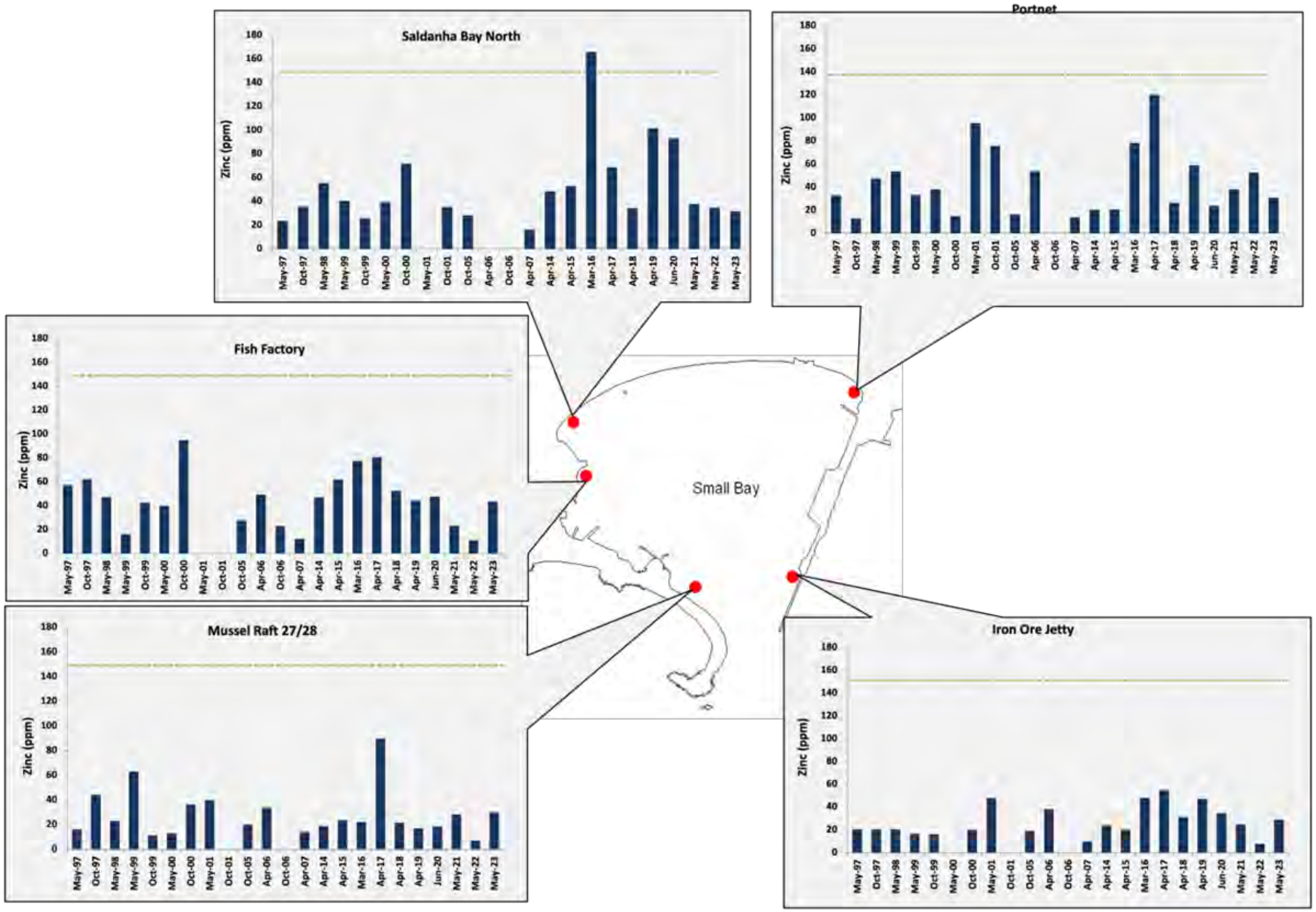


Figure 6.23. Zinc concentrations in mussels (wet weight) collected from five sites in Saldanha Bay from 1997–2007 as part of the Mussel Watch Programme (source: G. Kiviets, Department of Environmental Affairs) and by Anchor from 2014 to 2023. The recommended maximum limit for zinc in seafood (150 ppm) is shown by the green dotted line.

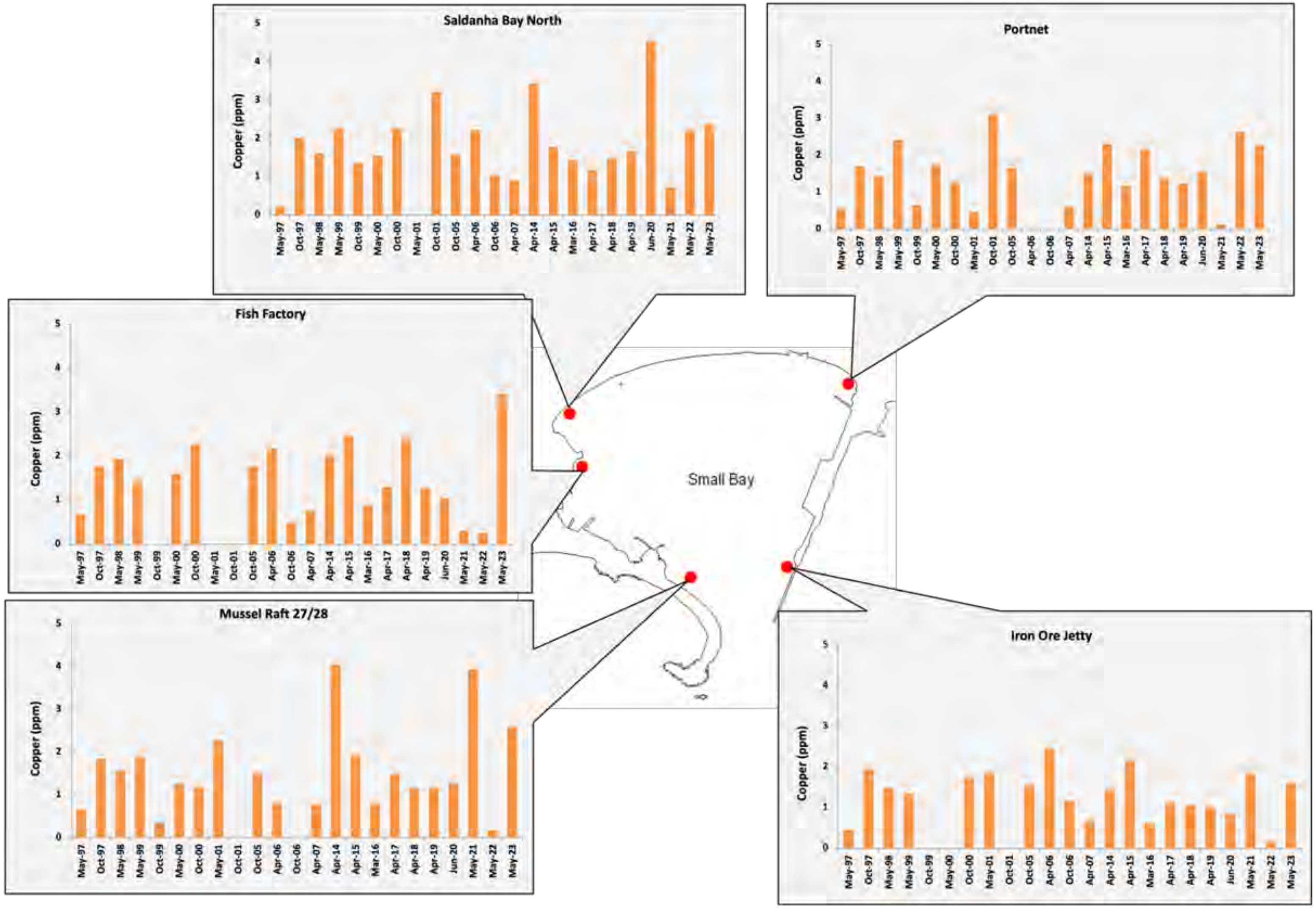


Figure 6.24. Copper concentrations in mussels (wet weight) collected from five sites in Saldanha Bay from 1997–2007 as part of the Mussel Watch Programme (Source: G. Kiviets, Department of Environmental Affairs) and by Anchor from 2014 to 2023. The recommended maximum limit for copper in seafood is 70 ppm (not indicated on graphs).

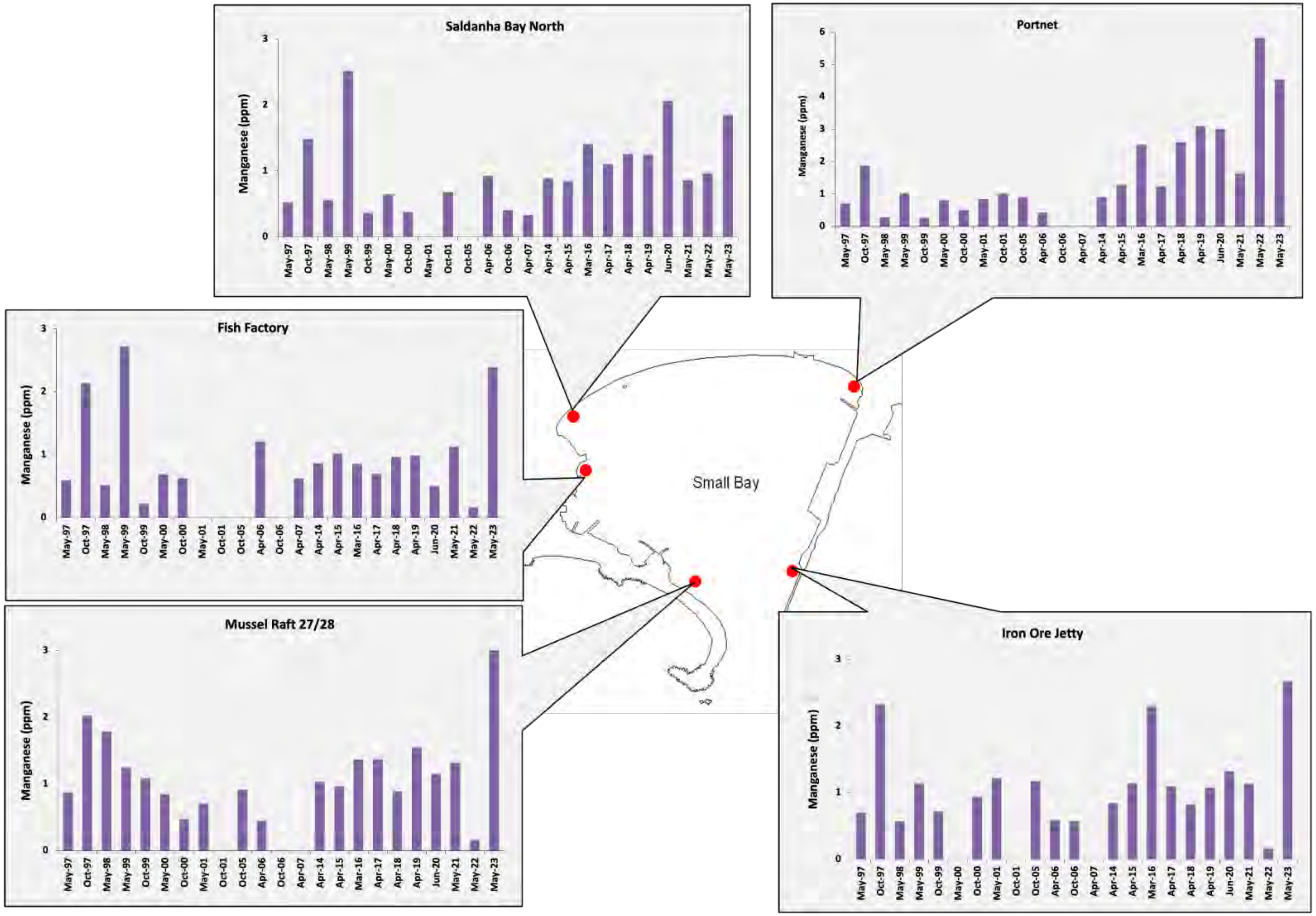


Figure 6.25 Manganese concentrations in mussels (wet weight) collected from five sites in Saldanha Bay from 1997–2007 as part of the Mussel Watch Programme (Source: G. Kiviets, Department of Environmental Affairs) and by Anchor from 2014 to 2023. No limits are specified for manganese in seafood.

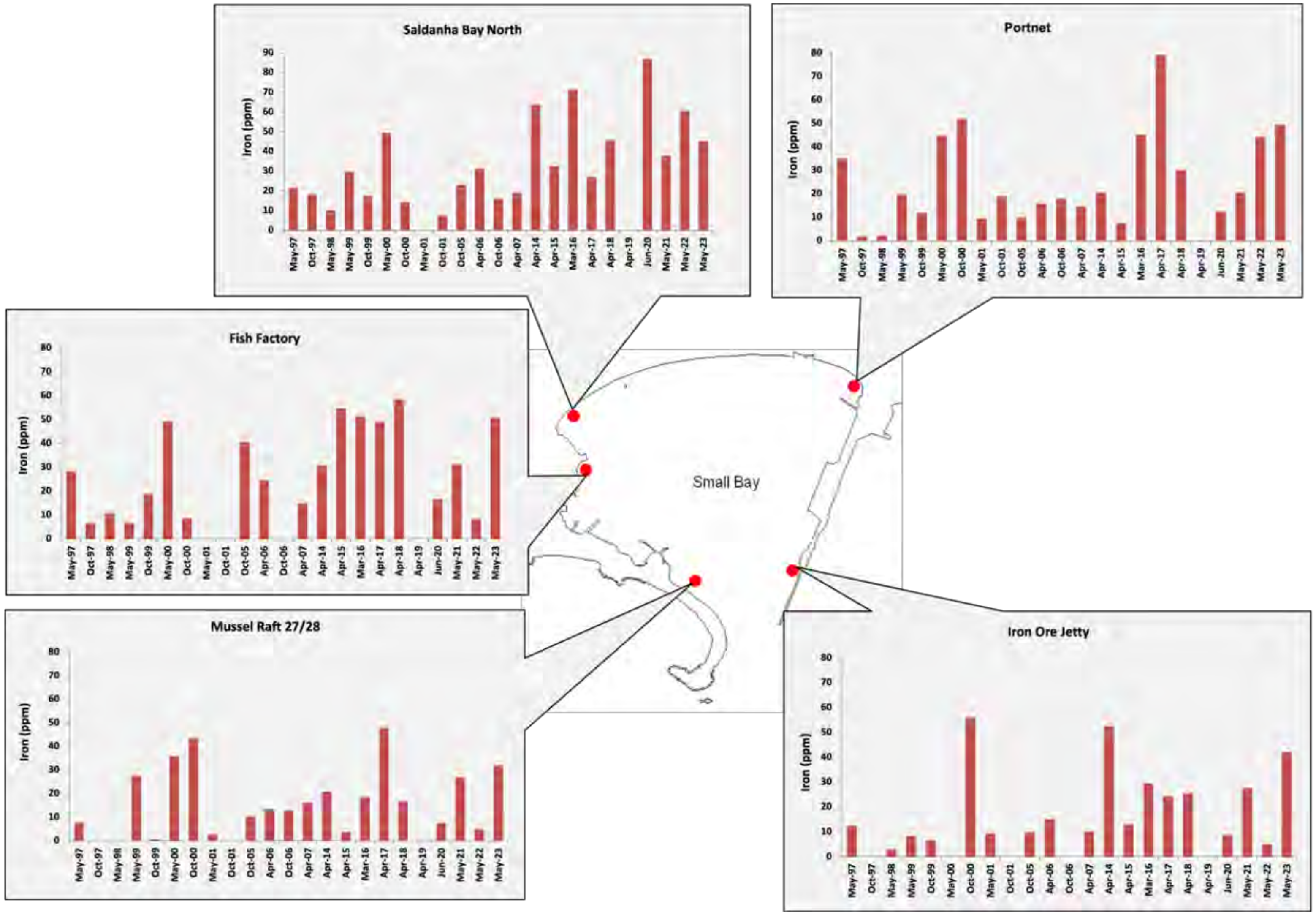


Figure 6.26. Iron concentrations in mussels (wet weight) collected from five sites in Saldanha Bay from 1997–2007 as part of the Mussel Watch Programme (Source: G. Kiviets, Department of Environmental Affairs) and by Anchor from 2014 to 2023. No limits are specified for iron in seafood.

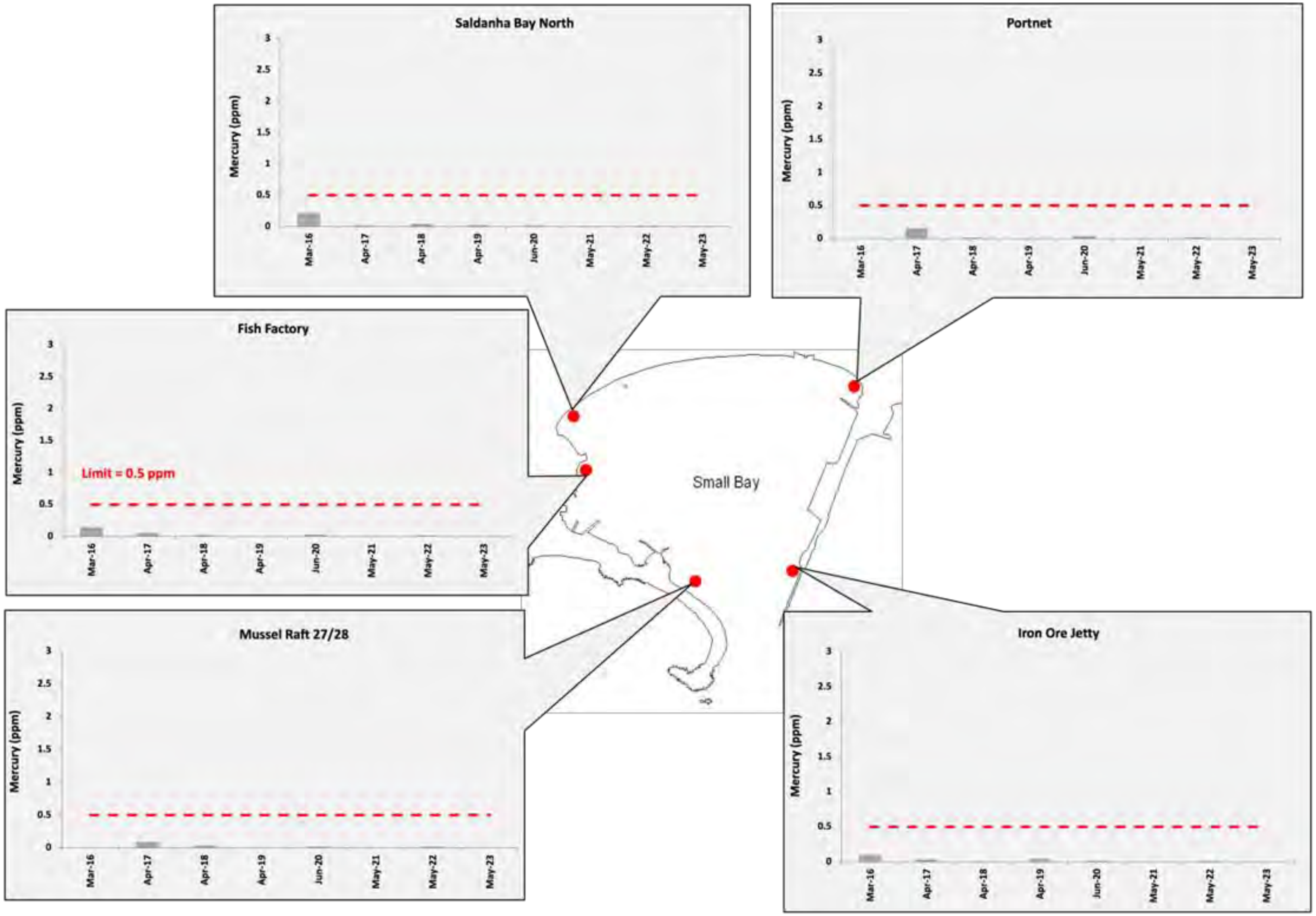


Figure 6.27. Levels of mercury in mussels (wet weight) collected by Anchor at five sites from 2016–2023 as part of the Mussel Watch Programme. The maximum guideline limit for mercury in mussels is 0.5 ppm (dotted red line).

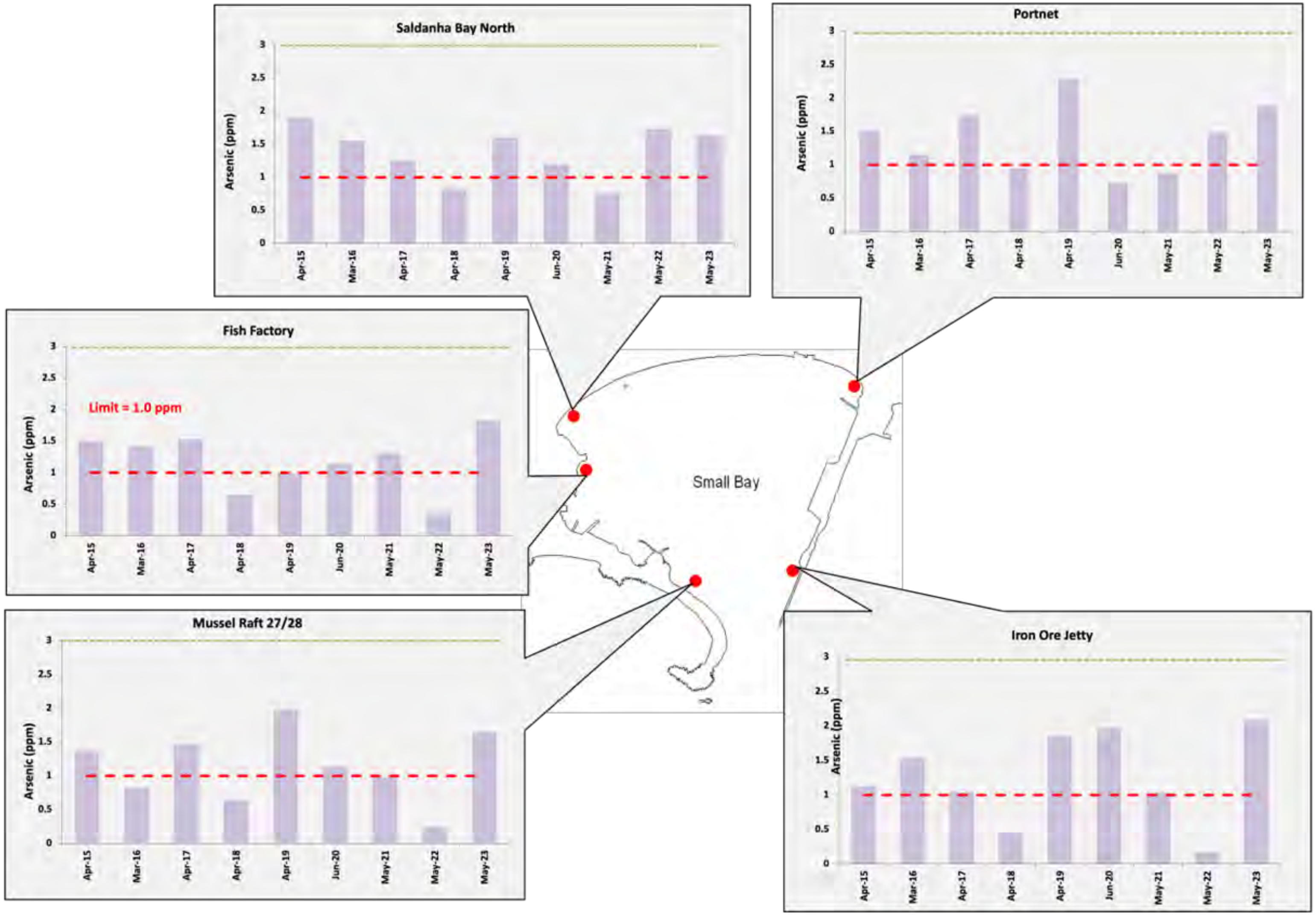


Figure 6.28. Levels of arsenic in mussels (wet weight) collected by Anchor at five sites from 2015–2023 as part of the Mussel Watch Programme. The maximum guideline limit for arsenic in mussels is 1 ppm (dotted red line). Historical maximum levels are shown by the green dotted line.

6.7.2 MARICULTURE BIVALVE MONITORING

A combined 884 ha of sea space are currently available for aquaculture production in Saldanha Bay. This includes space in Big Bay, Small Bay and Outer Bay North (North Bay). According to the Marine Aquaculture Rights Register, approximately 318.2 ha were leased to 28 individual mussel, oyster, finfish and algae mariculture operators (see Chapter 3 for the layout of concession areas) during 2020, although only 15 of these were actively operational at that time. As of July 2023, 23 farms were considered being actively operational. South African rights holders engaged in mussel and oyster culture are required to report on trace metal concentrations and bacterial indicators in harvested organisms on an annual basis. The DFFE therefore collects oysters and mussels from the aquaculture farms annually whereafter it is sent to an independent laboratory to test their flesh for four trace metal indicators (lead, cadmium, mercury and arsenic) Data has been obtained for mussels for the period 2009 to 2023 (Figure 6.29), and for oysters for the period 2005 to 2023 (Figure 6.30). Gaps in the data exist depending on the frequency of monitoring, the year each company was founded and whether the company was operational in that year or not. For comparative purposes, independent research data are also displayed on the graphs. For mussels, this includes data from research surveys by Bezuidenhout et al. (2015) and Pavlov et al. (2015) for the period 2014–2015, the Mussel Watch Programme by the DFFE (1997–2007), and the State of the Bay monitoring Programme conducted by Anchor (2014–2023) (although data for 2005 onwards only is shown). For oysters, data from a monitoring programme initiated by TPT for the period June 2018 until June 2020, were included. This programme encompassed deploying oyster baskets at channel marker buoys adjacent to the ore jetty and multipurpose quay. Oyster samples were harvested and stocked from these baskets at three-month intervals and analysed for the four trace metals. Closed triangles represent data recorded from aquaculture farms, whereas open circles represent data recorded during research studies. While the Mussel Watch and State of the Bay samples have only been collected within Small Bay, samples by Bezuidenhout et al. (2015) and Pavlov et al. (2015) were also collected from Langebaan Lagoon and Danger Bay, in addition to Small Bay. Research samples were collected from a variety of locations including the shore, port (oil jetty, multipurpose quay, channel markers), and mariculture infrastructure (mussel rafts, oyster longlines) and are collected close to the surface.

TRACE METALS IN MUSSELS FARMED IN SALDANHA BAY

Bezuidenhout et al. (2015) sampled mussels 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. This seasonal pattern has been reported in other studies and is thought to be associated with seasonal reproductive patterns, metabolic rate fluctuation and food type and availability associated with upwelling (increased bioavailability of cadmium is correlated with increased dissolved organic carbon which is elevated when diatom blooms decay) (Sparks et al. 2018). Bezuidenhout et al. (2015) suggested that the observed seasonal dynamics of trace metal concentrations could be a result of the spawning that takes place in summer; with the subsequent large release of gametes (Van Erkom Schurink and Griffiths 1991); effectively eliminating any trace metal accumulation in the gametes from the mussel's bodies. Lead and cadmium were the most prevalent trace metals in mussel tissue (Figure 6.29). Wild mussels (shore collected) typically had higher concentrations of lead, arsenic and mercury than those that were farmed. Higher concentration of cadmium, were, however, reported from farmed mussels in samples collected recently since 2018 from Outer Bay North and Big Bay (Figure 6.29). Concentrations of 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). This concurs with the results of the Mussel Watch and ongoing State of the Bay monitoring reported above (see Section 6.7.1).

Since the start of the sampling campaign, concentrations of lead in farmed mussels were generally below the historical guideline limit of 0.5 ppm, although mussels from some farms continued to exceed this limit on occasion. The highest levels of lead were recorded in 1988 where concentrations reached 5 ppm on two occasions. With the recent revision of the maximum concentrations of lead permitted in foodstuff by several countries, a new guideline limit of 1.5 ppm has been adopted for the purpose of this study. When applying this new limit to both historical and present data, lead concentrations in farmed mussels have rarely exceeded this threshold (only once in 2015 (Small Bay), Figure 6.29). Lead concentrations in farmed mussels have not exceeded 1.5 ppm in the last five years, however, sampling frequency by DFFE was low in 2021 and the start of 2022. The reported concentration of lead in farmed mussels are typically much lower than that measured in research samples collected from the nearshore (the "mussel watch" sample results described above). Both research and farm data do show lower lead concentration in mussel tissue samples collected from Big Bay and Outer Bay North than in mussel samples from Small Bay (Figure 6.29). Lead concentrations in both research samples and farmed mussels were below the 1.5 ppm limit so far in 2023. Periodic high concentrations of lead in Small Bay samples compared to elsewhere does indicate higher lead pollution within Small Bay (Figure 6.29), particularly in nearshore environments that are not well flushed.

Data received from mussel farms until June 2018, showed that cadmium concentrations in Small Bay never exceeded the prescribed historical limit of 3 ppm (limit applicable until June 2018) (Figure 6.29). Similarly, cadmium concentrations in mussel tissue collected from a Small Bay farm on 10 occasions between March 2015 and February 2017 ranged between 0.57–1.4 ppm, remaining below the limit in all samples (Firth et al. 2019). This regulatory limit was only exceeded once in May 2018 in a sample collected from Outer Bay North. Mussels collected by researchers, including DFFE and Anchor, from both the shore in Small Bay and off the Mussel Raft 27/28 had concentrations that frequently exceeded this limit (Figure 6.29). This is confirmed by analyses run on mussels collected in 2014 and 2015 by Bezuidenhout et al. (2015). In June 2018, the regulatory limit was decreased to 2 ppm. In recent samples collected since 2018, cadmium concentrations regularly exceeded the limit at aquaculture farms in Outer Bay North, and in two samples from Big Bay and one sample in Small Bay in May 2021. Reasons for this discrepancy are still to be determined, although, as described above, high levels exceeding prescribed limits have previously been recorded in research samples from Small Bay. Cadmium naturally occurs in high concentrations within the sediments of near-shore upwelling environments such as the southern Benguela (Griffiths et al. 2004, Summers 2012). High levels of cadmium within the mussels in previous studies have been attributed to disturbances such as dredging, causing trace metals buried in sediment to become re-suspended in the water. The link between cadmium concentration in mussel tissue and dissolved organic carbon associated with decaying diatom blooms described by (Sparks et al. 2018), may also play a role in these periodic peaks in cadmium in mussel tissue collected from different localities. In the latest data available, cadmium concentrations were below current limits for all farm mussels sampled and most research mussels collected, with one research sample exceeding 2 ppm in 2023 at the Iron Ore Jetty (Figure 6.29).

Mercury concentrations submitted to the DFFE have largely been within the regulatory limit of less than 0.5 ppm, apart from four samples collected in 1994 and one in 2009, all of which were collected from Small Bay. Since 2009, no exceedance has been recorded and 99% of samples collected contained less than 0.02 ppm of mercury (Figure 6.29). Research samples have also all been below the prescribed limit, but as with the other trace metals, mercury concentrations have generally been higher than farm samples.

Mussel samples from aquaculture farms were analysed for arsenic for the first time in 2011/2012. Scant data exist for 2012 and 2013 and arsenic was dropped from the suite of aquaculture farm measurements in September 2013 (except for one measurement that was made in 2018). For the purpose of this study, a median guideline limit of ppm for arsenic (based on that adopted for other countries) in shellfish has been applied to samples collected since 2021. This value was based on the limit for arsenic in fish as published in Regulation R.500 of 2004. Of the aquaculture farms assessed over this period exceedance of the concentration limit occurred three times, in 2012, 2017 and recently in 2022/2023 (Figure 6.29). Monitoring of arsenic in mussels continued for shore-based research samples. Mussel tissue has been consistently tested for arsenic at all sites sampled for research since 2013 (Figure 6.29). In 2023, all five wild mussel research samples had arsenic levels above 1 ppm, with an average arsenic concentration of 1.85 ppm.

Mussels are filter feeders which extract particulate matter out of the water column for food; thus, it is expected that organisms filtering clean water advected into the Bay from offshore will accumulate fewer toxins than mussels filtering potentially 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 the different depths at which these mussels occur and are collected. Mussels collected during research surveys are collected from intertidal zones close to the surface and are therefore exposed to air and other stressors for part of the tidal cycle. Farmed mussels, on the other hand, are permanently submerged several meters below the surface. This allows them to feed for extended periods of time per day, resulting in higher growth rates. The availability of phytoplankton in deeper areas of the Bay may also facilitate faster growth rates. Faster growth results in less time for the accumulation of toxins within the mussel tissue over the lifetime of the animal.

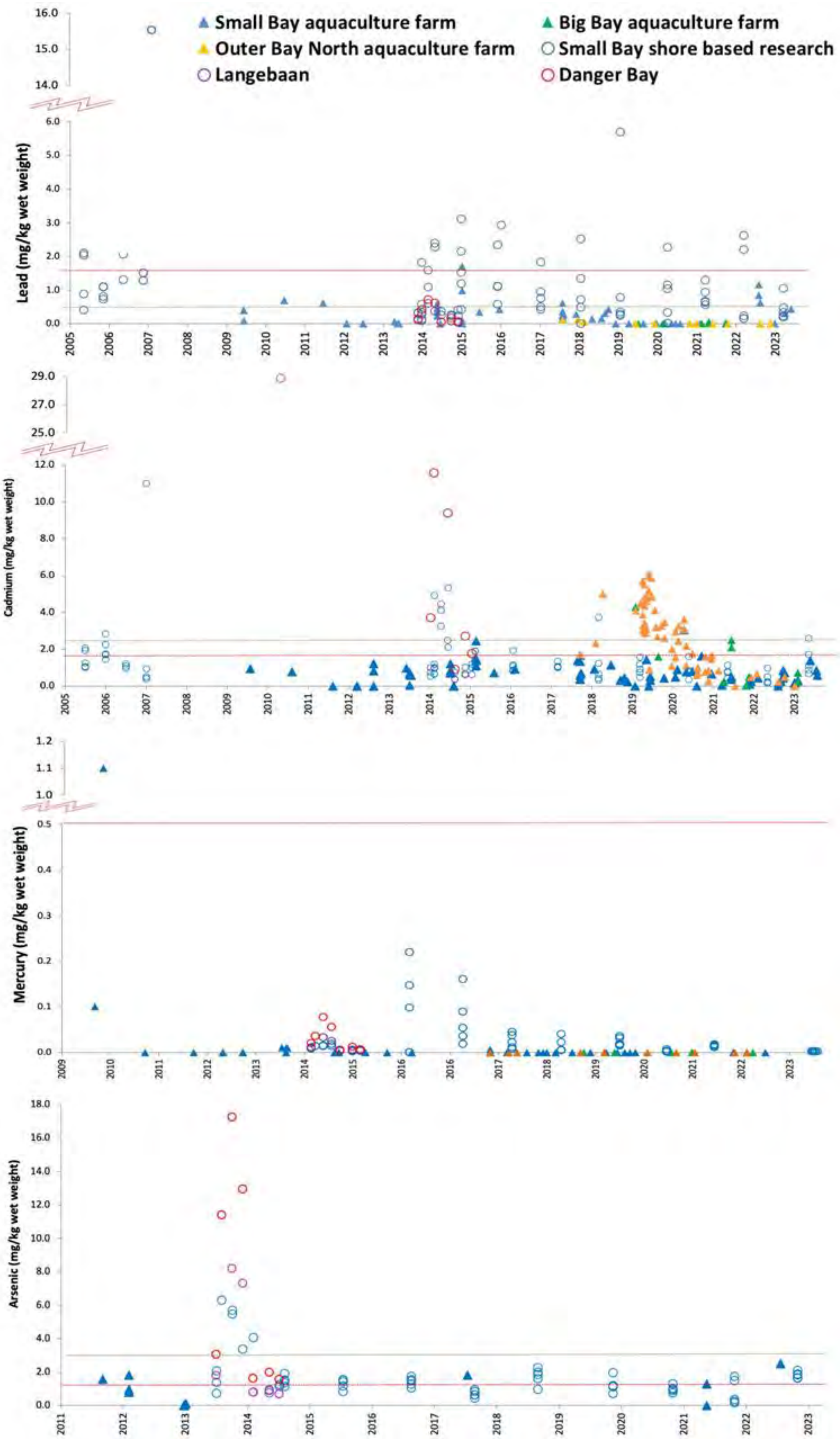


Figure 6.29. Trace metal concentrations (wet weight) in mussel tissue provided by aquaculture facilities (triangles) and samples collected by researchers, primarily from the shore (circles) from 2005–2023 where data were available. The green lines indicate the historical guideline limits applied to samples collected until 2018 for cadmium and 2021 for lead, mercury and arsenic. The red line indicates the revised guideline limits for all metals as applied since 2021.

TRACE METALS IN OYSTERS FARMED IN SALDANHA BAY

As no regulatory limits for metals in oysters have been implemented in South Africa, the median guideline limits for mussels were applied. Lead concentrations in farmed oyster tissue from both Small Bay and Big Bay occasionally exceeded the historical guideline value of 0.5 ppm, most recently in 2015 (Figure 6.30), where a level of 1.78 ppm was reached (Figure 6.30). Research samples collected as part of the Anchor Oyster Monitoring Programme over the period 2018 to 2020, from locations much closer to ore loading facilities than the mariculture farms, also show compliance with guideline levels (Figure 6.30). When applying the revised median guideline limit of 1.5 ppm, all samples, both research and farm samples, fall within the limits, except for the one sample in 2015. The oysters collected from aquaculture farms from Big Bay and Small Bay during recent years, including in 2023, have low lead concentrations (Figure 6.30). Like above, oysters collected from farms had lower concentrations of lead than oysters collected during research surveys.

A large number of the samples collected prior to 2017 would not have met the revised 2018 guideline for cadmium (2 ppm), although nearly all did meet the previous 3 ppm guideline. Farm and research oyster samples collected from 2017 onwards have nearly all met the revised cadmium guideline value of 2 ppm, with just two samples exceeding the limit (Figure 6.30). Cadmium concentrations in all research samples collected from Small Bay over the period 2018 to 2020 fell below the 2 ppm guideline, while one of the research samples from Big Bay exceeded the guideline. In 2023, all farmed oysters sampled and tested had cadmium concentrations below 2 ppm.

Mercury concentrations in farm and research samples have largely been within the regulatory limit of less than 0.5 ppm, apart from two samples collected in 2007 and 2011 (Figure 6.30). Samples were analysed for arsenic for the first time in 2012.

Arsenic concentrations in farmed oyster tissue previously exceeded the regulatory requirements (1 ppm) between 2012 and 2015 (Figure 6.30). Monitoring of arsenic in oysters continued for shore-based research samples as part of the TPT oyster monitoring programme during 2018–2020. Many of the samples collected from the shore exceeded the regulatory limit for arsenic (Figure 6.30). As the TPT oyster monitoring programme was discontinued in June 2020, no shore-based oyster samples have been analysed for arsenic since then. After being dropped, arsenic was once again screened for, for farmed oysters, in 2021 and 2023. Three of the four samples collected from farms recently have exceeded arsenic concentration limits including both samples collected in 2023.

In general, trace metal concentrations in farmed oyster samples have largely met the historical regulatory limits for the four trace metals tested, with high levels of compliance in samples collected since 2016. Oysters farmed in Saldanha Bay accumulate trace metals in their tissues at lower levels than mussels, but where occasional exceedance is observed, it is for the same two trace metals, namely lead and cadmium, that are most problematic in mussels. Some concern should be noted here that sampling frequency of farmed oysters recently may be an issue with most recent samples exceeding the limits for arsenic concentrations.

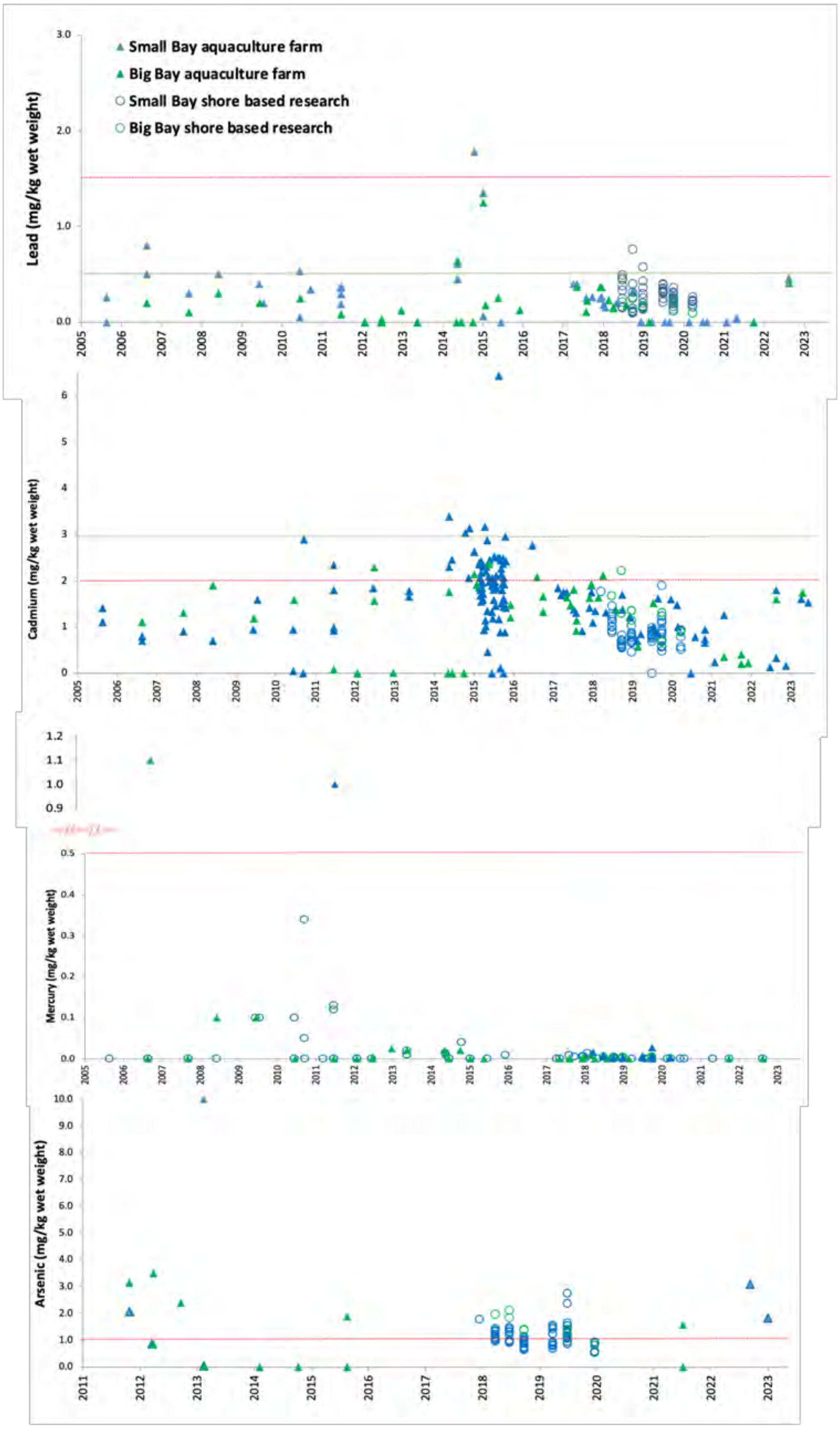


Figure 6.30. Trace metal concentrations (wet weight) in oyster tissue provided by aquaculture facilities and the Anchor Oyster Monitoring Programme (indicated by triangles and circles, respectively) from 2005–2023 where data were available. The green lines indicate the historical guideline limits applied to samples collected until 2018 for cadmium and 2021 for lead, mercury and arsenic. The red line indicates the revised guideline limits for all metals as applied since 2021.

6.8 SUMMARY OF FINDINGS

There are no clear long-term trends evident in the water temperature, salinity and DO 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 or long-term warming or cooling due to climate change (notoriously difficult to differentiate from natural variability). What may, however, be detected is an increase in frequency of “uncommon events” e.g., thermocline breakdown with cool water throughout the water column in summer, as observed in 2018. There is unfortunately limited pre-development data (pre-1975) against which to benchmark the prevailing oceanographic conditions. Although it is likely 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. Decreased DO in Small Bay after the harbour development is perhaps the clearest signal. The increase in the frequency of Small Bay hypoxic events occurred after the major harbour development in the 1970s, and the situation does not appear to have changed much since with similar data collected by continuous DO measurements around the turn of the century to those collected during the autumn-winter period in 2023. Natural, regional oceanographic processes (wind driven upwelling or downwelling and extensive coast to bay exchange), rather than internal, anthropogenic causes, appear to remain the major factors affecting physical water characteristics in Saldanha Bay. New data show that hypoxic and near anoxic conditions in the lower part of the water column are frequent occurrences during the summer-autumn season in Big and Small Bay (pointing to an external upwelled source of low oxygen water); whilst in Small Bay anthropogenic organic loading, appears to exacerbate the situation with decreased DO measured at sites under mariculture farms compared to control sites. The construction of physical barriers (the iron ore/oil jetty and the Marcus Island causeway) has 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 shifting climatic data towards higher average significant waves heights would suggest that wave action has, and will continue to, increase along the nearby coast, and inside, of Saldanha Bay.

Data from the microbial monitoring programme suggest that generally nearshore coastal waters in the system have improved considerably for recreational use since 2005 (Table 6.5). However, based on the 2023 *E. coli* count data, only 9 of the 20 sampled stations were categorized as having ‘Excellent’ water quality and with two rated as ‘Poor’ water quality and six rated as ‘Fair’. This is quite a substantial change from the 2022 results where 17 sites were rated as ‘Excellent’. The Seafarm TNPS site (11) was the only site to have improved its *E. coli* counts between 2022 and 2023, 8 other sites have deteriorated. Alarmingly, Langebaan Main Beach, a popular bathing water, fell from ‘Excellent’ to ‘Fair’ in one year. Other popular swimming and water sport sites close to Langebaan (i.e., Mykonos Beach) also declined.

The Bok River beach site that had previously had poor water quality for most of the monitoring record again has remained ‘Poor’ in 2023, as it had in both 2021 and 2022. Water quality at the Hoedjies Bay site has remained ‘Poor’ for the last six years. The general consensus was that reuse of the majority of treated wastewater, historically discharged via the Bok River Mouth, was having a positive effect. However, 2023 represents one of the most negative declines in recreational water quality since monitoring began which is a major concern.

Although this poor water quality could be related to once off or isolated events, immediate action should be taken to ensure an improvement is made.

Faecal coliform counts at all four sites in Big Bay were within the 80th percentile limits for mariculture in 2023. In Small Bay, more recent improvements have generally been seen at the small quay at Pepper Bay across the years 2017–2020. However, faecal coliforms were marginally above the 80th percentile values for mariculture were in 2021 and 2022, but in 2023 concentrations of faecal coliforms were below the limit which is an improvement (Figure 6.17). In 2022, the big quay at Pepper Bay met current guidelines for the first time in three years and this has continued into 2023 (Figure 6.17). The areas of particular concern have always been at Hoedjies Bay and the Bok River Mouth. In 2023, the Bok River mouth recorded its worst concentration since 2012. The Bok River mouth also fails to meet *E. coli* concentration limits as described previously. Although a sustained improvement in levels of compliance with mariculture WQGs has occurred at most Small Bay, 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 and reuse 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 continue to be implemented. 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 given the fluctuating nature of concentrations at some sites around Small Bay.

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 (lead, manganese, arsenic) are elevated at sites along the north shore within Small Bay and are frequently above published guidelines for foodstuffs (particularly for lead at the Portnet and Saldanha Bay-North sites). In 2023, all mussel watch samples had a lead concentration lower than the 1.5 ppm guideline and lead concentrations in shellfish collected from the deeper water at the mariculture farms in 2023 were overall lower than those recorded from shore-based samples and in nearly all cases. 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, while mussels along the shore are more exposed to land-based pollutants.

Similar to lead, cadmium levels in mussels and oysters have regularly exceeded the guideline limit (when considering both the historical and revised limit) at various locations in the Bay since the monitoring started. Higher concentrations of cadmium were recorded in mussel samples collected from farms in Outer Bay North between 2018 and 2020 than those collected from farms in Small and Big Bay and from shore-based research samples. Research samples collected from the Iron Ore jetty did exceed the guideline limit for cadmium concentration in 2023 (the first time since 2006 at this site) and should be carefully monitored. Generally though, cadmium concentrations have mostly been within guideline limits for recently collected bivalve samples. The cadmium levels remain on the border on the acceptable limit, and this is a concern.

Historically, manganese concentrations were highest at the Portnet site, and this was again the case in 2022 and 2023. 2022 saw a peak in concentration at 5.82 ppm, and concentration recorded in 2023 remained high at 4.54 ppm. These are highest on record and over double the concentrations recorded in all other sites since 1997. Furthermore, concentrations of manganese for samples collected at all other sites were either the highest recorded at that site (Mussel Raft, Iron Ore Jetty) or in above the 90th percentile (Fish Factory, Saldanha Bay North) since data has been collected.

Historically, arsenic concentrations in shellfish have mostly been below the guideline limit, apart from a few samples collected between 2012 and 2014. When considering the revised guideline limit, however, arsenic concentrations become problematic in that it regularly exceeds food safety guidelines, even in recent samples. Levels recorded in mussel watch research samples in 2023 exceeded the acceptable limit of 1.0 ppm. For this past year, arsenic levels above revised limits were recorded in all sites with an average of 1.81 ppm. Worryingly, three of the four samples collected from oyster farms in 2022/2023, and the one sample taken from mussel farms in 2022/2023 have exceeded arsenic concentration limits. This, in combination with shore-based research mussels showing elevated concentrations above recommended limits, is a concern and needs to be addressed. Especially considering as farmed shellfish should have lower levels of trace metals, as discussed previously. Mercury concentration in both mussels and oysters have remained well below the food safety limits in almost all cases throughout the monitoring campaign.

Fluctuating exceedance of food safety limits for lead, cadmium and arsenic in bivalves collected for research from the shore and the aquaculture farms throughout the Bay, points to the need for management interventions, as metal contamination poses a serious risk to the health of people harvesting mussels. Some concern should be noted here that sampling frequency by DFFE of farmed mussels and oysters in 2021 and 2022 was quite low, but 2023 had a much better sampling rate.

7 SEDIMENTS

7.1 BACKGROUND

The history of sedimentation has been studied extensively in previous State of the Bay reports, and therefore, relevant background information has been highly summarised to retain conciseness of this chapter. For an in-depth description of the sedimentation history of Saldanha, refer to Clark *et al.* (2021, 2022).

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 for short to very short-term changes in environmental health.

Coastal erosion is one of the main contributing factors that largely influences shoreline stability (López et al. 2017). It is often gradual, but occasionally, rapid removal of sediments from the shoreline. Coastal erosion can be caused by natural processes such as storm surges, extreme seasonal and tide changes, sediment morphology, as well as via anthropogenic factors in the form of harbour construction (i.e., dredging activities) (López et al. 2017, Woodworth et al. 2019). Coastal erosion effectively reshapes the shoreline and directly impacts the fauna/flora inhabiting these areas and can potentially threaten coastal property. Coastal erosion is a major problem in Saldanha Bay, affecting beach mostly in Big Bay and at the entrance to Langebaan Lagoon.

The particle size composition of the sediments is 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 sediment were previously much coarser. The quantity and distribution of different sediment grain particle sizes (gravel, sand and mud) influences the status of biological communities and the extent of organic and contaminant loading that may occur.

Organic matter (total organic carbon (TOC) and total organic nitrogen (TON)) 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 can lead to a range of different 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).

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. Contaminants are predominantly associated with fine sediment particles (mud and silt) as 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 trace metal contamination. 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.

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. In addition to total (absolute) metal concentrations, it is also important to factor in the influence of the composition of sediments and the relationships between metals, sediment mineral composition, and grain size, which can all influence metal bioavailability (the ability of the metals to be absorbed into the tissues of surrounding species), and thus represents the most important manner in which metals are able to cause damage within marine and aquatic environment.

When attempting to understand sediment composition, it is important to note the influence that individual sampling variability can have on the ultimate result. For instance, at times it is possible to take two samples several metres apart, with near completely different sediment characteristics. This indicates that it is important to exercise caution when attempting to infer conclusions based off individual samples in dynamic, anthropogenically altered areas. Instead, it is recommended that sediment results be considered across time, and between sites, to reduce the noise that sample variability can create.

7.2 2023 Sampling Campaign

Sediment samples were collected from a total of 31 sites in Saldanha Bay and Langebaan Lagoon in April 2023, as part of the annual State of the Bay sampling programme (Figure 7.1). This included 10 sites in Small Bay, 9 in Big Bay, and 12 in Langebaan Lagoon. These samples were analysed for their sediment particle size distribution, organic carbon and nitrogen content, trace metal hydrocarbon content using a suite of methdologies.

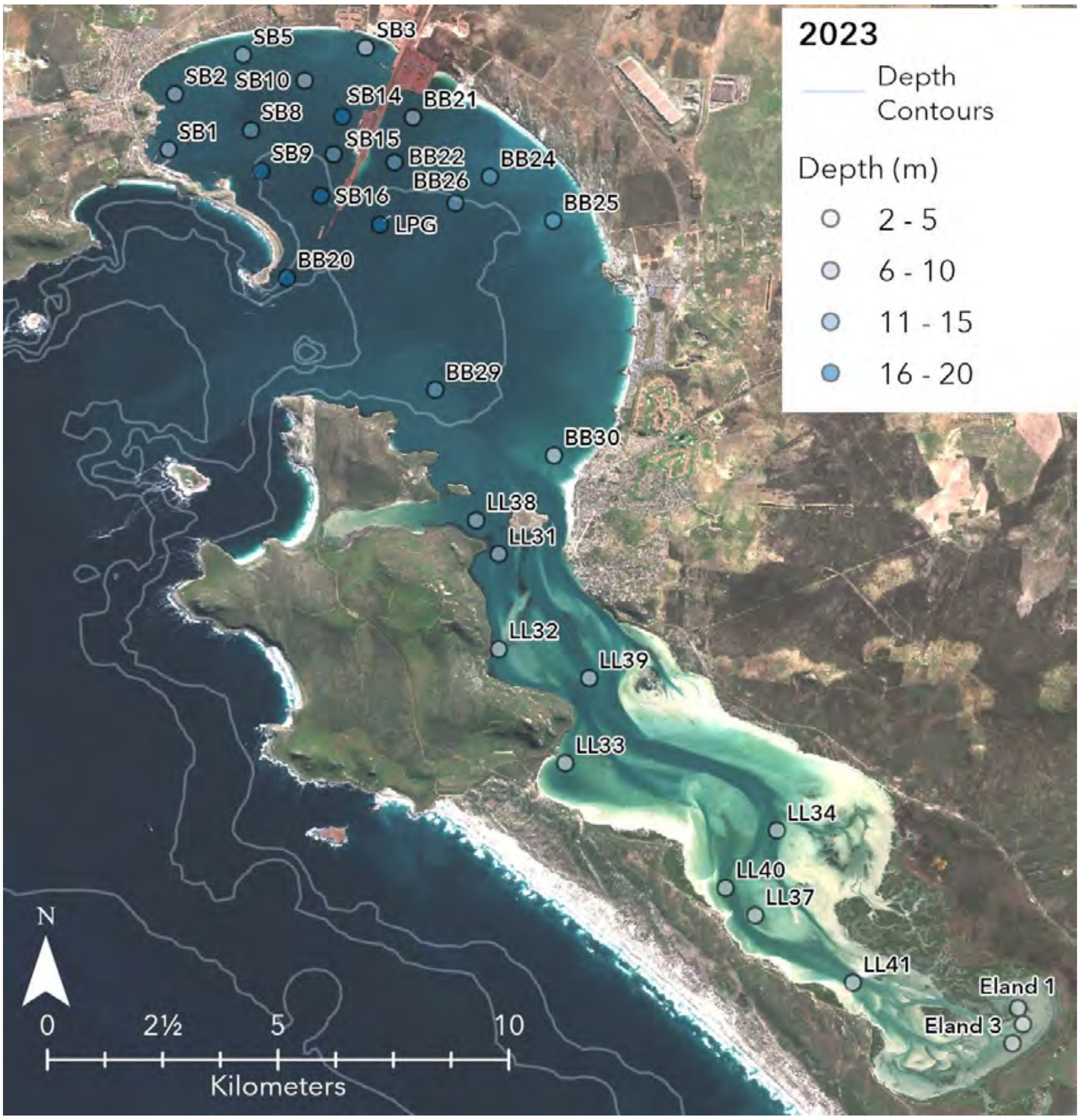


Figure 7.1. Sediment sampling sites and respective depth ranges (m) in Saldanha Bay, Langebaan Lagoon and Elandsfontein for 2023

7.3 Sediment particle size composition

7.3.1 Background and general trends

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. Since 1975, industrial developments in Saldanha Bay (Marcus Island causeway, Iron Ore Terminal (IOT), Multi-purpose Terminal (MPT) 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 sizes (gravel, sand and mud) through Saldanha Bay influences the status of biological communities and the extent of contaminant loading that occurs. 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), known as the "cohesive sediment fraction". This is because fine-grained particles have a relatively larger surface area for pollutants to adsorb and bind to. Mud, which is a catch-term for all sediment with a grain size <62.5 µm, is therefore the most important particle size component to monitor. Higher proportions of mud, relative to sand or gravel, can thus lead to high organic loading and trace metal contamination. It follows then that disturbances to natural wave action and current patterns can lead to an increase in the proportion of mud in the sediments of Saldanha Bay, which subsequently can result in higher organic loading and increased heavy metal accumulation (assuming that these pollutants continue to be introduced to the system). However, additional complexity results from high mud concentrations being frequently associated with the presence of clay minerals (approximated by Aluminium concentrations) which typically have higher naturally ocurring metal concentrations. These naturally ocurring elevated concentrations are not indicative of anthropogenic contamination and may not be available for update by local biota as these metals may be strongly bound to the sediment particles (Newman and Watling 2007). Therefore, to understand the significance of heavy metal concentrations in a given area, it is recommended to factor in the concentrations of metals in sediment, the degree of anthropogenic enrichment (or lack thereof), as well as the measurement of concentrations in the tissues of indicator species (such as mussels) to gain an understanding of the bioavailability of these metals (Voie et al. 2002). Of particular concern in Saldanha is the influence that disturbance to the sediment (e.g., dredging) which can lead to re-suspension of the mud component from underlying sediments, along with the associated organic pollutants and metals which may have accumulated from natural or anthropgenic processes. 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. During this time the associated pollutants may be able to accumulate within benthic species, and become suspended and/ or dissolved in the water column, thus directly affecting pelagic species (Voie et al. 2002). Furthermore, It has been demonstrated that the health of benthic macrofaunal communities can be compromised during periods of high mud accumulation, such as in 2008 at both the Yacht Club basin and adjacent to the MPT. At the time, benthic organisms were virtually absent in the Yacht club basin. Therefore, understanding current and historical changes in sediment particle size within Saldanha Bay, particularly with reference to the finer cohesive fraction (mud), is paramount to understanding sediment and water quality within the Bay. Results of prior sediment study are summarised in this section. However, it must be noted that this summary predominantly focusses on Saldanha Bay as there is a paucity of historical data available for the grain size composition of Langebaan Lagoon.

A recent study by Henrico & Bezuidenhout (2020) has demonstrated that harbour construction and associated dredging activities have had the greatest influence on hydrodynamic sediment processes in Saldanha Bay and Langebaan, which led to alterations of wave and tidal energy (Figure 7.2). These activities have led to changes in sediment deposition with the creation of calm depositional zones where they wouldn't have occurred historically, and conversely has potentially contributed to coastal erosion (and sediment removal) in other places, such as Langebaan Lagoon (Flemming 2016, Henrico and Bezuidenhout 2020). Historical studies by Flemming (1977a, 1977b) have indicated that the pre-development 'natural' sediment composition of Saldanha bay was 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) (Flemming 1977a, 1977b). The authors found that the mud content of most samples was less than 1% on preliminary examination, however, they did demonstrate that mud content varied substantially spatially, with levels of up to 10% being seen in some areas, which they suggested could be linked to organic activity. 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. Crucially, due to the very low levels of mud in the system, the authors procluded the measurement of mud from their bulk analysis, and therefore it cannot be used for comparative purposes.

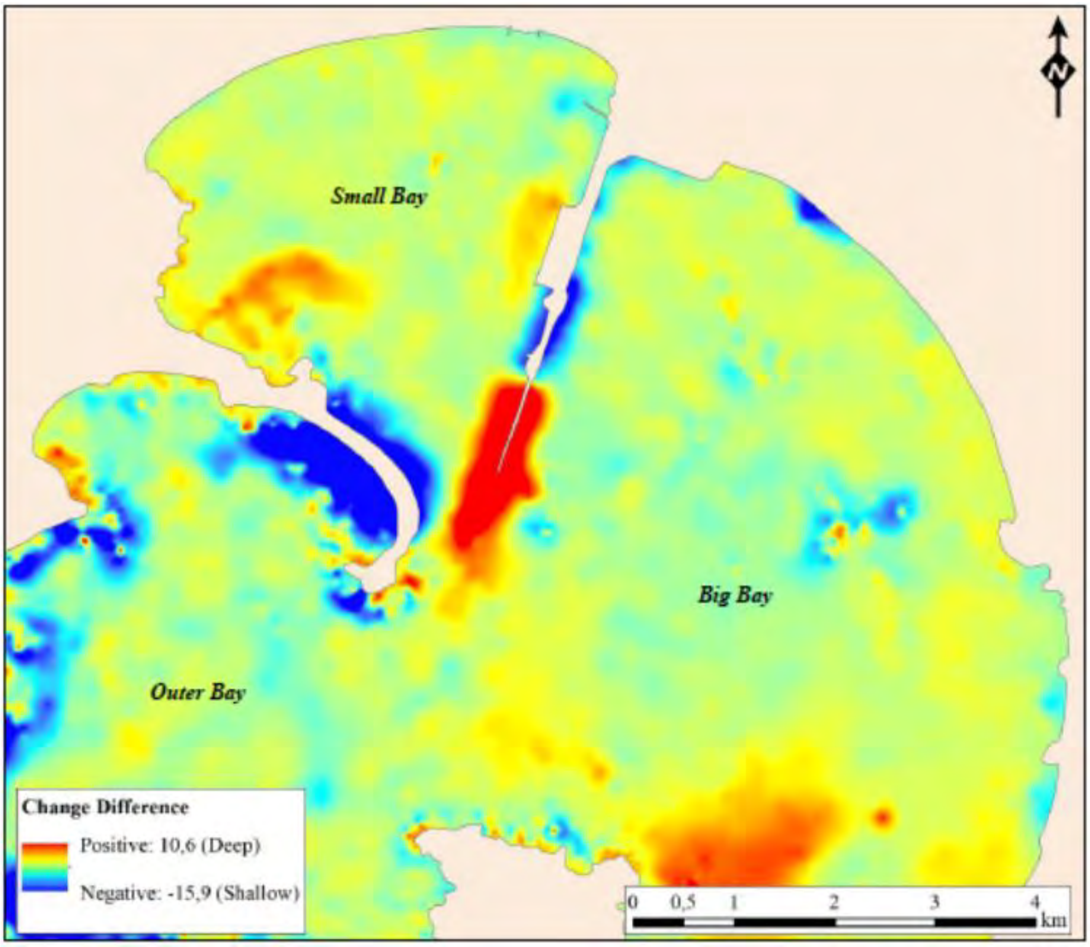


Figure 7.2. Changes in bathymetry in Saldanha Bay from before (1957) to after (1977) harbour construction. Source: Henrico & Bezuidenhout (2020).

Subsequent sediment sampling has occurred in1989–1990, and from 1999 onwards as part of the State of the Bay surveys. These surveys have demonstrated substantial fluctuations in sediment particle size and mud component, with muddy sediments prevailing at times (with the peak mud content in approximately 1999–2001), and sandier conditions prevailing in more recent years (post 2009), which is discussed in more detail below (Figure 7.3; Figure 7.4; Figure 7.4; Figure 7.5; Figure 7.6; Figure 7.7). These variations have largely been attributed to continued harbour development, which has led to permanent alterations to circulation and tidal flushing, as well as dredging activities (and associated periods without substantial dredging).

These factors have all resulted in spatial changes to sediment distributions within the Bay and Lagoon. Small Bay is the area most influenced by these modifications, and has resulted in consistently higher mud content throughout recent surveys when compared to Big Bay or Langebaan Lagoon. Within Small Bay, the Yacht club basin and Multi-Purpose Quay, and the Channel End of Iron Ore Jetty are particular hotspots, which is likely due to the combination of reduced circulation and recurrant dredging activities required to retain water depth for sailing and shipping activities respectively. These dredging activities, and the increased depth they create, can lead to reduced flushing forces in these 'holes' which leads to a concentration of the more dense (although more easily mobilised) mud component. This is additionally problematic, as Small Bay is also a nucleus for much of the shipping and industrial activities in Saldanha, and therefore represents an area where harmful effects (such as trace metal introduction, reductions in sedimentary dissolved oxygen, etc.) are likely intensified. On a positive note, the percentage mud in sediments declined at most sites in Small Bay over the period from 1999 till approximately 2010, thereafter it has fluctuated without statistically significant changes on a Bay-wide scale (Figure 7.3 – Figure 7.8).

This shift from the high mud contents seen from 1999–2009 to this reduced, fluctuating state, suggests a shift in the balance between the rate at which fine sediments are suspended and deposited and the rate at which currents and wave activities flushed fine sediments from the Bay. This suggests that sediments, particularly those in the vicinity of prior dredging activities, have reverted much closer to natural conditions, and are now fluctuating without significant change. It is, however, possible to see short-term spike in mud content following dredging events, which subsequently dissipates. Of note is that these recent dredging disturbances have not caused the same level of disturbance as the disturbances of the 1990s and early 2000s.

A persistent issue when intepreting the grain size time series data across the system has been the high degree of variation between sites which makes it difficult to establish unequivocally whether trends seen can be classified as significant or not. To partially overcome this lack of clarity, key sites around small and Big Bay in vicinity of the greatest disturbances linked to altered circulation, industrial activities, shipping etc. have been selected for further analysis as they likely represent worst-case scenarios for mud accumulation in Saldanha. Selected sites include the yacht club basin, multi-purpose quay, the channel end of ore jetty, the mussel farm, and Big Bay to the east of the Iron Ore Jetty (Figure 7.8). Whilst not representing system-scale changes, these sites give an indication of how the intensity of anthropogenic disturbance within these areas of high intensity utilisation has changed over the last quarter century (Figure 7.8). A positive statistic is that the proportion of fine material (mud) at these key sites has decreased significant between 1999 and 2023. The bulk of the change occurred in the period from 1999 to 2009. Despite lacking significant temporal trends, it is possible to identify a visible pattern in mud % relating to dredge events in which there are spikes in mud% following dredging. This is then followed by a recovery period whilst the system flushes itself of the introduced mud, after which mud content stabilises.

In summary, it now appears that, since the intermittent poor 1999–2009 conditions, sediment particle size has been largely stable throughout the system. This is further evidenced by the 2009–2023 ternary (triangle) diagrams (Figure 7.4–Figure 7.7) which show a high degree of sample variation and scatter in 2009 for Small Bay, Big Bay, and Langebaan Lagoon, followed by increased homogeneity in the period 2011–2023. In particular, both Big Bay and Langebaan Lagoon show almost no meaningful annual variation post 2011. However, Small Bay does show variation in given years, which is largely driven by dredging activities.

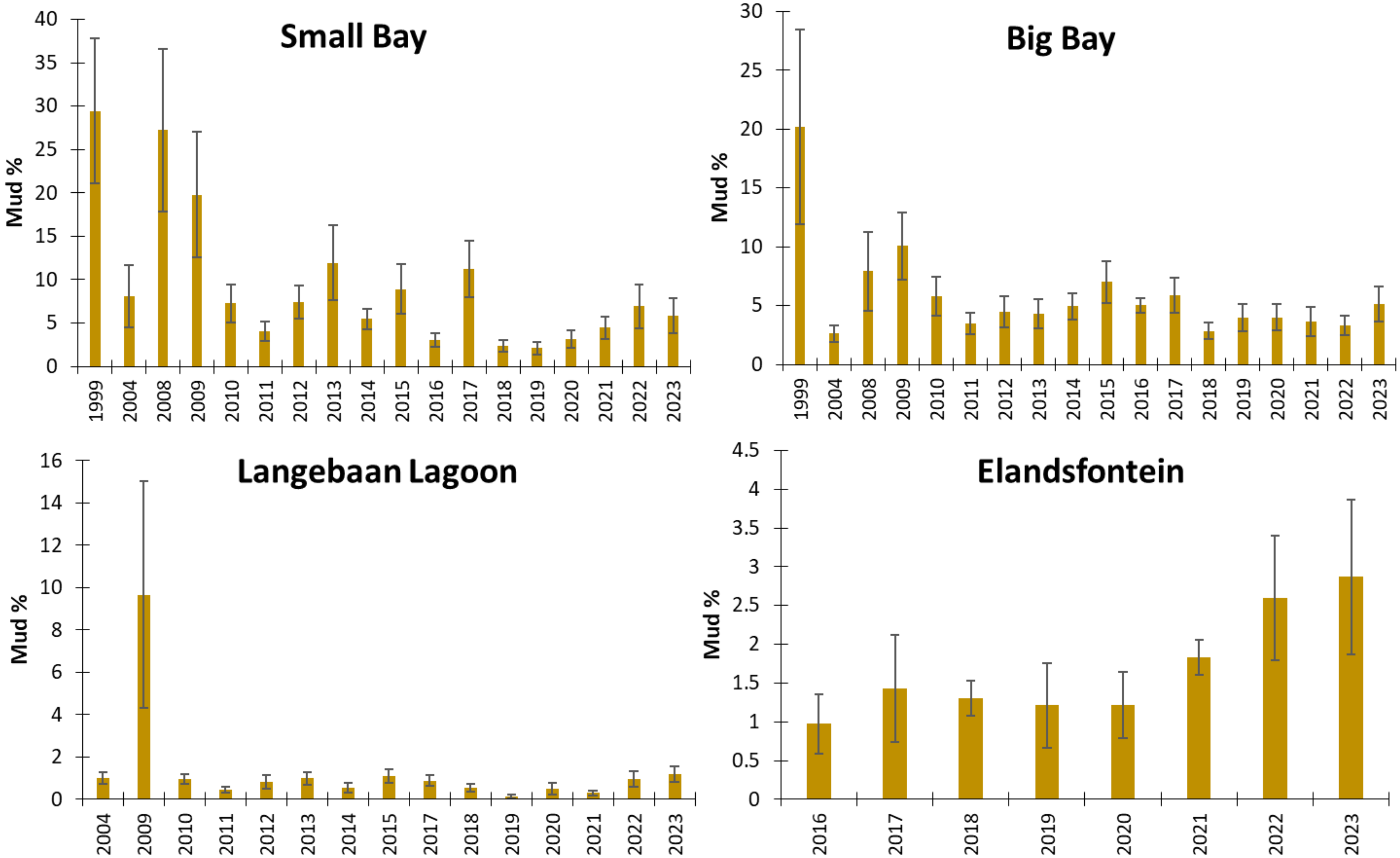


Figure 7.3. Average Mud% recorded from each area within Saldanha Bay and Langebaan Lagoon since 1999 with standard error indicated.

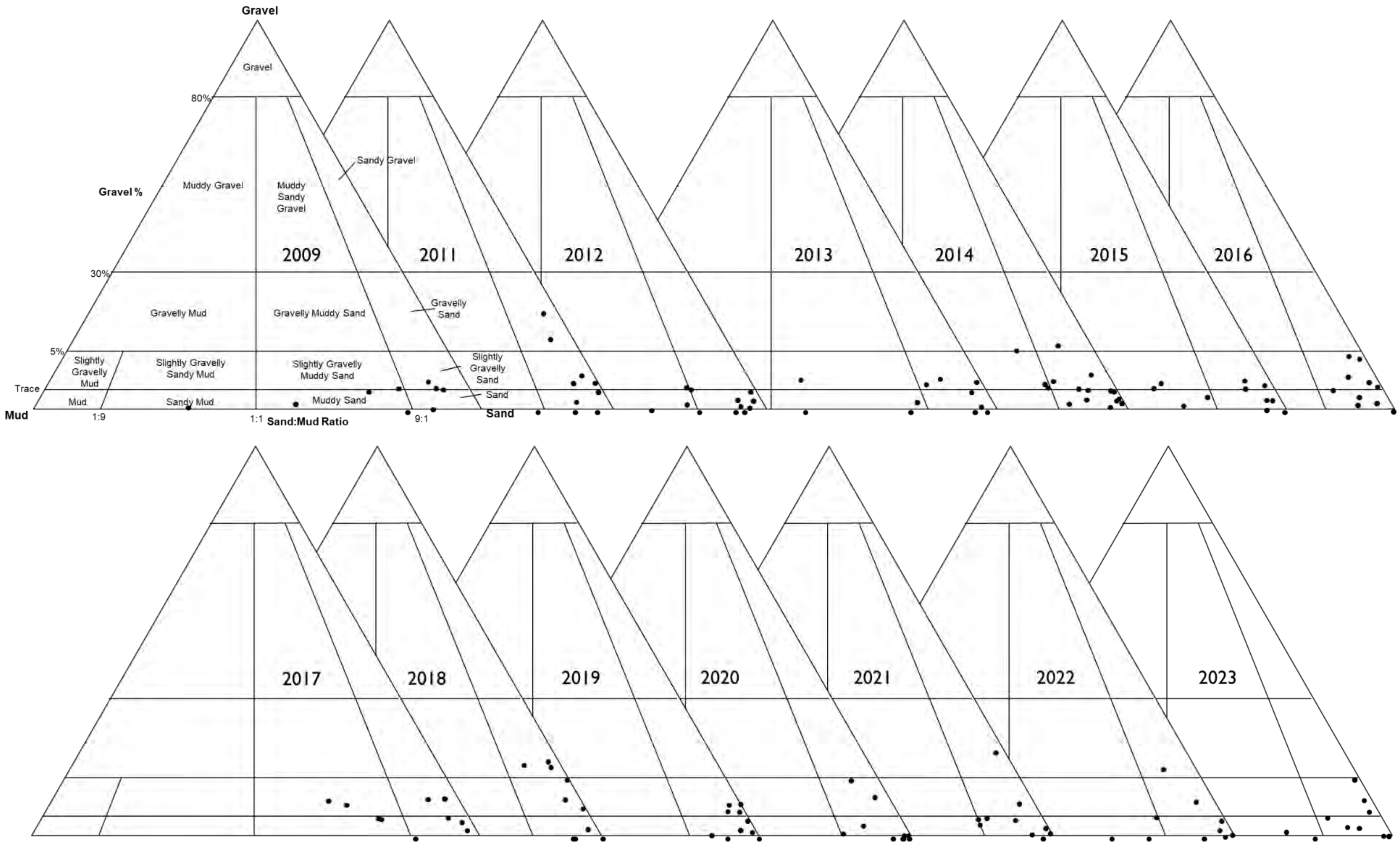


Figure 7.4. Ternary diagrams indicating Gravel/ Sand/ Mud composition in Small Bay throughout the State of the Bay monitoring.

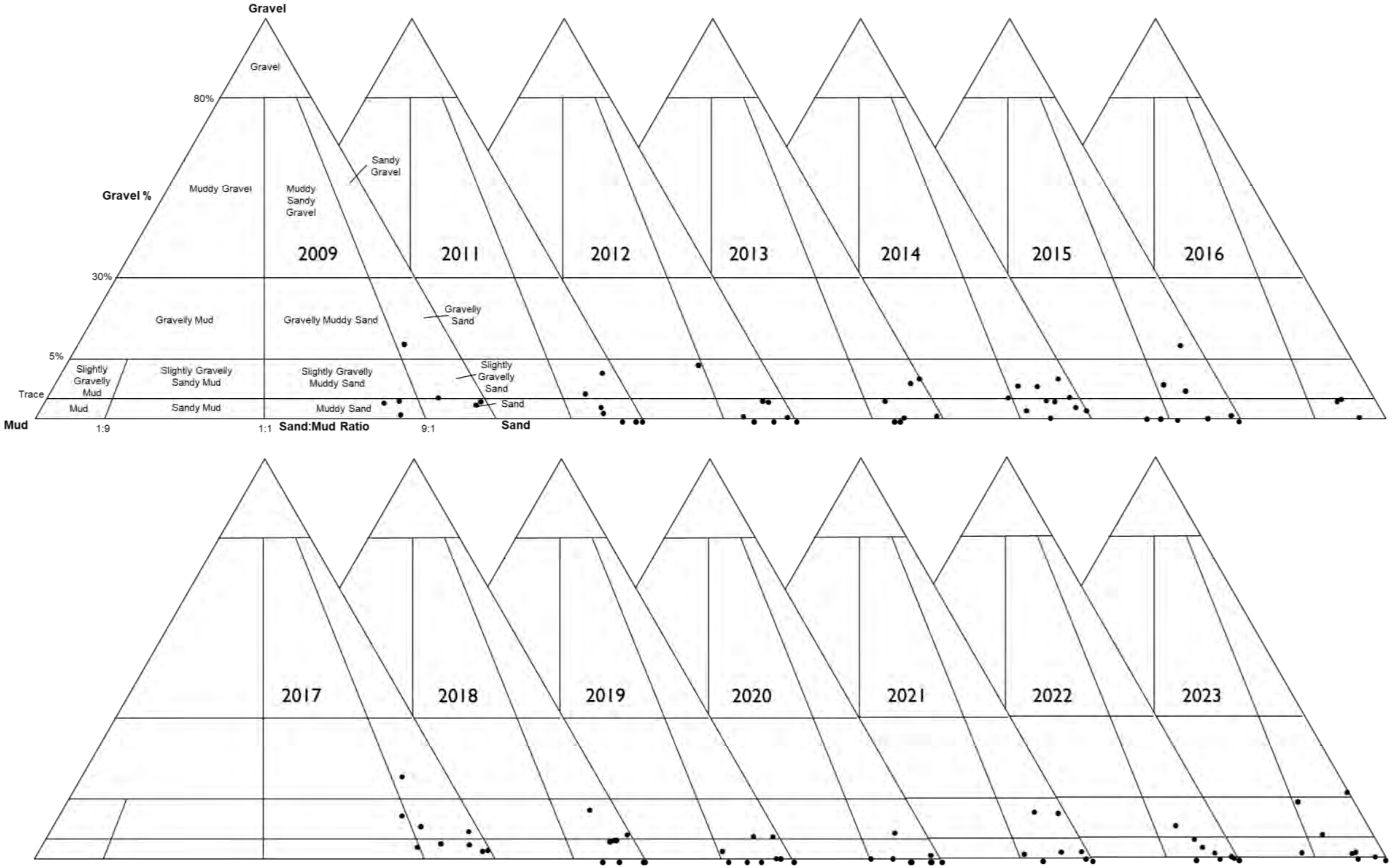


Figure 7.5. Ternary diagrams indicating Gravel/ Sand/ Mud composition in Big Bay throughout the State of the Bay monitoring.

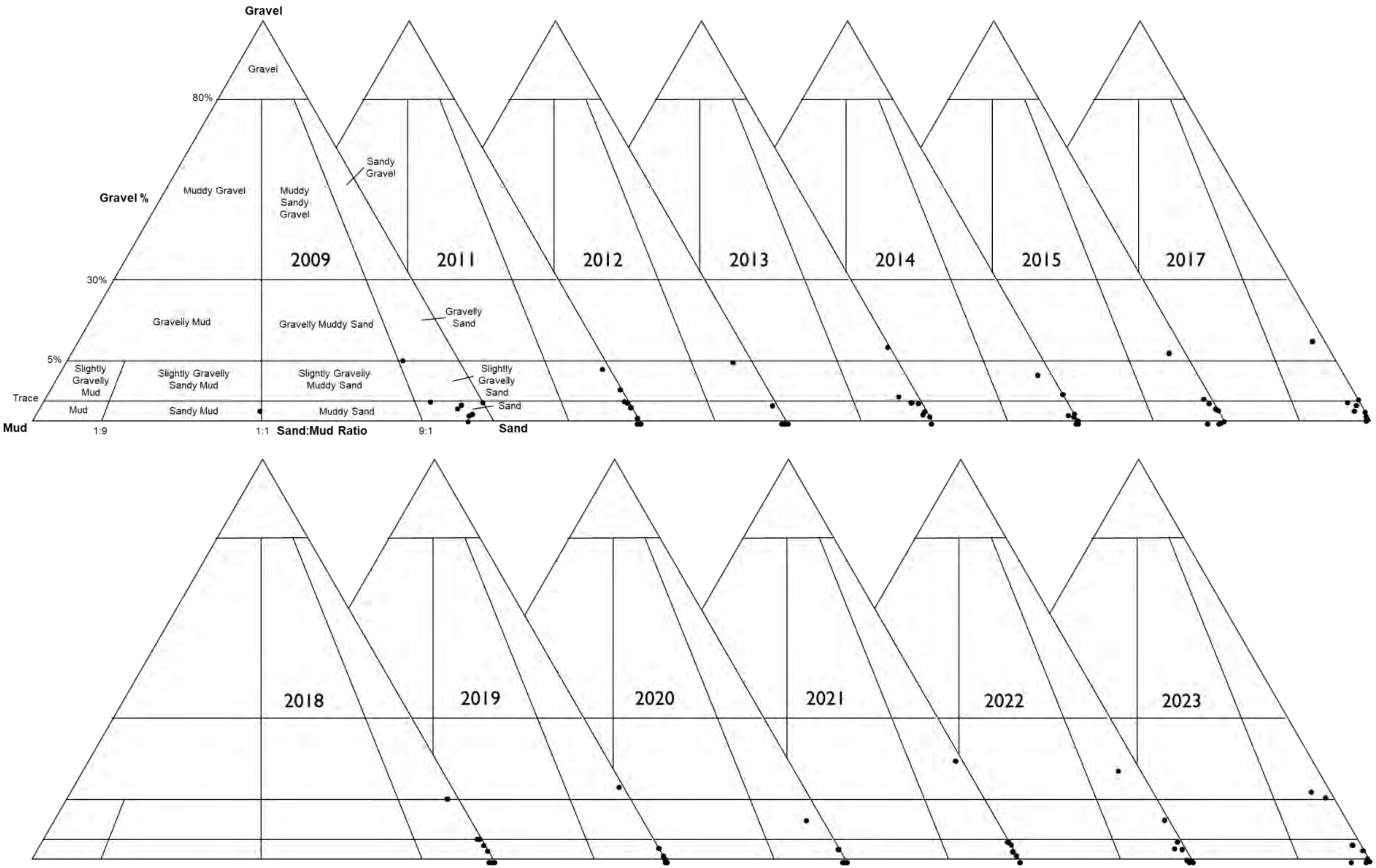


Figure 7.6 Ternary diagrams indicating Gravel/ Sand/ Mud composition in Langebaan Lagoon throughout the State of the Bay monitoring.

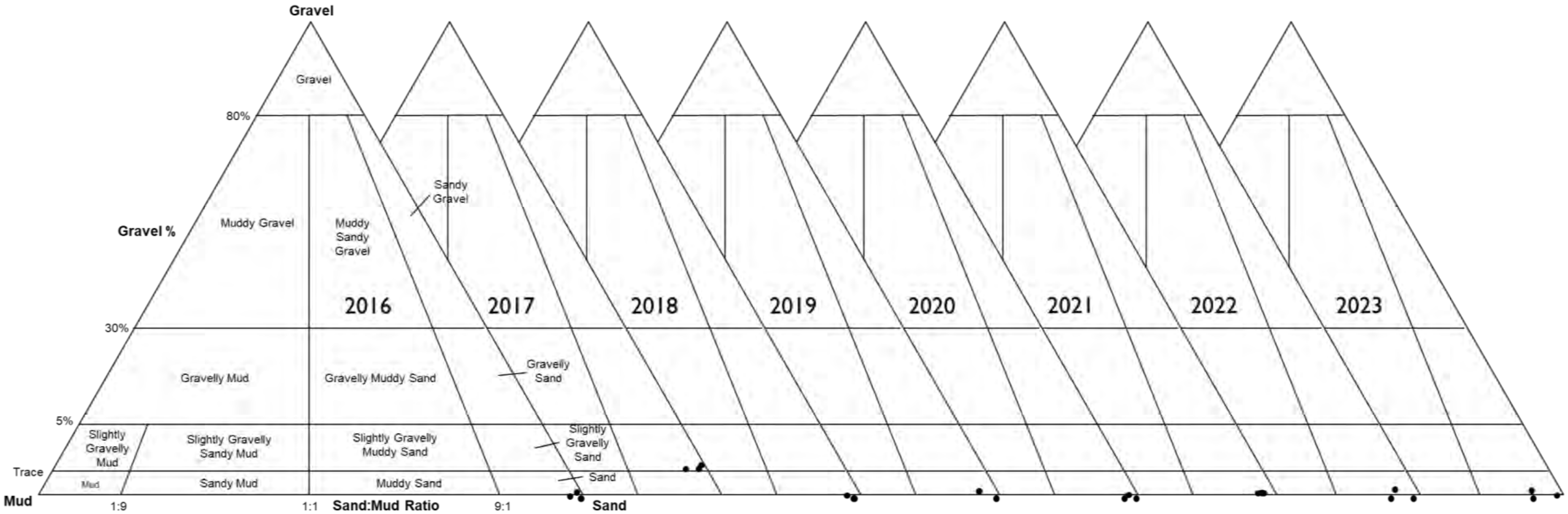


Figure 7.7. Ternary diagrams indicating Gravel/ Sand/ Mud composition in Elandsfontein throughout the State of the Bay monitoring.

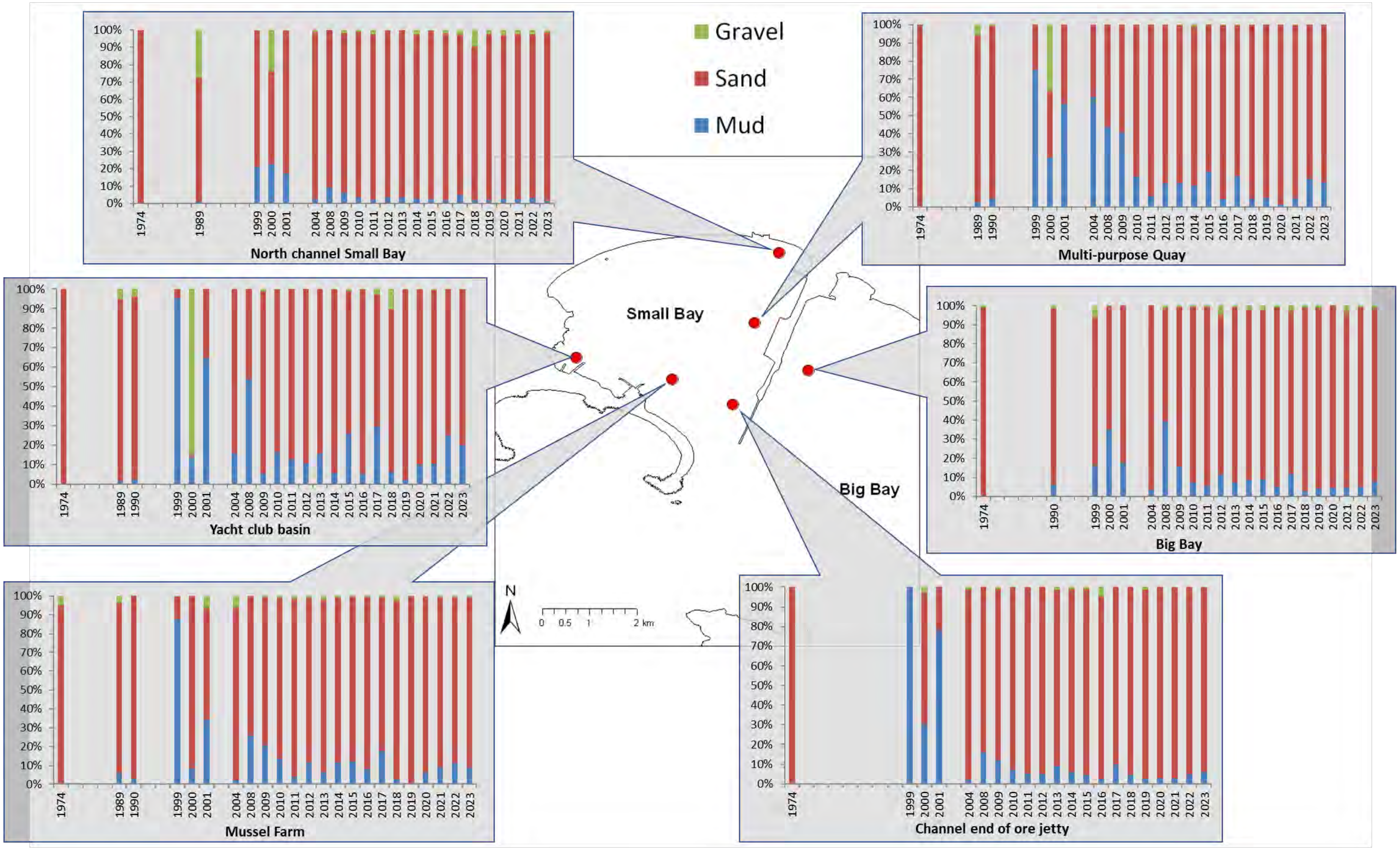


Figure 7.8. Particle size composition (percentage gravel, sand and mud) of sediments at six localities in the Small and Big Bay area of Saldanha Bay between 1974 and 2023. Data sources: 1974: Flemming (1977b). 1899–1990: Jackson & McGibbon (1991). 1999–2023: SBWQFT.

7.3.2 2023 Particle size

Current data indicated that sediments in Saldanha Bay and Langebaan Lagoon are comprised predominantly of sand (particle size ranging between 63 µm and 2000 µm) (Table 7.1). Sites located in Small Bay had on average the highest proportion of mud (5.84), followed by Big Bay (5.14), with the lowest average mud proportion being prevalent in Langebaan Lagoon (1.19).

Of greatest importance is the mud content of the sediment, with the 2023 results indicating a small reduction in the average mud component in Small Bay when compared to 2022 (6.94), and a small increase in Big Bay from (3.3%) in 2022. The reduction in mud content in Small bay is a positive development, as the mud component had increased substantially (doubled) between 2021 and 2022, and this may represent a partial reversion to 2021 conditions. However, this does not hold true for Big Bay, which also saw a near doubling in content from 2021 to 2022, and has increased further. Mud content in Langebaan and Elandsfontein have remained fairly consistent between 2022 and 2023. When looking at the distribution of mud throughout the system, it is clear that the distribution appears to be almost identical to 2022 (Figure 7.9).

Specific areas of high mud content are generally concentrated in Small and Big Bay, with those sites located near the Marcus Island causeway or shipping channel adjacent to the IOT being deepest due to recurrent maqintenace dredging in this area, and are therefore expected to have higher mud fractions than elsewhere in the Bay. This is confirmed by long term sampling and the current study, wherein most of the sites with the highest proportion of mud being located in the vicinity of the IOT, MPT, the mussel farms, and the Yacht Club Basin (Figure 7.8). The highest mud content in 2023 sampling was seen at the Yacht club Basin, SB1 (20.07%), however, this was slightly reduced from (24.97%) in 2022. Mud content at the multi-purpose quay (SB14) was also marginally lower in 2023, altough this may simply reflect sample variability.

The portion of gravel is typically very low in the sediments throughout the system, and appears to fluctate between the years, with maximum gravel % being much lower this year when compared to 2022, with a high of 8.58% at LL38, when compared to the high of 15.19% in 2022 at the same site. This indicates that this portion of Langebaan typically has a high average grain size, yet sample variability must once again be considered.

Table 7.1. Particle size composition and percentage TOC collected from Small Bay, Big Bay, Langebaan Lagoon and Elandsfontein in 2023 and 2022 (Particle size analysed by Scientific Services and TOC and TON analysed by the Council for Scientific and Industrial Research).

		2023			2022		
	Sample	**Gravel (%)**	**Sand (%)**	**Mud (%)**	**Gravel (%)**	**Sand (%)**	**Mud (%)**
Small Bay	SB1	0.17	79.76	20.07	0.00	75.03	24.97
	SB2	2.74	95.97	1.29	0.46	98.83	0.71
	SB3	1.38	97.08	1.54	2.55	94.35	3.09
	SB5	0.06	99.34	0.60	0.09	99.62	0.28
	SB8	0.07	98.56	1.38	0.22	97.94	1.84
	SB9	0.69	90.68	8.63	0.73	88.02	11.25
	SB10	5.38	93.66	0.95	0.05	98.44	1.51
	SB14	0.00	86.73	13.27	0.00	84.56	15.44
	SB15	0.28	95.28	4.44	8.77	85.71	5.52
	SB16	0.30	93.49	6.21	0.00	95.17	4.83
	Average	**1.11**	**93.06**	**5.84**	**1.29**	**91.77**	**6.94**
Big Bay	BB20	7.76	91.94	0.29	0.10	99.07	0.84
	BB21	0.21	95.65	4.14	0.19	96.79	3.02
	BB22	1.21	90.95	7.84	0.65	94.30	5.05
	LPG	4.92	85.86	9.21	2.21	90.99	6.81
	BB24	0.17	95.04	4.79	0.03	97.24	2.73
	BB25	0.09	98.31	1.60	0.06	99.38	0.57
	BB26	0.19	86.06	13.74	0.00	93.73	6.27
	BB29	0.04	95.68	4.29	0.33	95.22	4.45
	BB30	0.00	99.64	0.36	0.00	100.00	0.00
	Average	**1.62**	**93.24**	**5.14**	**0.40**	**96.30**	**3.30**
Langebaan Lagoon	LL31	0.00	99.25	0.75	0.00	99.39	0.61
	LL32	0.09	99.66	0.25	3.06	96.25	0.69
	LL33	0.02	99.36	0.62	0.00	99.95	0.05
	LL34	0.44	98.23	1.33	0.33	99.13	0.54
	LL37	6.74	91.92	1.34	0.61	98.78	0.61
	LL38	8.58	88.27	3.15	15.19	81.23	3.58
	LL39	0.30	99.47	0.23	0.03	99.77	0.20
	LL40	0.03	99.81	0.16	0.06	99.22	0.72
	LL41	0.00	97.09	2.91	0.35	98.00	1.66
	Average	**1.80**	**97.01**	**1.19**	**2.18**	**96.86**	**0.96**
Elandsfontein	Elands 1	0.00	95.99	4.01	0.00	96.13	3.87
	Elands 2	0.07	99.05	0.89	0.00	98.89	1.11
	Elands 3	0.17	96.12	3.71	0.19	97.00	2.81
	Average	**0.08**	**97.05**	**2.87**	**0.06**	**97.34**	**2.60**

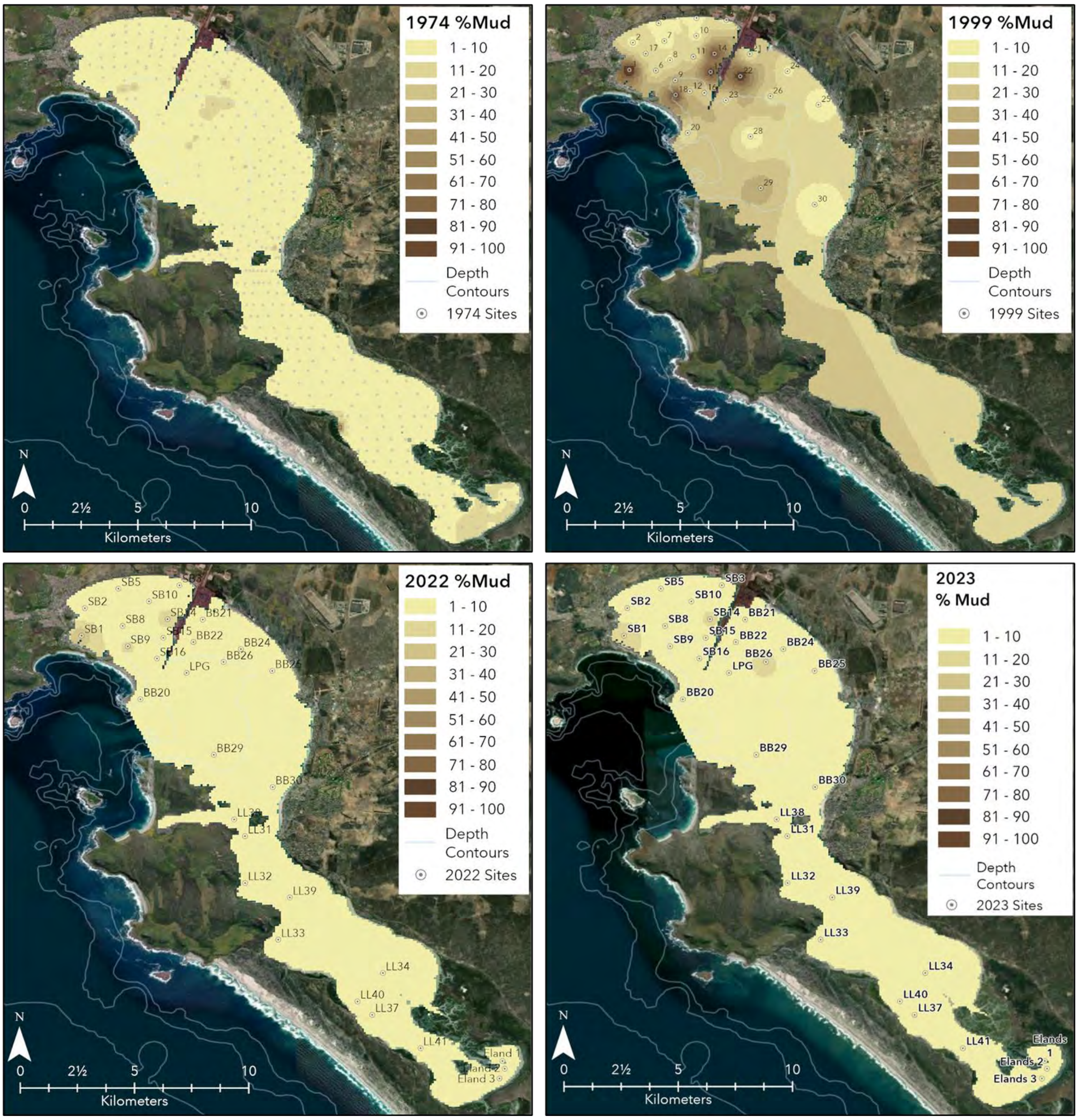


Figure 7.9. Change in the percentage mud in sediments in Saldanha Bay and Langebaan Lagoon between 1974 (top left), 1999 (top right), 2021 (bottom left) and 2022 (bottom right) survey results.

STATISTICAL ANALYSIS

A 2-way crossed PERMANOVA (Permutational multivariate analysis of variance) design was performed using Year (twelve levels: 2009–2011 and 2013–2022) and Region (eight levels: Small Bay, Big Bay, Langebaan Lagoon, Elandsfontein) as fixed factors. As is consistent with previous years, the results confirm that both factors have a significant effect on sediment composition (Year: Pseudo-F13 = 8,12, p < 0.001; Region: Pseudo-F7 = 43,113, p < 0.001). However, there was no significant interaction between Region and Year (Region × Year: Pseudo-F-42 = 1,0715, p > 0.28). This suggests that, despite significant differences existing between the particle size distributions in each region, and despite significant changes in particle size in the system over time, the combination of region and time does not seem to result in observed changes. This therefore suggests that changes are liekly a result of other factors, such as natural variability, oceanic conditions, etc. Prior State of the Bay reports have shown that Langebaan Lagoon has consistently remained different in sediment composition (separate grouping) from the rest of the sites from 2009–2023. Sediments in Big Bay and Small Bay are mostly quite similar, but inter-sample variation in Small Bay is clearly much higher than Big Bay or Langebaan Lagoon. Furthermore, these analyses have shown that dredging activities can have a visible effect on these relationships with time, with dredging near the LPG site in 2017 leading to a deviation from the nearby Big Bay sites when compared to 2016. This anomaly did, however, revert with time.

Given the consistent nature of these relationships in the prior State of the Bay reports, only the results from 2023 have been visually represented in a Multidimensional Scaling (MDS) plot (Figure 7.10) which depict the similarities/dissimilarities amongst sediment composition in each region for a given year. The plot shows clear clusters of sites corresponding with previous observations, however, BB20, located to the east of Marcus Island, has exhibited a high degree of dissimilarity from the other sites when compared to recent years. Of note is that a similar deviation from other Big Bay sites was seen at BB20 in 2015.

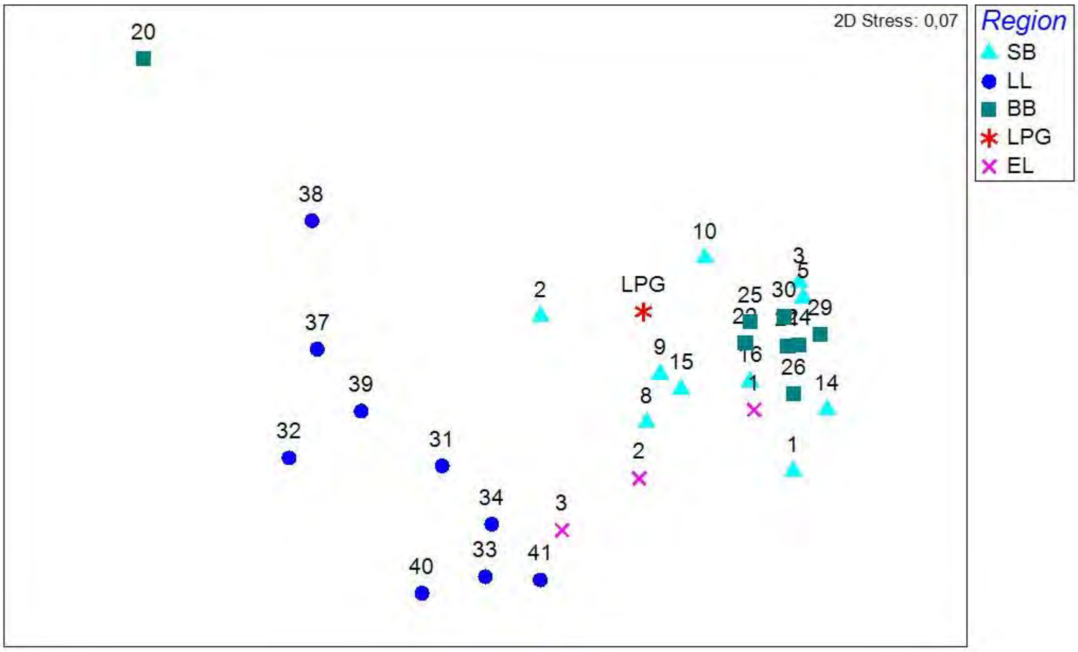


Figure 7.10. Plot of particle size distribution (PSD) from samples collected at sites from Saldanha Bay, Langebaan Lagoon and Elandsfontein 2023. Each region (SB: Small Bay, LL: Langebaan Lagoon, BB: Big Bay, LPG: Liquid Petroleum Gas, EL: Elandsfontein is represented by a unique symbol and colour

SUMMARY

In summary, the natural, pre-development state of sediment in Saldanha Bay comprised predominantly of 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. Therefter mud content remained elevated in areas of the Bay till approximately 2010, due to repeated dredge disturbances. Thereafter mud content has fluctuated without significant changes till present, with much of the Bay and Langebaan Lagoon having relatively similar mud content to what was present in

1974. Clear spatial variation exists in the grain size data, with sandier conditions being prevalent in Langebaan Lagoon, Elandsfontein, and to a lesser extent, Big Bay. However, Small Bay consisistely has higher mud content than the other regions, likely as a result of reduced circulation, and proximity to dredging and other disturbances.

Some site-specific year-on-year changes in the mud percentage are also visible in recent surveys and can be visually seen in selected sites from Small Bay, with mud content increasing from 2021 to 2022, which has subsequently reduced in 2023, although not to 2021 levels. However, this this is likely a reflection of sample and interannual variability, and does not represent a statistically significant change at a Bay-Scale (Figure 7.8).

Crucially, this report has demonstrated the high degree of intersample and spatial variability within the Bay, even during periods of extensive dredging disturbances. As a result, caution must be exercised when attempting to make regional or system-wide conclusions with respect to the impact of sediment composition, as changes are typically not statistically significant at a region or system-scale. What is clear, however, is that the sediments respond to changes in the degree of disturbance, with those site in proximity to the disturbance being must impacted. This leads to a pattern of short-term elevated mud content, followed by a short period of recovery and stabilisation, followed by another spike when further disturbances occur.

In conculsion, 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 extensive 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, potentially with accompanying increases in metal content, which is further discussed below.

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

TOC and TON accumulates in the same areas as mud as organic particulate matter is of a similar particle size range and density to that of mud particles (size <62.5 µm) and tends to settle out of the water column together with the mud. Hence, TOC and TON are most likely to accumulate in sheltered areas with low current strengths, where there is limited wave action and hence limited dispersal of organic matter. The accumulation of organic matter in the sediments doesn't necessarily directly impact the environment but the bacterial breakdown of the organic matter can (and often does) lead to hypoxic (low oxygen) or even anoxic (no oxygen) conditions. Under such conditions, anaerobic decomposition prevails, which results in the formation of sulphides such as hydrogen sulphide (H_2S). Sediments high in H_2S are characteristically black, foul smelling and toxic for 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 (WWTW) (Saldanha & Langebaan) and stormwater.

The molar ratios of carbon to nitrogen (C:N Redfield 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 1977b), 1989 and 1990 (Jackson and McGibbon 1991), from 1999, 2000 and 2001 by the CSIR (Monteiro et al. 1999, 2000, Monteiro 2001) and for 2004 and 2008–2023 from the State of the Bay sampling programme. According to data from (Flemming 1977b). 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 7.11, Figure 7.12).

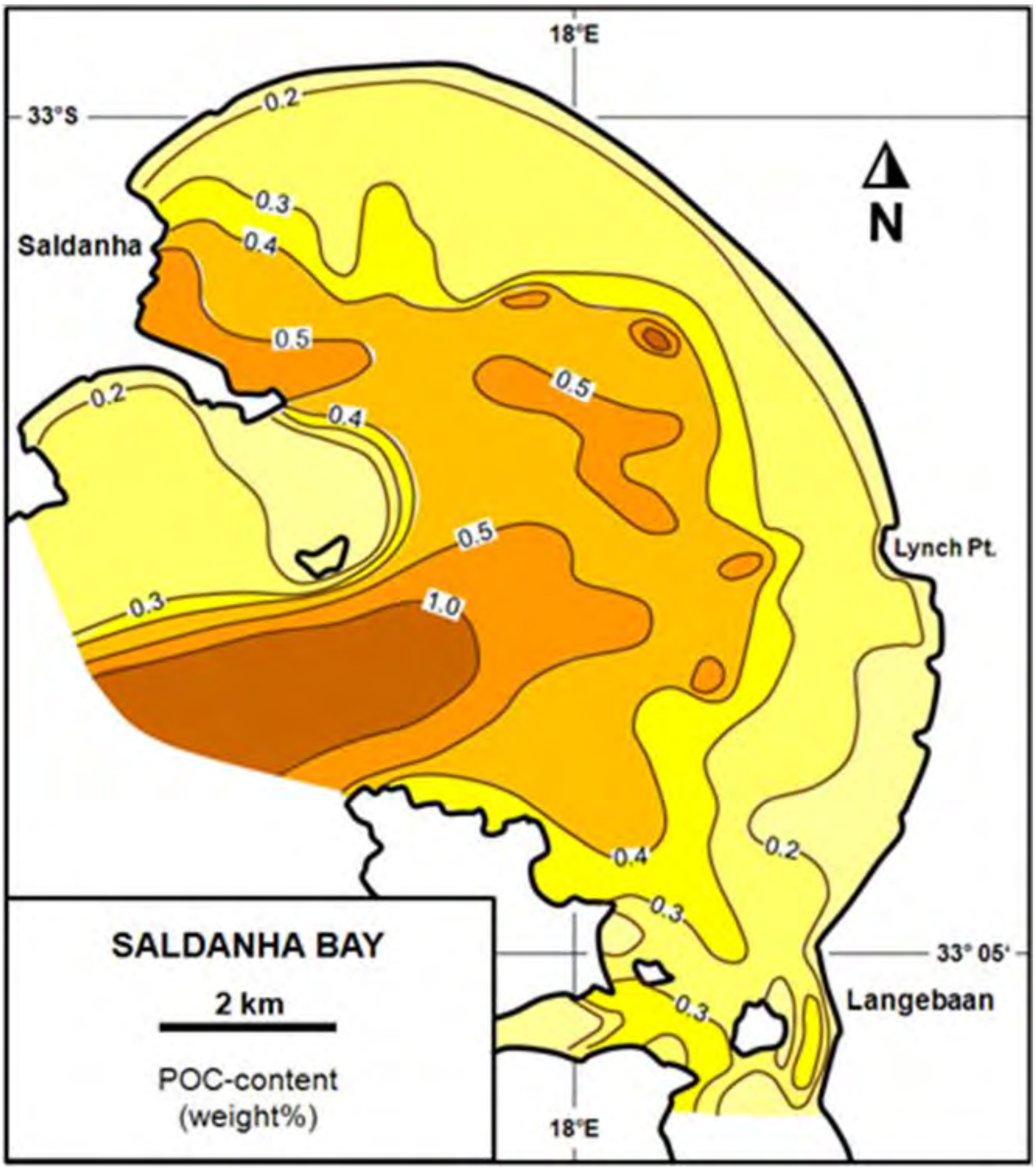


Figure 7.11. Levels of organic carbon in sediments Saldanha Bay in 1974. Source: Flemming (2015).

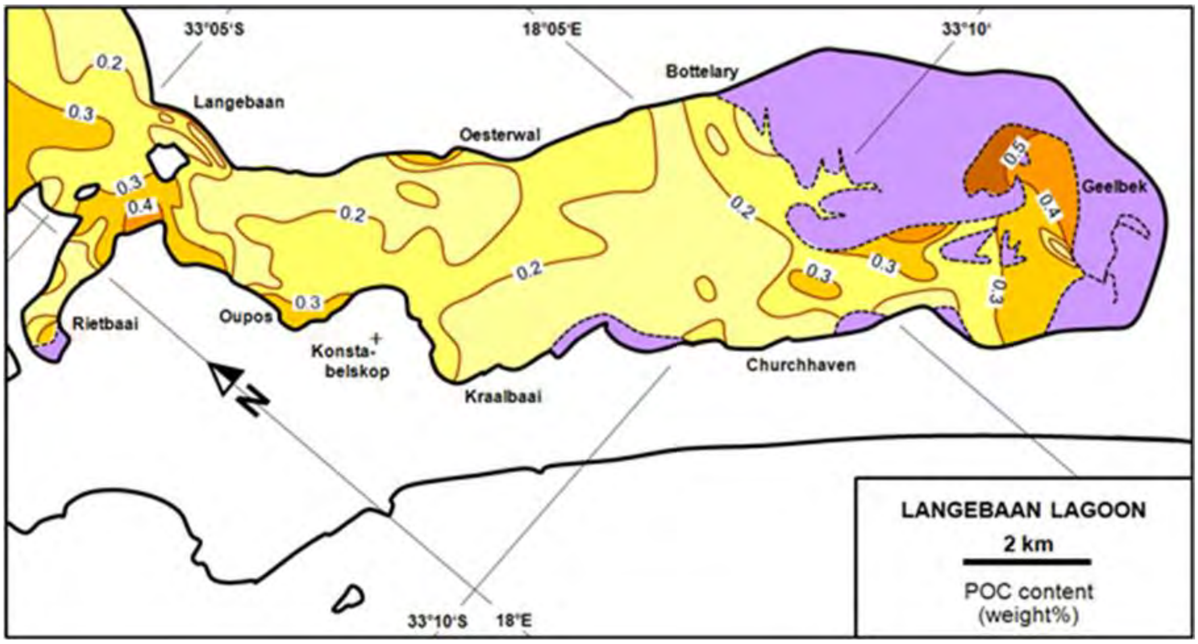


Figure 7.12. Levels of organic carbon in sediments in Langebaan Lagoon in 1974. Source: Flemming (2015).

Data on the spatial distribution of TOC from 1999, 2022 and the most recent survey (2023) are shown in (Figure 7.13; Figure 7.15), and Table 7.2 shows the 2023 laboratory results. These data suggest that TOC levels were relatively high from 1999 to 2012, particularly in Small Bay and Big Bay, with average concentrations that peaked in 2011 throughout the system. However, it must be stated that concentrations from 1999 till 2008 were a measure of Particulate Organic Carbon (POC) and not TOC. POC is a component of TOC, therefore indicating that these concentrations would have been higher should TOC have instead been reported at the time. Key sites with recurring high TOC concentrations in Small Bay are the Yacht Club Basin (SB1) and MPT (SB14). Positively, average TOC in the system appears to have decreased and stabilised from 2013 till present (Figure 7.15).

In general, TOC has been noticeably lower in the 2022 and 2023 surveys when compared to 1999, yet localised increases in TOC are evident between 2022 and 2023 in the Yacht club basin and in Big Bay alongside Marcus Island (Figure 7.13). In the current study, average TOC values have increased in Small Bay from 0.3 % in 2022 to 0.59%; they have reduced slightly at Big Bay from 0.62% in 2022 to 0.56% in 2023. There has been a greater decrease in Langebaan Lagoon from 0.21% in 2022 to 0.13% in 2023. Finally Elandsfontein exhibited almost identical TOC values, with 0.20% in 2020 and 0.19% in 2023. However, these shifts fall within range of variability seen in the past decade (Figure 7.15).

Levels of 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. These surveys found that nitrogen tends to be more elevated in Small Bay and in Big Bay in proximity to the IOT (Figure 7.14). Anthropogenic sources of organic nitrogen in Small Bay include fish factory wastes, biogenic waste from mussel and oyster culture as well as sewage effluent from the WWTW. Elevated levels of TON in Small Bay are considerably linked to the discharge of waste from the fish processing plants in this area, along with faecal waste accumulating beneath the mussel rafts and dredging operations at the MPT.

Results from the State of the Bay surveys conducted between 2008 and 2023 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 (Figure 7.16; Figure 7.15; Figure 7.15) the full 2023 results are available in Table 7.2.

Spatial variation in TON levels recorded in the sediments in Saldanha Bay and Langebaan Lagoon in 1999, 2022 and 2023 are presented in (Figure 7.14 and Figure 7.16).

TON content in 2023 appears very similar to the 2022 results, with the average TON results at Small Bay only shifting from 0.14% in 2022 to 0.13 in 2023; Big Bay shifting from 0.10% to 0.13%; Langebaan shifted from 0.03% to 0.04%; and finally, Elandsfontein remained approximately the same (0.03%). The prior 2022 State of the Bay report showed increased TON levels in Small Bay at the Yacht Club Basin, North Channel and Multi-purpose Quay when compared to the prior 2021 results. Additionally, similar increases were also evident at the Mussel farm and Channel end of ore jetty, albeit to a lesser degree.

The pattern for 2023 is similar to that in 2022, with all but two key sites (the Yacht Club Basin and North Channel – Small Bay) having a reduction in TON. However, the most substantial change was in Big Bay alongside Marcus Island (BB20), where TON has increased from 0.11% in 2022 to 0.47% in 2023, which was the highest TON recording from the survey. Despite the above changes, the average TON concentrations appear to fall within the typical range seen since 2013 (Figure 7.13). Importantly, the 2023 distribution TON appears to indicate higher TON content than what was observed in 1999 (Figure 7.14).

Table 7.2. Total Organic Carbon, Total Organic Nitrogen, and C:N Redfield Ratio collected from Small Bay, Big Bay, Langebaan Lagoon and Elandsfontein in 2023 and 2022.

		2023			2022		
		TOC (%)	**TON (%)**	**C:N**	**TOC (%)**	**TON (%)**	**C:N**
Small Bay	SB1	3.03	0.46	7.68	0.03	0.44	0.09
	SB2	0.17	0.06	3.34	0.21	0.03	8.01
	SB3	0.17	0.07	2.87	0.38	0.06	7.39
	SB5	0.13	0.07	2.23	0.13	0.03	5.17
	SB8	0.18	0.06	3.56	0.42	0.07	7.00
	SB9	0.48	0.12	4.67	0.01	0.19	0.07
	SB10	0.15	0.06	2.82	0.32	0.04	9.45
	SB14	0.85	0.18	5.48	0.02	0.30	0.07
	SB15	0.27	0.06	5.19	0.66	0.11	7.01
	SB16	0.46	0.12	4.47	0.80	0.15	6.25
	Average	**0.59**	**0.13**	**4.23**	**0.30**	**0.14**	**5.05**
Big Bay	BB20	2.38	0.47	5.91	0.73	0.11	7.77
	BB21	0.22	0.07	3.65	0.69	0.07	11.48
	BB22	0.31	0.09	4.03	0.49	0.13	4.39
	LPG	1.15	0.27	4.96	1.49	0.28	6.22
	BB24	0.19	0.08	2.79	0.35	0.07	5.90
	BB25	0.14	0.04	4.05	0.18	0.02	10.21
	BB26	0.30	0.07	5.00	0.85	0.14	7.05
	BB29	0.23	0.06	4.47	0.68	0.11	7.18
	BB30	0.13	0.04	3.68	0.09	0.01	10.73
	Average	**0.56**	**0.13**	**4.28**	**0.62**	**0.10**	**7.88**
Langebaan Lagoon	LL31	0.08	0.03	3.07	0.11	0.02	6.18
	LL32	0.08	0.03	2.92	0.15	0.03	5.68
	LL33	0.06	0.03	2.26	0.09	0.01	10.85
	LL34	0.10	0.05	2.36	0.10	0.02	5.95
	LL37	0.07	0.03	2.88	0.19	0.04	5.40
	LL38	0.57	0.10	6.65	0.73	0.11	7.77
	LL39	0.08	0.03	2.99	0.11	0.01	12.83
	LL40	0.04	0.02	2.57	0.20	0.03	7.89
	LL41	0.12	0.02	6.71	0.19	0.03	7.31
	Average	**0.13**	**0.04**	**3.60**	**0.21**	**0.03**	**7.76**
Elandsfontein	Elands 1	0.27	0.03	10.50	0.26	0.04	7.53
	Elands 2	0.15	0.02	8.69	0.14	0.02	7.88
	Elands 3	0.14	0.04	4.17	0.21	0.03	8.17
	Average	**0.19**	**0.03**	**7.79**	**0.20**	**0.03**	**7.86**

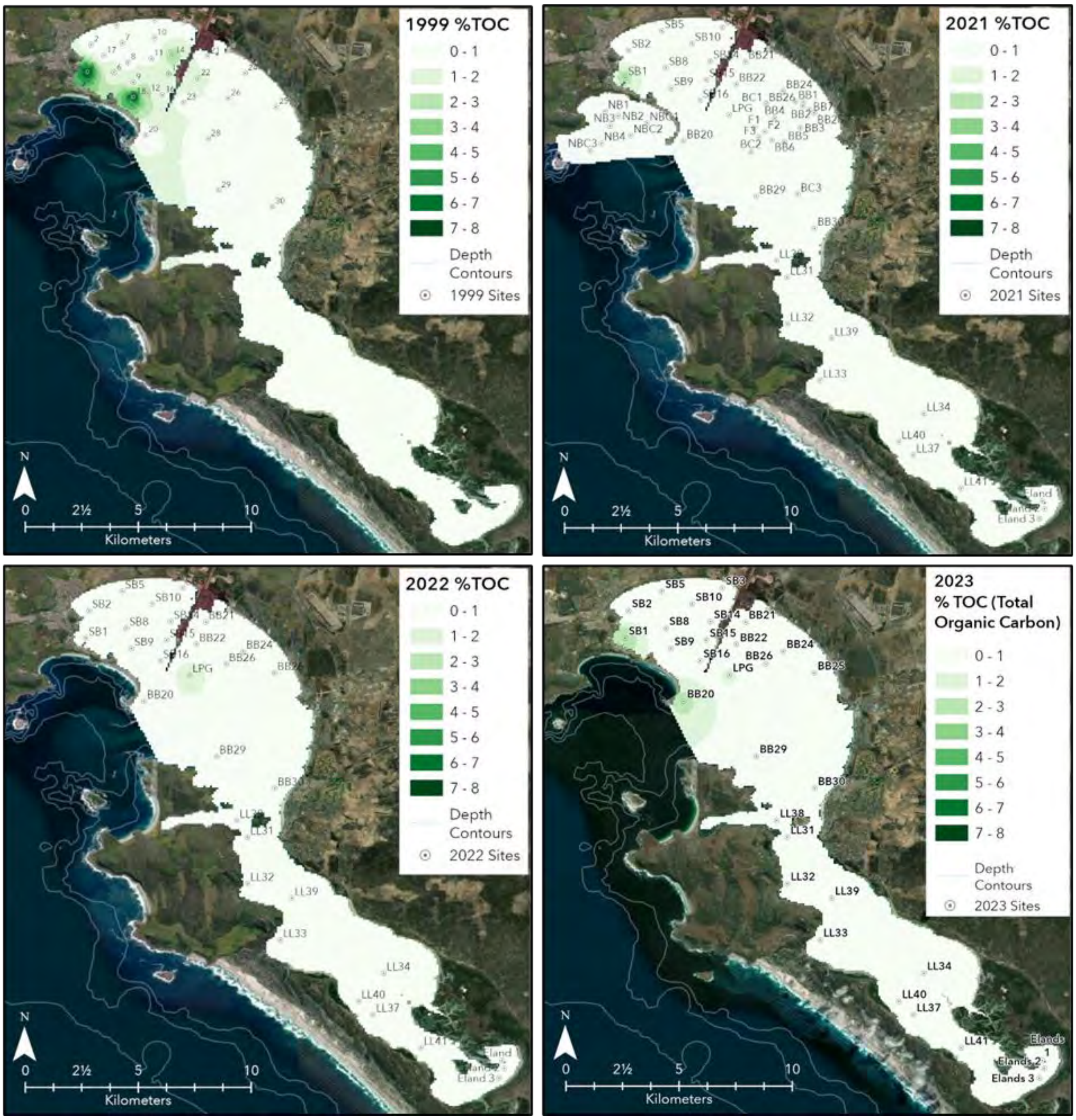


Figure 7.13. Total organic carbon (TOC) levels in sediments in Saldanha Bay in 1999 and 2021–2023 (Source: CSIR, 1999, Anchor Environmental Consultants 2020–2023.

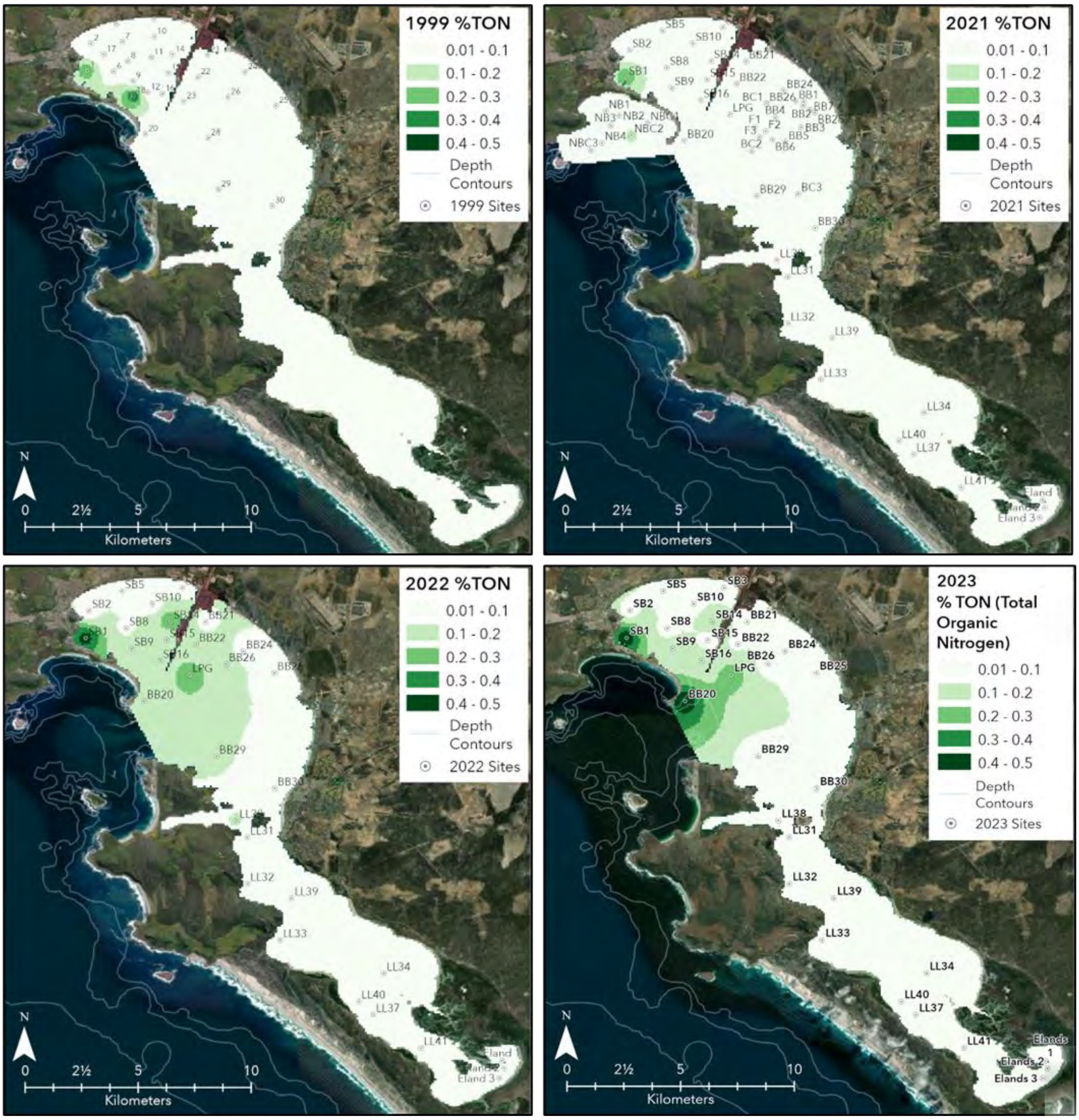


Figure 7.14. Total Organic Nitrogen (TON) levels in sediment in Saldanha Bay in 1999 and 2021–2023 (Source: CSIR 1999a, Anchor Environmental 2020–2023.

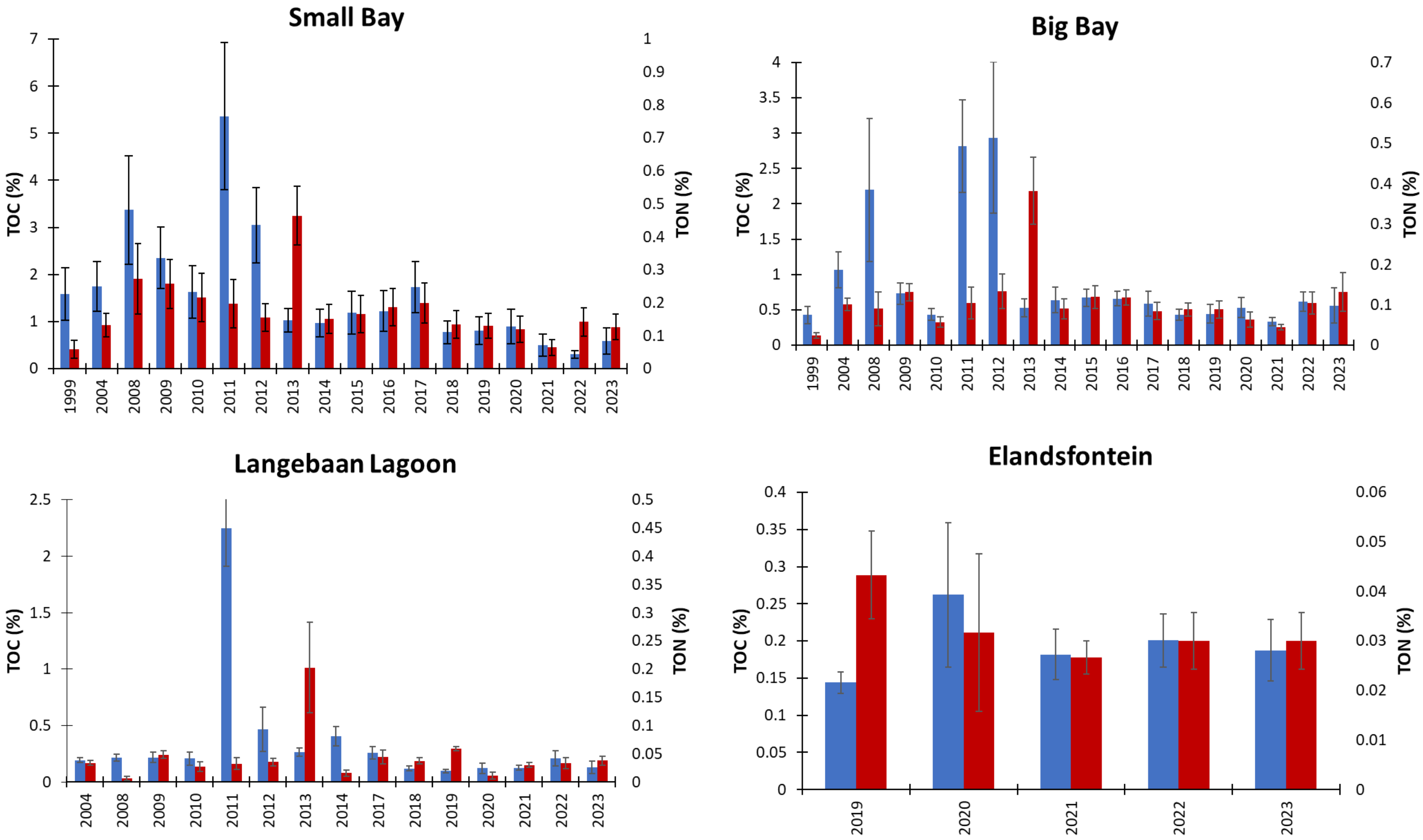


Figure 7.15. Average TOC and TON within each region of Saldanha, with standard error bars indicated.

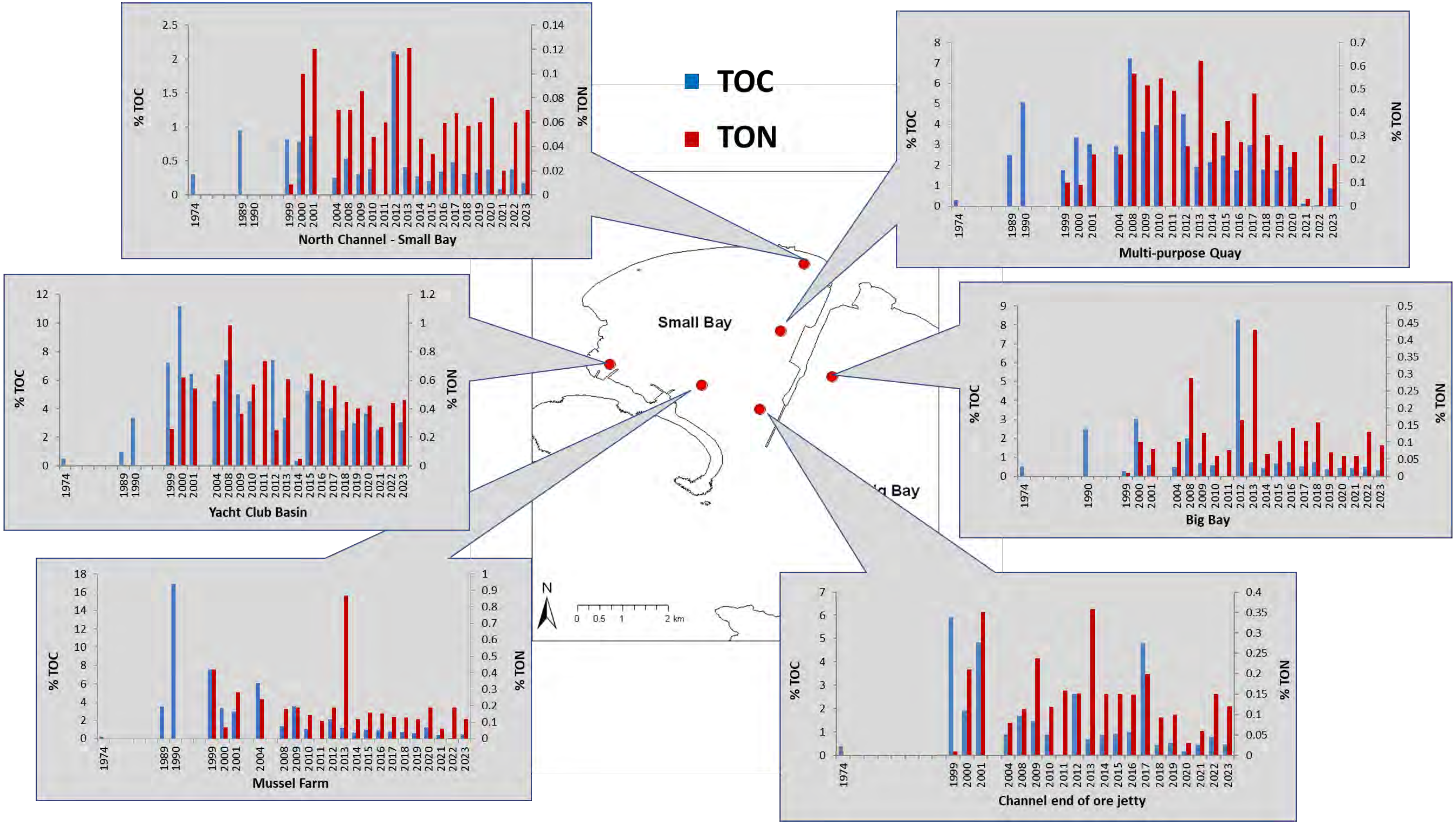


Figure 7.16. Total organic carbon and nitrogen (TOC and TON) in sediments of Saldanha Bay at six locations between 1974 and 2023. Data sources: 1974: Flemming (1977b), 1989–1990: Jackson & McGibbon (1991), 1999–2018: SBWQFT.

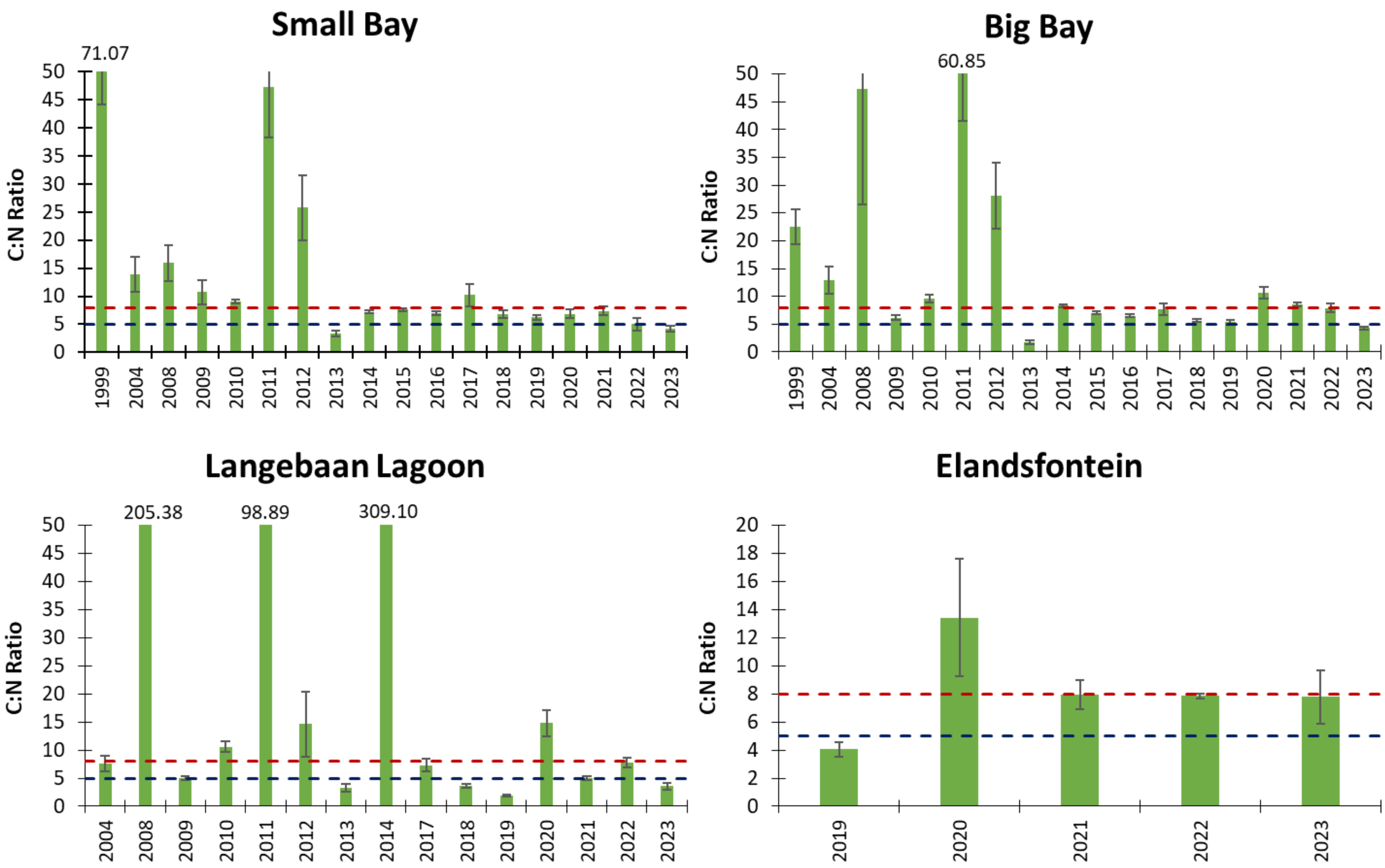


Figure 7.17. Average C:N Redfield Ratios in each region of the Bay, with the blue dashed line indicating the lower limit for marine organic production, and the red line indicating the upper limit.

C:N REDFIELD RATIO

In addition to assessing fluxes in TON and TOC in isolation, the relationship between these elements, know as the C:N Redfield ratio, can be a useful tool for understanding the conditions present in the sediment, and can give an indication of biological productivity, oxygen availability for decomposition, etc. C:N redfield ratios have fluctuated substantially in recent surveys, with the 2021 results indicating that most of Big Bay and selected areas of Small Bay, specifically the yacht club basin and sites adjacent to the MPT, all had elevated ratios in the sediment. This pattern nearly reversed in 2022, with the Yacht club basin, Marcus Island, and MPT having below expected C:N values. Converesely, areas of Langebaan that exhibited high low C:N values in 2021, fell above expected ranges in 2022 (Figure 7.18).

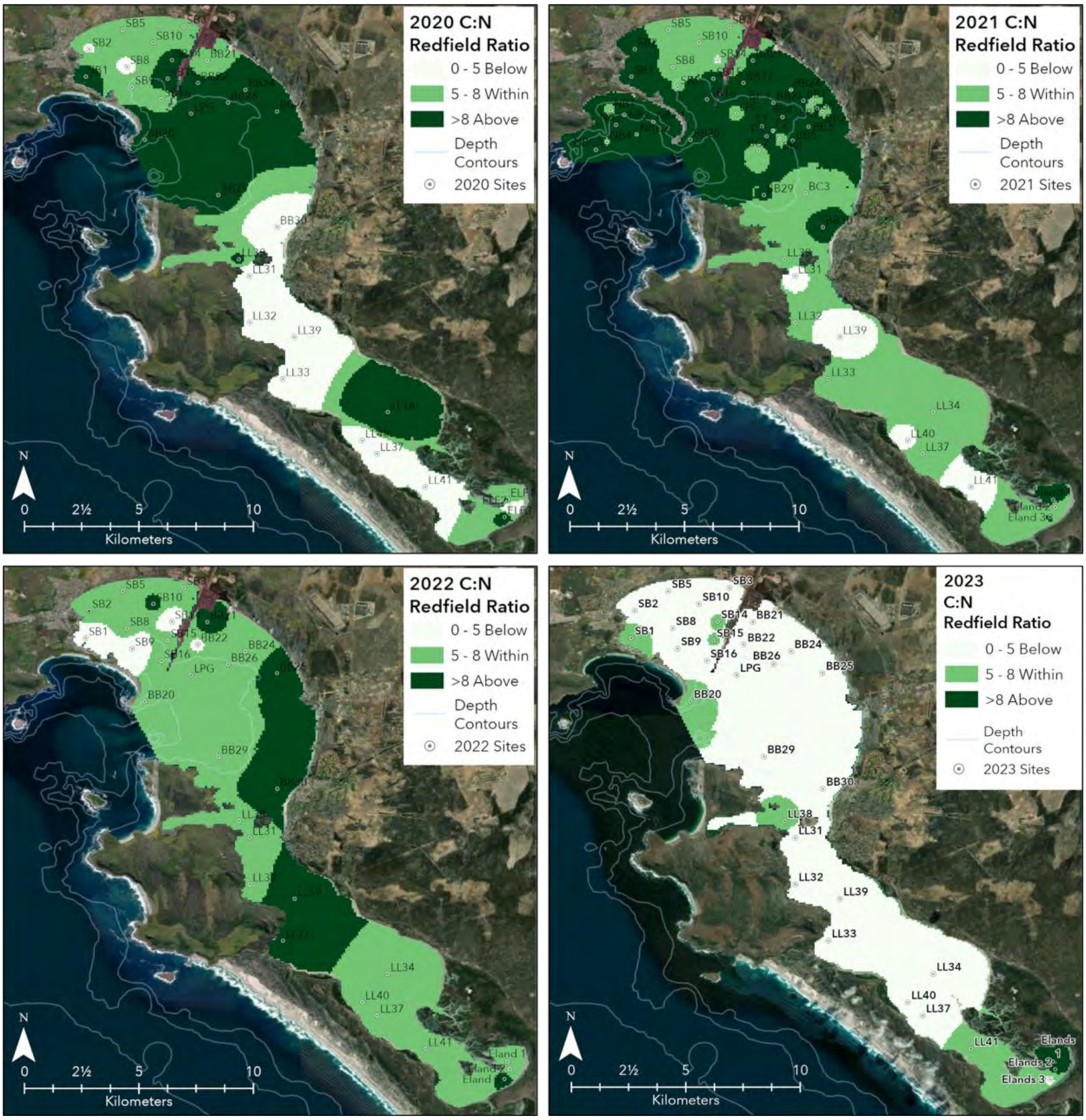


Figure 7.18. C:N ratios at different sites surveyed in Saldanha Bay, Langebaan Lagoon and Elandsfontein in 2020, 2021 & 2022 (dark green = exceeds the range expected for marine production; mild green = within the range expected for marine production and white = below range expected for marine production).

The 2023 results have subsequently shown a near system-wide decrease in C:N ratios, with most areas now falling below expected values for marine sediments. This is reflected in changes to the average ratios in each area, with Small Bay decreasing from 5.05% in 2022 to 4.23% in 2023, Big Bay decreasing from 7.88% in 2022 to 4.28% in 2023, and Langebaan Lagoon decreasing from 7.76 to 3.6. The shift in Big Bay and Langebaan Lagoon were therefore the must substantial, with Small Bay experiencing a lesser shift despite the colour representation in Figure 7.18 having a clear visual change. However, the current average C:N ratios in the system, although low, appear to fall within typical range seen during the past 10 years (Figure 7.17). The spikes in average C:N ratios seen intermittently in Small Bay and Big Bay between 1999 and 2014 are likely a product of nitrogen depletion (denitrification), rather than an introduction of terrigenous organic matter. Denitrification occurs in environments where oxygen levels have been depleted (anoxic or hypoxic) and nitrates are present. Under these conditions, denitrifying bacteria dominate as they are able to substitute oxygen, which is normally required for organic matter degradation, with nitrate reduction (Knowles 1982, Tyrrell and Lucas 2002). In areas where photosynthetic rates are very high, such as in upwelling systems, or where there is a high degree of organic input, a high biological oxygen demand deeper in the water column and sediments can lead to complete oxygen utilisation. The deeper areas of Small Bay and Big Bay greater levels of organic input, lower DO, and reduced circulation tend to be most susceptible to oxygen depletion and denitrification processes. However, the spikes in C:N seen in Langebaan Lagoon are unlikely to be purely due to denitrification, as the lagoon is typically quite shallow, with relatively high DO concentrations. In these area, high C:N ratios can occur as a results of terrigenous organic matter input which naturally has higher C:N ratios. The peaks in C:N ratio seen in Langebaan at the same time as spikes seen in the other regions, such as in 2011, may be due to a system-wide event rather than localised freshwater inflows in Langebaan. Furthermore, localised peaks in C:N ratios in Langebaan in the absence of peaks in the other regions may be caused by the issues quantifying TOC and TON when the values in sediment are very low, such as in 2014. For instance in 2014, all Langebaan sites with very high C:N values had very low TOC values (all < 0.61%), and very low TON values. At such low TOC concentrations, it is likely that the values may be distorted as a result of the ignition process (the methodology used to quantify TOC).

The highest C:N ratios in the current study were seen at the Elandsfontein sites (at the top of the Lagoon), with values at Eland 1 and Eland 2 being 10.50 and 8.69, respectively. In fact, the average C:N rations at the Elandsfontein sites were almost identical between 2022 and 2023, with 7.86% in 2022, and 7.79% in 2023. These conditions are almost certainly a product of the freshwater inputs at the head of the lagoon, and the associated input of terrestrial organic matter, which has a higher C:N ratio than marine biomass.

Despite being comparable to C:N ratios seen in Saldanha in the last decade, the reduction in the C:N ratios seen in 2022, and continued in 2023 might be indicative of some sort of system shift (Figure 7.18). Since the pattern is most emphasized in the less impacted areas of the system, i.e., Big Bay and Langebaan, it stands to reason that the shift is likely not occuring as a result of anthropogenic forcing, but rather a shift in oceanographic conditions. Prior research has demonstrated that shallow waters with high wave action and strong currents can result in a considerable amount of organic carbon being flushed out of the system (Atkinson et al. 2006). Average TOC results somewhat support this hypothesis, with TOC falling from 0.62% in 2022 to 0.56% in 2023 in Big Bay, and from 0.21% to 0.13% in Langebaan Lagoon. Furthermore, previous studies have also revealed that organic carbon content in terrestrial soils and marine sediments is often positively correlated with mud content (Baptista Neto et al. 2000, De Falco et al. 2004, Leipe et al. 2011, Serrano et al. 2016). It might therefore be argued that changes in mud content may thus account for corresponding reductions in the C:N ratios, as was asserted in the 2022 State of the Bay report. Indeed, this possibly holds true for Small Bay, where there has been a decrease in both mud content the C:N ratio since 2022. However, since Big Bay actually had a small average increase in mud content between 2022 and 2023 and the Mud content in Langebaan is near identical between the years, attributing the substantial changes in the C:N ratio purely to mud is not possible.

If one moves past attributing the C:N ratios to sediment composition, it seems reasonable to theorise that the recent temporal variability of C:N ratios in Saldanha Bay may reflect changes in prevailing oceanographic condition, such as upwelling intensity and benthic productivity over the summer period that precedes the annual surveys in April. Potential large-scale oceanographic drivers include the current El Niño phase, which refers to the periodic fluctuation in the thermal functioning of the Pacific Ocean, which can have global influences on temperature, rainfall, etc. At the time of 2023 sampling, there was a neutral El Niño phase, with the development of El Niño (warming conditions) in the Pacific expected to begin later in the year. This neutral phase has followed a persistent, strong La Niña period between 2020 and 2023 (Figure 7.19). The influence of these phases can have varying effects on the West Coast of South Africa. In general, El Niño phases are associated with hot, dry conditions in South Africa, such as the serious drought that occurred in 2017–2019 following a strong El Niño event (Figure 7.19 and Figure 7.20). Conversely, La Niña is typically associated with cold and wet conditions, which may partially explain the anomalously high rainfall that has been experienced in the South-Western Cape in 2023. Furthermore, El Niño events typically lead to a weakening of the South-westerly winds and associated upwelling off the West coast of South Africa. Upon inspection of annual rainfall graphs in conjunction with La Niña phase, it appears evident that particularly wet years appear to occur at the latter end of a La Niña phase (CSAG, 2023; Figure 2.17; Figure 2.18).

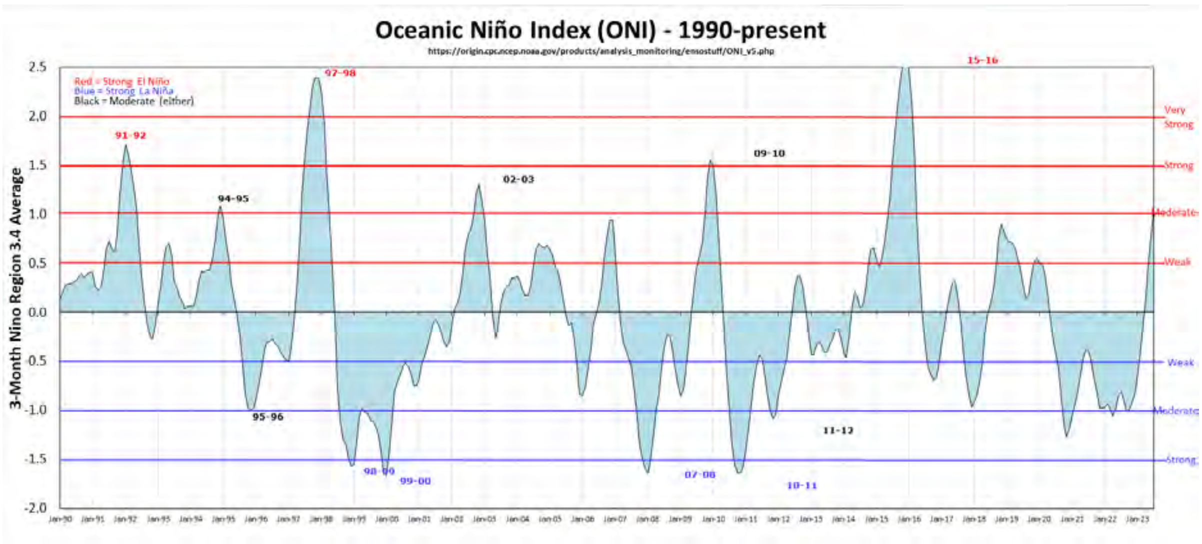


Figure 7.19. Oceanic Niño Index 1990–present (Figure source: (Golden Gate Weather Services 2023). Periods falling within the range of the blue lines indicate La Niña conditions, whilst periods falling within the red range indicate El Niño conditions. Finally, periods falling between these lines are considered ENSO neutral (such as the conditions persisting in 2023).

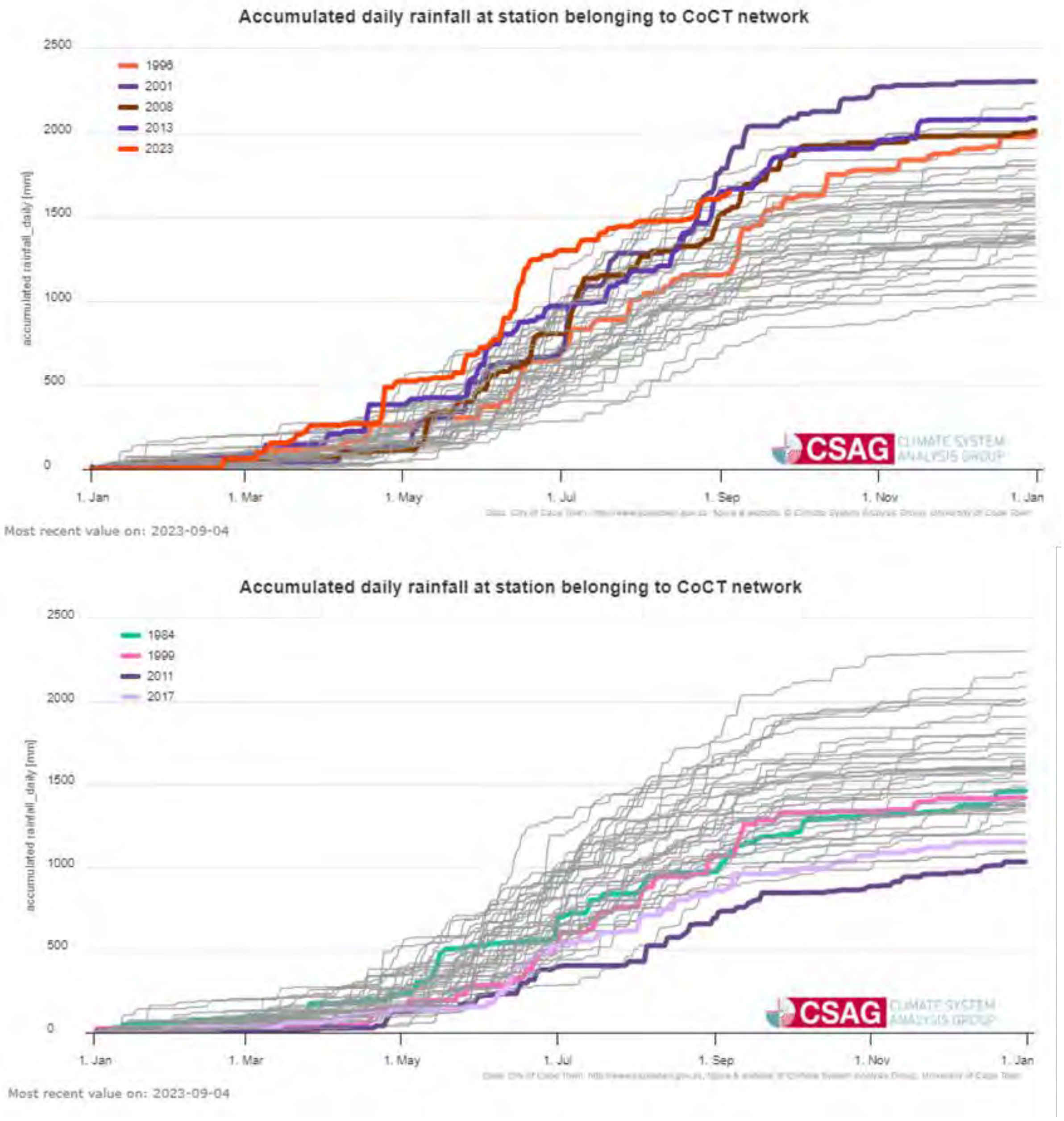


Figure 7.20. Accumulated rainfall in Newlands, Cape Town, highlighting rainfall in periods following La Niña events (top), and El Niño (bottom). Source: CSAG 2023.

In order to interpret the changes in Redfield Ratios since 2022, Reduction (Redox) Potential can be used to gain an understanding of the oxygen state of the sediment, which is explained as follows: Since denitrifying bacteria generally dominate when oxygen levels are low as they substitute the oxygen, required for organic matter degradation, with nitrate reduction which allows efficient energy extraction (Knowles 1982, Tyrrell and Lucas 2002). The measurement of the Reduction (Redox) Potential in unconsolidated sediments can be used to interpret such organic chemical processes. Positive redox values are generally characteristic of bottom deposits which are well oxygenated, consist of coarse sediments and are poor in organic matter. Negative values are characteristic of bottom deposits consisting of fine sediments which are rich in organic matter. In the presence of this organic matter, denitrifying bacteria create sulphurous conditions by which they reduce sulphate (SO_4^{2-}) to hydrogen sulphide

(H_2S), a gas that is toxic to most aerobic organisms (Jørgensen 1977, Brüchert et al. 2003, Van Der Plas et al. 2007) and which can play an important role in structuring benthic macrofaunal communities. Therefore, sediments with negative Redox values might be expected to have larger C:N ratios (since nitrogen is being lost), and conversely, positive Redox values would be expected to be associated with lower C:N rations, as nitrogen is being retained in the sediments.

The recent Aquaculture Develoopment Zone (ADZ) Chemical survey conducted as the same time as the State of the Bay sediment survey, involved testing sediment Redox potential using a Hach HQ40D portable meter equipped with an IntelliCAL® MTC101 ORP/redox probe from the undisturbed top layer of sediment (Dawson et al. 2023). In addition to measuring Redox potential, these samples were also analysed for their sulphide (S^{2-}) concentrations by the Council for Scientific and Industrial Research (CSIR).

For the purpose of this analysis, only Redox results for the control sites were considered in detail, which totalled 3 sites for Small Bay, Big Bay, and Outer Bay North. Unfortunately, since the monitoring was targeted towards the aquaculture development zone, results are not available for Langebaan Lagoon or Elandsfontein. Data for the aquaculture sites were largely excluded as they are almost certainly influenced by the aquaculture activities in their immediate proximity, and the objective of this analysis is to assess potential external factors on Redox potential and C:N ratios (Table 7.3; Figure 7.21; Figure 7.22).

The 2023 survey indicated that average Redox potential decreased for all three regions (Table 7.3). Furthermore, all but a single control site had triplicate average Redox potential which fell below those seen in 2022, indicating that nitrogen reducing reactions are more dominant than in the previous survey. The average Redox potential in 2023 for both Big Bay and Small Bay was also lower lower than what has previously been recorded for the same sites. This trend appears to be reflected in the Sulphide concentrations which were elevated in Big Bay and Outer Bay North relative to both the 2021 and 2022 results. However, this does not hold true for Small Bay, where sulphides were highest in 2021, yet these were based off very few measurements and likely are not representative of the area.

Table 7.3. Average Redox potential for each triplicate sediment control site sample analysed from 2019–2023 (Dawson et al. 2023).

		2019	2020	2021	2022	2023
Big Bay	BC 1	-122.0	-128.5	-235.4	-177.0	-182.2
	BC 2	162.0	-74.5	-103.0	180.0	-317.6
	BC 3	128.0	-109.6	-135.0	7.0	-164.2
	Average	**56.0**	**-104.2**	**-157.8**	**3.3**	**-221.3**
Outer Bay North	NBC 1	43	39.0	-199.0	1.5	-96.7
	NBC 2	52	117.8	0.7	-146.3	-127.7
	NBC 3		128.0	-121.3	69.9	-36.0
	Average	**47.5**	**94.9**	**-106.6**	**-25.0**	**-86.8**
Small Bay	SBC 1	ND	-119.7	-63.0	-78.9	-249.0
	SBC 2	ND	94.3	-97.5	-124.3	-213.8
	SBC 3	ND	-116.1	-75.1	-2.0	-203.3
	Average	**ND**	**-47.2**	**-78.5**	**-68.4**	**-222.0**

When viewed through the context of the reduced Redfield ratios in the sytem, the decrease in redox ratios is interesting. One would expect the La Niña period to have a strengthening effect on the Benguela upwelling system. This subsequently resulted in high relative nutrient abundance with an associated decrease in decline in dissolved oxygen, as oxygen-poor and nutrient rich water is upwelled. Consequently, an increase in primary production would be expected and, once these blooms subside, they will sink to the seafloor and begin to decay. However, due to the low oxygen conditions present due to the upwelling event, one would expect that much of this decay will occur in the absence of oxyen, and lead to reduction reactions instead of oxidation. As a result, a loss of sediment nitrogen would be expected, thus resulting in a high Redfield ratio. This pattern is evident through the 2020 and 2021 period, and somewhat 2022, however, this does not persist into 2023. It is therefore interesting that 2023 has the lowest recently recorded Redfield Ratios, yet the lowest Redox potential (and therefore the most suitable conditions for reduction, which should result in high C:N ratios). However, this may simply reflect a short-term lowering of dissolved oxygen in the water column due to upwelling events. Furthermore, this lowering of C:N ratios may also partially represent a dominance of marine phytoplankton in the sediments when compared to terrestrial organic matter.

In conclusion, it is possible that this yearly shift in C:N ratios indicates that the system is in a state of flux (change), which might be related to the shift from a La Niña phase to a neutral, and a rapidly approaching El Niño phase. However, it must be stated that this may simply be an issue of correlation not indicating causation, and the changes in Redfield ratios and Redox potential may be unrelated to this phenomenon. Regardless, it will be interesting to monitor these changes going forwards.

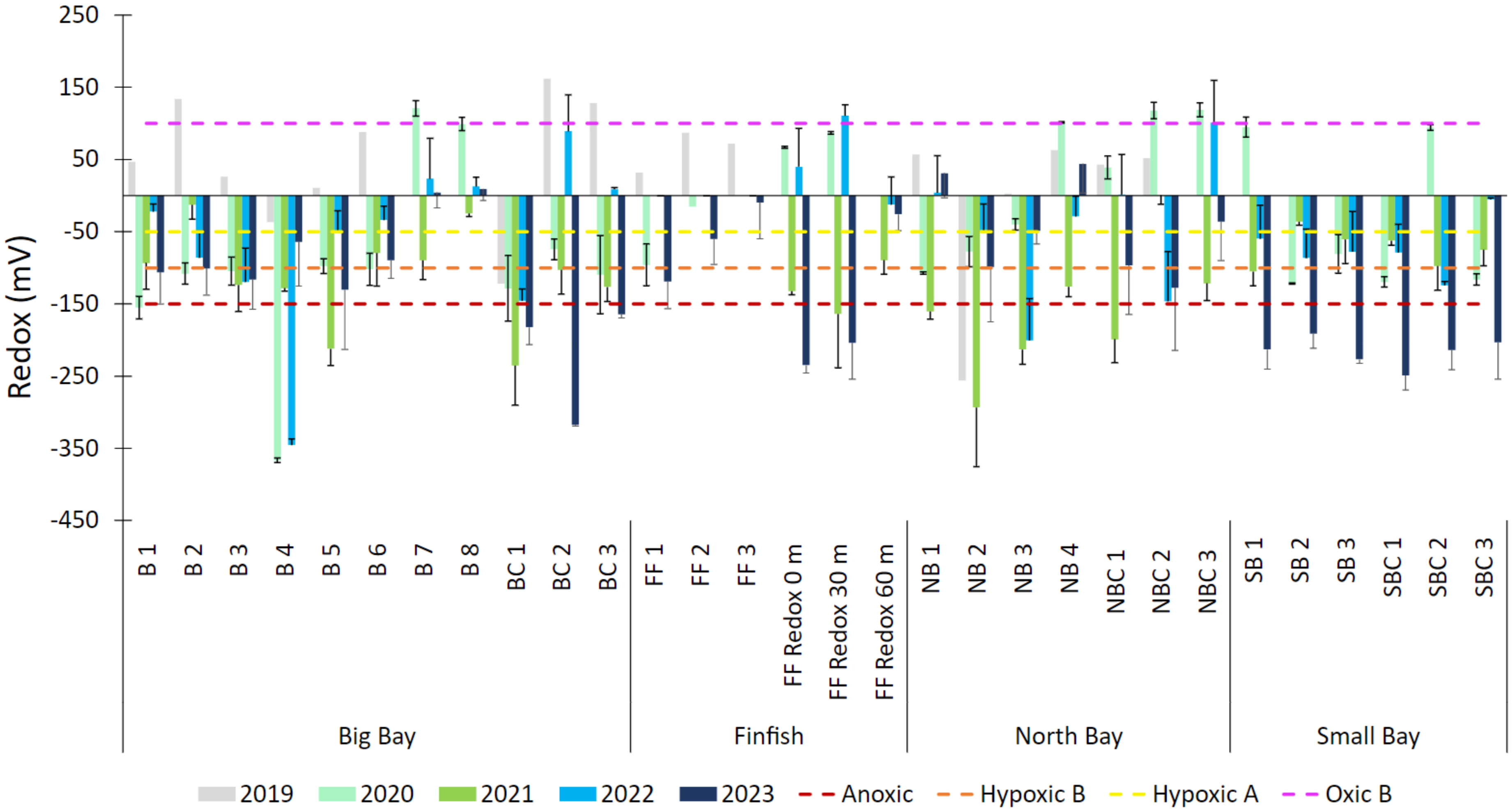


Figure 7.21. Redox ratios for the Saldanha Aquaculture Development Zone sites from 2019 till 2023 (Dawson et al. 2023). Redox ratios for the Saldanha Aquaculture Development Zone sites from 2019 till 2023 (Dawson et al. 2023).

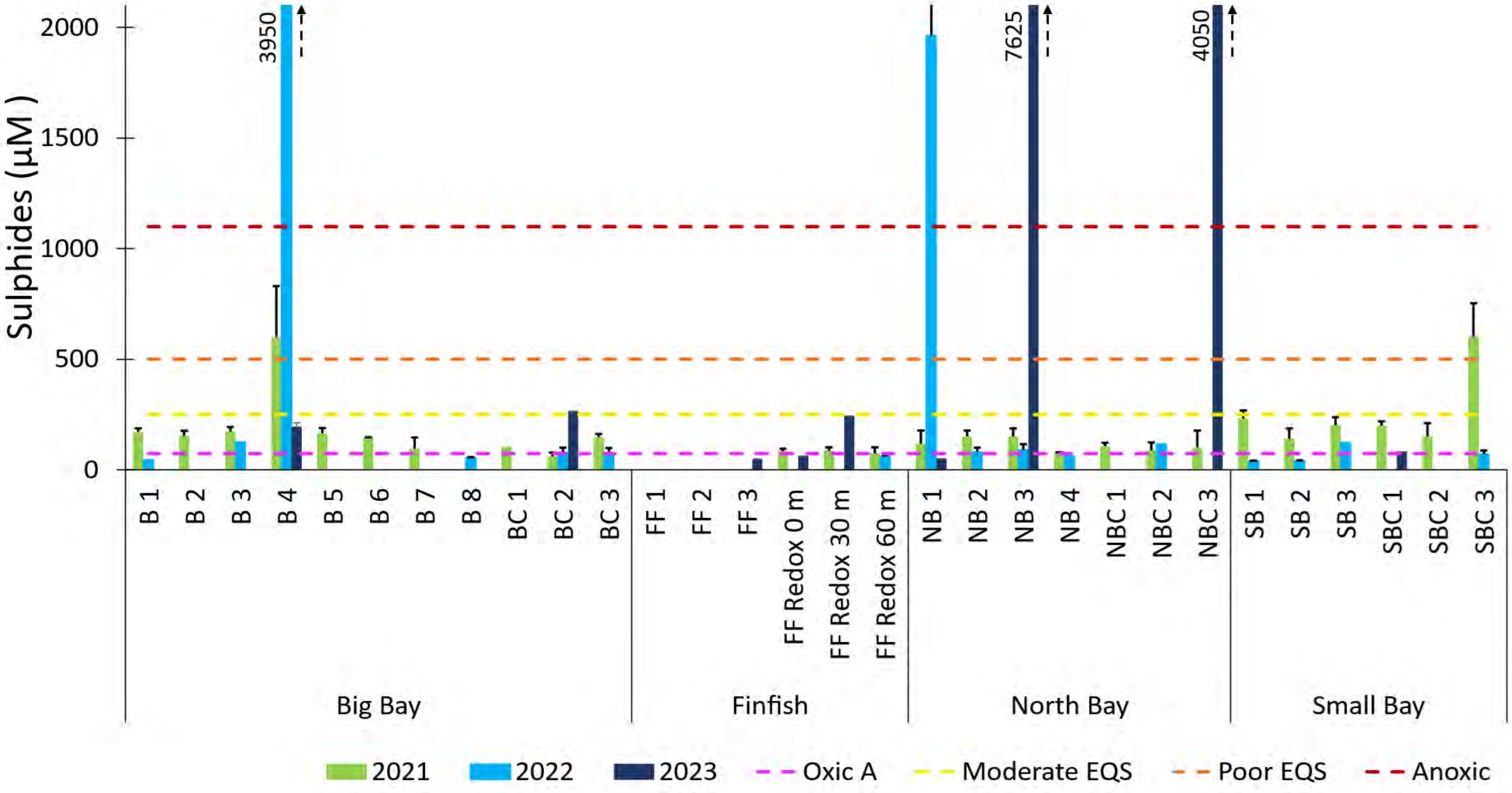


Figure 7.22. Sulphide concentrations measured in the recent ADZ chemical surveys (Dawson et al. 2023).

7.5 TRACE METALS

7.5.1 BACKGROUND

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 7.4). 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 7.4.

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

Table 7.4. Summary of Benguela Current Large Marine Ecosystem and National Oceanic and Atmospheric Administration (NOAA) metal concentrations in sediment quality guidelines.

Metal (mg/kg dry wt.)	BCLME region (South Africa. Namibia. Angola) (CSIR 2006)		NOAA (Buchman 1999)	
	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

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 time. 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), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn).

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. 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 are 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) along with the Mussel Farm and the small craft harbour (Yacht Club Basin) being 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 than in 1999. 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. Heavy metal concentrations in recent years appears to have largely stabilised without any significant trends, which is likely a product of the stability in sediment composition (particularly mud content) since 2010.

7.5.2 2023 Trace metal analysis

Sediments were analysed for concentrations of aluminium (Al), iron (Fe), Cd, Cu, Ni, Pb and manganese (Mn). Metals in the sediments were analysed by Scientific Services using a nitric acid (HNO_3) / perchloric acid ($HClO_3$)/ hydrogen peroxide (H_2O_2)/ microwave digestion and JY Ultima Inductively Coupled Plasma Optical Emission Spectrometer. Trace metal concentrations recorded in the sediments of Saldanha Bay are shown in Table 7.5 and the sections dedicated to each of the trace metals below.

The 2023 trace metal results indicate that concentrations in Saldanha mostly fall below the ERL guidelines, with the only exceptions being Cd and Cu in the vicinity of the Yacht Club Basin (SB1), with concentrations comparable to those in 2022. There was also a detectible concentration of Cd (1.11 mg/kg) at SB14, adjacent the Multi-Purpose Quay. A substantial limitation of the analysis methodology is the relatively low resolution of the Cd results, with the 1 mg/kg detection limits of Cd not allowing for effective determination of Cd contamination. This is because Cd concentrations below 1 mg/kg can be concerning in some circumstances, and the 1 mg/kg, depending on factors such as natural background Cd concentrations (Newman and Watling 2007).

Cu concentrations in Northern Small Bay (SB5) have increased greatly from <1 mg/kg in 2022 to 47.85 mg/kg in 2023, which now exceeds the ERL concentration. The only other metal to exceed ERL concentrations in 2023 was Mn adjacent to the IOT (SB14), with concentrations that have risen from 59.39 mg/kg in 2022 to 69.06 mg/kg in 2023. On a positive note, Pb concentration at the same site have fallen below the ERL concentration when compared to 2022, with the concentration in 2022 being 49.39 mg/kg, compared to 37.45 mg/kg in 2023.

When looking at average concentrations, both Fe and Al increased in concentration since 2022 for all regions. Average copper concentrations increased in Small Bay and Big Bay, with the majority of Cu concentrations recorded in Big Bay in 2022 falling below the detection limits. Positively, Ni concentrations fell across all domains by at least half since 2022.

Pb concentrations also fell in all regions, with Small Bay exhibiting the lowest decline (from 13.59 in 2022 to 10.93 in 2023), Big Bay falling from 6.15 mg/kg in 2022 to 2.25 mg/kg in 2023, Langebaan Lagoon falling from 2.78 mg/kg to a situation where most samples fell below detection limits. Finally, a dramatic decline was seen in Elandsfontein, where Pb concentrations fell from 9.08 mg/kg to below detection limits.

However, Mn concentrations in the Bay showing a differing trend to these other metals, with average concentrations in Small Bay remaining almost identical, concentrations in Big Bay increasing from 16.96 mg/kg in 2022 to 20.64 mg/kg in 2023. The change in Mn concentrations in Langebaan and Elandsfontein was most pronounced, with concentrations in Langebaan rising from 11.65 mg/kg in 2022 to 27.80 mg/kg in 2023, and from 14.21 mg/kg to 27.06 mg/kg in Elandsfontein.

Table 7.5. Concentrations (mg/kg) of metals in sediments collected from Saldanha Bay in 2023, with averages for 2022 included for reference. Values that exceed sediment quality guidelines are highlighted in red font. Averages have been calculated using a value of 0.5 for concentrations <1, should more than 50% of a region be <1, averages were not calculated.

	Sample	Al	Fe	Cd	Cu	Ni	Pb	Mn
*ERL Guideline (mg/kg)				1.2	34	20.9	46.7	56.5
Small Bay	SB1	12207	12771	3.13	47.57	13.83	22.86	53.76
	SB2	2312	4013	<1.0	1.53	2.02	4.12	22.40
	SB3	2473	4157	<1.0	2.33	1.95	13.95	31.96
	SB5	843	925	<1.0	47.85	3.31	3.96	5.41
	SB8	2677	4041	<1.0	1.35	3.07	5.37	23.67
	SB9	4620	6621	<1.0	2.93	5.01	6.15	35.53
	SB10	1728	4024	<1.0	<1.0	1.82	4.04	26.13
	SB14	6836	8837	1.11	14.76	8.12	37.45	69.06
	SB15	3075	3849	<1.0	1.98	3.04	6.01	25.89
	SB16	3632	4618	<1.0	3.36	4.51	5.37	32.88
	2023 Avg	**4040**	**5385**	**-**	**12.42**	**4.67**	**10.93**	**32.67**
	2022 Avg	**3335**	**3894**	**-**	**7.52**	**11.44**	**13.59**	**33.00**
Big Bay	BB20	826	1847	<1.0	2.59	<1.0	1.44	13.23
	BB21	3605	4249	<1.0	3.50	3.22	4.26	25.40
	BB22	3563	5587	<1.0	2.42	3.72	3.67	31.98
	LPG	3243	4876	<1.0	2.51	3.92	3.97	25.19
	BB24	2810	3176	<1.0	<1.0	2.81	2.37	20.71
	BB25	1487	2195	<1.0	<1.0	1.44	<1.0	14.88
	BB26	3533	4097	<1.0	1.06	4.06	3.03	23.21
	BB29	2156	2712	<1.0	<1.0	1.79	<1.0	16.38
	BB30	976	2117	<1.0	<1.0	1.11	<1.0	14.73
	2023 Avg	**2467**	**3428**	**-**	**1.56**	**2.51**	**2.25**	**20.64**
	2022 Avg	**2234**	**2523**	**-**	**-**	**8.08**	**6.15**	**16.96**
Langebaan Lagoon	LL31	2517	3836	<1.0	<1.0	2.11	1.33	22.48
	LL32	1880	5091	<1.0	<1.0	1.61	2.58	23.23
	LL33	1371	4580	<1.0	<1.0	1.46	<1.0	29.25
	LL34	2237	3232	<1.0	<1.0	1.93	<1.0	19.43
	LL37	1238	2139	<1.0	<1.0	<1.0	<1.0	26.75
	LL38	4848	7937	<1.0	<1.0	5.78	2.40	48.74
	LL39	1750	3009	<1.0	<1.0	<1.0	<1.0	21.75
	LL40	967	3349	<1.0	<1.0	<1.0	<1.0	32.46
	LL41	2094	4265	<1.0	<1.0	1.82	<1.0	26.11
	2023 Avg	**2100**	**4160**	**-**	**-**	**1.80**	**-**	**27.80**
	2022 Avg	**1863**	**1918**	**-**	**-**	**13.21**	**2.78**	**11.65**
Elandsfontein	Elands 1	3404	5590	<1.0	<1.0	3.16	<1.0	32.06
	Elands 2	2109	4233	<1.0	<1.0	1.96	<1.0	28.17
	Elands 3	2448	3791	<1.0	1.73	2.21	<1.0	20.93
	2023 Avg	**2654**	**4538**	**-**	**-**	**2.44**	**-**	**27.06**
	2022 Avg	**2341**	**2798**	**-**	**-**	**8.97**	**9.08**	**14.21**

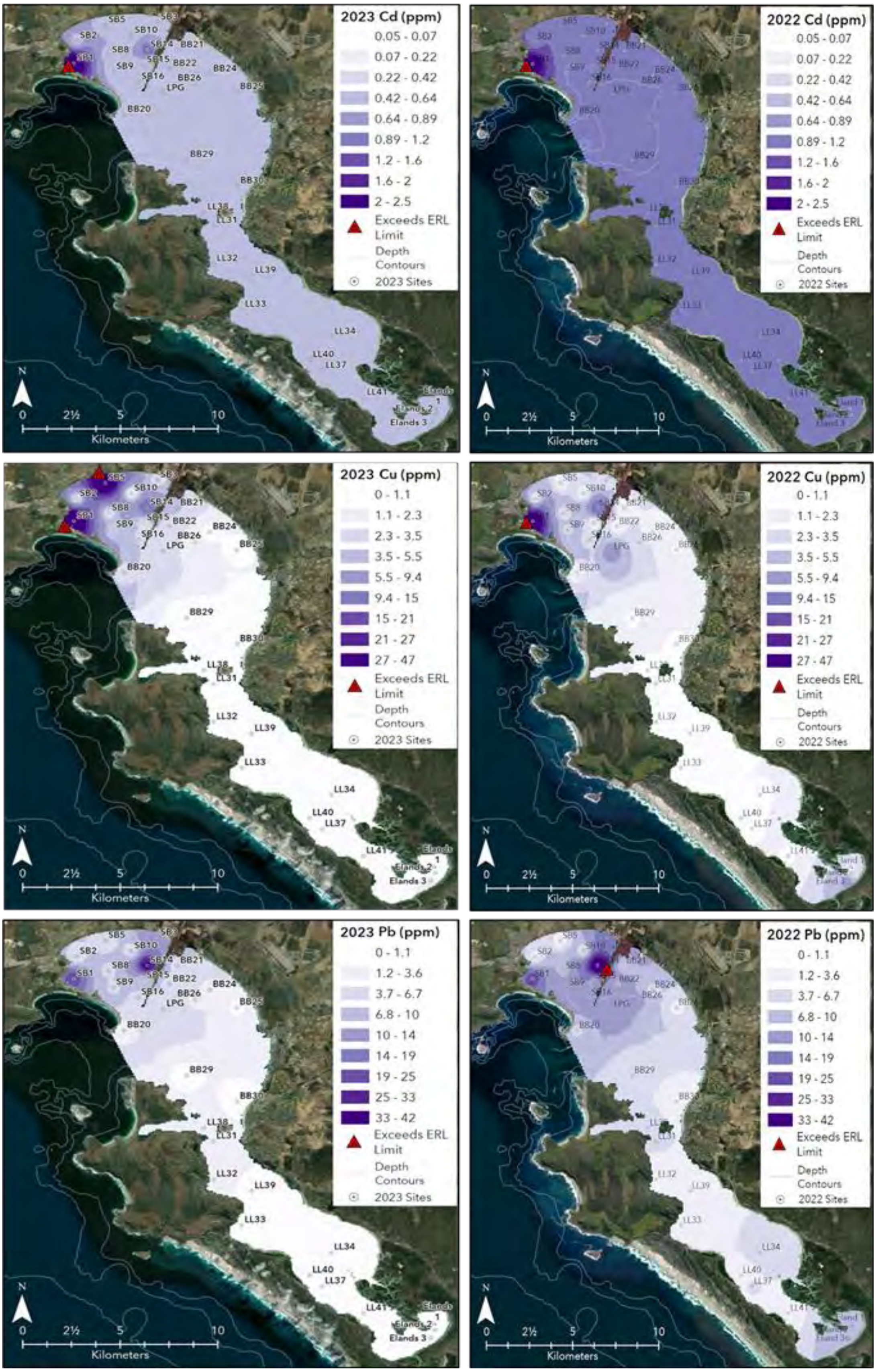


Figure 7.23. Spatial interpolation of total Cd, Cu, and Pb concentrations between 2022 and 2023. Note that the colouration of Cd in 2022 is misleading, and the majority of the system falls into the same class in both 2022 and 2023. Red triangles indicate sites that exceed the ERL limit

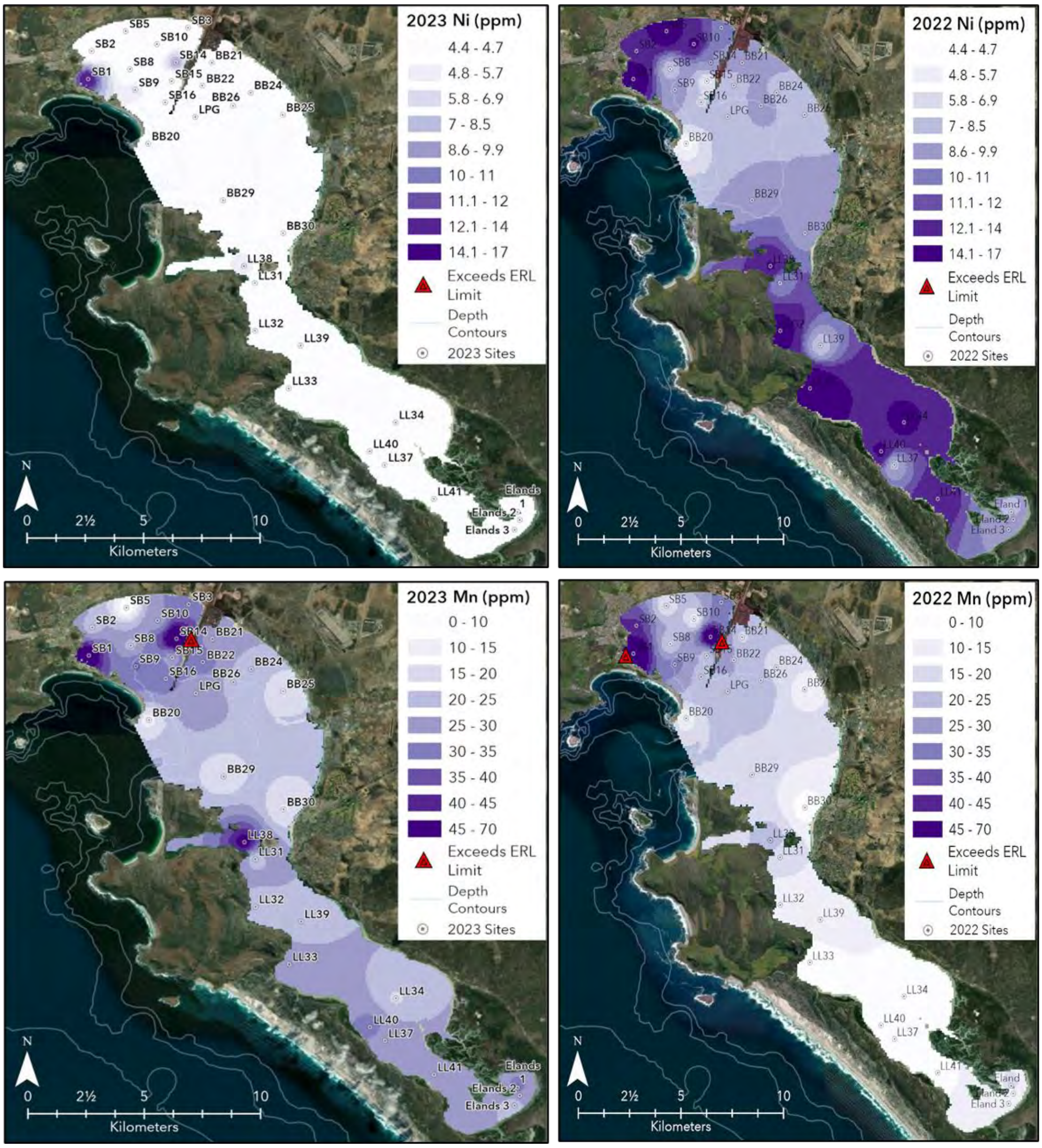


Figure 7.24. Spatial interpolation of total Ni, and Mn concentrations between 2022 and 2023. Red triangles indicate sites that exceed the ERL limit

7.5.3 Heavy metal normalisation and enrichment factor

The concentrations of metals in sediments are affected by grain size, total organic content and mineralogy. Since these factors vary in the environment, one cannot simply use high absolute concentrations of metals as an indicator for anthropogenic metal contamination. Metal concentrations are therefore commonly normalized to a grain-size parameter or a suitable substitute for grain size; and only then can the correct interpretation of sediment metal concentrations be made (Summers et al. 1996). A variety of sediment parameters can be used to normalize metal concentrations, and these include aluminium (Al), iron (Fe) and TOC. Aluminium or iron are commonly used as normalisers for trace metal content as they ubiquitously coat all sediments and occur in proportion to the surface area of the sediment (Gibbs 1994); they are abundant in the earth's crust and are not likely to have a significant anthropogenic source (Gibbs 1994, Summers et al. 1996); and ratios of metal concentrations to Al or Fe concentrations are relatively constant in the earth's crust (Summers et al. 1996).

Normalized metal/aluminium ratios can be used to estimate the extent of metal contamination within the marine environment and to infer whether there has been enrichment of metals from anthropogenic activities. Due to the known continuous anthropogenic input of iron from the iron ore quay and industrial activity in Saldanha Bay; Al represents a more appropriate normaliser than iron, and therefore, metal concentrations were normalized against (divided by) aluminium and not iron. Importantly, prior trace metal studies in South Africa have indicated that the relationship between Al and Cd is very poor, and therefore normalising Cd concentrations with Al is not appropriate (Newman and Watling 2007). This, coupled with the fact that all but three Cd samples fell below the detection limits of the ICP-OES machine, Cd has been excluded from this analysis.

Table 7.6. Metal concentrations normalised with aluminium. Results captured as BDL, indicates that the concentrations falls Below Detection Limits (< 1 mg/kg)

	Sample	Cu:Al	Mn:Al	Ni:Al	Pb:Al
Small Bay	SB1	38.97	44.04	11.33	18.73
	SB2	6.61	96.92	8.72	17.81
	SB3	9.44	129.22	7.90	56.39
	SB5	567.76	64.16	39.24	47.02
	SB8	5.05	88.43	11.47	20.04
	SB9	6.35	76.90	10.84	13.30
	SB10	BDL	151.22	10.53	23.39
	SB14	21.59	101.03	11.87	54.78
	SB15	6.44	84.20	9.88	19.53
	SB16	9.26	90.53	12.42	14.77
Big Bay	BB20	31.30	160.17	BDL	17.48
	BB21	9.71	70.47	8.93	11.80
	BB22	6.78	89.75	10.44	10.29
	LPG	7.75	77.68	12.08	12.25
	BB24	BDL	73.72	10.02	8.43
	BB25	BDL	100.07	9.66	BDL
	BB26	2.99	65.68	11.48	8.58
	BB29	BDL	75.99	8.28	BDL
	BB30	BDL	150.97	11.33	BDL
Langebaan Lagoon	LL31	BDL	89.30	8.37	5.28
	LL32	BDL	123.56	8.57	13.74
	LL33	BDL	213.36	10.66	BDL
	LL34	BDL	86.87	8.64	BDL
	LL37	BDL	216.00	BDL	BDL
	LL38	BDL	100.53	11.92	4.94
	LL39	BDL	124.26	BDL	BDL
	LL40	BDL	335.73	BDL	BDL
	LL41	BDL	124.69	8.71	BDL
Elandsfontein	Elands 1	BDL	94.19	9.29	BDL
	Elands 2	BDL	133.57	9.29	BDL
	Elands 3	7.08	85.52	9.02	BDL

Al normalised concentrations indicate that the most Cu contaminated site is SB5 (Northern Small Bay), which has a normalised concentration more ten times that at than any other site. Normalised manganese (Mn) values indicate a high degree of variation in Mn concentrations throughout the system, which is not concentrated in Small Bay, as is the case with Cu and Pb. In fact, the highest normalised Mn concentrations were recorded in Langebaan Lagoon, which is strange since once would expect anthropogenic Mn inputs to be concentrated in Small Bay. The highest normalised concentration of nickel (Ni) was found in Small Bay, at SB5, which is consistent with the Cu results. Besides SB5, there does not appear to be a large degree of variation in normalised Ni concentrations, however, concentrations in Langebaan and Elandsfontein appear lower than Small Bay and Big Bay. Normalised Pb concentrations show a much clearer spatial variation, with substantially higher concentrations evident in Small Bay relative to all other domains. On a positive note, Langebaan Lagoon and Elandsfontein have Pb concentrations which are all below detection limits.

Another means of evaluating the extent of contamination of sediments by metals, which builds upon the same principle of the normalisation mentioned above, is to calculate the extent to which the sediments have been enriched by such metals since development started (Barbieri 2016). This is calculated by comparing the concentrations of a given metal of concern (for instance Pb) with the concentrations of Al in a modern sample, with the concentrations of Pb with Al in a historical sample, according to the simple formula: $[(Pb_{current}/Al_{current)}/(Pb_{historical}/Al_{historical})]$. This provide a value (a ratio) which can be used to determine the extent of contamination in the sample (Table 7.7).

Table 7.7. Enrichment Factor Categories (Barbieri 2016).

Value	Soil dust quality
EF<2	Deficiency to minimal enrichment
2< EF <5	Moderate enrichment
5< EF <20	Significant enrichment
20< EF <40	Very high enrichment
EF > 40	Extremely high enrichment

Since the natural dynamics governing sediment and trace metal accumulation can vary based on regional/ site specific conditions, the best data to normalise against are concentrations recorded pre-development at a specific site. This is seldom available, however, as the onset of recording typically occurs in tandem with concerns around pollution associated with development. Saldanha is a fringe case in that there is some metal data available prior to most of the industrial development in the bay (1980–1985) for Cd, Pb, Cu, and Ni, and Fe, however, these results do not include readings Al and, as previously asserted, Fe is not suitable given the local Fe contamination. Thus, it is not possible to calculate EF based on background readings for Saldanha specifically, and instead it is necessary to calculate these ratios based off another set of known geochemical background ratios, with the background ratios in the Earth's crust being selected as per CSIR (1999). Despite not capturing the site-specific conditions in Saldanha and Langebaan, this ratio does allow for site-specific conditions from other systems to be ruled out. Furthermore, since these are not site-specific values, the caveat must be made that they may not be indicative of the exact degree of enrichment.

Unfortunately, enrichment factors were not calculated for manganese as reference concentrations were not available in the prior CSIR report (CSIR 1999). Furthermore, prior trace metal studies in South Africa have indicated that the relationship between Al and Cd is very poor, and therefore normalising Cd concentrations with Al is not appropriate (Newman and Watling 2007). The Benguela upwelling system is also known for having localised natural Cd enrichment, so the application of global crustal ratios is not appropriate. Therefore, it is more appropriate to assess the degree of Cd contamination by its absolute concentration.

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 (Table 7.7). The extent of contamination for cadmium, copper, nickel and lead is discussed below using both metal concentrations and the metal enrichment factors. Metal enrichment factors are highlighted in Table 7.8 for Cu, Ni, and Pb.

Table 7.8. Enrichment factors for the 2023 sediment sampling. BDL indicates samples found to be below detection limits for their respective metal. Green highlighting indicates "Deficiency to minimal enrichment", yellow indicates "Moderate enrichment", orange Indicates "Significant enrichment", light red indicates "Very high enrichment", and dark red indicates "Extremely high enrichment" (Barbieri 2016).

Sample	Al %	Cu	Ni	Pb
Average Crustal Ratios		4.6	7.1	2.3
SB1	1.22	8.47	1.60	8.14
SB2	0.23	1.44	1.23	7.75
SB3	0.25	2.05	1.11	24.52
SB5	0.08	123.43	5.53	20.44
SB8	0.27	1.10	1.62	8.71
SB9	0.46	1.38	1.53	5.78
SB10	0.17	BDL	1.48	10.17
SB14	0.68	4.69	1.67	23.82
SB15	0.31	1.40	1.39	8.49
SB16	0.36	2.01	1.75	6.42
BB20	0.08	6.80	BDL	7.60
BB21	0.36	2.11	1.26	5.13
BB22	0.36	1.47	1.47	4.48
LPG	0.32	1.69	1.70	5.33
BB24	0.28	BDL	1.41	3.67
BB25	0.15	BDL	1.36	BDL
BB26	0.35	0.65	1.62	3.73
BB29	0.22	BDL	1.17	BDL
BB30	0.10	BDL	1.60	BDL
LL31	0.25	BDL	1.18	2.30
LL32	0.19	BDL	1.21	5.97
LL33	0.14	BDL	1.50	BDL
LL34	0.22	BDL	1.22	BDL
LL37	0.12	BDL	BDL	BDL
LL38	0.48	BDL	1.68	2.15
LL39	0.18	BDL	BDL	BDL
LL40	0.10	BDL	BDL	BDL
LL41	0.21	BDL	1.23	BDL
Elands 1	0.34	BDL	1.31	BDL
Elands 2	0.21	BDL	1.31	BDL
Elands 3	0.24	1.54	1.27	BDL

EF results indicate that the contaminants of greatest concern in Saldanha are Pb and Cu. In particular, Cu concentrations at SB5 are considered extremely enriched, with an EF value of 123.43, indicating a significant degree of localised contamination. However, besides SB5, the next most enriched site is SB1 located at the Yacht club basin. This site has an EF of 8.47, indicating a significant degree of enrichment. Of note here is that SB1 and SB5 have almost identical total Cu concentrations, yet vastly different degrees of enrichment, which underscores the importance of normalisation (Table 7.5; Table 7.7). Besides these two sites, only one other site is considered to have significant enrichment, and another 5 sites have a moderate degree of enrichment. Seven sites have concentrations considered to represent background levels. The remaining sites all had Cu concentrations less than the analytical detection limits, which is a positive result. Pb concentrations appear to vary less than Cu, with three sites having EF ratios exceeding 20, and falling within the category of very high enrichment. These sites include SB3, SB5, and SB14, and are all found within the north-eastern portion of Big Bay. A further 11 sites fall within the category of significant enrichment, with all but four of these falling within Small Bay, with three of the remaining sites being located in Big Bay and one in Langebaan (LL32). A point of concern is that all the Small Bay sites have, at minimum, significant Pb enrichment. A further four sites are found to have a moderate degree of enrichment, with three of these being located in Big Bay, and two in Langebaan Lagoon. On a positive note, most of the sites from Langebaan Lagoon and all the sites from Elandsfontein had concentrations falling below detection limits, and therefore it was not possible to conduct EF analysis. Nickel concentrations appear to fall within baseline concentrations in the entire system aside from SB5, which has a significant degree of Ni enrichment.

7.5.4 SPATIAL VARIATION IN TRACE METALS LEVELS IN SALDANHA BAY

The following section describes the spatial variations in trace metal concentrations throughout the Saldanha system, with reference to the spatial interpolation maps (Figure 7.23 and Figure 7.24) which indicate the variation in total metal concentrations throughout the bay. Additionally, Metal concentrations in Key site sites around small bay have also been mapped in (Figure 7.25 to Figure 7.30).

CADMIUM

In the current survey, only two sites were found to exceed the detection limits of the ICE-OES machine (1 mg/kg) for Cd, with only SB1, the Yacht Club Basin site, having Cd concentrations that exceed ERL limits (3.13 mg/kg). Site SB14, adjacent to the Multi-Purpose Quay had a detectible concentration for Cd. However, since Cd concentrations can be concerning at concentrations below 1 mg/kg, and since the ERL concentration for Cd is 1.2 mg/kg, the bulk of the samples falling below this detection threshold gives only limited insights into Cd contamination in the Bay (Newman and Watling 2007). Of note is the fact that the Cd distribution in Figure 7.23 appears to indicate higher Cd concentrations throughout the bay when compared to 2022, however, this is simply a visual representation issue, and concentrations in 2023 are very similar to those seen in 2022. Cadmium is a trace metal used in electroplating, in pigment for paints, in dyes and in photographical process. The likely sources of cadmium to the marine environment are in emissions from industrial combustion processes, from metallurgical industries, from road transport and waste streams (OSPAR 2010). A common source for cadmium contamination in the marine environment is storm water runoff. 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 observed, it is unlikely that the contamination of Cd in the Bay is a result of storm water drainage, but rather linked to shipping and boat repair operations. 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.

COPPER

Copper concentrations were highest near the Yacht club and near the Saldanha Bay Multi-Purpose Quay within Small Bay (Table 7.5; Figure 7.23). 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 there are no sampling sites 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 both the Yacht Club Basin (SB1) and Northern Small Bay (SB5) exceeded the ERL guideline. In fact, the normalized values indicate that SB5 is in excess of an order of magnitude higher than SB1, indicating substantial enrichment. (Table 7.6). Furthermore, enrichment factor results indicate that SB5 has "Extremely High Enrichment", with SB1 only having enrichment categorized as "Significant", despite having near identical absolute concentrations. These results together suggest that Cu contamination is anthropogenically-derived, with activities near the MPT likely representing a key source. Finally, BB20, located to the west of Marcus Island, also had a "Significant" degree of Cu enrichment. On a positive note, the degree of Cu enrichment is much lower in other parts of Small and Big Bay, with the entirety of Langebaan Lagoon and Elandsfontein having concentrations falling within baseline concentrations or below detection limits (Table 7.8).

NICKEL

Nickel values measured in 2023 were elevated at the yacht club and Multi-Purpose Quay within Small Bay, however, all sites fell below the ERL guideline levels. 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 and Nikel 2006). Common anthropogenic sources include the combustion of fossil fuels and the incineration of waste and sewerage (Cempel and Nikel 2006). The nickel concentrations in the 2023 appear to decline across the majority of sites when compared to 2022 data (Figure 7.24). The enrichment factor results indicate that only one site, SB5 in the northern part of Small Bay, had an EF value in excess of what can be considered background levels. The EF value of SB5 is indicative of significant Ni enrichment. This apparent decline in Ni concentrations is a positive sign, as the 2022 State of the Bay report indicated concern based on the increasing Ni concentrations since 2021.

LEAD

Lead is a persistently problematic metal in Saldanha Bay. The 2023 survey found elevated Pb concentrations predominantly at the Yacht club basin (SB1), MPT (SB14), and SB3 in the north-eastern sector of Small Bay (Table 7.5; Figure 7.23). On a positive note, all sites fell below the ERL limits, which represents an improvement over 2022, where SB14 exceeded ERL concentrations for Pb with a concentration of 49.39 mg/kg. 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 MPT had the highest lead values indicating that this area is subject to high levels of lead pollution, which is reflected in the normalized results. Finally, Pb enrichment factor results for Small Bay were concerning, with all Small Bay sites falling within at least the category of significant enrichment (Table 7.8). Furthermore, three sites, SB3, SB5, and SB14 all had EF values indicative of very high enrichment. Given that all these sites are located in northern and eastern Small Bay, this likely indicates that activities around the MPT are a source of Pb contamination. On a positive note, as mentioned previously, much of Saldanha Bay has seen a decrease in total Pb concentrations since 2022.

MANGANESE

Manganese concentrations were highest in Small Bay, with SB14, adjacent to the Multi-Purpose Quay, exhibiting Mn concentrations exceeding ERL guidelines. The Yacht club basin (SB1) also had a Mn concentration just below the ERL guideline of 56.5 mg/kg. 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. Positively, the Mn concentration at SB1 fell from 2022. It can be postulated that the recently elevated concentrations of manganese may be associated with the recent start of manganese exports (Section 3.3). This may be further reinforced by the increase in average Mn concentrations for all areas in Saldanha, except for Small Bay.

7.5.5 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 IOT in Big Bay) relative to the ERL guidelines is discussed below.

CADMIUM

There was a considerable increase in the concentration of cadmium detected in the sediments of Saldana Bay between 1980 and 1999. In 1999, the levels of cadmium recorded at the Mussel Farm, the Yacht Club Basin and the Channel End of the IOT exceeded the ERL toxicity threshold of 1.2 mg/kg established by NOAA (Figure 7.25). After this peak in 1999, Cd concentrations decline dramatically at the Yacht Club Basin and Mussel Farm by the time of the 2000 survey, likely indicating a localized Cd pollution event prior to the 1999 survey. Cd concentrations around Small Bay thereafter appear to have remained relatively low till approximately 2010 (although the Yacht Club Basin largely remained above ERL limits during this period. Between 2010 and 2013 the Cd concentrations at SB1 increased and have thereafter fluctuated without significant changes until present, with the exception being a low reading in 2014 which is likely indicative of sample variability and not an actual change in condition. Concentrations at the Multi-Purpose Quay also appear to have increased over this such that they exceeded ERL guidelines between 2013 and 2015, and thereafter fell below guidelines till 2018. A problem representing the interpretation of Cd concentrations is the change in laboratory method which occurred in 2019, which altered the minimum detectable concentrations of Cd from 0.1 mg/kg to 1 mg/kg. This therefore means that it is not possible to infer recent trends in Cd concentrations for site with typically lower concentrations (namely North Channel Small Bay, Big Bay, the Channel end of ore jetty, the Mussel Farm, and to some degree the Multi-Purpose Quay. However, the only site which consistently exceeds the analytical detection limit, the Yacht Club Basin, has had Cd concentrations which have fluctuated in the past 10 year without significant changes. This means that it's reasonable to assume that Cd concentrations in Small Bay have remained fairly constant.

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 7.26). Apart from the (potentially anomalous) low levels recorded in 2014, copper concentrations at the Yacht Club Basin have remained high (above the ERL guideline) since 2011. The 2023 results indicate that Cu concentrations have remained very similar to 2022 and the years prior. Average concentrations have increased in Small Bay and Big Bay since 2022, ret remain relatively similar in Langebaan Lagoon and Elandsfontein.

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 7.27). Since 1999, nickel concentrations have declined markedly at both sites, never again exceeding the ERL threshold. Peak nickel concentration at the remaining four sites were 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 up to the 2018 survey. From 2019 onwards, nickel concentrations have been fluctuating at all six localities, with all key sites having an increase in Ni concentrations in 2022. However, this has returned to prior conditions in 2023, indicating that there may have been a localized Ni contamination event leading up to the 2022 survey. This is further evidenced by the average Ni results in the system, which indicate a substantial decline in Ni concentrations in all regions in the 2023 survey.

LEAD

The concentration of lead peaked and exceeded the ERL threshold at the Yacht Club Basin and Mussel farm site in 1999 (Figure 7.28). The concentration of lead at these sites has not exceeded the ERL level since this time. Lead concentrations in sediments adjacent to the MPT have frequently exceeded the ERL threshold over the last 18 years. This result suggests that industrial and shipping activities taking place at the MPT continue to contaminate the adjacent marine environment with lead. However, concentrations at the terminal have only exceeded ERL the ERL threshold once since 2011 (in 2022), which has subsequently returned to concentrations below the ERL threshold again in 2023. Despite remaining enriched, Pb concentrations appear to have remained fairly consistent around small Bay with only minor fluctuations since approximately 2010. This indicates that the situation has not worsened. In fact, average Pb concentrations have decreased in all domains since 2022, with the largest decreases occurring in Big Bay and Elandsfontein, with the smallest decrease occurring in Small Bay.

MANGANESE

The temporal variation in manganese concentrations in sediments around the ore terminal in Saldanha Bay is shown in Figure 7.29. Manganese concentrations at sites located along the ore terminal within Small Bay have fluctuated over recent years. Relatively high Mn concentrations were seen at most sites around the IOT in 2014 and 2015. These concentrations then appear to have decreased in 2017 and 2018 before increasing to relatively high levels in 2019 and 2020. Thereafter the concentrations decreased again for all sites except the MPT, till 2022. All sites have thereafter seen a small increase in Mn concentrations from 2022 till the present study, with concentrations at the MPT remaining the highest and exceeding ERL thresholds in 2023. This increase in Mn concentrations is likely reflective of the increase in Mn exports from the port. The average Mn concentrations in the Bay reflect this change, with average concentrations in Small Bay remaining consistent, and concentrations in Big Bay increasing by a relatively small amount. The greatest increases in Mn were seen in Langebaan and Elandsfontein, which saw more than a doubling of concentrations in Langebaan and close to a doubling at Elandsfontein.

IRON

The temporal variation in the concentration of iron in sediments around the ore terminal in Saldanha Bay is shown in Figure 7.30. 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 MPT. 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 MPT in 2007 and the removal of iron rich sediment at SB15 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 Consulting 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 2022 (Figure 7.30). However, the concentration of iron at SB15 has fluctuated dramatically since 2012; but has shown an overall decrease in the last ten years. This does suggest that the improved dust control methods implemented since 2007 have been successful in reducing the input to the marine environment. The present survey has indicated increase in iron concentrations for all sites around the Terminal. Importantly, when one looks at Iron concentrations for the entire study area, iron concentrations have increased at all sites besides SB5 since 2022. The fact that this shift has persisted across all domains (including Langebaan Lagoon and Elandsfontein) indicates that the increased Fe concentrations seen around the terminal is not restricted to this locality. aluminium concentrations have also increased within the system, however, the average percentage increase in Al concentrations is consistently lower than that of Fe, particularly in Langebaan and Elandsfontein, indicating that this is unlikely to be exclusively due to natural factors. On-going monitoring of sediment iron concentration will reveal whether the increase recorded across these sites will continue or if it simply reflects the conditions seen at the time of sampling.

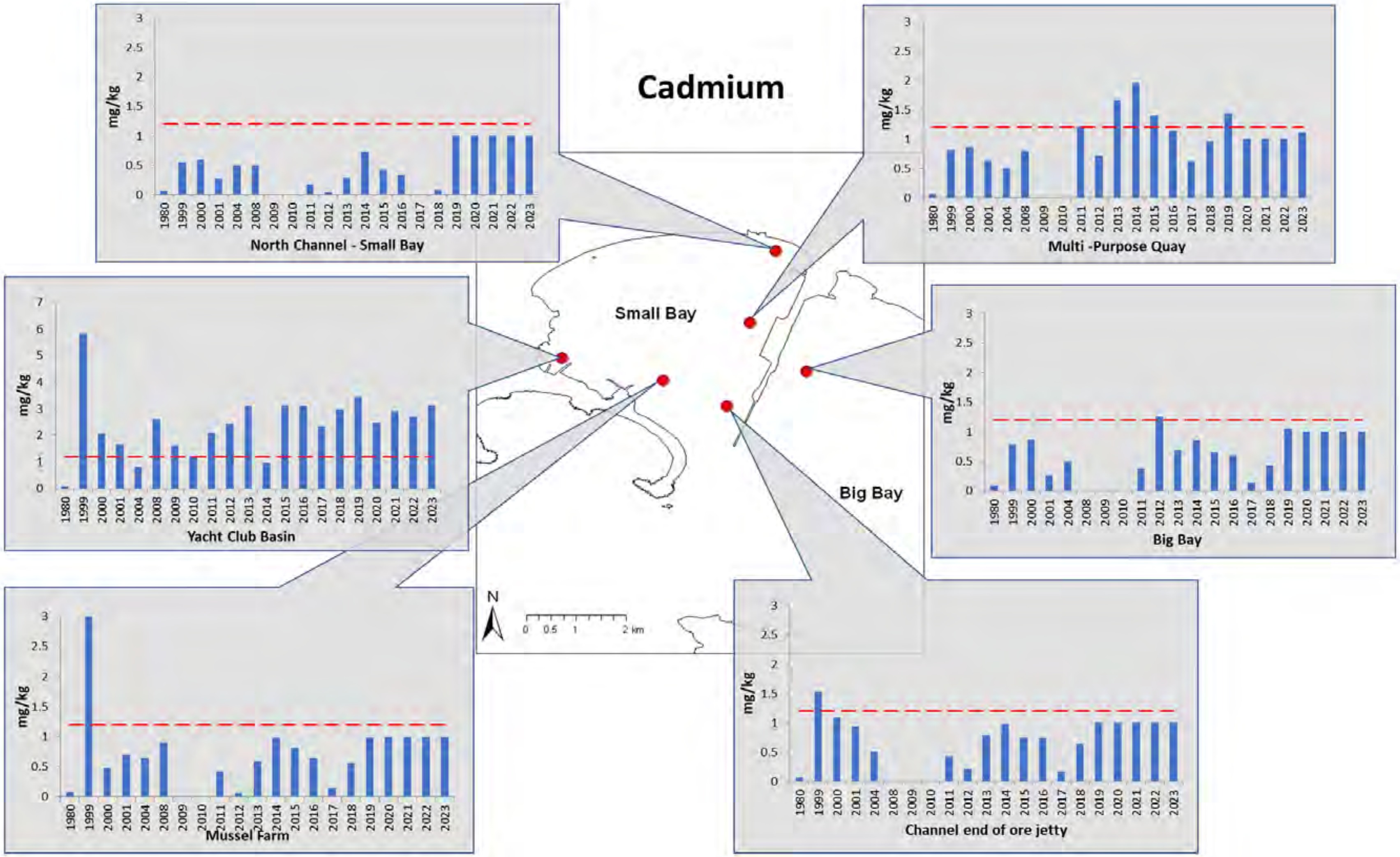


Figure 7.25. Concentrations of cadmium (Cd) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2023. Dotted lines indicate Effects Range Low values for sediments.

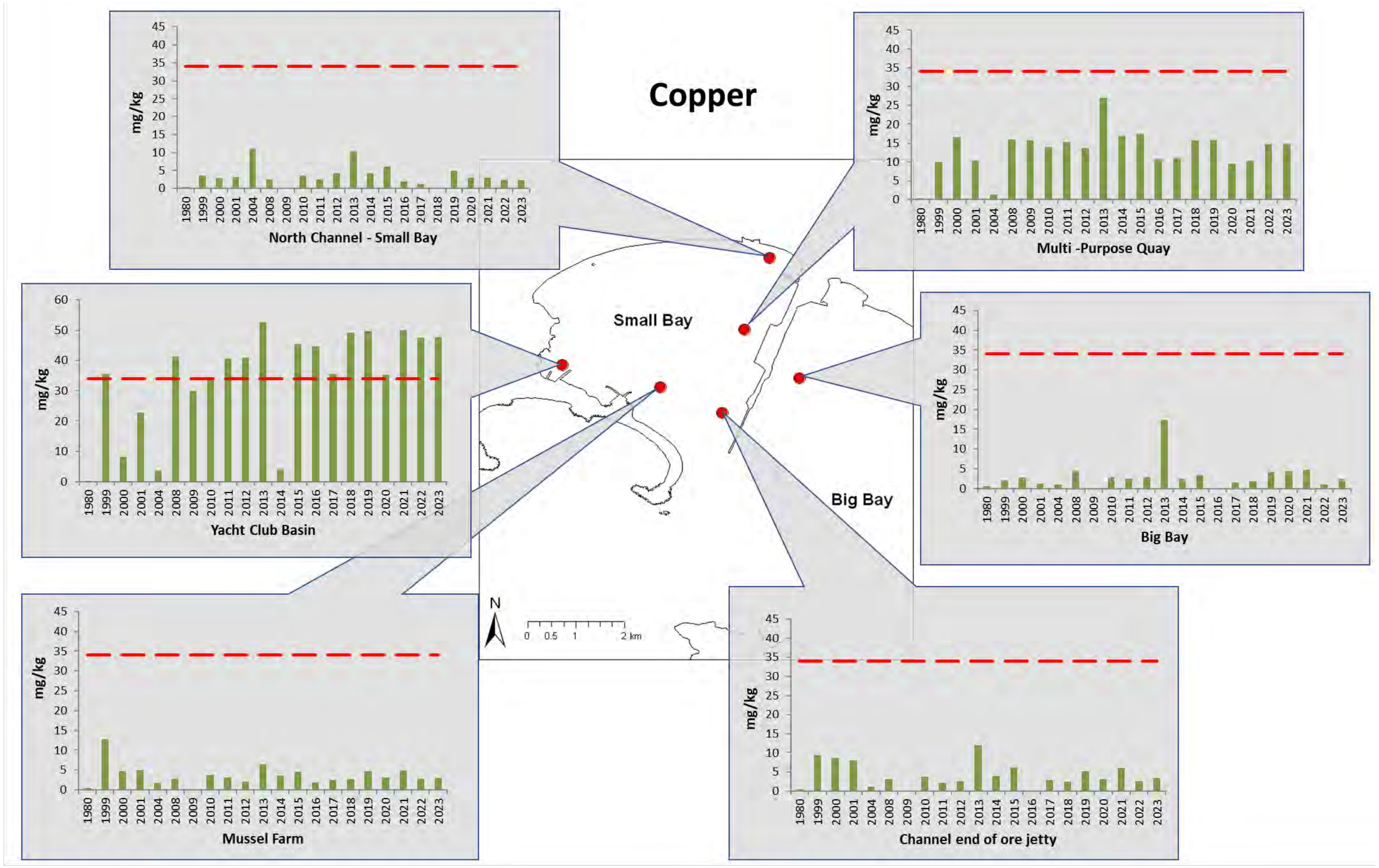


Figure 7.26. Concentrations of Copper (Cu) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2022. Dotted lines indicate Effects Range Low values for sediments.

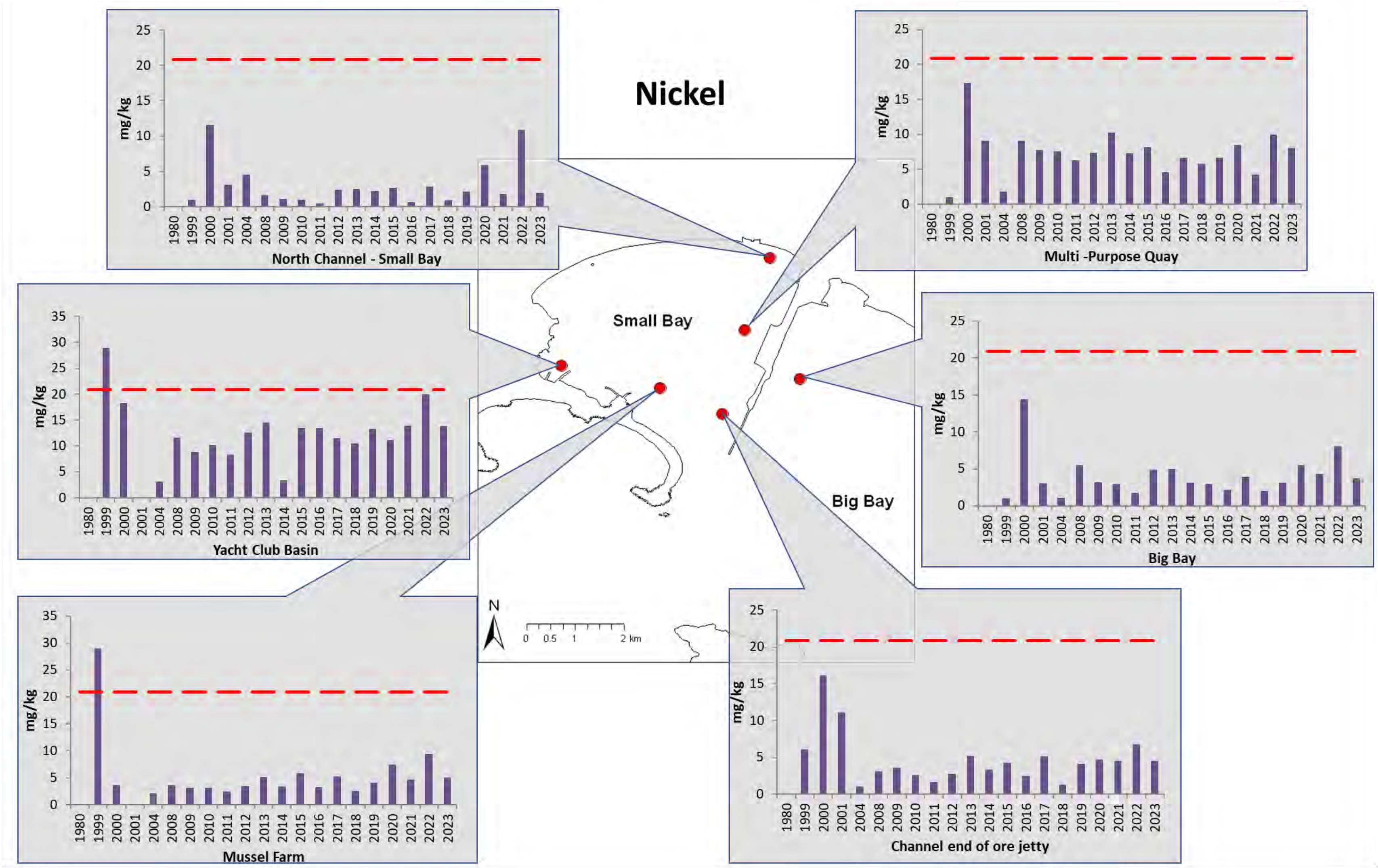


Figure 7.27. Concentrations of nickel (Ni) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2023. Dotted lines indicate Effects Range Low values for sediments.

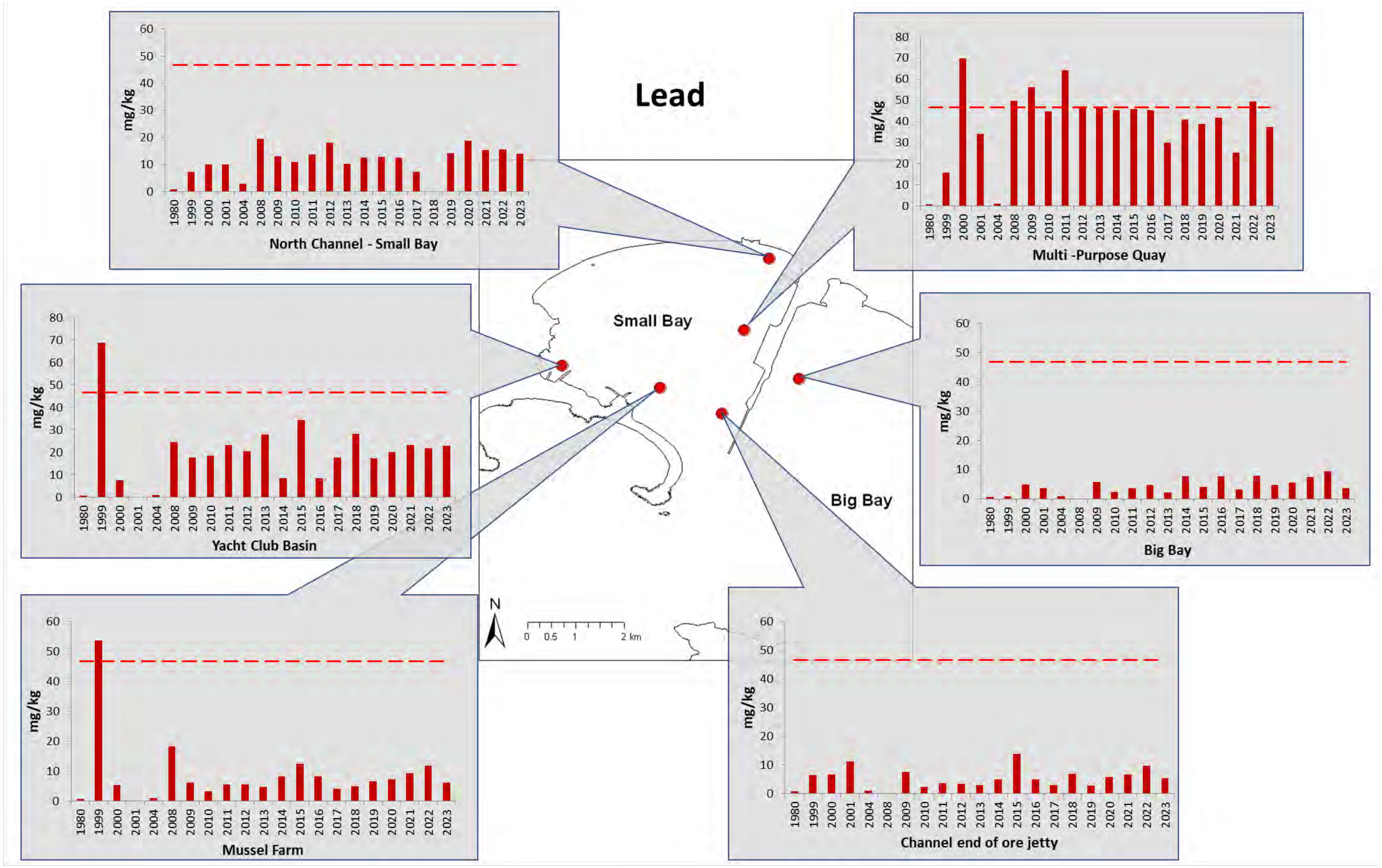


Figure 7.28. Concentrations of lead (Pb) in mg/kg recorded at six sites in Saldanha Bay between 1980 and 2023. Dotted lines indicate Effects Range Low values for sediments.

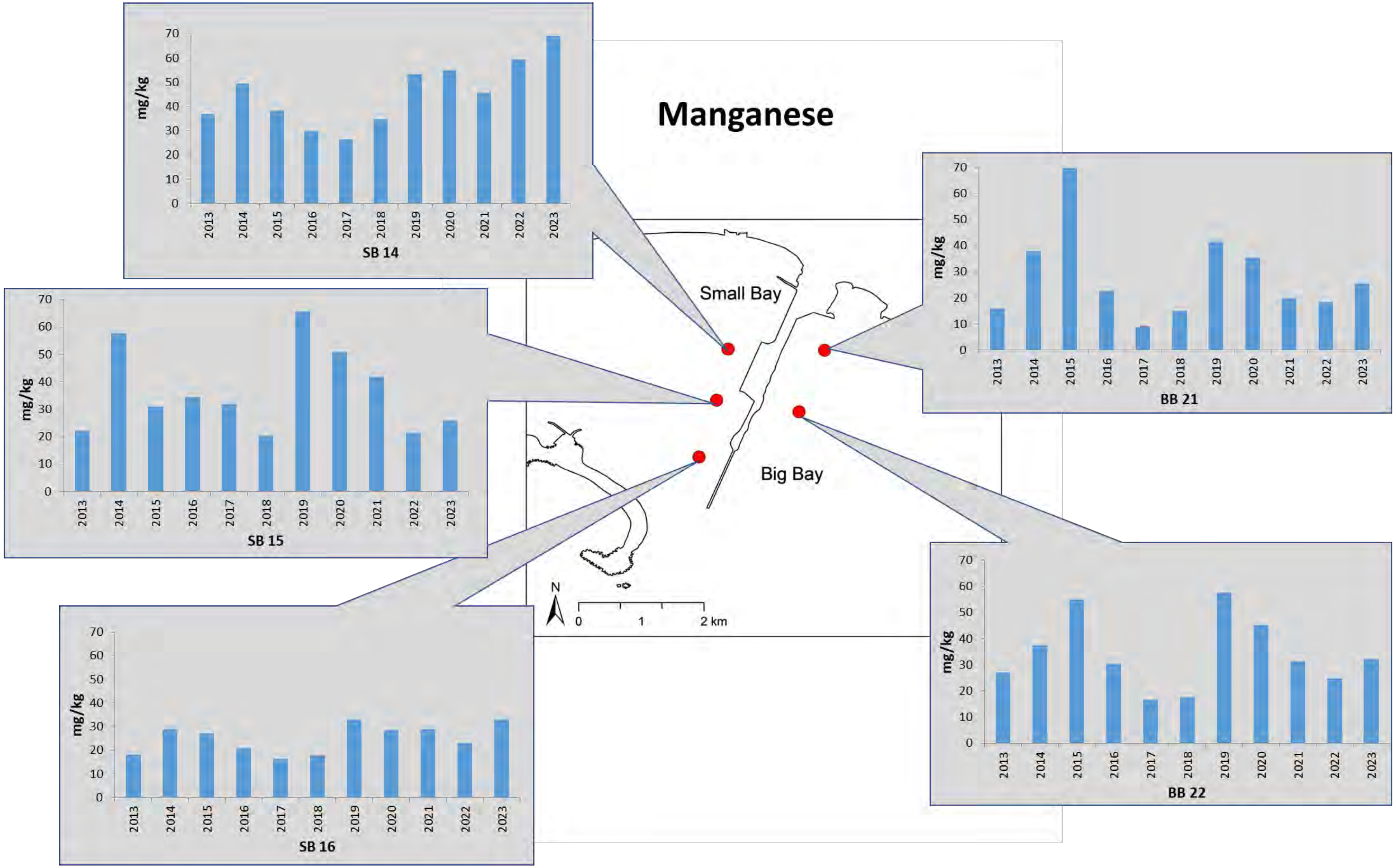


Figure 7.29. Concentration of manganese (Mn) in mg/kg recorded at five sites in Saldanha Bay between 2013 and 2023.

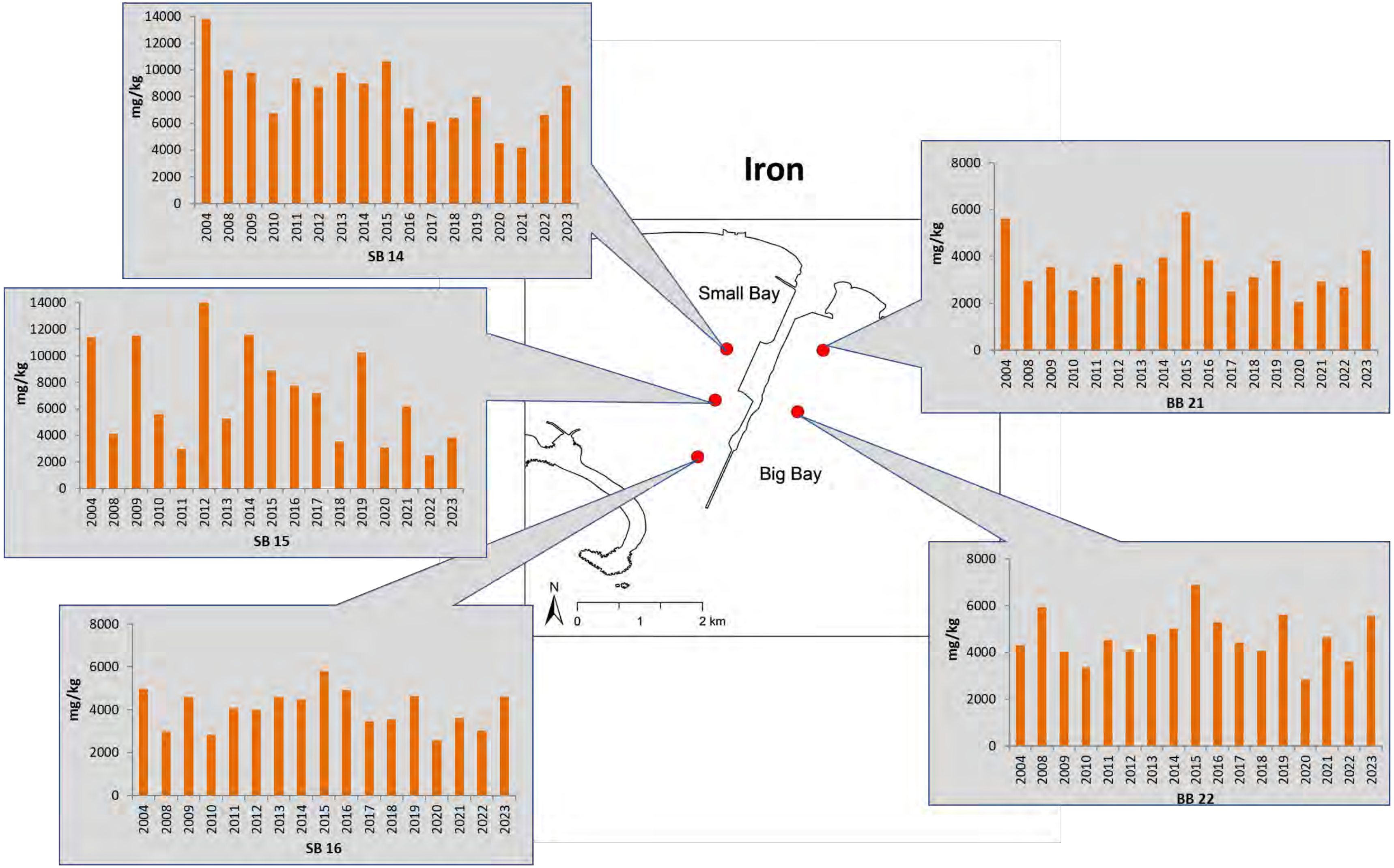


Figure 7.30. Concentrations of iron (Fe) in mg/kg recorded at five sites in Saldanha Bay between 2004 and 2022.

7.6 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 as well as 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 7.9. Total petroleum hydrocarbons (mg/kg) in sediment samples collected over the period 2011–2023 from five stations in Saldanha Bay. Values in red indicate exceptionally high total petroleum hydrocarbon levels. ND indicates no data available.

Sample #	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
SB14	<20	34	130	19	<38	<38	<38	<38	<38	<38	<22	<22	<22
SB15	<20	35	ND	53	<38	<38	<38	<38	<38	<38	<22	<22	<22
SB16	<20	24	28	14649	<38	<38	<38	<38	<38	<38	<22	<22	<22
BB21	<20	20	32	20	<38	<38	<38	<38	<38	<38	<22	<22	<22
BB22	<20	17	27	<0.2	<38	<38	<38	<38	<38	<38	<22	<22	<22

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 and have remained at this level at all five sites to present.

Sediment samples collected in 2023 had low PAH levels across all sites (Table 7.10). 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 in order to identify the frequency of occurrence of pollution incidents; like that recorded in 2014 and assess the ecological implications to the Bay.

Table 7.10. Sediment Quality guidelines and Poly-aromatic hydrocarbons concentrations measured in sediment samples collected from Saldanha Bay in April 2023.

Hydrocarbon (mg/kg)	ERL* (mg/kg)	ERM** (mg/kg)	SB14	SB15	SB16	BB21	BB22
Acenaphthene.	0.016	0.5	<0.004	<0.004	<0.004	<0.004	<0.004
Acenaphthylene.	0.044	0.64	<0.004	<0.004	<0.004	<0.004	<0.004
Anthracene.	0.0853	1.1	<0.004	<0.004	<0.004	<0.004	<0.004
Benzo(a)anthracene.	0.261	1.6	<0.004	<0.004	<0.004	<0.004	<0.004
Benzo(a)pyrene.	0.43	1.6	<0.004	<0.004	<0.004	<0.004	<0.004
Benzo(b+k)fluoranthene.	-	-	<0.008	<0.008	<0.008	<0.008	<0.008
Benzo(g,h,i)perylene.	-	-	<0.008	<0.008	<0.008	<0.008	<0.008
Chrysene.	0.384	2.8	<0.004	<0.004	<0.004	<0.004	<0.004
Dibenz(a,h)anthracene.	0.0634	0.26	<0.008	<0.008	<0.008	<0.008	<0.008
Fluoranthene.	0.6	5.1	<0.004	<0.004	<0.004	<0.004	<0.004
Fluorene.	0.019	0.54	<0.004	<0.004	<0.004	<0.004	<0.004
Indeno(123-cd)pyrene.	-	-	<0.008	<0.008	<0.008	<0.008	<0.008
Naphthalene.	0.16	2.1	<0.004	<0.004	<0.004	<0.004	<0.004
Phenanthrene.	0.24	1.5	<0.004	<0.004	<0.004	<0.004	<0.004
Pyrene.	0.665	2.6	<0.004	<0.004	<0.004	<0.004	<0.004
Total PAH	4	44.7					

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

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

8 AQUATIC MACROPHYTES

8.1 COMMUNITY COMPOSITION AND DISTRIBUTION

Four distinct intertidal habitats exist within Langebaan Lagoon: seagrass beds, such as those of the eelgrass *Zostera capensis;* salt marsh dominated by cordgrass *Spartina maritima* and *Sarcocornia perennis,* and the dune slack rush *Juncus kraussi*, and unvegetated sandflats dominated by the sand prawn, *Kraussillichirus krausii* and the mudprawn *Upogebia capensis* (Siebert and Branch 2005). The other major vegetation type present in the upper lagoon area, particularly where groundwater inflow occurs, are reed beds dominated by common reed *Phragmites australis.* The most recent, detailed vegetation map[8] of the area surrounding Langebaan Lagoon dates to 2013 (Figure 8.1) (Van Der Linden 2014).

Figure 8.1. Vegetation and habitat structure at Langebaan Lagoon. (Source: Shapefiles provided by van der Linden 2014).

8 In this map, eelgrass falls within the submerged macrophyte category.

Salt marsh communities are generally comprised of herbaceous plants, shrubs and grasses, and are located in 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 PSU) 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. 2011).

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 et al. 2002). Salt marshes are often separated into three zones, subtidal, intertidal and supratidal (Figure 8.1). Zonation is influenced by biotic interactions and by spatial and temporal gradients in physical variable such as salinity and soil moisture (Álvarez Rogel et al. 2001, Noe and Zedler 2001). Subtidal and intertidal zones are generally structured by stress tolerances, especially by high salt gradients, while the supratidal zone may be characterised by competition (Emery et al. 2001).

Sand and mud pawns are considered ecosystem engineers as their feeding and burrowing activities modify the local environmental conditions, which in turn modify the composition of the faunal communities (Siebert and 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 salt marsh plants stabilize the sediments (Siebert and Branch 2005). In addition, the three-dimensional leaf canopies of the seagrass and salt marsh plants reduce the local current velocities thereby trapping nutrients and increasing sediment accretion (Kikuchi 1977, Whitfield et al. 1989, Hemminga and Duarte 2000). The importance of seagrass and salt marsh beds as ecosystem engineers has been widely recognized. The increased food abundance, sediment stability, protection from predation and habitat complexity offered by seagrass and salt marsh 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 1977, Whitfield et al. 1989, Hemminga and Duarte 2000, Heck et al. 2003, Scheibling and Gagnon 2006, Siebert and Branch 2007). It is therefore surprising that recent research in the Langebaan Lagoon by Pillay et al. (2011) showed that the opposite was true when comparing sediment penetrability and species richness between habitats dominated by the sandprawn *K. kraussi* and cordgrass *S. maritima*. 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 salt marsh 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 and Loworn 1994, Ganter 2000, Orth et al. 2006).

8.2 Long-term changes in aquatic macrophytes in Langebaan Lagoon

8.2.1 Reed and sedge communities

Prior to 2021, no long-term assessment of changes in reeds and sedges in and around Langebaan Lagoon had been conducted. However, concern has been voiced about potential impacts that the use of groundwater from the Langebaanweg and Elandsfontein aquifers may be having on groundwater quality and flows to Langebaan Lagoon. 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 & Stickle, 2001). Diagnostic plants indicate significant contributions of groundwater (Adams and Bate 1999). For example, reeds (*P. australis* and *Typha capensis*) occur at discrete points on the shoreline surrounding Langebaan lagoon (Figure 8.1). 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 PSU (Scott et al. 1994, Nondoda 2012). The salinity of the water in the lagoon is generally the same (or occasionally higher) than that of seawater — i.e., 35 PSU, and these species are only found at sites where freshwater is seeping into the lagoon (i.e., the main groundwater input sites in the southeast 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 PSU) and normal seawater (35 PSU), most species are not tolerant of salinities in excess of 35 PSU.

Reduced freshwater inflow into Langebaan Lagoon that may result from groundwater use 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 where possible, as in the case of the phosphate mining operation conducted by Kropz at their Elandsfontein site, the extracted water must be 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 will 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 (see Chapter 5: Groundwater for more details on this), Kropz Elandsfontein 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 water level, temperature, salinity (Chapter 6: Water Quality), reeds and sedges (this chapter) and biota (Chapter 9: Benthic Macrofauna at the head of the lagoon.

Results of our 2020 analysis suggests that variation in reed cover over time is relatively modest, having remained more or less constant over the last 31 years (1989–2020, Figure 8.2). The biggest perturbations in reed cover correspond with the two largest droughts that have been experienced in the region in this period (a 1:20 year event that occurred in the period 2002–

2003) and an even more intense drought that occurred recently (a 1:100-year event in the period 2015–2017).

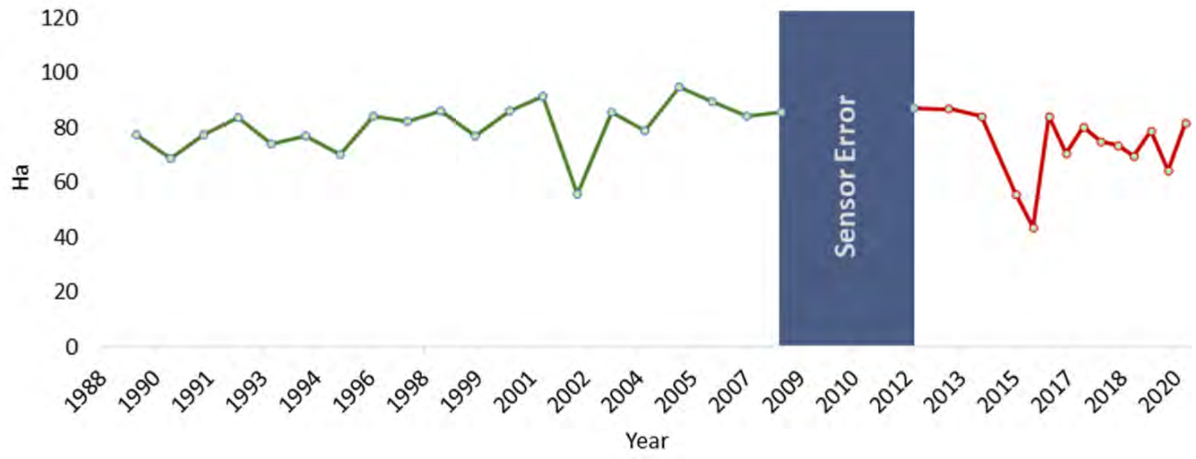


Figure 8.2. *Phragmites australis* trends between 1989 and 2020 as per the unsupervised image classification performed in 2020. Green indicates annual Landsat imagery values, red indicates biannual Sentinel-2 imagery. Note the reduction in cover during the droughts in 2002 and 2015/2016.

8.2.2 SEAGRASS

Seagrass beds are particularly sensitive to disturbance and are declining around the world at rates comparable to the loss of tropical rainforests, placing them amongst the most threatened ecosystems on the planet (Waycott et al. 2009). The loss of seagrass beds is attributed primarily to anthropogenic impacts such as deterioration in water quality through nutrient enrichment or eutrophication, alterations to food webs caused by the overexploitation of predatory fish, modified sediment dynamics associated with coastal and harbour development, and direct physical damage through bait collection (Waycott et al. 2009, Pillay et al. 2010). Most recently, research has shown that warmer temperatures and longer exposure to air resulted in significantly lower biomass of seagrass in the Langebaan Lagoon (University of Cape Town, Cloverly Lawrence, pers. comm. 2014).

The loss of seagrass meadows has been shown to have profound implications for the biodiversity associated with them, including loss of invertebrate diversity, fish populations that use the sheltered habitat as nurseries, and waterbirds that use the seagrass meadows as foraging grounds during their non-breeding period (Hughes et al. 2002). Loss of seagrass is also associated with increased fragmentation of large seagrass beds, which leads to the reduced species diversity. For example (Källén et al. 2012) demonstrated that large seagrass beds were home to significantly greater epifaunal richness and abundance of *Assiminea globules*. *A. globules* is a gastropod which favours seagrass bed edges. Species composition was found to differ between the edges and the interior of seagrass beds and interestingly, it was shown that species composition was more homogenous in more fragmented seagrass beds (Källén et al. 2012).

Long-term changes in seagrass beds in Langebaan Lagoon have been investigated by (Angel et al. 2006) and (Pillay et al. 2010). Angel et al. (2006) focused on long-term trends at Klein Oesterwal and Bottelary, and was able to show that the width of the *Z. capensis* beds 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 1980s, 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 exclusively 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).

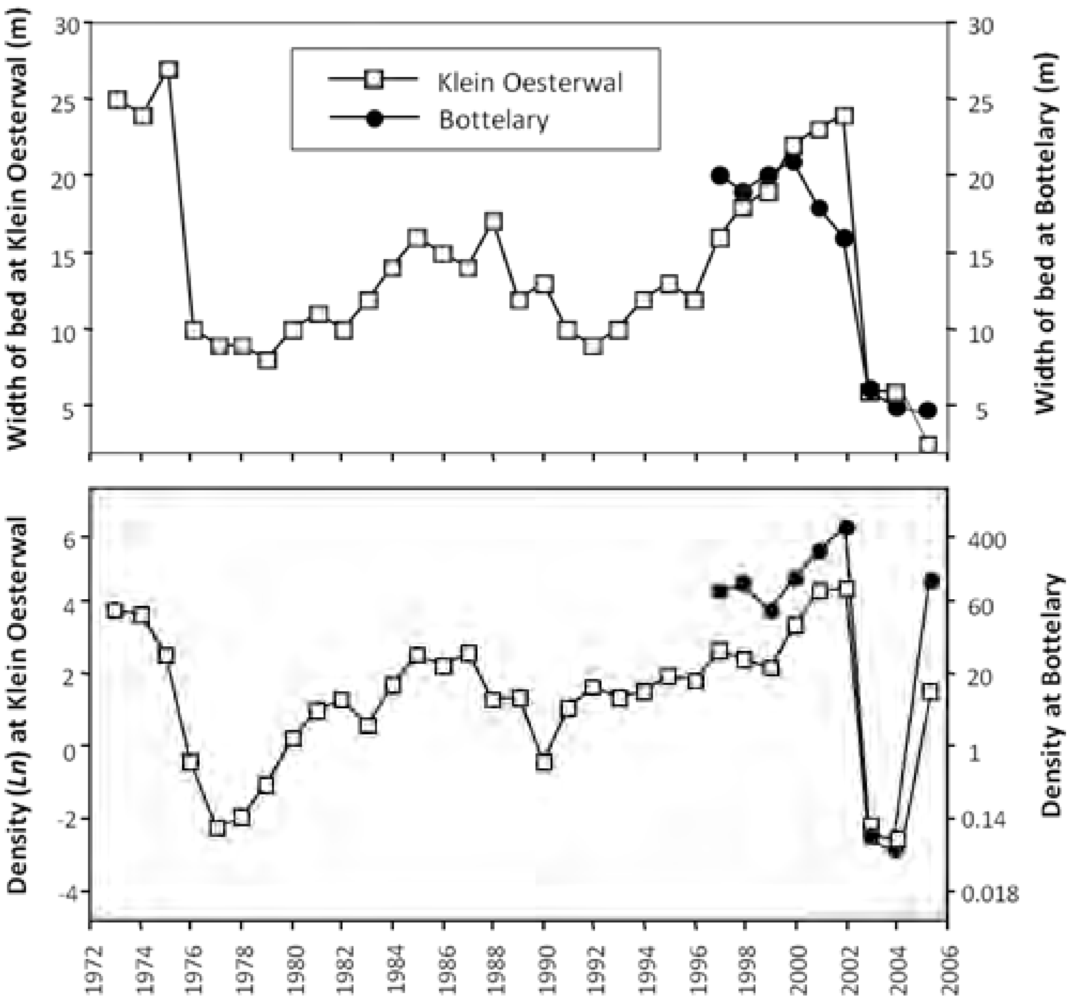


Figure 8.3. Width of the *Zostera capensis* beds and density of *Siphonia* sp. at Klein Oesterwal and Bottelary in Langebaan Lagoon, 1972–2006. Source: (Angel et al. 2006).

Pillay et al. (2010) documented changes in seagrass *Z. capensis* abundance at four sites in the Lagoon — Klein Oesterwal, Oesterwal, Bottelary and the Centre banks using a series of aerial photographs covering the period 1960 to 2007. During this time, the total loss of *Z. capensis* amounted to 38% or a total of 0.22 km^2 across these sites. The declines were most dramatic at Klein Oesterwal where close to 99% of the seagrass beds were lost during this period, but were equally concerning at Oesterwal (82% loss), Bottelary (45% loss) and Centre Bank (18% loss) (Pillay et al. 2010). Corresponding changes were also observed in densities of benthic macrofauna at these sites, with species that were commonly associated with Zostera beds such as the starfish *Parvulastra exigua*, the limpets *S. compressa* and Fisurella mutabilis and general surface dwellers such as the gastropods *Assiminea globules, Littorina saxatilis*, and *Hydrobia* sp. declining in abundance. Species that burrowed predominantly in unvegetated sand, such as amphipods *Urothoe grimaldi* and the polychaetes *Scoloplos johnstonei* and *Orbinia angrapequensis* increased in density over that same period. Pillay et al. (2010) were also able to show that the abundance of at least one species of wading bird, the Terek Sandpiper *Xenus cinereus* (which feeds exclusively in *Z. capensis* 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 *K. 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 re-colonization by seagrass and the species associated with it (Siebert and Branch 2005, Angel et al. 2006). The long-term effects of the loss of seagrass at Klein Oesterwal, and to 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 (Pillay et al. 2010). 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 seagrass loss have not been detected. This may be due to several reasons; certainly, the timing of seagrass 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 (*Z. capensis*) at 85.8 ha indicating that substantial *Z. capensis* 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 seagrass loss on higher trophic level species. This does not imply that the loss of seagrass 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: Birds and Seals). However, continued loss of seagrasses could cause a "tipping point" beyond which major ecosystem changes would occur throughout the lagoon.

8.2.3 SALT MARSHES

Salt marshes 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 J(2008) using aerial photographs taken in 1960, 1968, 1977, 1988 and 2000. He found that overall salt marsh area had shrunk by only a small amount between 1960 and 2000, losing on average 8 000 m^2 per annum. Total loss during this period was estimated at 325 000 m^2, or 8% of the total (Figure 8.4). Most of this loss has been from the smaller patches of salt marsh that existed on the seaward edge of the main marsh. This is clearly evident from the change in the number of salt marsh 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 (Figure 8.5). Gericke J(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 aeolian sand due to stabilization by alien vegetation and development).

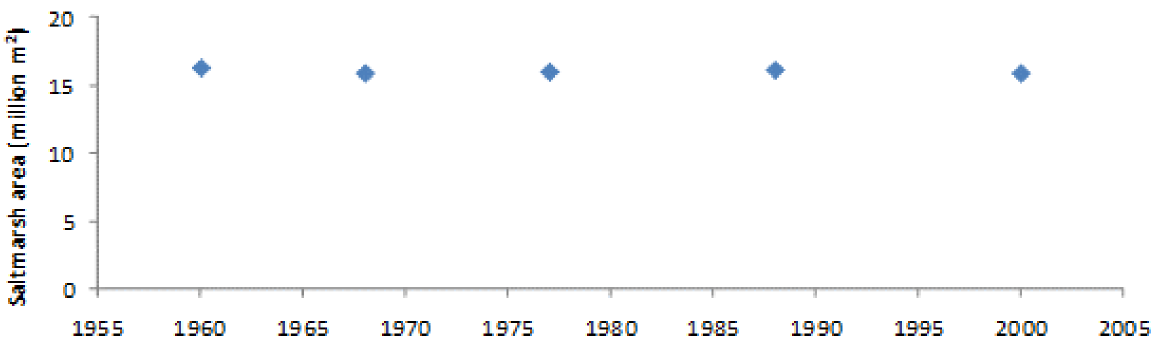


Figure 8.4. Change in salt marsh area over time in Langebaan Lagoon (Data from Gericke 2008).

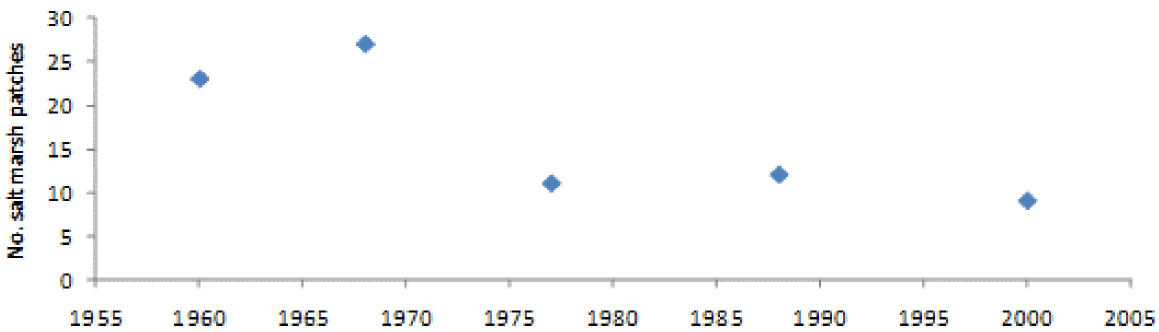


Figure 8.5. Change in the number of discrete salt marsh patches over time in Langebaan Lagoon (Data from Gericke 2008).

8.3 MAPPING RECENT CHANGES IN AQUATIC MACROPHYTE DISTRIBUTION USING REMOTELY SENSED DATA AND SATELLITE IMAGERY: 2016–2023

Satellite and aerial image data offer a unique opportunity to identify areas where change in surface properties can be mapped and linked to land condition variability. Within the last decade, these efforts have increased as resources become more readily available through open-source databases and catalogues and increased spatial and temporal resolution of remotely sensed data (Figure 8.6). Taking advantage of these new developments, a framework was created as part of the State of the Bay monitoring programme to assess and visualise spatial variability in vegetation communities surrounding Langebaan Lagoon using an open-source geospatial platform called Google Earth Engine (GEE). GEE is a cloud-based geospatial processing platform centred on processing satellite imagery and derivates. The platform is often applied in global- or regional-scale environmental monitoring and analysis efforts, especially where large quantities of data and/or over long time periods are required. This web-based platform provides access to publicly available remote sensing imagery, as well as high-speed parallel processing and machine learning algorithms using Google's computational infrastructure. Within this infrastructure, a library of Application Programming Interfaces (APIs) can be utilised and modified for a multitude of environmental analysis (Tamiminia et al. 2020).

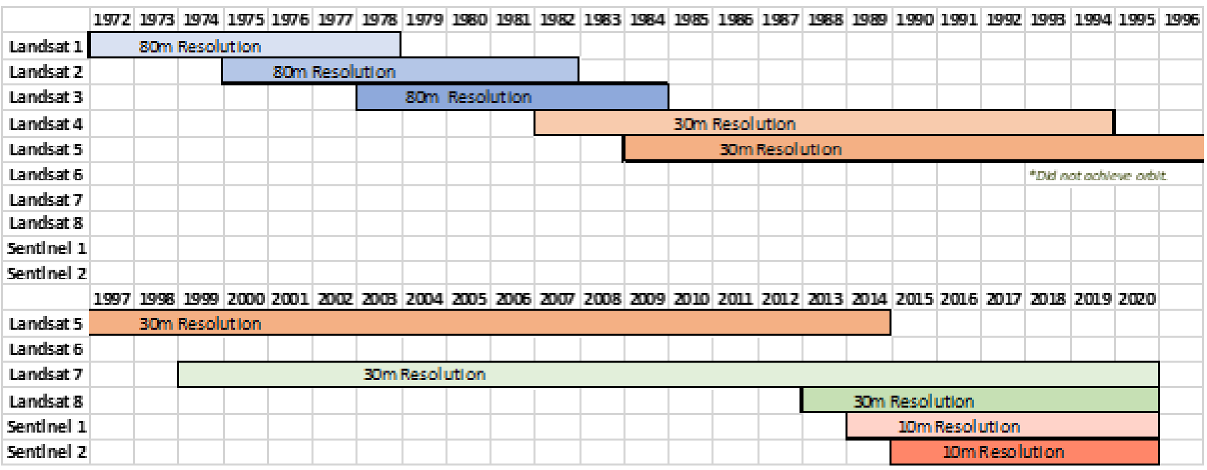


Figure 8.6. Differences in spatial resolution (m^2) for the various satellites launched by the LANDSAT and Sentinel earth observation from space campaigns from 1972–2020. The highest resolution imagery (10 m^2) available to present day is from the most recent Sentinel 1 and 2 satellites, deployed in 2014 and 2015, respectively.

In 2020, we used GEE to assess changes in the common reed cover variability at the pixel level, at a nominal spatial resolution of 10–30 m (high to moderate). We illustrate our approach using over three decades of Landsat 5,7 and 8 as well as Sentinel-2 satellite imagery (1989 to 2020). Common reed dominates the flora of the reedbeds where groundwater inflow occurs. At Langebaan Lagoon this is predominantly along the southern and south-eastern shores, near Geelbek. We needed to refine our study area in which to conduct analyses and thus used the vegetation cover shapefile developed by van der Linden (2014) of nine habitat types in the area around Langebaan Lagoon prepared using aerial photography. We excluded permanent water (and derived transition classes) from this by eliminating permanent water using an existing method for dynamic reference cover with the Global Surface Water (GSW) dataset (Pekel et al. 2016) from 1984–2015. A stable permanent water class (i.e., permanent water throughout the period) was delineated and used as an exclusion shapefile for spatial analyses of coastal and land vegetation classes (common reed and salt marsh), and as the processing extent for aquatic vegetation classification (seagrass beds). Sentinel-2 MSI: Multispectral Instrument Level-2A (Sentinel-2) imagery for 2015–2020 was temporally aggregated into seasonal composites of Summer (September to March), and Winter (March to September) using the colour infrared band combination (8,4,3) which emphasises different vegetation spectral signatures. Landsat 8 (2013–2014), 7 (1999–2012) and 5 (1989–1998) imagery were temporally aggregated into annual composites using the same band combinations. All temporal aggregation was done by determining the medoid of a season or a year of the imagery, creating a specific data point instead of an averaged or blended value (Flood 2013) utilising only images with cloud cover of 10% or less. The end result creates a regular temporal sequence by minimizing missing data and cloud contaminations.

In the approach adopted in 2020, we undertook an unsupervised (computer-based automated rather than user-influenced and defined) image classification approach once the temporal imagery sequence was generated. We used a statistical machine learning method known as "clustering". This can be defined as a case where a statistical relationship is established between the spectral bands or frequencies used and the variable measured (field-based) without there necessarily being a causal relationship (Holloway and Mengersen 2018). Clustering is an unsupervised learning method that attempts to combine objects into clusters based on similarity criteria of input variables without training data (Holloway & Mengersen 2018). We specified ten groups (clusters) and assumed that a permanent water class was excluded from this cluster assignment due to the methodology mentioned previously. Per temporal aggregation, each clustering effort was then exported from GEE into GeoTIFF (.tiff) format and overlaid on the respective imagery composites within ArcGIS (geographic information system software).

In 2021, we developed a supervised image classification scheme and subsequently expanded this assessment to other vegetation classes (specifically seagrass beds and salt marsh). This year we expanded our spatio-temporal analysis to include imagery from the years 2022 and 2023. For the years 2015–2023, we utilised the highest resolution imagery available to date (10 m resolution, Sentinel 2) to map the level and extent of spatial variability per vegetation class over time. Supervised classification entails manually isolating or segmenting remotely sensed imagery such as satellite imagery into different unique classes. In this way, pixels with similar characteristics are grouped together to represent specific features on the earth's surface. Based on a preliminary desktop analysis which queried all cloud-free Sentinel satellite imagery collections of the Bay and lagoon between 2016–2021, the months of June and July provided sufficient cloud free images and showed the greatest sub-monthly difference in coastal vegetative spectral reflectance. This difference in spectral reflectance is linked to the change from dry to rainy season, where common reed and salt marsh were observed to be more spectrally similar to surrounding vegetation in November to May. Due to low rainfall during summer season, much of the low-lying ground cover is characteristically brown which subsequently turns green with the coming rainy season. When viewed from satellite imagery, grassland and low bushland vegetation typically responds almost immediately to increases in rainfall with stark colouration changes (late April to June) and thereby provides enough colour contrast in June at vegetation transition zones to be easily differentiated from larger macrophyte classes both by the naked eye and by a machine learning driven classifier.

8.3.1 REED AND SEDGE COMMUNITIES

Based on the isolated spectral signature analyses conducted in 2021 for common reed, we extracted band values for 13 different frequency bands of the most cloud-free Sentinel-2 satellite images for the years 2016 to 2023.

All pixels within each band that were within the ranges were isolated (with the exception of bands 10 and 11 which were not applicable) and reclassified into a single value raster surface. The surfaces were summed, and the pixels which had a value in every band were isolated within the study area (i.e., terrestrial areas within a certain vicinity of the Langebaan Lagoon) and deemed to be likely areas comprising common reed. This had relatively high agreement with the supervised classification effort undertaken, but no quantitative accuracy assessment has been undertaken at this stage. Further ground-truthing across as much of this range as possible will enhance the accuracy and reliability of the mapping in future, and a more comprehensive effort for mapping common reed is recommended for 2024. This year, the key area of common reed occurrence near Geelbek was retained as the focal area.

The spatial differences observed in common reed beds are primarily influenced by their significant contribution to the ecosystem dynamics of shallow coastal regions (Figure 8.7). Specifically, factors such as soil composition and level of protection play a crucial role. These reed beds flourish when exposed to prolonged periods of submerged water or in areas where flooding emerges as the dominant determinant. This often results in the dominance of a single reed species, accompanied by only a small number of other species, consequently restricting biodiversity at the broader landscape level.

The average spatial variation of common reeds exhibited minor similarities between the years 2016 and 2020, with a standard deviation of less than two. The outcomes of the supervised classification method showed the lowest distribution in mapping common reeds in the year 2020, covering an area of 40.48 hectares. This could potentially be attributed to the residual impacts of a drought period endured from 2015 to 2017 within this region.

Common reeds have the ability to withstand water depths of up to 2 meters. A reduction in water levels has a positive influence on these plants, leading to an expansion of their growth area. Conversely, elevated water levels might hinder the process of rhizosphere self-oxidation through radial oxygen loss, possibly resulting in hypoxia. A positive impact on the expansion of the common reed bed is clearly visible in the year 2022 (50.21 ha), and this trend has continued to grow throughout the year 2023 (53.15 ha).

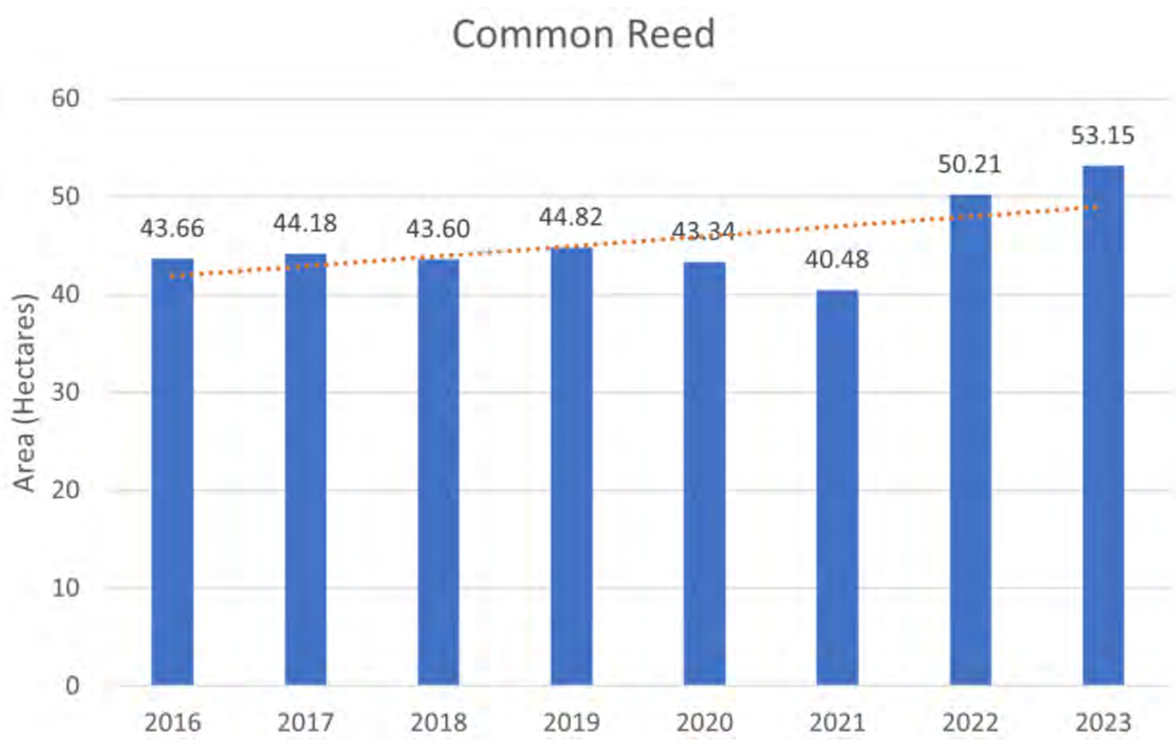


Figure 8.7. Spatial variability in hectares of common reed (2016–2023).

Light green pixels indicate currently present new growth of common reed, whereas dark green indicate long standing (and currently present) growth (Figure 8.8). Areas which are red show pixels where common reed was not present in June 2021 but was present any number of years prior to 2021. Light red areas are pixels which were present for one year between 2016–2020, and the darker the red pixel the more years that macrophyte was historically present (i.e., long-term presence lost in 2021). Common reed patches in the south-east of the lagoon, just east of the Geelbek bird hide, are losing their upland dry-shore growth fairly rapidly and are losing their near shore growth at a slower rate but are expanding inwards and northwards at a modest rate presumably in response to seasonal variations in rainfall.

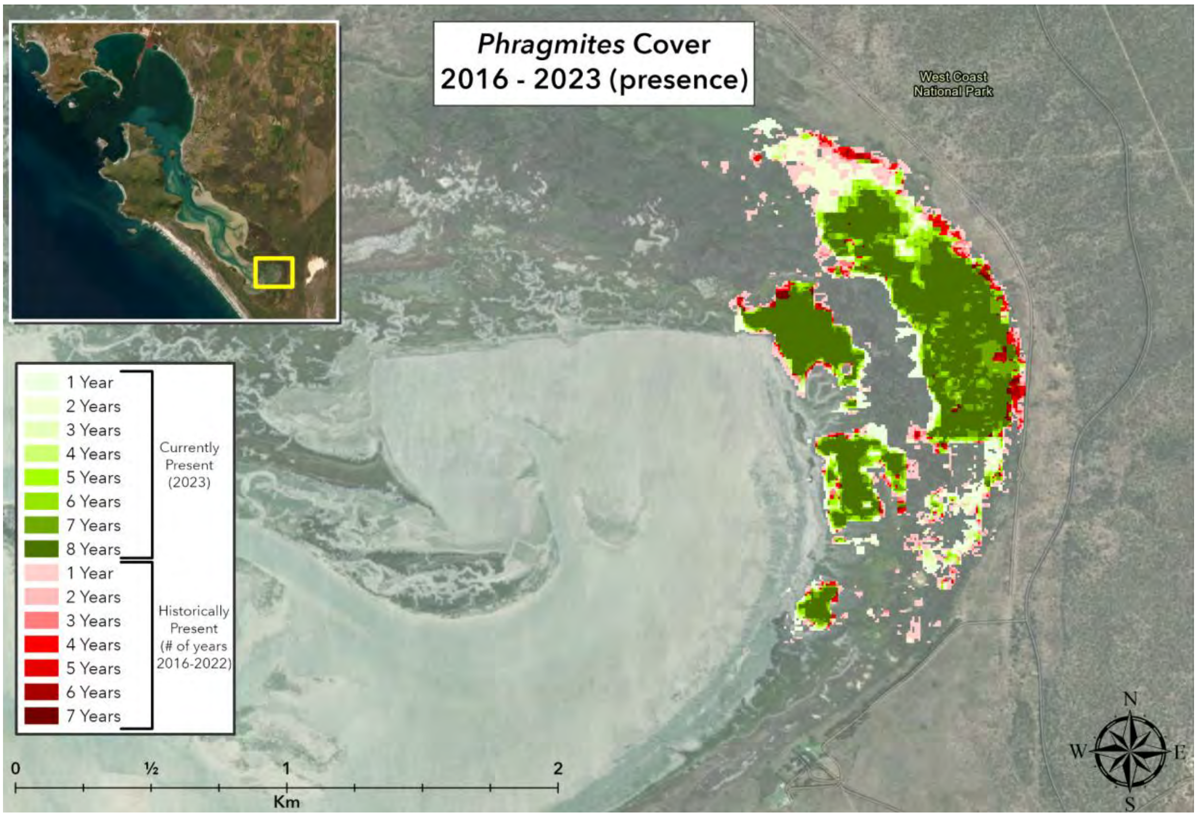


Figure 8.8. Spatio-temporal variability of common reed (10 m spatial, 2016–2023 temporal).

8.3.2 Seagrass

The supervised classification effort performed for seagrass beds across Saldanha Bay and Langebaan lagoon is a preliminary, unvalidated (no ground-truthing) attempt to assess general extent and spatial variability of submerged macrophytes over time (Figure 8.9). Seagrass beds show a similar spectral profile to other aquatic classes such as shallow water and water channels for Image Bands 4 and 5 but were unique for Bands 1–3 and 6–9 (Figure 8.10). Satellite imagery was viewed under different combinations of bands (4-3-2, 8-4-3) which enabled the inferred exclusion of transition depth zones and coastal areas which appeared to be seagrass beds to the naked eye.

Change in the extent of seagrass beds in 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 changes are certain to have long-term implications, not only for the invertebrate fauna but also for species of higher trophic levels.

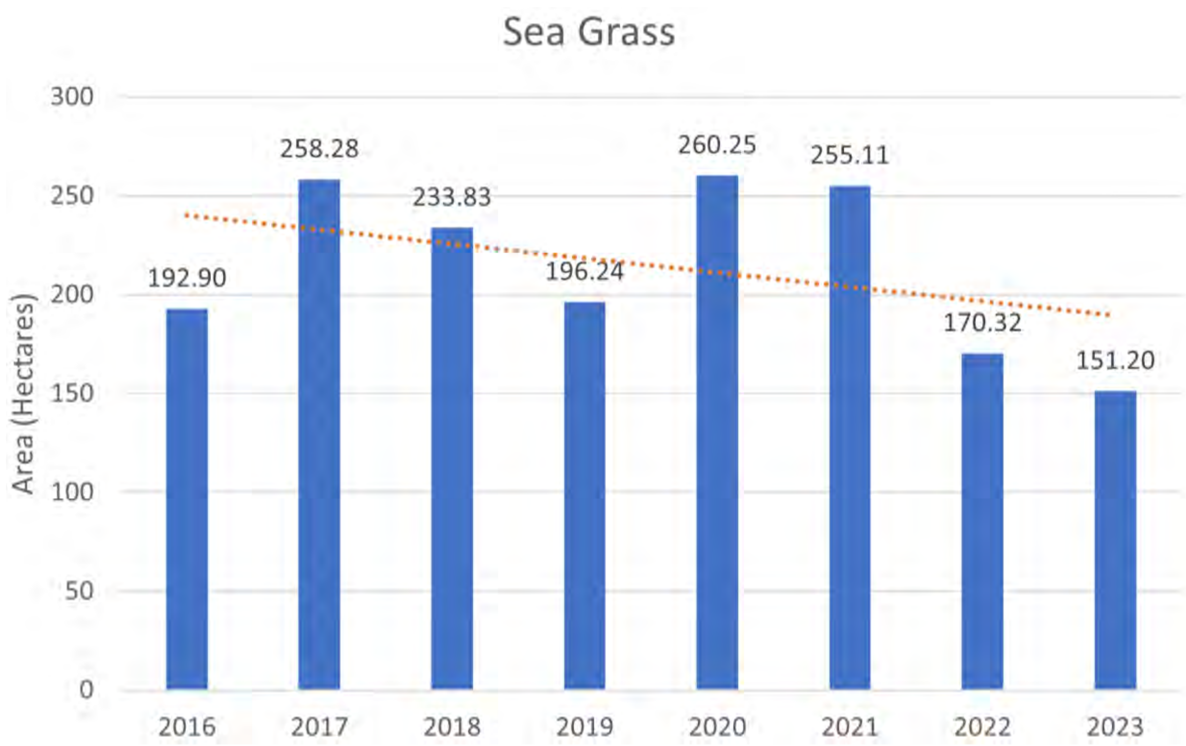


Figure 8.9. Spatial variability in hectares of seagrass beds (2016–2023).

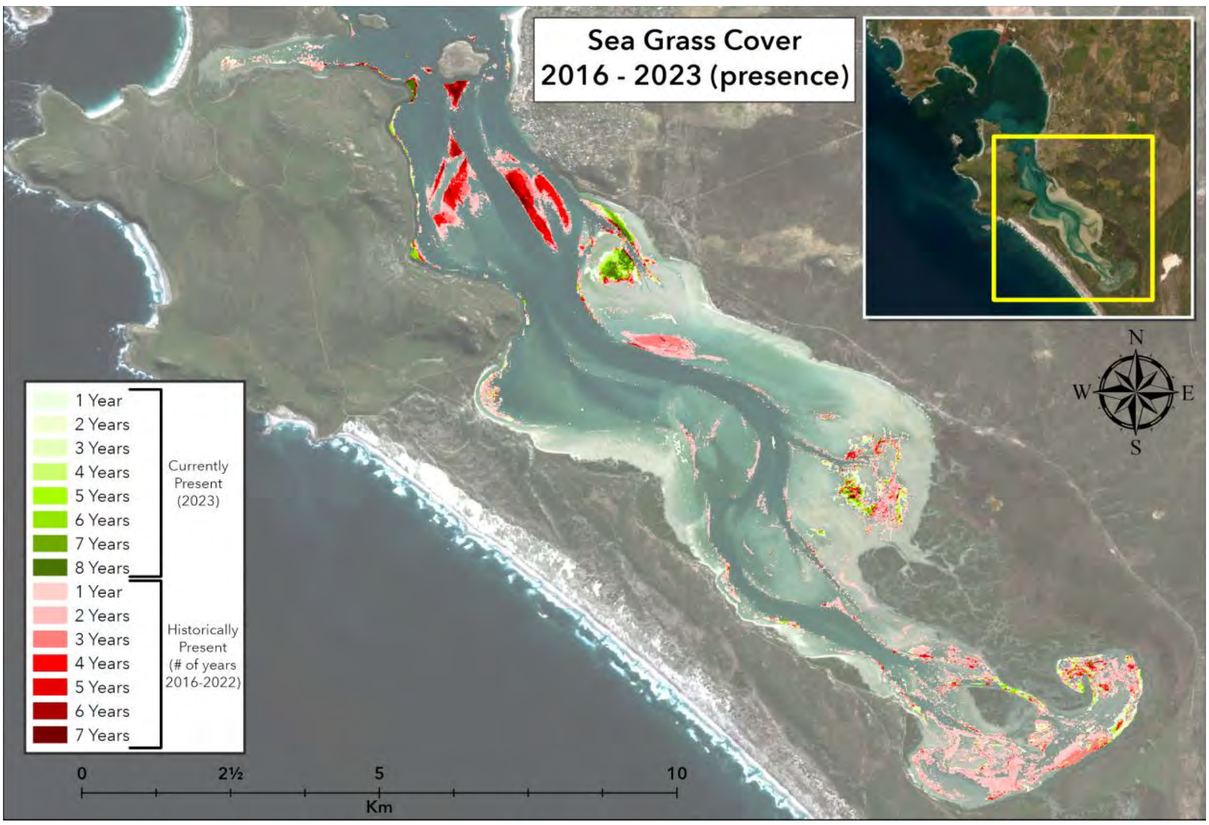


Figure 8.10. Spatio-temporal variability of seagrass beds (10 m spatial, 2016–2023 temporal).

Seagrass beds throughout the lagoon have proven to be highly variable over the last 6 years, with the longest standing current growth at the north of the lagoon, a smaller patch to the mid-east of the Lagoon, and some recently established beds in the south of the Lagoon near Geelbek. The greatest loss of seagrass beds was seen 6 kilometres south-east of Langebaan beach, where long growth beds were not identified through spectral profile analysis or classification efforts in 2021. Light green pixels indicate new growth seagrass, whereas dark green indicate long standing (and currently present) growth. Areas which are red include pixels where seagrass was not present in June 2021 but was present any number of years prior to 2021. Light red areas are pixels which were present for one year between 2016–2020, and the darker the red pixels that seagrass bed was historically present in most years.

The spatial variability of seagrass beds refers to the natural differences and patterns in seagrass distribution, composition, and health across a given area. Seagrass beds are dynamic and complex ecosystems found in coastal and shallow marine environments. As depicted by Figure 8.9, seagrasses are sensitive to changes environmental factors, and their presence or absence can vary based on local conditions. The years 2017, 2020, and 2021 displayed the greatest distribution of seagrass beds, suggesting that the most optimal conditions—such as water quality, light availability, temperature, and salinity—were conducive to the expansion of seagrasses. Furthermore, the potential connection between an increase in common reeds and the decline of seagrass in the years 2022 and 2023 remains uncertain. It might be worthwhile to conduct further investigations to determine if there is a succession relationship between these two phenomena. There is a general decline in seagrass beds since 2016 to date. The loss of seagrass due to anthropogenic pressures, including sediment and pollutant discharge from local runoff, as well as global climate-driven seasonal changes, poses significant concerns that require effective mitigation strategies to safeguard this vital resource. It is important to note that while seagrass growth is generally more robust during the warmer months, specific growth patterns can vary based on regional climate, local water conditions, and the specific species of seagrass present. Additionally, some tropical seagrass species may exhibit more continuous growth throughout the year due to the consistent warm temperatures in their habitat.

8.3.3 SALT MARSHES

Salt marsh vegetation shows a similar spectral profile to other coastal vegetation classes for Image Bands 1–4 but was unique for Bands 6–9. Satellite imagery was viewed under different combinations of bands (8-4-3) which enabled the inferred exclusion of vegetation boundaries and coastal areas which were perceived to be salt marsh to the naked eye. Salt marsh exhibited a very tight spectral range for Bands 1–4. Salt marsh extent has been consistent for the period of 2016–2020 but has shown a 10.3% increase in extent for 2021 mostly nearshore of Geelbek (Figure 8.11). Light green pixels indicate currently present new growth seagrass beds, whereas dark green indicate long standing (and currently present) growth (Figure 8.12). Red pixels indicate areas where saltmarsh was not present in June 2021 but was present any number of years prior to 2021. Light red areas are pixels where salt marsh was present for one year between 2016–2020. The dark red pixels indicate areas where salt marsh was present for many years but was absent in 2021.

Salt marshes exhibit substantial spatial variability from year to year with no distinct pattern. This may be due to the hydrodynamic forces between vegetation and sedimentation. Additionally, salt marshes undergo cycles of extensive accumulation followed by lateral erosion, causing the advancing vegetation edge and eroding sections to shift over time. Consequently, distinguishing developmental patterns in existing salt marshes stemming from environmental changes poses a major challenge. The distribution of salt marshes was at its minimum between the years 2017 and 2020, with the lowest point occurring in 2018 (378.13 ha). If salt marshes become inundated more frequently it leads to erosion and loss of habitat. Marshes may also migrate inland if suitable space is available, but in developed areas, migration is often restricted. Coastal development in this region could have led to habitat loss and fragmentation of salt marshes. It is known that land reclamation, construction of roads and buildings, and shoreline modifications can alter hydrology, reduce marsh area, and disrupt natural processes. The outcomes of the supervised classification method showed the highest distribution in mapping salt marshes in the year 2021, covering an area of 429.50 hectares. From 2016 to the present, there has been an overall upward trend in the expansion of salt marsh beds. Salt marsh migration is this area may have been possible. In addition, accumulation of sediment, organic matter, and debris in marsh areas could have led to marsh accretion.

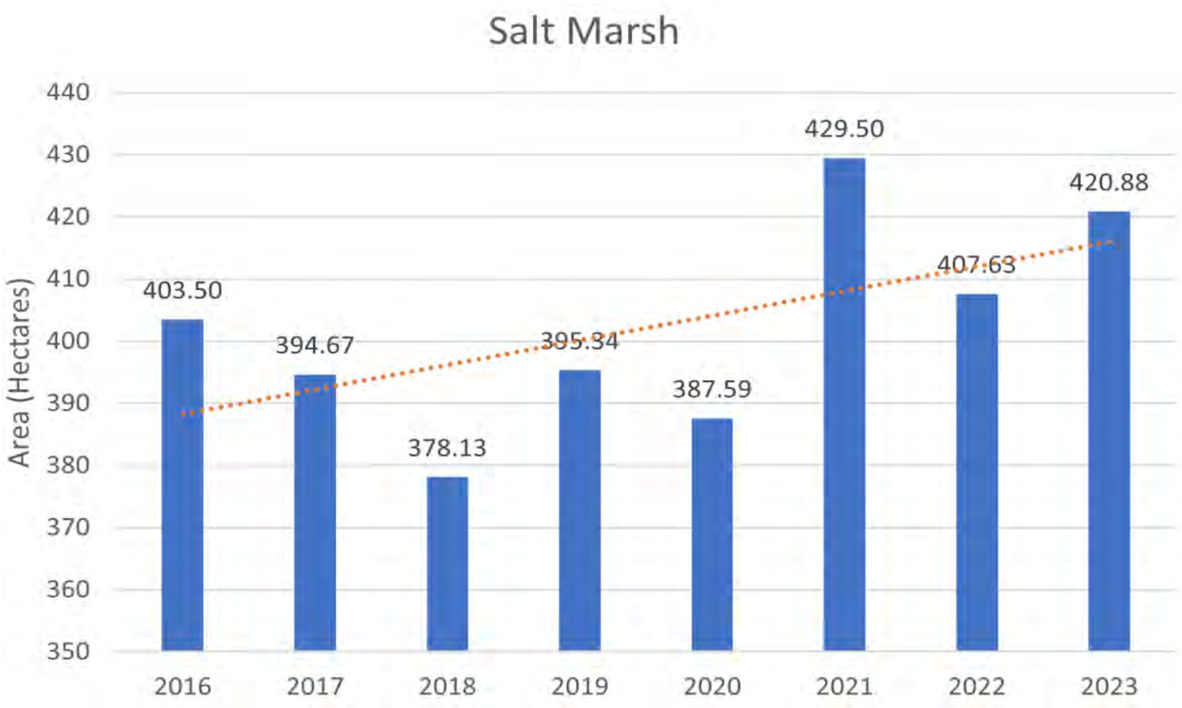


Figure 8.11. Spatial variability in hectares of salt marsh (2016–2023).

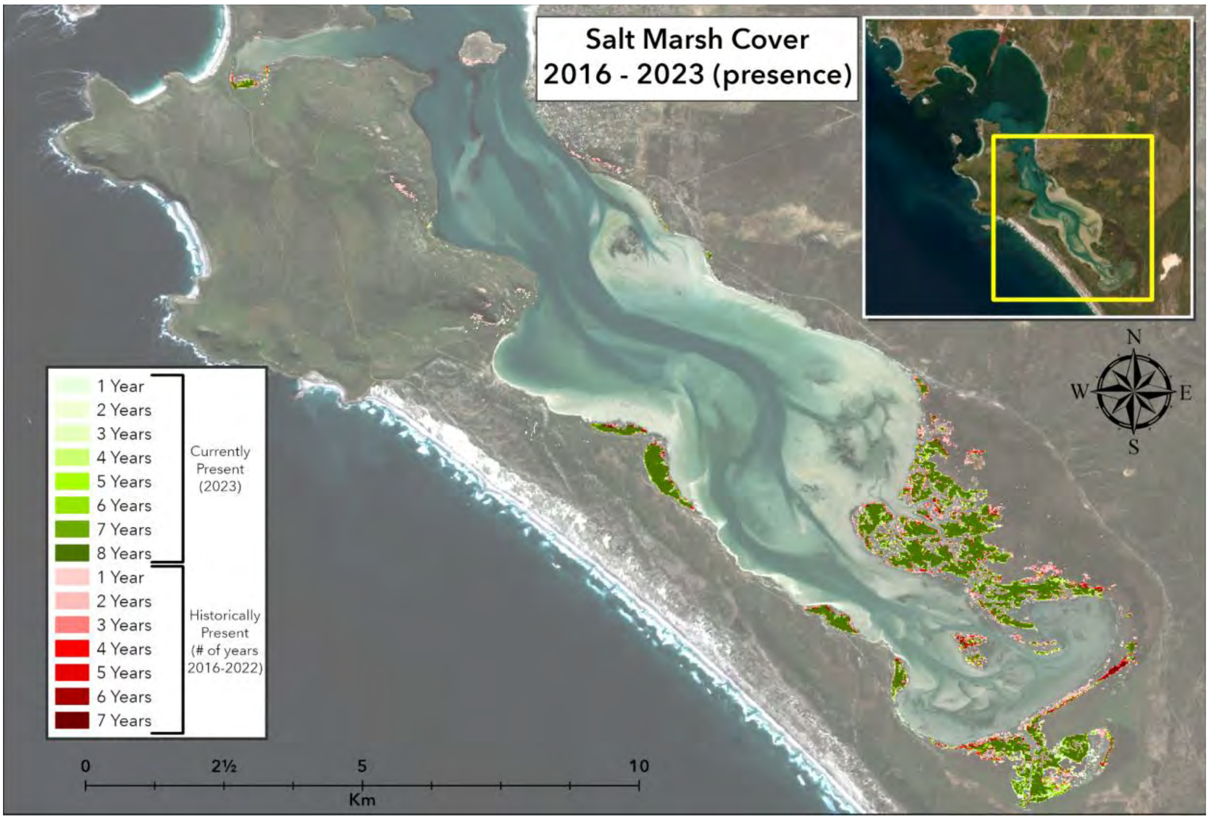


Figure 8.12. Spatio-temporal variability of salt marsh (10 m spatial, 2016–2023 temporal).

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 at a selected point 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 can lead to a range of different 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 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 as opposed to larger, longer lived 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, abundance and biomass of soft bottom benthic macrofauna samples, collected in Saldanha Bay from 1999 to 2023 (with additional 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 (IOT) 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 & 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 (Anchor) in 2004 and 2008–2022 do, however, provide benthic macrofauna data from Saldanha Bay and Langebaan Lagoon that are comparable with those collected in recent years. Direct comparisons to earlier studies are complicated owing to the fact that different equipment was used in the earlier surveys than those undertaken from 1999 to present. The 1975 study, for example, made use of a modified van Veen grab weighted to 20 kg which sampled an area of 0.2 m^2 from the surface fraction of sediment. Subsequent surveys, from 1999 to present, made use of a diver-operated suction sampler with a sampling area of 0.12 m^2 to a depth of 30 cm. The former sampling technique (van Veen grab) would be expected to sample a smaller proportion of benthic macrofauna due to its limited ability to penetrate the sediment beyond the surface layers. The suction sampler is effective in penetrating to a depth of 30 cm, which is within range of larger species such as prawns and crabs. The study conducted in 1975 in Langebaan Lagoon (Christie and Moldan 1977), and those conducted for all State of the Bay surveys have all made use of a diver-operated suction sampler which samples an area of 0.12 m^2. However, in 1975 a depth of 60 cm was sampled while in surveys since 2004 a depth of only 30 cm has been sampled. Thus, considering the differences in sampling techniques employed, it is likely that the changes reflected by the data between the 1975 and 1999–2008 in Saldanha Bay and Langebaan Lagoon are a function both of real changes that occurred in the Bay and an artefact of differences in sampling methodology. The location of sites sampled during 1975 and the 1999–2022 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.

In 2021 an additional 21 sites were sampled as part of the Saldanha Aquaculture Development Zone (ADZ) Monitoring Survey: consisting of 11 impact sites within the Big Bay ADZ (three within the fin fish area and eight in the shellfish area), four impact sites within the Outer Bay North ADZ and six reference sites falling outside the ADZ boundaries in Big Bay (n=3) and Outer Bay North (n=3). The aim of this study was to determine whether the aquaculture operations in these areas were having measurable benthic impacts (Probyn et al. 2023). It was found that the sediment thickness was less than 20 cm at most of the ADZ sampling sites effectively excluding large burrowing taxa (such as prawns) and therefore explaining the lower biomass observed. However, the abundance of benthic macrofauna observed at the ADZ sampling sites was comparable to that observed at the traditional suite of State of the Bay monitoring sites. This is because of the numerous smaller surface-dwelling taxa (amphipods, isopods and various polychaetes) are typically found within the top layer of sediment.

The Saldanha Bay sea-based ADZ baseline benthic survey report (Mostert et al. 2020b) mentioned that divers encountered calcrete reef at some of the sampling sites during the 2019 baseline survey (Capfish 2019) and that difficulties in obtaining grab samples at several stations were encountered in Big Bay during the 2020 sediment surveys (Mostert et al. 2020a). Further to this observation, Anchor's divers deploying water quality monitoring instruments during April 2020, indicated the presence of reef in several areas of the Big Bay ADZ precinct. A subsequent literature review revealed the existence of an extensive abrasion platform (areas of exposed calcrete rock) throughout much of Big Bay (Flemming 2015). Additionally, the finfish lease holder provided a bathymetry map of their precinct which indicated extensive low-profile reef throughout the site (Mostert et al. 2020b).

During the 2021 field survey Anchor divers collected video footage at two stations where reef was encountered (B5 and FF2). This footage was then used to provide a qualitative description of the reef epibenthos at each site (presented in the 2021 State of the Bay report). A total of 21 species were identified. Common species included West Coast Rock Lobster *Jasus lalandii*, red starfish *Callopatiria granifera* and reticulated starfish *Henricia ornata*, cape urchins *Parechinus angulosus*, and beds of the common feather star *Comanthus wahlbergii*. It was recommended that future surveys and monitoring of this reef habitat take place.

9.3 APPROACH AND METHODS

9.3.1 SAMPLING

Benthic macrofauna have been sampled at more than 30 sites in Big Bay (9 sites), Small Bay (ten sites) and Langebaan Lagoon (12 sites) since the inception of the State of the Bay monitoring programme in 2004. The localities and water depth ranges of the sites sampled in 2023 are illustrated in Chapter 7. Samples are, by convention, collected using a diver-operated suction sampler, which sampled an area of 0.12 m^2 to a depth of 30 cm and retained benthic macrofauna in a 1 mm mesh sieve bag. At sites less than 2 m deep, three hand-core samples were taken totalling a sampling surface area of 0.08 m^2. In 2016 and 2017 Elandsfontein samples were collected using the same hand-core. It was later agreed that the use of a Van Veen grab to collect samples at Elandsfontein was most appropriate and from 2018 onwards a Van Veen grab with a bite size of 0.14 m^2 was used. It was noted that the grab was more effective at sampling benthic macrofauna in this area, and we recommend this be continued for future monitoring. All macrofauna abundance and biomass data were ultimately standardised per unit area (m^2). Samples were stored in plastic bottles and preserved with 5% formalin.

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

9.3.2 STATISTICAL ANALYSIS

The data collected from this survey were used for two purposes 1) to assess spatial variability in the benthic macrofauna community structure and composition between sites in 2023 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.

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 (Newell et al. 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 rates and short life-cycles are able to rapidly invade and colonise disturbed areas (Newell et al. 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 natural 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 v7, was used to analyse benthic macrofauna abundance data (Anderson et al. 2008). 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. A Similarity Percentages (SIMPER) analysis was used to identify species principally responsible for the clustering of samples. These results were used to characterise different regions of the system based on the communities present at the sites. It is important to remember that the community composition is a reflection of not only the physico-chemical health of the environment but also the ability of communities to recover from disturbance.

Diversity indices 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 V6:

$H' = -\Sigma p_i(\log_e(p_i))$ [9]

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 2023 survey results — Spatial comparison

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 and at certain sites in Big Bay (LPG, LL37, LL33, Eland3, LL34 and LL32) and was lowest in proximity to low-profile reef in Big Bay (BB30 and BB26) and in the yacht basin and around the iron ore jetty in Small Bay (SB1 and SB14). The low diversity indices reported for SB1 and SB14 in Small Bay are most likely attributable to the high levels of anthropogenic disturbance (e.g., dredging) and the presence of elevated levels of contaminants (trace metals, organic material, etc.) in the sediment at these sites. The low diversity observed at sites BB26 and BB30, however, is unclear and is not likely a result of pollution or other anthropogenic disturbance. It is well known that high levels of anthropogenic and/or natural disturbance can allow opportunistic, short-lived or r-selected species to colonize the affected area and prevent a more diverse community comprising longer living k-strategist species from becoming established. The high diversity observed at the LPG site is equally puzzling; this could be attributed to localised increased habitat heterogeneity emanating from the construction of the single point mooring at this site.

9.4.2 Community structure

A multivariate ordination (a technique that groups samples with similar macrofaunal communities close together and separates dissimilar samples) prepared from 2023 macrofaunal abundance data, is presented in Figure 9.2. These data show a very similar pattern as for the diversity data, with macrofaunal communities at Langebaan Lagoon (LL) and particularly Elandsfontein (Eland) standing out as being clearly different to those in Big Bay (BB) and Small Bay (SB). The Big Bay and Small Bay sites are also distinct from one another, but to a lesser extent in comparison to 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 forming a separate cluster that is separate to 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 anthropogenic disturbance are

9 Where pi is the proportion of the total count arising from the ith species. This is the most commonly used diversity measure and it incorporates both species richness and equability.

present in abundance at Elandsfontein and in Langebaan Lagoon but are largely absent from the Sea Harvest, Big Bay and Small Bay sites — particularly those in proximity to the IOT. It should be noted that differences in macrofaunal community structure are also partly explained by the physical and environmental parameters present at each site.

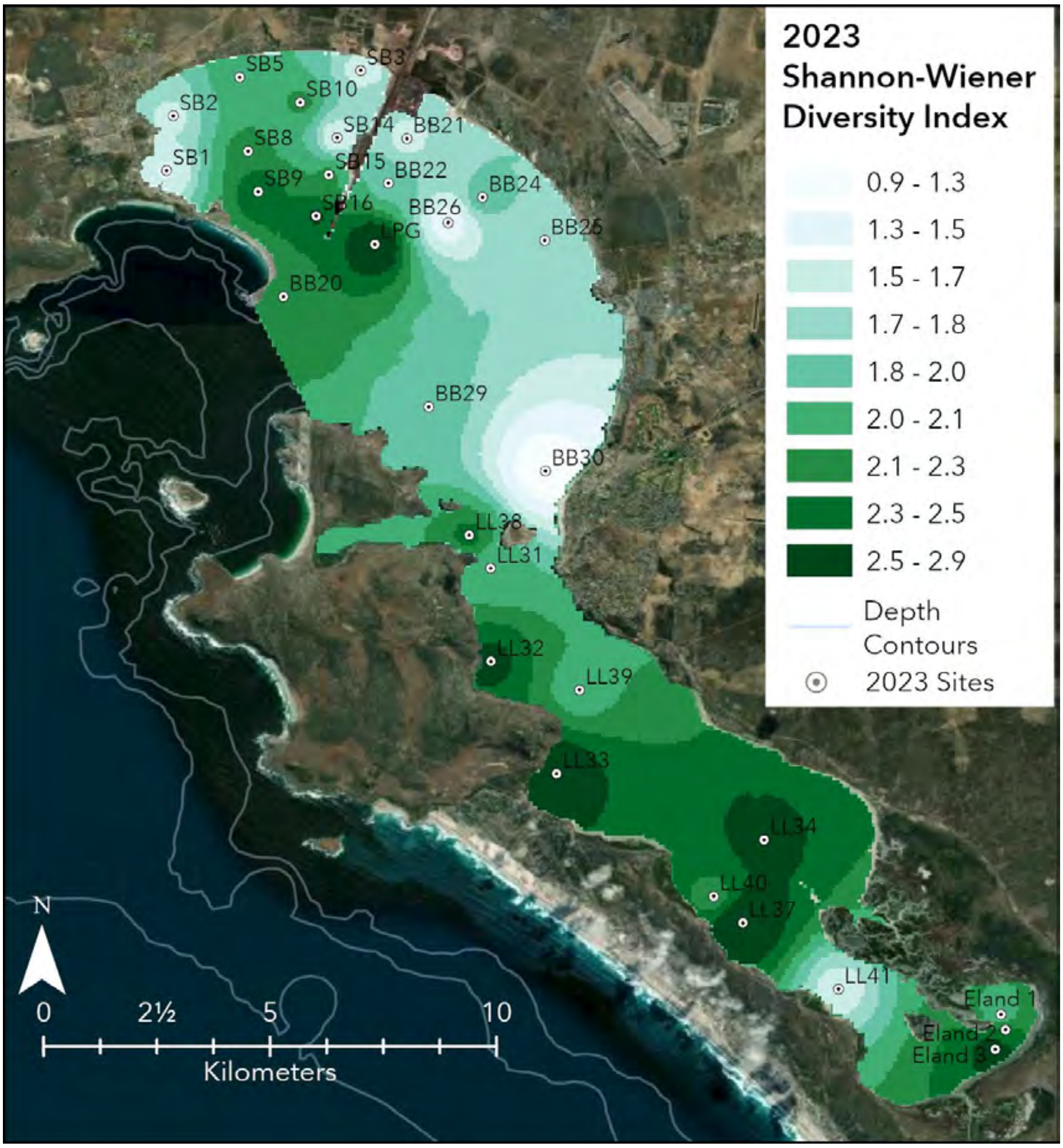


Figure 9.1. Variation in the diversity of the benthic macrofauna in Saldanha Bay and Langebaan Lagoon as indicated by the 2023 survey results (H' = 0 indicates low diversity, H' = 2.9 indicates high diversity).

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 *Macomopsis ordinaria* and the tongue worm *Listriolobus capensis* were notably more abundant in Big Bay than Small Bay. Similarly, the sea pen *Virgularia schultzei*, widely regarded as a "sensitive species" was found only in Big Bay.

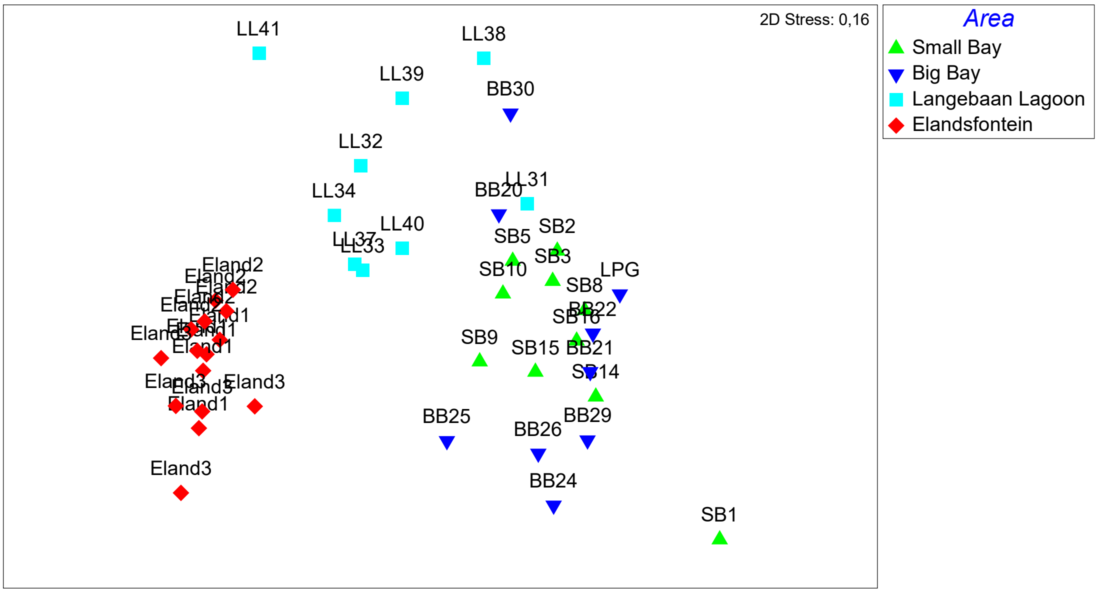


Figure 9.2 Ordination showing similarity among sample sites based on benthic macrofauna abundance in 2023. Areas included are: Small Bay (SB), Big Bay (BB), Langebaan Lagoon (LL) and Elandsfontein (Eland).

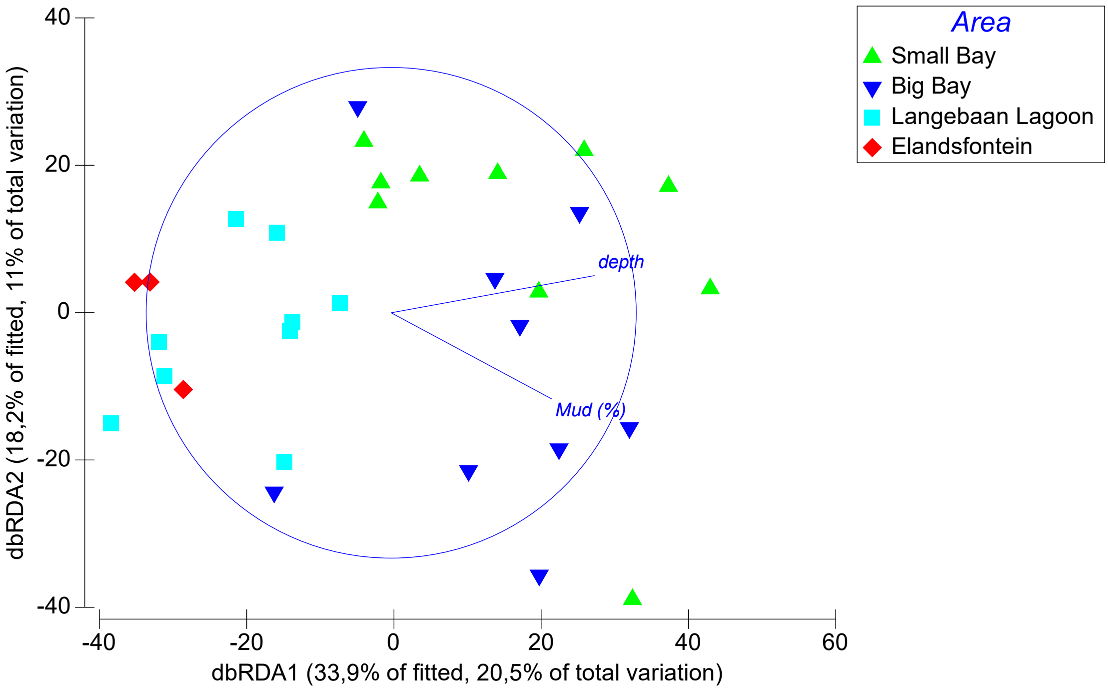


Figure 9.3 dbRDA plot of 2022 macrofaunal abundance data. Sediment fractions, Total Organic Carbon (TOC), Total Organic Nitrogen (TON), carbon to nitrogen (C:N) and trace metal concentrations were included as categorical predictors in this design. Sediment fractions were arcsine transformed prior to 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 relationship between 2023 macrofaunal abundance data and abiotic data (depth, 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 ~60% of the variation observed in the macrofaunal abundance data, with depth (15%) explaining the greatest amount, followed by % mud (8%). Previous monitoring surveys have indicated that these are well known predictors of benthic macrofaunal community structure throughout Saldanha Bay and Langebaan Lagoon. The full model can be visualised by examining the distance-based redundancy analysis (dbRDA) ordination (Figure 9.3). The first two axes capture 52% of the variability in the fitted model, and 31.5% of the total variation in the data cloud. The blue 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. Depth and mud fraction clearly separate the shallow lagoon sites from the deeper sites in Small Bay and Big Bay.

Species that contributed significantly to the dissimilarity between the Saldanha Bay and Langebaan Lagoon samples include the coastal mudprawn *Upogebia capensis* and the polychaete *Mediomastus capensis* 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*, estuarine mudprawn *Upogebia africana*, the isopod *Natatolana hirtipes*, the crown crab *Hymenosoma orbiculare* and polychaete *Orbinia angrapequensis* were more abundant in the lagoon samples.

The community structure of benthic macrofauna at Elandsfontein was dominated by small crustaceans (mostly amphipods), and polychaetes. The presence of unique species such as the sandflat crab, *Danielella edwardsii* and the abundance of the sand prawn, *Callichirus kraussi*, the mud prawn, *Upogebia africana*, and polychaete, *Marphysa depressa*, 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 are shown in Figure 9.4. Polychaetes (bristle worms) were the dominant taxonomic group in all areas. The next most abundant taxonomic group were Crustaceans (this diverse group includes prawns, shrimps, mysids, crabs, amphipods and isopods) (Figure 9.4). Numerically, detritivores were the dominant functional group in all areas followed by filter feeders, yet filter feeders contributed the most towards overall biomass (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. In general, overall biomass was found to be significantly lower at the Langebaan and Elandsfontein sites in comparison to the sampling sites at Big Bay and Small Bay.

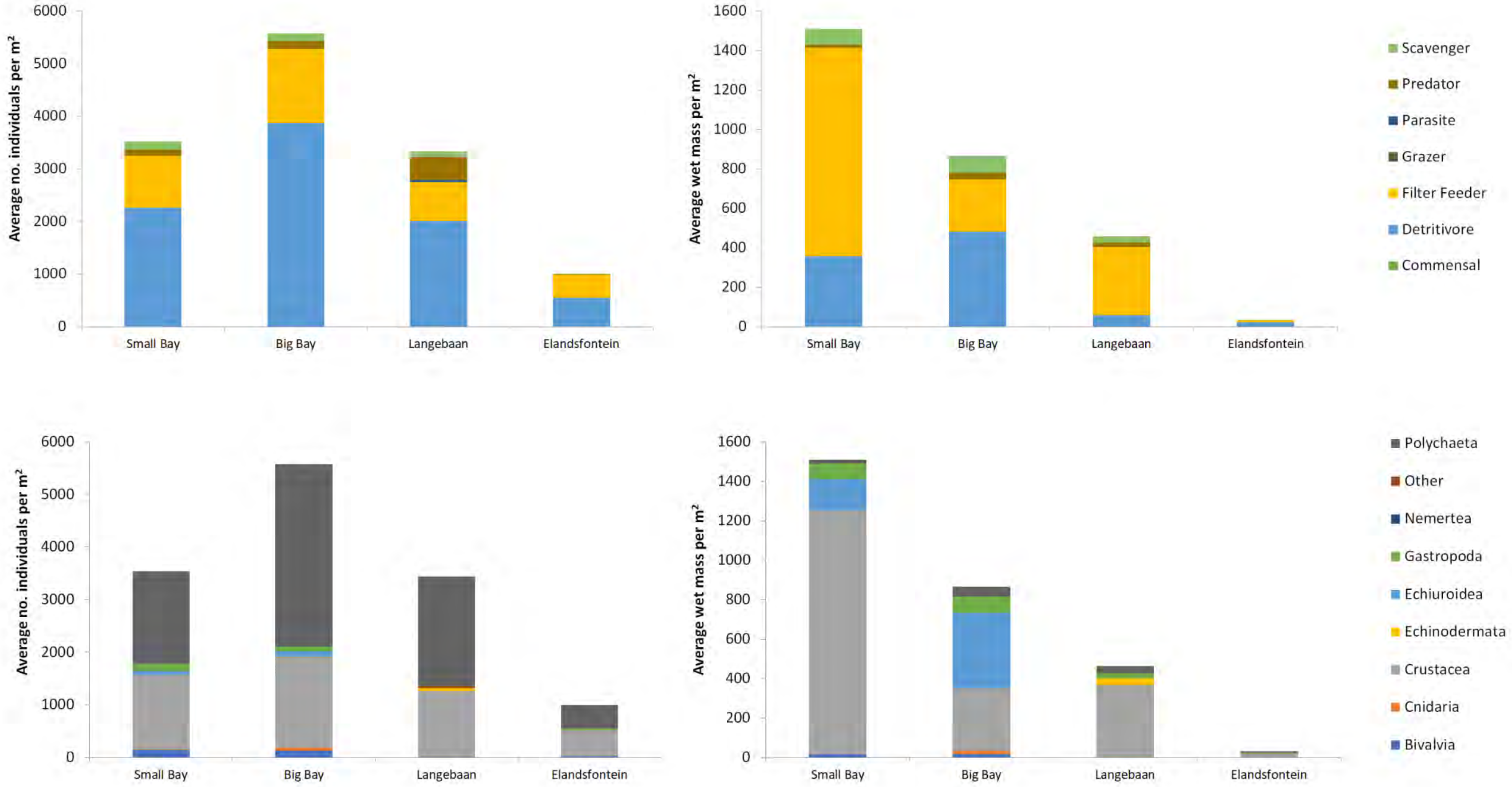


Figure 9.4. Average abundance and biomass (g/m^2) of benthic macrofauna by functional and taxonomic group in Big Bay (n=9), Small Bay (n=10), Langebaan Lagoon (n=9), Elandsfontein (n=15) in 2023.

9.5 BENTHIC MACROFAUNA 2023 SURVEY RESULTS - TEMPORAL TRENDS

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 2023 is shown in Figure 9.5. The slight increase in the numbers of species recorded over time is likely due 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 and 2016). If one considers these data 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 construction of the original port in 1973, the most significant dredging events were implemented in 1996/7 (when 2 million m^3 of material was removed from the Small Bay side of the IOT for the construction of the Multi-Purpose Terminal (MPT)), the second in 2007/2008 (when approximately 50 000 m^3 of seabed material was removed from the area of the Mossgas quay and the MPT) and the third in 2009/2010, (when 7 300 m^3 of material was removed from the Saldanha side of the IOT). 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, 2013–2023).

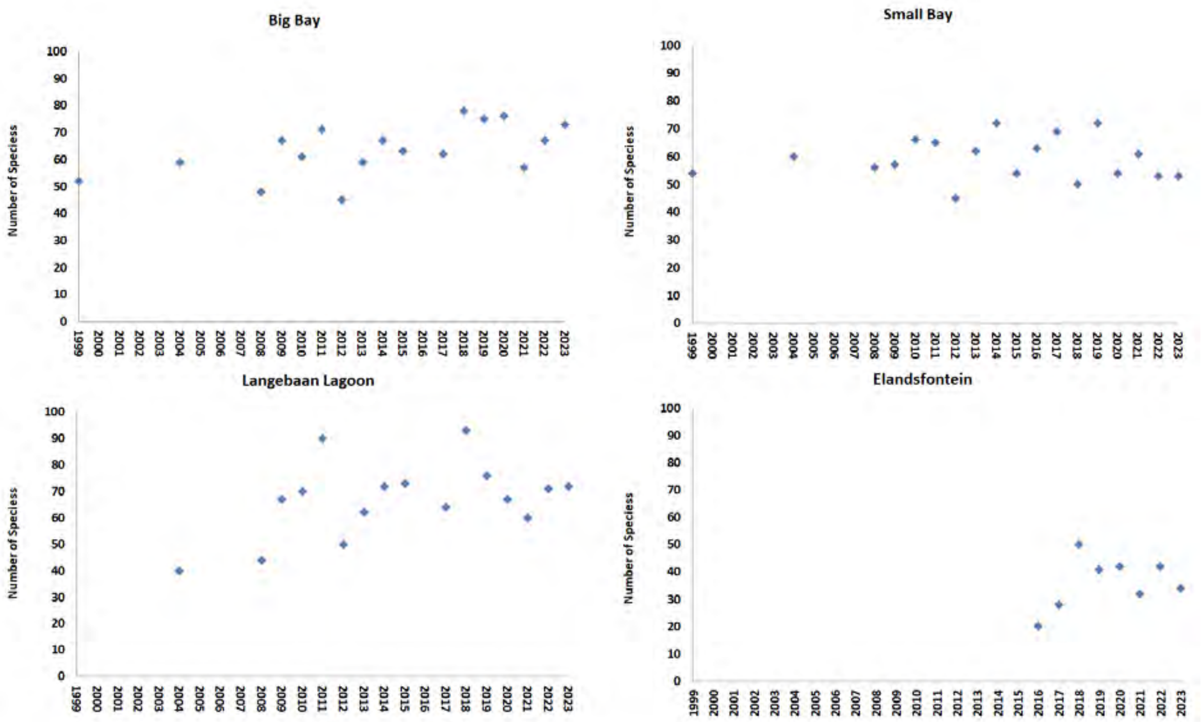


Figure 9.5 Variation in the number of species recorded at Small Bay, Big Bay, Langebaan Lagoon (1999–2023) and Elandsfontein (2016–2023).

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 and gave rise to 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 started to die off and by mid-2001 only dead shells and anoxic sediment remained. To prevent the re-settlement of the mussel, South African National Parks (SANParks) 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 thus have been linked to a residual impact of the mussel invasion.

Species richness at Elandsfontein is low in comparison to rest of the system. This is likely a result of high natural disturbance (variation in temperature and salinity). Significantly more species were recorded here in 2018–2023 — this is most certainly attributable to the change in sampling gear used (from hand-core to Van Veen grab). The Van Veen grab does appear to be more effective at sampling benthic macrofauna in this area, and we recommend this be continued for future monitoring.

9.5.2 Abundance, biomass and community composition

Changes in the abundance and biomass of benthic macrofauna in Small Bay, Big Bay and Langebaan Lagoon and Sea Harvest are presented in Figure 9.6, Figure 9.7 and Figure 9.8. 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. Monitoring of benthic macrofaunal communities over the period 1999–2023 has revealed a pattern of decreased abundance and biomass in response to dredging events (2008, 2012, 2015 and 2017) followed by rapid recovery. There are some clear changes in the relative contribution of major taxonomic groups (Bivalvia, Crustacea, Gastropoda, etc.) in the periods of reduced abundance/biomass but the changes in the relative contributions by the different feeding groups is much more pronounced. The slight increase in the overall biomass and abundance indices recorded in Langebaan Lagoon in 2020 was attributed to a greater number of sand prawns, *Kraussillichirus kraussi*, in the samples collected during the 2020 survey. This species is a harvested extensively for bait and it is encouraging to see an increase in both abundance and biomass in Langebaan Lagoon.

The relative contribution by the group known as filter feeders (i.e., those that feed by filtering particulate matter out of the water column) dropped dramatically during these perturbations in all three areas of the Bay while the contribution by the group known as detritivores (those that feed on particulate organic matter in or on the surface of the sediment) tended to increase. Filter feeders tend to be more sensitive to levels of suspended sediment that the other feeding groups, and this certainly lends weight to the argument that these 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 (*Listriolobus capensis*) and polychaetes belonging to the genera *Polydora* and *Mediomastus*. 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.

9.5.3 COMMUNITY STRUCTURE

In this and previous reports, multivariate analyses have revealed clear differences in the macrofaunal communities inhabiting Small Bay, Big Bay, Langebaan Lagoon and Elandsfontein and that these differences 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.

SMALL BAY

The Small Bay ordination plot 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 was a high abundance of detritivores such as the shrimp *Betaeus jucundus*, the polychaetes *Mediomastus capensis* and *Maldanidae sp*., and crustaceans of the taxon 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 *Listriolobus capensis*, scavenger whelks of the genus *Nassarius*, 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 2009–2023 suggests that the smaller 2009 dredging event had a limited impact with little change in macrobenthic community structure over the last fourteen years.

BIG BAY

The 2008 Big Bay macrobenthos samples also clustered separately from all other years on the ordination plot indicting that they were dissimilar to the others in some way (Figure 9.9). Species primarily responsible for the dissimilarity of 2008 samples from all other years include very low abundance or absence of detritivores, *Orbinia angrapequensis* and *Listriolobus capensis*, 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*.

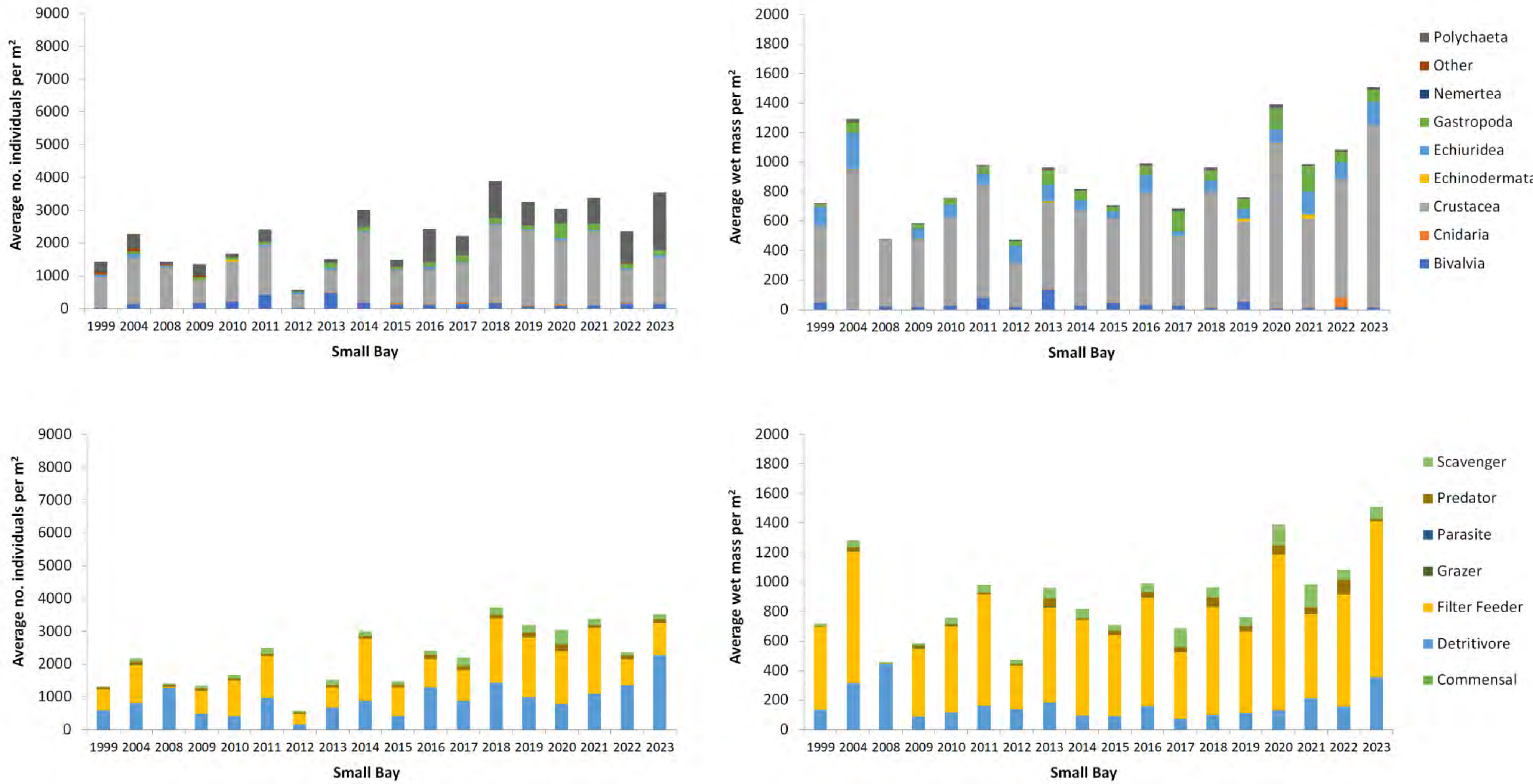


Figure 9.6. Overall trends in the abundance and biomass (g/m^2) of benthic macrofauna in Small Bay as shown by taxonomic and functional groups.

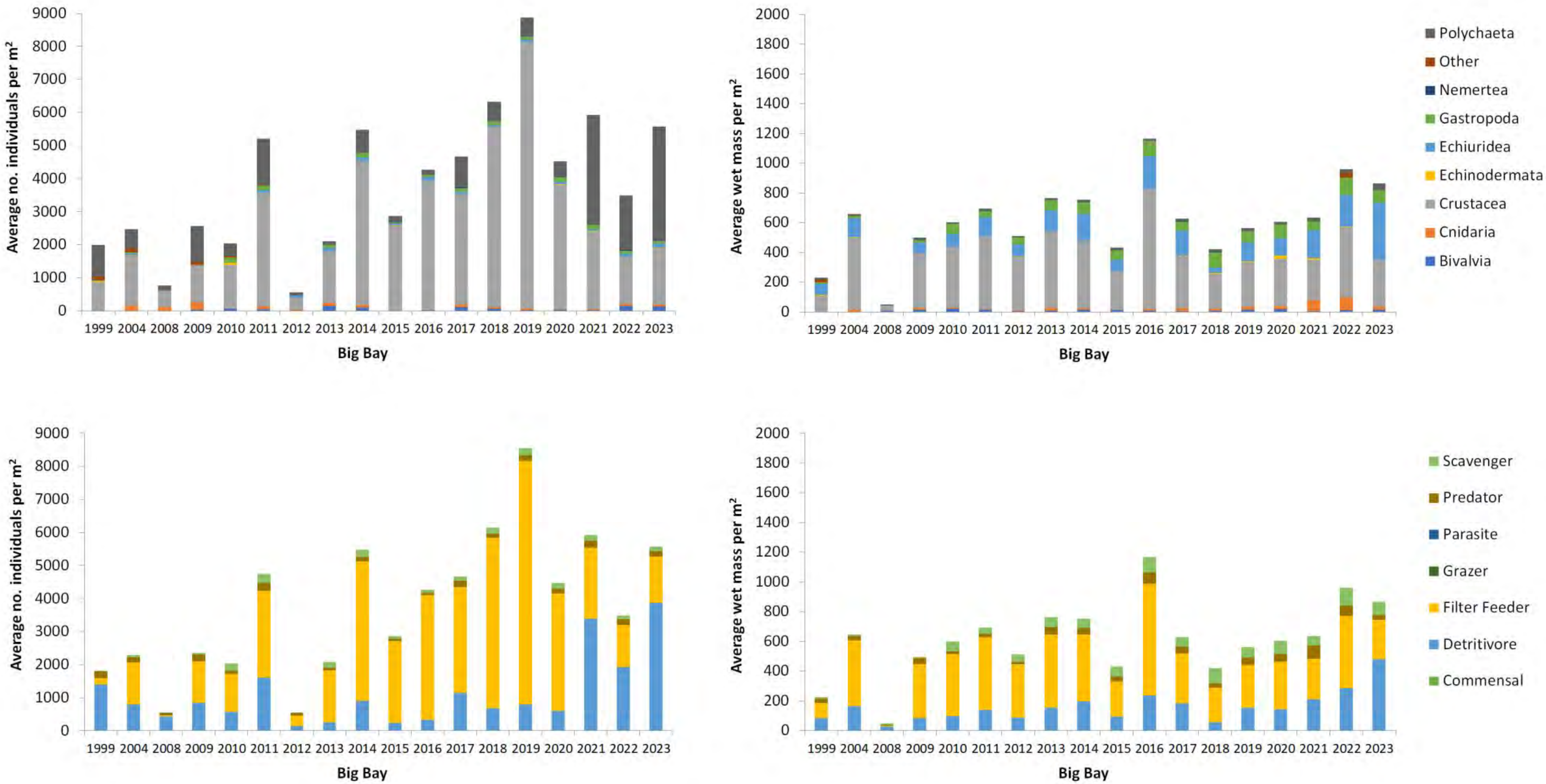


Figure 9.7. Overall trends in the abundance and biomass (g/m²) of benthic macrofauna in Big Bay as shown by taxonomic and functional groups.

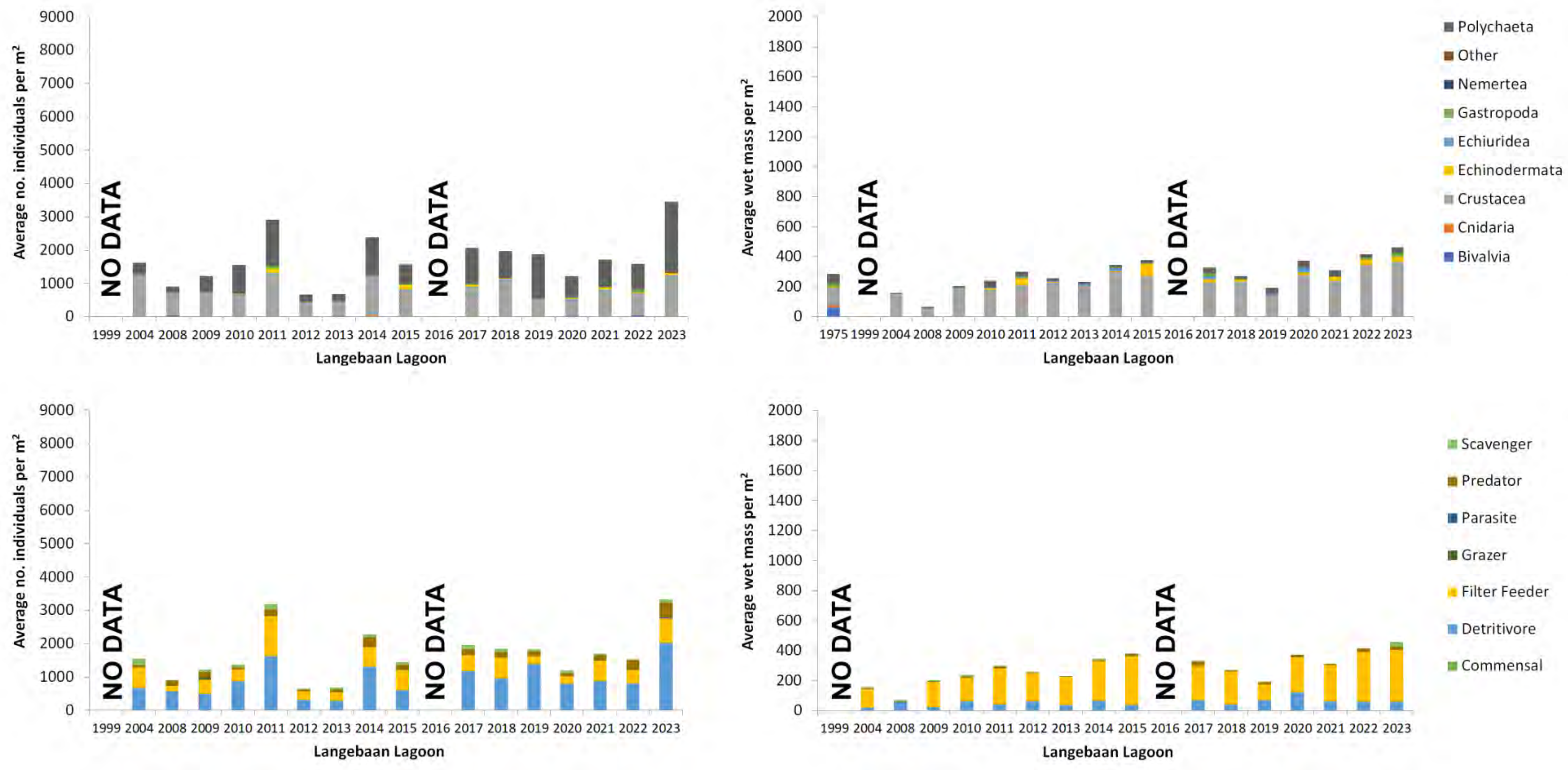


Figure 9.8. Overall trends in the abundance and biomass (g/m^2) of benthic macrofauna in Langebaan Lagoon as shown by taxonomic and functional groups.

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 *Natatolana hirtipes*; and high abundance of *Betaeus jucundus* and the polychaetes *Marphysa sanguine* and *Eteone foliosa* in 2008 samples were the species consistently responsible for the dissimilarity of 2008 Lagoon samples from those collected in other years. As mentioned above, these changes in macrobenthic community structure are thought to be related to the extensive dredging activities undertaken during 2007 and early 2008 that appeared to have had Bay-wide impacts, resulting a temporary loss of less tolerant species and a shift in community composition to one dominated by more tolerant species. Multivariate analysis of the macrobenthic samples collected over the period 2009–2023 suggests that the smaller 2009 dredging event had a limited impact with little change in macrobenthic community structure over the last fourteen years.

9.6 ELANDSFONTEIN 2023 SURVEY RESULTS

The State of the Bay monitoring activities were expanded to include monitoring of benthic macrofauna at three new sampling sites near the head of the Lagoon at Elandsfontein in 2016. Concern had been raised around potential impacts that the proposed phosphate mine at Elandsfontein might 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 eighth 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 2023 macrofauna abundance data, is 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 between the Saldanha Bay and Elandsfontein clusters which implies that the macrofaunal community composition at the Elandsfontein sites are most similar to that present in Langebaan Lagoon (80% dissimilarity) and in turn are most dissimilar to those in Saldanha (Small Bay and Big Bay - 89% dissimilarity). 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 sites.

To date, a total of 81 species (consisting of polychaetes, crustaceans, gastropods, bivalves, a nemertean and a cnidarian (Figure 9.10) have been recorded at Elandsfontein. Six of these are found nowhere else in the system namely the polychaete *Ancistrosyllis rigida*; the crabs *Danielella edwardsii* and *Paratylodiplax algoensis*; the gastropod *Nassarius kraussianus*; and an isopod belonging to the family Sphaeromatidae. Macrofaunal abundance and biomass results from 2016 to 2023 (broken down into taxonomic and functional feeding groups) are shown in Figure 9.10. A decreasing trend in abundance and biomass, opposite to that observed in other samples from the lagoon, is evident in recent years although it is not clear why this is the case.

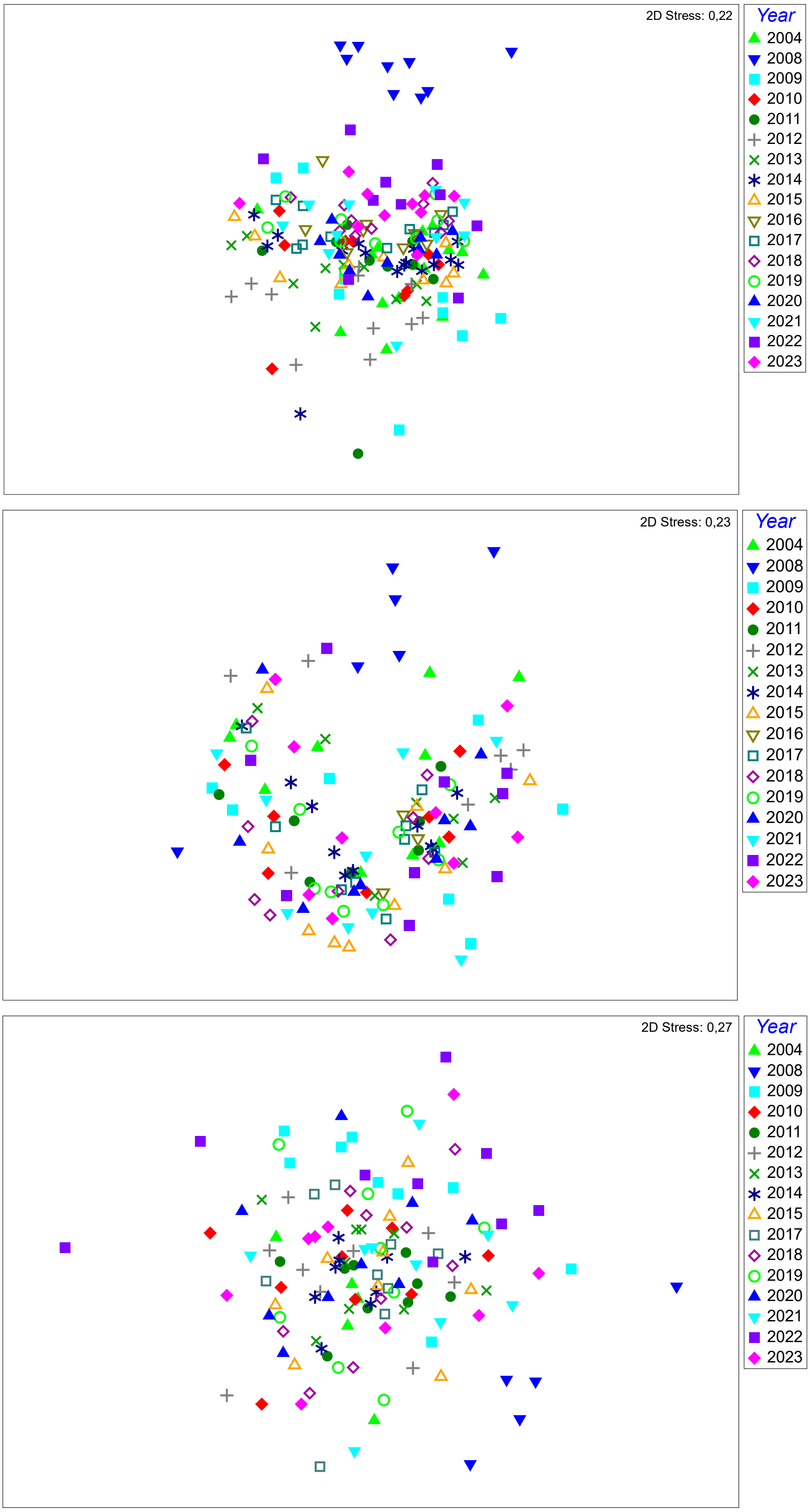


Figure 9.9 MDS plots based on macrofaunal abundance data from samples collected in Small Bay (top), Big Bay (middle) and Langebaan Lagoon (bottom) during the period 2004–2023.

On a community composition level, the samples collected from 2018 to 2023, group separately to those collected in 2016 and 2017 (Figure 9.11) – this is attributed to the aforementioned change in sampling equipment. There are further differences in macrofaunal community structure among 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). 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 groundwater in what appears to be a more estuarine habitat. This is supported by trends in water quality data (recorded by an instrument in the vicinity), which show that variations in salinity at Elandsfontein are linked to groundwater inflow as opposed to surface water inflow.

9.7 SUMMARY OF 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. Earlier studies showed 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). Indeed, reduced indices of abundance, biomass and diversity observed at the LPG site in 2019 and 2021 appear to be linked with increased disturbance at this site since the SPM was installed in this area. The latest results, however, indicate a marked improvement in these indices suggesting that some recovery in benthic macrofaunal community structure has taken place.

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-García and García-Gómez 2004). Beckley (1981) found that the marine benthos near the iron-ore loading terminal in Saldanha Bay was dominated by pollution-tolerant, hardy polychaetes. 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).

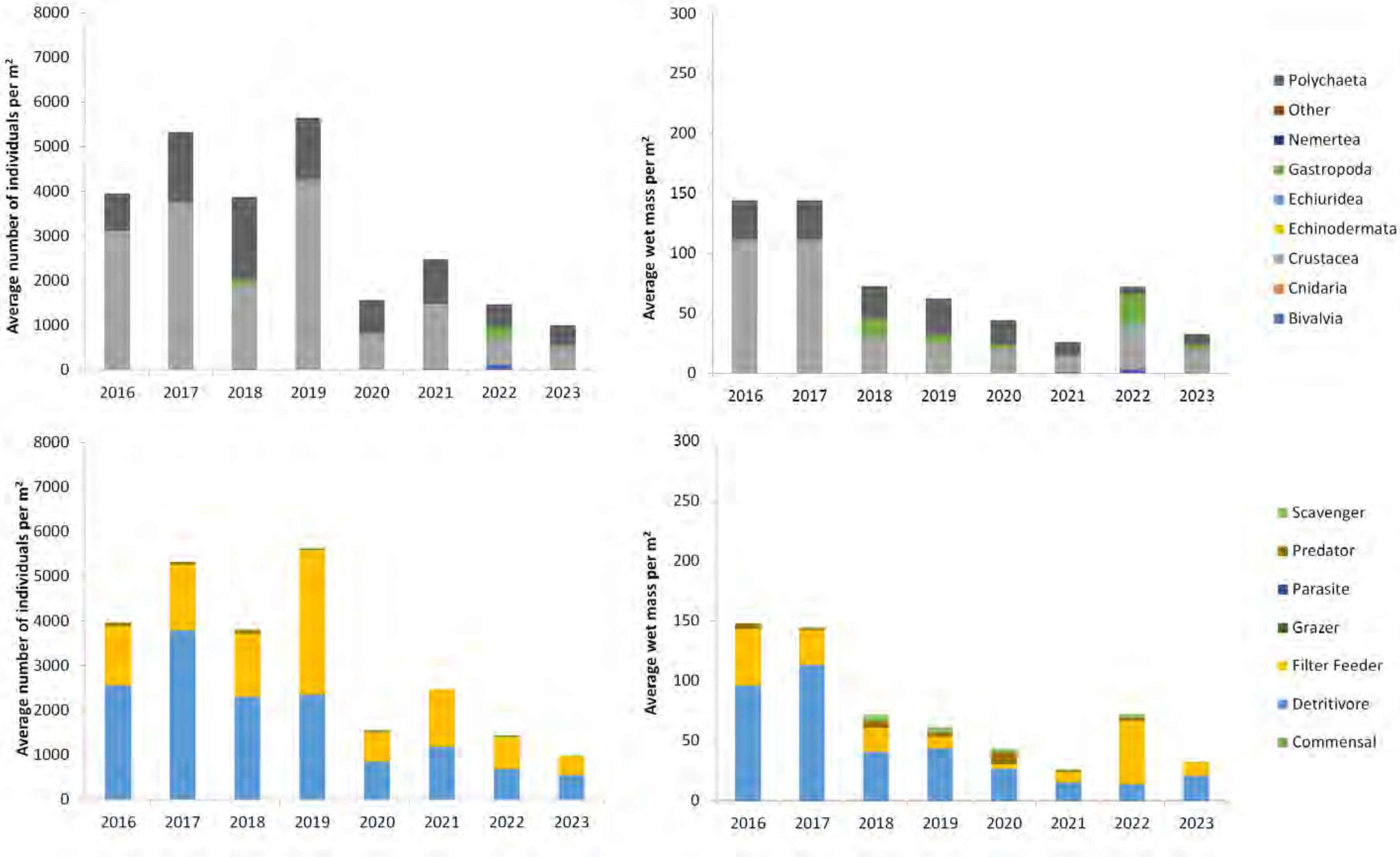


Figure 9.10. Overall trends in the abundance and biomass (g/m^2) of benthic macrofauna at Elandsfontein as shown by taxonomic and functional groups.

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 2023 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). Recent survey results indicate an increase in the prevalence of the sand prawn, *Kraussillichirus kraussi*, in Langebaan Lagoon. This is a popular bait species and it is encouraging to see an increase in both abundance and biomass in Langebaan Lagoon. At this stage we can only speculate as to why this might be the case.

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 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 establishments 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 (Clark et al. 2011, 2012). Invasion of Langebaan Lagoon by the Mediterranean 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.

Video footage taken by Anchor divers in 2021 allowed for a qualitative description of the epifaunal community on the reef habitat at two designated ADZ sampling sites in Big Bay — a total of 21 species were recorded. The reef appeared to be mostly low profile (<1 m in height), periodically inundated with sand with scattered outcrops of reef >1 m in height. This is a poorly/unstudied habitat type within Saldanha Bay and there is a dearth of information on its extent, and the nature and type of biotic communities present. The ADZ monitoring programme has been updated to include suitable reef surveys for monitoring potential aquaculture impacts on this habitat type. In addition to this, a detailed bathymetry survey using side scan sonar or multibeam echosounder of the ADZ precinct and historical extent of the abrasion platform has been recommended to map the current extent of the abrasion platform in Big Bay.

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 2023 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.

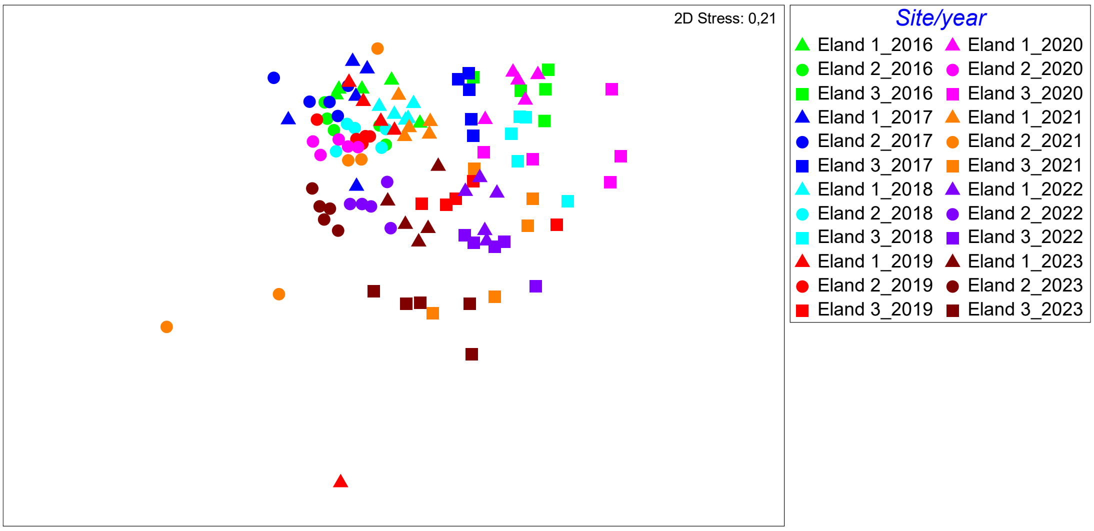


Figure 9.11 MDS plot based on macrofaunal abundance data from samples collected at Elandsfontein from 2016 to 2023.

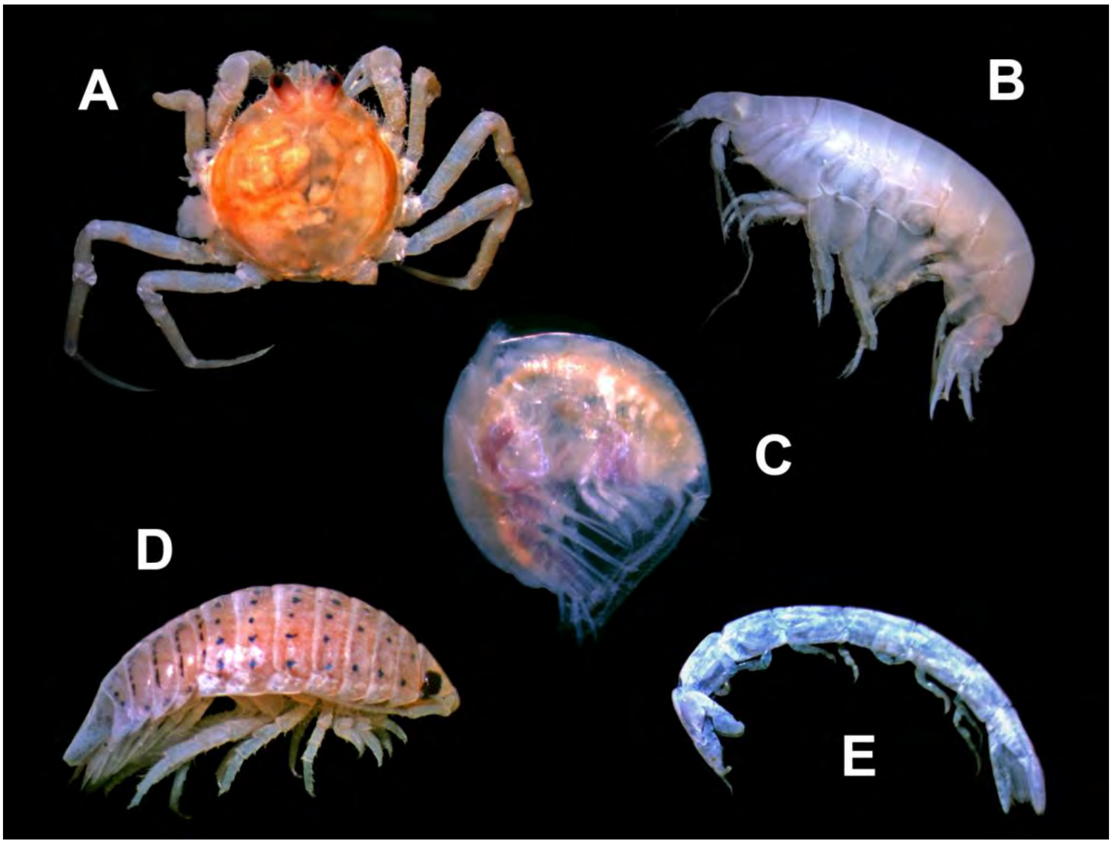


Figure 9.12 Benthic macrofauna species frequently found to occur in Saldanha Bay and Langebaan Lagoon, photographs by: A Biccard. A – *Hymenosoma obiculare*, B – *Socarnes septimus*, C – *Ampelisca palmata*, D – *Eurydice longicornis*, E – *Centrathura caeca*.

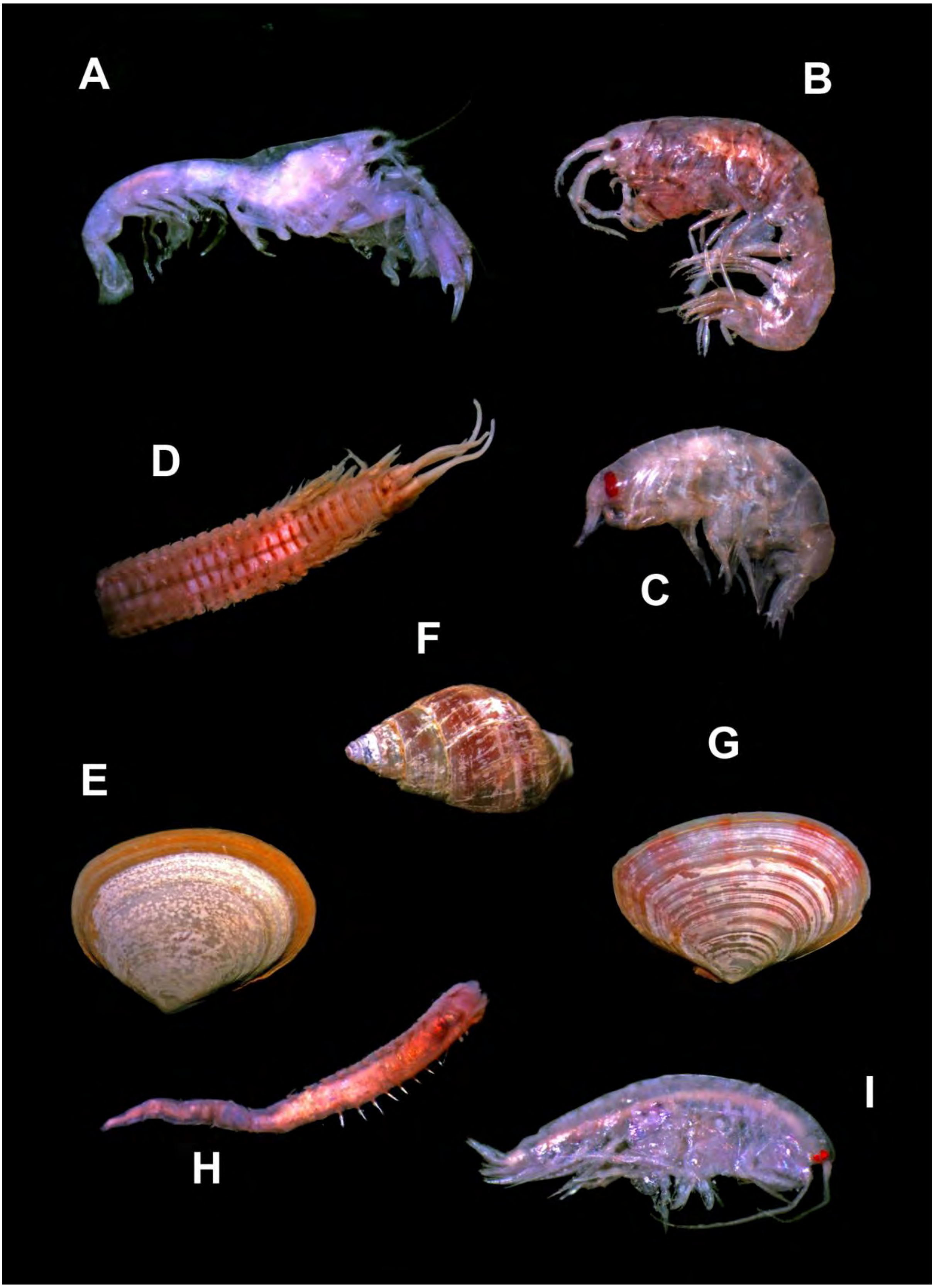


Figure 9.13 Benthic macrofauna species frequently found to occur in Saldanha Bay and Langebaan Lagoon, photographs by: A. Biccard. A – *Upogebia capensis*, B – *Idunella lindae*, C – *Hippomedon normalis*, D – *Diopatra monroi*, E – *Macoma c. ordinaria*, F – *Nassarius vinctus*, G – *Tellina gilchristi*, H – *Sabellides luderitzi*, I – *Ampelisca anomola*.

10 ROCKY SHORES

10.1 BACKGROUND

Intertidal rocky shores experience cycles of submersion and exposure due to tidal cycles. Species more tolerant to desiccation (drying out) inhabit higher elevations, while those less tolerant are closer to the water's edge. Five distinct zones are typically found on rocky shores of South Africa's southwest coast each characterised by distinct biological communities (Stephenson and Stephenson 1972, Menge and Branch 2001). These zones (moving in a landward or vertical direction) are the Infratidal zone, the Cochlear zone, the Lower Balanoid zone, the Upper Balanoid zone and the Littorina zone (Branch and Branch 2018) (Figure 10.1).

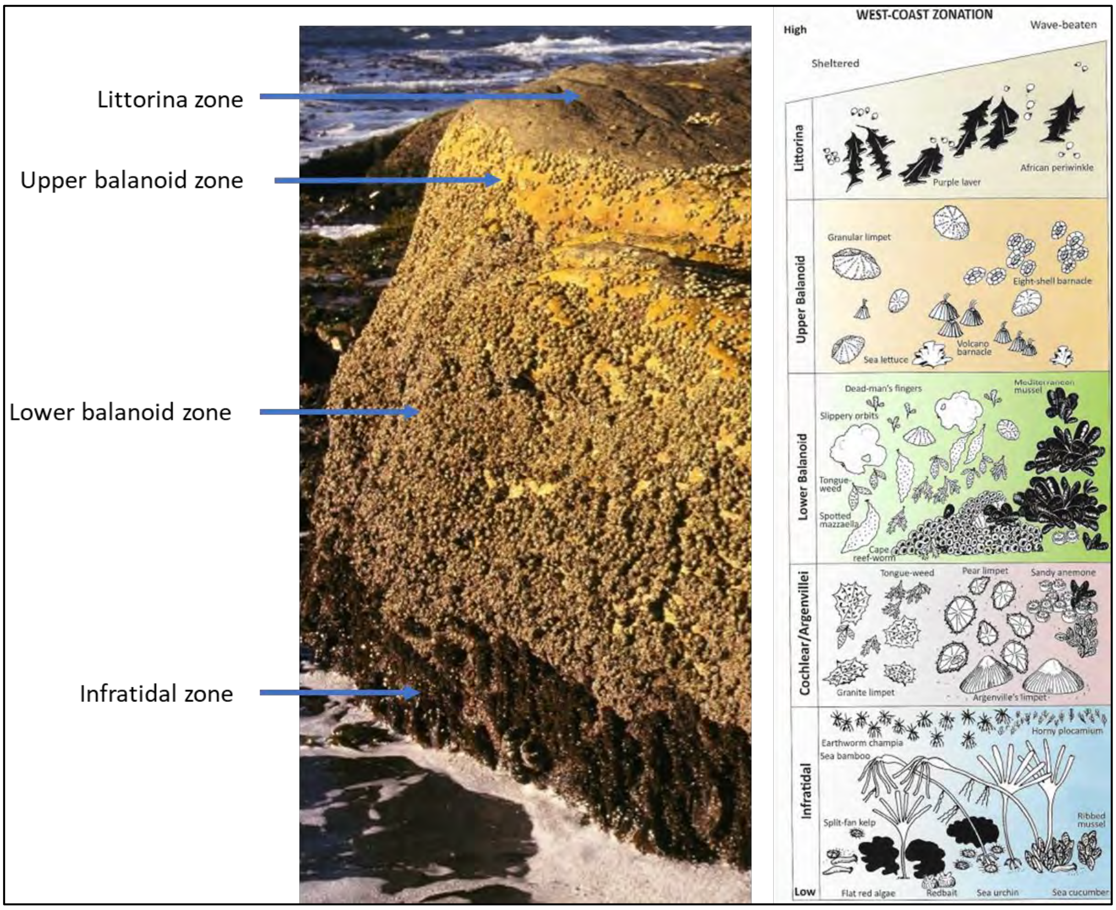


Figure 10.1. Typical pattern of zonation evident on rocky shores (modified from Clark 2009 and Branch and Branch 2018).

The Littorina zone (splash zone), which occasionally receives wave splashes, represents the harshest environment and is dominated by the southern periwinkle seasnail, *Afrolittorina knysnaensis*. The Cochlear zone is exclusive to wave-exposed shores and is densely populated by the pear limpet *Scutellastra cochlear*. It is primarily exposed during low spring tides but submerged during low neap tides. The Infratidal zone is predominantly submerged, housing species incapable of enduring prolonged exposure to air.

Monitoring of rocky intertidal communities in Saldanha Bay and Langebaan Lagoon was initiated as part of the State of the Bay Monitoring Programme in 2005. The first rocky shore survey for this programme was conducted in the same year, the results of which were presented in the first 'State of the Bay' report (Anchor Environmental Consultants 2006). Eight rocky shore sites, 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 conducted more or less annually from 2008 to 2023.

The abundance and distribution of rocky intertidal species were found to vary across different sites in Saldanha Bay. The baseline survey report concluded that wave exposure was the primary physical driver shaping intertidal rocky shore communities across the study area. It was suggested that the construction of the Marcus Island causeway and the IOT reduced wave energy reaching rocky shores across much of Small Bay, and consequently led to a change in community structure. However, the lack of historical data precluded confirmation of this hypothesis. There was a noticeable rise in percentage coverage of species as wave exposure increases with algae constituting the most substantial portion of the coverage at all sites. Sheltered sites were dominated by seaweeds, while those exposed to higher wave energy were dominated by filter-feeders. In fully sheltered sites, there is a nearly uniform distribution of percentage cover among the various functional groups, i.e., each group occupies a roughly equal proportion of the overall cover.

Further results indicated that the topography and substratum type of the shore influenced community structure. Indeed, sites consisting of rocky boulders had different biotic cover when compared to those of a flatter profile. Geographic location was also found to be an important factor. 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, which facilitates algal growth. Nevertheless, the Saldanha Bay rocky shore communities were deemed overall healthy, despite the presence of a seven alien invasive species. These included the Mediterranean mussel *Mytilus galloprovincialis,* bisexual mussel *Semimytilus patagonicus,* blue mussel *M. edulis* and bay mussel *M. trossulus* (all collectively referred to as the mytilid mussel species complex), the acorn barnacle *Balanus glandula*, the North West African porcelain crab *Porcellana africana* and the red-rust bryozoan *Watersipora subtorquata*. This marks the first record of *M. edulis* and *M. trossulus* in South Africa. Additionally, *W. subtorquata* was first reported in South Africa (and Saldanha Bay) in 1935 (O'Donoghue and de Watteville 1935) although this is the first time it was recorded during a rocky shore survey. This chapter presents results from the sixteenth annual monitoring survey conducted in March 2023.

10.2 Approach and methodology

10.2.1 Study sites

The locations of the eight rocky shore survey sites are shown in Figure 10.2. The Dive School and Jetty sites are situated along the northern shore in Small Bay. The Marcus Island, Iron Ore Terminal (IOT) and Lynch Point sites are in Big Bay, while the Schaapen Island East and West sites are located at the entrance to Langebaan Lagoon. Finally, the North Bay site is situated in Outer Bay at the outlet of Saldanha Bay.

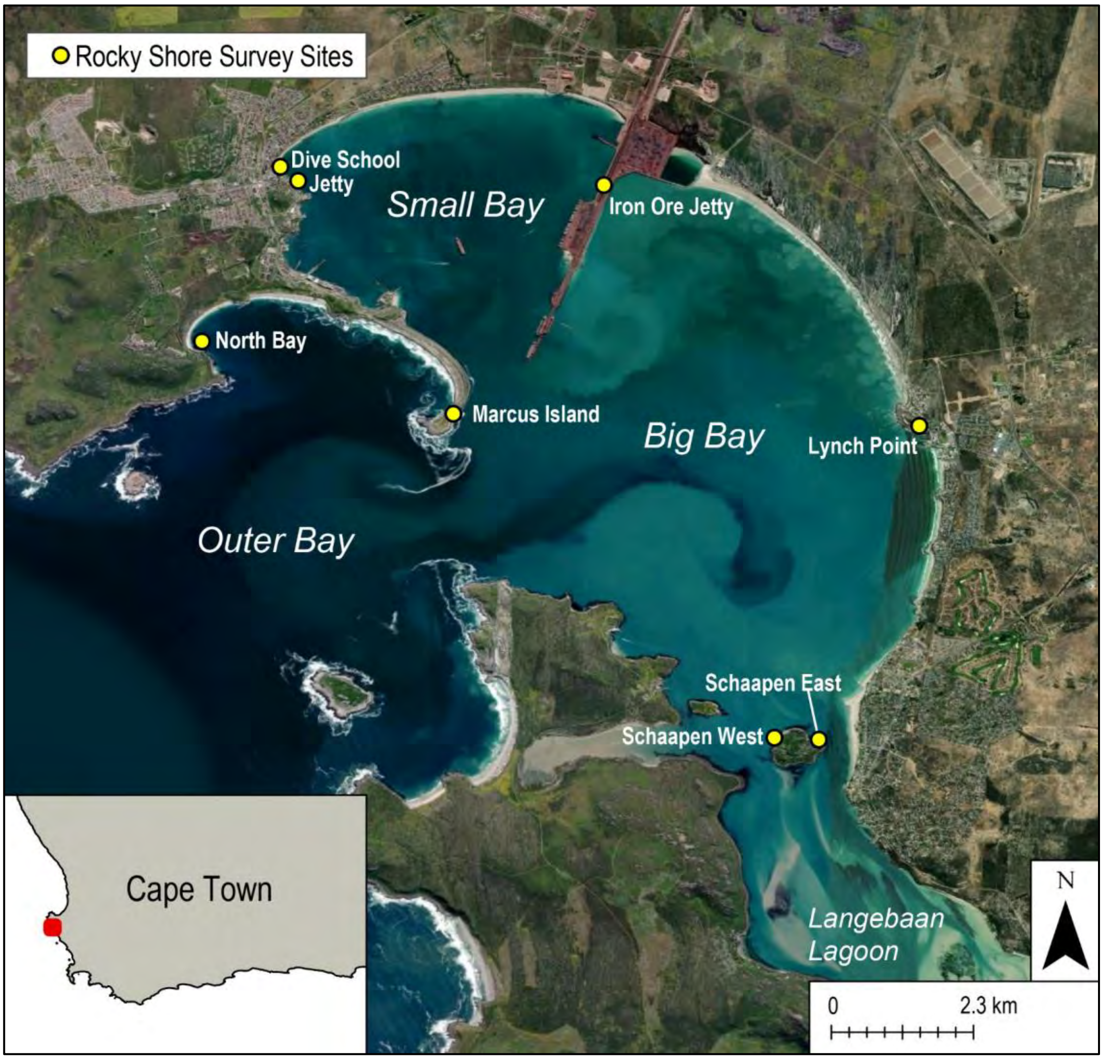


Figure 10.2. Locations of the eight rocky shore survey sites in Saldanha Bay.

The sampling sites were selected to include the different rocky shore habitats found in Saldanha Bay 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 a gentle slope, and are comprised of boulders and rubble interspersed with sandy gravel (Figure 10.3). Schaapen Island East (SE) is situated in a little baylet and is relatively sheltered and mostly flat with some ragged rock outcrops. Schaapen Island West (SW) is a little less sheltered and mostly flat with some elevated topography. The site at the IOT is semi-exposed with a 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 piled up to support a side arm of the IOT, 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, while the low shore consists of large unmovable square boulders separated by channels. Finally, the rocky intertidal site on Marcus Island (M) is flat and openly exposed to the prevailing south-westerly swell.

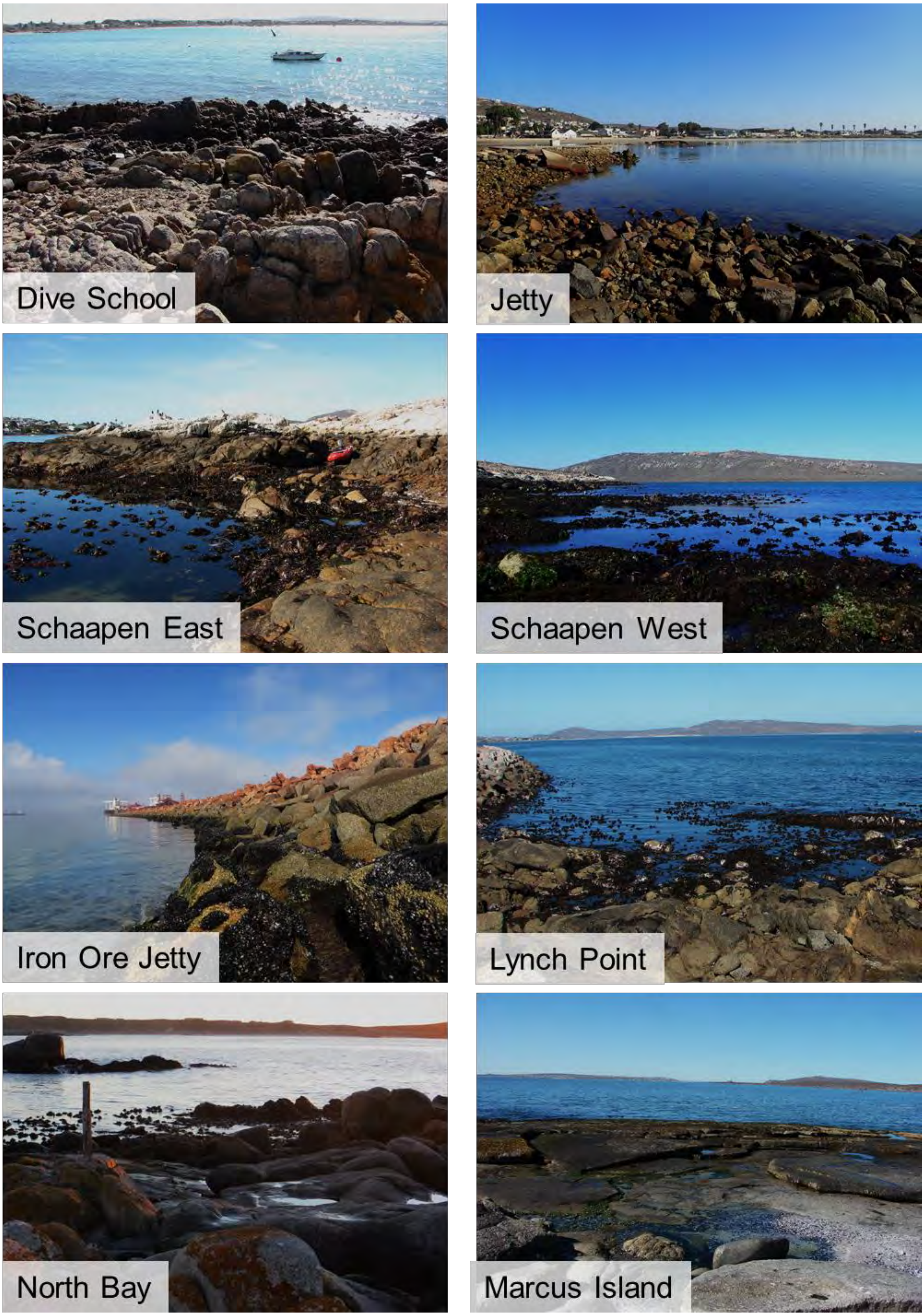


Figure 10.3. Rocky shore survey sites in Saldanha Bay. Dive School and Jetty (very sheltered) are situated in Small Bay, Schaapen Island East and West (sheltered) are in Langebaan Lagoon, Iron Ore Jetty and Lynch Point (semi-exposed) are in Big Bay, and North Bay and Marcus Island (exposed) are in Outer Bay.

10.2.2 METHODS

Each site was divided into three zones: the high, mid and low shore. In each of these zones, six quadrats (100 x 50 cm in size) were randomly placed on the shore and the percentage cover of all visible species was recorded (Figure 10.4). Individual mobile organisms were then counted to calculate densities within the quadrat area (0.5 m^2). Percentage cover refers to the space that organisms occupy on the rock surface, while abundance refers to the number of organisms present. This survey protocol has remained consistent for all surveys.

Figure 10.4. Quadrat used to survey the shore (top) and an example of the survey design (bottom) with white blocks representing the quadrats.

As no biota were removed from the shore, 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. Algae and invertebrates that could not be easily identified to genus or species level in the field were recorded under a higher classification (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

Each year, the biotic data from the eight rocky shore sites are analysed using multivariate statistical techniques available on the software package PRIMER 7. Various diversity indices, such as the total number of species, Evenness, and Shannon-Wiener diversity index, are also employed to assess and utilise as indicators of community structure. However, as there hasn't been a discernible trend in the diversity indices observed since the survey's inception in 2005, both spatially and temporally, and given the challenge of interpreting the PRIMER statistics for the general public, this year's report presents the results differently. The findings are visually represented using bar graphs, and descriptive statistics are used to make it more reader-friendly in identifying patterns and understanding changes. For a more detailed interpretation of diversity indices, readers can refer to the 2022 State of Saldanha Bay report (Clark et al. 2022).

10.3 Results and discussion

10.3.1 General trends in community composition

In 2023, a total of 111 species were recorded across all rocky shore sites. Many of these species had been previously documented in one or more of the earlier monitoring surveys, and their presence is confirmed by various studies conducted in the Saldanha Bay area (e.g., (Simons 1977, Schils et al. 2001, Robinson et al. 2007a). These species are also characteristic of what is found on the South African west coast as reported in (Day 1974) and (Branch et al. 2022). Since the start of the surveys in 2005, the cumulative count of recorded species has now surpassed 200.

Out of the 111 species recorded in the 2023 survey, 39 (representing 35%) were algae, while 72 (comprising 65%) were invertebrate animals. These species spanned diverse taxonomic groups, including Chlorophyta (green algae), Rhodophyta (red algae), and Ochrophyta (brown algae), as well as porifera (sea sponges), gastropods (sea snails and limpets), bivalves (mussels), echinoderms (sea urchins, sea cucumbers, feather stars, and sea stars), ascidians (sea squirts like redbait), Cnidarians (sea anemones, soft corals, and hydroids), polychaetes (bristle worms), arachnids (sea spiders), and crustaceans (barnacles and crabs) (Figure 10.5). Amongst these species, seven were identified as alien species. These included the Mediterranean mussel *Mytilus galloprovincialis,* bisexual mussel *Semimytilus patagonicus,* blue mussel *M. edulis* and bay mussel *M. trossulus* (all collectively referred to as the mytilid mussel species complex), the acorn barnacle *Balanus glandula*, the North West African porcelain crab *Porcellana africana* and the red-rust bryozoan *Watersipora subtorquata*. This marks the first record of *M. edulis* and *M. trossulus* in South Africa. Additionally, *W. subtorquata* is recorded for the first time as part of a rocky shore survey, with its presence noted at several sites. However, its presence in Saldanha Bay was noted in 1935 (O'Donoghue and de Watteville 1935). The alien porcelain crab *P. africana* was first recorded in a State of the Bay Survey from a site on the western shore of Small Bay in 2021. This species is native to North West Africa and is believed to have been introduced to Saldanha Bay through shipping activities. Its initial discovery occurred in dense beds of the alien mytilid mussels back in 2012 (Griffiths 2018). In 2022, the species was observed at multiple sites in Saldanha Bay displaying higher densities and occupying kelp holdfasts as well (Clark et al. 2022). In 2023, it was observed in lower densities and only at the Iron Ore Terminal and Jetty.

M. galloprovincialis and *S. patagonicus* (previously *S. algosus*) were believed to be the only alien mussels present in Saldanha Bay (and were collectively referred to as *Mytilus* spp. in previous reports). However, recent DNA (Deoxyribonucleic acid) analysis suggests the potential presence of two other morphologically similar species, the blue mussel *M. edulis* and the bay mussel *M. trossulus*. Detailed information on this discovery is presented in Chapter 13: Alien and Invasive Species. Given the difficulty in reliably distinguishing these species based on morphological characteristics, they are collectively referred to as the mytilid species complex. Nonetheless, it's important to note that *M. galloprovincialis* is still considered the dominant mussel species, as inferred from DNA barcoding analysis and supported by previous studies (Daguin and Borsa 2000, Westfall et al. 2010, Ab Rahim et al. 2016).

It's noteworthy that the overall number of taxa observed at the study sites has remained relatively stable over the years, as reported in previous State of the Bay reports (Anchor Environmental Consultants 2009, 2010, Clark et al. 2011, 2012, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022). The percentages cover represented by each taxon in the 2023 dataset are presented below.

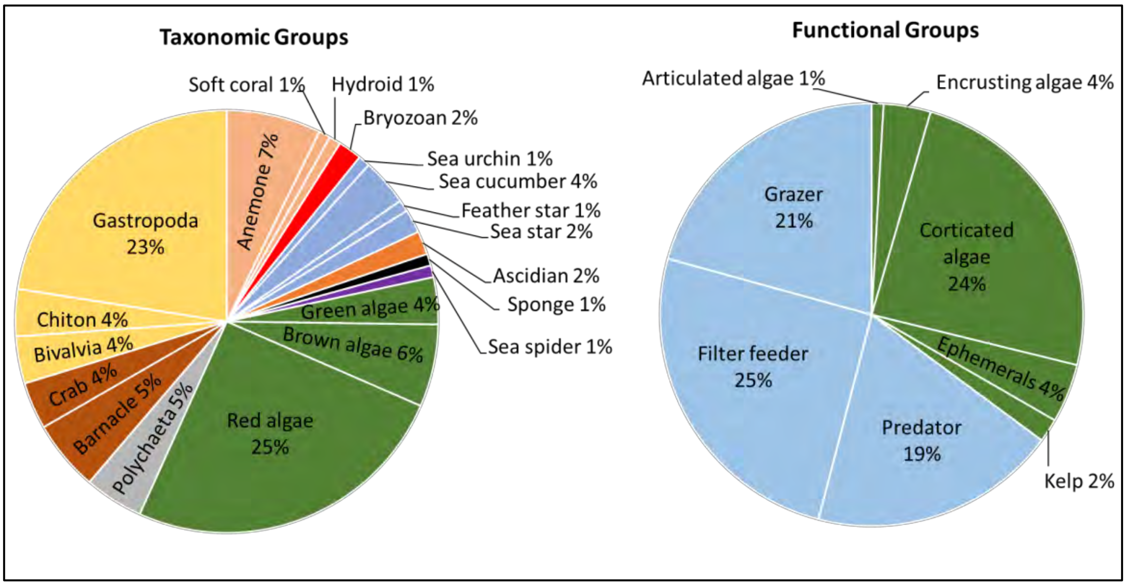


Figure 10.5. Proportions of taxonomic (right) and functional groups (left) that made up the 111 species that were recorded during the survey.

Functional groups categorise organisms with similar ecological roles in ecosystems, providing insights into how species influence community structure and ecosystem health in rocky shores. The most common functional groups found in rocky shore ecosystems are listed below:

- Grazers feed on algae or plants, helping to control algal growth and maintain the balance of the ecosystem. Examples include limpets, certain gastropods and echinoderms.
- Filter feeders obtain their nutrients by filtering small particles from the water, e.g., barnacles and mussels. They are highly susceptible to pollution, and a decline in their population can serve as an indicator of pollution.
- Predators consume other animals and play a crucial role in controlling prey populations. Examples include predatory gastropods, crabs and anemones.
- Ephemeral algae are fast-growing, short-lived algae that can rapidly colonise bare rock surfaces after disturbance events.
- Corticated algae are typically large and structurally complex algae that attach to rocks and provide habitat for other organisms.

- Crustose algae form thin, encrusting layers on the rocks. They can help stabilise the substrate and provide a surface for other organisms to attach to. A decline could indicate habitat degradation.

Of the species recorded, the faunal component was represented by 28 species of filter feeders (25%), 23 grazers (21%), and 21 predators/scavengers (19%) (Figure 10.5). The algal component comprised 27 corticated (24%) seaweeds, five ephemerals (4%), four encrusting algae (4%), one articulated alga (1%) and two kelp species (2%). Coralline algae taxa are likely underestimated as most species are not identifiable in the field and are thus combined into larger groups.

Monitoring functional groups in rocky shore ecosystems provides valuable information about the impacts of human activities, pollution, and environmental changes. The diversity of functional groups and changes in diversity can mean a shift in biodiversity and health of the ecosystem.

10.3.2 Spatial variation in community composition within sites

Species that are more tolerant to desiccation (drying out) are found near the high-water mark, while those that cannot stand long periods of water recession are found near the low-water mark. Total biotic cover generally increased from high to low shore from an average of 40% to 60% cover.

High shore

The high shore is typically characterised by barren rock, which constitutes over 80% of this zone. Algal cover is notably sparse in this area, with occasional occurrences of the encrusting algae *Hildenbrandia* spp. and the purple laver algae *Porphyra capensis* in more exposed sites (Figure 10.6).

Mobile species are scarce, but include the broad-rayed limpet *Helcion pectunculus*, the Cape false limpet *Siphonaria capensis*, the serrate false limpet *S. serrata*, and the spiny chiton *Acanthochitona garnoti*. At sheltered boulder shores (Dive School and Jetty), common species include the variegated topshell *Oxystele antoni* and tiger topshell *O. tigrina* and the shore crab *Cyclograpsus punctatus*. In contrast, the periwinkle *A. knysnaensis* is more prevalent at the more exposed sites (Lynch Point, Marcus Island and North Bay). These periwinkles are often found in moist cracks and crevices, or between the toothed barnacle *Chthamalus dentatus* and the invasive barnacle *B. glandula*. This alien is prominently found across various sites, although the extent of coverage may vary (Clark et al. 2022).

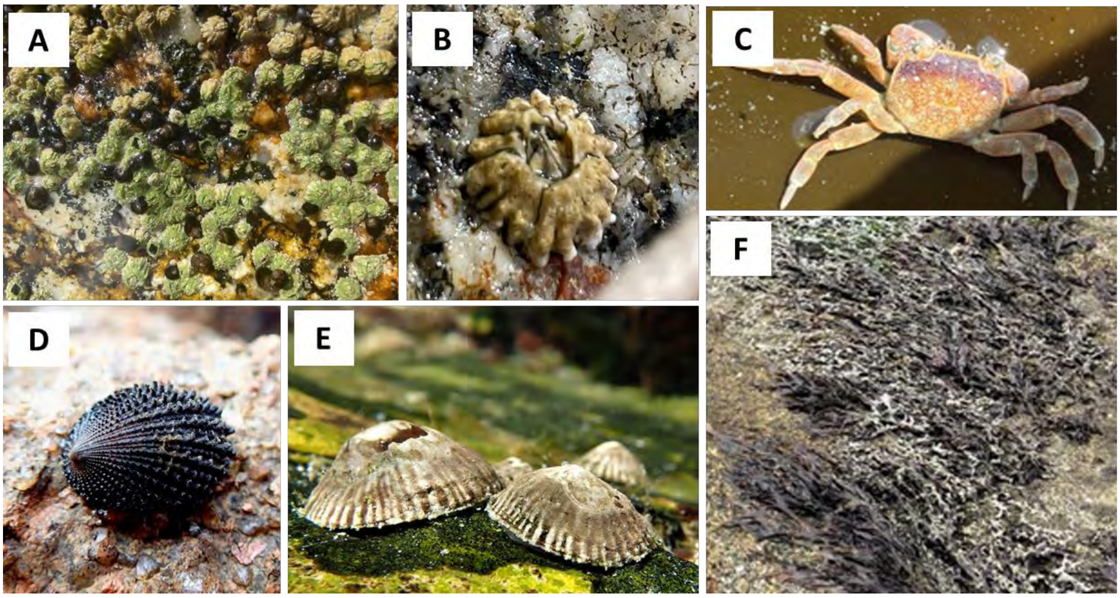


Figure 10.6. Examples of species commonly found at the high shore sites included A) the southern periwinkle *Afrolittorina knysnaensis* interspersed with the alien barnacle *Balanus glandula*, B) the toothed barnacle *Chthamalus dentatus*, C) the shore crab *Cyclograpsus punctatus*, D) the broad rayed-limpet *Helcion pectunculus*, E) the Cape false limpet *Siphonaria capensis* and F) the purple laver algae P*orphyra capensis*.

MID SHORE

Within sheltered sites, the mid shore was relatively barren, while the more exposed sites with higher wave action had more biotic cover as has been the case in most years (Clark et al. 2019, 2020, 2021, 2022). Grazers are common and include various limpets, chitons and topshells. The dwarf cushion starfish *Parvulastra exigua* was typically found in moist rock-depressions and small pools, while the whelk *Burnupena spp*. and the variegated topshell periwinkle *O. antoni* were frequently observed sheltering in depressions created by mussel beds (Figure 10.7).

Dominant filter feeding taxa comprised mussels from the mytilid species complex, the ribbed mussel *Aulacomya atra* and the barnacles *Tetraclita serrata* and *B. glandula*. The tiny periwinkle *A. knysnaensis* was found nestling in amongst the barnacles at sites inundated with *B. glandula*. This periwinkle is normally abundant primarily in the upper intertidal where it congregates in crevices to escape the heat of the day, emerging at night or on moist days to feed (Branch et al. 2010). In the high shore where wave stress is minimal, *A. knysnaensis* is naturally abundant but in the mid shore, where wave stress is greater, this species normally declines in abundance without shelter (Laird and Griffiths 2008, Griffiths et al. 2011). Encrusting Bryozoa are also more common on the mid shore. A common sight on the exposed Marcus Island site were extensive beds of alien mytilid mussels, often covered with the sea lettuce *Ulva* spp. on the higher reaches and by the spiky turf weed *Caulacanthus ustulatus* lower down (Figure 10.9).

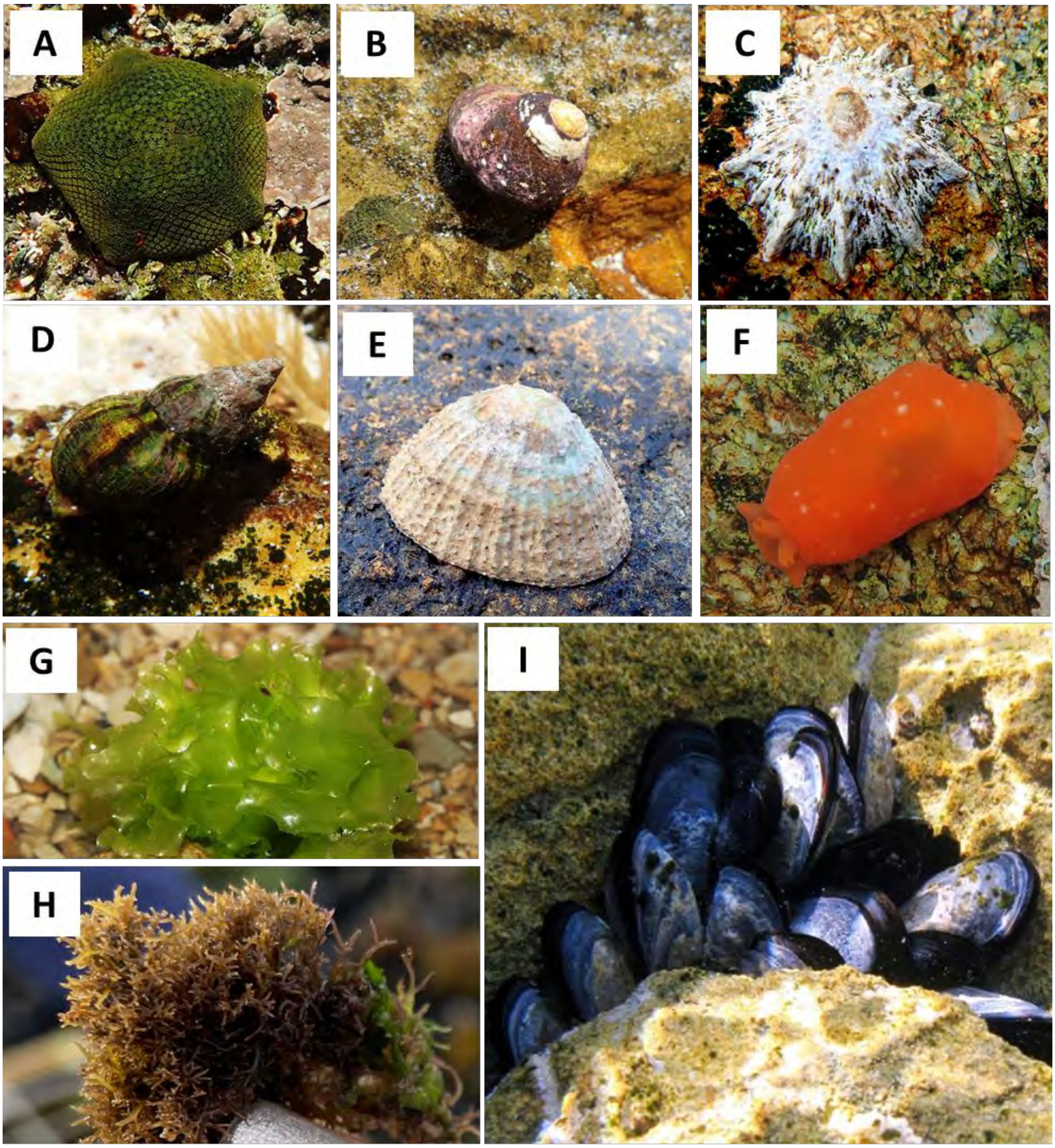


Figure 10.7. Examples of species commonly found at the mid shore sites included A) the dwarf cushion-star *Parvulastra exigua*, B) the variegated topshell *Oxystele antoni*, C) the granite limpet *Scutellastra granatina,* D) burnupena whelks *Burnupena spp*, E) the granular limpet *Cymbula granularis*, F) various nudibranchs, G) the sea lettuce *Ulva* spp., H) spiky turf weed *Caulacanthus ustulatus* and I) the mytilid mussel species complex.

Figure 10.8. Commonly observed along the mid shore of the exposed Marcus Island site are extensive beds of the blackish alien mytilid mussels and *Balanus glandula* barnacles, often covered with the green sea lettuce *Ulva* spp. on the higher reaches and by the reddish-brown spiky turf weed *Caulacanthus ustulatus* lower down.

LOW SHORE

The low shore exhibits the highest species diversity and percentage cover, mainly dominated by algae, with 38 recorded species. Crustose Coralline is the predominant algae across all sites, with an average percentage cover of 16%, reaching up to 36% at the exposed Lynch Point site. Other dominant algal species include various seaweeds like *Gigartina bracteata*, *Gigartina polycarpa*, *Sarcothalia stiriata*, *Champia lumbricalis*, *Hypnea spicifera*, *Gelidium pristoides*, and kelps like *Ecklonia maxima* and *Laminaria pallida*.

At very sheltered sites like Dive School and Jetty, both faunal and algal cover is notably lower compared to exposed sites like North Bay and Marcus Island. The most dominant species in these sheltered areas include alien mytilid mussels, the indigenous ribbed mussel *A. atra*, pear limpets *S. cochlear*, and the cape sea urchin *Parechinus angulosus*. The indigenous mussel predominantly inhabits the low shore, residing deep within the mytilid beds where they take advantage of the moisture trapped within the overlaying dense mussel matrix. While *A. atra* showed significant presence and even outcompeted the alien mytilid mussels at Marcus Island in 2011 (Clark et al. 2012), recent surveys indicate that mytilids have consistently outnumbered this local mussel in most locations over the past few years, often overshadowing the indigenous mussel. However, surveys indicate *A. atra* is still common at all sites, with some variation in percentage cover from year to year. During the 2023 survey, this mussel was more prevalent at North Bay, Lynch Point, and Dive School. As these populations cannot be seen without destructive sampling, it is possible that the changes in *A. atra* cover recorded between survey years is at least partly due to the mytilid layers being removed from the rocks by waves, exposing the indigenous mussel beneath.

Other dominant species include *O. tigrina*, *S. argenvillei*, *Crepidula porcellana,* slipper limpets, sponges, tubeworms, *Pyura stolonifera* redbait, colonial ascidians, various sea anemones (*Bunodactis reynaudi*, *Bunodosoma capense*, *Actinia equina*), the starfish *Henricia ornata*, various species of sea cucumbers (*Pentacta doliolum*, *Pseudocnella insolens* and *Thyone aurea*), and several crab species (such as *Guinusia chabrus* and *Paguristes gamianus*). Some less frequently encountered species include sea spiders (Pycnogonida), soft corals (*Alcyonium fauri*), nudibranchs such as *Doris granulosa*, and hydroids (Figure 10.9).

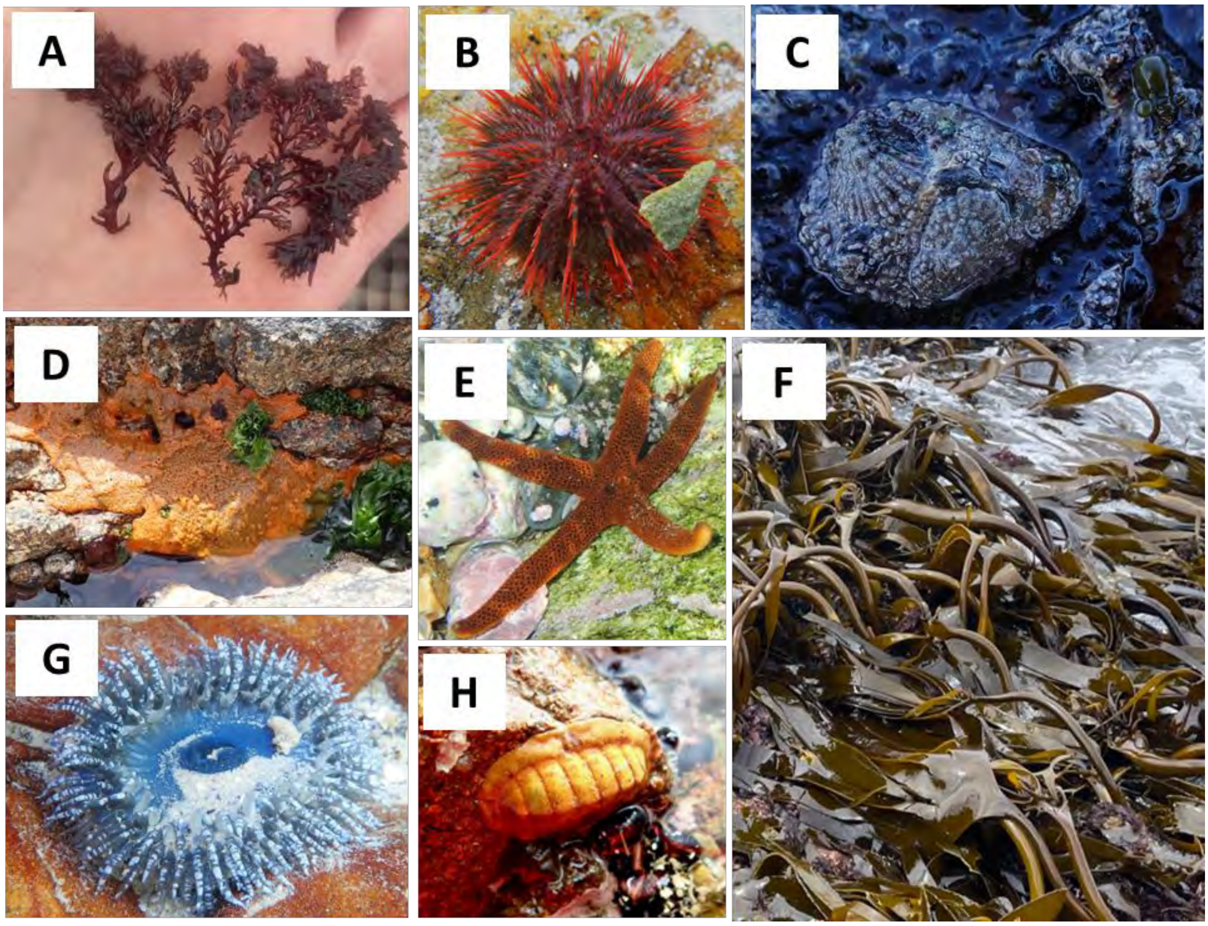


Figure 10.9. Common occupants of the low shore include A) little hands algae *Portieria hornemannii*, B) the Cape sea urchin *Parechinus angulosus*, C) the pear limpet *Scutellastra cochlear*, D) crumb-of-bread sponge *Hymeniacidon perlevis*, E) the reticulated starfish *Henricia ornata*, F) split-fan kelp *Laminaria pallida* and G) sandy anemone *Bunodactis reynaudi* and H) the broad chiton *Callochiton dentatus*.

10.3.3 Spatial variation in community composition across sites

The biotic cover of rocky intertidal species varies across Saldanha Bay (Figure 10.10). This can be attributed to various factors including natural variability, settlement rate, substratum availability, predation, competition and disturbance, with the most important factor responsible for community differences amongst sites being exposure to wave action and, to a lesser extent, shoreline topography (Mcquaid and Branch 1984). The biotic cover of the various functional groups across the shore is depicted in Figure 10.10 and arranged in order of increasing wave action.

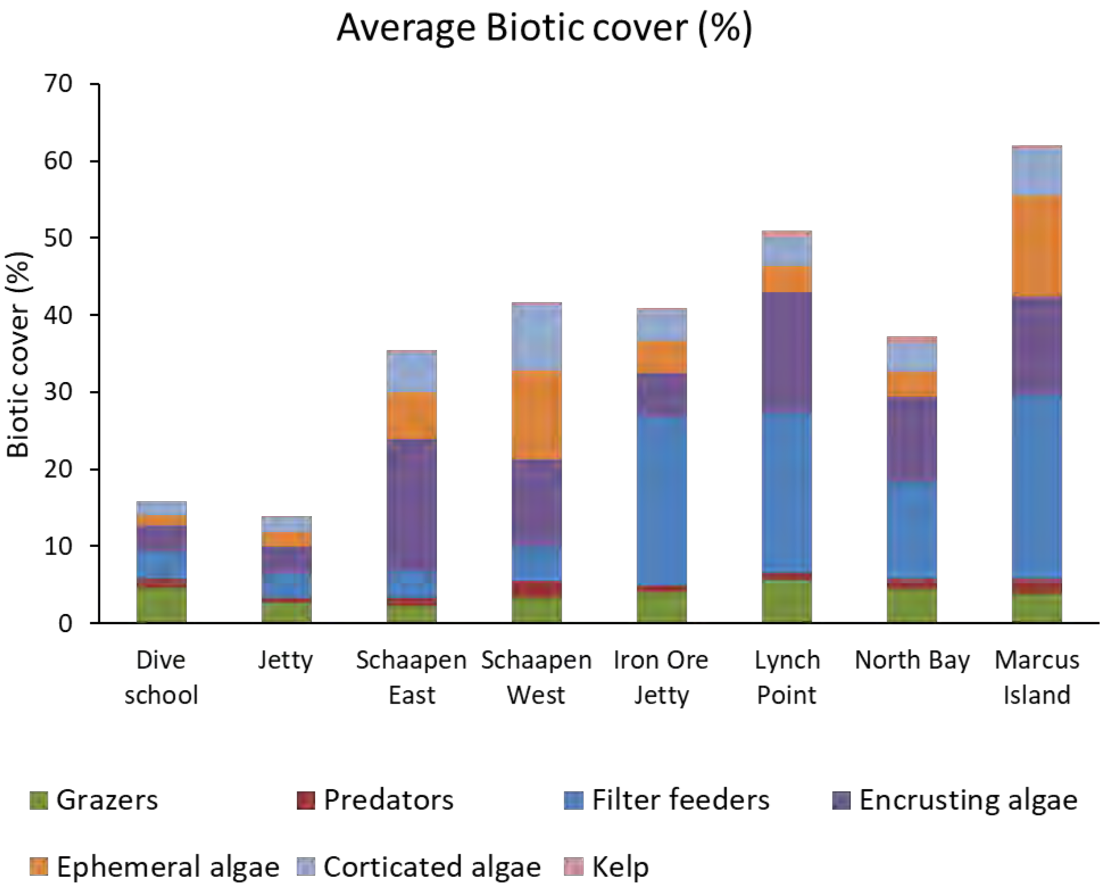


Figure 10.10. Average percentage cover of the seven functional groups, averaged over the period 2005–2023 at the eight rocky sore sites, arranged in order of increasing wave action. Functional groups include grazers (green), filter feeders (dark blue), predators (red), kelp (pink), ephemeral algae (orange), corticated algae (light blue) and encrusting algae (purple).

Sheltered sites have lower faunal and algal cover compared to exposed sites. Exposed sites have a balanced presence of flora and fauna, with filter-feeders being the predominant faunal group. There is a noticeable increase in the percentage coverage of species as wave exposure intensifies, especially among filter-feeding taxa and encrusting algae. In fully sheltered areas, functional groups occupy a roughly equal proportion of the overall cover. Grazers and predators maintain relatively stable prevalence across all sites, regardless of exposure levels.

Many studies have been conducted worldwide on the effect of wave action on the distribution of rocky shore organisms (Lewis 1964, Mcquaid and Branch 1984, Raffaelli and Hawkins 1996, Bustamante et al. 1997, Menge and Branch 2001, Denny and Gaines 2008). The effect of wave exposure varies according to phyla and functional form group depending on abilities to withstand hydrodynamic forces (Denny and Gaylord 2002, Nishihara and Terada 2010). Increasing exposure reduces siltation and increases the supply of dissolved oxygen and particulate food matter, facilitating the presence of certain sessile, filter-feeding species (Mcquaid and Branch 1985, Bustamante et al. 1995, Steffani and Branch 2003) such as mussels and barnacles (Pfaff et al. 2011). In contrast, sheltered shores are typically dominated by algae (Mcquaid and Branch 1985). Hydrodynamic forces can cause extensive damage to exposed rocky shore communities, fundamentally altering their structure and function. Consequently, these shores are highly dynamic and unstable, whereas protected shores and their communities tend to be more stable.

While wave force is the main factor driving differences in the rocky shore communities, factors like topography, micro-topography and substratum type or smoothness can be crucial factors driving species richness, abundance and even body size (Kostylev et al. 2005, Guarnieri et al. 2009) Boulder shores have greater microhabitat diversity compared to more level shores. This is mainly because the top of larger boulders stays exposed for a 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 configuration increases the surface area for the attachment of organisms but may also reduce water movement, which could 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 downstream. Smaller boulders may be unstable and often have a more impoverished community than their larger counterparts (McGuinness 1987, Guichard and Bourget 1998, Londoño-Cruz and Tokeshi 2007, McClintock et al. 2007). All of these factors result in boulder fields supporting different species assemblages when compared to those of level shores (Sousa 1979a, McGuinness 1984, Mcquaid and Branch 1985, McGuinness and Underwood 1986, Takada 1999, Cruz Motta et al. 2003, Davidson et al. 2004, Le Hir and Hily 2005).

The 2023 surveys corroborated these findings as sites featuring large boulders (Iron Ore, Lynch Point, and North Bay) were found to have a high percentage cover of faunal species compared to the other sites, However, it's noteworthy that Marcus Island, characterised by extensive flat surfaces, also displays an exceptionally high percentage cover of fauna. This phenomenon could likely be attributed to the extremely high wave action experienced at Marcus Island. Sites with extensive, smooth surfaces displayed a more substantial encrusting algae coverage compared to sites with smaller boulders and rougher surfaces, such as the Jetty, Dive School, and Iron Ore locations.

Other factors might also contribute to differences in community composition. For example, the islands exhibited a higher presence of ephemeral and corticated algae. These sheltered sites are home to numerous birds and receive substantial nutrient input from seabird guano, promoting algal growth and explaining the higher percentage of this algae in these areas.

Differences in community structure between Schaapen Island and the other two sheltered sites may 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 a slight difference in water quality (e.g., temperature) compared to the water in the Bay, which in turn leads to differences in biological communities (Day 1959, Grindley 1977, Robinson et al. 2007a, Clark et al. 2012).

10.3.4 Temporal variations in abundance of functional groups

Understanding changes in benthic diversity over time is important because increasing levels of environmental stress generally results in changes in biotic composition (types of taxa and functional groups encountered). This includes a loss of certain species and an increase in others. The total percentage cover of the seven functional groups over the period 2005–2023 is presented in Figure 10.11 and Figure 10.12 below. The functional groups include grazers (green), filter feeders (dark blue), predators (red), kelp (pink), ephemeral algae (orange), corticated algae (light blue) and encrusting algae (purple). There have been fluctuations in the percentage cover and composition of biota on the rocky shores during the survey period. Among these sites, Marcus Island has shown the most stability in terms of total percentage biotic cover, although the types of organisms recorded have changed. A notable trend across most sites has been the increase in encrusting algae, particularly over the last three to five years.

Since 2005, faunal presence at the Dive School has decreased, likely linked to a decline in grazers, while the presence of algae has increased. Encrusting algae has become notably more prevalent over the past three years at this site while corticated algae also exhibited higher percentages in 2023 compared to the previous decade. A decline in biota was also evident between 2012 and 2020. At the Jetty, both percentage cover and composition of biota have remained relatively stable over the past three years, with a slightly higher presence of predators and grazers. Schaapen Island East experienced a decline in 2020 but has since seen a steady increase in the percentage cover of species over the past four years, reaching its highest-ever recorded cover in 2023. This is nearly double what has been observed in many previous surveys.

Apart from 2020, encrusting algae have consistently comprised the largest proportion of the biotic cover on the shore since 2018, making up approximately 50% of the total percentage biotic cover in 2023. This represents the highest percentage cover of this species at any of the sites over any of the sampling years. The percentage cover of species at Schaapen Island West has been lower over the past six years compared to most years prior to 2018. Notably, almost no encrusting algae were recorded for 2022, although they made a return in 2023, this time occupying larger areas. Corticated algae have consistently been present in great numbers since 2020 compared to some previous years.

Over the past four years, the Iron Ore Jetty has experienced a noticeable decline in both percentage cover and community composition of biota. One notable observation is the decrease in filter feeders, specifically in *B. glandula* and mytilid mussels. While filter feeders have consistently made up most of the biotic cover on the shore, they have shown a severe decline over the past five years. This decline can be attributed to severe weather events and wave action, which frequently displace these species from the shore. Conversely, encrusting algae have shown a steady increase over the same period and is likely due to them occupying this open space. Between 2014 and 2019, low percentage biotic cover was recorded Lynch Point. However, in recent years, there has been an increase in biotic cover. Following this period of low biotic cover, the community composition shifted from being dominated by filter feeders to being dominated by encrusting algae, a trend similar to what was observed at Iron Ore. The highest recorded percentage cover at Lynch Point was in 2023. This increase was primarily driven by the significant presence of encrusting algae and filter feeders. In 2022, the biotic cover at North Bay reached its highest recorded levels, with over 70% of the sampled shoreline supporting biota. Encrusting algae have consistently maintained elevated levels since 2014, while filter feeders have demonstrated relatively consistent percentages, with a slight decline in 2023. Additionally, corticated algae were more abundant than usual in 2022. Among the surveyed sites, Marcus Island has displayed the most stability in terms of total percentage cover, despite undergoing changes in community composition since 2014. Prior to 2014, the shore was primarily dominated by ephemeral algae. However, a significant decrease in algae occurred between 2014 and 2017, after which the coverage of algae shifted to being dominated by encrusting algae.

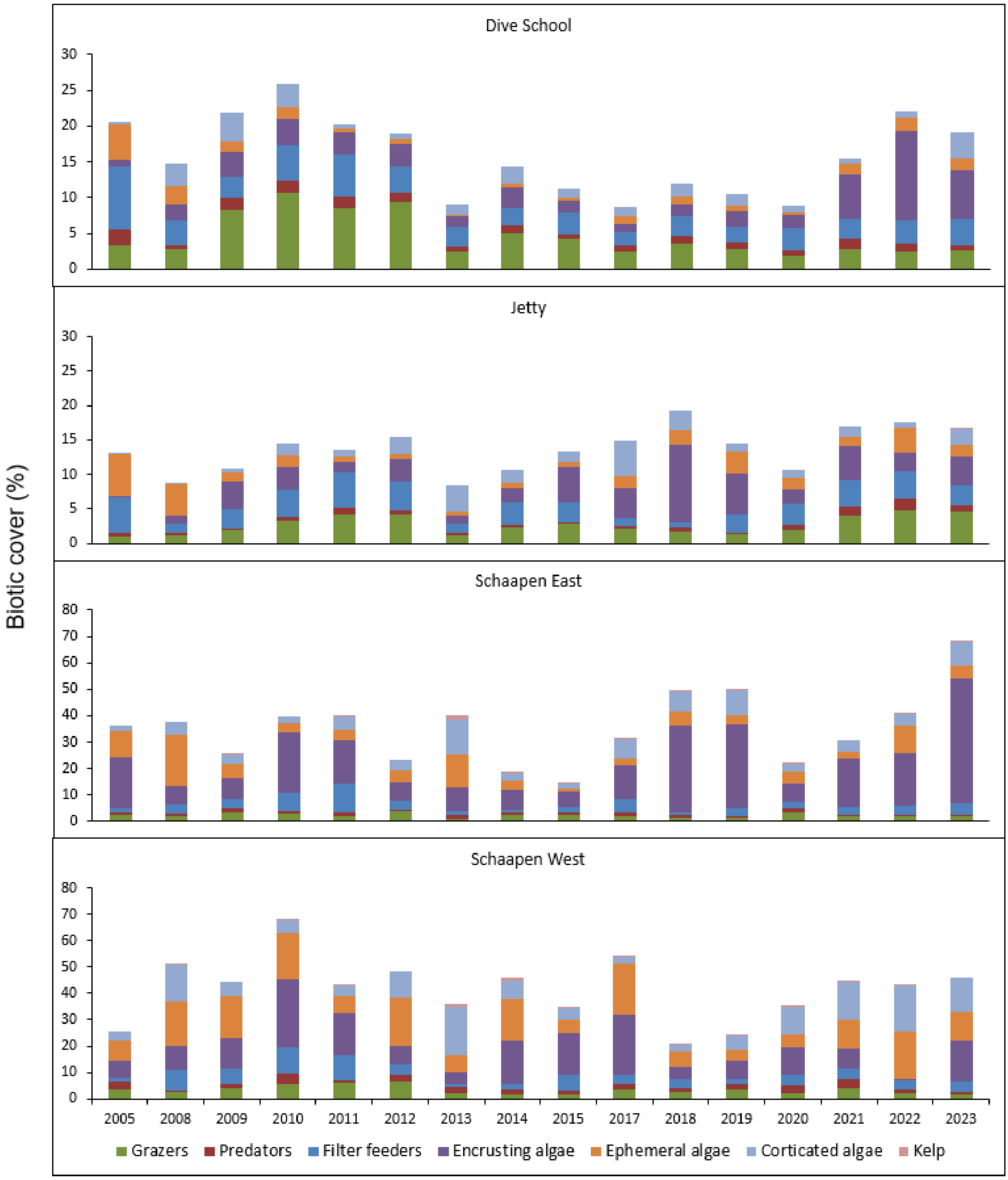


Figure 10.11. Total percentage cover of the seven functional groups over the period 2005–2023. Data are presented for the two very sheltered (Dive School, Jetty) and the two sheltered study sites (Schaapen Island East and West). Functional groups include grazers (green), filter feeders (dark blue), predators (red), kelp (pink), ephemeral algae (orange), corticated algae (light blue) and encrusting algae (purple).

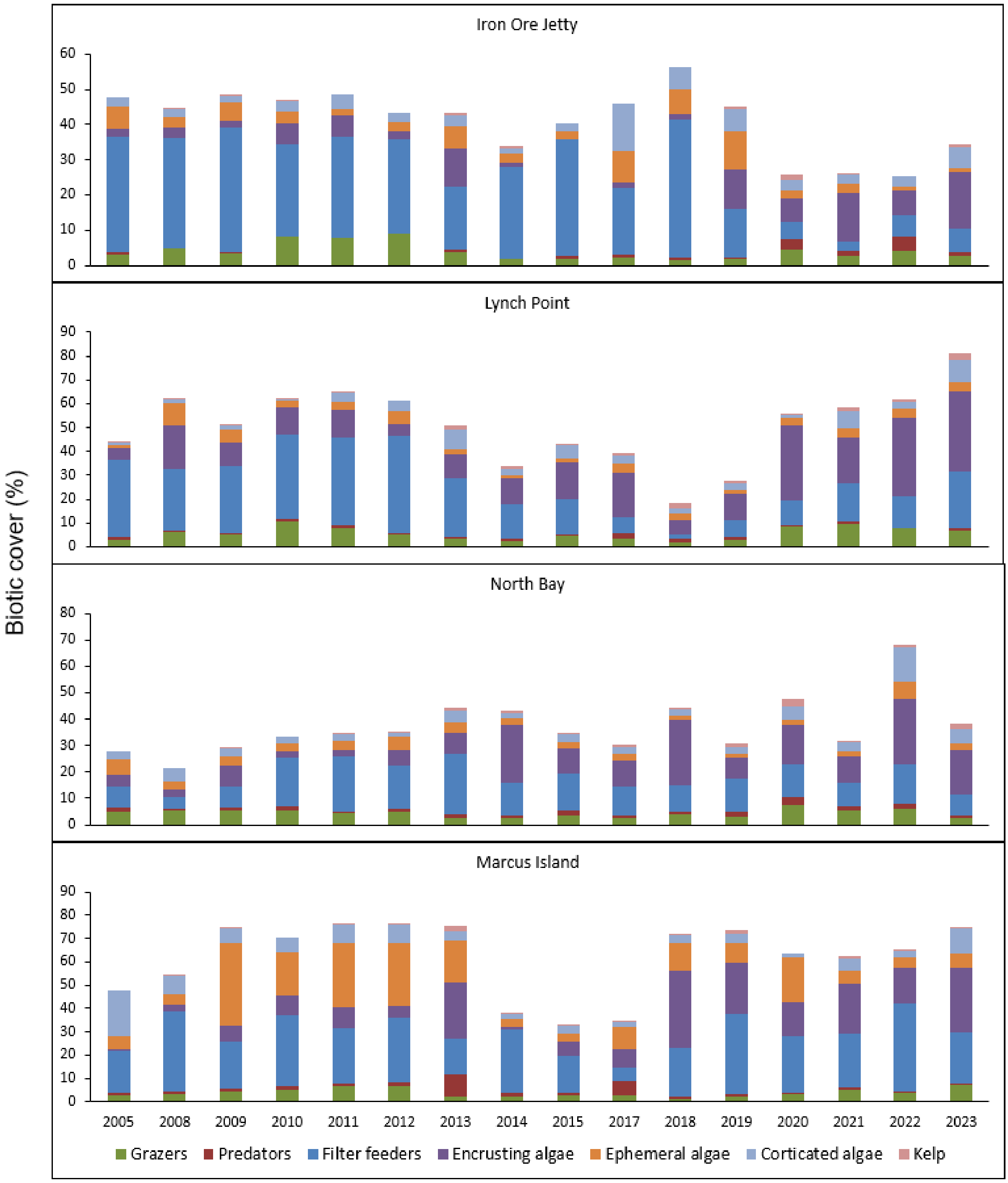


Figure 10.12. Total percentage cover of the seven functional groups over the period 2005–2023. Data are presented for the two semi-exposed (Iron Ore Jetty and Lynch Point) and the two exposed study sites (North Bay and Marcus Island). Functional groups include grazers (green), filter feeders (dark blue), predators (red), kelp (pink), ephemeral algae (orange), corticated algae (light blue) and encrusting algae (purple).

Monitoring functional groups provides valuable insights into the impacts of human activities, pollution, and environmental changes on ecosystems. Changes in the diversity and composition of these functional groups can serve as indicators of shifts in overall biodiversity and ecosystem health. For instance, elevated nutrient levels, often resulting from pollution or effluent discharge, can lead to the proliferation of specific algae types, such as ephemeral algae. Conversely, a decrease in filter feeder populations can indicate pollution, as pollutants can harm these organisms, reducing their feeding efficiency and even causing suffocation and mortality. Notably, Iron Ore and, to a lesser extent, Lynch Point experienced significant declines in filter feeder populations. Other noteworthy declines include grazers at the Dive School and ephemeral algae at Marcus Island. While these changes may be associated with pollution or other human-induced factors, it's essential to consider natural variability and habitat changes as potential causes. For instance, a decline in grazers could result from decreased algae availability or increased predation pressure. Confirming pollution or human influence as the sole cause of these declines typically requires additional assessments and data.

The noteworthy increase in encrusting algae observed at most sites, particularly over the past three to five years, may also have natural drivers. Firstly, encrusting coralline algae are known for occupying extensive space in rocky intertidal systems (Steneck et al. 1991, Keats and Maneveldt 1994) and can thrive in areas with high herbivore activity (Dethier 1994, Steneck and Dethier 1994). Additionally, encrusting algae, along with others like ephemeral algae such as *Ulva* spp. are usually the first to colonize rock space denuded of biota due to physical (e.g., wave action) or biological (e.g., grazing) disturbance (Sousa 1979b, 1984, Monserrat et al. 2022). The decline in filter feeders and some other species may have created an ecological niche for encrusting algae, enabling them to occupy the available rock space and potentially explaining their substantial increase in abundance.

In the ecological succession that follows, these algae are replaced by longer-lived late successional corticated algal species. Interestingly, research on crustose coralline algae suggests divergent effects; some studies propose that they may impede the recruitment of later colonisers (Bulleri et al. 2002a), while others suggest they could enhance biodiversity by facilitating the settlement of subsequent colonists, including invertebrates (Bulleri et al. 2002b, Irving et al. 2005, Maggi et al. 2011, Asnaghi et al. 2015). To date, no definitive trend or answer has emerged in this regard, although future surveys may shed light on the role of crustose coralline algae in Saldanha Bay's biodiversity.

Despite changes and declines in community and functional group composition, none of the sites demonstrated a temporal change in their rocky shore communities that would suggest a dramatic alteration such as the arrival or loss of a key species. Furthermore, no major pollution events or point sources of pollution are apparent in these data. Instead, the fluctuations of functional groups over the years are considered a natural seasonal and inter-annual phenomenon. While shifts may be attributed to natural variability, anthropogenic events and climate changes as possible contributors should be explored.

10.4 SUMMARY OF FINDINGS

In 2023, a total of 111 species were recorded during the rocky shore, with algae accounting for 35% of the species and invertebrate animals constituting the remaining 65%. These species spanned diverse taxonomic groups, including Chlorophyta, Rhodophyta, and Ochrophyta, as well as porifera, gastropods, bivalves, echinoderms, ascidians, Cnidarians, polychaetes, arachnids and crustaceans. Amongst these species, several were identified as alien including the mytilid mussels species complex, the acorn barnacle, the volcano barnacle, the North West African porcelain and the red-rust bryozoan. This marks the first documented appearance of the latter species in a rocky shore survey, with its presence noted at several sites. Interestingly, there have been fewer records of the alien porcelain crab.

The overall biotic cover within a site typically varied, with an increase observed from the high shore to the low shore, averaging between 40% to 60% cover. The high shore typically featured barren rock. The more exposed shores were characterised by the presence of the southern periwinkle, nested within beds containing a mix of the alien acorn barnacle and indigenous toothed barnacle. On the exposed mid shore sites, algae, grazers (such as limpets, chitons, and topshells) as well as filter feeders, specifically the alien mussels and barnacles were common. In contrast, sheltered sites tended to be more barren. The low shore, on the other hand, exhibited the highest biotic diversity and percentage cover, primarily dominated by algae, particularly crustose coralline algae. The most dominant species included both indigenous and alien mussels, pear limpets, and urchins. While the indigenous mussel used to be the dominant mussel on the shore, recent surveys indicate that mytilids have consistently outnumbered this local mussel in most locations over the past few years.

Biotic cover varied considerably among different sites, and the main factor accounting for these differences was the level of exposure to wave action. Sheltered sites generally had lower biotic cover compared to exposed sites. As wave exposure increased, there was a notable increase in the coverage of different species. This increase was primarily driven by the higher presence of filter-feeding organisms and encrusting algae on these exposed shores. These exposed sites exhibited a balanced presence of both flora and fauna, with filter-feeders being the dominant group among the fauna. In contrast, in fully sheltered areas, various functional groups contributed roughly equally to the overall biotic cover.

The community structure of rocky shorelines was also influenced by the topography and substratum type of the shoreline. Sites with large rocky boulders had a higher percentage cover of faunal species compared to sites with smoother and flatter profiles. Sites with smoother profiles had a more significant presence of encrusting algae compared to those with smaller boulders and rougher surfaces. The islands, which are sheltered sites, exhibited a higher presence of ephemeral and corticated algae. These islands, being home to numerous birds, received substantial nutrient input from seabird guano, which promoted algal growth. Additionally, Schaapen Island's location in the transition zone between Saldanha Bay and Langebaan Lagoon leads to differences in water quality, such as temperature, which further influences biological communities.

Over the years, rocky intertidal areas in Saldanha Bay have experienced fluctuations in the percentage cover and composition of biota. Understanding these changes is crucial as they often signal shifts in biodiversity due to environmental stress. One significant observation has been the notable increase in encrusting algae across most sites and a decline in filter feeders at some locations. Historically, alien species like mussels from the mytilid species complex (including the Mediterranean mussel *Mytilus galloprovincialis* and bisexual mussel *Semimytilus algosus* and potentially the blue mussel *M. edulis* and bay mussel *M. trossulus*) and the Pacific barnacle *Balanus glandula* dominated these shores, outcompeting native species. Their spread throughout the Bay has significantly altered natural community structure in the mid and lower intertidal, particularly in wave exposed areas. However, recent surveys show a decline in these aliens, likely due to severe weather and wave events displacing them. The decline in filter feeders observed during surveys can be attributed to the reduction in these alien species. This decline may have created an ecological niche for encrusting algae, facilitating their colonisation of available rock space and potentially explaining their substantial increase in abundance. Overall, while fluctuations in functional groups are considered natural seasonal and inter-annual phenomena, it's important to explore potential contributions from anthropogenic events and climate changes.

11 FISH

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 *Chelon 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 permit holders continue to target harders. Species such as white stumpnose, white steenbras, silver kob *Argyrosomus inodorus*, elf *Pomatomus saltatrix*, steentjie *Spondyliosoma 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 research 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 and Lamberth 2002a) A once-off survey for small cryptic species utilizing rotenone, a fish-specific, biodegradable toxin that prevents the uptake of oxygen by small fish, was conducted by Anchor Environmental Consultants (Anchor) during April (Awad et al. 2004). 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 1996), 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 (Arendse 2011).

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 guitarfish (Næsje et al. 2008, Kerwath et al. 2009, Tunley et al. 2009, Attwood et al. 2010, Hedger et al. 2010, Schultz 2010, da Silva et al. 2013, 2021). Key findings of these studies include evidence that the Langebaan Lagoon Marine Protected Area (MPA) provides some protection for white stumpnose, particularly during the summer months that coincide 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 most of the study period (up to two 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 smooth 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 smooth 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 (da Silva et al. 2013). Tag-recapture data confirm the site fidelity of smooth hound sharks to Langebaan lagoon, with 27 of 32 recaptured sharks reported within the lagoon, and some sharks recaptured after seven years at liberty (Klein et al. 2022). These acoustic telemetry and tag-recapture studies have clearly demonstrated that these three priority fishery species all derive protection from the Langebaan MPA. Research on guitarfish indicated that the common species in Bay and Lagoon is actually *Rhinobatos blockii*, not *R. annulatus* as previously thought (Schultz 2010).

White stumpnose within the Saldanha-Langebaan system grow more rapidly and mature earlier than populations elsewhere on the South African coast (Attwood et al. 2010). Male white stumpnose in Saldanha Bay reach maturity in their second year at around 19 cm fork length (FL) and females in their third year at around 22 cm FL (Attwood et al. 2010). Similar differences in growth rate and the onset of maturity for steentjies between Saldanha Bay and south coast populations were reported by Tunley *et al.* (2009). These life history strategies (relatively rapid growth and early maturity) in combination with the protection afforded by the MPA are probably part of the reason that stocks fishery species in Saldanha and Langebaan had until recently been resilient to rapidly increasing recreational fishing pressure (but see paragraph below on stock status). Results from angler surveys undertaken during the early 2000s indicated that approximately 92 tonnes of white stumpnose were landed by anglers each year (Næsje et al. 2008).

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 et al. 2017). 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 levels. 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 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 (Arendse 2011). 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) provided an updated analysis of angler survey data, commercial linefish catch returns and the juvenile white stumpnose catch in the annual 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.

An investigation of the age, growth and stock assessment of the harder *Chelon richardsonii* stock in the Saldanha Bay-Langebaan system was completed in 2019 (Horton et al. 2019). Results of this study show that gill net fishers have seen substantial declines in harder catches and Catch-Per-Unit-Effort (CPUE) over the last two decades (Horton et al. 2019). By comparing monitored landings with reported catches, Hutchings and Lamberth (2002b); estimated that 590 tonnes of harders, valued at approximately R1.8 million, was landed during 1998–1999. The reported catch has declined from around 130 tonnes per year over the period 2008–2012 to about 90 tonnes per year over the period 2013–2016, whilst effort remained fairly constant (Horton et al. 2019). The average size of harders in catches has declined significantly over the same period and a stock assessment indicated that the stock was at risk of recruitment failure (the current spawner biomass was estimated at less than 25% of the pristine level). A reduction in fishing mortality (approximately 30%) and an increase in mesh size to 51 mm was recommended to help rebuild the stock (Horton et al. 2019).

A study of the trace metal concentrations in the tissue of smooth hound sharks in Langebaan lagoon reported elevated levels of arsenic and methyl mercury above the regulatory limits for foodstuffs (Bosch et al. 2016). The relatively high arsenic levels were attributed to smooth hound sharks' diet of benthic invertebrates in Langebaan lagoon, and the authors note the fact that organic arsenic, which is the most abundant form in fish, is not considered toxic and the measurements of total arsenic are therefore not truly representative of the toxicity of the samples (Bosch et al. 2016). The high methyl mercury levels were attributed to mercury uptake through prey and bioaccumulation over the shark's lifespans (Bosch et al. 2016). There was no statistically significant relationship between trace metal concentrations (16 metals and three Hg species: inorganic Hg, ethylmercury, methylmercury) and shark size in this study. This was an unexpected result that could reflect the similarity in diet of small and large smooth hound sharks in Langebaan lagoon (Bosch et al. 2016). The most recent research published research of fish in the system was a life history study on the reproductive biology, diet, and growth of smooth hound sharks in Langebaan Lagoon (da Silva et al. 2021). It was found that they attained a total length of approximately1.6 m at the maximum observed age of 13 years; female parturition, ovulation and mating takes place in early summer (November – December); and their diet comprised predominantly crustaceans (two species of prawns and a crab species) (da Silva et al. 2021). This study concludes that Langebaan Lagoon represents a pupping, nursery and feeding area for the largest and oldest hound sharks globally, emphasising the conservation importance of the MPA (da Silva et al. 2021).

In February 2019, the South African National Parks (SANParks) implemented a fish, shark and ray monitoring project in the West Coast National Park (WCNP) MPA using Baited Remote Underwater Video cameras (BRUVs). BRUVs are a non-destructive and cost-effective monitoring tool which is popularly used along the South African coastline. The aim of this monitoring programme is to describe relative abundance and diversity of fish and sharks across different management zones of the WCNP MPA over time. To date, a total of 90 BRUV deployments (90 hours of video) were made across all three MPA zones and outside of the MPA, over summer and winter. Preliminary analysis of the videos identified 15 species from eleven families (Table 11.1). The most frequently observed species were steentjie (*Spondyliosoma emarginatum*), white stumpnose (*Rhabdosargus globiceps*) and white seacatfish (*Galeichthys feliceps*). Overall, MPA Zone A had the greatest species diversity, while Zone B had higher relative abundance of important recreational and commercial species, such as white stumpnose and blacktail. Zone C had the greatest abundance of juvenile fish. Unfortunately, the visibility of the water outside of the MPA in Saldanha Bay was poor on most of the sampling days and BRUV deployments provided limited information. Summer months had greater abundance and diversity of most species and juvenile fish, most likely because the average water temperature is greater in summer (22 °C) than in winter (15 °C). This was especially the case for steentjies and white stumpnose.

The preliminary results demonstrate that BRUVs are a viable method for monitoring fish and shark species in the lagoon and detecting species of special concern, such as white stumpnose. SANParks recommendations are to continue deploying BRUVs as a long-term monitoring tool and to expand to the islands of the MPA when capacity and resources are available. A longer time-series will allow for investigating the influence of the level of protection on the abundance and diversity of fish and shark species in the MPA.

Table 11.1. Fish and elasmobranch diversity and relative abundance recorded across seasons at West Coast National Park Marine Protected Area. The recorded species were detected by BRUVs over two years (2018–2019). Source: SANParks Cape Research Centre. International Union for Conservation of Nature (IUCN) Red List classification is provided (En = Endangered, Vu = Vulnerable, DD = Data Deficient, LC = Least Concern, NE = Not Evaluated) (IUCN 2022a).

Family	Species	Scientific name	IUCN Status	# Sites	Frequency of occurrence	
					Summer	Winter
Clinidae	Super klipfish	*Clinus superciliosus*	LC	8	0.13	0.03
Atherinidae	Cape silverside	*Atherina breviceps*	NE	18	0.29	0.06
Sparidae	Steentjie	*Spondyliosoma emarginatum*	LC	29	0.47	0.09
Sparidae	White stumpnose	*Rhabdosargus globiceps*	Vu	18	0.29	0.06
Sparidae	Hottentot	*Pachymetopon blochii*	LC	1	0.02	0
Ariidae	White seacatfish	*Galeichthys feliceps*	NE	4	0.05	0.03
Sparidae	Strepie	*Sarpa salpa*	LC	1	0.02	0
Rajidae	Spearnose skate	*Rostroraja alba*	En	1	0	0.03
Chaetodontidae	Doublesash butterflyfish	*Chaetodon marleyi*	LC	1	0.02	0
Sparidae	Blacktail	*Diplodus capensis*	LC	3	0.05	0
Triakidae	Smooth-hound shark	*Mustelus mustelus*	Vu	1	0.02	0
Scyliorhinidae	Puffadder shyshark	*Haploblepharus edwardsii*	En	3	0	0.03
Triglidae	Cape gurnard	*Chelidonichthys capensis*	LC	4	0.07	0
Pomatomidae	Elf	*Pomatomus saltatrix*	Vu	2	0.04	0
Sepiidae	Cuttlefish	*Sepia vermiculata*	DD	1	0.02	0

As part of the sampling for the detection and identification of invasive alien species, environmental DNA (eDNA) sampling was undertaken at 10 sites. This is DNA that is collected from a variety of environmental samples (water or sediment) rather than directly sampled from an individual organism. As organisms interact with the environment, DNA is expelled and accumulates in their surroundings. Examples of eDNA sources include, among other things, faeces, mucus, gametes, shed skin, carcasses and hair. Sampling using eDNA has the advantage of being able to detect organisms in an area that are otherwise not found with other sampling methods, because they are, for example, evasive, elusive, or endangered. This is particularly useful in an aquatic environment, where once-off "snapshot sampling" using traditional methods (e.g., grabs, cores, nets, or lines) may not necessarily reveal all species present.

Filtered water samples collected from each site were submitted to an established eDNA service provider, Nature Metrics in the United Kingdom, for analysis of vertebrate genetic sequences using markers from their "vertebrate" and "fish" pipelines[10]. Species level resolution using eDNA/metabarcoding is, however, dependent on the available databases of DNA sequence data (which is growing continuously) and the sequence matching algorithms employed. The identifications range in terms of the proportion of DNA sequences detected within each sample. This signal may be linked to abundance of species in the environment but only as a coarse measure because the signal is also impacted by biological (e.g., biomass, life stage, activity, body condition), environmental (e.g., temperature, pH, salinity, conductivity), and technical factors.

The results of the eDNA sampling indicated the presence of 37 taxa of fish, chimaeras, and elasmobranchs, of which at least 19 were also recorded during beach seine net sampling for juvenile fish (Table 11.2). The eDNA sampling also picked up many pelagic and reef taxa that are not targeted by the seine net sampling and provides insight into other species present in the Bay.

The Saldanha Bay Water Quality Forum Trust (SBWQFT) commissioned Anchor to undertake experimental seine-net sampling of near shore fish assemblages at a number of sites throughout the Saldanha-Langebaan system during 2005, and annually over the period 2008–2023 as part of the monitoring of ecosystem health "State of the Bay" programme. Seine-net surveys were conducted during late summer to early autumn, as this was the timing of peak recruitment of juveniles to the near-shore environment, as well as the timing of most of the earlier surveys. Since 2008, seine-net surveys have therefore been conducted during March – April of each year. These studies have made a valuable contribution to the understanding of the fish and fisheries of the region. This chapter presents and summarises the data for the 2023 seine-net survey and investigates trends in the fish communities by comparing this with data from previous seine-net surveys (1986/87, 1994, 2005, 2008–2022) in the Saldanha-Langebaan system.

10 Refers to a data processing pipeline that takes the raw sequence data from high-throughput sequencing (often 20 million sequences or more) and transforms it into usable ecological data. Key steps for metabarcoding pipelines include quality filtering, trimming, merging paired ends, removal of sequencing errors such as chimeras, clustering of similar sequences into molecular Operational Taxonomic Units, and matching one sequence from each cluster against a reference database. The output is an OTU-by-sample table showing how many sequences from each sample were assigned to each OTU.

Table 11.2. Fish and elasmobranch taxa identified in eDNA samples from Langebaan Lagoon and Saldanha Bay, and the number of sample sites in which they were present. Taxa in bold were also recorded in State of the Bay seine net samples.

Family	Taxon	Common Name	No. Sites
Hexanchidae	*Notorynchus cepedianus*	Broadnose sevengill shark	1
Callorhinchidae	***Callorhinchus capensis***	Cape elephantfish	1
Ophichthidae	*Ophisurus* sp.	Snake eels	3
Atherinidae	***Atherina breviceps***	Cape silverside	1
	***Atherinidae* sp.**	-	4
Blenniidae	***Parablennius* sp.**	Combtooth blennies	3
Carangidae	*Decapterus macarellus/Decapterus muroadsi*	Mackerel scad/Amber-striped scad	1
	Seriola lalandi	Yellowtail kingfish	3
	Seriola lalandi/Seriola quinqueradiata	Yellowtail kingfish/Japanese amberjack	3
	Trachurus trachurus	Atlantic horse mackerel	1
Cheilodactylidae	*Cheilodactylus* sp.	Morwongs	1
Engraulidae	*Engraulis encrasicolus*	Cape anchovy	3
	Engraulis encrasicolus/***Engraulis japonicus***	Cape anchovy/Japanese anchovy	2
Sciaenidae	*Argyrosomus inodorus*	Silver kob	2
	Argyrosomus sp.	-	1
Sparidae	*Diplodus puntazzo*/***Diplodus sargus***	Sheephead bream/White seabream	4
	Diplodus sargus	White seabream	5
	***Diplodus* sp.**	-	3
	Rhabdosargus globiceps	White stumpnose	2
	Sparus sp.	-	1
	Spondyliosoma cantharus	Black seabream	5
	***Spondyliosoma* sp.**	-	6
	Stenotomus sp.	Porgies/scups	2
	Sparidae sp. 1	-	1
	Sparidae sp. 2	-	2
Merlucciidae	*Merluccius capensis*	Shallow-water Cape hake	3
	Merluccius paradoxus	Deep-water Cape hake	4
Gobiidae	***Gobiidae* sp.**	Gobies	1
Mugilidae	*Chelon dumerili*	Grooved mullet	1
	Chelon richardsonii	Southern mullet	9
	Chelon richardsonii/*Chelon tricuspidens*	Southern mullet/Striped mullet	2
Triglidae	***Chelidonichthys kumu***/*Chelidonichthys lucerna*	Bluefin gurnard/Tub gurnard	1
Triglidae	***Chelidonichthys* sp.**	-	2
Gempylidae	***Thyrsites atun***	Snoek	2
Pomatomidae	***Pomatomus saltatrix***	Bluefish	2
Scombridae	*Scomber* sp.	Mackerel	1
Ariidae	*Galeichthys ater*/***Galeichthys feliceps***	Black seacatfish/White barbel	3

11.2 Methods

11.2.1 Field sampling

Experimental seine netting for all surveys 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 both 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 Rietbaai (Figure 11.1). Large hauls were sub-sampled on site, the size of the sub-sample estimated visually, and the remainder of the catch released alive.

11.2.2 Data analysis

Numbers of fish caught were corrected for any sub-sampling of large hauls 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.

Trends in the average abundance of key species that are of importance in local fisheries were analysed using a one-way ANOVA (analysis of variance) and post-hoc unequal N HSD tests using R (R Core Team 2022) and RStudio (Posit team 2023). Abundance data for all sites throughout the Bay were log (x + 1) transformed to account for heteroscedasticity (unequal variance) prior to analysis.

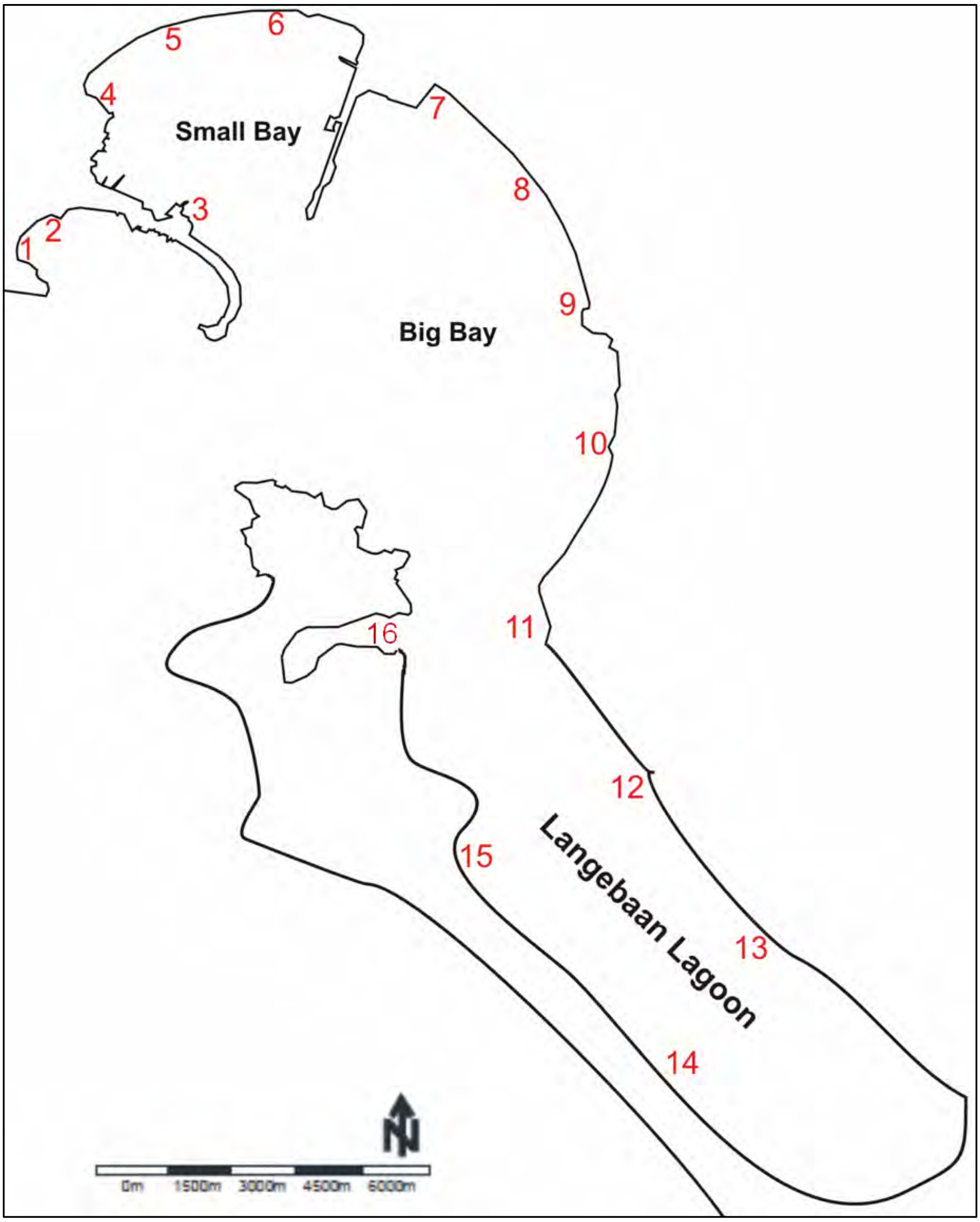


Figure 11.1. Sampling sites within Saldanha Bay and Langebaan lagoon where seine net hauls were conducted during the 2005 and 2007–2023 annual sampling events. 1: North Bay west, 2: North Bay east, 3: Small craft harbour, 4: Hoedjiesbaai, 5: Caravan site, 6: Blue water Bay, 7: Sea farm dam, 8: Spreeuwalle, 9: Lynch point, 10: Strandloper, 11: Schaapen Island, 12: Klein Oesterwal, 13: Bottelary, 14: Churchhaven, 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 52 (Table 11.3). Fish diversity (total number of species caught) across all surveys remains highest and most similar in Big Bay (43) and in Small Bay (42), compared to the Lagoon (27). Species richness is typically similar in Small Bay and Big Bay, although the number of species sampled has been less variable over time especially 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 2023 samples, fish diversity in Small Bay was on par with the average (14 species). Diversity in Langebaan Lagoon samples was slightly below average (average of 11, 9 species caught). Fish diversity in Big Bay was one species above the average (14 species caught), and an improvement over the low 2022 catch of 9 species (Figure 11.2).

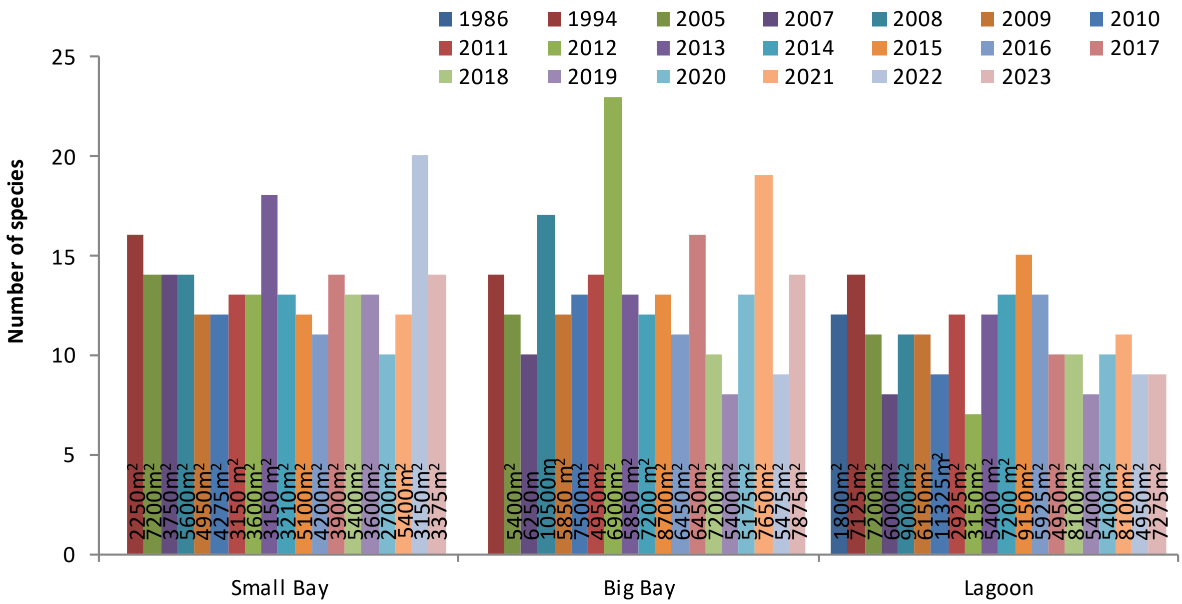


Figure 11.2. Number of fish species caught during 20 seine-net surveys in Saldanha Bay and Langebaan lagoon conducted over the period 1986–2023. The total area netted in each area and survey is shown.

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, at least six species (Cape silverside, gobies of the genus *Caffrogobius*, super klipvis, Cape sole, harders, and white stumpnose) have occurred in all surveys to date. Until their absence in the 2023 catches, bluntnose guitarfish had also occurred in all Small Bay surveys. However, the sampling methods used are not a reliable indicator of guitarfish in the system, as they are not designed to sample mature fish such as the guitarfishes.

Four of the 43 species recorded in Big Bay occurred in all surveys (gurnard, Cape sole, harders and white stumpnose). Both False Bay klipvis and Cape silverside have been absent in just two surveys each. Elf were only absent in one of the 13 surveys conducted over the period 1994–2017, but they were not recorded in Big Bay during the 2018–2021 surveys. While only one elf was caught in the 2022 survey, 59 elf were caught in the 2023 survey, suggesting a slight improvement in recruitment in the Bay.

Six of the 27 species found in the lagoon (silversides, *Caffrogobius* sp. gobies, Cape sole, harders, Knysna sandgobies and white stumpnose) occurred in all surveys and these species were all present in 2023 samples. Small Bay has the highest proportion of "resident" species that are there consistently, whilst a larger proportion of the Big Bay ichthyofauna, although more diverse, occur seasonally or sporadically in catches. 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 1996).

Table 11.3. Fish and elasmobranch species caught during 20 seine-net surveys in Saldanha Bay and Langebaan lagoon conducted over the period 1986–2023.

Species	Common name	Species	Common name
Amblyrhynchote honckenii	Evil eye blaasop	*Gilchristella aestuaria*	Estuarine round herring
Argyrozona argyrozona	Carpenter	*Gonorhynchus gonorhynchus*	Beaked sand eel
Atherina breviceps	Cape silverside	*Haploblepharus* sp.	Shyshark sp.
Blennophis sp.	Blenny sp.	*Heteromycteris capensis*	Cape sole
Brama brama	Angelfish/pomfret	*Lichia amia*	Leervis
Caffrogobius sp.	Goby sp.	*Lithognathus* sp.	Steenbras sp.
Callorhinchus capensis	St Joseph's shark	*Mustelus mustelus*	Smooth hound shark
Cancelloxus longior	Snake eel	*Myliobatis aquila*	Eagle ray
Chelidonichthys capensis	Cape gurnard	*Parablennius cornutus*	Horned blenny
Chelidonichthys kumu	Bluefin gurnard	*Parascorpus typus*	Jut jaw
Chelon richardsonii	Harder	*Pomatomus saltatrix*	Elf
Chorisochismus sp.	Suckerfish sp.	*Poroderma africanum*	Striped catshark
Clinus agilis	Agile klipfish	*Psammogobius knysnaensis*	Knysna sandgoby
Clinus heterodon	West Coast klipvis	*Pterogymnus laniarius*	Panga
Clinus latipennis	False Bay klipvis	*Raja clavata*	Thornback skate
Clinus robustus	Robust klipvis	*Rhabdosargus globiceps*	White stumpnose
Clinus sp. *larvae*	Klipvis larvae	*Rhabdosargus holubi*	Cape stumpnose
Clinus superciliosus	Super klipvis	*Rhinobatos blockii*	Bluntnose guitar fish
Clinus venustris	Bluntnose klipvis	*Sardinops sagax*	Sardine
Cynoglossus capensis	Toungue fish	*Sarpa salpa*	Strepie
Dasyatis chrysonota	Blue stingray	*Solea turbynei*	Blackhand sole
Dichistius capensis	Galjoen	*Spondyliosoma emarginatum*	Steentjie
Diplodus sargus capensis	Blacktail	*Syngnathus temminckii*	Longsnout pipefish
Engraulis japonicus	Anchovy	*Thyristes atun*	Snoek
Etrumeus terres	Red-eye round herring	*Trachurus trachurus*	Horse mackerel
Galeichthyes feliceps	White seacatfish	*Zeus faber*	John Dory

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 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 years. Overall, the catches made during the 2012 survey were the lowest on record for all three areas. Over the last ten years, 2014–2023, the overall abundance of fish has compared favourably with earlier surveys, but as mentioned above, this largely reflects the abundance of harders and silversides (Figure 11.3).

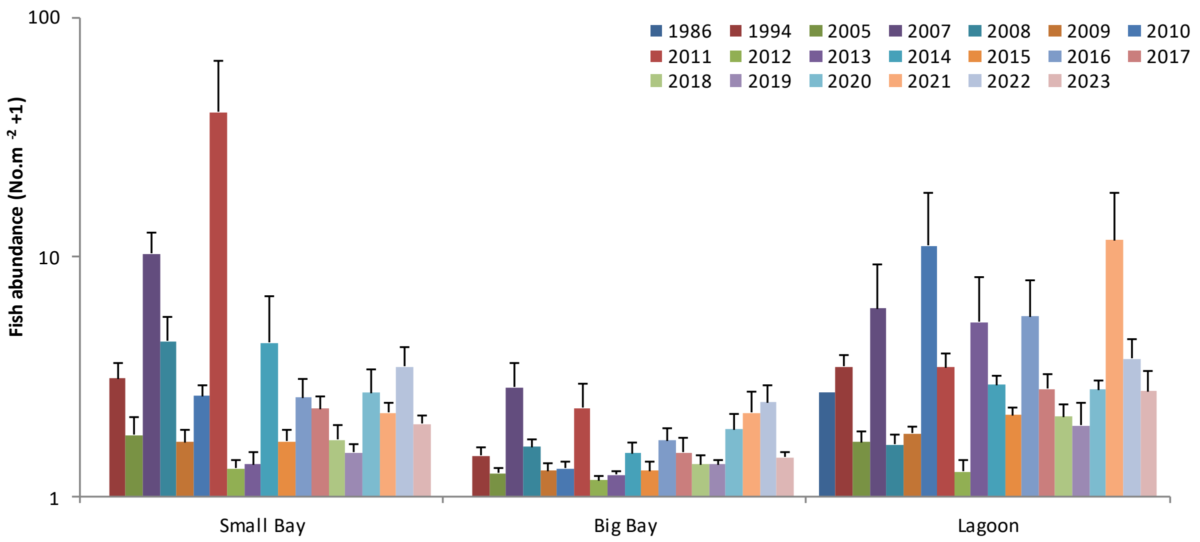


Figure 11.3. Average fish abundance (all species combined) during 20 seine-net surveys conducted in Saldanha Bay and Langebaan lagoon. (Error bars show one Standard Error of the mean). The data are transformed (x + 1) and displayed on a logarithmic axis.

Abundances of white stumpnose, *Caffrogobius* sp. (gobies) and blacktail in seine net hauls were above average in Small Bay during the 2007 and 2008 surveys but have remained below these maxima 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 densities of *Caffrogobius* gobies show signs of slight improvement, with 249 individuals captured in 2023, just above the average density for these species. The concerning declining trend in white stumpnose and blacktail abundance over the 2012–2015 period in Small Bay was thought to have reversed with the third highest white stumpnose abundance and second highest blacktail abundance recorded in 2016 samples, but unfortunately this moderate "recovery" was not sustained. Although white stumpnose abundance in Small Bay is still well below the historical peaks in 2007 (12 331 individuals), with 371 individuals caught in 2023, this is an improvement over 2022 (54 individuals) and closer to the 437 individuals caught in 2021. Catches of blacktail juveniles have shown great variability in abundance since 1994, with absences in many years, and although they showed small signs of recovery in 2019 (61 individuals), they were still scarce in 2023 with just two individuals caught. The Small Bay fish community does appear to have deteriorated in health since the start of the fish monitoring programme, with substantial and consistent declines in abundance of several of the more common species, this trend continuing into 2023 (Figure 11.4).

Within Big Bay, average harder and white stumpnose abundance observed during the 2023 sampling compared favourably to earlier surveys (Figure 11.4). White stumpnose abundance within Big Bay over the period 2015–2018 had recovered somewhat from the very low 2013 and 2014 results, crashed again in 2019 and then recovered slightly in 2020 to levels similar to the 2013–14 period (Figure 11.4). The white stumpnose abundance in Big Bay has continued to improve since 2020, and although the 2023 abundance is lower than that of the previous year, the abundances are still better than most years since 2011 (Figure 11.4). The sustained recovery in white stumpnose abundance suggests a relatively good recruitment to juvenile nursery habitats took place during the summer of 2021–22. The strong elf recruitment in Big Bay evident in the 2016 and 2017 sampling has not re-occurred, with zero to very few individuals caught since. However, the 2023 sampling captured 59 elf individuals in Big Bay, suggesting a slight improvement in recruitment. Elf start to become sexually mature at one 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 will be able contribute significantly to recruitment in the Bay (presuming the cohort survives beyond maturity and does not emigrate from the Bay). The abundance of Cape sole was down from recent years, but still above the historic average. Overall species diversity in Big Bay was up, as well as the average abundance of the most common species, suggesting a better state of fish community health in 2023 (Figure 11.4).

The abundances of harders, silversides and white stumpnose in Langebaan lagoon in the 2023 survey have all declined since the 2021 survey (Figure 11.4). White stumpnose in particular were well below the historic average abundance. Although the average densities of harders and silversides in 2023 are below some of the historical peaks, their abundances are still comparable with historical data, and the harder abundance suggests a positive trend over time, indicating the possibility of a healthier recruitment (Figure 11.4). The *Caffrogobius* goby species showed some recovery since the previous survey, with abundances slightly above the long-term average and at their highest since 2016. The Knysna sandgoby recovery in 2021 has mostly been sustained, with abundances just above the average (Figure 11.4). In short, the fish communities of Langebaan Lagoon in 2023 range in their condition, from very low abundances in white stumpnose to relatively healthy abundances of Knysna sandgoby.

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, 2017 and 2021 surveys suggested improved environmental conditions that facilitated survival of eggs, larvae and juveniles during the preceding summer. Although the Small Bay fish community appears to be in a poor state, most of the Lagoon and Big Bay communities of the most common species appear to be in relatively good condition, suggesting that the spawning capacity of the adult stock may have recovered to a degree. Without data on the status of the adult stock (e.g., catch per unit effort from the fisheries or research angling) this is speculation, as the high fecundity of serial batch spawning marine fish means that a good recruitment can arise from a small spawner stock under favourable environmental conditions. Further monitoring will reveal if the apparent recovery is sustainable. The concerning scarcity of elf recruits may likewise be a result of reduced spawner biomass due to high fishing mortality or environmental factors (almost certainly both).

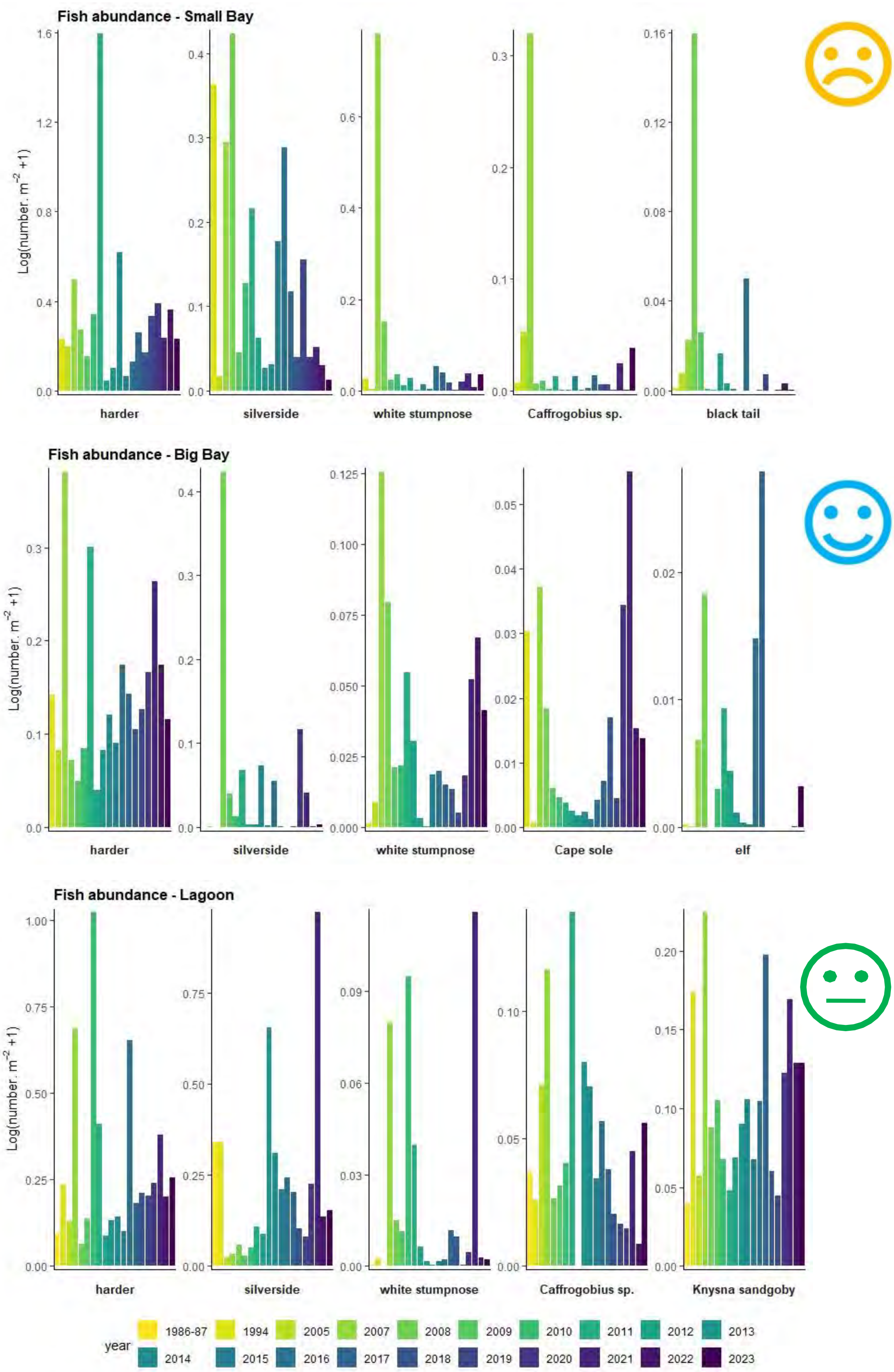


Figure 11.4. Abundance of the most common fish species recorded in annual seine-net surveys within Saldanha Bay and Langebaan Lagoon (1986/87, 1994, 2005 & 2007–2023).

11.3.3 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 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 (Figure 11.4). The 2016 and 2021 surveys revealed some encouraging signs of increased white stumpnose recruitment in Small Bay, but the catches of all other years since 2017 have been much 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 Parker *et al.* (2017), it appears that recruitment overfishing was 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. Recent research suggests that the Saldanha bay harder stock is also overexploited with changes to management measures (increased mesh size, reduced fishing mortality) required to rebuild stocks (Horton et al. 2019).

To further investigate temporal variation in recruitment of species important in the Bay's fisheries (blacktail, elf, harders, steentjies and white stumpnose) univariate statistical analysis (ANOVA) was used to test for significant differences in the average abundance of each species between survey years. Saldanha Bay and Langebaan Lagoon appears to function as a semi-closed system with respect to the demographics of many of the key fishery species (based on tagging and life history studies, e.g., harders (Horton et al. 2019), white stumpnose (Kerwath et al. 2009, Attwood et al. 2010), steentjies (Tunley et al. 2009), elf (Hedger et al. 2010), and smooth hound sharks (da Silva et al. 2013). Furthermore, different sites may be more intensively utilized by juvenile fish in different years depending on prevailing weather and oceanographic conditions. To assess trends in recruitment of key fishery species to surf zone habitats for the Bay and Lagoon as a whole, abundance data from all sites were therefore combined for this analysis. These analyses revealed statistically significant inter-annual variation in the densities of blacktail, harders, elf and white stumpnose, but not in the density of steentjies (Figure 11.5).

Estimated white stumpnose abundance in 2007 and 2008 was significantly greater than nearly all other years, while the estimated abundance from the 2021 survey was higher than average and was only significantly less than the very high abundance recorded in 2007. This trend has not carried into 2023, with abundance back down to previous levels but still higher than what has been observed in the last ten years (Figure 11.5). Harders are the most abundant harvested species and inter annual variation in abundance of recruits was greater than for the other species, with estimated abundance in 2007, 2010 and 2011 being significantly greater than most other sampling events (Figure 11.5). Steentjie and elf abundance also showed high inter-annual variation with relatively high average abundance of steentjie juveniles recorded in 2005 and 2011 and substantially higher average abundance of elf juveniles in 2008, 2011, 2016 and 2017 (the highest recorded to date), which was followed by zero catches in in most years since. The 2023 catch of 59 elf is the greatest abundance observed in the last five years. The intra annual variability in abundance of these two species, a result of zero catches at many sites, however, means that these differences are not statistically significant. The density of blacktail juveniles in sampled habitats was significantly higher in 2008 than in all other years, but there has been an absence or scarcity of blacktail recruits since (Figure 11.5).

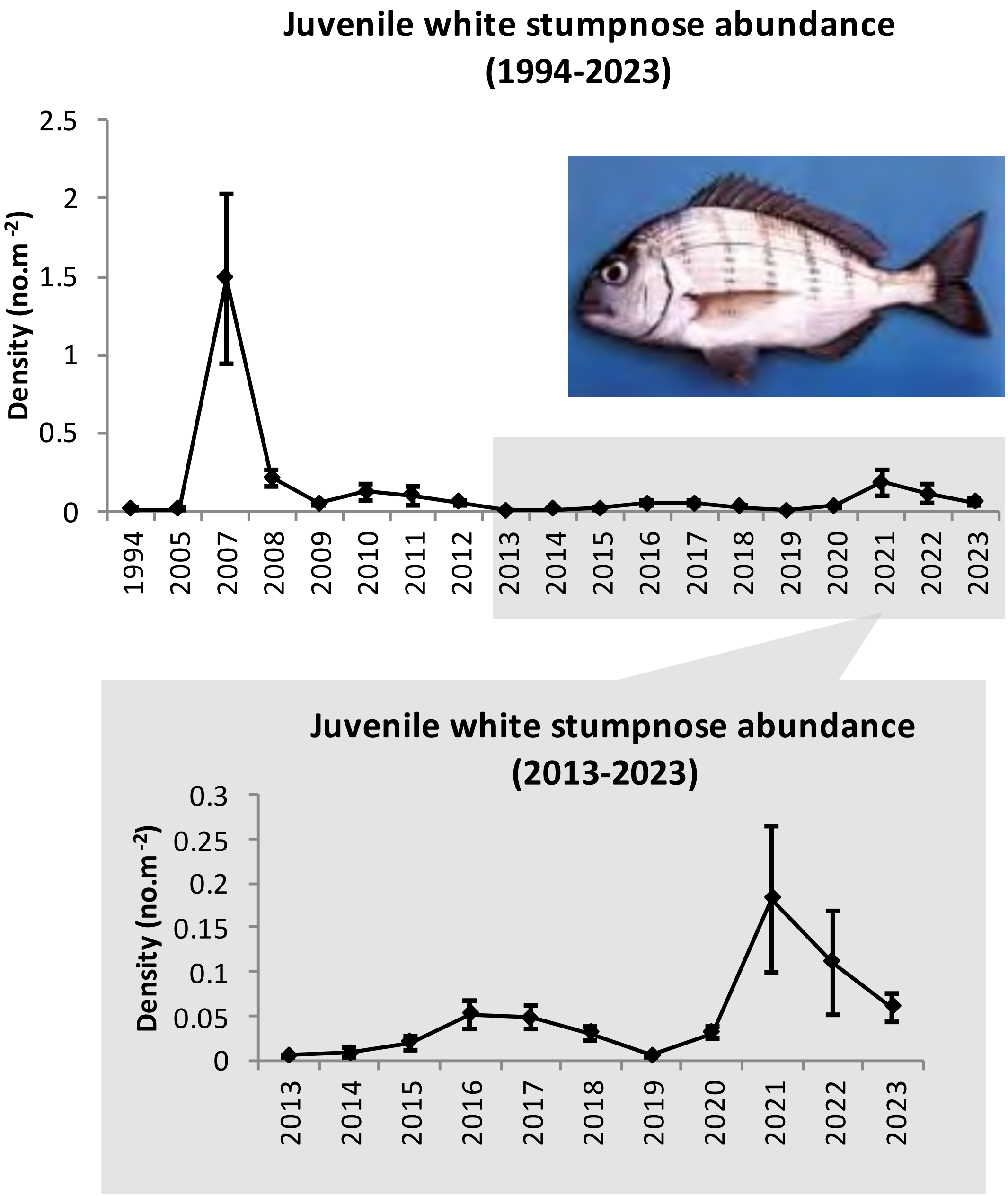


Figure 11.5. Average annual density of key fishery species at all sites sampled in all surveys (1994–2023). Error bars indicate SE.

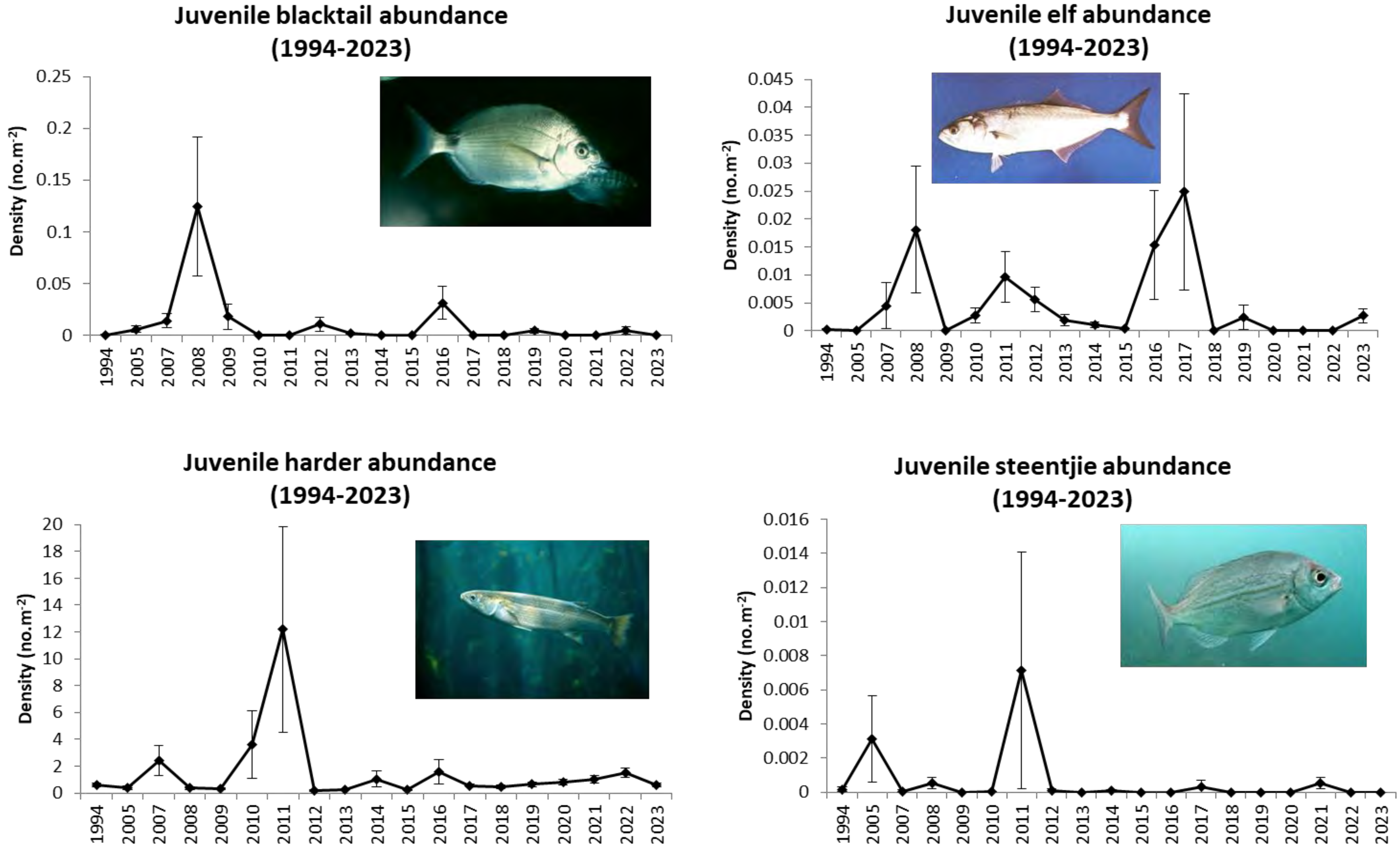


Figure 11.5 (Continued). Average annual density of key fishery species at all sites sampled in all surveys (1994–2023). Error bars indicate SE.

11.4 SUMMARY OF FINDINGS

Fish diversity and overall fish abundance does not show a declining trend in the Bay as a whole, but it must be acknowledged that overall abundance is dominated by harders, which appear resilient to decreases in water quality. The abundance of most of the other common species in Small Bay (white stumpnose, gobies and blacktail) remain low relative to earlier surveys, although the gobies do show some sign of recovery. The fish community health in Small Bay in 2023 is considered to be in a poor state compared to historical levels. With increases in abundance of white stumpnose, elf, and Cape sole, Big Bay is considered to be in better health than in previous years. Low abundances of white stumpnose, harders, and silversides, but high abundances of Knysna sandgobies and *Caffrogobius* gobies leave the fish communities in Langebaan Lagoon rated as having average health overall. This finding is consistent with most of the seine net survey history, where fish abundance at sites within or near the Langebaan MPA appeared to be largely stable with some 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. Studies by Hedger *et al.* (2010); Kerwath *et al.* (2009); 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. 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 et al. 2019).

The significant declines in juvenile white stumpnose abundance that occurred throughout the system over the period 2007–2020 suggested that the protection afforded by the Langebaan MPA was not enough to sustain the fishery at the historical high effort levels. Arendse (2011) found the adult stock to be overexploited using data collected during 2006–2008 already, and the evidence from the seine net surveys conducted since then certainly suggested that recruitment overfishing has occurred. The annual seine net surveys did act as an early warning system that detected poor recruitment and should have allowed for timeous adjustments in fishing regulations to reduce fishing mortality on weak cohorts and preserve sufficient spawner biomass. Unfortunately, despite repeatedly expressing concern about the collapse of white stumpnose recruitment in State of the Bay Reports since at least 2013 and supporting the implementation of the harvest control measures recommended by Arendse (2011); namely a reduction in bag limit from 10 to 5 fish per person per day and an increase in size limit from 25 cm TL to 30 cm TL, the warning calls were not heeded. A statistically comprehensive analysis of fishery dependent and survey data confirmed the collapse of the Saldanha-Langebaan white stumpnose stock and the fishery yield in recent years is a fraction of its historical peak or potential (Parker et al. 2017). The 2021 seine net survey revealed an encouraging increase in juvenile white stumpnose in Big Bay and Langebaan Lagoon, with estimated abundance similar to levels last seen during the 2008–2011 period. Unfortunately, the 2022–2023 seine net surveys have not continued this trend of recovery, and white stumpnose abundance is once again low, although still higher than it has been in ten years. It is likely that the protection of spawner biomass in the Langebaan MPA and the high fecundity of female white stumpnose, in conjunction with the reduced targeting of the species allowed for some recovery of the stock, but this apparent recovery in recruitment was not sustained. Continued monitoring is needed to assess further recovery. To facilitate recovery it remains prudent to lobby for increased harvest control measures for this important fishery.

The last six seine net surveys have, however, revealed some concerning declines in elf recruitment to surf zone nurseries, and it is recommended that this should also be carefully monitored in the future, despite the slight increase in juvenile elf abundance in the 2023 survey. Interpretation of the recruitment signal of exploited fish species would be greatly enhanced if there was ongoing monitoring of recreational catch and effort in the system. Only commercial linefishers are required to submit catch returns and, as most of the white stumpnose and elf fishing effort is recreational, there is a substantial gap with respect to catch-per-unit-effort data for this sector. Such data would provide another direct line of evidence as to the status of exploited fish stocks in the Saldanha Bay-Langebaan lagoon system. 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 once popular white stumpnose fishery was 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 the Bay and Lagoon 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 developments in the region 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. As fishing effort continues to increase, at some point fishing mortality will need to be contained, if the fisheries are to remain sustainable. We think that point arrived at least ten 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 the Department of Forestry, Fisheries and the Environment (DFFE), 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. Indeed, there is circumstantial evidence that a reduction in fishing mortality occurred in response to poor catch rates and this possibly started to result in improved white stumpnose recruitment as observed in the 2021–2023 seine net surveys. We also support the recommendation of (Horton et al. 2019) for a reduction in harder fishing effort and gear changes (increase in minimum mesh size) to facilitate stock recovery. Short term reductions in fishing mortality will have an economic cost but will yield substantially greater socio-economic benefits for fishers in the medium to longer term as the sustainable catch from an optimally exploited fish stock greatly exceeds that from a collapsed stock.

12 BIRDS AND SEALS

12.1 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 International Union for Conservation of Nature (IUCN) red data list criteria), Cape Gannet (Vulnerable), Cape Cormorant (recently up-listed to Endangered under IUCNs red data list criteria), White-breasted Cormorant, Crowned Cormorant (Near Threatened), Bank Cormorant (Endangered), Kelp and Hartlaub's gulls, Caspian Tern and Swift Tern.

The Department of Forestry, Fisheries and the Environment (DFFE) conducts bird counts on all islands to track population trends of each of these species over time. Each island is normally 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. Normally, all islands are visited roughly three times per calendar year except for Malgas (nine times) and Vondeling (less than three times due to accessibility) (Rob Crawford, Department of Environmental Affairs, pers. comm. 2016). Due to the corona virus lockdowns, however, counts during 2020 were much reduced with surveys only taking place at four of the islands (Jutten, Malgas, Meeuw and Schaapen) and no counts available for Cape Gannet, Caspian Tern, Swift Tern and White Breasted Cormorants (Azwianewi Makhado, DFFE personal communication). The normal sampling event took place during 2021 and 2022 (five visits to the five main bird Islands) and these more recent data are considered to be valid estimates of the breeding populations on these Islands (Makhado et al. 2023). However, no counts have been conducted on Caspian and Marcus Islands since 2020.

12.2 ECOLOGY AND STATUS OF THE PRINCIPAL BIRD SPECIES

The **African Penguin** *Spheniscus demersus* is endemic to southern Africa, and breeds in three regions: central to southern Namibia, Western Cape and Eastern Cape in South Africa (Whittington et al. 2005b). The species has recently been up-listed to Endangered, under IUCNs 'red data list' due to data revealing rapid population declines as a result of numerous factors including pollution (from oil spills), changes in the abundance and distribution of small pelagic fish populations, competition with commercial fisheries and seals for food and predation pressure from Kelp Gulls and Cape Fur Seals, as well as potential exposure to conservation-significant pathogens (David et al. 2003, Crawford 2009, Pichegru et al. 2009, Crawford et al. 2011, 2014, Weller et al. 2014, 2016, de Moor and Butterworth 2015, Grémillet et al. 2016, Parsons et al. 2016, Sherley et al. 2020, BirdLife International 2023). The Namibian population collapsed in tandem with the collapse of its main prey species, the sardine *Sardinops sagax* (Ludynia et al. 2010b). In South Africa the penguins breed mainly on offshore islands in the Western and Eastern Cape with strongly downward trends at all major colonies (Whittington et al. 2005a).

The global population of African penguins (including birds breeding on four Namibian Islands) hit a historical low of ~17 700 breeding pairs in 2019 with a high probability of having declined by almost 65 % since 1989 (Sherley et al. 2020). Throughout South Africa, the African Penguin population declined from an average of 48 000 pairs over the period 1979–2004 to just 17 000 pairs in 2013, 13 600 pairs in 2019 and a record low of just 10 400 pairs in 2021(Crawford et al. 2014, Boersma et al. 2020, Sherley et al. 2020). The latest counts from 2022 show the decline continuing, with an estimated breeding population of ~10 000 pairs (Punt et al. 2023). The number of African penguins breeding in the Western Cape decreased in a similar fashion from some 92 000 pairs in 1956, to 18 000 pairs in 1996. There was a significant recovery to a maximum of 38 000 pairs in 2004, before another dramatic collapse to 11 000 pairs in 2009, equating to a total decline of 60.5% in 28 years (Crawford et al. 2008c, 2008b). West Coast penguin colonies (north of Cape Town) have fared the worst in South Africa, with an unsustainable average annual decline of 10 % over the last 20 years (Sherley et al. 2020). This thought to be linked to a distribution shift of their main prey species sardines and anchovies (see below), with the Eastern Cape penguin colonies now holding ~41 % of the national breeding population, up from ~27% in 1979 (Sherley et al. 2020).

In Saldanha Bay the population initially grew from 552 breeding pairs in 1987 to a peak of 2 156 breeding pairs in 2001 and then underwent a severe and continuous decline to just three pairs recorded in 2020 (this was likely an underestimate due to a COVID-19 caused decrease in 2020 sampling effort) and 125 pairs in 2022 (Figure 12.1). The decline in the number of breeding pairs on the Saldanha Islands appears to have continued and is consistent with the national downward trend and strongly reinforces the argument that immediate conservation action is required to prevent further losses of these birds. In light of the ongoing decline in African Penguin numbers nationally, a Biodiversity Management Plan for the African Penguin was gazetted in 2013, with aims: "To halt the decline of the African Penguin population in South Africa within two years of the implementation of the management plan and thereafter achieve a population growth which will result in a downlisting of the species in terms of its status in the IUCN Red List of Threatened Species". Despite the successful implementation of many of the actions listed in the plan, these aims were not attained, and African Penguins in South Africa have continued to decline. This has led to several revisions of the Biodiversity Management Plan (Government Gazette No. 42775 18 October 2019, Government Gazette No. 47061 22 July 2022). This latest plan attributes population declines mostly to a scarcity of prey and recommends pelagic fishery exclusion zones around colonies, seasonal closures at penguin feeding grounds before and post moult, oil spill risk management and colony specific management such as predator control.

The changes in African Penguin population size at the islands in Saldanha is believed to be partially linked to patterns of immigration and emigration by young birds recruiting to colonies other than where they fledged, with birds tending to move to Robben and Dassen Islands (Whittington et al. 2005a). However, once they start breeding at an island, they will not breed anywhere else.

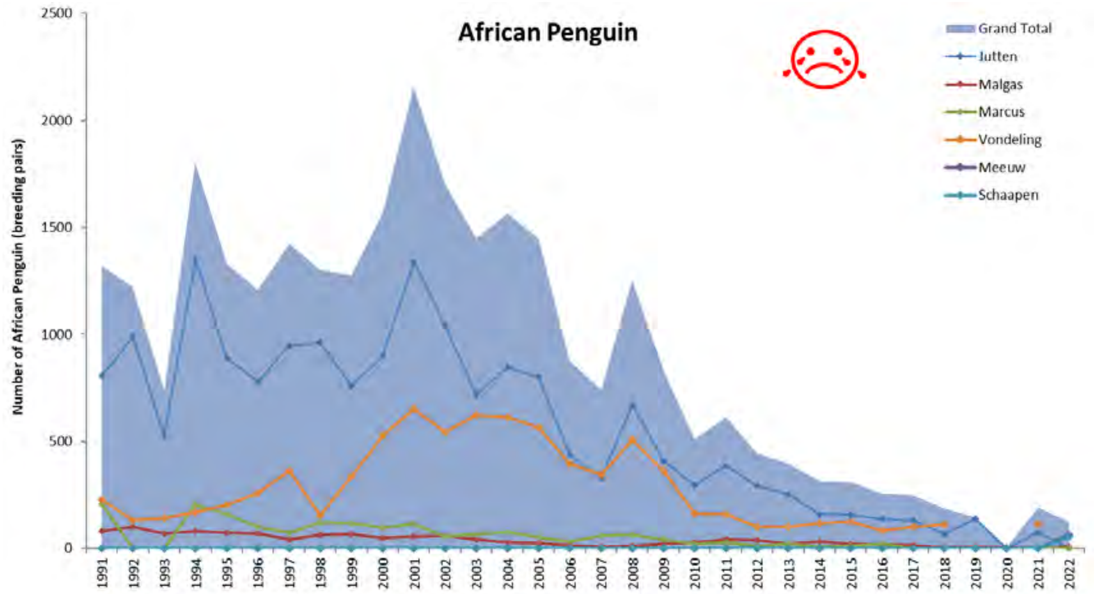


Figure 12.1. Trends in African Penguin populations at Jutten, Malgas, Marcus and Vondeling islands in Saldanha Bay from 1991–2022 measured in number of breeding pairs (Data source: (Makhado et al. 2023).

Penguin survival and breeding success has been linked to the availability of pelagic sardines *Sardinops sagax* and anchovies *Engraulis encrasicolus* within 20–30 km of their breeding sites (Pichegru et al. 2009). Diet samples taken from penguins at Marcus and Jutten Islands showed that the diet of African penguins in the Southern Benguela from 1984 to 1993 was dominated by anchovy (Laugksch and Adams 1993). During periods when anchovies are abundant, food is more consistently available to penguins on the western Agulhas Bank than at other times (older anchovy remain there throughout the year and sardines are available in the region in the early part of the year). The reduced abundance of anchovy in the 1980s may partly explain the decrease in the African penguin population evident from 1987 to 1993 clearly reflected in the Saldanha data ((Figure 12.2). Subsequently the penguin population at Saldanha bay increased in tandem with a "boom" period for the South African sardine stock that increased from less than 250 000 tonnes in 1990 to over four million tons in 2002 (Figure 12.2). Anchovy biomass also increased from the late 1990s, peaked at over 7 million tonnes in 2001, remained relatively high (compared to the 1980s and 1990s) at between 2–4 million tonnes in most years until 2014 (Figure 12.2). Although both anchovy and sardine were still abundant along the west coast during the "boom" period around the turn of the century, much of the growth in biomass in these small pelagic stocks occurred to the east of Cape Agulhas benefiting seabirds at colonies along the south and east coast. Subsequently, the sardine stock crashed over the period 2004–2007 and the proportion of the sardine stock along the west coast declined dramatically at this time. The numbers of African Penguins on the Saldanha Bay Islands followed a similar trajectory, despite anchovy remaining abundant off the West Coast and an increase in the proportion of the sardine stock west of Cape Agulhas up until 2013 (Figure 12.1, Figure 12.2). In the last decade, however, the estimated sardine biomass along the west coast has declined dramatically, with almost none detected in the 2018–2020 acoustic surveys (Figure 12.2). Anchovy biomass too declined from nearly 4 million tonnes in 2013 to about 800 000 tonnes in 2019, the second lowest estimate in the last two decades and the estimated biomass on the west coast was at its fourth lowest level since the turn of the century (Figure 12.2). Despite a recovery in anchovy stocks during the 2020 acoustic survey this was short lived with around one million tonnes estimated in the 2022 survey. However, penguin survival rates do not appear to be correlated with anchovy biomass, but a strong correlation between adult survival and sardine stock biomass has been reported in most years of particularly low sardine stock biomass (Robinson et al. 2015b, Crawford et al. 2022). Both studies found little relationship between adult survival and sardine stock biomass in years when stock biomass was average, or above average. A small increase in sardine biomass along the west coast was detected in the 2022 survey, but it remains at less than 20% of the peak 2003 west coast biomass (Figure 12.2). Small pelagic fish availability (especially sardines) remains relatively low for penguins breeding along the west coast, including the Saldanha Bay Islands.

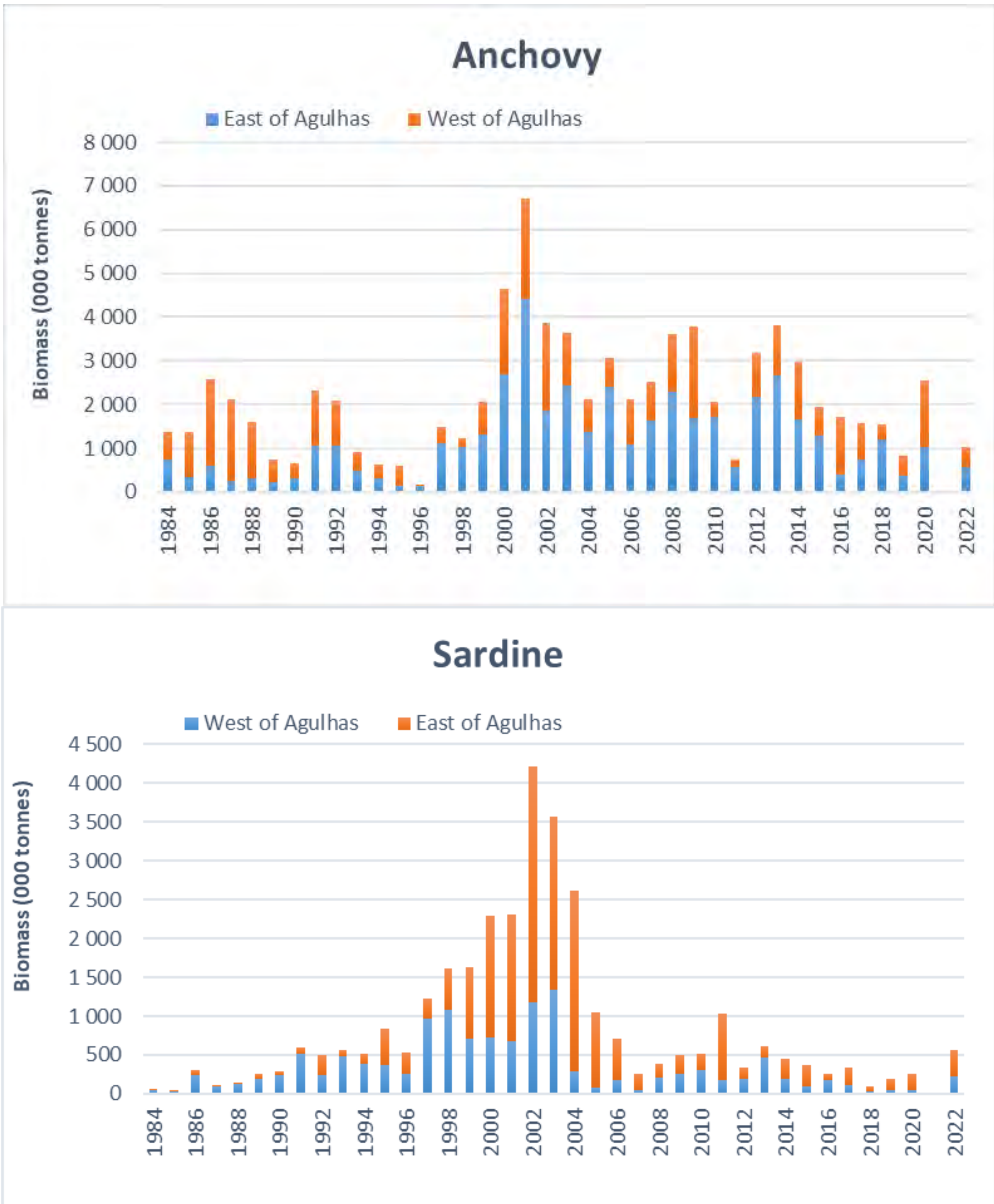


Figure 12.2. Long term trends in the biomass of small pelagic fish (sardine and anchovy) to the west and east of Cape Agulhas based on hydro acoustic surveys conducted bi-annually from 1984–2022 (Data source: Department of Environment, Forestry and Fisheries, 2023).

Several studies have identified additional drivers of African Penguin populations at the colony level; these include oiling and predation by seals and kelp gulls, with the importance of fishing and food availability decreasing at small colony size (<3 500 breeding pairs) (Ludynia et al. 2014, Weller et al. 2014, 2016). It has also been suggested that underwater noise associated with increased vessel traffic may have contributed to a recent decline in penguin numbers at St Croix Island in Algoa Bay and that increased shipping noise may represent an increasing threat to African penguins in South African waters in general (Pichegru et al. 2022). There is considerable uncertainty around the causes of African penguin population decreases which is a result of multiple pressures, some operating throughout the species range and others operating at different intensities at different colonies. One of the measures currently being employed to curb these declines is the use of no-take zones for purse-seine fishing. This strategy, was tested initially at St Croix Island in the Eastern Cape, was effective in decreasing breeding penguins' foraging efforts by 30% within three months of closing a 20 km zone to purse-seine fisheries (Pichegru et al. 2010). In this case, the use of small no-take zones presented immediate benefits for the African penguin population dependent on pelagic prey, with minimum cost to the fishing industry, while protecting ecosystems within these habitats and important species. However, experimental fishing closures at Dassen and Robben Islands have not delivered such positive results, resulting in published rebuttals labelling the findings of Pichegru et al. (2010) premature. More recent revisions of the Biodiversity Management Plan for the African penguin do still consider a decline of food availability as a major driver of African Penguin population decline and recommends fishery closures around colonies (Government Gazette No. 42775 18 October 2019, Government Gazette No. 47061 22 July 2022).

On the 16 September 2022 the DFFE announced closures for small pelagic fishing around the major penguin breeding colonies of Dassen Island, Robben Island, Stony Point, Dyer Island, St Croix Island and Bird Island (www.gov.za/speeches/forestry-fisheries-and-environment). The closures around Dassen Island and Robben Island could benefit penguin colonies on the west coast as a whole and the Dassen Island closure may benefit penguins nesting on the Saldanha Islands as it is within the foraging range of the species (Pichegru et al. 2009). Recently, an expert panel reviewed the results of the Island Closure Experiment and noted that "excluding fishing around island breeding colonies is likely to reduce the rate of decline in the population to a small extent, mediated through improvements in reproductive success" (Punt et al. 2023). Other benefits for penguins, such as increased adult survival was also thought to be a benefit of excluding purse seine fishing around breeding colonies although the Island Closure Experiment did not test for such effects (Punt et al. 2023). Following the completion of the review report, in August 2023 the minister of DFFE announced a decision to extend the purse seine fishing limitations in the waters around important penguin colonies for a minimum of 10 years, with a review after 6 years of implementation and data collection.

The reduction in colony sizes at most of the islands in Saldanha Bay will have had severe negative consequences for penguins. When penguins breed in large colonies, packed close to one another, they are better able to defend themselves against egg and chick predation by Kelp gulls. Also, these losses are trivial at the colony level. However, the fragmented colonies and the rise in gull numbers associated with the rapidly expanding human settlements in the area during the 1980s, meant that gull predation became problematic. Kelp gull numbers in Saldanha Bay have decreased dramatically in recent years (see below), but the population remains at more than 2 000 pairs and gull predation on penguin eggs almost certainly remains problematic. Research has indicated that the provision of correctly designed artificial nest sites that provide protection both from gull predation and extreme temperatures (half concrete pipes were found to be superior to fibreglass artificial burrows) can be effective in enhancing fledging success (Pichegru 2013). Similarly, predation by seals (on land and around colonies) is having an increasingly negative impact on these dwindling colonies (Makhado et al. 2006, 2009). Additional stress, such as turbidity and increased vessel traffic, will not only impact penguins directly, but is likely to influence the location of schooling fish that the penguins are targeting and their ability to locate these schools. There are also concerns that toxin loads influence individual birds' health, reducing their breeding success and/or longevity (Game et al. 2009).

A large-scale health assessment on the African Penguin and found that this species is potentially exposed to conservation-significant pathogens (Parsons et al. 2016). Disease constitutes a major ecological force and has been shown to play an even greater role in threated populations Parsons et al., 2016). The effect of diseases on seabird population dynamics is currently poorly understood. Both, disease outbreaks as well as chronic diseases should both be considered as potential threats to the African Penguin and should be investigated further as part of the conservation efforts Parsons et al., 2016).

In summary, the initial collapse of the penguin colonies in the area is probably related to food availability around breeding islands and in areas where birds not engaged in breeding are foraging, particularly before and after moulting. However, now that colonies have shrunk so dramatically, the net effect of local conditions at Saldanha Bay are believed to be an increasingly important factor in the continued demise of African penguin colonies at the islands. The biomass of sardines along the west coast remains at a historically low level, shipping traffic is increasing (Chapter 3) and the challenges to a population recovery remain great. The realization of any potential benefits to penguin numbers locally and nationally of the small pelagic fishery closures around important breeding colonies will only become apparent over time.

The **Kelp Gull** *Larus dominicanus vetula* breeds primarily on offshore islands, as well as a small number of mainland sites. The Islands in Saldanha Bay support a significant proportion of South Africa's breeding population. Within this area, the majority breed on Schaapen, Meeuw and Jutten Islands, with additional small but consistent breeding populations on Vondeling and Malgas islands. Small numbers of breeding kelp gulls were recorded on Marcus Island in 1978, 1985 and 1990–92, but breeding has since ceased, probably due to the causeway connecting the island to the mainland allowing access to mammal predators (Hockey et al. 2005). Kelp Gulls are known to eat the eggs of several other bird species (e.g., African penguins, Cape Cormorants and Hartlaub's Gulls). Prior to the 1960s, numbers of Kelp Gulls on offshore islands were controlled to protect the guano and egg producing species (Crawford et al., 1982).

Post 1970, Kelp Gull populations were no longer controlled, which, together with the supplementary food provided by fisheries and landfill sites resulted in the doubling of breeding pairs in South Africa by 2002 (Whittington et al. 2016). The introduction and spread of the invasive alien mussel species *Mytilus galloprovincialis* could also have contributed toward the increased availability of food. Consequently, pressures on guano-producing seabird populations shifted from guano exploitation to egg predation by increasing Kelp Gull numbers.

Since 2000, the populations on the islands have been steadily decreasing following large-scale predation by Great White Pelicans *Pelecanus onocrotalus* that was first observed in the mid-1990s (Crawford et al., 1997). During 2005 and 2006 pelicans caused total breeding failure of Kelp Gulls at Jutten and Schaapen Islands (de Ponte Machado 2007) the effects of which are still apparent (Figure 12.3). Recent counts show that Kelp Gull numbers remain below those at the start of the comprehensive counting period although the decline appears stopped around 2015 and numbers are increasing with about 4 500 pairs recorded in 2022 (Figure 12.3). The loss of breeding pairs at the Saldanha Bay Islands since 2000 were to some degree offset by an increase in numbers breeding on mainland sites, especially around greater Cape Town and along the south coast (Whittington et al. 2016).

Anthropogenic debris has been found in Kelp Gull nests, especially in colonies located near landfill sites and coastal sites where there was a limited vegetation available for construction (Witteveen et al. 2017). Debris in nests can lead to injury or death as a result of entanglement of chicks and adults. Often ropes and straps are used by Kelp Gulls to construct nests. Plastic bags and food wrappers mostly appear to accumulate during the chick rearing period as those items were mostly regurgitated. The fact that the decline of Kelp Gull populations off the Saldanha Islands has stopped since 2015 suggests that Pelican predation rather than anthropogenic debris was the main driver of population decline over the period 2000–2015.

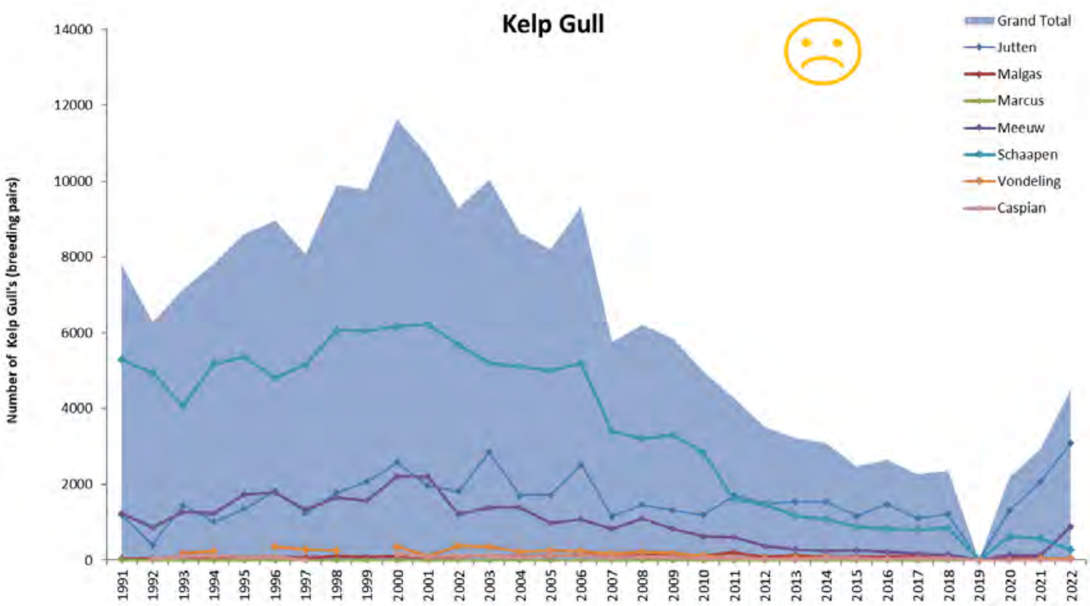


Figure 12.3. Trends in breeding population of Kelp gulls at Jutten, Malgas, Marcus, Meeuw, Schaapen, Vondeling and Caspian Islands in Saldanha Bay from 1985–2021 measured in number of breeding pairs (Data source: (Makhado et al. 2023).

Hartlaub's Gull, *Chroicocephalus hartlaubii*, is about the 10th rarest of the world's roughly 50 gull species. It is endemic to southern Africa, occurring along the West Coast from Swakopmund to Cape Agulhas. It breeds mainly on protected islands but has also been found to breed in sheltered inland waters. Hartlaub's Gulls are relatively nomadic and can alter breeding localities from one year to the next (Crawford & Underhill, 2003). The numbers breeding on the different islands are highly erratic, as are the total numbers in the Bay. The highest and most consistent numbers of breeding birds are found on Malgas, Jutten and Schaapen islands, with a few birds breeding Vondeling Island between 1991 and 1998 and last in 2006 when 30 pairs were recorded. They have also been recorded breeding on Meeuw Island in 1996, from 2002 to 2004, 2012–2014, 2017 and 2020–2021. There are substantial inter-annual fluctuations in numbers of birds breeding, suggesting that in some years an appreciable proportion of the adults do not breed (Crawford and Underhill 2003). Natural predators of this gull are the Kelp Gull, African Sacred Ibis and Cattle Egret, which eat eggs, chicks and occasionally adults (Williams et al. 1990). In Saldanha Bay there is no discernible upward or downward trend over time. The total number of breeding pairs recorded in 2018 was just 36 pairs on Jutten and Malgas Islands, whilst over the period 2019–2022 between 644–996 breeding pairs were recorded with the majority on Jutten, Malgas, Meeuw and Schaapen Islands (Figure 12.4). Overall throughout its range, the population is increasing and the species is not currently facing any threats that are thought to have a significant effect on the population (BirdLife International 2023).

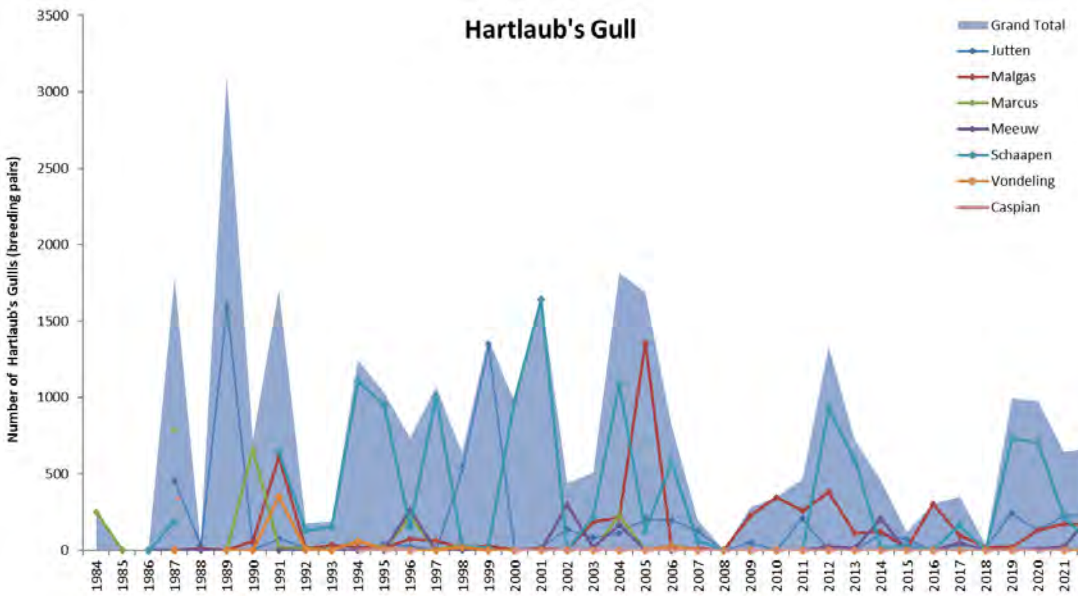


Figure 12.4. Trends in breeding population of Hartlaub's Gulls at Jutten, Malgas, Marcus, Meeuw, Schaapen, Vondeling and Caspian Islands in Saldanha Bay from 1984–2021 measured in number of breeding pairs (Data source: (Makhado et al. 2023).

The **Swift Tern**, *Thalasseus bergii*, is a widespread species that occurs as a common resident in southern Africa. Swift Terns breed synchronously in colonies, usually on protected islands, and often in association with Hartlaub's Gulls. Sensitive to human disturbance, their nests easily fall prey to Kelp Gulls, Hartlaub's Gulls and Sacred Ibis (Gochfeld et al. 2018). During the breeding season, fish form 86% of all prey items taken, particularly pelagic shoaling fish, of which the Cape Anchovy (*Engraulis encrasicolus*) is the most important prey species. The steady increase in Swift Tern numbers between 2002 and 2005 coincided with a greater abundance of two of their main prey species, sardines and anchovies (Figure 12.5). However, since 2005, the population in the Western Cape has shifted south and eastward, coinciding with a similar shift of their prey species (Crawford 2009). In southern Africa, Swift Terns show low fidelity to breeding localities, unlike the African Penguin, Cape Gannet and Cape Cormorant, which enables them to rapidly adjust to changes in prey availability (Crawford 2009, 2014).

In Saldanha Bay, Jutten Island has been the most important island for breeding Swift Terns over the past 30 or more years, but breeding numbers are erratic at all the islands. The breeding population shifted to Schaapen Island in 2007, but no swift terns were reported breeding on islands in the Bay for the three years following this, the longest absence on record. Subsequent to this, Swift Terns have bred on the Saldanha Islands nearly every year, albeit with the typical, erratic variability. In the last five years, numbers recorded have fluctuated from amongst the highest on record in 2018, to just two pairs in 2019, zero in 2020 and 2021 and 56 in 2022 (Figure 12.5).

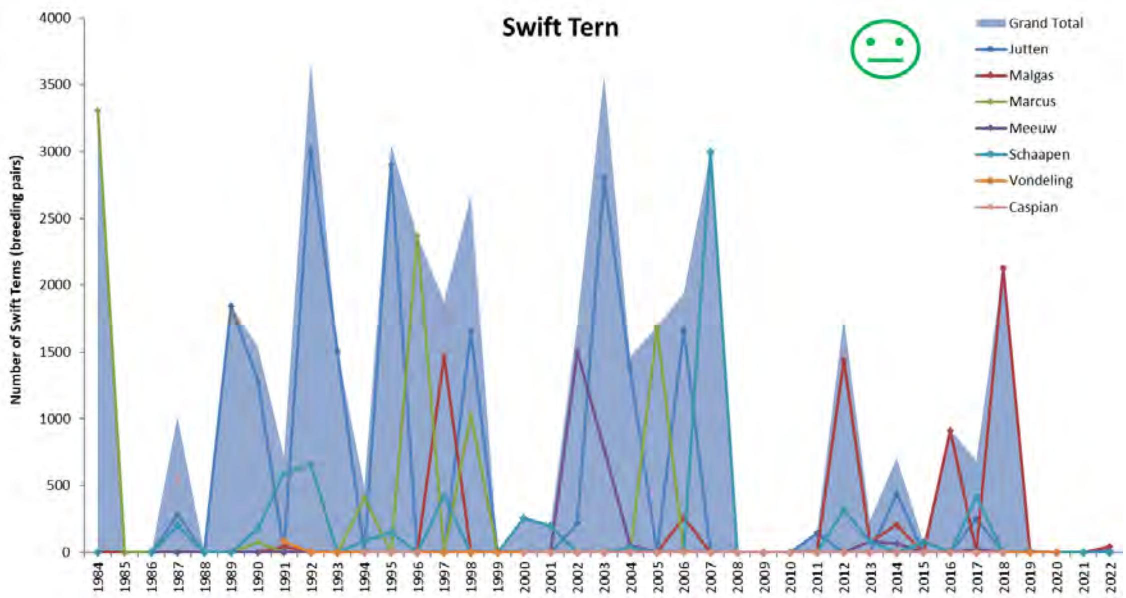


Figure 12.5. Trends in breeding population of Swift Terns at Jutten, Malgas, Marcus, Meeuw, Schaapen, Vondeling and Caspian Islands in Saldanha Bay from 1984–2022 measured in number of breeding pairs (Data source: (Makhado et al. 2023).

Cape Gannets *Morus capensis* are restricted to the coast of Africa, from the Western Sahara, around Cape Agulhas to the Kenyan coast. In southern Africa they breed on six offshore islands, three off the Namibian coast, and two off the west coast of South Africa (Bird Island in Lambert's Bay and Malgas Island in Saldanha Bay), and one (Bird Island) at Port Elizabeth. The Cape Gannet is listed as Endangered on the IUCNs global Red Data List, due to its restricted range and population declines (BirdLife International 2018a). Cape Gannets breed on islands which afford them protection from terrestrial predators. They feed out at sea and will often forage more than a hundred kilometres away from their nesting sites (Adams and Navarro 2005). This means that only a small proportion of foraging takes place within Saldanha Bay. The quality of water and fish stocks in Saldanha Bay should therefore not have a significant effect on the Cape Gannet population.

The bird colony at Malgas Island has shown substantial population fluctuation since the early 1990s and an erratic decline over the period 1996–2015, which appears to have stabilized since (Figure 12.6). Numbers of breeding pairs have recovered somewhat in recent years with highs of 30 350 in 2017 and 36 500 thousand in 2022. The decline in numbers at Malgas Island coincided with population figures for Bird Island, off Port Elizabeth, where numbers initially increased over the same period. The total South African gannet population appears to respond to the population dynamics of small pelagic fish (particularly sardines), with the number of breeding pairs averaging at 123 thousand pairs since 1995 (Crawford et al. 2014). A study suggested that Cape Gannet population trends are driven by food availability during their breeding season (Lewis et al. 2006). Pichegru et al. (2007) showed that Cape Gannets on the west coast have been declining since the start of the eastward shift of the pelagic fish in the late 1990s. This has resulted in west coast gannets having to increase their foraging efforts. During the breeding season, they forage in areas with very low abundance of their preferred prey, and feed primarily on low-energy hake trawl fishery discards which constituted 93% of total prey intake (Crawford et al. 2007, Pichegru et al. 2007). A bioenergetics model showed that enhanced availability of low-energy hake fishery discards does not seem to compensate for the absence of natural prey and a study of foraging energetics suggested that Gannets tracked from Malgas Island were not maintaining their energy budget during feeding flights (Pichegru et al. 2007, Grémillet et al. 2016). Despite only a small, documented overlap (13%) in Cape Gannet foraging zones from Malgas Island with the purse-seine fishery, the total fishery catch was estimated at 41% of the food requirements of the colony (Okes et al. 2009). Some of these studies have called for increased restrictions on purse-seine fishing in the vicinity of bird colonies, but these conclusions have been challenged by fishery scientists who point out that small pelagic fish biomass was actually increasing in the area at the time the Cape Gannet numbers started declining (Figure 12.6).

Gannets with their extensive foraging range and diverse diets have proved adaptable to the changes in pelagic fish distribution and nationally, until recently, numbers were thought to have not declined (Crawford et al. 2014). The most recent IUCN Red List Assessment, however, upgraded Cape Gannets from Vulnerable (2017) to Endangered (2018) due to a large population reduction (51.5 % between 1956 and 2015) over the past three generations with projected further declines over the next three generations (BirdLife International 2018a). A revised assessment estimated the population decline at 44.7% over the preceding three generations with the balance of evidence suggesting that a global classification of Vulnerable would be the most appropriate status (Sherley et al. 2019). The IUCN red list status, however, remains Endangered (BirdLife International 2018a). As with African Penguins a food shortage due to the collapse of the sardine stocks and an eastwards displacement of small pelagic fish are considered the major driver of population declines. Competition with purse-seine fisheries in South Africa is associated with negative impacts on foraging success, adult body condition and chick growth rates (Okes et al. 2009, Cohen et al. 2014, Grémillet et al. 2016) but there is little evidence for impacts on the local population size or a decrease in adult survival rate (Crawford et al. 2014). The impacts of global warming including sea level rise, increased frequency and magnitude of storms constitutes a further risk to Gannet colonies due to coastal flooding that may exacerbated by historical guano mining (BirdLife International 2018a). Direct predation by Cape fur seals *Arctocephalus pusillus,* Kelp gulls and the Great White Pelican *Pelecanus onocrotalus* constitute further threats to Cape Gannet populations (Makhado et al. 2006, Pichegru et al. 2007, Sherley et al. 2019).

The latter is possibly of greater significance and of more concern at a local level for the Malgas Island Cape Gannet Colony, as high rates of predation by Cape fur seals, and Kelp Gulls accounts for between one and two thousand gannet breeding failures per season in average years (Pelican Watch pers. comm. 2017). Furthermore, Cape Fur Seals prey on fledgling sea birds that land in the waters around their home islands for the first time (David et al. 2003, Makhado et al. 2009, Strydom et al. 2022). Seal numbers nationally increased at an average of 3.5% per annum since 1971 until 1993 when aerial census of seal colonies was undertaken (David et al. 2003). In Saldanha waters, seal numbers have increased dramatically since 2000 when they started re-colonising Vondeling Island. Annual census of seal pups on Vondeling Island recorded a dramatic increase up until 2013 after which numbers have fluctuated around 20 000 (see Section 12.4.1) and the consequent increase in competition for already depleted food resources has led groups of young male seals to augment their normal diet by hunting cormorant and gannet fledgling on their first forays from the islands (Pelican Watch pers. comm. 2017).

Estimates of Cape Gannet mortality caused by Cape Fur Seals were 6 000 fledglings around Malgas Island in the 2000/01 breeding season, 11 000 in 2003/04 and 10 000 in 2005/06 (Makhado et al. 2006). This amounted to about 29%, 83% and 57% of the overall production of fledglings at the island in these breeding seasons respectively, despite an ongoing "problem" seal culling programme around Malgas Island that was initiated in 1993 (David et al. 2003, Makhado et al. 2009). These seal predation rates were considered unsustainable and largely responsible for the 25% decline in the Malgas Island Cape Gannett population between 2001 and 2006 (Makhado et al. 2006). Seal predation of seabirds is ongoing, and it was estimated by the Department of Environmental Affairs seal culling team that in January 2016 "… all young gannets landing on the waters around Malgas were taken by seals…" (Pelican Watch pers. comm. 2017). These recent findings have changed the overall health of the Gannet population on Malgas Island from Fair to Poor based on the ongoing predation by fur seals. Management measures were implemented between 1993 and 2001, and 153 fur seals seen to kill Gannets were shot (Makhado et al. 2006). This practice has continued in an effort to improve breeding success (Makhado et al. 2009, Sherley et al. 2019). The effects of this, along with other measures (Dassen Island closure to small pelagic fishing) may be manifest in the slight recovery in Gannet numbers. Food availability, however, remains problematic in light of ongoing low small pelagic fish biomass along the west coast. Unfortunately, no counts of Gannet breeding pairs were conducted during 2020 but the counts in 2021 and 2022 estimated around 24 000–36 540 breeding pairs on Malgas Island (50–75% of the number of pairs recorded over the period 1986–2001).

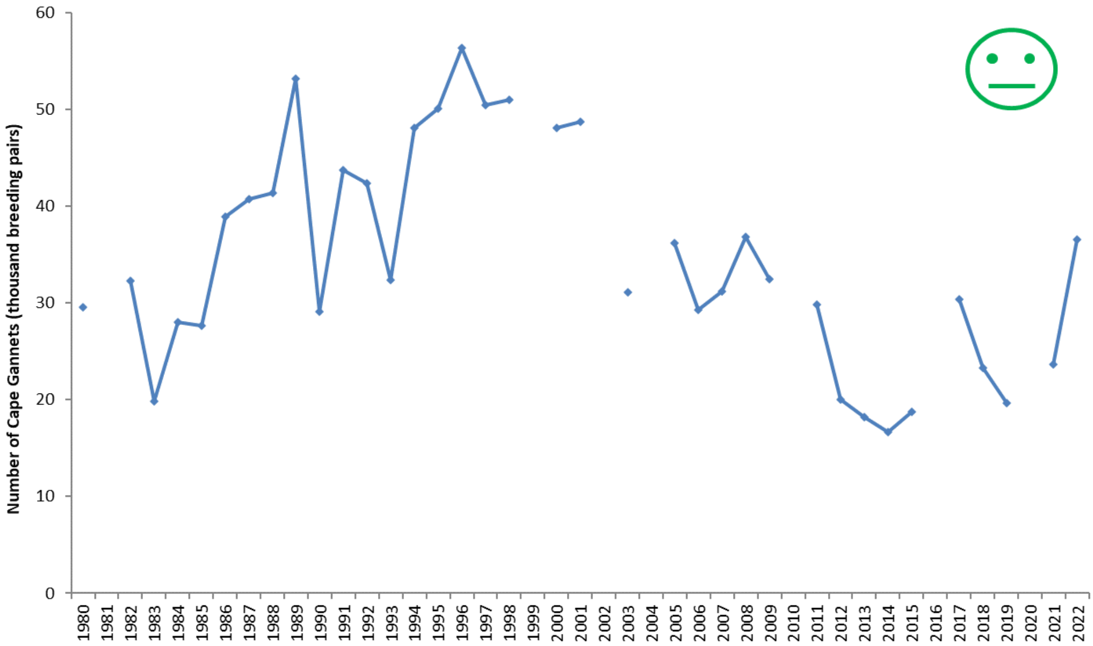


Figure 12.6. Trends in breeding population of Cape Gannets at Malgas Island, Saldanha Bay from 1980–2022 measured in number of breeding pairs (Data source: (Makhado et al. 2023).

Cape Cormorants *Phalacrocorax capensis* are endemic to southern Africa, where they were historically abundant on the west coast but less common on the east coast, occurring as far east as Seal Island in Algoa Bay. They breed between Ilha dos Tigres, Angola, and Seal Island in Algoa Bay, South Africa. They generally feed within 10–15 km of the shore, preying on pelagic goby *Sufflogobius bibarbatus*, Cape anchovy *Engraulis encrasicolus* pilchard *Sardinops sagax* and Cape horse mackerel *Trachurus trachurus* (Crawford et al. 2016, Masiko et al. 2021).

Key colonies of the Cape Cormorant in South Africa and Namibia have undergone very rapid population declines over the past three generations and the Cape Cormorant has therefore been up listed to Endangered (BirdLife International 2018b). Declines are primarily believed to have been driven by collapsing pelagic fish stocks (BirdLife International 2015). However, pelagic fish stocks increased greatly in the late 1990s and early 2000s, and although sardine biomass subsequently crashed, anchovy biomass remained relatively high (Figure 12.2). This suggests that other factors are also involved in declining Cape Cormorant numbers. The species is susceptible to oiling and avian cholera outbreaks. Overall the numbers of Cape Cormorant breeding in South Africa decreased by nearly 57 % from ~107 000 pairs in 1977–1981 to 57 000 pairs in 2010–2014 (Crawford et al. 2016). This decline largely occurred along the west coast north of Dassen Island, whilst the number of breeding pairs at colonies to the south and east of Dassen Island stayed relatively stable or increased in the 2000s (Crawford et al. 2016). This decline and distributional shift was linked to the movements in the stocks of anchovies and sardines, two of their main prey species (Crawford et al. 2016).

In South Africa, numbers decreased during the early 1990s following an outbreak of avian cholera, predation by Cape fur seals and White Pelicans as well as the eastward displacement of sardines off South Africa (Crawford 2007, Crawford et al. 2016). A semi-systematic count by the Pelican Watch on Jutten in December 2015, suggests that about 3 000 young Cape Cormorants were taken by seals during the fledging period. There are large inter-annual fluctuations in breeding numbers due to breeding failure, nest desertion and mass mortality related to the availability of prey, for which they compete with commercial fisheries (Masiko et al. 2021). This makes it difficult to accurately determine population trends on the Saldanha Islands. In addition, during outbreaks of avian cholera, tens of thousands of birds die (Crawford et al. 2016). Cape Cormorants are also vulnerable to oiling and are difficult to catch and clean. Discarded fishing gear and marine debris also entangles and kills many birds. Kelp Gulls prey on Cape Cormorant eggs and chicks and this is exacerbated by human disturbance, especially during the early stages of breeding, as well as the increase in gull numbers (Crawford et al. 2016).

The Saldanha Bay population has been quite variable since the start of monitoring in 1988, with the bulk of the population residing on Malgas and Jutten Island in recent years, until 2019 when the 2 089 breeding pairs recorded were found exclusively on Malgas Island, but in 2020 and 2021 they were again abundant on Jutten Island (Figure 12.7). Overall, the number of breeding pairs declined gradually since the 1990s, and although interannual variability is high there appears to be no trend in the last decade. In 2013, a total of only 801 breeding pairs were recorded, representing the lowest level recorded to date (Figure 12.7). Between 2013 and 2016, a short-lived recovery of breeding pairs to 9 273 was linked to an increase in the number of breeding pairs on Malgas Island. The numbers of breeding pairs dropped once again to a total of 2 089 in 2019 but recovered to between 6000–9000 pairs over the period 2020– 2022 (Figure 12.7).

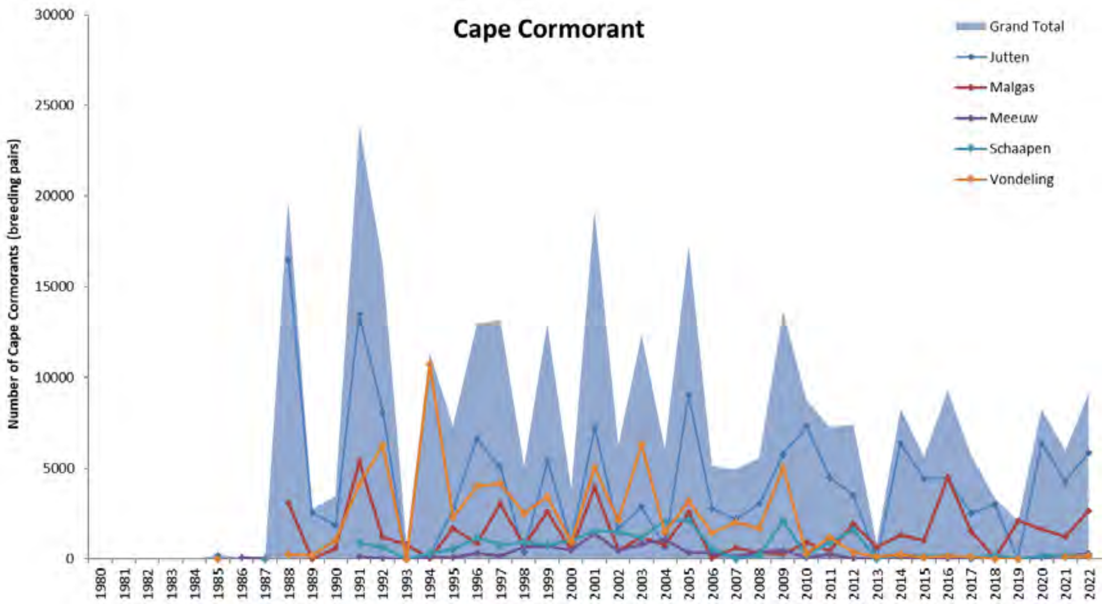
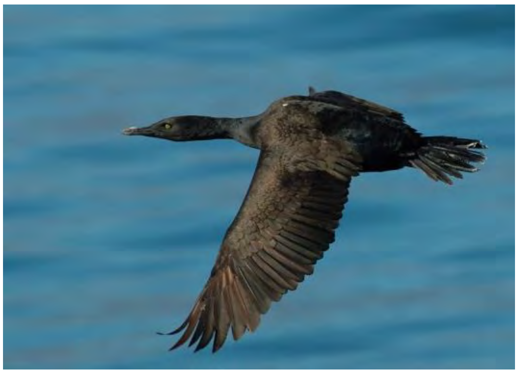


Figure 12.7. Trends in breeding population of Cape Cormorants at Jutten, Malgas, Meeuw Schaapen, and Vondeling islands in Saldanha Bay from 1980–2022 measured in number of breeding pairs (Data source: (Makhado et al. 2023).



Bank Cormorants *Phalacrocorax neglectus* are endemic to the Benguela upwelling region of southern Africa, breeding from Hollamsbird Island, Namibia, to Quoin Rock, South Africa. They seldom range farther than 10 km offshore. Their distribution roughly matches that of kelp *Ecklonia maxima* beds. They prey on various species of fish such as the pelagic goby *Sufflogobius bibarbatus*, crustaceans and cephalopods, feeding mainly amongst kelp where they catch West Coast rock lobster, *Jasus lalandii* (Ludynia et al. 2010). The total population decreased from about 9 000 breeding pairs in 1975 to less than 5 000 pairs in 1991–1997, to 2 800 pairs in 2006 and was estimated at 2 500 pairs in 2015 (Kemper et al. 2007, BirdLife International 2018c)). The South African population approximately halved from 1500 pairs in 1978–1980 to 800 pairs in 2011–2013 (Crawford et al. 2015). One of the main contributing factors to the decrease in the North and Western Cape colonies was a major shift in the availability of the West Coast rock lobster from the West Coast to the more southern regions, observed between the late 1980s and early 1990s to the turn of the century (Cockcroft et al. 2008). The abundance of lobsters was further severely affected by an increase in the number and severity of mass lobster strandings (walkouts) during the 1990s and increases in illegal fishing, with the national stock rock lobster status now estimated less than 2% of pristine biomass (Cockcroft et al. 2008, DAFF 2018). Ongoing population declines led to the Bank Cormorant's status being changed from Vulnerable to Endangered (BirdLife International 2018c)

Breeding pair count data from the Saldanha Bay area shows the dramatic decrease in the population at Malgas Island, which was previously the most important island for this species. The number of breeding pairs on Jutten, Marcus and Vondeling has declined steadily since 2003 on all the islands. Overall, the population in Saldanha Bay has declined drastically by approximately 97% since 1990 (Figure 12.8). Numbers of breeding pairs in the last four years are the lowest on record, with between three and nine pairs recorded. These declines are mainly attributed to scarcity of their main prey, the rock lobster which in turn has reduced recruitment to the colonies (Crawford 2007, Crawford et al. 2008a). Bank Cormorants are also very susceptible to human disturbance and eggs and chicks are taken by Kelp Gulls and Great White Pelicans. Increased predation has been attributed to the loss of four colonies in other parts of South Africa and Namibia (Hockey et al. 2005). Smaller breeding colonies are more vulnerable to predation which would further accelerate their decline. Birds are also known to occasionally drown in rock-lobster traps, and nests are often lost to rough seas (Sherley et al. 2012, BirdLife International 2018c).

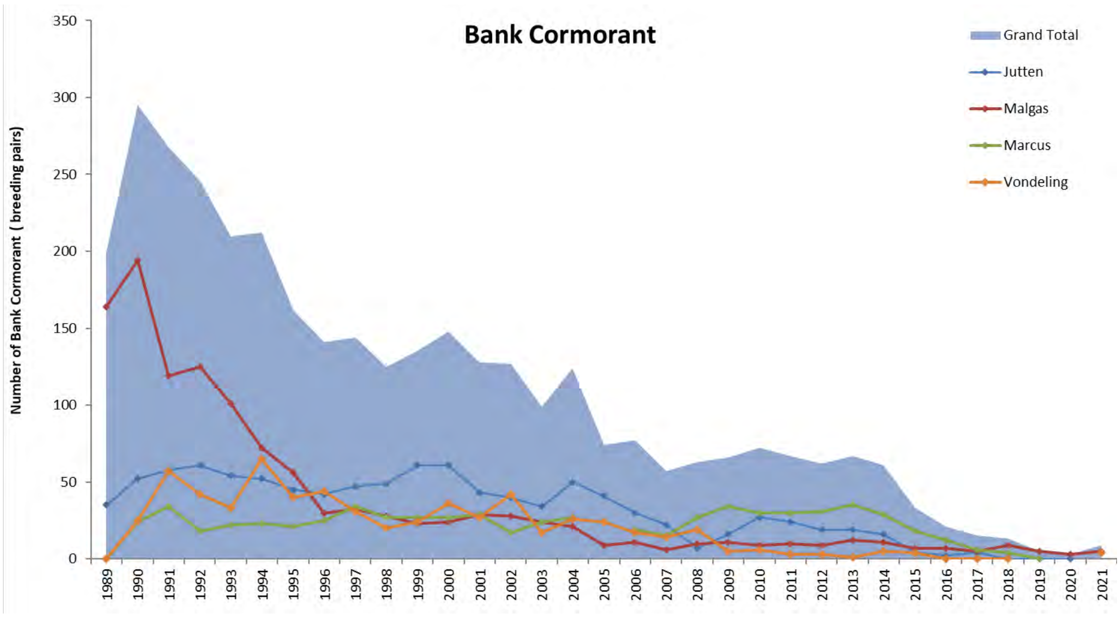


Figure 12.8. Trends in breeding population of Bank Cormorants at Jutten, Malgas, Marcus and Vondeling islands in Saldanha Bay from 1980–2022 measured in number of breeding pairs (Data source: (Makhado et al. 2023).

The **White-breasted Cormorant** *Phalacrocorax lucidus* also known as Great Cormorant, occurs along the entire southern African coastline, and is common in the eastern and southern interior, but occurs only along major river systems and wetlands in the arid western interior. The coastal population breeds from Ilha dos Tigres in southern Angola, to Morgan Bay in the Eastern Cape. Along the coast, White-breasted Cormorants forage offshore, mainly within 10 km of the coast, and often near reefs. White-breasted Cormorants that forage in the marine environment feed on bottom-living, mid-water and surface-dwelling prey, such as sparid and Mugillid fishes e.g., Steentjies, white stumpnose and harders (BirdLife International 2023). This species forages in Saldanha Bay and Langebaan Lagoon, making it susceptible to local water quality and fishing activities (Hockey et al. 2005)

Within Saldanha Bay, breeding effort has occasionally shifted between islands. White-breasted Cormorants bred on Malgas Island in the 1920s, and low numbers of breeding pairs were counted on Marcus and Jutten Islands intermittently between 1973 and 1987 when they stopped breeding there and colonized Schaapen, Meeuw and Vondeling islands (Crawford et al. 1994). Most of the breeding population was on Meeuw in the early 1990s but shifted to Schaapen in about 1995. By 2000, the breeding numbers at Schaapen had started to decline and the breeding population had shifted entirely back to Meeuw by 2004, where it has remained since (Figure 12.9). Overall, numbers of breeding pairs were more or less stable until 2012 but have declined steeply since then. The last seven annual counts (2015–2022) were substantially down from the 100–150 breeding pairs recorded in most years prior to 2012. Only 16 pairs were recorded in 2019 representing the lowest number recorded in the past 31 years, whilst no data were provided for White-breasted Cormorants in 2020 (this may have been a result of reduced sampling effort). The 2021 count revealed 32 breeding pairs, an improvement on 2019 but very similar to the average post-2015 population size and well below earlier counts (Figure 12.9). No count of White-breasted Cormorants was made in 2022.

Human disturbance poses a threat at breeding sites. These cormorants are more susceptible to disturbance than the other marine cormorants, and leave their nests for extended periods if disturbed, exposing eggs and chicks to Kelp Gull predation. Other mortality factors include Avian Cholera, oil pollution, discarded fishing line and hunting inland (BirdLife International 2023). White Breasted Cormorants also predate on fish caught in gill nets utilized in the harder fishery and risk becoming entangled in the gear and drowning. Effort in the harder fishery has increased in recent years and the average size of harders in the Saldanha- Langebaan fishery has decreased (see Chapter 11: Fish), potentially negatively affecting foraging opportunities for White Breasted Cormorants in the Bay. Due to Schaapen Islands' close proximity to the town of Langebaan, the high boating, kite-boarding and other recreational uses of the area may have been an important source of disturbance to these birds. The substantial growth in participation in recreational water sports (particularly kite boarding) over the last two decades could have been a contributing factor to the shift in breeding location from Schaapen to Meeuw Island in 2004, but this appears unlikely given that the opposite shift happened ten years previously.

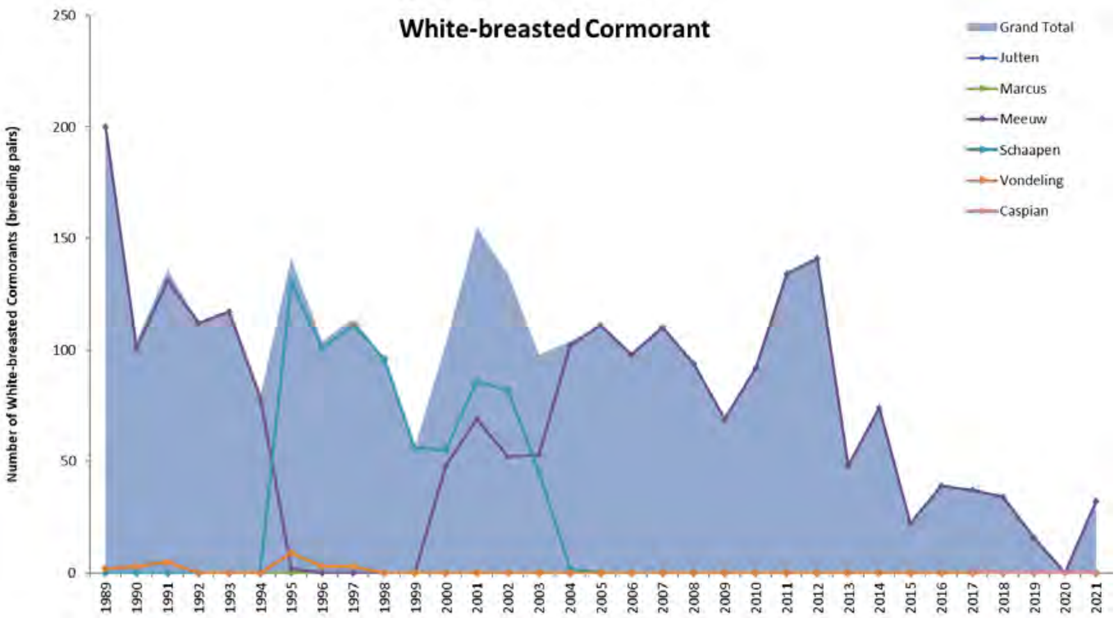


Figure 12.9. Trends in breeding population of White-breasted Cormorants at Jutten, Marcus, Meeuw, Schaapen, Vondeling and Caspian islands in Saldanha Bay from 1980–2022 measured in number of breeding pairs (Data source: (Makhado et al. 2023).

The **Crowned Cormorant** *Microcarbo coronatus* is endemic to Namibia and South Africa, occurring between the Bird Rock Guano Platform in southern Namibia and Quoin Rock, South Africa. It is listed Least Concern on the IUCNs Red Data List and despite being small (~4 300 individuals) and range restricted, its population trend is stable (IUCN 2022b). This species is highly susceptible to human disturbance and predation by fur seals, particularly of fledglings (David et al. 2003). Crowned Cormorants generally occur within 10 km from the coastline and occasionally in estuaries and sewage works up to 500 m from the sea. They feed on slow-moving benthic fish and invertebrates, which they forage for in shallow coastal waters and among kelp beds (BirdLife International 2023). Populations of this species have been comprehensively counted since 1991 (Figure 12.10). Since then, numbers have shown considerable interannual variations with an overall decreasing trend (Figure 12.10). Currently, numbers are well below average, and the fourth lowest in the last three decades. Furthermore, the trajectory in population size has been downwards for the last decade. In recent years Crowned Cormorants have started breeding under the iron ore jetty in Saldanha Bay where at least 30 pairs were observed nesting in 2023 (Figure 12.11). This shift in breeding location may account for some of the decline in the number of pairs breeding on the islands.

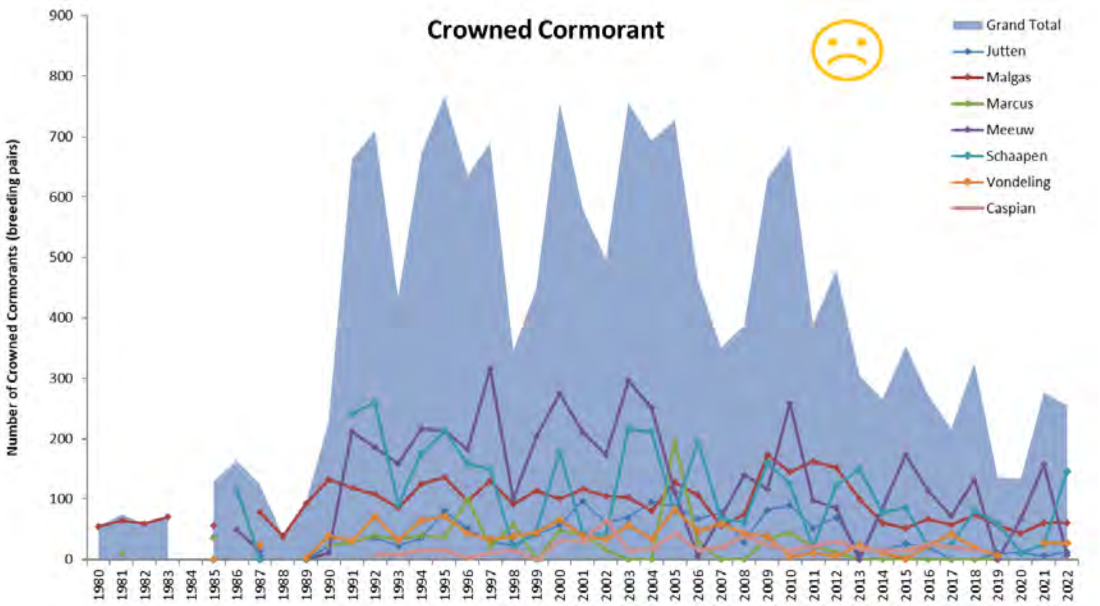


Figure 12.10. Trends in breeding population of Crowned Cormorants at the Jutten, Malgas, Marcus, Meeuw, Schaapen, Vondeling, and Caspian islands in Saldanha Bay from 1980–2022 measured in number of breeding pairs (Data source: (Makhado et al. 2023). Birds breeding on the Iron Ore Terminal (IOT) are also include in these data.

Figure 12.11. Crowned Cormorants nesting under the ore jetty in Saldanha Bay 2023.

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 globally and around the South African coast (Zöckler et al. 2003, Essig 2016). Decreases in numbers of migrants can be attributed to loss of breeding habitat and hunting along their migration routes, human disturbance and habitat loss on their wintering grounds, climate change, pollution and other forms of direct human disturbance (Zöckler et al. 2003). 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 (WCNP)), 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 three decades and the more recent increases in sporting activities impact on some of the important feeding areas in the lagoon. The area most impacted by increased visitor numbers and water sports activities are the sandflats near Oesterwal, that in the 1970s, were identified as one of the most important feeding areas for waders. The COVID-19 pandemic provided an opportunity to investigate whether there was any correlation between human activities and wader numbers in Langebaan Lagoon as the WCNP was closed to visitors for an extended period during 2020.

12.3.2 THE MAIN GROUPS OF BIRDS AND THEIR USE OF HABITATS AND FOOD

The waterbirds of Langebaan Lagoon can be grouped into seven categories, namely (1) Cormorants, darters, and pelicans; (2) wading birds; (3) waterfowl; (4) waders (5) gulls and terns (6) kingfishers; and (7) birds of prey (Table 12.1). The relative contribution of the various bird groups to the bird numbers in the lagoon differs substantially in summer and winter, due to the prevalence of migratory birds in summer (Figure 12.12). On average, over the last six years, waders account for about 75% of the birds in Langebaan Lagoon during summer, nearly all of these being migratory. In winter, the contribution by resident waders increases to around 7%, and numbers of wading birds increase from 14 % to 62% 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 15% 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).

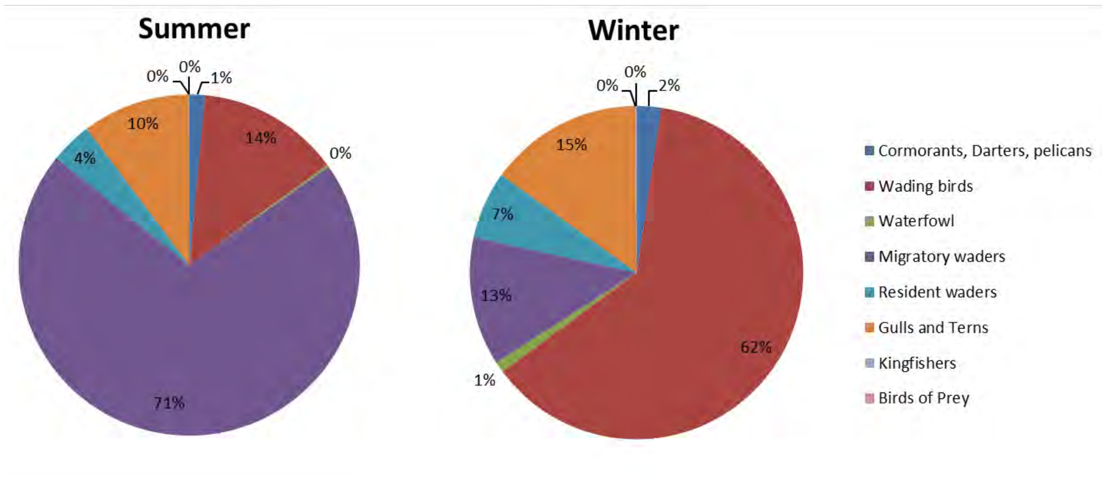


Figure 12.12. Present average numerical composition of the waterbirds on Langebaan Lagoon during summer (2018–2023) and winter (2016–2022) (Data source: CWAC data, Animal Demography Unit at the University of Cape Town).

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

Bird group	Defining features, typical/dominant species
Cormorants, darters & pelicans	Cormorants, darters and pelicans are common as a group, but are dominated by the marine cormorants which breed on the Saldanha Bay islands. Great White Pelicans visit the bay and lagoon to feed, but they breed beyond the area at Dassen Island. African Darters *Anhinga rufa* are uncommon and are more typical of lower salinities and habitats with emergent vegetation which 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 Shoveler. 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, plovers). 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 Palaearctic migrants depart quite synchronously around early April, but the immature birds of many of these species remain behind and do not don the breeding plumage of the rest of the flock. The resident species take advantage of relief in competition for resources and use this period to breed. The migrants return more gradually in spring, with birds beginning to trickle in from August, and numbers rising rapidly during September to November. Waders require undisturbed sandflats in order to feed at low tide and undisturbed roosting sites at high tide. In the 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).
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.

12.3.3 INTER-ANNUAL VARIABILITY IN BIRD NUMBERS

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 water bird numbers (Figure 12.13). In the 1970s and 1980s, migratory waders commonly numbered over 35 000 during summer, and over 10 000 in winter. Migratory wader bird numbers have since decreased significantly and fluctuated around 6 000 (range: 2 352–12 940) individuals in summer counts conducted over the period 2011–2023 (Figure 12.13). The 12 940 migratory waders counted in the summer of 2021 is the highest in the last decade. The reasons for this increase are not known but it is postulated that reduced human activity throughout their range due to global COVID-19 lock downs in 2020, may have facilitated the modest recovery (still only about 40% of the pre-1990 average of ~33 000 birds). Unfortunately, the count of migratory waders in the summers of 2022 and 2023 was about half that recorded in the summer of 2021, and it appears that the "recovery", was only temporary. Note that the increase in wading bird counts in 2021 probably did not represent a demographic recovery i.e., a population increase, as the time frame of COVID-19 lockdowns is probably too short for such a response (although some reduction in human caused mortality may have occurred e.g., hunting). It does, however, show a local increased use of the Langebaan habitat during the summer of 2020–2021, possibly in response to decreased human activity.

Drastic population declines in four species, including the Ruddy Turnstone, Red Knot, Grey Plover, and Curlew Sandpiper typify this downward trend in summer migratory bird numbers. Most importantly, Curlew Sandpiper numbers dropped from a pre-1990 average of just over 20 000 birds to 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. The overall recovery in migrant wader numbers in 2021 was not seen in all species, for example Curlew Sandpiper, Ruddy Turnstone and Grey plover counts were recovered to a similar level (approximately 30–40% of pre 1990 numbers), whilst Red Knot numbers showed almost no increase and remained well below their historical peak and subsequently were not found in the summer count undertaken in 2023. The most recent summer count reveals how short-lived this recovery was with all four species of the formerly most abundant migrants either absent (Red Knot) or at a fraction of their former abundance between 1–9%: Curlew Sandpiper, Grey Plover and Ruddy Turnstone) of their pre-1990 average abundance. Migratory waders that until recently have not seen such drastic declines also appear to have fared poorly in 2023. These include Common Greenshank (4% of pre-1990 average in 2023), Common Ringed Plover (21%) and Common Whimbrel (15%) and Little Stint (14%). Counts of these species seldom numbered more than a thousand birds historically, and interannual variability in the counts has always been high, but it is alarming that in the summer of 2023, with the exception of Sanderling, the counts of every other migrant wader were substantially lower than both historical and recent counts.

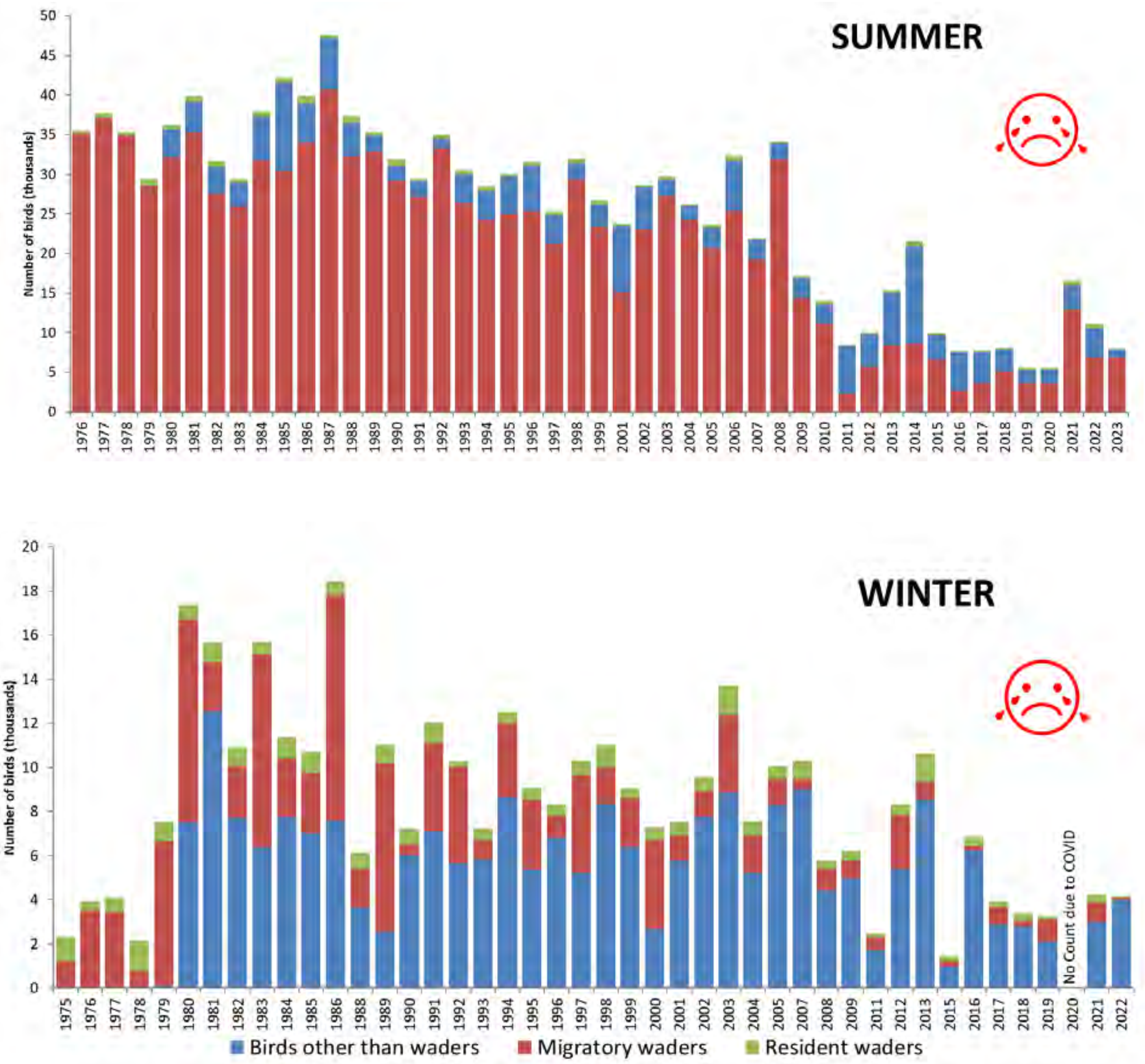


Figure 12.13. Long-term trend in the numerical composition of waterbirds in the Langebaan Lagoon during summer (top) and winter (bottom) (1975–summer 2023). Note that no data were collected in the summer of 1975, as well as in the winter of 1987, 2006, 2010, 2014 and 2020 (Data source: Coordinated Waterbird Count data, Animal Demography Unit at the University of Cape Town 2023).

Resident wader numbers have also fluctuated widely over time and resident bird numbers appeared to be on a negative trajectory since 2007 with no signs of recovery in the last six years. The winter 2019 count was the lowest on record and unfortunately there was no count for the winter of 2020 (Figure 12.13). The 2021 winter count of resident waders (338) was similar to the average in recent years, which suggests that if these residents had benefited from reduced disturbance during 2020 COVID-19 lockdowns (as suggested by the summer 2021 resident wader count of 605), it too was short-lived. The most recent winter data confirm the poor status of resident wader populations in Langebaan Lagoon, with a new all-time low winter count of just 142 birds recorded August 2022.

The reasons for the long-term 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 (Zöckler et al. 2003, Dias et al. 2006). Hunting of migratory waterbirds is a strong tradition in several European and North African countries and is thought to contribute towards global declines in migratory water birds (Zöckler et al. 2003). Ryan (2013) 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 suggests that factors outside of the Western Cape were at least partially responsible for the observed trends and probably reflected global population declines (Ryan 2013). Conditions at Langebaan Lagoon could also have contributed to the decline in wader 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: Aquatic Macrophytes), and human disturbance, which has been shown to have a dramatic impact on bird numbers in other estuaries (Turpie and Love 2000). In 1985, Langebaan Lagoon was declared a National Park (WCNP), and recreational activities such as boating, angling, kite surfing and swimming have since been controlled within the Lagoon through zonation. Nevertheless, some important feeding areas such as Oesterwal, lie within the zones that are highly utilised for recreation.

12.4 SEALS

12.4.1 Cape Fur Seals

The Cape fur seal *Arctocephalus pusillus pusillus* is the only seal species that breeds in Southern Africa. Its range extends from the centre of Angola to the east coast of South Africa, with breeding colonies extending south from Baia dos Tigres on the southern border of Angola, through Namibia, down the west coast of South Africa and around to Algoa Bay in the Eastern Cape of South Africa (Figure 12.14). Historically (before 1900), it is likely that seals were present on most (if not all) islands off South Africa and Namibia, where they prefer to breed as they are protected from mainland predators. However, populations on many of the islands were significantly depleted or disappeared completely as a result of uncontrolled hunting, and human occupation of the islands for the collection of guano and other seabird related products (Kemper et al. 2007). Subsequent to the ban on seal hunting, the Cape Fur seal population recovered, showing an almost 20-fold growth in numbers in the 20th century before stabilizing at about two million animals (Kemper et al. 2007). In addition, the number of breeding colonies have increased since 1970 from 23 to 40 colonies (Kirkman et al. 2013). The overall population count has reportedly remained largely unchanged since 1993 and is estimated at 1.5–2.0 million, however, the distribution of these seals has been shown to vary in relation to prey distribution and shortages (Kemper et al. 2007, Kirkman et al. 2013, 2019).

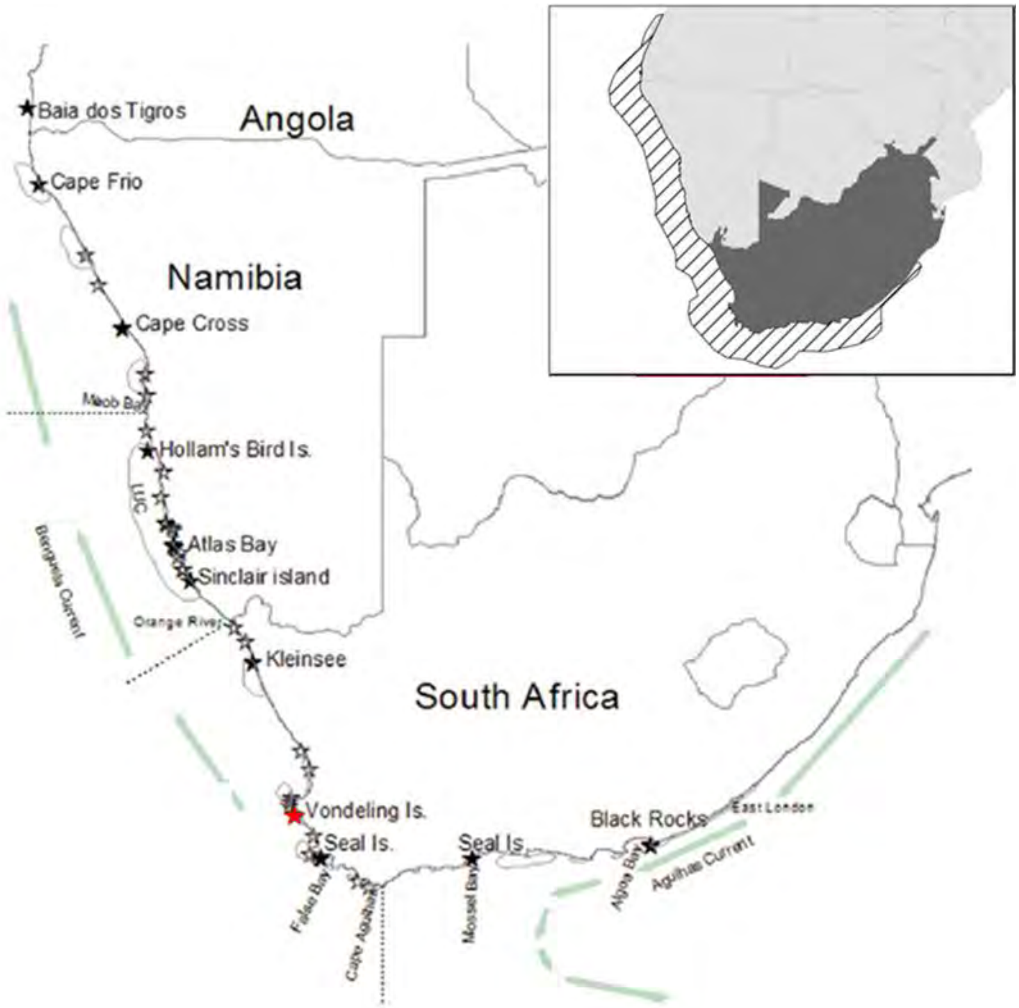


Figure 12.14 Distribution of selected Cape fur seal breeding colonies of Southern Africa with insert showing complete distribution of seal sightings in Southern Africa. The red star indicates the location of the recently established breeding colony at Vondeling Island just outside Saldanha Bay. (Adapted from Kirkman et al. 2013).

Seal populations along the west coast of South African exhibited a fairly stable distribution over the period 1976 to 2006, with the centre of the distribution of the breeding colonies remaining fixed within the region (Kirkman et al. 2013). However, more recently, it has been noted that there is a general shift southwards of St Helena Bay with new breeding colonies being established on Vondeling Island, at Cape Point and potentially on the south coast near Betty's Bay (DFFE, Mduduzi Seakamela, pers. comm. 2020). It is possible that this southward shift coincides with the eastwards shift of small pelagic fish species which are a key food source for the seals (see Figure 12.2). Although seals historically would frequent the seabird islands (Jutten, Malgas, Marcus and Vondeling) around Saldanha Bay, coming on land (hauling out) to rest or sun themselves (David and Van Sittert 2008), it is only since the turn of the century that a breeding colony has been established on Vondeling Island - south of the entrance to Saldanha Bay (Seakamela et al. 2022).

The DFFE monitors seal populations at 11 colonies in South Africa through aerial surveys which are undertaken to count pup numbers and hence to track seal population trends over time. Although these counts are normally only undertaken every three years, because it is a newly established breeding colony, aerial surveys have been conducted at Vondeling Island every year since 2006 (DFFE, Mduduzi Seakamela, pers. comm. 2020). The only exceptions to this being in 2007, 2016 and 2021 when counts were not undertaken as a result of logistical constraints (Seakamela et al. 2022). Initially, the number of pups on the island increased dramatically up until 2010, thereafter (2010–2013), the rate of increase slowed and pup numbers on the island have fluctuated significantly in recent years - peaking at 23.4 thousand pups in 2014 and dropping to 16.7 thousand in 2018 (Figure 12.15). These fluctuations suggest that the island may have reached carrying capacity, with the annual changes linked to the availability of prey resources and increases and decreases in the colony size mirroring those of sardines and anchovies on the West Coast (Figure 12.15).

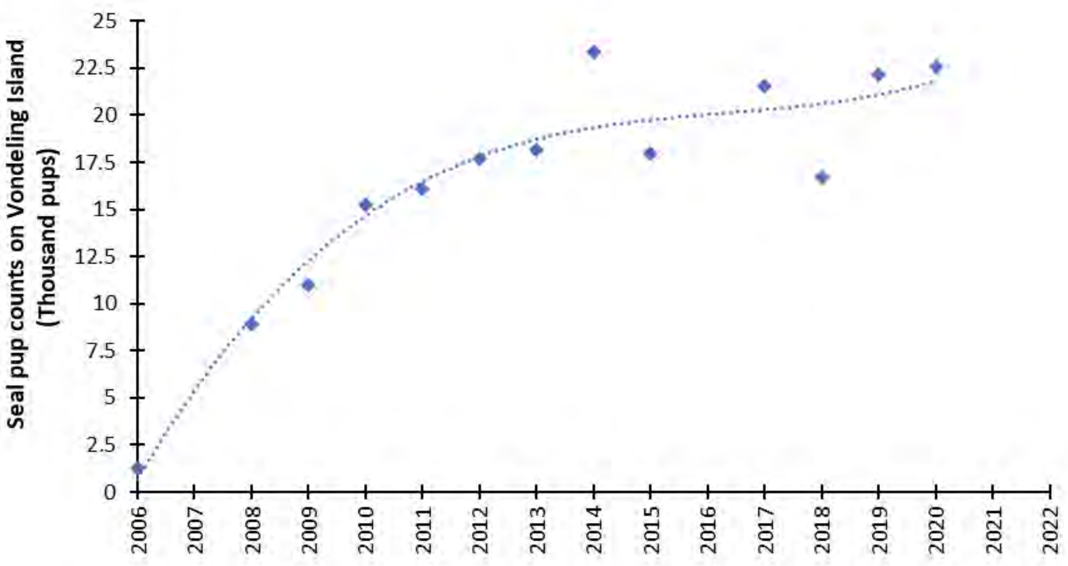


Figure 12.15. Trends in seal pup counts collected during aerial surveys conducted at Vondeling Island, Saldanha Bay from 2006–2020. No data available for 2007, 2016, 2021 or 2022. (Source: Seakamela et al 2022).

Cape Fur Seals are amongst the largest marine top predators found in and around Saldanha Bay. They are opportunistic, generalist feeders that have been shown to benefit from human activities including utilisation of discards from fishing boats, or taking fish directly from fisherman (Wickens et al. 1992, Makhado et al. 2009). In addition, seals compete with seabirds, such as penguins and gannets, as well as with commercial fisheries, for small pelagic fish which form a key part of their diets (Crawford et al. 2011, de Moor and Butterworth 2015). Kirkman et al. (2013) suggested that the increasing numbers of seals on Vondeling island may lead to increased pressure to cull seals both from a fisheries perspective as well as to protect important seabird species on which seals are known to prey. In fact, some culling has been undertaken of seals off the west coast in recent years in an attempt to limit the mortality of seabirds that are of conservation importance. The culling of 'problem' seals seen killing Cape gannet fledglings at Malgas Island, located northwest of the Vondeling breeding colony, resulted in a reduced mortality of gannet fledglings, however, seals learnt to avoid the boat used for culling, and the predation of seabirds around the island is ongoing (Makhado et al. 2009)).

Studies investigating the predation of seabirds by seals at Malgas Island outside Saldanha Bay show that the 'problem' seals are restricted to sub-adult males which average less than five years old (Makhado et al. 2006, 2009). These individuals are not confined to the breeding colonies and are too young to be part of a breeding harem, and therefore tend to be more nomadic with inconsistent feeding areas. Conversely, data collected by DFFE using GPS trackers attached to female Cape Fur Seals tagged on Vondeling Island, indicates that these animals favour offshore feeding grounds and do not enter Saldanha Bay at all (Figure 12.16 and Mduduzi Seakamela pers. comm. 2020). It is likely that in order to maintain sufficient body fat and health to produce enough milk to support their pups, these females prefer the high-quality food provided by the small pelagic fish species as opposed to irregular and limited food sources associated with fledgling birds. In addition, the females are more likely to be disturbed by human activities, selecting to avoid contact with humans to reduce the risk of conflict and therefore the risk of not returning to the breeding colony and their pups. This is supported by research showing that breeding and pupping harbour seals on the west coast of North America have been displaced by shellfish aquaculture activities (Becker et al. 2011). Therefore, although seals are likely attracted to the aquaculture sites within Saldanha Bay, chances are that their numbers will not continue to increase significantly as they are restricted to sub-adult males. Additionally, the carrying capacity of Vondeling Island appears to have been reached and the overall population within Southern Africa has remained stable over the last 30 years.

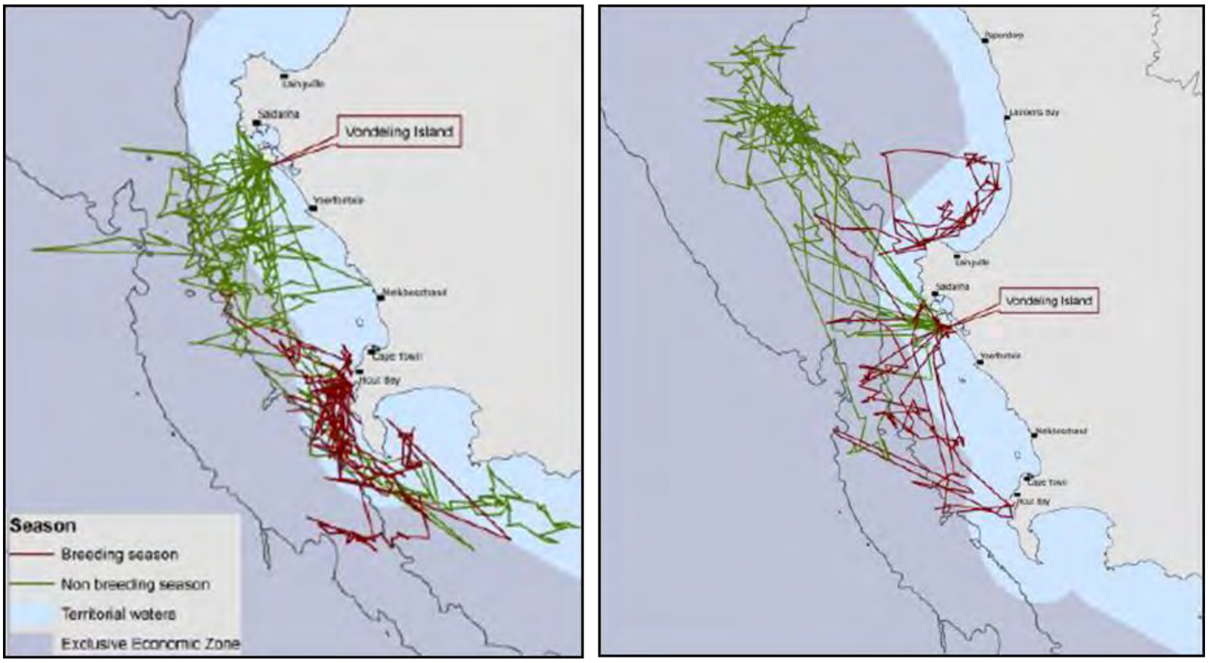


Figure 12.16. GPS tracks of female Cape fur seals tagged on Vondeling Island showing the routes travelled during the breeding and non-breeding season (Source: DFFE: Oceans and Coasts).

13 ALIENS AND INVASIVES

13.1 Background

13.1.1 General information and definitions

Human-induced biological invasions have become a major cause for concern worldwide. The life history characteristics of alien species, the ecological resilience of the affected areas, the presence of suitable predators, biotic resistance and propagule pressure are some of the many factors that influence whether an alien species becomes a successful invader or not. Biological invasions can have a negative impact on biodiversity, and result in local or even global extinctions of indigenous species. Alien species invasions can also have tangible and quantifiable socio-economic impacts, and management of these species is vital. A pre-cautionary approach to prevent biological invasions is often considered the most efficient method of management and can include identifying and managing important pathways of introduction. If species are already present, however, regular monitoring and management protocols should be implemented to reduce the impacts of these invaders on the receiving environment and biota.

The revised, internationally accepted approach recognises an alien species as invasive if it has self-replacing populations over several generations, and 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).

13.1.2 Patterns related to invasion success of alien species

Marine scientists aim to enhance the early detection and focused management of alien species. One method has been exploring the link between biological traits and invasion success. One study found that invasive species are often more efficient at utilising resources when compared to native species. For example, the success of the invasive *Mytilus galloprovincialis* on the west coast of South Africa can be partially attributed to its efficient resource utilisation when compared to other mussel species (invasive *Semimytilus patagonicus* and native *Aulacomya atra*) (Alexander et al. 2015). Conversely, a recent study exploring predatory crab invasions could not identify any specific traits associated with their success, possibly due to a gap in basic biological knowledge (Swart et al. 2018). Insufficient knowledge hinders our ability to link traits with invasion success, highlighting the importance of basic species knowledge in understanding invasion drivers.

Aquaculture farm structures provide a novel surface for the quick colonisation and proliferation of various fast-growing and highly competitive epifaunal marine species (Fitridge et al. 2012, Megina et al. 2013, Janiak and Branson 2021). These fouling communities are commonly dominated by sessile, suspension-feeding organisms including ascidians, barnacles, bivalves, bryozoans, hydroids, polychaetes and sponges (Millard 1951, Dicken et al. 2011, Fitridge et al. 2012) and frequently include alien species (Fitridge et al. 2012, Megina et al. 2016, Leclerc and Viard 2018). Hard artificial substrata within ports also facilitate the introduction, establishment and regional spread of alien species (Janiak and Branson 2021, Outinen et al. 2021). Harbours are one of the most invaded habitats of the marine realm (Leclerc and Viard

2018), and comprise the highest concentration of marine alien species in South Africa (Picker and Griffiths 2017).

13.1.3 Marine alien species in South Africa

The most recent review of marine alien species in South Africa identified a total of 95 alien marine species, with 56 classified as invasive (Robinson et al. 2020). These species largely comprise crustaceans (barnacles, copepods, amphipods, isopods, and crabs) cnidarians (anemones and hydrozoans) and molluscs (gastropods and bivalves) (Figure 9.1).

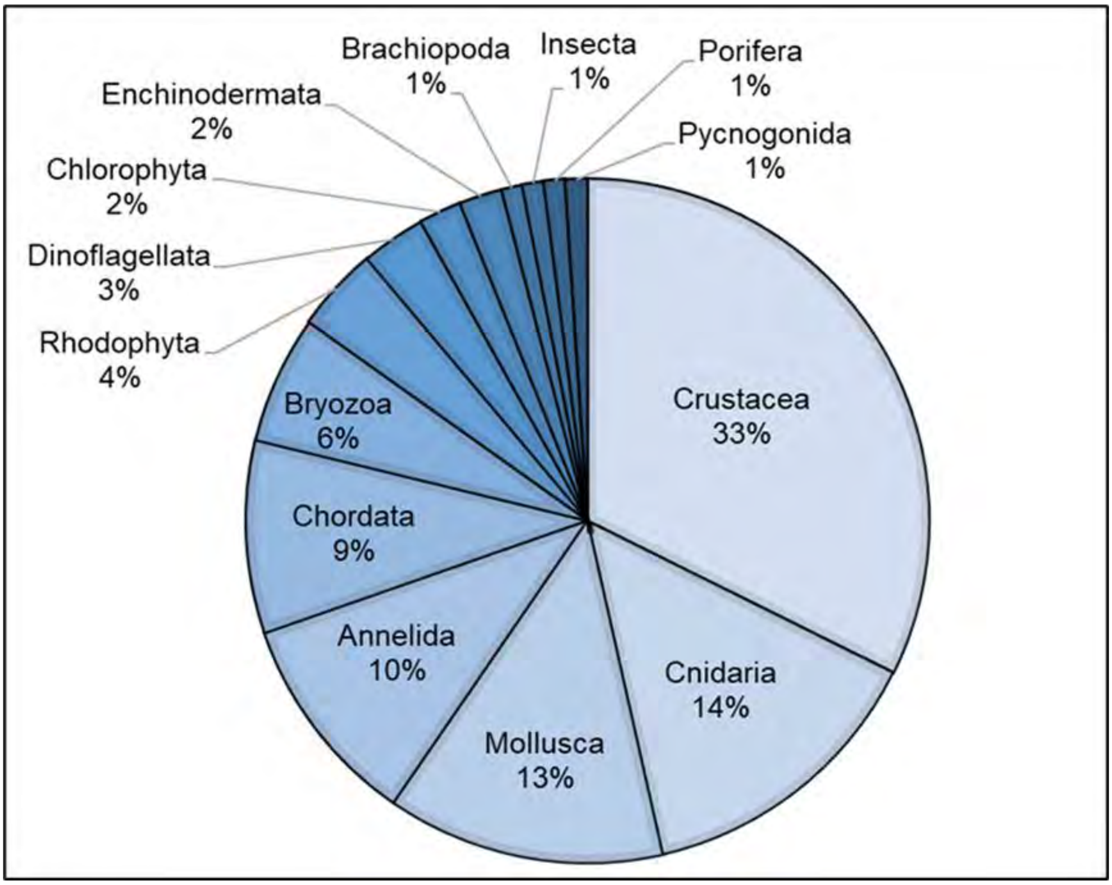


Figure 13.1. The taxonomic breakdown and proportion of alien taxa known from South Africa.

A further 39 species are currently regarded as cryptogenic (of unknown origin and potentially introduced) (Mead et al. 2011a). It is considered very likely that these have been introduced to South Africa (Robinson et al. 2016). Given ongoing discoveries and evolving species statuses (Mead et al. 2011b, Robinson et al. 2016, 2020), the list of alien species in South Africa is dynamic. One such an example is the alien spider crab *Pyromaia tuberculata* (Griffiths et al. 2018a, Landschoff et al. 2022), which was only recently reported, and therefore not included in the latest list of marine alien species.

Of the 95 marine alien species recognised in South Africa, 91% of these introductions are associated with shipping activities such as ballast water discharge and hull fouling. In addition, 50 of these are confined to sheltered areas such as harbours. These findings emphasise the importance of shipping as a pathway of introduction (Robinson et al. 2020), and highlights the need for implementing more efficient protocols to monitor vessels entering harbours, the treatment of hull fouling, and regular monitoring for alien species. Another important vector of introduction includes land and sea-based mariculture.

13.1.4 MARINE ALIEN AND INVASIVE SPECIES IN SALDANHA BAY

According to Robinson et al. (2020), there are at least 67 documented alien species present along the west coast, with 29 of these species having been detected in Saldanha Bay and/or Langebaan Lagoon (Mead et al. 2011b, Robinson et al. 2016, 2020, Peters and Robinson 2017, 2018, Griffiths et al. 2018b). Of the 39 cryptogenic species, 19 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 the cryptogenic species (Griffiths et al. 2008).

These include the tuberculate pear crab *Pyromaia tuberculata,* skeleton shrimp *Caprella mutica*, pitted barnacle *Balanus trigonus*, fat-feeler amphipod *Monocorophium acherusicum*, pink-mouthed hydroid *Ectopleura crocea,* thin-walled obelia *Obelia dichotoma,* amphipod *Ericthonius brasiliensis,* blue mussel *Mytilus edulis* and the bay mussel *M. trossulus.* It's important to note that the identity of some new species, particularly those identified through eDNA metabarcoding, require additional morphological taxonomic and DNA work to confirm their presence in the Bay.

13.2 APPROACH FOR MONITORING ALIEN SPECIES WITHIN SALDANHA BAY

13.2.1 BENTHIC AND ROCKY INTERTIDAL MONITORING

Sampling and monitoring of alien species within Saldanha Bay forms part of the State of the Bay monitoring programme, and various methods have been employed to monitor these species. Quantitative data for this initiative are obtained from both the Benthic Macrofauna (Chapter 8) and Rocky Intertidal (Chapter 10) monitoring surveys. Details on the methods and results for these surveys can be found in the respective chapters.

13.2.2 BIOFOULING SURVEYS

Qualitative Aquaculture Development Zone (ADZ) biofouling surveys were conducted by Anchor Environmental Consultants (Anchor) for, and on behalf of, the Department of Forestry, Fisheries and the Environment (DFFE) in 2021 and 2022. Fouling organisms were collected and identified from aquaculture farm structures (buoys, ropes, chains and rafts) at two (September 2021) and seven (July 2022) sites in the Saldanha ADZ Big Bay and Small Bay shellfish precincts. This entails a scientific diver scraping biological material off a 20 cm length of chain or rope. Alternatively, on larger structures, wall scrapes were undertaken using 0.04 m^2 quadrats. The sites sampled in 2022 coincided with wall scrape locations surveyed in the eDNA-based monitoring study described below. Further information on these surveys is available in the reports produced form these studies (Payne et al. 2022, Payne et al. 2023b).

13.2.3 DNA-BASED MONITORING SURVEY

A qualitative eDNA-based survey was conducted by Anchor and NatureMetrics for Anglo Shipping in 2022. This included eDNA metabarcoding analyses undertaken by NatureMetrics on ballast water, sea water, sediment and wall scrape samples from Saldanha Bay.

All sampling was carried out by Anchor, except the collection of ballast water, which comprised seven samples of 1000 ml each. Twenty seawater (4 000 ml) and sediment (100 g) samples were collected at locations coinciding with the Saldanha Bay Water Quality Forum Trust (SBWQFT) long-term macrofauna and sediment monitoring stations, while 20 wall scrape samples were collected from hard artificial habitats within the Bay. At each wall scrape sampling station, the contents of a 25 cm × 25 cm quadrat from two depths (-0.5 m and -5.0 m) were combined, with 100 g sent for eDNA metabarcoding, while the remainder was preserved in 95% ethanol for the morphological-based identification of taxa by staff at Anchor. Fifteen voucher specimens from the wall scrape material were identified by Anchor to species level where possible, using conventional morphology-based taxonomic methods, and were sent to the African Centre for DNA Barcoding. Sequences obtained were used to validate the presence of alien species, and augment existing genetic reference libraries.

All material for metabarcoding was processed using either the NatureMetrics aquatic (0.8 µm filter) or sediment eDNA kits, and frozen. Purified DNA was amplified with PCR for a hypervariable region of the 18S, 16S, 12S and COI rRNA genes that were used to target marine eukaryotes, bacteria, vertebrates and invertebrates, respectively. Consensus taxonomic assignments were made for each taxon using sequence similarity searches on reference databases appropriate for the dataset, including SILVA 18S (v138.1), SILVA 16S (v138.1), NCBI nt (GenBank) and the Barcode of Life Data System (BOLD). The Global Biodiversity Information Facility (GBIF) taxonomic backbone was used for consistency between databases.

No alien species were found in the ballast or sea water samples, while both morphology-based taxonomy and eDNA metabarcoding detected two and 17 alien species from the sediment and wall scrape samples, respectively. Overall, the eDNA-based survey detected more non-native taxa than the other long-term monitoring protocols, with 18 alien species identified. Most of these species had been previously detected in Saldanha Bay through State of the Bay collections or previous research (Table 13.1). However, five species were identified from Saldanha Bay, or as part of the State of the Bay survey, for the first time including *Caprella mutica*, *Balanus trigonus*, *Ectopleura crocea*, *Mytilus edulis* and *M. trossulus*. The presence of the tuberculate pear crab *Pyromaia tuberculata* in Saldanha Bay was also confirmed during this survey, via DNA barcoding.

It is important to note that alien species were not detected by genetics alone, and therefore the physical collection of specimens should be included in future DNA-based surveys. This technique is also limited by incomplete genetic reference databases, which could lead to the misidentification of taxa as alien. Further information on this survey is available in the produced report (Payne et al. 2023).

Table 13.1 Alien species identified in Saldanha Bay and Langebaan Lagoon from various surveys, including Benthic Macrofauna, Rocky Shore, ADZ biofouling, DNA-based, as well as previous research. SA = South Africa; SOB = State of the Bay.

Species	Common Name	Status	Taxa	Class	Benthic Macro	Rocky Shore	ADZ Biofouling	DNA-based	Other Research	Update
Mytilus edulis	Blue mussel	Invasive	Mollusca	Bivalvia				X		New to SA
Mytilus trossulus	Bay mussel	Invasive	Mollusca	Bivalvia				X		New to SA
Mytilus galloprovincialis	Mediterranean mussel	Invasive	Mollusca	Bivalvia	X	X	X	X	X	Important update
Semimytilus patagonicus	Bisexual mussel	Invasive	Mollusca	Bivalvia		X		X	X	Important update
Pyromaia tuberculata	Tuberculate pear crab	Invasive	Crustacea	Decapoda	X			X		New to Saldanha
Caprella mutica	Japanese skeleton shrimp	Invasive	Crustacea	Amphipoda			X	X		New to Saldanha
Balanus trigonus	Pitted/ triangle barnacle	Invasive	Crustacea	Cirripedia				X		New to Saldanha
Monocorophium acherusicum	Fat-feeler amphipod	Alien	Crustacea	Amphipoda	X			X		New to Saldanha
Ectopleura crocea	Pink-mouthed hydroid	Alien	Cnidaria	Hydrozoa			X	X		New to Saldanha
Obelia dichotoma	Thin-walled obelia	Alien	Cnidaria	Hydrozoa				X	X	New to SOB
Ericthonius brasiliensis	Amphipod	Invasive	Crustacea	Amphipoda	X					New to SOB
Watersipora subtorquata	Red-rust bryozoan	Invasive	Bryozoa	Gymnolaemata		X		X	X	New to SOB
Balanus glandula	Pacific barnacle	Invasive	Crustacea	Cirripedia		X		X	X	Important update
Rathbunixa occidentalis	Western pea crab	Invasive	Crustacea	Decapoda	X				X	Important update
Porcellana africana	Porcelain crab	Invasive	Crustacea	Decapoda		X	X	X	X	Important update
Perforatus perforatus	Perforated barnacle	Alien	Crustacea	Cirripedia		X		X		Important update
Ciona robusta	Sea vase	Invasive	Chordata	Ascidiacea			X	X	X	Important update
Clavelina lepadiformis	Light-bulb sea squirt	Invasive	Chordata	Ascidiacea				X	X	New to SOB
Discinisca tenuis	Disc lamp shell	Invasive	Brachiopoda	Lingulata			X	X	X	Important update
Polydora hoplura	Shell-boring spionid	Invasive	Annelida	Polychaeta				X	X	New to SOB

Species	Common Name	Status	Taxa	Class	Benthic Macro	Rocky Shore	ADZ Biofouling	DNA-based	Other Research	Update
Codium fragile subsp. fragile	Fragile upright codium	Invasive	Chlorophyta	Ulvophyceae		X			X	Important update
Cylista ornata	Brooding anemone	Alien	Cnidaria	Anthozoa					X	Important update
Magallana gigas	Pacific oyster	Invasive	Mollusca	Bivalvia					X	No updates
Boccardia proboscidea	Shell worm	Invasive	Annelida	Polychaeta					X	No updates
Jassa slatteryi	Hitchhiker amphipod	Invasive	Crustacea	Amphipoda					X	No updates
Littorina saxatilis	Lagoon snail	Invasive	Mollusca	Gastropoda					X	No updates
Diplosoma listerianum	Jelly crust tunicate	Invasive	Chordata	Ascidiacea					X	No updates
Coryne eximia	Hydroid	Invasive	Cnidaria	Hydrozoa					X	No updates
Cerapus tubularis	Tubular amphipod	Invasive	Crustacea	Amphipoda					X	No updates
Chelura terebrans	Wood-boring amphipod	Invasive	Crustacea	Amphipoda					X	No updates
Conopeum seurati	Encrusting bryozoan	Invasive	Bryozoa	Gymnolaemata					X	No updates
Cryptosula pallasiana	Red crust bryozoan	Invasive	Bryozoa	Gymnolaemata					X	No updates
Antithamnionella spirographidis	Red Algae	Invasive	Rhodophyta	Florideophyceae					X	No updates
Orchestia gammarellus	Beach hopper	Invasive	Crustacea	Amphipoda					X	No updates
Heliaster helianthus	South American sunstar	Alien	Echinodermata	Asteroidea					X	No updates
Homalaspis plana	Chilean stone crab	Alien	Crustacea	Decapoda					X	No updates
Carcinus maenas	European shore-crab	Invasive	Crustacea	Decapoda					X	No updates

13.3 ALIEN AND INVASIVE SPECIES CONFIRMED IN SALDANHA BAY AND/OR LANGEBAAN LAGOON

A comprehensive list of alien species in Saldanha Bay and Langebaan Lagoon has been compiled based on findings from the State of the Bay surveys (including ADZ biofouling and DNA-based studies), as well as other research (Mead et al. 2011b, Robinson et al. 2016, 2020, Peters and Robinson 2017, 2018, Griffiths et al. 2018a, 2018b, Landschoff et al. 2022)(Table 13.1).

The alien species in Saldanha Bay and Langebaan largely comprise crustaceans (40%), molluscs (16%) and cnidarians (11%). Chordata and bryozoans each contribute 8% (Figure 13.2).

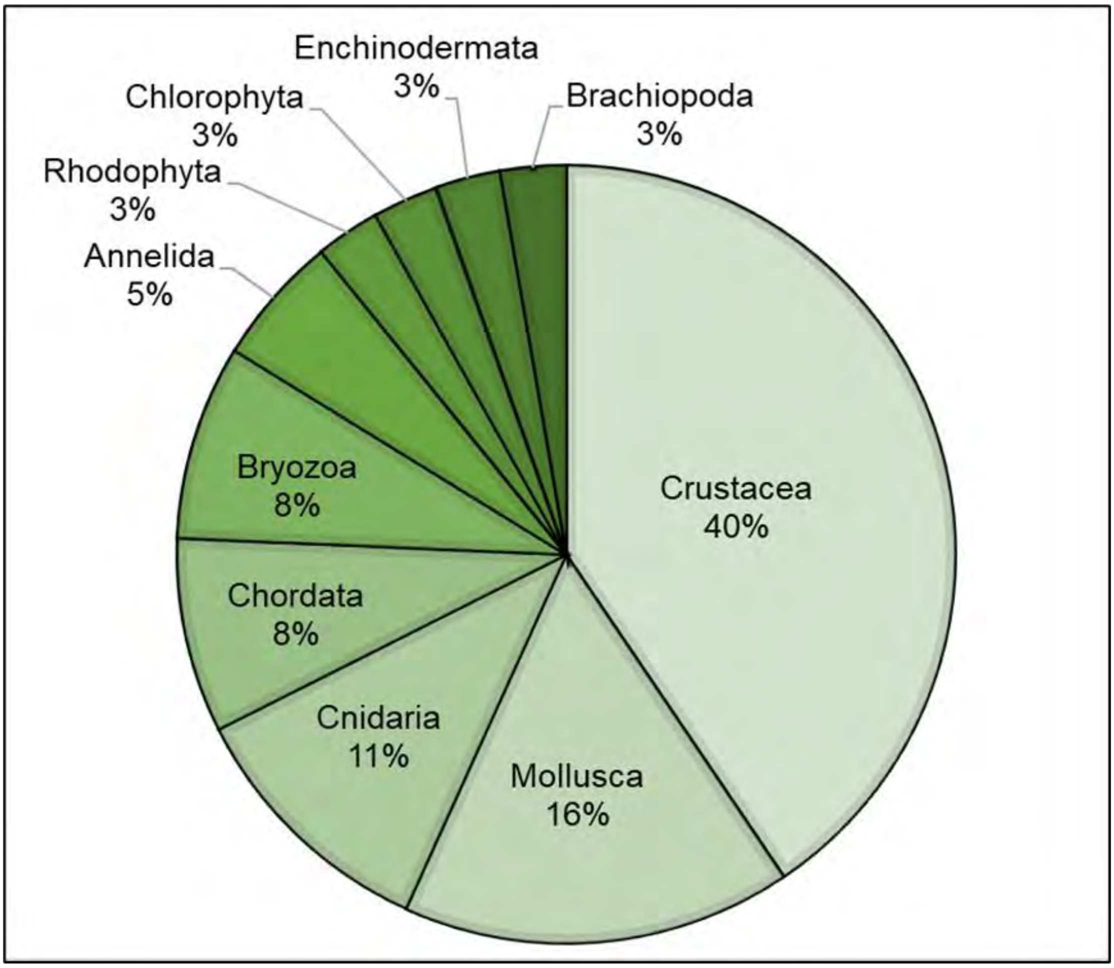


Figure 13.2. The taxonomic breakdown and proportion of marine alien taxa known from Saldanha Bay and Langebaan Lagoon.

Certain species are routinely recorded during the State of the Bay surveys, including the Mediterranean mussel *M. galloprovincialis*, bisexual mussel *S. patagonicus*, Pacific barnacle *B. glandula*, perforated barnacle *P. perforatus*, fragile upright codium *C. fragile* spp., porcelain crab *P. africana* and the western pea crab *R. occidentalis*.

Some species, although known from South Africa, were recorded for the first time in Saldanha Bay, indicating range expansions for a number of species (i.e., *P. tuberculata, C. mutica, B. trigonus, M. acherusicum* and *E. crocea*). Other species, despite previous records in Saldanha Bay, are reported for the first time in a State of the Bay programme (e.g., *W. subtorquata, C. lepadiformis, O. dichotoma* and *P. hoplura*). Most notably, two mytilid mussel species, *M. edulis* and *M. trossulus,* are documented for the first time in South Africa, challenging previous assumptions about the identity and current understanding of mytilids in South Africa. This report also presents quantitative data on the abundance and biomass of three invasive species for which sufficient data spanning several years have been compiled. These include the Pacific barnacle *B. glandula*, mytilid species complex (described below), and western pea crab *R. occidentalis*. These data were obtained through the rocky shore survey for the two former species, and the benthic macrofauna survey for the latter.

In summary, nine new alien species have been discovered in Saldanha Bay in the last 12 months, bringing the total to 37. Including the two newly identified alien mussels, and the recently reported alien spider crab, the total number of known alien species in South Africa is now 98. It's important to acknowledge that the identity of some new species, particularly those identified through eDNA metabarcoding, requires further morphological taxonomic and DNA verification. Future surveys in Saldanha Bay will aim to confirm the presence of unconfirmed listed species, and investigate the potential presence of additional or newly introduced species.

13.3.1 Mytilid mussel species complex

The DNA-based survey detected three *Mytilus* species (*Mytilus edulis*, *M. galloprovincialis*, and *M. trossulus*). These are collectively referred to as the *Mytilus edulis* species complex (Ab Rahim et al. 2016), which is a subject on intensive research worldwide (Koehn 1991, McDonald et al. 1991, Väinölä and Hvilsom 1991, Spencer 1994, Skurikhina et al. 2001, Beaumont et al. 2008, Elliott et al. 2008). Of these species, the former two are the most closely related (Wonham 2004), while the latter is the most genetically divergent when analysed through genomic DNA and mtDNA (Wonham 2004). *Mytilus edulis* and *M. galloprovincialis* exhibit a bipolar distribution (Hilbish et al. 2000, Gérard et al. 2008), and tend to prefer the more temperate waters of the northern and southern hemispheres (Jones et al. 2010), resulting in a poleward range contraction. In contrast, *M. trossulus* is limited to the northern hemisphere region (Hilbish et al. 2000, Riginos and Cunningham 2005, Beaumont et al. 2008) While their distributions are mainly distinct, all of them are globally widespread. In areas where their ranges overlap, hybridisation can occur (Hilbish et al. 2000, Riginos and Cunningham 2005, Gérard et al. 2008). Despite hybridisation, these three species generally remain genetically distinct (Rawson et al. 1996), and researchers have identified several barriers to gene flow between them.

Prior to the DNA-based survey, the Mediterranean mussel *M. galloprovincialis* and the bisexual mussel *Semimytilus patagonicus* (previously *S. algosus*) were believed to be the only alien mussels present in Saldanha Bay (and were collectively referred to as *Mytilus* spp. in previous reports). The potential presence of these two other morphologically similar species, the blue mussel *M. edulis* and the bay mussel *M. trossulus* is therefore noteworthy. Given the difficulty in reliably distinguishing these species based on morphological characteristics, they are collectively referred to as the mytilid species complex (Figure 13.3). Nonetheless, it's important to note that *M. galloprovincialis* is still considered the dominant mussel species, as inferred from DNA barcoding analysis, and supported by previous studies (Daguin and Borsa 2000, Westfall et al. 2010, Ab Rahim et al. 2016).

Figure 13.3. The bisexual mussel *Semimytilus patagonicus* (top left) (Photo: Joop Trausel and Frans Slieker), Mediterranean mussel *Mytilus galloprovincialis* (top right)(Photo: Prof. G.M. Branch), bay mussel *Mytilus trossulus* (bottom left) (Photo: Joop Trausel and Frans Slieker) and blue mussel *Mytilus edulis* (bottom right) (Photo: Rudolf Kapeller). Source: https://www.marinespecies.org.

MONITORING THE STATUS OF MYTILIDS IN SALDANHA BAY:

Rocky shore surveys indicate that mytilids occur predominantly at exposed rocky shore sites (i.e., Marcus Island, Lynch Point, North Bay, Iron Ore Terminal), reaching higher densities than at the more sheltered sites (Dive School, Jetty and Schaapen Island East and West)(Figure 13.4). Over the past 15 years, the mussels' percentage cover at these sheltered sites has never exceeded 5% and was frequently recorded as 0% at Schaapen Island East and West. Observations suggest that these invasive mussels are by far the most dominant faunal species on the rocky shore. This species complex reaches its highest densities on the lower shore, in areas exposed to high wave action.

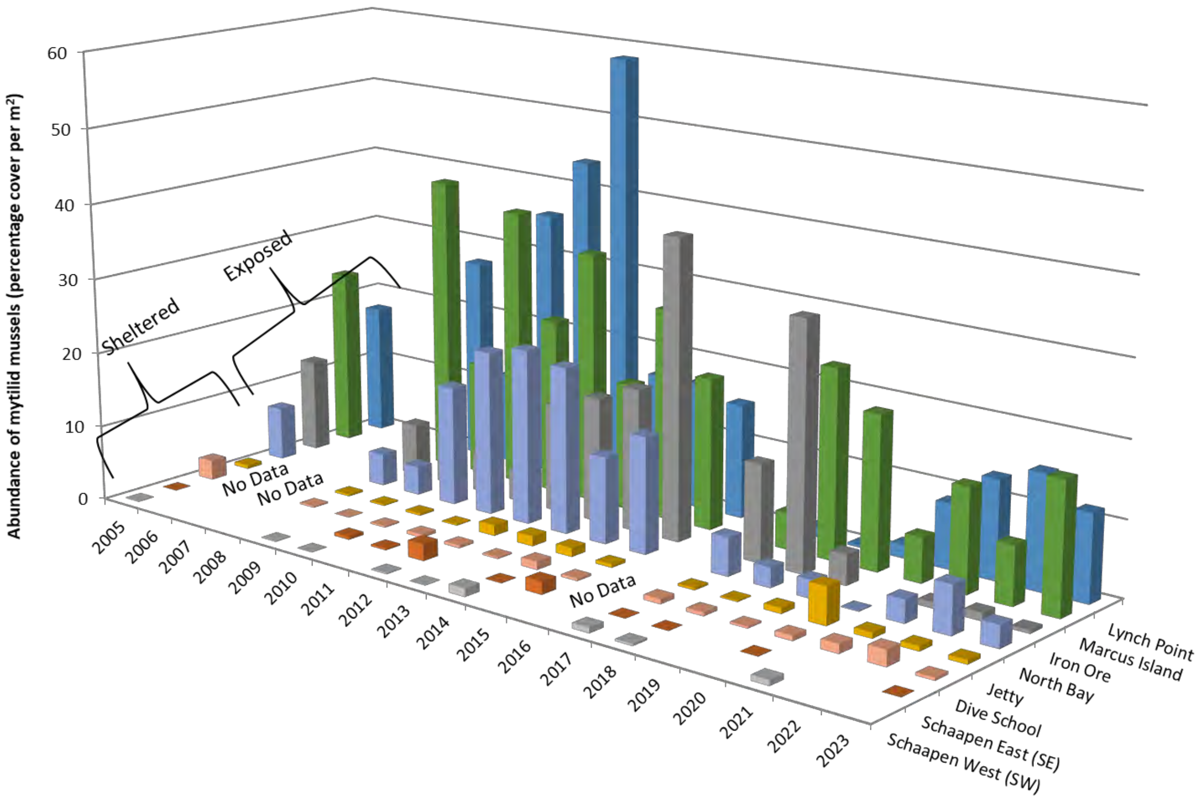


Figure 13.4. Changes in the abundance (% cover) of the mytilid mussel species complex at eight intertidal rocky shore sites in Saldanha Bay, over the period 2005–2023. Data are shown as an average of percentage cover on the mid and low shore. No samples were collected in 2006, 2007 and 2016.

Since the start of the rocky intertidal surveys, up until 2015, mytilid densities were high at the exposed sites, reaching maximum densities at Marcus Island in 2008 (39%), Lynch Point (58%) and North Bay (23%) in 2012, and at the iron ore terminal in 2015 (40%). Although fluctuations in mussel abundance is common, recent surveys suggest that populations have declined at these exposed sites. Mytilids are considerably less abundant in the years post-2016 compared to pre-2016, with Schaapen Island sites frequently lacking mussels. The reason for this decline remains unclear, although similar trends have been observed for *M. galloprovincialis* in the past (Hanekom and Nel 2002, Robinson et al. 2007b). Several factors could potentially contribute to this decline.

One hypothesis is that this decreasing trend may reflect a new ecosystem equilibrium, as predator numbers have probably responded to mytilids as a new food source, and now exert more control on the abundance of this invasive species (Zardi et al. 2009). Additionally, marine alien mussels like *M. galloprovincialis* have been found to become parasitised by endolithic bacteria leading to shell damage, reduced attachment ability and mortality. While such parasitism has been documented in South Africa (Zardi et al. 2009), it remains speculative and hasn't been confirmed in Saldanha Bay. High concentrations of trace metals in the environment could also impact mussel survival. Laboratory studies on *Mytilus edulis* have shown that even low concentrations of trace metals such as lead (Pb), manganese (Mn), and cadmium (Cd) can affect reproduction and survival (Fraser et al. 2017). In Saldanha Bay, elevated trace metal concentrations were reported in mussels in 2020 (Clark et al. 2020), sometimes exceeding recommended levels for foodstuffs (as discussed in Chapter 0). These elevated metal levels could be a contributing factor to the decrease in mussel populations. However, the most probable cause of the decline is severe weather events and wave action. Despite the overall lower abundances, there has been an increasing trend in mytilids at Lynch Point, Marcus Island, and North Bay over the past four years. In contrast, densities at the Iron Ore site have remained consistently low.

BLUE MUSSEL MYTILUS EDULIS

2023 Update: *New addition to South Africa*

Physical Description: This mussel is between 2–20 cm in length (Figure 13.3). The shell is usually purple, blue, or dark brown. It is characterised by a smooth, inequilateral shell marked by concentric growth lines originating from the hinge. The shell's interior is pearl-white (Bonham and Roberts 2022)

Native range: Northern Atlantic Ocean, encompassing North America, Europe and the northern Palearctic. Its range extends from the White Sea in Russia to southern France, covering the British Isles, including commercial beds in areas such as the Wash, Morecambe Bay, Conway Bay, southwest England, north Wales, and west Scotland. In the west Atlantic, *M. edulis* is present in the southern Canadian Maritime provinces down to North Carolina (FAO 2023).

Detection in South Africa and Saldanha Bay: The detection of this species through the DNA-based survey in 2022 marks the first record of this species in South Africa and Saldanha Bay. Although *M. edulis*, along with *M. trossulus*, may have been present for as long as *M. galloprovincialis*, their presence has most likely been obscured by the dominance of *M. galloprovincialis* in the mussel beds. The introduction could have occurred through import of *M. galloprovincialis* spat for commercial aquaculture, or via shipping activities.

Notes: Can occur subtidally and intertidally on rocky shores (FAO 2023). Settling in more exposed coastal areas makes individuals significantly more vulnerable to bird predation. Mussels that settle in exposed locations can experience mortality up to 98% per year (Nordsieck 2006, Tyler-Walters and Seed 2006). *M. edulis* has a high tolerance for elevated sediment levels, and may help to remove sediment from the water column (FAO 2023).

Monitoring and status in Saldanha Bay: The recent identification through the 2022 eDNA-based survey represents the first record of this species in Saldanha Bay and South Africa. Nonetheless, given that this species likely existed in the *M. galloprovincialis* beds, albeit in limited numbers, ongoing monitoring of these beds as part of the State of the Bay surveys would have included this species over the years.

Recommendation: To validate this identification, it is recommended that further specimens are examined morphologically, and sent for DNA barcoding. Additionally, ongoing monitoring of the mytilid species complex in Saldanha Bay is advised.

BAY MUSSEL MYTILUS TROSSULUS

2023 Update: *New addition to South Africa*

Physical Description: The shell exhibits a smooth blue-black surface with concentric lines and a glossy brown-black periostracum. It is elongated, measuring between 70–110 mm (Coe 1945, Kozloff 1974).

Native range: This mussel has been recorded as having a native range limited to the northern hemisphere (Hilbish et al. 2000, Riginos and Cunningham 2005, Beaumont et al. 2008). Specifically, it has been described as native to the Northeast Pacific, ranging from the Arctic to central California (Kafanov 1999), but has also been documented as native to Hokkaido in the northwest Pacific (Suchanek et al. 1997)

Detection in South Africa and Saldanha Bay: The detection of this species through the 2022 eDNA-based survey marks the first record of this species in South Africa and Saldanha Bay. Although *M. trossulus*, along with *M. edulis*, may have been present for as long as *M. galloprovincialis*, their presence would likely have been obscured by the dominance of *M. galloprovincialis* in the mussel beds. The introduction could have occurred through import of *M. galloprovincialis* spat for commercial aquaculture or via shipping activities.

Notes: Previous intertidal guides (Haderlie and Abbott, Ricketts and Calvin 1952, Hedgpeth 1984, Kabat and O'foighil 1987) mistakenly identified *M. trossulus* as *Mytilus edulis*. However, recent studies using molecular methods have properly differentiated the two species (McDonald and Koehn 1988, Varvio et al. 1988, McDonald et al. 1991, Väinölä and Hvilsom 1991, Sarver and Foltz 1993, Geller 1994, Beynon and Skibinski 1996, Burzyński et al. 2003, Wood et al. 2003).

Monitoring and status in Saldanha Bay: The recent identification through the 2022 eDNA-based survey represents the first record of this species in Saldanha Bay and South Africa. Nonetheless, given that this species likely existed in the *Mytilus* beds, albeit in limited numbers, ongoing monitoring of *Mytilus* as part of the State of the Bay surveys would have included this species over the years.

Recommendation: To validate this identification, it is recommended that further specimens are examined morphologically, and sent for DNA barcoding. Additionally, ongoing monitoring of the mytilid species complex in Saldanha Bay is advised.

MEDITERRANEAN MUSSEL MYTILUS GALLOPROVINCIALIS

2023 Update: ***Important update***

Physical description: A relatively elongated (60–140 mm) smooth mussel (Figure 13.3). Typically has a blue or black coloration, occasionally with brown hues on the lower surface. This species has a broad profile, with the widest part located at the base. Easily confused with the indigenous black mussel, *Choromytilus meridionalis* (Griffiths et al. 1992), but differentiated by the presence of pits in the resilial ridge.

Native range: Europe, where it is known to form dense subtidal beds directly on sandy bottoms (Ceccherelli and Rossi 1984).

Detection in South Africa and Saldanha Bay: First detected in Saldanha Bay in 1979 (Mead et al. 2011b), but its presence was only confirmed in 1984 (Grant et al. 1984, Grant and Cherry 1985).

Notes: In 1979, this mussel was widespread in the country, being the most abundant mussel species on rocky shores between Cape Point and Lüderitz (Griffiths et al. 1992). It subsequently extended its range as far as East London (Robinson et al. 2005a). *Mytilus galloprovincialis* (or at least what was identified as *M. galloprovincialis* at the time) began establishing dense intertidal beds on the sandy centre banks of Langebaan Lagoon in the mid-

1990s (Hockey and Van Erkom Schurink 1992, Robinson and Griffiths 2002), with biomass peaking at an estimated eight tonnes in 1998 (Robinson and Griffiths 2002). The population subsequently crashed, decreasing in size by 88% by early 2001 (Hanekom and Nel 2002), and had died off completely by mid-2001 (Robinson et al. 2007a). This mussel is commercially cultured in Saldanha Bay, and elsewhere, and is widely exploited by recreational and subsistence fishers (Robinson et al. 2005a, 2007b).

At Marcus Island, a comparison of intertidal communities pre- and post-invasion of *M. galloprovincialis*, *S. patagonicus* and *B. glandula* (1980 vs. 2012), demonstrated that the indigenous mussel *C. meridionalis* disappeared by 2012, and *A. atra* decreased in abundance. 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 *A. atra* on the mid shore. Here, *M. galloprovincialis* was responsible for a reduction in the abundance and diversity of other species (Sadchatheeswaran et al. 2015). *Mytilus galloprovincialis* has also been documented obscuring 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).

Monitoring and status in Saldanha Bay: See "Monitoring and status of mytilids in Saldanha Bay" above. This species has been routinely monitored as part of the State of the Bay survey since 2005, and was also detected in the ADZ biofouling and DNA-based surveys.

Recommendation: Monitoring of the mytilid species complex in Saldanha Bay should continue. In light of the fact that *M. galloprovincialis* occurs subtidally in its native range, and has recently been reported subtidally elsewhere in South Africa, the presence of this species should be monitored subtidally within Saldanha Bay.

BISEXUAL MUSSEL SEMIMYTILUS PATAGONICUS

2023 Update: ***Important update***

Physical Description: A small brown mussel, up to 50 mm in length, characterised by its elongated, relatively flat, and smooth appearance with a green-tinged shell (Figure 13.3). This species is hermaphroditic, exhibiting both male and female reproductive organs.

Native range: Originally from Chile (Kensley and Penrith 1970).

Detection in South Africa and Saldanha Bay: Has been present in Namibia since the 1930s (Kensley and Penrith 1970), but was first recorded in South Africa in 2009. The exact date of its arrival in South Africa remains uncertain, but it likely migrated southward from Namibia, either through shipping as a new invasion, or via range expansion from the Namibian population (de Greef et al. 2013). Extends 500 km, from Bloubergstrand in the south to Groenriviersmond in the north (de Greef et al. 2013).

Notes: Previously known as *S. algosus.* It has a strong preference for wave-exposed shores, forming dense intertidal beds along the west coast of South Africa, and contributing significantly to intertidal biomass (de Greef et al. 2013, Skein et al. 2018). Subtidal surveys have also revealed its dominance at sheltered sites on the west coast, and it forms equally dense beds at exposed sites compared to indigenous species (Skein et al. 2018). This adaptability may explain its presence on mussel farm ropes in Saldanha Bay. Subtidal specimens tend to be larger than their intertidal counterparts, with some exceeding 120 mm in size compared to 54 mm in the intertidal zone (Skein et al. 2018). Larger mussels play a greater role in the reproductive output of the population (Van Erkom Schurink and Griffiths 1991, Skein et al. 2018), suggesting the need for close monitoring of this species due to its potential for further future invasions.

Monitoring and status in Saldanha Bay: See "Monitoring and status of mytilids in Saldanha Bay" above. This species has been routinely monitored, along with *M. galloprovincialis*, as part of the State of the Bay survey. This species was also detected in the 2022 DNA-based survey.

Recommendation: Monitoring of the mytilid species complex in Saldanha Bay should continue. In light of the fact that this species occurs subtidally in its native range, the presence of this species should be monitored subtidally within Saldanha Bay.

13.3.2 TUBERCULATE PEAR CRAB *PYROMAIA TUBERCULATA*

2023 Update: ***New addition to Saldanha Bay***

Status: Invasive.

Physical Description: *Pyromaia tuberculata* is a spider crab with an oval carapace, featuring one anterior and three larger posterior tubercles, each covered by smaller knobs (Figure 13.5). Males exhibit inflated chelae, while females have slender ones. The legs are long and slender, with elongated dactyls (Landschoff et al. 2022).

Figure 13.5. The tuberculate pear crab *Pyromaia tuberculata* (Photo: Robin Leslie in Landschoff et al. 2022).

Native range: Pacific North America.

Detection in South Africa and Saldanha Bay: The timeline of the introduction of this species to South Africa remains uncertain. The Emmerson (2016) review of decapods in the country did not uncover its presence (Branch 2016). However, in 2018, the species was reported for the first time south of Gouritz River Mouth on the South Coast (Griffiths et al. 2018a), and its official addition to the regional fauna was formally acknowledged by Landschoff et al. (2022). Interestingly, the species was previously detected by Anchor during the 2013 State of the Bay benthic macrofauna survey in Saldanha Bay. As it wasn't positively identified at that time, it was catalogued as 'spiny crab' in the database, without an official report as *P. tuberculata*.

Notes: This species is believed to have been introduced to Brazil, Argentina, Japan and Eastern Australia (Ahyong 2005).

Monitoring and status in Saldanha Bay: This species was first detected as an unknown crab as part of the benthic macrofauna survey in 2013. It was subsequently often encountered in Small Bay. In 2021, several individuals were discovered during the ADZ biofouling survey. Further material was collected during the 2022 eDNA-based survey, and DNA barcoding confirmed that the crab was indeed *P. tuberculata*. These findings represent the second record of this species in South Africa, and the first record of a (growing) population in Saldanha Bay. No monitoring has been done as of yet as this species has only recently been identified.

Recommendation: To better understand its abundance and distribution in Saldanha Bay, dedicated sampling efforts targeting this species should be implemented.

13.3.3 JAPANESE SKELETON SHRIMP *CAPRELLA MUTICA*

2023 Update: *New addition to Saldanha Bay*

Status: Invasive.

Physical Description: *Caprella mutica* is a species of large skeleton shrimp, orange to red in colour, that can reach a length of 49 mm. Females typically measure 15 mm, while males are notably elongated, reaching up to three times the length of females, with an average size of 35 mm. Females are easily recognized by the presence of a brood pouch covered with dark red spots (Turcotte and Sainte-Marie 2009) (Figure 13.6).

Native range: This species is indigenous to north-east Asia, specifically Japan.

Detection in South Africa and Saldanha Bay: First identified in South Africa in 2017 at False Bay Marina (Peters and Robinson 2017). It was likely introduced through ship fouling. Its rapid reproductive cycle and high reproductive output are causes for concern, as it has already attained significant densities in the marina environment since its first detection. Its recent detection through the 2022 DNA-based survey represents the second record of this species in South Africa, and the first record in Saldanha Bay.

Notes: *Caprella mutica* has invaded several regions, including North America, Europe and New Zealand.

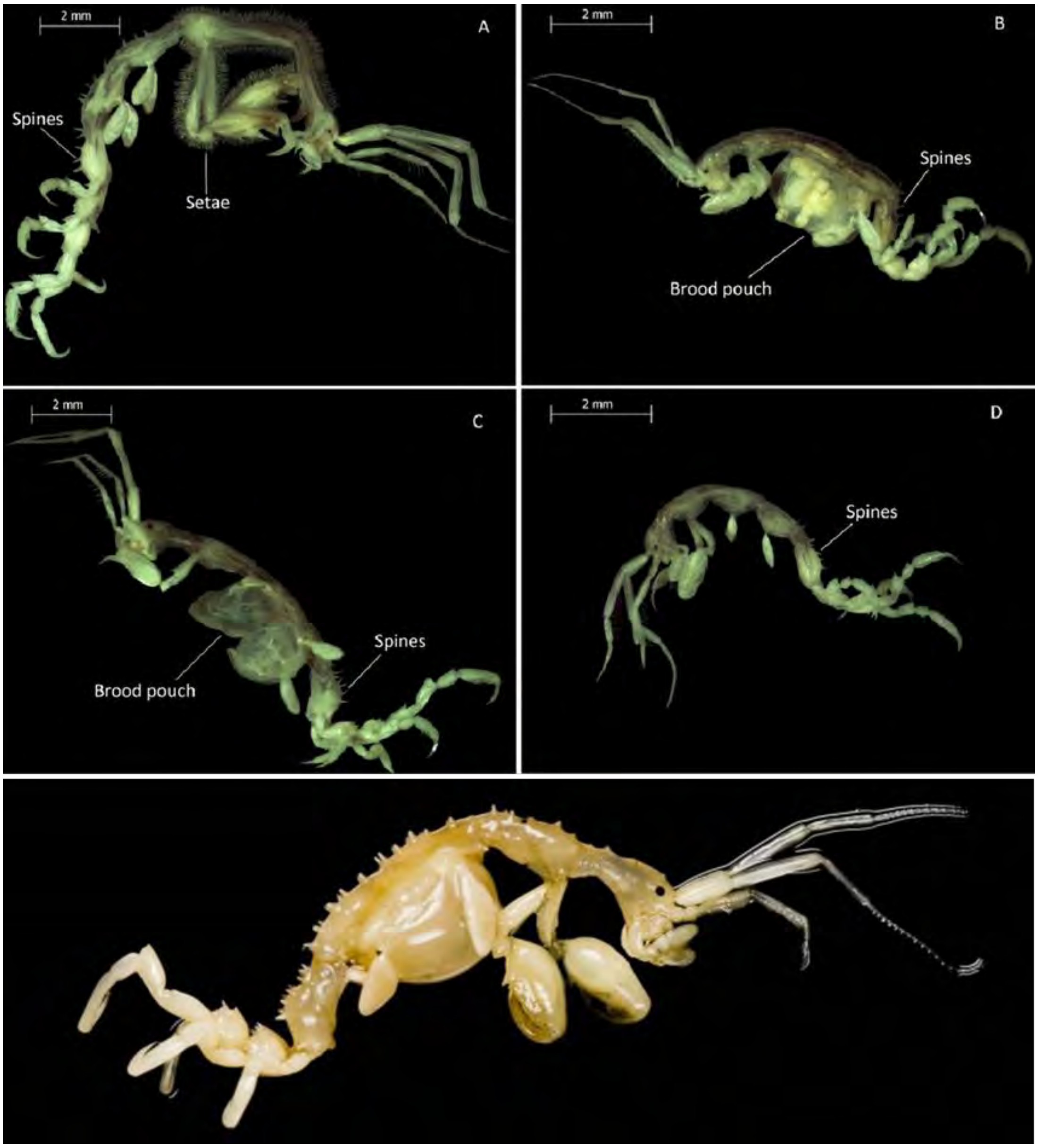


Figure 13.6. Japanese skeleton shrimp *Caprella mutica*. (Top photos: Peters and Robinson 2017. Bottom photo: Thierry Gosselin (Source: https://www.marinespecies.org)).

Monitoring and status in Saldanha Bay: Its recent detection in the 2022 DNA-based survey marks the first record of this species in Saldanha Bay. This species is likely found on hard infrastructure as a fouling organism, and on rocky shores. It might have been missed in rocky shore surveys in the past as the survey protocol doesn't include removal of biota from the shore, thus potentially overlooking smaller infaunal species like *C. mutica* in the complex matrix of mussel beds and algae. The reasons for its elusive detection on hard substrata are unclear; it could be due to its potentially limited distribution or existing in low numbers, escaping routine sampling efforts.

Recommendation: To better understand its abundance and distribution in Saldanha Bay, dedicated sampling efforts targeting this species should be implemented.

13.3.4 PITTED OR TRIANGLE BARNACLE *BALANUS TRIGONUS*

2023 Update: *New addition to Saldanha Bay*

Status: Invasive.

Physical Description: This barnacle, measuring 15–20 mm in size, has six ribbed shell plates that are predominantly white with distinct pink ridges (Biccard and Griffiths 2012) (Figure 13.7). It has a thick, triangular operculum (scutum), distinguished by the arrangement of one to six rows of pits (holes) in longitudinal patterns on the operculum. The colour of the scuta can vary, ranging from white to dark red or purple, sometimes making the pits harder to distinguish.

Figure 13.7. Triangular or pitted barnacle *Balanus trigonus* (Photo: Auguste Le Roux, wikipedia.org).

Native range: Native to the Pacific, although it has been reported to have a cosmopolitan distribution (Zullo 1992a, Carlton et al. 2011).

Detection in South Africa and Saldanha Bay: Although the exact introduction date remains unknown, records of this species in South Africa date back over half a century to the Knysna Estuary, as documented by Millard (1949). Subsequently, it has been acknowledged as being well-established along the entire South African coastline (Biccard and Griffiths 2012, Branch et al. 2022), spanning multiple bioregions. Here, it typically occurs at depths ranging from two to 67 meters (Biccard and Griffiths 2012). It is believed to have been introduced from the Pacific via shipping activity.

Notes: In South Africa, it is a common fouling species, attaching to various substrata. Flourishing in warmer waters, especially in harbours and estuaries, it exhibits resilience to reduced salinity levels (Millard 1949). It has been introduced to numerous other regions around the world, with recorded distributions ranging from the littoral zone to depths of 450 meters (Zullo 1992a, Carlton et al. 2011)

Monitoring and status in Saldanha Bay: Its recent detection in the 2022 DNA-based survey marks the first record of this species in Saldanha Bay. This species is likely present on hard infrastructure as a fouling organism, as well as on rocky shores. It may have been overlooked during rocky shore surveys due to it being very similar in appearance to the cryptogenic acorn barnacle *Amphibalanus amphitrite amphitrite*.

Recommendation: Dedicated sampling efforts on both rocky shores, specifically targeting infauna, and on hard substrata in the Bay, should be conducted to monitor the abundance and distribution of this alien species.

13.3.5 Fat-feeler amphipod *Monocorophium acherusicum*

2023 Update: ***New addition to State of the Bay (SOB)***

Status: Alien.

Physical Description: A small amphipod, brown in colour, that measures 5 mm in size. This species has a very short abdomen and is characterised by three small spines on its enlarged second antennae. Rows of hair on its anterior legs serve as a filter to extract food from the water (de Kluijver and Ingalsuo 1999, Branch et al. 2022). (Figure 13.8).

Figure 13.8. Fat-feeler amphipod *Monocorophium acherusicum* (Photo: Eric A. Lazo-Wasem, wikidata.org).

Native range: Northern Atlantic.

Detection in South Africa and Saldanha Bay: This species was reported as present in Langebaan Lagoon in 2009, although the exact date of introduction is unknown (Hanekom et al. 2009).

Notes: This cosmopolitan species lives in tubes constructed from fine sediment. Its omnivorous diet encompasses mesozooplankton fragments, seagrass tissue, benthic diatoms, and detritus (Ashton Acton 2013). Typically occurring subtidally, it thrives in habitats of reduced salinity, building tubes on various substrata like algae, hydroids, and buoys (Crawford 1937, Lincoln 1979).

Monitoring and status in Saldanha Bay: It was first identified in a State of the Bay survey in 2014. Here it was recorded at three Danger Bay sites during the benthic macrofauna survey with an average abundance of six individuals/m^2. However, subsequent surveys have not recorded its presence at these, or any other sites, and it was therefore omitted from the State of the Bay report in subsequent years. Despite this, the species was detected in the 2022 DNA-based survey, suggesting its likely continued presence in the Bay.

Recommendation: To better understand its abundance and distribution in Saldanha Bay, dedicated sampling efforts targeting this species should be implemented.

13.3.6 PINK-MOUTHED HYDROID *ECTOPLEURA CROCEA*

2023 Update: ***New addition to SOB***

Status: Alien.

Physical Description: This hydroid has a long, unbranched stem that is encased in a sheath (Figure 13.9). It has a single large pink and white polyp with short tentacles forming a ring around the mouth. It has a second ring of longer and larger tentacles that usually have bunches of round reproductive sporosacs.

Figure 13.9. Pinkmouth hydroid *Ectopleura crocea* (Photo: Lazo-Wasem, EA; Source: https://www.marinespecies.org/).

Native range: Northern Atlantic, including Europe.

Detection in South Africa and Saldanha Bay: The initial record of this species dates back to Millard's (1952) report under the name *Tubularia crocea*, based on specimens collected in 1947–1949 from Table Bay Harbour. Mead et al. (2011a) presumed that the species identified by Millard (1952) was likely *Pinauay ralphi* and maintained the latter as the accepted species name. Consequently, 1947 was considered as the first record of this species in South Africa. This name was later synonymised with *E. crocea*, which is now the accepted name (Schuchert 2023a). Its recent detection in the 2022 DNA-based survey marks the first record of this species in Saldanha Bay.

Notes: This species is commonly found in South African harbours, specifically on ship hulls and dock piles, with documented occurrences in Durban Harbour and Lüderitz Bay (Ewer 1953, Millard 1975). This species has recently undergone a complex taxonomic re-evaluation. Over the past century and a half, various authors have described it under multiple names, including *E. ralphi, T. warren, T. crocea, P. crocea*, and *P. ralphi* (Millard 1952, 1959, 1975, Ewer 1953, Petersen 1990, Mead et al. 2011a). This has led to taxonomic confusion, revisions, and eventually synonymisation of most of these names. Certain sources initially considered some of the described species as native to South Africa due to taxonomic uncertainties (Millard 1975). However, following subsequent taxonomic and genetic revisions, it was reclassified as an introduced species (Petersen 1990). Additionally, Mead et al. (2011a) explicitly identified it as an alien species under the name *P. ralphi*. This name was later synonymised with *E. crocea*, the currently accepted name (Schuchert 2023a). Interestingly, Branch et al. (2022) lists this species as native to South Africa, reflecting the taxonomic confusion. Until further genetic analyses and taxonomic revision provide clarity, this hydrozoan maintains its name and alien status in this report.

Monitoring and status in Saldanha Bay: Its recent detection in the 2022 DNA-based survey marks the first record of this species in Saldanha Bay.

Recommendation: Until further genetic analyses and taxonomic revision provides clarity, this hydrozoan maintains its name and alien status in this report. To better understand its abundance and distribution in Saldanha Bay, dedicated sampling efforts targeting this species should be implemented.

13.3.7 THIN-WALLED OBELIA *OBELIA DICHOTOMA*

2023 Update: ***New addition to SOB***

Status: Alien.

Physical Description: *Obelia dichotoma* is a colonial hydroid with a characteristic root-like base and an unbranched, upright stem that is 10 mm long and pink to white (Figure 13.10). The polyps are shielded by bell-shaped, smooth encasings (hydrothecae) that rise directly from the stem. Juvenile individuals may appear unbranched and elongated. In the early stages, the primary stems of *O. dichotoma* are slender and single, but they thicken as the colony grows and become more complex and numerous with age (Cornelius 1990).

Native range: The lack of molecular genetic data on global populations makes it challenging to determine the biogeographic origin of this and other *Obelia* species. Native range is therefore unknown.

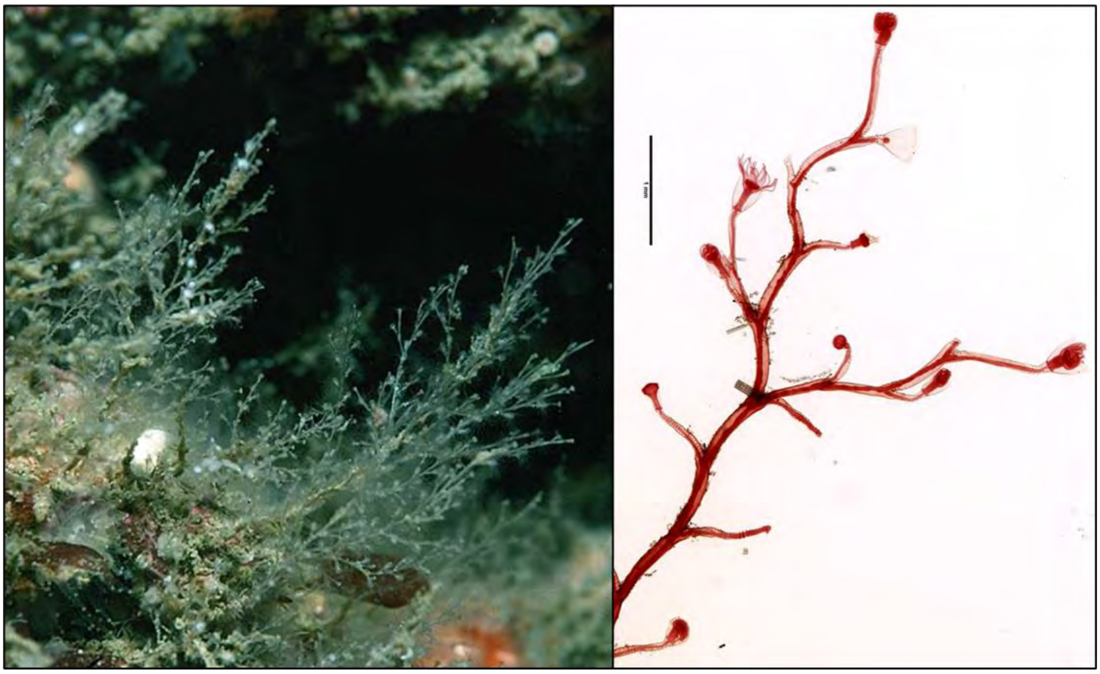


Figure 13.10. Thin-walled obelia *Obelia dichotoma* (Photo: Bernard Picton (left) and DJ Drew (right). Source: https://www.marinespecies.org/).

Detection in South Africa and Saldanha Bay: The first known collection of this species in South Africa dates back to 1938 (Mead et al. 2011a). Initially, its distribution was thought to range from Lambert's Bay on the west coast to Algoa Bay on the south coast, as described by Millard (1975). However, it has since been identified as a highly prevalent species, particularly in harbours, with a distribution covering the entire coastline of southern Africa (Branch et al. 2022). Its recent detection in the 2022 DNA-based study marks the first record of this species in a State of the Bay survey.

Notes: *Obelia dichotoma* is globally a widespread species that is commonly found on ships, dock piles, and seaweed. Its reproductive cycle occurs in mid to late summer, releasing medusae from the gonophores. Interestingly, it can release medusae even at a young stage of development (Richards 2007). In South Africa, populations of this species in areas such as harbours, ports, and lagoons are considered introduced (Mead et al. 2011a). This species commonly occurs on other species such as other hydroids, algae, sharks (*Squalus acutipinnis*), mussels (*Aulacomya ater*) and turtles (*Caretta caretta*) (Millard 1975). Non-harbour habitats may contain native clades. However, the status of populations of *Obelia* in areas other than harbours remains unknown until genetic data are available.

Monitoring and status in Saldanha Bay: This species is widespread in harbours along the South African coastline, and is probably present throughout Saldanha Bay. Its recent detection in the 2022 DNA-based study constitutes the first record of this species in a State of the Bay survey. It could have been missed in biofouling surveys due to its small size and the challenge of identifying hydroids without intensive microscopic analysis.

Recommendation: Given its potential presence as a fouling organism on hard infrastructure, ongoing biofouling surveys on hard substrata in Saldanha Bay is recommended, with a particular emphasis on targeted sampling efforts for this species. This approach will enhance the monitoring of the abundance and distribution of this alien species.

13.3.8 AMPHIPOD *ERICTHONIUS BRASILIENSIS*

2023 Update: ***New addition to SOB***

Status: Invasive.

Physical Description: The first antenna measures about half the body length (Myers and McGrath 1984), while the second antenna is slightly longer. Notably, it possesses small coxa (side plates). In males, the second gnathopods are marked by a distinctive size, featuring a prominently large postero-distal projection that concludes with two teeth, separated by a V-shaped incision. This species differs from others in the same genus due to its comparatively smaller eyes (Milne and Griffiths 2013) (Figure 13.11).

Figure 13.11. The amphipod Ericthonius brasiliensis (Photo: enciclovida.mx).

Native range: Originally described from the North Atlantic, this species has expanded its distribution and is now widely found in tropical and temperate areas (Mead et al. 2011a). Its range includes the Eastern Pacific Ocean, extending from Puget Sound, Washington, southward to Punta Centinela, Ecuador. It can be found in the Gulf of California up to Puerto Peñasco, as well as at the Galapagos and Cocos Islands. Overall, it is generally considered cosmopolitan (Faasse and Van Moorsel 2000, Horton et al. 2023).

Detection in South Africa and Saldanha Bay: Initially recorded in South Africa in 1910 by Stebbing (1910), this amphipod is now present along the entire South African coastline, ranging from Olifants River on the west coast to Mozambique on the east coast (Mead et al. 2011a). Its distribution suggests that it may have been transported on ships as a fouling organism.

Notes: This amphipod is found in the littoral zone down to a depth of 200 meters (Horton et al. 2023). It creates muddy tubes on the stems and branches of hydroids and other fouling species (Mead et al. 2011a). There is a possibility that it represents a species complex.

Monitoring and status in Saldanha Bay: This species, known to be widespread along the South African coastline, is likely present throughout Saldanha Bay. Initially recorded as part of the State of the Bay survey in 2019, in benthic macrofauna samples from Small Bay, it hasn't been encountered or detected in subsequent samples, including those collected for DNA analysis. This species is likely present on hard infrastructure as a fouling organism in the benthic environment, and also on rocky shores. The reason for its elusive detection remains unknown, but it could be due to its potentially limited distribution in the Bay, or its low abundance.

Recommendation: Ongoing surveys in Saldanha Bay is advised, with a particular emphasis on targeted sampling efforts for this species. This approach will enhance the monitoring of the abundance and distribution of this alien species.

13.3.9 RED-RUST BRYOZOAN *WATERSIPORA SUBTORQUATA*

2023 Update: ***Important update***

Status: Invasive.

Physical Description: A encrusting bryozoan that is red-rust in colour. It forms calcareous crusts on hard surfaces (Figure 13.12).

Figure 13.12. Red-rust bryozoan *Watersipora subtorquata* (Photo: Anchor).

Native range: The exact native range of this bryozoan is unknown, primarily because of taxonomic confusion and the notion that it might be a species complex (Fofonoff et al. 2019).

Detection in South Africa and Saldanha Bay: First reported in 1935 as *W. cucullata* (O'Donoghue and de Watteville 1935), and later synonymised with *W. subtorquata* (Florence et al. 2007). However, it has probably been present for longer than that. Its distribution has been reported as Saldanha Bay on the west coast to False Bay on the south coast (Florence et al. 2007).

Notes: A shallow-water fouling organism and suspension feeder, feeding predominantly on phytoplankton. It forms calcareous crusts on hard surfaces such as rocks, shells, pilings, ship hulls, floating objects, fouling plates and oil platforms, and creates secondary habitat for the settlement of other marine invertebrates (Mackie et al. 2006, Cohen and Zabin 2009, Ryland et al. 2009). A recent taxonomic revision of the genus *Watersipora* revealed unexpected changes in the distribution and nomenclature (Vieira et al. 2014). Until further studies and genetic analysis can resolve the confusion, this bryozoan will retain its name where it has been identified previously (Florence et al. 2007, Fofonoff et al. 2019). It has been widely distributed throughout the world via hull fouling and ballast water. Introduced populations have also been recorded from New Zealand, Australia, Hawaii, Europe and possibly the west coast of North America (Mead et al. 2011a).

Monitoring and status in Saldanha Bay: This species was newly identified in the State of the Bay survey, with its presence noted during the 2023 rocky shore survey. Additionally, it was detected through samples analysed from the 2022 DNA-based survey.

Recommendation: Given its potential presence as a fouling organism on hard infrastructure, ongoing biofouling surveys on hard substrata in Saldanha Bay are advised, with a particular emphasis on targeted sampling efforts for this species. This approach will enhance the monitoring of the abundance and distribution of this alien species.

13.3.10 Pacific barnacle *Balanus glandula*

2023 Update: ***Important update***

Status: Invasive.

Physical Description: Typically off-white or yellowish in colour, conical in shape, and measures between 5–10 mm (Figure 13.13). Its distinctive features include six vertically ridged shell plates, and the tendency to leave a calcareous base on rocks when it's removed. The junction between the four upper shell plates forms an M-shaped line. This species looks very similar to the indigenous tooth barnacle, *Chthamalus dentatus.*

Figure 13.13. Pacific barnacle *Balanus glandula* (Photo: Prof. C.L. Griffiths).

Native range: Pacific coast of North America.

Detection in South Africa and Saldanha Bay: First recognized in 2008 (Laird and Griffiths 2008, Simon-Blech et al. 2008), it has been in South Africa since at least the early 1990s. The confusion with the native species may account for it going undetected for so long. Probably introduced from the Pacific coast of North America via shipping given the high amount of shipping traffic in Saldanha Bay (Laird and Griffiths 2008).

Notes: The most abundant intertidal barnacle in Saldanha Bay, and along much of the southern west coast (Laird and Griffiths 2008). It has also spread east, past Cape Point (Robinson et al. 2015a). Recent research shows that when compared to the indigenous barnacle species *Notomegabalanus algicola, B. glandula* is more efficient at algae uptake irrespective of water temperature or algal cell concentration (Pope et al. 2016). This species has displaced populations of the indigenous and formerly abundant *C. dentatus* which is now very rare on South African west coast shores (Laird and Griffiths 2008).

Monitoring and status in Saldanha Bay: As was expected, this species was detected in samples collected and analysed as part of the 2022 DNA-based survey. This species has also been routinely monitored as part of the State of the Bay rocky shore survey, since its first detection in 2010.

This and other studies suggest it competes directly with other intertidal species for space on the shore. Historical data from the State of the Bay surveys suggest that *B. glandula* predominantly occupied the mid shore and was most abundant at the semi-exposed rocky shore sites (i.e., the Iron Ore terminal and Lynch Point) followed by the exposed rocky shore sites (i.e., Marcus Island and North Bay) (Figure 13.14). When first detected more than a decade ago it was relatively abundant at most of the monitoring sites. Notably, barnacles are considerably less abundant in the years post-2016 compared to pre-2016.

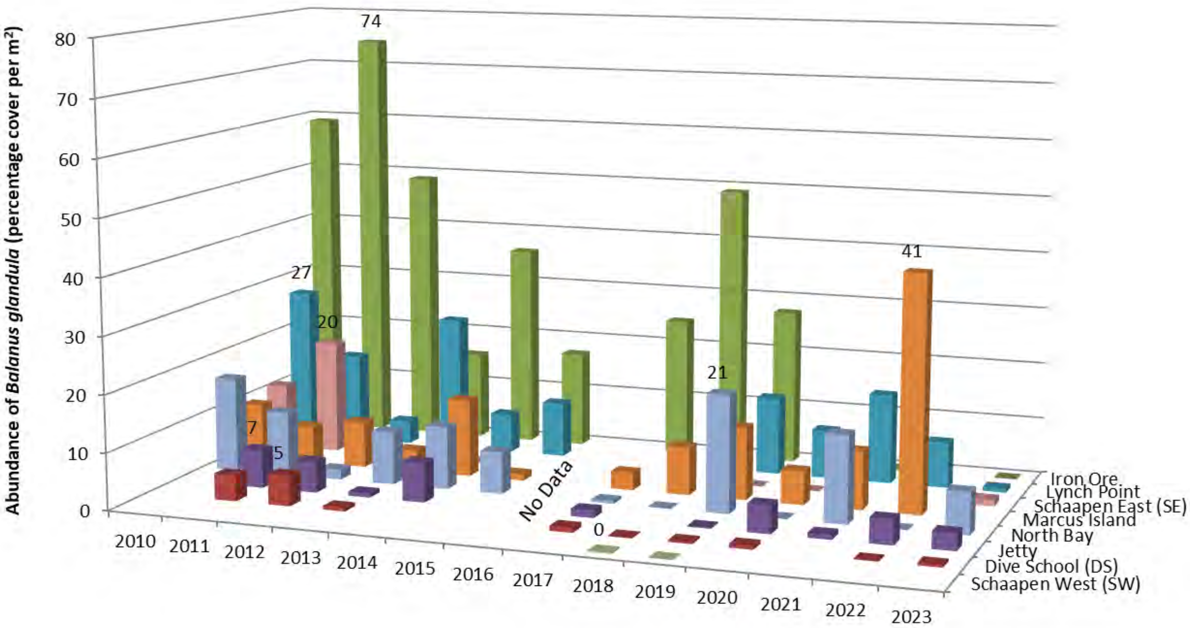


Figure 13.14. Changes in the abundance (% cover) of the Pacific barnacle *Balanus glandula* at eight rocky shore sites on the mid shore in Saldanha Bay over the period 2010–2022. Data are shown as an average of percentage cover on the mid shore. No samples were collected in 2016. See Figure 10.2 for locations of these monitoring stations.

The greatest densities recorded for this species since the start of the survey was at the Iron Ore terminal in 2011. Here it covered 74% of the rocky shore. Although the percentage cover at this site has, in the past, always been relatively high, the consistently low percentage cover over the past four years is noteworthy. In fact, this barnacle occupied less than 0.2% of the mid shore over the past four years. Maximum densities recorded at each of the other intertidal monitoring sites include 27% cover at Lynch Point in 2010, 20% cover at Schaapen East in 2011, 41% cover at Marcus Island in 2022, 21% cover at North Bay in 2019, 7% at the Jetty in 2014, 5% cover at the Dive school in 2011 and 0.22% cover at Schaapen West in 2018. In the 2022 survey, *B. glandula* was most abundant at Marcus Island, occupying 41% of the mid shore, marking the highest recorded densities at this site, four times greater than the 2021 survey. Fluctuations in abundance across different years and sites are common.

The presence of this species has always been low at the very sheltered Dive school and Jetty sites, although not as sparse as at the sheltered Schaapen Island East and West sites. On this Island, *B. glandula* populations have never exceeded 1.5%. Two exceptions include 2010 and 2011, where densities on Schaapen East reached 11% and 20%, respectively. The lowest total percentage cover for all sites over the past decade was recorded during the 2023 survey. Considering the trend observed over the past decade, the percentage cover of *B. glandula* is expected to continue to fluctuate in the future, with several factors likely playing a role. Barnacles compete with other species, such as limpets, for space on the mid shore. The presence of limpets is known to decrease population sizes by dislodging newly settled barnacles (Miller and Carefoot 1989). It should be noted that any major increases in population size for *B. glandula* would be an indication of an influx of new propagules from elsewhere, as this barnacle cannot self-fertilise (Kado 2003). In light of recent findings that there is no significant impact of *B. glandula* on community structure at Marcus Island (Sadchatheeswaran et al. 2018), this barnacle is not believed to have any significant impacts on communities in Saldanha Bay, and even less so when population sizes are small. In summary, this species has decreased in density at almost all sites in recent years. The percentage cover of *B. glandula* is expected to continue to fluctuate in the future and monitoring of this species should, however, continue, especially since it is one of the more abundant species on the shore in Saldanha Bay.

Recommendation: Due to the fluctuating density of this species, monitoring should continue, especially since it is one of the more abundant species on the rocky shore in Saldanha Bay.

13.3.11 Western pea crab *Rathbunixa occidentalis*

2023 Update: ***Important update***

Status: Invasive.

Physical Description: A small pinnotherid crab with a carapace width of <2.5 cm (Zmarzly 1992) (Figure 13.15).

Native range: This species was originally described from California by Rathbun (1984), although its native range is presently reported to include North America's entire west coast, from Alaska to Mexico (Zmarzly 1992).

Detection in South Africa and Saldanha Bay: First detected in Saldanha Bay. Probably became established in Saldanha Bay in the period between 1999 (at which time no specimens were recorded in a comprehensive set of samples from Saldanha Bay) and 2004, where it was recorded at three sites in Big Bay and at one site in Small Bay. At this stage, it was still listed as unidentified. The vector of introduction is unclear, although this crab was potentially introduced via ship fouling or ballast water (Clark and Griffiths 2012). It was only identified as *R. occidentalis* in the collections from the State of the Bay surveys in 2010 (Clark et al. 2011).

Figure 13.15. Western pea-crab Rathbunixa occidentalis (Photo: Clark and Griffiths 2012).

Notes: Formerly called *Pinnixa occidentalis*. This crab is a deep-water species and prefers depths ranging from 11–319 m. This species can be free-living, although it is commonly known to live in symbiosis with other animals. Mutualistic relationships are known to facilitate the establishment and spread of introduced species. (McDermott 2009).

Monitoring and status in Saldanha Bay: Continuous monitoring of the pea crab as part of the State of the Bay survey in Saldanha Bay has been ongoing since 2004, covering multiple monitoring stations at Big Bay, Small Bay, Langebaan Lagoon and Danger Bay. Abundance fluctuates annually, with this species being more abundant in Big Bay, followed by Small Bay (Figure 13.16).

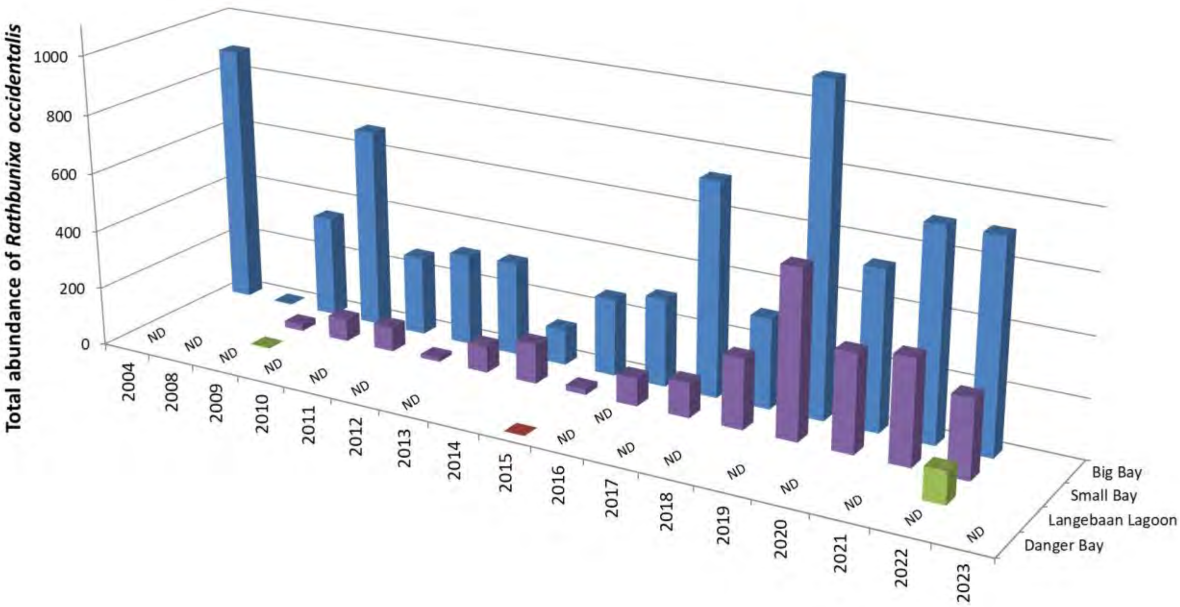


Figure 13.16. Average abundance of the western Pea crab *Rathbunixa occidentalis* in Big Bay, Small Bay, Langebaan Lagoon and Danger Bay from the period 2004–2023. Note that Langebaan Lagoon and Danger Bay were first sampled in 2004 and 2014, respectively. No data were collected in the period 2005–2007. 'ND' denotes that no data were collected in the region for that year.

The highest number of individuals (1 483) was recorded in Big Bay in 2019, while in Small Bay 567 individuals were recorded during the same year. *Rathbunixa occidentalis* has been documented in Langebaan Lagoon only twice during the monitoring campaign. Notably, this crab was also identified in Danger Bay during 2015, suggesting the potential for the species to extend its distribution beyond Saldanha Bay. However, subsequent sampling has not been conducted in this region to verify the ongoing presence of this crab. Despite continued sampling efforts in each campaign, certain sites in the Bay consistently showed no presence of crabs. This could indicate that the crab has not yet extended to these sites, or it may prefer a specific habitat type. The data suggest that this pea crab prefers deeper water habitats and is generally scarce, or occurs in lower densities near the iron ore and multi-purpose terminals.

Despite the high numbers recorded at Big Bay, Small Bay, and Langebaan Lagoon (707, 265, and 108 individuals, respectively) in 2022, no crabs were detected at any sampling stations during the 2023 survey. Although data until 2022 suggested potential establishment in Big Bay and Small Bay, the absence of detection in 2023 raises questions about the population's status. The reason for the decline in 2023 is unclear, emphasising the need for continuous monitoring to establish conclusive trends. The impact and role of the pea crab in Saldanha Bay's benthic community remain undetermined, highlighting the necessity for more in-depth studies and potential management actions.

Recommendation: Continuous monitoring is crucial to establish a conclusive trend in the population dynamics of *R. occidentalis*. The impact and role of this crab in the benthic community of Saldanha Bay remains undetermined, emphasising the need for more in-depth studies and potential management action. The status of this crab within Danger Bay is currently unconfirmed, necessitating additional sampling effort at this site.

13.3.12 Porcelain crab *Porcellana africana*

2023 Update: ***Important update***

Status: Invasive.

Physical Description: A small porcelain crab with a flattened body and fine nodules on the left chela. It is characterised by a dense fringe of hairs covering all its limbs (Figure 13.17).

Figure 13.17. European porcelain crab *Porcellana africana* (Photos: Prof. C.L. Griffiths (left) and Dr Jess Dawson (right)).

Native range: Native to the region between Senegal and Western Sahara in North-West Africa. Here, it occurs intertidally on rocky shores and boulder beaches, and subtidally to a depth of 22 m (Chace 1949).

Detection in South Africa and Saldanha Bay: This species was first discovered in South Africa in relatively high numbers on Schaapen Island (Langebaan Lagoon) in 2012 (Prof. G.M. Branch 2012, pers. obs.), in dense beds of the alien Mediterranean mussel *M. galloprovincialis* (Griffiths et al. 2018b). It was probably introduced between 2003 and 2009. This is the first and only known alien porcelain crab in South Africa (Griffiths et al. 2018a). Based on abundance recorded in 2016, it is estimated that the population densities of this crab can range from 15 to 976 crabs per linear metre of shoreline.

Notes: Previously misidentified as the European porcelain crab, *P. platycheles* (Griffiths et al. 2018a). Porcelain crabs, unlike true crabs, possess only three pairs of walking legs (with the fourth pair being small and rudimentary). They feature long antennae, and their flat bodies and claws are adapted for dwelling in rock crevices.

Monitoring and status in Saldanha Bay: This crab is commonly found during rocky shore surveys and was recorded in the ADZ biofouling and 2022 DNA-based surveys. Multiple individuals were discovered in various sampling stations within Small Bay during the 2022 benthic macrofauna survey. Unfortunately, since none were recorded inside the sampling quadrats, the abundance of this crab within Small Bay has not been quantified at this stage.

This crab was first recorded in a State of the Bay Survey from the Dive School site in 2021, as part of the rocky shore survey. Here, it was found at low densities, with individuals of varying size discovered sheltering in a dense bed of *M. galloprovincialis* and *A. atra.*

During 2022, dozens of individuals were documented at the Dive School, Jetty, and Schaapen West rocky shore sites. Numerous individuals were observed inhabiting kelp holdfasts at the latter site (Clark et al. 2022). Notably, in 2023, this crab was observed in significantly lower densities, only present at the Iron Ore and Jetty sites.

The ecological impact of this alien crab has not yet been identified. However, no major impact on native benthic invertebrates is anticipated. This species is not a typical prey item and, due to its feeding habits, it is not expected to pose a major threat or compete with native species. Nonetheless, it is recommended that populations be monitored (Griffiths et al. 2018b).

Recommendation: Continuous monitoring of this species is crucial, as it has the potential to expand its range and increase in numbers rapidly (Griffiths et al. 2018b). Subsequent subtidal surveys should be conducted to accurately quantify the abundance of this crab within the Bay.

13.3.13 Perforated barnacle *Perforatus perforatus*

2023 Update: ***Important update***

Status: Alien.

Physical Description: This species is included in the Sub-family Concavinae (Pitombo 2004), which includes barnacles with an extended sheath and longitudinal abutment present on the inner surface of the radii, and a bifid sutural edge present on the outer surface. It has characteristic terga, a pronounced beak, closed spur-furrow and no longitudinal striations (Newman 1982, Zullo 1992b) (Figure 13.18).

Figure 13.18. The perforated barnacle *Perforatus perforatus* (Photo: Peter Barfield, MarLIN website).

Native range: This species originates from the Pacific coast of North America, with live material recorded intertidally from Baja California, Mexico (Pilsbry 1916).

Detection in South Africa and Saldanha Bay: The presence of *P. perforatus* in Saldanha Bay was first recognised in 2011 when it was picked up as "an unfamiliar barnacle" at the Dive School as part of the Rocky Shore Intertidal survey. This constituted the first known record of this barnacle species in South Africa (Biccard & Griffiths pers. comm. 2017). It is difficult to determine when exactly it was introduced to Saldanha Bay as, to the untrained eye, 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 *T. serrata* has never been recorded at the dive school, and that *P. perforatus* appeared for the first time in April 2011. It is likely that the introduction of this species occurred via shipping given the high amount of shipping traffic in Saldanha Bay (Laird and Griffiths 2008).

Notes: This species was previously misidentified and reported as *Menesiniella regalis* in Saldanha Bay. Characters of the terga, a pronounced beak, closed spur-furrow and absence of longitudinal striations confirm the identification to species level.

Monitoring and status in Saldanha Bay: This species was detected in samples collected and analysed as part of the 2022 DNA-based survey. It is frequently encountered on the rocky shores during surveys, although in relatively low numbers. In 2021, for example, this barnacle was only recorded at the Dive School where it comprised less than 1% (i.e., 0.71%) of biota on the low shore. In 2022, it was recorded only on Marcus Island with a percentage cover of only 0.19% on the low shore. It was not recorded during the 2023 survey.

Recommendation: Continued monitoring of this species in the rocky shore survey is recommended.

13.3.14 Sea vase *Ciona robusta*

2023 Update: ***Important update***

Status: Invasive.

Physical Description: The solitary ascidian *Ciona robusta* is tall (15 cm), cylindrical and yellowish with a soft transparent tunic (Figure 13.19). It can reach 100 mm in size.

Figure 13.19. A typical aggregation of *Ciona robusta* in Saldanha Bay (Photo: Anchor).

Native range: North Atlantic.

Detection in South Africa and Saldanha Bay: This species was first collected in Durban (Millar 1955), and was probably introduced prior to 1955 (Mead et al. 2011a). *Ciona robusta* was initially misidentified as *C. intestinalis*, which was recently found to represent two morphologically separate species. Of these two species, *C. robusta* is in fact the one that occurs in South Africa (Brunetti et al. 2015, Robinson et al. 2016), where it forms large aggregations on submerged structures in harbours and lagoons all along the coastline.

Notes: This species is present in temperate waters worldwide (Mead et al. 2011a), where it attaches to harbour ropes, kelp or mussel farm rafts in sheltered and shadowed areas (Mead et al. 2011a). It is an economically important pest as it rapidly fouls hard marine surfaces and is known to smother and kill mussels on aquaculture facilities, especially mussel ropes (Robinson et al. 2005a). This presents a problem as this species is one of the more abundant fouling species on the aquaculture farm structures in the Saldanha Bay ADZ.

Monitoring and status in Saldanha Bay: This species was detected in both the ADZ and 2022 DNA-based surveys.

Recommendation: Monitoring of this species in Saldanha Bay should be ongoing, considering its prevalence. There may be a need to explore control or eradication programs for effective management.

13.3.15 Light-bulb sea squirt *Clavelina lepadiformis*

2023 Update: ***Important update***

Status: Invasive.

Physical Description: This tunicate has transparent zooids with yellow, white or pink bands around the dorsal lamina and oral siphon, earning it the name the light-bulb sea squirt (Figure 13.20).

Figure 13.20. The Light-bulb sea squirt Clavelina lepadiformis (Photo: Esculapio, https://commons.wikimedia.org).

Native range: This species originates from Europe, where it occurs from the Mediterranean Sea to Southern Norway (Tarjuelo et al. 2001).

Detection in South Africa and Saldanha Bay: It was first reported in South Africa in Port Elizabeth and Knysna (Monniot et al. 2001), and subsequently from numerous areas around the coast, including Saldanha Bay (Rius et al. 2014).

Notes: Colonial tunicates can reproduce both sexually and asexually through budding. They feed primarily on phytoplankton and detritus (Fofonoff et al. 2019). This species was most likely introduced via ship fouling to South Africa, the east Coast of America, Azores and South Korea. This tunicate occurs in rocky, shallow water areas and is commonly found in harbours, marinas, and ports where it attaches to the bottom and sides of jetties and boats (Mead et al. 2011b).

Monitoring and status in Saldanha Bay: This species is widespread in harbours along the South African coastline, and is likely present throughout Saldanha Bay, especially on hard infrastructure as a fouling organism. Its recent identification in the 2022 DNA-based study represents the first record of this species in a State of the Bay survey. The reason for its elusive detection remains unknown, but could be due to its potentially limited distribution in the Bay or its low abundance.

Recommendation: To better understand its abundance and distribution in Saldanha Bay, dedicated sampling efforts specifically targeting this species should be conducted, including epibenthic or reef surveys.

13.3.16 Disc lamp shell *Discinisca tenuis*

2023 Update: ***Important update***

Status: Invasive.

Physical Description: The disc lamp shell is a small (20 mm diameter) disc shaped brachiopod with a semi-transparent, hairy, fringed shell (Figure 13.21).

Figure 13.21. The disc lamp shell *Discinisca tenuis* (Photo: Prof. C.L. Griffiths).

Native range: This species is endemic to Namibia (Haupt et al. 2010).

Detection in South Africa and Saldanha Bay: This species was first recorded 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 thought to have been introduced to South Africa via cultured oyster imports from Namibia (Haupt et al. 2010).

Notes: This species reportedly reaches very high densities in its home range. Even though no previous history of invasion exists for this brachiopod, it could become a significant fouling species in Saldanha Bay, especially since it has been recorded amongst the biofouling samples collected in the Saldanha ADZ.

Monitoring and status in Saldanha Bay: This species was detected in both the ADZ biofouling and 2022 DNA-based surveys.

Recommendation: Given its potential presence as a fouling organism on hard infrastructure, ongoing biofouling surveys on hard substrata in Saldanha Bay are advised, with a particular emphasis on targeted sampling efforts for this species. This approach will enhance the monitoring of the abundance and distribution of this alien species.

13.3.17 Shell-boring spionid *Polydora hoplura*

2023 Update: ***Important update***

Status: Invasive.

Physical Description: This robust worm, reaching lengths of up to 40 mm, and featuring 180 segments with a width of 2 mm, is known for burrowing in shells or limestone (Figure 13.22). Its head is characterised by a pair of slender, grooved palps, typical of the Spionidae family, which often display black bars. There may be dark pigmentation along the prostomium (head), and it can have up to two pairs of eyes. Notably, it possesses long and filiform branchiae (gills) almost throughout its entire body, with a saucer-shaped pygidium (tail end) (Van Niekerk and Simon 2012)

Figure 13.22. The shell-boring spionid *Polydora hoplura* (Photo: Prof. C.A. Simon).

Native range: Europe, where it occurs from the Mediterranean to England.

Detection in South Africa and Saldanha Bay: It was first recorded in South Africa in 1947 in Table Bay (Millard 1952). Subsequently, Day (1967) reported it in the intertidal and shallow waters from Saldanha Bay to Plettenberg Bay.

Notes: A shell-boring spionid polychaete that bores into calcareous materials including mollusc shells, barnacles, sponges, coralline algae, and limestone (Fofonoff et al. 2019). It is commonly found on cultivated oyster beds and culture facilities for abalone and oysters. This polychaete has a wide alien distribution including California, Australia, New Zealand, Japan, Chile, Brazil, the Canary Islands and South Africa. This species commonly infests the commercially cultured oysters (Nel et al. 1996) and abalone *Haliotis midae* in Saldanha Bay

(Simon et al. 2006, Boonzaaier et al. 2014), which can have negative economic implications as it decreases their condition and survival (Fofonoff et al. 2019).

Monitoring and status in Saldanha Bay: This species is commonly found in harbours along the South African coastline and is likely present throughout Saldanha Bay, particularly on aquaculture infrastructure and cultured molluscs. Its recent identification in the 2022 DNA-based study marks the first record of this species in a State of the Bay survey. The reason for its elusive detection might be its small size or boring nature. This behaviour means it may not necessarily occur on top of structures where it can be easily seen, potentially leading to its evasion of routine sampling efforts.

Recommendation: Given its potential presence as a fouling organism, especially on cultured molluscs, ongoing biofouling surveys in Saldanha Bay are advised, with a particular emphasis on targeted sampling efforts for this species. This approach will enhance the monitoring of the abundance and distribution of this alien species.

13.3.18 Fragile upright Codium *Codium Fragile* spp.

2023 Update: ***Important update***

Status: Invasive.

Physical Description: This is an intertidal green algae with distinctive thick, spongy branches (Figure 13.23).

Figure 13.23. The green algae *Codium fragile* spp.(Photo: Wikicommons).

Native range: This species is native to the northwest Pacific and waters around Japan.

Detection in South Africa and Saldanha Bay: First recorded date of introduction and its presence in South Africa is undetermined, primarily because it can be mistaken for the native species found from Namibia's west coast to Plettenberg Bay on the east coast (Stegenga et al. 1997).

Notes: This species has introduced populations documented in North and South America, Europe, Greenland, and New Zealand. This species thrives in various habitats, including rocky and sandy environments, where it attaches to natural and artificial solid surfaces (Bulleri and Airoldi 2005, Geraldi et al. 2014). *Codium fragile* is also known to invade kelp beds (Scheibling and Gagnon 2006) and *Zostera marina* eelgrass beds (Ramus 1971). This species is also considered euryhaline and tolerant of a wide range of temperatures (-2 to 30°C) and desiccation, all traits that could contribute towards its introduction and invasion success (Malinowski and Ramus 1973, Hanisak 1979, Schaffelke and Deane 2005).

The persistent confusion surrounding this algae arises from its potential misidentification, as it closely resembles the native species found along the coast from Namibia to Plettenberg Bay (Stegenga et al. 1997). Additionally, there has been uncertainty surrounding its nomenclature. The invasive strain was previously identified as *C. fragile ssp. tomentosoides*(GISD 2023), and the native strain as *C. fragile subsp. fragile capense* (Mead et al. 2011b). However, neither of these names is currently recognised by the World Register of Marine Species (WoRMS), which acknowledges *C. fragile subsp. fragile* as the accepted name (Guiry and Guiry 2023). While the specific impacts in Saldanha Bay are yet to be quantified, it's worth noting that in other invaded locations this species has both positive and negative effects, serving as an important food source and habitat for numerous invertebrates (Cruz-Rivera and Hay 2001, Scheibling and Anthony 2001, Harris and Jones 2005)

Monitoring and status in Saldanha Bay: This species is frequently encountered during rocky shore surveys. However, due to taxonomic confusion, it's not certain whether the species encountered is the native or invasive strain.

Recommendation: Until the taxonomic status is clarified, it should remain on the list of species alien to South Africa and Saldanha Bay. It will remain on the list as *C. fragile* spp. Comprehensive surveys and genetic analysis are essential to determine the precise identity and distribution of this species in Saldanha Bay and Langebaan Lagoon. Ongoing rocky shore surveys for monitoring the presence of this species should continue.

13.3.19 Brooding anemone *Cylista ornata* (previously *Sagartia ornata*)

2023 Update: ***Important update***

Status: Alien.

Physical Description: A small anemone, measuring 15–20 mm, featuring an off-white base and a green-brown upper portion covered with adhesive discs for attaching gravel or shells (Figure 13.24). The oral disc exhibits a greenish colour, with a paler tone around the mouth. When disturbed, it has the ability to eject sticky threads.

Native range: Western Europe, Great Britain and the Mediterranean (Manuel 1981),

Detection in South Africa and Saldanha Bay: This species was first detected in Langebaan Lagoon in 2001 (Acuña et al. 2004).

Notes: Previously called *Sagartia ornata*. Due to taxonomic revisions, disagreements among taxonomists, and incorrect assignments, it was determined that "*Sagartia*" is not a valid genus name. Species previously classified under this genus are now assigned to the valid genus name "*Cylista*." As a result, *S. ornata* has been reassigned to the genus *Cylista* and now referred to as *C. ornata* (Sanamyan and Sanamyan 2020, Rodríguez et al. 2023).

Figure 13.24. The brooding anemone Cylista ornata (Photo: Prof. C.L. Griffiths. Source: https://www.sanbi.org/).

In its native range, this species occurs in crevices on rocky shores and on kelp holdfasts (Gibson et al. 2001). In South Africa, it is only known from Langebaan Lagoon (West Coast National Park (WCNP)), where it occurs intertidally in seagrass beds (*Nanozostera capensis*), attached to rocks covered by sand, and in loose rocks resting on fossilized oyster beds (Acuña et al. 2004, Robinson et al. 2004, Picker and Griffiths 2011, Robinson and Swart 2015). Introduced species commonly exploit novel habitats, which may reflect the adaptive ability of this species in South Africa. It was probably introduced unintentionally through shipping via the Saldanha Bay harbour (Robinson et al. 2004). Robinson and Swart (2015) reported an increase in the abundance of this species from 426±81 in 2001 (Robinson et al. 2004) to 508±218 individuals/m^2 in 2014. It has further been found to alter community structure, supporting a higher invertebrate abundance, biomass and diversity where it occurs (Robinson and Swart 2015).

Monitoring and status in Saldanha Bay: This brooding anemone has exclusively been documented in Langebaan Lagoon and there are no records of its presence in Saldanha Bay. It has not been identified in the State of the Bay surveys or the DNA-based survey conducted in the area.

Recommendation: Dedicated sampling efforts should be conducted to specifically monitor this species in Langebaan Lagoon. Additionally, individuals should be collected for DNA analysis.

13.3.20 Pacific oyster *Magallana gigas* (previously *Crassostrea gigas*)

2023 Update: ***No updates***

Status: Invasive.

Physical Description: The oyster has a length double its width, featuring robust concentric corrugation and rippling valves (Figure 13.25). The interior is white without lustre. One valve exhibits a slight indentation below the apex, measuring around 200 mm in size.

Figure 13.25. The Pacific oyster Magallana gigas (Photo: H. Zell, wikipedia.org).

Native range: Japan and Southeast Asia.

Detection in South Africa and Saldanha Bay: This oyster 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 including Algoa Bay, Saldanha Bay and Alexander Bay (Robinson et al. 2005a).

Notes: Initially, this species was never considered an invasive threat as the oyster seemed unable to reproduce and settle successfully under the local environmental conditions. However, farmed populations have spread throughout the country. Using DNA sequencing, Robinson et al. (2005b) confirmed the presence of three naturalised populations of *M. gigas* in South Africa (specifically the Breede, Knysna and Goukou estuaries). The highest densities of individuals were found in the Breede Estuary (approximately 184 000 individuals).

Translocated oysters act as a vector for the introduction of marine alien species. Oysters attach to rocks, walls and other surfaces and are colonised by fouling organisms, which can then 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)

Monitoring and status in Saldanha Bay: In Saldanha Bay, *M. gigas* was originally farmed in the Seafarm dam east of the iron ore terminal, and is 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. It has not been identified in the State of the Bay, ADZ biofouling or 2022 DNA-based surveys conducted in the area.

Recommendation: Ongoing surveys in Saldanha Bay is advised, with a particular emphasis on targeted sampling efforts for this species.

13.3.21 Shell worm *Boccardia proboscidea*

2023 Update: ***No updates***

Status: Invasive.

Physical Description: This spionid polychaete has a long, somewhat flattened, body that tapers towards the rear (Figure 13.26). With length increasing with age, specimens can reach up to 30–35 mm. Their distinctive features include thick anterior palps and a yellow-orange coloration with red branchiae. Dusky areas are observed around the prostomium and parapodia. The prostomium is long, rounded, without a medial groove, and snout-like in appearance (Hiebert 2015).

Figure 13.26. The shell worm *Boccardia proboscidea* (Photo: Geoffrey Read).

Native range: Pacific coast of North America and Japan (Simon et al. 2009, Picker and Griffiths 2011).

Detection in South Africa and Saldanha Bay: In South Africa, this species is known to occur at a number of oyster and abalone farms, and has also been recorded in Saldanha Bay outside aquaculture facilities (Haupt et al. 2010).

Notes: This species creates shallow, sand-lined burrows on the surface of oysters, abalone and other shellfish (Figure 12.2). Oceanographic modelling and population genetic approaches revealed that *B. proboscidea* has the potential to disperse and establish itself along the South African coastline, despite biogeographic boundaries. Although this is partly attributed to its broad thermal tolerance and flexible reproductive strategy, it is believed that anthropogenic movement will be the primary factor governing its spread and establishment in southern Africa (David et al. 2016).

Monitoring and status in Saldanha Bay: This species has not been identified in the State of the Bay, ADZ biofouling or 2022 DNA-based surveys conducted in the area. It is likely found on hard infrastructure as a fouling organism, and on rocky shores. It might have been missed in rocky shore surveys as biota are not removed from the shore, and thus smaller infaunal species in the complex matrix of mussel beds and algae are often overlooked. Its elusive detection on hard substrata could be due to its potentially limited distribution or low abundance.

Recommendation: Ongoing surveys in Saldanha Bay is advised, with a particular emphasis on targeted sampling efforts for this species.

13.3.22 Hitchhiker Amphipod *Jassa slatteryi*

2023 Update: ***No updates***

Status: Invasive.

Physical Description: This small amphipod, measuring 5–9 mm, is easily overlooked (Figure 13.27). Adult males have notably large second nippers, featuring a prominent 'thumb' on the palm. The outer branch of the third uropod is distinctive, characterised by an upturned tip and two triangular teeth on the upper surface.

Figure 13.27. The hitchhiker amphipod *Jassa slatteryi* (Photo: Prof. C.L. Griffiths).

Native range: Pacific North America.

Detection in South Africa and Saldanha Bay: This species was first collected in South Africa in the 1950s, but was incorrectly identified as the South African species *Jassa falcata*. It was only after the genus was revised, that it was correctly identified as *J. slatteryi* and determined to be alien.

Notes: This species is known as a cosmopolitan species, having been introduced to various locations worldwide via aquaculture and shipping (Beermann et al. 2020). Consequently, this species has been termed a 'hitchhiker'.

Monitoring and status in Saldanha Bay: This species has not been observed in the State of the Bay, ADZ biofouling, or 2022 DNA-based surveys conducted in the area. It is likely found on hard infrastructure as a fouling organism, and on rocky shores. It might have been missed in rocky shore surveys as biota is not removed from the shore, thus smaller infaunal species in the complex matrix of mussel beds and algae may be overlooked. Its elusive detection on hard substrata could be due to its potentially limited distribution or low abundance.

Recommendation: Ongoing surveys in Saldanha Bay is advised, with a particular emphasis on targeted sampling efforts for this species.

13.3.23 Lagoon snail periwinkle *Littorina saxatilis*

2023 Update: ***No updates***

Status: Invasive.

Physical Description: A globular periwinkle snail, 5–8 mm in size (Figure 13.28). It has a round aperture that flanges forward at the front. Colour is variable, ranging from uniformly off-white to pale brown with darker rings.

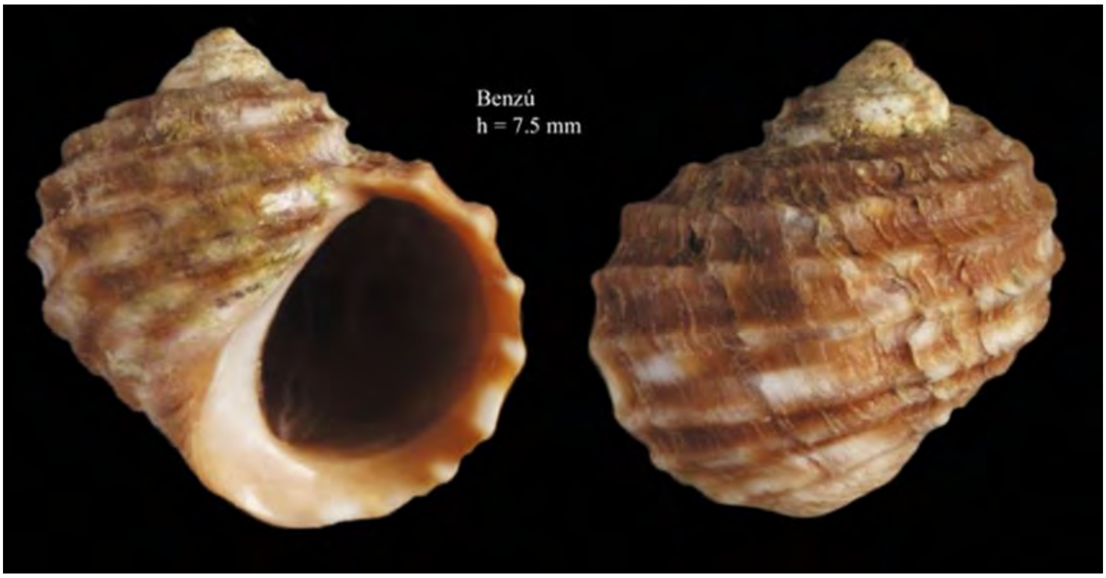


Figure 13.28. The lagoon snail Littorina saxatilis (Photo: Serge Gofas, marinespecies.org).

Native range: North Atlantic.

Detection in South Africa and Saldanha Bay: *Littorina saxatilis* was first recorded in South Africa in 1974 (Day 1974), and the only known populations are those in the Langebaan and Knysna lagoons (Hughes 1979, Robinson et al. 2004, Picker and Griffiths 2011).

Notes: In its home range, this species occupies crevices on rocky shores (Gibson et al. 2001). However, 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).

Monitoring and status in Saldanha Bay: This species only occurs in the upper reaches of Langebaan Lagoon, between Bottelary and Churchhaven, and has not spread further in the last 20 years (Robinson et al. 2004). It is not considered to be a major threat to the Lagoon or Bay ecosystems. It has not been identified in the State of the Bay, ADZ biofouling, or 2022 DNA-based surveys conducted in the area.

Recommendation: Dedicated sampling efforts should be conducted specifically to monitor this species in Langebaan Lagoon.

13.3.24 JELLY CRUST TUNICATE *DIPLOSOMA LISTERIANUM*

2023 Update: ***No updates***

Status: Invasive.

Physical Description: A colonial sea-squirt that forms thin, fragile, yellow to dark grey, jelly-like sheets up to 50 cm in diameter (Figure 13.29).

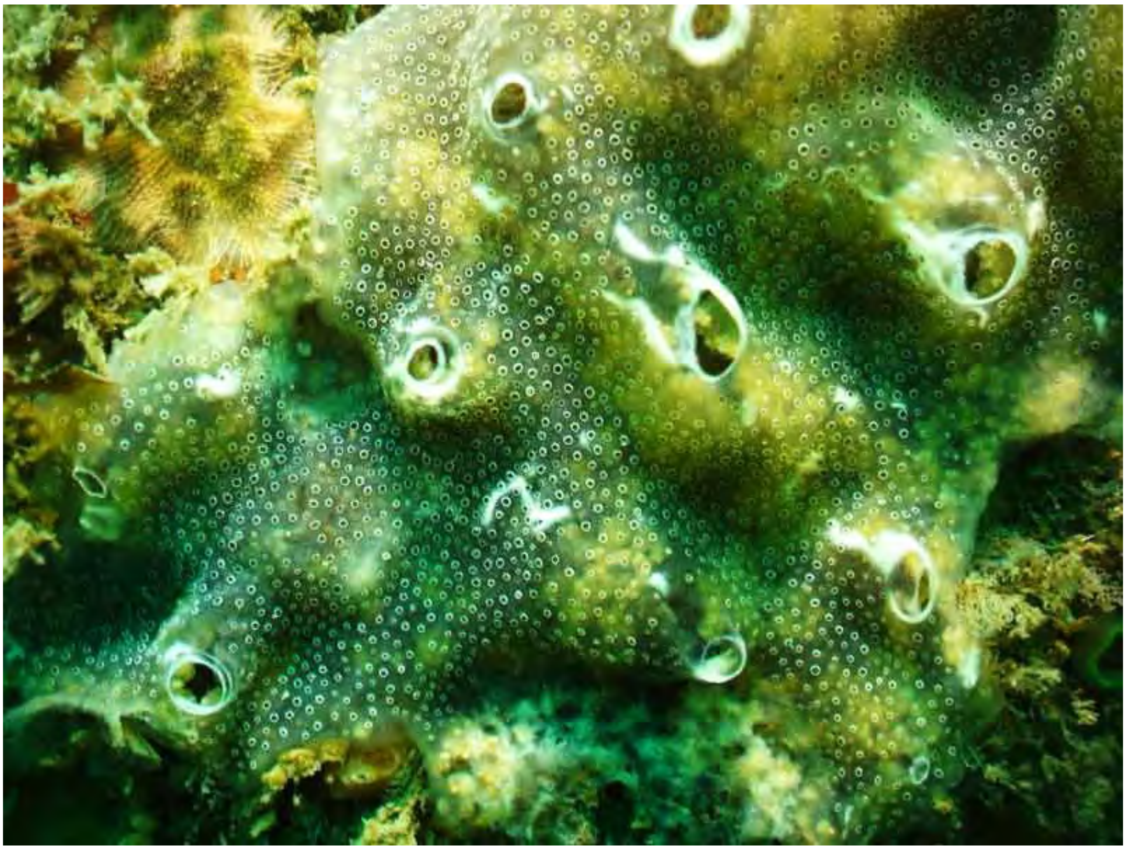


Figure 13.29. The jelly crust tunicate *Diplosoma listerianum* (Photo: Fiona Crouch, MarLIN website).

Native range: Europe.

Detection in South Africa and Saldanha Bay: This species is believed to have been accidentally introduced to South Africa from Europe prior to 1949.

Notes: Encrusts all types of substrata on sheltered shores between Alexander Bay and Durban (Monniot et al. 2001, Picker and Griffiths 2011). Probably introduced as a fouling organism.

Monitoring and status in Saldanha Bay: This species has not been identified in the State of the Bay, ADZ biofouling, or 2022 DNA-based surveys conducted in Saldanha Bay. Given its widespread distribution along the South African coastline, it is likely present throughout Saldanha Bay, possibly on hard infrastructure as a fouling organism. The elusive detection of this species remains unexplained, possibly attributed to its limited distribution in the Bay or low abundance. Furthermore, identifying ascidians is challenging and they are often categorised under a broad taxon name or misidentified, potentially as a native species, contributing to potential oversight.

Recommendation: To better understand its status, abundance and distribution in Saldanha Bay, dedicated sampling efforts specifically targeting this species should be conducted.

13.3.25 Hydroid *Coryne eximia*

2023 Update: ***No updates***

Status: Invasive.

Physical Description: A hydroid characterised by its red or pink colour, growing up to 15 cm, although typically reaching about half that size (Figure 13.30). The branches emerge from one side of each stem, and both are mostly smooth with small, irregular ringed sections. At the end of each branch, there is a polyp featuring a cluster of knobbed tentacles(Barrett and Yonge 1958, Schuchert 2023b).

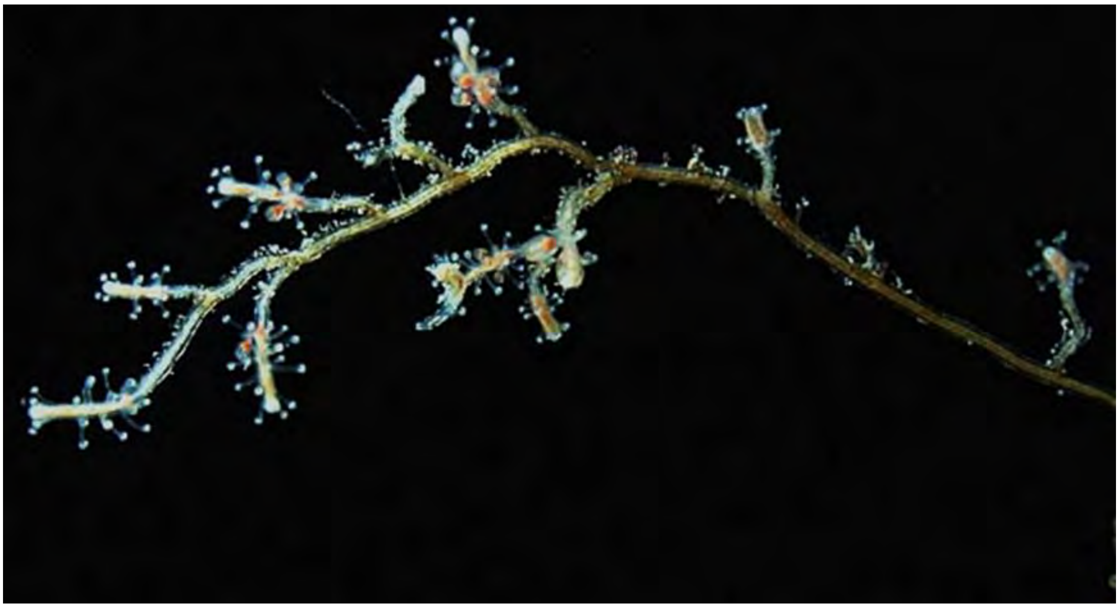


Figure 13.30. The hydrozoan Coryne eximia (Photo: Peter Schuchert, marinespecies.org).

Native range: Assumed to be the North Atlantic or North Pacific region (Millard 1975).

Detection in South Africa and Saldanha Bay: First discovered in South Africa in 1946. This species occurs along the West Coast where it has been found from Cape Town docks to Llandudno, and also in Langebaan Lagoon.

Notes: A fouling organism which commonly occurs in shallow water down to a depth of 25 m on anchoring chains of buoys, rafts, mussels, rocks and seaweed (Millard 1975, Schuchert 2005). It can be considered a cosmopolitan species. It has been recorded as alien in the Pacific Ocean from California to Alaska, Chile, Brazil, Papua New Guinea, Western Australia and New Zealand; in the Atlantic Ocean from Norway to Galicia, the east coast of North America and Canada, as well as in the Mediterranean (Schuchert 2001, Puce et al. 2003).

Monitoring and status in Saldanha Bay: This species has only been recorded from Langebaan lagoon. It has not been identified in the State of the Bay, ADZ biofouling, or 2022 DNA-based surveys conducted in the area. It could have been overlooked in biofouling surveys due to its small size, and/or the challenge of identifying hydroids without extensive microscopic analysis. Alternatively, it might not have spread outside of the Lagoon.

Recommendation: Given its potential presence as a fouling organism on hard infrastructure, ongoing biofouling surveys on hard substrata in Saldanha Bay are advised, with a particular emphasis on targeted sampling efforts for this species. This approach will enhance the monitoring of the status, abundance and distribution of this alien species.

13.3.26 Tubular amphipod *Cerapus tubularis*

2023 Update: ***No updates***

Status: Invasive.

Physical Description: A small and slender tube-dwelling amphipod (Figure 13.31).

Native range: North America.

Detection in South Africa and Saldanha Bay: This species was first recorded from South Africa, off the coast of KwaZulu-Natal in 1901, but was incorrectly reported as *C. abditus* (Barnard 1916). The most recent publication reports this species as extending from Saldanha Bay to the east coast of South Africa (Mead et al. 2011a).

Notes: An intertidal, tube-dwelling amphipod. It occurs on sandy substrates with shell fragments, large sand grains, and amongst algae. Its alien range includes areas within the tropical and temperate oceans. It was most likely introduced to South Africa via ballast water or ship fouling.

Monitoring and status in Saldanha Bay: Although this species has been reported from Saldanha Bay by previous research, it has not been recorded in the State of the Bay, ADZ biofouling or 2022 DNA-based surveys conducted in the area. The reason for its elusive detection might be attributed to its potentially limited distribution, small size or tube-dwelling nature. Furthermore, it might have been missed in rocky shore surveys as biota is not removed from the shore, and thus smaller infaunal species may be overlooked in the complex matrix of mussel beds and algae.

Figure 13.31. The tubular amphipod Cerapus tubularis (Photo: enciclovida.mx).

Recommendation: Ongoing surveys in Saldanha Bay is advised, with a particular emphasis on targeted sampling efforts for this species. This approach will enhance the monitoring of the abundance and distribution of this alien species.

13.3.27 Wood-boring amphipod *Chelura terebrans*

2023 Update: ***No updates***

Status: Invasive.

Physical Description: A wood-boring amphipod with a body length of 3.5–6 mm (Figure 13.32). Easily distinguishable due to its enlarged third uropod, fused urosomites and reddish appearance. It is pale brown, mottled with pink.

Native range: Europe

Detection in South Africa and Saldanha Bay: Some of the first specimens in South Africa were collected in 1888 and reported by Stebbing (1910). More recently, it has been reported in all harbours between Langebaan and Port Elizabeth, although further surveys are required to determine if it has spread to the open coast (Mead et al. 2011b).

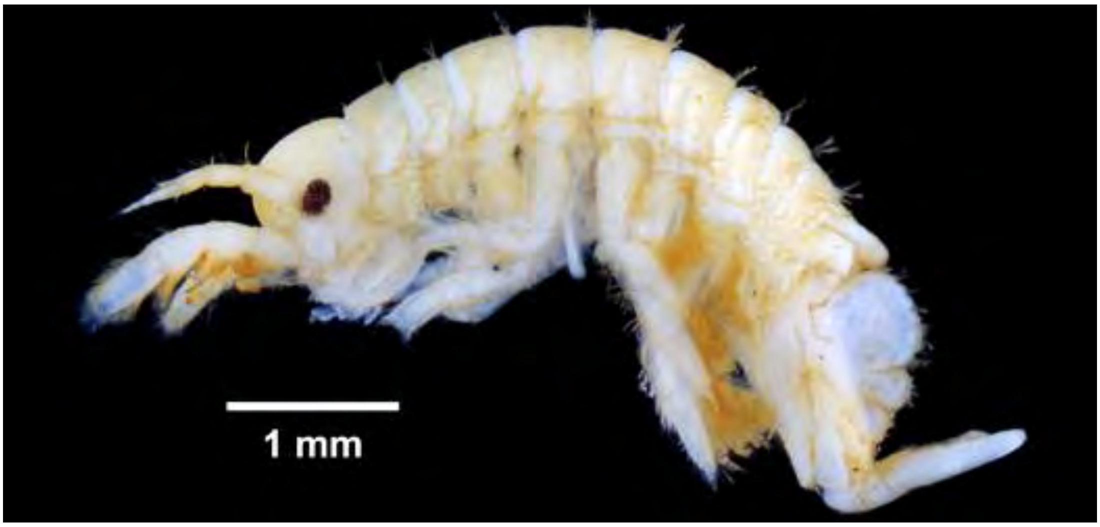


Figure 13.32. The wood-boring amphipod *Chelura terebrans* (Photo: Eric A. Lazo-Wasem).

Notes: In addition to South Africa, it has a very broad alien distribution which includes New Zealand, the west and east coasts of North America and Hong Kong (Fofonoff et al. 2019). The most likely mode of introduction is hull fouling of the wooden ships used in the past (Kuhne and Becker 1964). A wood-boring amphipod, it is dependent upon wood-boring isopods of the genus *Limnoria* for shelter and food as it inhabits their burrows and feeds on their faecal matter (Kuhne and Becker 1964, Borges et al. 2010). Its diet also includes bacteria, protists, and decaying wood. It is believed that this amphipod will, under certain circumstances, be able to create its own burrows (Green Etxabe 2013). Due to its wood-boring nature, it is considered a pest, but only in the presence of *Limnoria*. This species thus has the potential to negatively impact the economy by destroying wooden structures.

Monitoring and status in Saldanha Bay: Although this species has been reported from Langebaan in previous research, it has not been identified in the State of the Bay, ADZ biofouling, or 2022 DNA-based surveys conducted in the area. The reason for its elusive detection might be attributed to its potentially limited distribution, small size or burrow-living nature. Additionally, it only occurs in the presence of isopods of the genus *Limnoria*.

Recommendation: Ongoing surveys in Saldanha Bay is advised, with a particular emphasis on targeted sampling efforts for this species. This approach will enhance the monitoring of the abundance and distribution of this alien species.

13.3.28 Bryozoan *Conopeum seurati*

2023 Update: ***No updates***

Status: Invasive.

Physical Description: Colonies of this species take on various forms, appearing as brownish-white sheets, irregular encrustations, or spherical balls of zooids (Figure 13.33). The shape of the colony is influenced by the nature of the substrate it settles on. On flat surfaces, lace-like colonies with a regular pattern are common, while on uneven substrates like plant stems, irregular encrustations prevail, often forming bilaminar lobes. The zooids themselves are elongated rectangles, with sizes ranging from 0.5 to 0.7 mm in length, and 0.28 to 0.4 mm in width, varying based on the substrate.

Figure 13.33. The colonial bryozoan *Conopeum seurati* (Photo: Alison M. Fortunato, wikipedia.org).

Native range: Native to brackish water, lagoons and estuaries in Europe (Poluzzi and Sabelli 1985), although its exact distribution is unknown.

Detection in South Africa and Saldanha Bay: It was first recorded in South Africa in Saldanha Bay in 2001 (Awad et al. 2005), although it has probably been present for decades, if not centuries.

Notes: This species potentially also occurs in Zandvlei Lagoon (False Bay), although proper identification is required (Mead et al. 2011a). It is a fouling organism and has been introduced via ship fouling to the east coast of North America, New Zealand, Australia (Gordon and Mawatari 1992, Winston 1995, Wyatt et al. 2005, Rouse 2011) and South Africa (Awad et al. 2005). Overlooked alien populations are likely to occur in estuaries all around the globe. This species is a filter feeder of phytoplankton and tends to form small colonies on shells, seagrasses, seaweeds, and other hard surfaces, including man-made structures.

Monitoring and status in Saldanha Bay: Although this species has been reported from Saldanha Bay in previous research, it has not been identified in the State of the Bay, ADZ biofouling or 2022 DNA-based surveys conducted in the area. The elusive detection of this species could be attributed to its potentially limited distribution or low abundance. The correct identification of bryozoans is also challenging, with the risk of misidentification, particularly as a native species, potentially leading to oversight. Comprehensive microscopic analysis is crucial for accurate identification.

Recommendation: Ongoing surveys in Saldanha Bay is advised, with a particular emphasis on targeted sampling efforts for this species. This approach will enhance the monitoring of the abundance and distribution of this alien species.

13.3.29 Red crust bryozoan *Cryptosula pallasiana*

2023 Update: ***No updates***

Status: Invasive.

Physical Description: A bryozoan (moss animal) that forms pink, white or orange encrusting colonies (Occhipinti Ambrogi and D'Hondt 1981) (Figure 13.34).

Figure 13.34. The red crust bryozoan *Cryptosula pallasiana* (Photo: Fredrik Pleijel/SLU Art data bank).

Native range: Europe, specifically the Black Sea, and also suitable habitats ranging from the Mediterranean Sea to Norway (Barnes 1983).

Detection in South Africa and Saldanha Bay: It was first recorded in South Africa in Table Bay harbour, as *Lepralia pallasiana*, based on specimens collected during 1947–1949 (Millard 1952). It was later recorded in Simon's Town (Henschel et al. 1990), and Saldanha Bay (Awad et al. 2005), although it is most likely widespread throughout South African estuaries (Mead et al. 2011b).

Notes: This species is a filter feeder, feeding mainly on phytoplankton (Barnes 1983). It occurs in brackish waters, where it forms encrusting colonies (Occhipinti Ambrogi and D'Hondt 1981) on eelgrass beds and hard structures including shells, oyster beds, rocks, hulls of ships and other man-made structures (Hayward and Ryland 1999, Fofonoff et al. 2019). It has been reported from numerous harbours around the globe (Gordon and Mawatari 1992). Cryptogenic populations occur along the east coast of North America and the Northwest Pacific. Alien populations are known from South Africa, the Pacific coast of North America, Argentina, New Zealand and Australia (Fofonoff et al. 2019).

Monitoring and status in Saldanha Bay: Although this species has previously been reported from Saldanha, it has not been identified in the State of the Bay, ADZ biofouling, or 2022 DNA-based surveys conducted in the area. Given its widespread distribution along the South African coast, it is likely present in Saldanha Bay. The elusive detection of this species is possibly attributed to its limited distribution in the Bay or low abundance. Furthermore, identifying bryozoans is challenging and they are often categorised under a broad taxon name or misidentified, potentially as a native species, contributing to potential oversight.

Recommendation: Ongoing surveys in Saldanha Bay is advised, with a particular emphasis on targeted sampling efforts for this species. This approach will enhance the monitoring of the abundance and distribution of this alien species.

13.3.30 Red Algae *Antithamnionella spirographidis*

2023 Update: ***No updates***

Status: Invasive.

Physical Description: A small red algal species with features visible only under a microscope (Figure 13.35).

Figure 13.35. Stained slide of the algae *Antithamnionella spirographidis* with tetrasporangium (Photo: (Anderson et al. 2016).

Native range: Most likely native to the North Pacific (Lindstrom and Gabrielson 1989).

Detection in South Africa and Saldanha Bay: In sheltered areas of Saldanha Bay attached to jetties in 1989 (Stegenga et al. 1997).

Notes: Introduced, most likely via ship fouling or aquaculture activities. Alien populations are reported from England, Wales, Ireland, Scotland, northern France, the Mediterranean and Australia (Wollaston 1968, Maggs and Hommersand 1993, Eno et al. 1997). It is commonly associated with harbours and docks (Wollaston 1968), and its success as an invader is attributed to its vegetative, rapid reproduction.

Monitoring and status in Saldanha Bay: Although this species has previously been reported from Saldanha, it has not been identified in the State of the Bay, ADZ biofouling, or 2022 DNA-based surveys conducted in the area. The elusive detection of this species is possibly attributed to its small size, or low abundance.

Recommendation: Ongoing surveys in Saldanha Bay is advised, with a particular emphasis on targeted sampling efforts for this species. This approach will enhance the monitoring of the abundance and distribution of this alien species.

13.3.31 BEACH-HOPPER *ORCHESTIA GAMMARELLUS*

2023 Update: ***No updates***

Status: Invasive.

Physical Description: This beach-hopper is a semi-terrestrial amphipod, reaching a maximum length of 1.8 cm (Figure 13.36). It typically exhibits a brown or greenish-brown colouration, and possesses a layer of pores through which it secretes wax to prevent desiccation.

Native range: Norway to the Mediterranean, as well as Madeira, Canary Islands and the Azores (Henzler and Ingólfsson 2008).

Figure 13.36. The beach-hopper *Orchestia gammarellus* (Photo: jungledragon.com).

Detection in South Africa and Saldanha Bay: This species was first discovered in South Africa in Langebaan Lagoon during a UCT ecological survey, but was incorrectly described as a new endemic species, *Talorchestia inaequalipes,* by Barnard (1951). It was later correctly identified by Griffiths (1975). Alien populations have also been recorded in the Knysna Estuary (Griffiths 1974) and in Table Bay (Milnerton Lagoon; Mead et al. 2011a).

Notes: This species occurs in the rocky shore upper intertidal, primarily in the drift-line, under rocks, debris, and vegetation (Mead et al. 2011a, Fofonoff et al. 2019). *Orchestia gammarellus* is mainly herbivorous, but is also known for its scavenging behaviour. It feeds on detritus, algae, seaweed, seagrasses and microorganisms (Persson 1999). It was most likely introduced via solid ballast. Alien populations are also known from North America (Newfoundland to Maine), South America (Argentina and Chile) and Iceland (Fofonoff et al. 2019).

Monitoring and status in Saldanha Bay: Although this species has been reported from Langebaan, it has not been observed in Saldanha Bay. The reason for its elusive detection might be attributed to its potentially limited distribution, or semi-terrestrial nature. Furthermore, it might have been missed in rocky shore surveys as biota is not removed from the shore, thus smaller infaunal species are often overlooked in the complex matrix of mussel beds and algae.

Recommendation: Ongoing surveys in Saldanha Bay is advised, with a particular emphasis on targeted sampling efforts for this species. This approach will enhance the monitoring of the abundance and distribution of this alien species.

13.3.32 South American Sunstar *Heliaster helianthus*

2023 Update: ***No updates***

Status: Alien.

Physical Description: A large sea star that can grow up to 20 cm in diameter (Barahona and Navarrete 2010), and have up to 40 arms (Madsen 1956) (Figure 13.37).

Native range: Southern Peru and Chile, where it occurs in the intertidal and shallow subtidal (Castilla and Paine 1987).

Detection in South Africa and Saldanha Bay: First discovered in Saldanha Bay in 2015, under a pier within Small Bay, close to Hoedjiesbaai (Peters and Robinson 2018).

Notes: Commonly known as the South American multiradiate sunstar, *Heliaster helianthus* is a ferocious, generalist predator, with a diet consisting mainly of the local mussels *Semimytilus patagonicus* and *Perumytilus purpuratus* (Tokeshi et al. 1989). It occasionally shifts its diet to other prey species when mussels are scarce (Barahona and Navarrete 2010). In its native range, it is a keystone species, playing an important role in structuring intertidal and subtidal communities (Paine et al. 1985, Navarrete and Manzur 2008). It is mostly free from natural predators within the intertidal zone, although the sea star *Meyenaster gelatinosus* (Gaymer and Himmelman 2008), crab *Homalaspis plana* (Castilla 1981), and rockfish *Graus nigra* (Fuentes 1982), are known to predate upon this species in the subtidal zone. This species reproduces sexually via external fertilisation (Castilla et al. 2013), and has planktotrophic larvae with extended longevity. This allows for long distance dispersal (Navarrete and Manzur 2008), a trait that could facilitate invasion.

Figure 13.37. The South American sunstar *Heliaster helianthus* (Lamarck, 1816) (Photo: MNCN).

Monitoring and status in Saldanha Bay: The specimen that was recorded from Saldanha Bay was a large adult measuring 33 cm in diameter, with 35 arms. Only a single individual was found, and subsequent subtidal and intertidal surveys in the surrounding rocky shore habitats in 2016 revealed no other individuals (Peters and Robinson 2018). This species has the ability to survive and spread in Saldanha Bay as its natural prey (*S. patagonicus*) is already abundant. With its ferocious, generalist predatory nature (Navarrete and Manzur 2008, Peters and Robinson 2018), this species is expected to greatly impact native biodiversity. However, to date, no other individuals have been detected in the Bay.

Recommendation: As Saldanha Bay offers a suitable sheltered habitat with abundant prey (i.e., *S. patagonicus*), it is important that the area be routinely monitored, as reintroduction of this species is probable.

13.3.33 Chilean Stone Crab *Homalaspis plana*

2023 Update: ***No updates***

Status: Alien.

Physical Description: A relatively large purple crab with distinctive markings on its carapace (Figure 13.38). Juveniles are polychromatic (multicoloured), a trait that might protect them from predation (Fernández and Castilla 2000).

Figure 13.38. The Chilean stone crab *Homalaspis plana* (H. Milne Edwards, 1834) (Photo: Dr Koebraa Peters).

Native range: Sheltered habitats along the Chilean coast (Morales and Antezana 1983).

Detection in South Africa and Saldanha Bay: *Homalaspis plana* was first discovered in Saldanha Bay in 2017, in the same area *as Heliaster helianthus*, under a pier within Small Bay (Peters and Robinson 2018).

Notes: This crab is an important fishery species in its native range (Fernández and Castilla 2000). Juveniles occur intertidally on boulder shores in shell fragments, sand, and rock platforms (Fernández and Castilla 2000). This crab is a generalist predator, feeding predominantly on the barnacle *Balanus laevis*, mussel *Semimytilus patagonicus*, porcelain crab *Petrolisthes tuberculatus*, and gastropod *Tegula atra* (Morales and Antezana 1983). Not much is known about the habitat preference or life history of this species (Fernández and Castilla 2000), although no invasion history has been documented.

Monitoring and status in Saldanha Bay: The specimen detected in Saldanha Bay was a purple, adult male, with distinctive markings on its carapace. Only a single individual was found, and subsequent subtidal and intertidal surveys in the surrounding rocky shore habitats in 2018 revealed no other crabs (Peters and Robinson 2018). This species is not anticipated to survive along the open coast.

Recommendation: As Saldanha Bay offers a suitable sheltered habitat with abundant prey species (i.e., *S. patagonicus*), it is important that the area be routinely monitored, as reintroduction of this species is probable.

13.3.34 EUROPEAN SHORE-CRAB *CARCINUS MAENAS*

2023 Update: ***No updates***

Status: Invasive.

Physical Description: The carapace is oval and displays a mottled khaki-green colouration (Figure 13.39). A distinctive characteristic is the presence of five marginal teeth on each side of the carapace. The legs are robust with flattened but pointed tips. The nippers are strong and smooth textured, featuring about 12 teeth on both the "finger" and "thumb." The width is approximately 50 mm.

Figure 13.39. The European shore crab *Carcinus maenas* (Photo: Prof. C.L. Griffiths).

Native range: Europe.

Detection in South Africa and Saldanha Bay: In South Africa it was first collected from Table Bay Docks in 1983, and later in Hout Bay Harbour.

Notes: This species has been introduced to both the Atlantic and Pacific coasts of North America, Australia, Argentina, Japan and South Africa (Carlton and Cohen 2003). It is typically restricted to sheltered, coastal sites and appears thus far unable to establish on the open wave-swept coastline of South Africa (Hampton and Griffiths 2007). This crab has established dense populations in Table Bay and Hout Bay harbours, where it has reportedly decimated shellfish populations (Robinson et al. 2005a).

Monitoring and status in Saldanha Bay: Surveys in Saldanha Bay have not detected any living individuals, but a single dead specimen was recorded in the Small Bay Small Craft Harbour (Robinson et al. 2004). To date, no further specimens have been found. It is unlikely that there exists an extant population in Saldanha Bay.

Recommendation: Ongoing surveys should continue to monitor for the presence of this species.

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 increases 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 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 Lagoon. 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, Marine Protected Areas (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 recent development proposals. This applies especially to the cumulative impacts that will arise from future development within the Saldanha Bay IDZ and the 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 WASTEWATER

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). An average annual growth rate of 2.1% as been projected between now and 2026 for the entire Saldanha Bay municipal area. Numbers of tourists visiting the Saldanha Bay and Langebaan Lagoon area peaked in 2016/17, especially those visiting the West Coast National Park (WCNP) (Average rate of increase of 12% per annum since 2005). Although overall visitor numbers have been declining steadily since then. The numbers do still peak annually in the flower season (August/September) and the summer holidays. This rapid population growth and seasonal tourism influxes translate to corresponding increases in the amount of infrastructure required to house and accommodate these people, and in the amount of waste and wastewater that is produced which must 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 of reducing the volume of wastewater from the Wastewater treatment works (WWTW) that enter the marine environment. With the closure of Arcelor Mittal the Saldanha WWTW no longer receives industrial wastewater from the plant, however the plant also no longer requires treated waste for use in the Reverse Osmosis (RO) plant. Therefore, the balance of treated wastewater currently not being used by other water users for irrigation is being discharged into the Bok river. Although the results show that the quality of this wastewater is generally acceptable, the actual volume of wastewater entering the bay is unknown. A flow meter has reportedly been installed at the Bok River discharge point; although, it is not known whether the discharge volume is recorded as these results have not been made available. It is strongly recommended that in order to ensure continued compliance with the General Discharge Authorisation's 2000 m^3/day discharge limit, this flow gauge must be installed/monitored to keep a continuous record of effluent volumes entering the bay.

The amount of hardened (as opposed to naturally vegetated) surfaces surrounding 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 on sensitive habitats and species, especially seagrass, water birds and fish in Langebaan Lagoon. A collaboration between SBM and Sea Harvest was piloted prior to the COVID-19 pandemic to install litter traps on stormwater drains to minimize pollution entering the bay via these waterways, however, this has not yet resumed post COVID-19.

14.1.2 Dredging

Dredging interventions in the Bay in the past, particularly those associated with the Iron Ore Terminal (IOT) have been shown to have devastating impacts on the ecology of the Bay. Effects of the most recent -large scale 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 relatively 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 has issued six Coastal Waters Discharge Permits to facilities discharging wastewater into Saldanha Bay. Sea Harvest was first issued a CWDP on 26 June 2017 (as amended subsequently to accommodate a change in discharge location and effluent composition) and further amended on 7 November 2019 to include discharge from the fish processing plant, the RO plant and the value-added factory. This CWDP authorises Sea Harvest to dispose a maximum quantity of 2 190 000 m^3 per annum at a maximum daily discharge volume of 6 000 m^3. Following the drought in the Western Cape, Sea Harvest reclaims potable water by means of a RO plant with the intention to save municipal water and to improve effluent quality. Sea Harvest is committed to meeting effluent quality thresholds and environmental monitoring requirements as stipulated in the CWDP. However, the effluent results at the Sea Harvest Fish Processing Plant are no longer assessed in this report.

14.1.4 Marine Aquaculture

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. In January 2018, the then Department of Agriculture, Forestry and Fisheries was granted EA to establish a sea-based ADZ in Saldanha Bay and expand the total area available for aquaculture to 884 ha, located within four precincts (Small Bay, Big Bay North, Outer Bay North and South). By the end of December 2019, approximately 36% of the ADZ had been leased, but less than 60% of the actively leased area was being utilised, and this is a very dynamic value that changes constantly as new leases and rights are granted or as the economic climate changes. As of September 2023, 30 companies within the Saldanha Bay ADZ were registered on the Marine Aquaculture Right Register, of which 24 companies were actively operational. 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. DEFF specialist scientists are however conducting environmental monitoring (which includes a rapid synoptic survey of oxygen and nutrient levels in the Bay) and long-term monitoring undertaken by an independent service provider. This is to ensure that the effects of aquaculture operations are well monitored and that should any thresholds be exceeded the appropriate action is taken and mitigation measures can be implemented to prevent negative impacts. International monitoring standards recommend that full macrobenthic surveys should be conducted every 3–5 years, however, the scale of the expanded ADZ is significant and the macrofaunal communities within Saldanha Bay show an inherently high level of variation. Therefore, it has been recommended that the frequency of these monitoring surveys should be reduced to every 3 years 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 yet the reported volume of ballast water discharged into the Bay does not always seem to match this trend suggesting some error or inaccuracy in these data or the data capture method. As a result, environmental impacts are increasing, including but not limited to oil spills, introduction of alien species, trace metal pollution as well as direct disturbance of marine life and sediment in the bay. 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 have 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 (TNPA) 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 (WQG) 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. A flow gauge monitoring volume of waste water entering the bay via the Bok river should be installed and/or monitored.
- The SBM 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 GROUNDWATER

While Saldanha Bay and Langebaan Lagoon receive 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, and in preventing widespread hypersaline conditions from developing in the summer months. There are two main aquifer systems from which groundwater discharges into the Bay — the Langebaan Road Aquifer System and the Elandsfontein Aquifer System, which are interconnected and discharge to the sea occurring through deep paleochannels in the area.

Growth of the reeds *Phragmites australis* and *Typha capensis* as well as *Juncus kraussi* 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 PSU (the salinity of the water in the lagoon is generally the same, or occasionally higher, than the 35 PSU of seawater).

The potential bigger impacts on groundwater resources surrounding Saldanha Bay and Langebaan Lagoon have been identified as (1) the agricultural sector (1 529 744 m^3/a) (this registered quantity is groundwater abstraction for agriculture as in 2016 and probably increased significantly during the drought of 2015 to 2018); (2) abstraction from the Langebaan Road Aquifer wellfield (intermittently operational since 1999, however, frequently non-operational due to regular and persistent vandalism. The Langebaan Road Wellfield was used less frequently during 2023 due to above-average rains experienced in the area); and (3) the Hopefield wellfield (not yet operational) where it is planned to abstract 5.1 Mm^3/a and 1.8 Mm^3/a, respectively.

The Langebaan Road Wellfield has been operational for 20 years but only used intermittently and the long-term monitoring trends indicate insignificant groundwater level drawdowns. Overall, groundwater levels in the area have recovered well over the past year due to above average rainfall experienced in the area. The total utilisable groundwater exploitation potential (UGEP) under normal conditions is estimated at 15.2 Mm^3/a from the SBM area, so it is important to try and reduce the impact of this nett abstraction by using Managed Aquifer

Recharge methodologies and it is quite possible the wellfields will only be used in times of severe drought, so they need to be kept as "full" as possible in non-drought times. If the UGEP is adhered to, available evidence suggests that there is unlikely to be an impact on the outflow to the marine environment, however, the positioning of the abstraction is crucial to ensure there is no impact on these outflows. Comprehensive groundwater monitoring and associated database within the entire region is also essential for the long-term management and preservation of the aquifers and freshwater inflows into the Langebaan Lagoon. Within the Greater Saldanha Bay area, it is imperative to ensure all groundwater abstraction above the General Authorisation (GA) limit is authorised and that the associated compliance conditions are adhered to.

Elandsfontein Exploration and Mining (Pty) Ltd/Kropz recently 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 downstream (towards the lagoon), in an effort to ensure that surrounding ecosystems (including the Lagoon) are not affected. Available evidence suggests that this activity is unlikely to impact the lagoon, however, Kropz Elandsfontein in conjunction with the Saldanha Bay Water Quality Forum Trust (SBWQFT) elected to initiate monitoring a range of biological and physicochemical variables associated with Langebaan Lagoon to establish an appropriate baseline against which any potential future changes in the Lagoon can be benchmarked. This includes monitoring of temperature and salinity (see below) and biota (see Chapter 9) as well as macrophytes (see Chapter 8) around the top end of the lagoon.

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. The Star ODDI was subsequently replaced with an Aqua TROLL 200 data logger (August 2019) which has been yielding considerably better and more useful data to date. These data records show clear diurnal/tidal and seasonal trends in water temperature and salinity. The diurnal fluctuations in temperature are similar across all seasons, with temperatures increasing over the course of the day, peaking in the early afternoon, then declining through the afternoon and night, reaching a minimum at the time of sunrise each day.

The trend in salinity is more interesting though, exhibiting a similar diurnal oscillation to that for temperature, but this oscillation is linked to the state of the tide (not the time of day) and changes through the year. In winter, salinity oscillates between that of normal seawater (around 35.0 PSU) at high tide and a slightly fresher state (between 32.0 and 34.0 PSU) at low tide. Salinity appears to drop as the tide recedes and is most likely linked with the outflow of freshwater from the aquifer at this time. In summer, the pattern reverses with salinity increasing from that of normal seawater (35.0 PSU) at the peak of the high tide becoming hyper-saline (39–40 PSU) as the tide recedes. It is likely that this is a function of increased evaporation at this time of year (linked to higher prevailing air temperatures), and that the water emerging from the marshes at the head of the lagoon becomes severely hypersaline as a result, and even though it is diluted by freshwater flowing out of the aquifer, this is not sufficient to bring the level below that of normal seawater. It is likely that this effect (development of hypersaline conditions) is quite localised at present (i.e., restricted to the extreme upper reaches of the lagoon only) but could become much more pervasive if freshwater outflow from the aquifer were to drop in future.

There appears to be no link between rainfall and salinity levels in the lagoon which strongly suggests that variations in salinity in the lagoon are linked with groundwater inflow as opposed to surface water inflow, which is consistent with observations made by others and points to the need for continued monitoring to track any changes over time.

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, over the last seven years/eight year, monitored water temperature in Small Bay and temperature and salinity in Langebaan Lagoon. These activities are yielding valuable insights into the functioning and health of the Bay but urgently ned to be expanded to other areas and need to be extended to include a range of other parameters such as DO, turbidity, nutrients, chlorophyll a (as measure of phytoplankton production). As part of the environmental monitoring programme for the Saldanha ADZ (DAFF 2018), the Department of Forestry, Fisheries and the Environment: (DFFE) initiated monitoring of DO at four sites, a control and ADZ site in Small Bay and Big Bay with hourly DO recordings made close to the bottom (0.5 m above the seabed). DFFE have also proposed installing a fluorometer (which provides an indication of phytoplankton or at least chlorophyll concentration in the water column) in the entrance channel of Langebaan Lagoon. The ADZ monitoring programme also makes provision for collection of phytoplankton samples for calibration of the fluorometer readings. This would entail collecting discrete samples of water, sieving a portion of each sample through a 2–5 µm mesh (to extract the picoplankton component), and extracting the chlorophyll from both the screened and unscreened samples to obtain an estimate of the relative contribution from each component. DFFE are also reportedly collecting water samples on a frequent basis (a number of times a week) in the existing shellfish growing areas in the entrance to Small Bay and in North Bay as part of the South African Live Molluscan Shellfish Monitoring and Control Programme (DAFF 2019) for species identification and enumeration of phytoplankton. The ADZ monitoring programme recommends extending this sampling effort to include collection of discrete samples for size-fractionated chlorophyll analysis at least three sites that are paired as close as possible in time. DO data from this ADZ monitoring (2020–2023) has been presented in this report. These data have already provided some insights into the effects of bivalve mariculture on water quality (Lower DO in Small Bay farm sites relative to control sites). Inclusion of the nitrate and other data to the State of the Bay Monitoring Programme in the future would be welcomed.

The Mussel Watch Programme (DFFE) has been responsible for monitoring the concentrations of metals in the flesh of mussels from Saldanha Bay for the periods 1997–2001 and 2005–2007. Sampling was continued again in 2014 as part of the State of the Bay monitoring programme and mussel samples collected from the same five sites during the annual field surveys. These samples collected from the shore and port infrastructure were analysed for the metals lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), manganese (Mn), iron (Fe), mercury (Hg) and the metalloid arsenic (As). Data on trace metals concentrations in mussels and oysters from the mariculture farms in the Bay were also obtained from the DFFE (courtesy of the farm operators). In addition, data on trace metals concentrations in oysters were obtained from the Transnet Port Terminals (TPT) oyster monitoring programme for June 2018 until June 2020.

Concentrations of lead have regularly exceeded the historical food safety limits in mussels and oysters collected from some locations in Saldanha Bay. The average concentration of lead in the tissues of mussels collected at the five sites within Small Bay has fluctuated from 0.9 ppm to 1.7 ppm over the last seven years with an average of 0.46 ppm in 2023, which was much lower than the 2022 average. This indicates that the lead pollution situation in Small Bay overall has improved slightly compared to last year but caution is still advised as the level of lead in mussels at the Portnet site and Saldanha Bay North sites have frequently exceeded the limit considered safe for human consumption in recent years. Concentrations of lead reported for mariculture farm operations, on the other hand, are lower and in nearly all cases within the food safety limits.

Similar to lead, cadmium levels in mussels and oysters have regularly exceeded the guideline limit (when considering both the historical and revised limit) at various locations in the Bay since the monitoring started. Research samples collected from the Iron Ore jetty did exceed the guideline limit for cadmium concentration in 2023 (the first time since 2006 at this site) and should be carefully monitored. Generally, though, cadmium concentrations have mostly been within guideline limits for recently collected bivalve samples. The cadmium levels remain on the border on the acceptable limit, and this is a concern.

No regulatory limits exist for manganese in mollusc flesh as elevated levels have not been shown to have an adverse effect on marine life. In 2023 mussel watch samples, a high concentration of manganese was recorded in all sites (Mussel Raft, Iron Ore Jetty, Fish Factory = highest ever recorded, Portnet, Saldanha Bay North = top 90th percentile). Manganese export volume has been steadily increasing from 95 000 tonnes in 2013/2014 to just over 4.5 million tonnes in 2017/2018. Concentrations recorded at Portnet seem to coincide with the export volumes of manganese. Although the manganese loading terminal is midway between the General Purpose Quay at the base of the iron ore jetty and the IOT, currents and onshore winds will cause manganese dust to move towards the base of the jetty and accumulate in this area. As this trend appears to be ongoing, and with the anticipated increased in manganese storage and handling, measures should be put in place to prevent excessive amounts of manganese dust from entering the Bay, especially considering the high concentrations seen in Portnet in 2023 and the dramatic increase in manganese concentrations at all other sites this year.

When considering the revised guideline limit, arsenic concentrations become problematic since around 2019 as levels regularly exceed food safety guidelines, even in recent samples. In 2023.

Mercury concentration in both mussels and oysters have remained well below the food safety limits in almost all cases throughout the monitoring campaign. Exceedance of food safety limits for lead, cadmium and arsenic in bivalves collected for research from the shore and the aquaculture farms throughout the Bay, points to the need for management interventions, as metal contamination poses a serious risk to the health of people harvesting mussels.

Metal contamination poses a very serious risk to the health of people harvesting mussels from the shore (large qualities of shellfish are harvested and consumed by recreational and subsistence fishers from the shore of the Bay). 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 metal concentrations within seafood is a human health concern. The sustained increase in manganese should be investigated further as although evidence is lacking regarding the ecological and human impacts of manganese consumption, the levels recorded here may still be of 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., Hoedjies Bay).

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 generally nearshore coastal waters in the system have improved considerably for recreational use since 2005. However, based on the 2023 *E. coli* count data, 2023 represents one of the most negative declines in recreational water quality since monitoring began which is a major concern. The worst offending sites in previous years (E.g., Bok River mouth) continue to be so, with very high concentrations of *E. coli* recorded in 2023. Although this poor water quality in 2023 could be related to once off or isolated events, immediate action should be taken to ensure an improvement is made. Particularly for populating bathing sites (E.g., Langebaan Main Beach rated as 'fair') that are used for recreation and have previously been compliant with water quality limits.

With respect to mariculture, the situation in Small Bay remains a concern, with all the sites sampled along the northern shore exceeding the guideline for safe mariculture practices. Faecal coliform counts at all four sites in Big Bay were within the 80th percentile limits for mariculture in 2023. Given the current importance of mariculture operation to Saldanha Bay, it is imperative that whatever efforts have been taken in recent years to combat pollution by harmful microbes in Small Bay should continue to be implemented.

The revised guidelines for water quality in South Africa (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. Incorporation this into the State of the Bay monitoring program would be welcomed, considering the current status of water quality around and human activity around the bay, most importantly being recreational swimming and mariculture development.

14.4 SEDIMENTS

Trace metal concentrations are mostly well within safety thresholds except for a few sites in Small Bay, where thresholds have been exceeded on a number of occasions between 2016 and 2023.

Key areas of concern regarding trace metal pollution within Small Bay include the Yacht Club Basin, where Cd and Cu have exceeded recommended thresholds for eight years in a row as well as adjacent to the Multi-Purpose Terminal (MPT) where levels of Cd and Pb are below internationally accepted guidelines, but still remain highly enriched relative to historic levels. Furthermore, the MPT is also the only site where Mn concentrations exceed guideline concentrations. Spatially, average Cu concentrations increased in both Small Bay and Big Bay. Average Mn concentrations have increased in all areas despite Small Bay, with the greatest increases seen in Langebaan Lagoon and Elandsfontein. This increase in Mn concentrations is concerning, and ongoing monitoring will indicate if the trend continues. Positively, average Ni concentrations appear to have decreased substantially since 2022 in all domains, suggesting a lessening of Ni contamination. Finally, Pb concentrations have also declined in the system, with the greatest declines occurring in Elandsfontein, followed by Big Bay, and Langebaan Lagoon.

Another relevant result in this year's survey is the system-wide increase in Iron concentrations relative to 2022 which will need to be monitored in following years to see if it represents a trend or simply relates to the conditions prior to the April 2023 sampling.

Enrichment Factor (EF) analysis revealed that SB5, located in the North of Small Bay, was of concern in this survey, with very high EF values, with copper (Cu) having "Extremely High" enrichment, followed by Pb and Ni, with "Very High" and "Significant" enrichment respectively. The most persistent pollutant in the system seems to be Pb, with enrichment factor results for small bay indicating that the area has at least "Significant" enrichment, with three sites having "Very High" enrichment. Spatially, trace metal enrichment remains most intense in Small Bay, with areas of Big Bay, particularly those close to the IOT, also having relatively high amounts of trace metal enrichment. Conversely, Langebaan Lagoon and Elandsfontein have very little trace metal enrichment besides some notable lead enrichment at LL32 (located to the south of Schaapen Island). Another relevant result in this years survey is the system-wide increase in Iron concentrations relative to 2022 which will need to be monitored in following years to see if it represents a trend or simply relates to the conditions prior to the April 2023 sampling.

Despite the relative stability in trace metal concentrations throughout the system, continued regular monitoring of trace metal concentrations is strongly recommended to provide an early warning of any future changes. It is also recommended that the methodology for the analysis of cadmium be refined to allow for the detection of concentrations below 1 mg/kg. Furthermore, it is recommended that two contaminants of possible concern: zinc and mercury, be added to the analysis suite, as they can both have harmful consequences should they become elevated.

Sediment particle size showed little change between 2022 and 2023, and this chapter has demonstrated that there have been no significant changes in particle size and the highly important mud (fine) component since approximately 2010.

A highly interesting finding in this year's report is the shift in Carbon to Nitrogen Redfield ratios, which have indicated that there is relatively more nitrogen in the system compared to carbon than in previous years. It appears likely that this shift is occurring as a result of natural conditions, and not anthropogenic forcing, and it is interesting to consider that there is a global shift from a La Niña to El Niño phase in the pacific, which can influence the rainfall and oceanography along the west coast of South Africa, and could potentially have some influence on the carbon: nitrogen balance, although this cannot be confirmed.

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 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. Furthermore, it is Redox potential be measured in all sediment samples after collection to better understand the causes of the changes in sediment carbon and nitrogen concentrations.

Sediment samples collected in 2023 had low Poly-aromatic hydrocarbons (PAH) levels across all sites. While the Total Petroleum Hydrocarbon (TPH) and PAH findings present no major concern, it is recommended that TPH monitoring within the vicinity of the IOT is continued annually in order to identify the frequency of occurrence of pollution incidents; like that recorded in 2014, and assess the ecological implications to the Bay.

14.5 Macrophytes

Three distinct intertidal habitats exist within Langebaan Lagoon: seagrass beds, such as those of the eelgrass Zostera capensis; salt marsh dominated by cordgrass *Spartina maritima* and *Sarcocornia perennis* and the dune slack rush *Juncus kraussi,* and unvegetated sandflats dominated by the sand prawn, *Callianassa krausii* and the mudprawn *Upogebia capensis* (Siebert and 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 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.

Salt marshes 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 salt marsh area had shrunk by only a small amount between 1960 and 2000, losing on average 8 000 m^2 per annum.

The common reed dominates the flora of the reedbeds where groundwater inflow occurs. Results of our analysis suggests that variation in reed cover over time is relatively modest and that this has remained more or less constant over the last 31 years (1989–2020; See Chapter 8). The biggest perturbations in reed cover correspond with the two largest droughts that have been experienced in the region in this period (a 1:20 year event that occurred in the period 2002–2003) and an even bigger drought that occurred recently (a 1:100-year event in the period 2015–2017). Within the last 6 years, seagrass beds to the north of the lagoon have been either shrinking or almost entirely lost as of June 2021. New growth of seagrass beds at the south of the lagoon near Geelbek and the rapid loss to the north are indicative of a coastal community shift driven by eutrophication. Salt marsh has remained fairly consistent in extent for the last 5 years but increased in coverage as of June 2021 by more than 10% with respect to previous years.

Future efforts in this field will entail expanding ground-truthing tasks to other macrophyte classes (specifically seagrass and salt marsh) and expanding the assessment of variability in each vegetation class over time.

14.6 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. These species are mostly short lived and, consequently, their community composition responds rapidly to environmental changes. Monitoring of benthic macrofaunal communities over the period 1999–2023 has revealed a pattern of decreased abundance and biomass in response to dredging events (2008, 2012, 2015 and 2017) followed by rapid recovery. During these perturbations a general decrease in filter feeders and an increase in shorter lived opportunistic detritivores has been recorded. Aside from these Bay-wide effects, localised improvements in health have been detected at sites in the Yacht Club Basin and at Salamander Bay following construction of the boat dock. Disturbance at the LPG site in Big Bay initially resulted in reduced indices of abundance, biomass and diversity since the installation of the SPM at this site. Recent findings, however, indicate a marked improvement in these indices suggesting that some recovery in benthic macrofaunal community structure has taken place — further monitoring is required to determine whether full recovery has been achieved or not. Other notable improvements in the health of benthic communities include the return of the 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 *Listriolobus capensis*, 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. 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. The regularity (annually) and intensity of benthic macrofauna monitoring should continue at all the current stations.

The presence of low-lying reef was noted during the baseline surveys and deployment of monitoring instruments in the Saldanha Bay sea-based Aquaculture Development Zone finfish area. The potential effects of aquaculture on patches of this habitat type and its associated epifaunal communities has not previously been assessed in the Big Bay precinct beyond Lynch Blinder. The reef has been described as low-profile reef, roughly <1 m in height from the sea floor, which may be subject to periodic, natural sand inundation. Additionally, substantial outcrops >1 m in height are present in places and may form habitat for a well-established epifaunal community. Given this information, the 2021 monitoring survey included the collection of video footage of the reef at any sampling site where hard substrate was encountered. Footage was collected at two sites in Big Bay where reef was encountered, and this was used to provide a qualitative description of the epifaunal species present at each site. A total of 21 species were recorded with common species including: the West Coast rock lobster *Jasus lalandii*, red starfish *Patiria granifera* and reticulated starfish *Henricia ornata*, cape urchins *Parechinus angulosus*, and beds of the common feather star *Comanthus wahlbergii*. Given the identification of reef in the Big Bay precinct it is recommended that further studies be conducted to provide a quantitative assessment of the epifaunal reef communities present. In addition, the extent of the reef in Big Bay is yet to be determined and a detailed bathymetry survey should be undertaken.

14.7 Rocky intertidal

A total of 111 species were recorded across eight rocky shore sites, most of which had been found in previous survey years. Of these, 35% were algae, while 65% were invertebrate animals. These species spanned diverse taxonomic groups, including Chlorophyta (green algae), Rhodophyta (red algae), and Ochrophyta (brown algae), as well as porifera (sea sponges), gastropods (sea snails and limpets), bivalves (mussels), echinoderms (sea urchins, sea cucumbers, feather stars, and sea stars), ascidians (sea squirts like redbait), Cnidarians (sea anemones, soft corals, and hydroids), polychaetes (bristle worms), arachnids (sea spiders), and crustaceans (barnacles and crabs). Rocky shore community composition has undergone changes since the start of the survey, with substantial increases in encrusting algae at most sites and declines in filter feeders at some sites. While shifts may be attributed to natural variability, anthropogenic events and climate changes as possible contributors should be explored.

One of the greatest threats to rocky shore communities in Saldanha Bay is the introduction of alien species via shipping and mariculture, and their potential to become invasive. Amongst the recorded species, seven were identified as alien species. These included the Mediterranean mussel *Mytilus galloprovincialis,* bisexual mussel *Semimytilus patagonicus,* blue mussel *M. edulis* and bay mussel *M. trossulus* (all collectively referred to as the mytilid mussel species complex), the acorn barnacle *Balanus glandula*, the North West African porcelain crab *Porcellana africana* and the red-rust bryozoan *Watersipora subtorquata*. This marks the first record of *M. edulis* and *M. trossulus* in South Africa. Additionally, *W. subtorquata* is recorded for the first time as part of a rocky shore survey, with its presence noted at several sites. This species can become a significant fouling organism and its present should be monitored, especially on hard and artificial surfaces throughout the bay. Although there has been fewer records of the alien porcelain crab, populations should be closely monitored as its ecological impacts are unknown.

Key changes in the rocky intertidal ecosystem reflect the regional invasion by mytilid mussels and the Pacific barnacle *B. glandula,* both of 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. The abundance these species on the rocky shore has fluctuated over the years with recent surveys indicate a decline in their presence. Their decline can be attributed to severe weather events and wave action, which frequently displace these species from the shore. The establishment of new alien species can potentially have negative impacts on native rocky shore species, and it is important that this is 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 throughout the system over the period 2008–2020 suggested that the protection afforded by the Langebaan MPA was not enough to sustain the fishery at the high 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/day and an increase in the minimum size (to 30 cm TL). Similarly, an analysis of commercial harder catch return data indicated that the stock was overexploited and recommended a reduction in fishing effort to rebuild biomass. It is also recommended that monitoring of fish stocks, catch and effort in the Bay be expanded to include regular catch and effort monitoring of the Bay's fisheries which would provide complementary data to the recruitment strength estimates emanating from the seine net surveys. An economic study should be undertaken to assess the value of the recreational fishery and the impacts of different management options.

Historically, 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 in Small Bay were similar to, or lower than that recorded in both Big Bay and Langebaan Lagoon. The juveniles of other species were historically also more abundant in Small Bay. This gives an indication of the importance of Small Bay as a nursery habitat for the fish species that support the large fisheries throughout the Bay. Small Bay is often viewed as the more developed or industrialized portion of the Bay, with further port and industrial development planned for the near future (including ship repair facilities) 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 ecologically sound management of this portion of the Bay. The collapse of the white stumpnose stock and continued poor recruitment throughout the Bay makes it even more critical that the quality of what was demonstrably the most important white stumpnose nursery habitat is improved.

The 2018 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 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 freshwater rivers) in the region. At the current experimental scale of fish farming, the number of escapees is not expected to be having significant impacts on indigenous fauna. However, at the proposed commercial scale of finfish cage farming, the number of alien salmonids introduced into the Bay and the Lagoon via ongoing escapes could 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 2023 study for as long as possible. This sampling should be confined to the same seasonal period each year for comparative purposes.

14.9 BIRDS AND SEALS

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; eleven species 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 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 15 years (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 Bank Cormorants feed. The recent extension for 10 years of the September 2022 closure of a 20 km radius around important seabird breeding islands to small pelagic purse seine fishing was largely in response to continuing declines of endangered African penguins. Time will tell if the closure around Dassen Isalnd, (which lies within the foraging range of several species) brings any benefits to penguins and other seabirds inhabiting the Saldanaha Bay Islands. 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 initiatives (particularly the Pelican Watch programme) 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 or modification of habitat, climate change, predaion, pollution, hunting and other forms of human disturbance. The fact that numbers of resident waders have also declined, however, suggests that unfavourable conditions persisting in Langebaan Lagoon as a result of anthropogenic disturbance may be partly to blame. Resident wader numbers in the winter of 2019 dropped to the lowest recorded in the 40-year count record and the post subsequent winter counts showed no recovery with a new low of just 142 recorded in August 2022. This is a continuation of the largely declining trend over the last two decades. Migratory wader counts in summer appeared to stabilize at around 3 000–6 000 birds over the period 2015–2023 with the exception of 2021 when nearly 13 000 were counted. In Langebaan Lagoon, drastic population declines in four species of migratory waders, including the Ruddy Turnstone, Red Knot, Grey Plover and Curlew Sandpiper have signified this downward trend in summer migratory bird numbers. Despite notable increases in 2021, the 2022 and 2023 summer counts of migratory waders were unfortunately much lower and revealed that the observed "recovery" was a once-off anomaly associated with the extraordinary global COVID-19 pandemic. It is highly recommended that the status of coastal and wading bird species continues to be monitored and that these data are used to inform and assesses the efficacy of management interventions aimed at halting the observed declines and supporting recovery of the region's birds.

Cape Fur Seals are amongst the largest marine top predators found in and around Saldanha Bay. They are opportunistic, generalist feeders that have been shown to benefit from human activities including utilisation of discards from fishing boats, or taking fish directly from fisherman. In addition, seals compete with seabirds, such as penguins and gannets, as well as with commercial fisheries, for small pelagic fish which form a key part of their diets. It has been suggested that the increasing numbers of seals on Vondeling island may lead to increased pressure to cull seals both from a fisheries perspective as well as to protect important seabird species on which seals are known to prey. Concerns have also been raised that, with the increased number of seals along the shores surrounding Saldanha Bay and should finfish aquaculture develop in the Bay, seal numbers within the Bay will likely increase, along with the occurrence of problem seals.

Although seals are likely attracted to the aquaculture sites within Saldanha Bay, chances are that their numbers will not continue to increase significantly as they are restricted to sub-adult males. Additionally, the carrying capacity of Vondeling Island appears to have been reached and the overall population within Southern Africa has remained stable over the last 30 years.

14.10 ALIEN INVASIVE SPECIES

Human induced biological invasions have become a major cause for concern worldwide. 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 via ballast water and hull-fouling. These findings highlight the need to implement more efficient protocols to prevent and monitor alien species.

The most recent review in South Africa identified a total of 95 marine alien species in South Africa, with 56 classified as invasive (Robinson et al. 2020). With new introductions and discoveries every year, and the changing status of species as more research is conducted, the list of alien species in South Africa remains dynamic.

In total, 37 alien and invasive species have been confirmed from Saldanha Bay and Langebaan Lagoon to date, while nine new alien species have been added to the State of the Bay list in the last 12 months. These include the tuberculate pear crab *Pyromaia tuberculata,* skeleton shrimp *Caprella mutica*, pitted barnacle *Balanus trigonus*, fat-feeler amphipod *Monocorophium acherusicum*, pink-mouthed hydroid *Ectopleura crocea,* thin-walled obelia *Obelia dichotoma,* amphipod *Ericthonius brasiliensis,* blue mussel *Mytilus edulis,* and the bay mussel *M. trossulus.* Most notably, the latter two mytilid mussel species are documented for the first time in South Africa. This challenges previous assumptions about the identity and state of knowledge of mytilids in South Africa, as *M. galloprovincialis* and *Semimytilus patagonicus* were believed to be the only alien mussels present. These four mussel species are collectively referred to as the mytilid species complex.

Surveys indicate that mytilids were generally predominant and reached high densities at exposed rocky shore sites, being the most dominant faunal species. However, recent surveys suggest that populations have declined, being considerably less abundant in the years post-2016, with some sites frequently lacking mussels. The reason for this decline remains unclear, although similar trends have been observed in the past, and monitoring should therefore continue. *Balanus glandula,* most abundant in semi-exposed rocky shore sites, has shown decreased abundance post-2016, reaching the lowest cover in 2023. While not believed to significantly impact rocky shore communities, continuous monitoring is recommended due to its sustained abundance in Saldanha Bay. *Rathbunixa occidentalis* is more abundant in Big Bay than Small Bay, with a potential presence in Langebaan Lagoon. Despite high numbers recorded in 2022, no crabs were detected in 2023, emphasising the need for ongoing monitoring to understand their status and impact in Saldanha Bay. *Porcellana africana* is well-established and abundant on Saldanha Bay's northern, eastern, and western shores, inhabiting the intertidal zone. The ecological impact of this species remains unclear, highlighting the necessity for the continuous monitoring of populations.

The discovery of nine new alien species highlights the need for proactive management. As managing these species is a challenging and resource-intensive task, prioritising actions is crucial. The primary focus should be on managing existing invasive species in Saldanha Bay, followed by measures to prevent future invasions. Future surveys must confirm the presence of unconfirmed listed species through morphological taxonomic and DNA verification. Additionally, dedicated sampling efforts are necessary to understand the abundance, distribution, and potential impacts of these alien species. Some species may require control or eradication programs for effective management. Furthermore, prioritising certain alien species for management is recommended, using impact-based ranking systems like the Environmental Impact Classification for Alien Taxa (EICAT) (Blackburn et al. 2014). However, its application in the marine context is limited due to the lack of species-specific impact knowledge. In South Africa, for example, impacts have only been quantified for only 16% of taxa known to be alien (Alexander et al. 2015, Robinson et al. 2016). In addition, impacts are context dependent and as such, impacts in one area cannot be used to infer impacts in another. Studies investigating the impacts of these species in Saldanha Bay are needed to prioritise management actions.

Preventing further invasions should be a priority, employing watchlists based on invasion history, pathways, and biological traits of species. Routine monitoring, coupled with watchlists, enhances early detection and successful eradication. In-depth research is needed to understand invasion drivers, traits, and associated impacts. This, in turn, could be used to support directed management actions for successfully controlling invasions and mitigating impacts.

Preventing further introductions also involves identifying and managing key pathways, with shipping activities identified as a significant contributor to marine introductions in South Africa. Approximately 91% of marine introductions are associated with shipping, emphasising the need for robust port control protocols (Robinson et al. 2020). Saldanha Bay, being a crucial international port with substantial shipping traffic, requires enhanced measures to monitor vessels entering its harbours. This includes treatment of hull fouling and ballast water before port entry, along with regular monitoring for alien species within harbours. Recreational yachts, often overlooked as vectors, pose a considerable risk for introducing alien species (Peters et al. 2019). International yachts frequenting Saldanha Bay increase this risk, and currently, there are no regulatory measures to manage alien species fouling on yachts entering

South Africa. Encapsulation, as explored in a recent study, shows promise as a tool to minimise and manage fouling on vessels, and similar experiments are encouraged for Saldanha Bay (Keanly and Robinson 2020).

In summary, managing invasive species in Saldanha Bay necessitates a dual approach: addressing existing species, particularly those with known impacts, through dedicated sampling efforts, and proactively preventing further invasions. Utilising watchlists as a preventive measure, alongside identifying and managing crucial pathways of introduction, is important. Further research into alien and invasive species is also important and will not only enhance our understanding of invasion drivers, but also provide insights into associated impacts, supporting targeted management actions for effective control and mitigation.

14.11 Summary of Findings

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 14.1. Tabulated summary of Environmental parameters reported on in the State of the Bay: Saldanha Bay and Langebaan Lagoon.

Parameter monitored	Time period	Anthropogenic induced impact	Rating
ACTIVITIES AND DISCHARGES AFFECTING THE HEALTH OF THE BAY			
Wastewater treatment works (WWTW) discharges	Current-2023	Monitoring results show a significant improvement in the compliance of most of the parameters tested for both the Langebaan and Saldanha Bay WWTW. However, the surplus volume of treated effluent from the Saldanha WWTW, not used by local industry for irrigation or dust suppression etc., that enters the bay via the Bok estuary is not currently known. It is therefore strongly recommended that a flow gauge be installed and monitored to record continuous discharge volumes entering the Bay.	☹
Ballast water discharge volumes	Current-2023	Discrepancies or inconsistencies in the total volume of ballast water discharge recorded annually relative to the number of vessels entering to port suggest a possible error or data gap in this aspect. It is suggested that a Standard Operating Procedure be implemented to improved data capture.	☹
GROUND WATER			
Aquifer and Lagoon: Physical aspects (extraction rates, volumes, recharge rates, volumes, temperature, salinity, tidal height, rainfall)	1984–2023	It is recommended that Managed Aquifer Recharge methodologies are employed in this area and that the aquifer only be used in times of severe drought and be kept as "full" as possible in non-drought times. Ongoing monitoring of water use from and water levels in the aquifer is considered essential as is the establishment of baseline conditions in Langebaan Lagoon.	😐

Parameter monitored	Time period	Anthropogenic induced impact	Rating
WATER QUALITY			
Physical variables (temperature, salinity, dissolved oxygen, nutrients and chlorophyll)	1974–2000, 2010–2011, 2014–2023	DO levels in bottom water in Small Bay are frequently lower than they were historically or at least prior to port development. DO concentration is lower in Small Bay than in Big Bay and measurements below bivalve farms are consistently lower than at control sites. This is attributed to organic loading in Small Bay and reduced flushing time. No consistent changes are evident with any other physico-chemical parameters. Anomalous water column temperature profiles (cooler water) were recorded during 2017 and 2018, corresponding with the dominance of the South Atlantic High-Pressure system during the prolonged drought.	
Current circulation patterns, current strengths, wave energy	1975 vs. 2020, 1960–2022	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). Increasing significant wave heights near to Saldanha Bay over time (1960 to present day), supporting well-documented observations of changing weather and wave climates around Southern Africa.	
Microbiological	1999–2023	Counts of *E. coli* increased in many (8) sites in 2023. Only one site increased in terms of their recreational water quality which is alarming. Excellent rated sites fell from 17 (in 2022) to nine. Faecal coliform counts at Small Bay sites frequently exceed guideline levels and although there have been improvements at some sites, others remain a concern. Big Bay remains within safety levels for faecal coliform pollution. However, faecal coliform may underestimate actual harmful microbiological concentrations. There is a need to monitor intestinal *Enterococci* as well.	
Trace metal contaminants in water	1997–2008, 2014–2023	Concentrations of lead in mussel flesh collected in research samples has improved since 2022 with all levels below the guideline limits. However, trace concentrations arsenic levels are now of concern considering revised guideline limits and recent exceedances thereof. All research samples and farmed oyster and mussel samples (bar one) were above the guideline concentration for arsenic which is worrying. In 2023 concentrations of manganese in research samples remained high at the sites that showed high concentrations in 2022, while all other sites (previously low in manganese) have shown a dramatic increase in manganese concentration in 2023. Although elevated manganese levels have not been shown to have an adverse effect on marine life measures should be put in place to prevent excessive amounts of manganese dust from entering the Bay. One research sample also exceeded the limit for cadmium concentration in 2023.	
SEDIMENTS			
Particle size (mud/sand/gravel)	1974–2023	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 and has stabilised since 2010.	

Parameter monitored	Time period	Anthropogenic induced impact	Rating
Total organic carbon (TOC)	1974–2023	Elevated levels of TOC at the Yacht Club basin and near the mariculture rafts (negative impacts) are of particular concern, with concentrations increasing by a factor of 10 since 2022 at the Yacht Club Basin. Average TOC has increased in Small Bay, yet has decreased slightly in Big Bay, and decreased substantially in Langebaan Lagoon.	
Total organic nitrogen (TON)	1974–2023	TON remains elevated at the Yacht Club basin and has seen a large increase to the east of Marcus Island. TON concentrations at key sites appear very similar to those seen in 2022 yet are still higher than those seen in 2021. However, they are typical of concentrations seen since 2010. Average TON appears fairly consistent throughout the system. Finally, the ratio of carbon to nitrogen has also decreased significantly since 2022, indicating a system shift likely linked to natural processes.	
Trace metal contaminants in sediments	1980–2023	Cadmium, lead, and copper are currently elevated considerably above historic levels. Concentrations were highest in 1999 following major dredge event. Lead, copper and nickel elevated in 2008–2016, whereas cadmium and copper increased in 2019 at the Yacht Club and Multi-Purpose Terminal, which may be related to shipping activities and maintenance dredging. In the recent April 2023 survey, concentrations of cadmium and copper remain elevated in the Yacht Club Basin (above ERL). Copper concentrations also exceeded ERL guidelines in northern small Bay. Average copper concentrations have also increased in both Small Bay and Big Bay since 2022. Despite average manganese concentrations remaining consistent in Small Bay, a small increase has been seen at the Multi-Purpose Terminal (with concentrations exceeding ERL guidelines). Additionally, average manganese concentrations have increased in all other regions, with Langebaan Lagoon and Elandsfontein seeing the greatest increase. Positively, average nickel concentrations have decreased substantially in all regions since 2022. Finally, despite a high amount of lead enrichment in Small Bay, average lead concentrations have decreased substantially in Big Bay, Langebaan, and Elandsfontein, with a small decrease seen in Small Bay.	
MACROPHYTES			
Seagrasses, salt marsh, reeds and sedges	Seagrass beds: 2016–2023 Salt marsh: 2016–2023 Reeds and sedges: 1988–2020 *P. australis*: 2016–2023	Seagrass (*Zostera capensis*) beds have experienced a radical reduction in size with associated fragmentation of large beds. This phenomenon has been attributed to direct and indirect anthropogenic changes such as physical disturbance, pollution, specifically eutrophication and most recently, seagrass biomass was found to be further south in the lagoon in warmer waters. Analyses of changes in salt marsh cover indicate a modest (~10%) increase in cover for this vegetation type for 2023. Reeds and sedge cover, by contrast, appears to have remained more or less constant over the last 30 years whereas common reed (*Phragmites australis* has shown a slight decrease in external perimeter extent over the last 3 years.	

Parameter monitored	Time period	Anthropogenic induced impact	Rating
BENTHIC MACROFAUNA			
Species abundance, biomass, and diversity	1999–2023	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.	
ROCKY INTERTIDAL SPECIES			
Shifts in intertidal communities and impacts of alien species	1980–2023	Community composition changed. Declines in filter feeders observed at certain sites and increases in encrusting algae at most sites. Shifts may be attributed to natural variability, but anthropogenic events and climate changes should be explored. Although the alien mussels and barnacles have displaced the local mussel and some other native species from much of the shore, there has been a decline in these alien species over the past few years. Keep monitoring. An alien bryozoan is recorded in a rocky shore survey for the first time during this year's survey where its presence was noted at several locations. Impacts and status elsewhere unknown. The new alien barnacle species found in 2014 must be closely monitored. There have been fewer records of the alien porcelain crab. It was absent at one site although it appeared at a new site. Monitor populations closely as impacts are unknown.	
FISH			
Community composition and abundance	1986–2023	White stumpnose abundance and fishery landings declined dramatically over the last decade, with the hoped 2021 recovery not carried forward into 2023, although their abundance is still higher than it has been since 2011. Elf recruitment has been poor for five years, but shows a slight improvement in 2023. Abundance of fish in Small Bay has been declining in recent years, and this is of some concern given the ongoing industrial development in this area. Abundance and diversity were up in Big Bay in 2023, and while trends in abundance varied in Langebaan Lagoon, with white stumpnose particularly low, most likely due to fishing pressure.	
BIRDS			
Population numbers of key species in Saldanha Bay and islands	1977–2023	Populations of some 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 15 years, (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 Bank Cormorants feed. It is yet to be seen if the extended 20 km radius closure to small pelagic fishing around Dassen Island benefits the seabirds nesting on the Saldanha Bay Islands.	

Parameter monitored	Time period	Anthropogenic induced impact	Rating
Population numbers of key species in Langebaan Lagoon	1976–2023	Populations of migrant waders utilising Langebaan Lagoon have decreased dramatically over the last 30 years, attributed to offsite impacts on breeding grounds and local impacts (habitat changes) and disturbance in the lagoon. The apparent recovery in migratory wader numbers in Langebaan lagoon recorded during 2021 that was possibly due to reduced anthropogenic impacts during the COVID-19 pandemic, was short-lived and subsequent counts were again well below historical levels. Numbers of resident waders have also declined and is likely due to changes in the lagoon itself, particularly increased disturbance at historically important, feeding sandflats.	
SEALS			
Population numbers of seals	1970–2023	Cape Fur seal population stable over the past 30 years.	
ALIENS AND INVASIVES			
Total number of alien and invasive species in Saldanha Bay and Langebaan Lagoon	Current-2023	Nine new alien species have been reported since 2022. These include *Mytilus edulis, Mytilus trossulus, Pyromaia tuberculata, Caprella mutica, Balanus trigonus, Monocorophium acherusicum, Ectopleura crocea*, *Obelia dichotoma* and *Ericthonius brasiliensis*. Thirty-seven species are now confirmed from Saldanha Bay and/or Langebaan Lagoon, of which all but seven are considered invasive. Quantitative data on the abundance and biomass of three invasive species for which sufficient data spanning several years have been compiled. These include the Pacific barnacle *B. glandula*, the mytilid species complex, and the Western pea crab *R. occidentalis*. Notably, barnacles and mussels are considerably less abundant in the years post-2016 compared to pre-2016. This decline is also notable in 2023. No crabs were detected at any sampling stations during the 2023 survey.	

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16 APPENDICES

16.1 Appendix I: Long-term water level and electrical conductivity graphs for the SBM control points

Borehole:	**G46064**
Location:	Saldanha Bay Municipality
Borehole details:	
East (dd_WGS84):	18.23050
South (dd_WGS84):	-33.00985
Elevation (mamsl):	76 m
Aquifer:	Lower Aquifer
Collar height (m):	0.28 m
Borehole depth (m):	83 m

Field Measurements:			
Date	*Time*	*Water Level (WL) (mbgl)*	*Field Comment*
2023/06/08	12:18	31.66	Water levels (WL) at this borehole fluctuate between 30–35 mbgl. There are no concerns and a rising water level trend is observed since January 2022. EC displays an increasing trend at this borehole between January 2022 – June 2023. Conductivity values will likely begin decreasing after the winter rainfall.

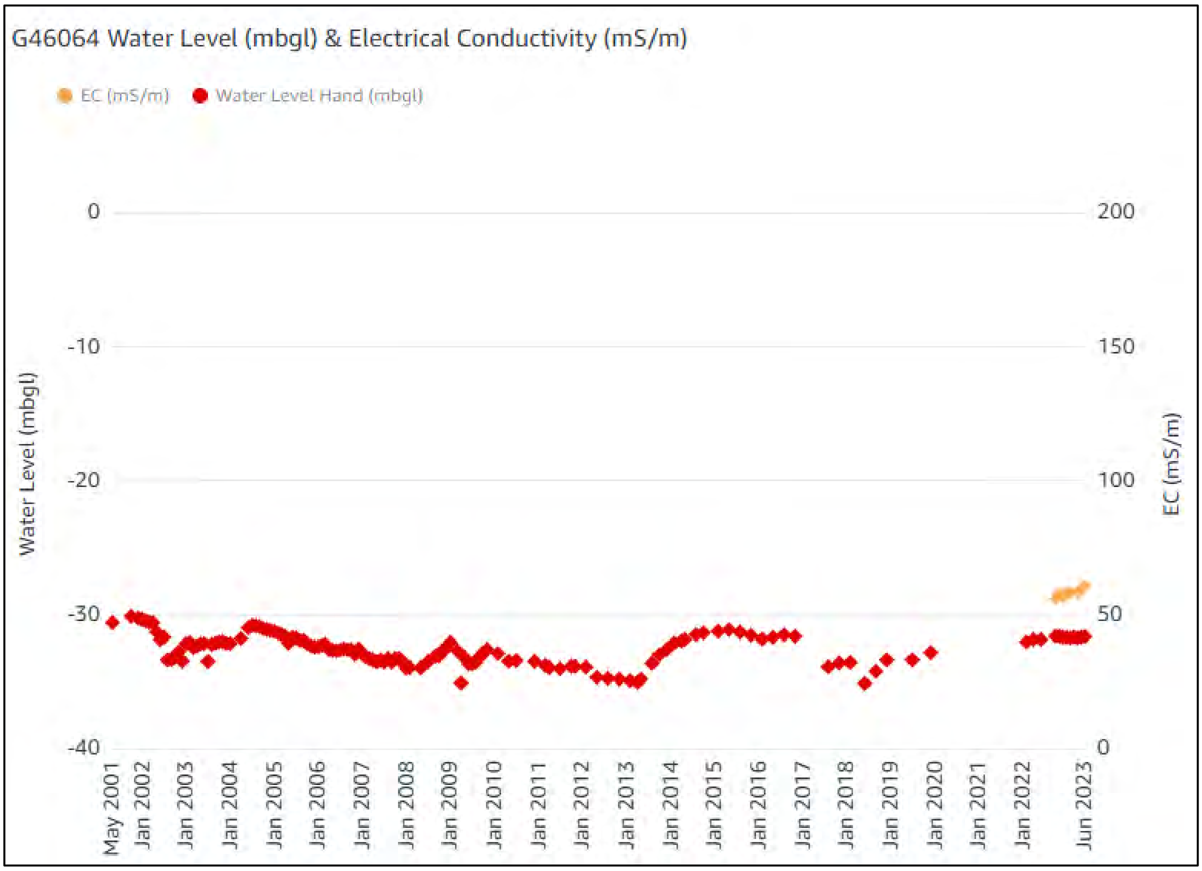

Figure 16.1 G46064 long-term water level graph.

Borehole:	**G46025**
Location:	Saldanha Bay Local Municipality
Borehole details:	
East (dd_WGS84):	18.238470
South (dd_WGS84):	-33.012720
Elevation (mamsl):	80 m
Aquifer:	Upper Aquifer
Collar height (m):	0.63 m
Borehole depth (m):	65 m

Field Measurements:			
Date	*Time*	*WL (mbgl)*	*Field Comment*
2023/06/08	12:12	14.39	A long-term dewatering trend is observed at this site since 1999. However, water levels seem to have stabilised between October 2022 and June 2023. EC at this site fluctuates between 50–60 mS/m.

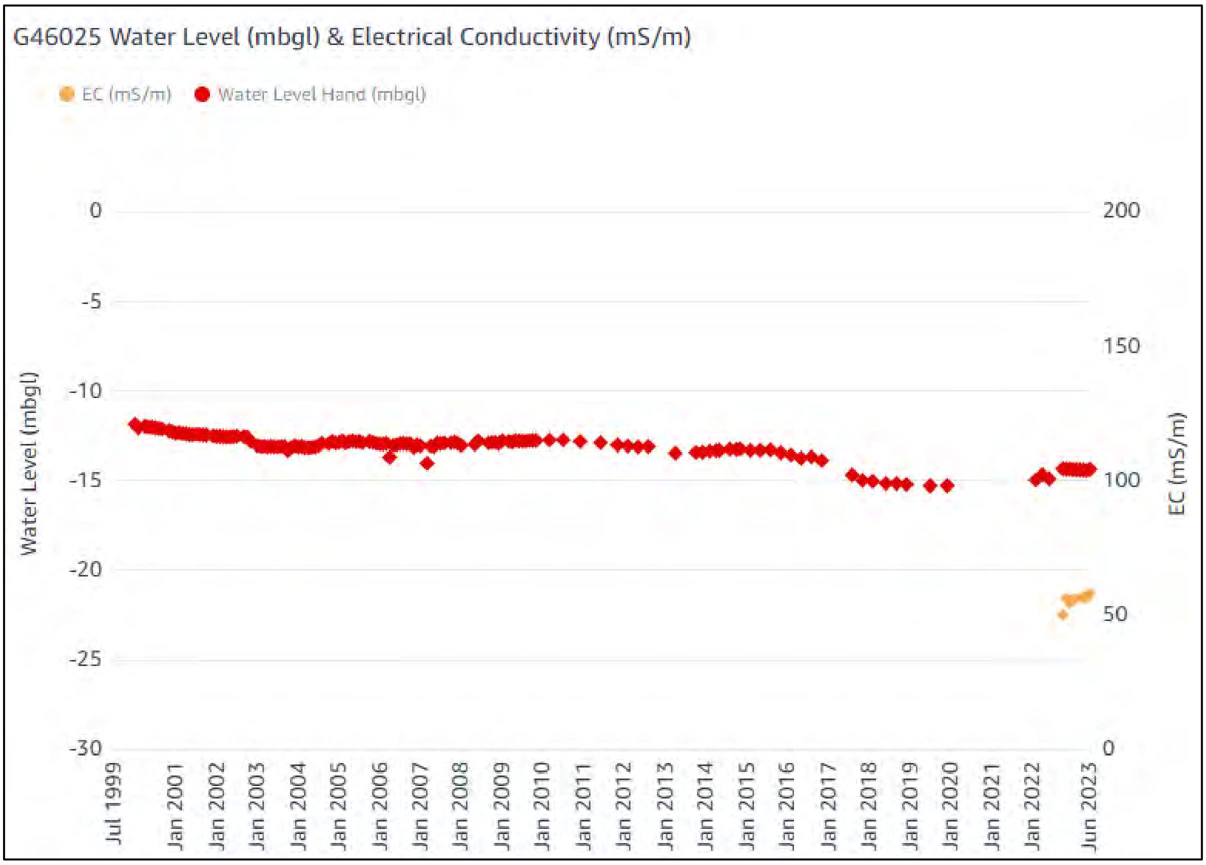

Figure 16.2 G46025 long-term water level graph.

Borehole:	**G46031**	
Location:	Saldanha Bay Local Municipality	
Borehole details:		
East (dd_WGS84):	18.179020	
South (dd_WGS84):	-33.024110	
Elevation (mamsl):	54 m	
Aquifer:	Unknown	
Collar height (m):	0.61 m	
Borehole depth (m):	88 m	

Field Measurements:			
Date	*Time*	*WL (mbgl)*	*Field Comment*
2023/06/08	15:42	8.04	A recovering trend in water levels is observed since 2017. Electrical conductivity values at this site ranged between 74 mS/m and 80 mS/m.

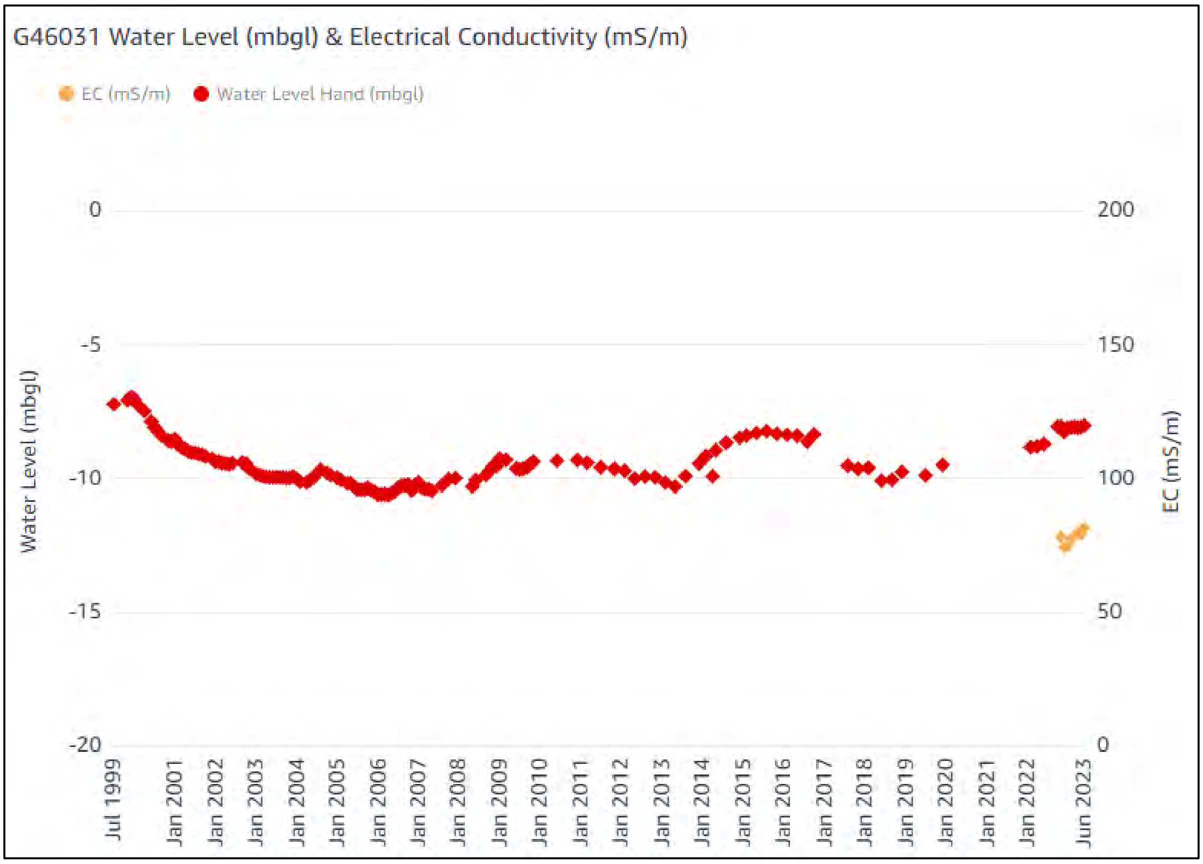

Figure 16.3 G46031 long-term water level graph.

Borehole:	**G46030**	
Location:	Saldanha Bay Local Municipality	
Borehole details:		
East (dd_WGS84):	18.183600	
South (dd_WGS84):	-33.035270	
Elevation (mamsl):	66 m	
Aquifer:	Bedrock (shale)	
Collar height (m):	0.60 m	
Borehole depth (m):	119 m	

Field Measurements:			
Date	*Time*	*WL (mbgl)*	*Field Comment*
2023/06/08	15:24	12.81	Groundwater levels are relatively stable at this site over the long term and fluctuate around a base water level of 12 mbgl. ECs at this site are measured between 56 mS/m and 61 mS/m.

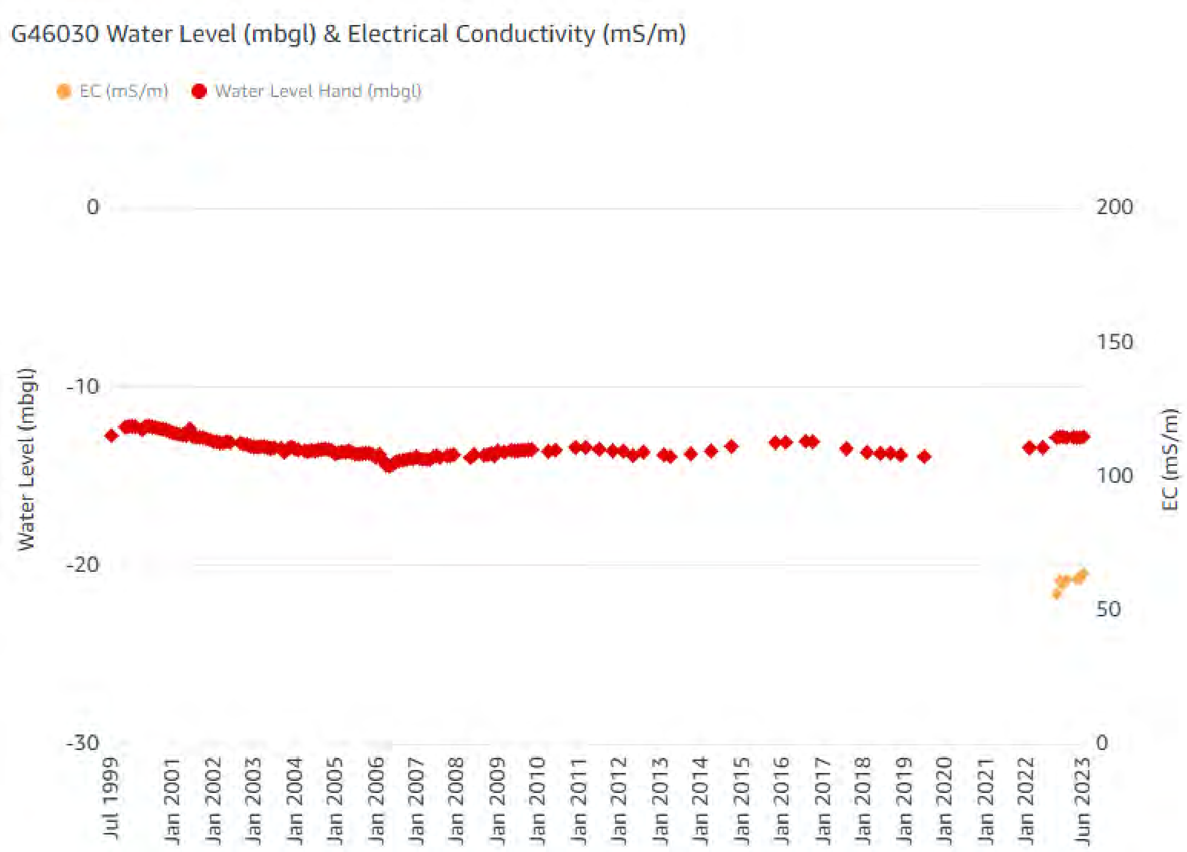

Figure 16.4 G46030 long-term water level graph.

Borehole:	**BG00062**	
Location:	Saldanha Bay Local Municipality	
Borehole details:		
East (dd_WGS84):	18.111760	
South (dd_WGS84):	-33.045360	
Elevation (mamsl):	23 m	
Aquifer:	Bedrock (granite)	
Collar height (m):	0.52 m	
Borehole depth (m):	27 m	

Field Measurements:			
Date	*Time*	*WL (mbgl)*	*Field Comment*
2023/06/09	08:54	5.79	A deepening trend is seen at this site between 2015 and 2020 as a result of the drought experienced in the area. Water levels have become shallower over the past year as a result of above average rainfall experienced in the area. The EC at this borehole is very high (exceeds health standards by 557 mS/m). This is, however not of concern as the bedrock aquifer in the area is characterised by higher conductivities.

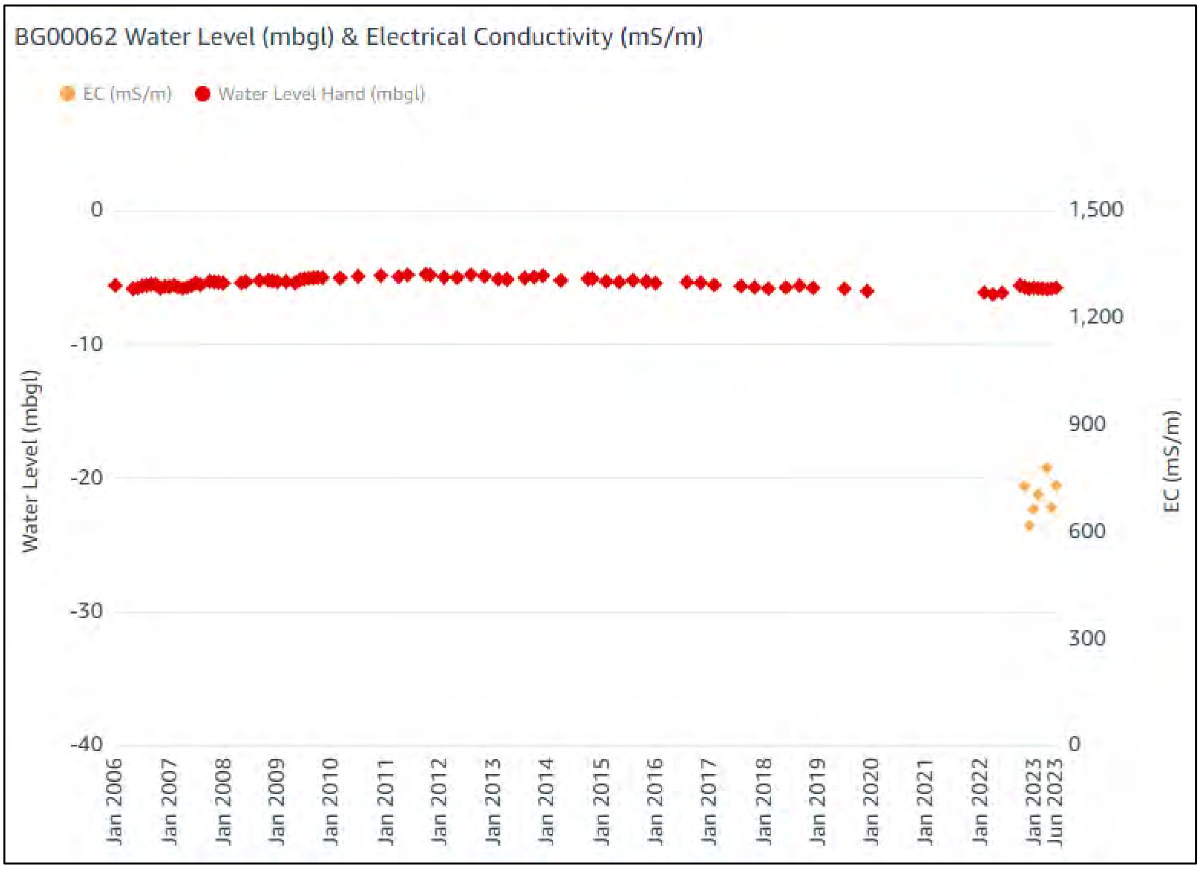

Figure 16.5 BG00062 long-term water level graph.

Borehole:	**G33313**
Location:	Saldanha Bay Local Municipality
Borehole details:	
East (dd_WGS84):	18.128970
South (dd_WGS84):	-33.106630
Elevation (mamsl):	63 m
Aquifer:	Upper Aquifer
Collar height (m):	0.10 m
Borehole depth (m):	57 m

Field Measurements:			
Date	*Time*	*WL (mbgl)*	*Field Comment*
2023/06/08	16:15	12.04	A marginal decline of 0.66 mbgl is observed between 1985–present. Groundwater levels have remained stable at this site over the past five months at approximately 12 mbgl. Fluctuations in EC are a result of natural variation and are of no concern.

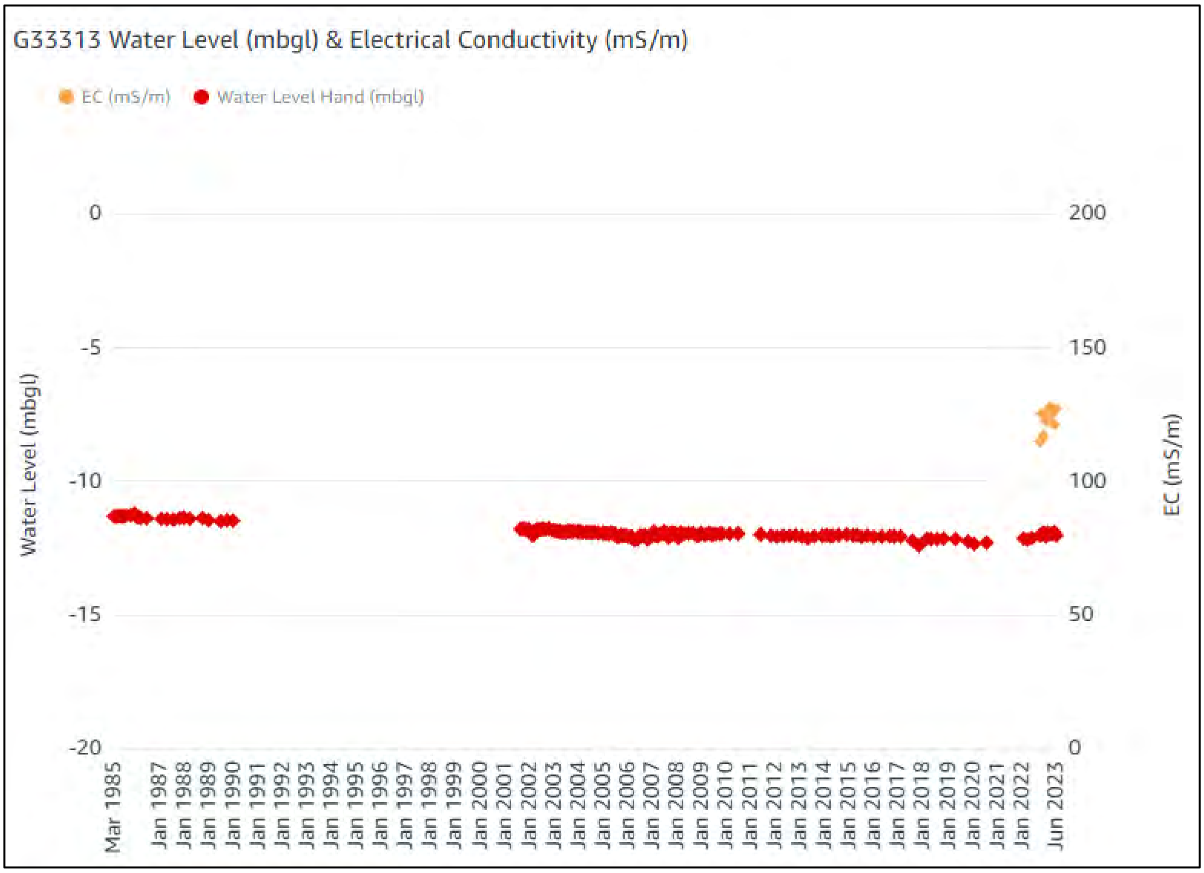

Figure 16.6 G33313 long-term water level graph.

Borehole:	**G46092**
Location:	Saldanha Bay Local Municipality
Borehole details:	
East (dd_WGS84):	18.087620
South (dd_WGS84):	-32.944730
Elevation (mamsl):	26 m
Aquifer:	Lower Aquifer
Collar height (m):	1.05 m
Borehole depth (m):	28 m

Field Measurements:			
Date	*Time*	*WL (mbgl)*	*Field Comment*
2023/06/09	09:43	artesian	This borehole is currently artesian. Historically, water levels at this site fluctuated between 0 and 1.85 mbgl. EC is highly variable and ranges from 340 mS/m to 500 mS/m.

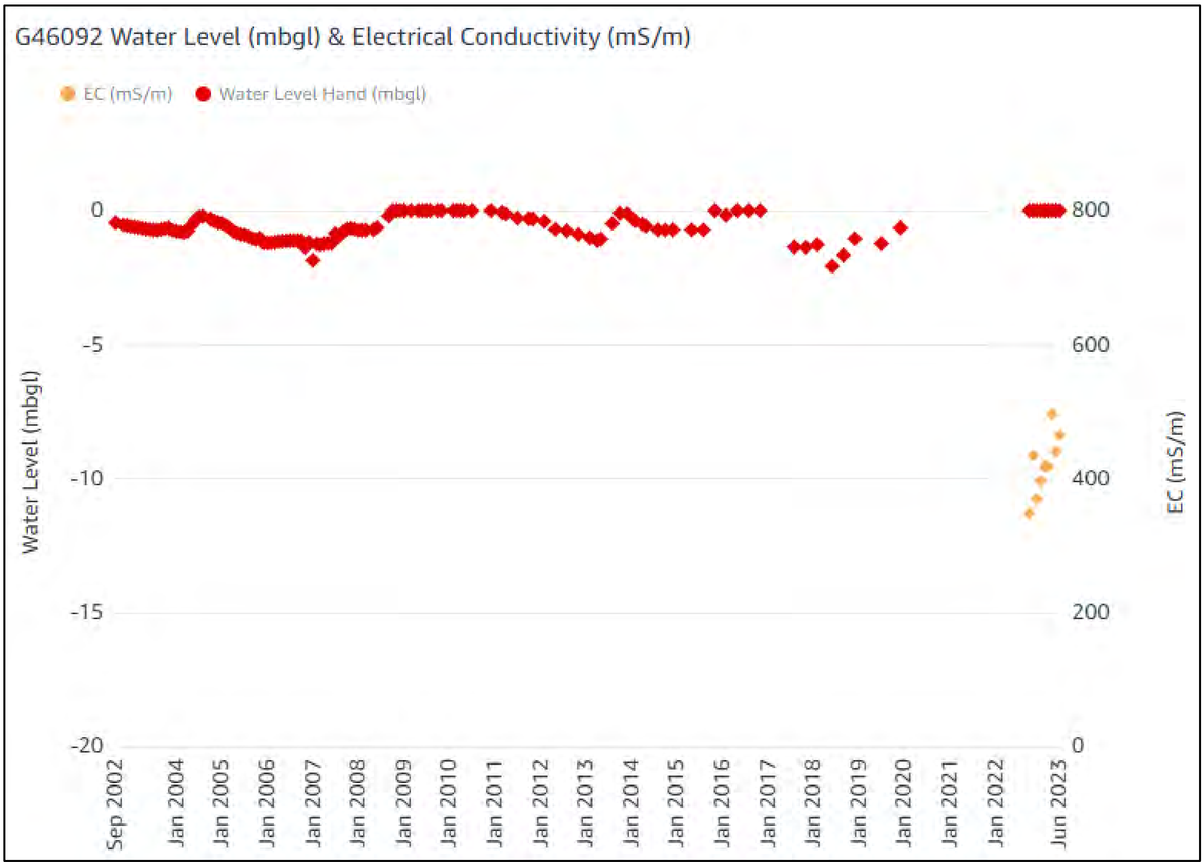

Figure 16.7 G46092 long-term water level graph.

Borehole:	**G33327**	
Location:	Saldanha Bay Local Municipality	
Borehole details:		
East (dd_WGS84):	18.127610	
South (dd_WGS84):	-32.963480	
Elevation (mamsl):	42 m	
Aquifer:	Unknown	
Collar height (m):	0.4 m	
Borehole depth (m):	83 m	

Field Measurements:			
Date	*Time*	*WL (mbgl)*	*Field Comment*
2023/06/09	09:56	15.15	Fluctuations in water levels are likely due to abstraction taking place at the Langebaan Road Wellfield. Water levels fluctuate within a stable range and no concerning trends have been noted in water levels and electrical conductivity.

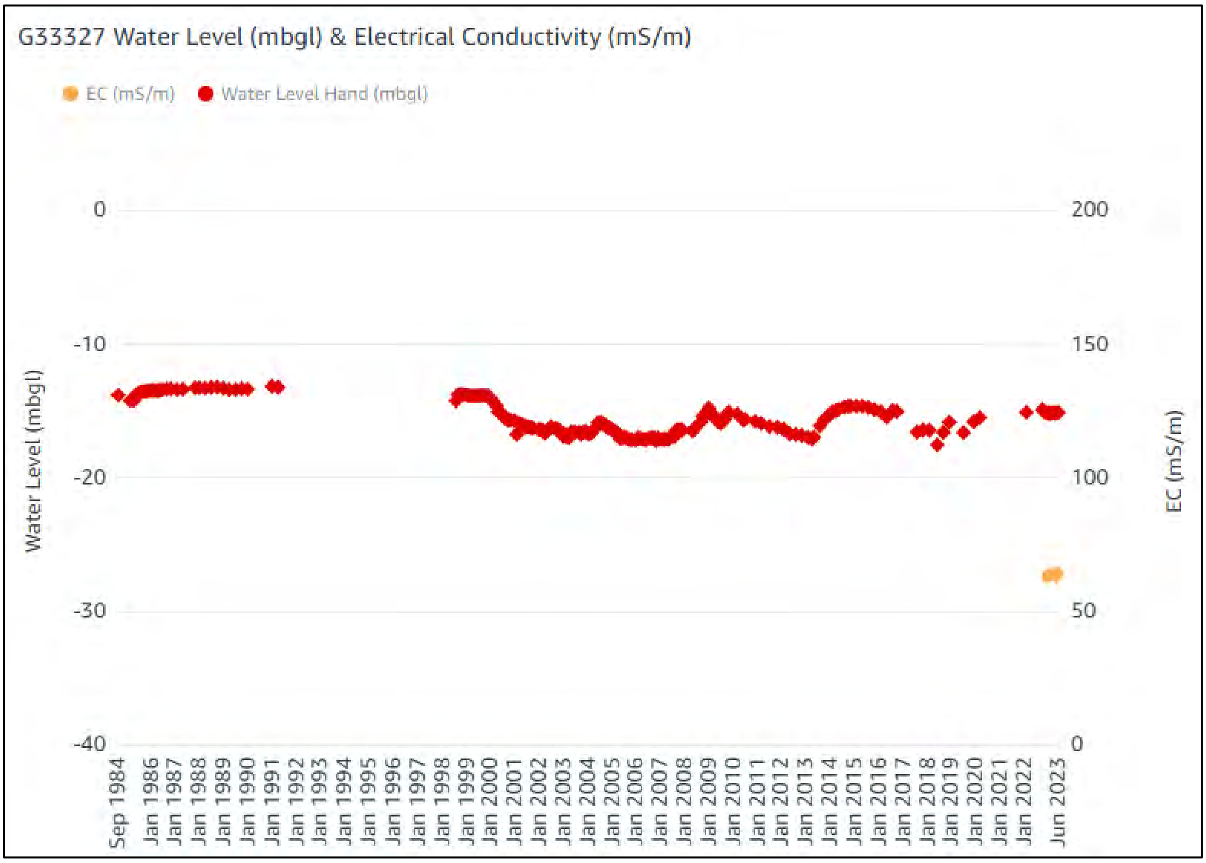

Figure 16.8 G33327 long-term water level graph.

Borehole:	**BG00054**
Location:	Saldanha Bay Local Municipality
Borehole details:	
East (dd_WGS84):	18.157050
South (dd_WGS84):	-32.961460
Elevation (mamsl):	31 m
Aquifer:	Unknown
Collar height (m):	0.30 m
Borehole depth (m):	45 m
Logger:	No logger

Field Measurements:			
Date	*Time*	*WL (mbgl)*	*Field Comment*
2023/06/09	10:54	3.78	There are no concerns at this site. A rising trend in water levels are observed over the 2005–2023 period. EC is relatively stable at ~60 mS/m.

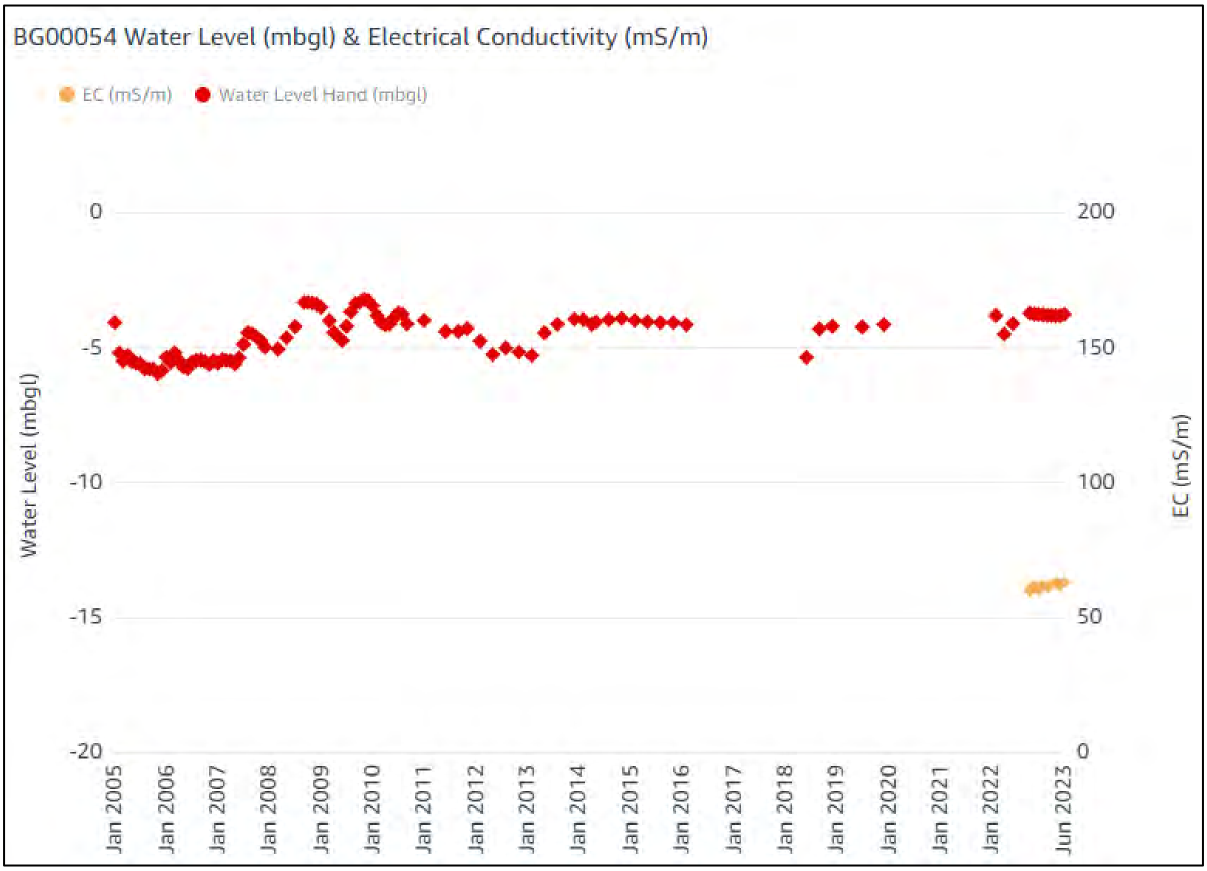

Figure 16.9 BG00054 long-term water level graph.

Borehole:	**G33246**	
Location:	Saldanha Bay Local Municipality	
Borehole details:		
East (dd_WGS84):	18.336530	
South (dd_WGS84):	-32.901000	
Elevation (mamsl):	9 m	
Aquifer:	Upper Aquifer	
Collar height (m):	0.10 m	
Borehole depth (m):	25 m	

Field Measurements:			
Date	*Time*	*WL (mbgl)*	*Field Comment*
2023/06/09	12:06	5.20	Groundwater levels are relatively stable over the long term and fluctuate between 4–6 mbgl. Fluctuations in EC are a result of natural variation and are of no concern.

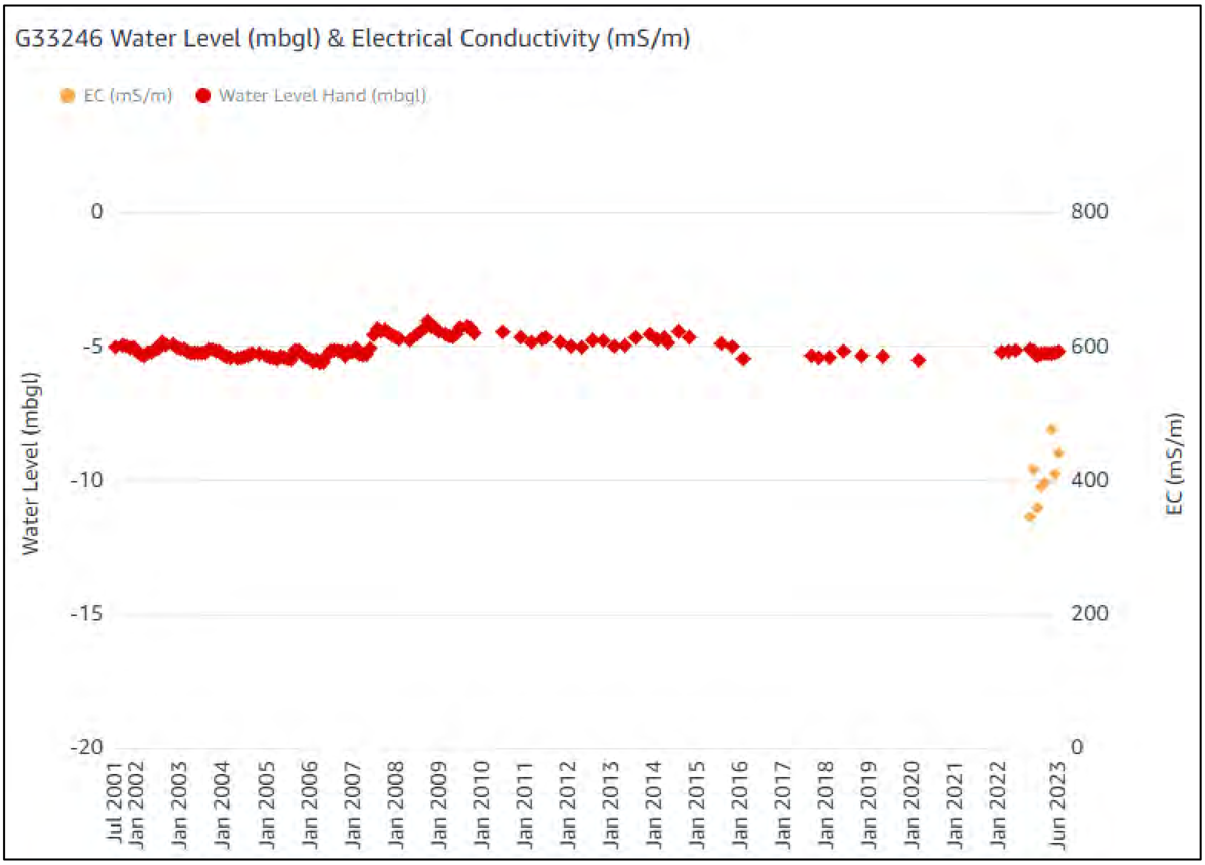

Figure 16.10 G33246 long-term water level graph.

Borehole:	**G33326**	
Location:	Saldanha Bay Local Municipality	
Borehole details:		
East (dd_WGS84):	18.271270	
South (dd_WGS84):	-32.933970	
Elevation (mamsl):	37 m	
Aquifer:	Upper Aquifer	
Collar height (m):	0.10 m	
Borehole depth (m):	80 m	

Field Measurements:			
Date	*Time*	*WL (mbgl)*	*Field Comment*
2023/06/09	11:40	6.31	Marginal fluctuations are observed at this borehole due to wellfield abstraction. However, no concerning trends have been identified. EC values at this site ranged between 85–110 mS/m.

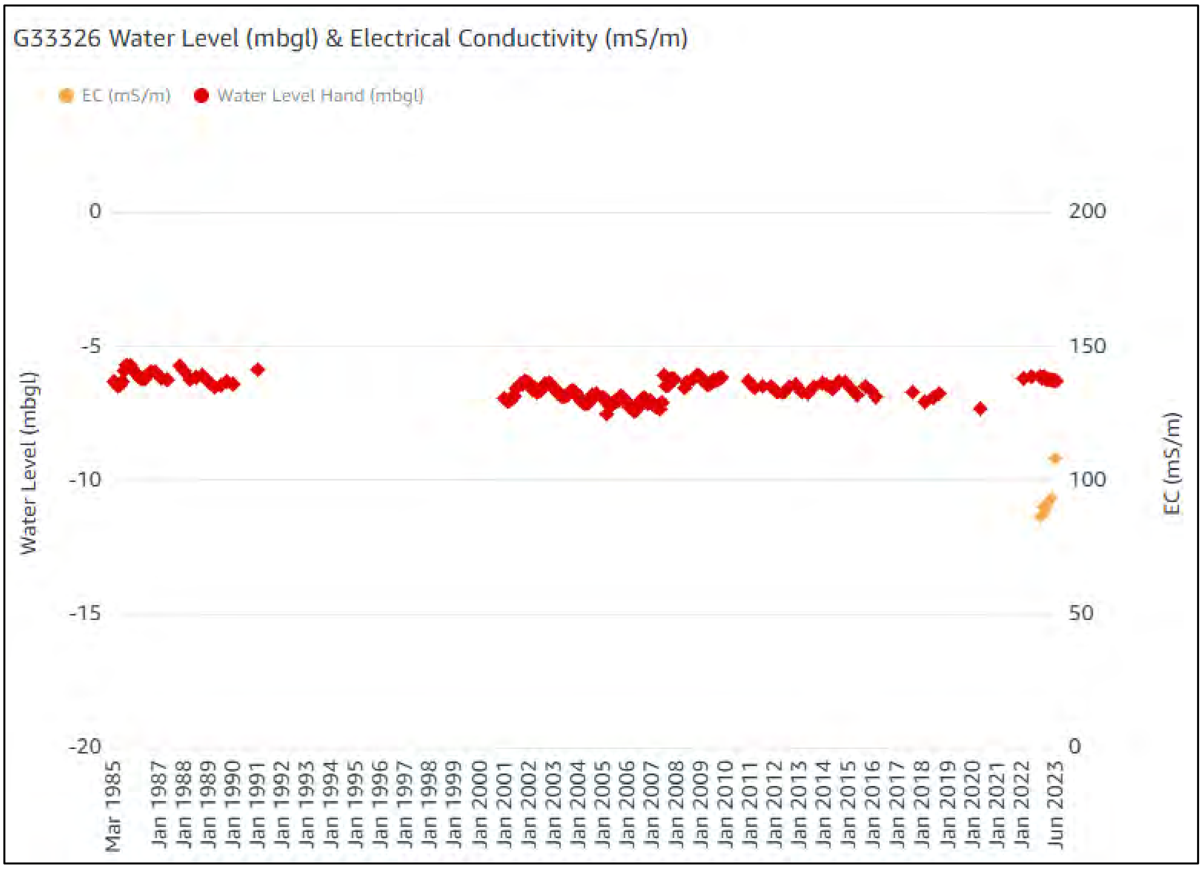

Figure 16.11 G33326 long-term water level graph.

Borehole:	**G46065**
Location:	Saldanha Bay Local Municipality
Borehole details:	
East (dd_WGS84):	18.271270
South (dd_WGS84):	-32.933970
Elevation (mamsl):	30 m
Aquifer:	Lower Aquifer
Collar height (m):	0.44 m
Borehole depth (m):	34 m

Field Measurements:			
Date	*Time*	*WL (mbgl)*	*Field Comment*
2023/06/09	11:25	2.72	Marginal fluctuations in groundwater levels at this borehole can be attributed to seasonal variation. ECs range between 80–95 mS/m – no concerns are noted.

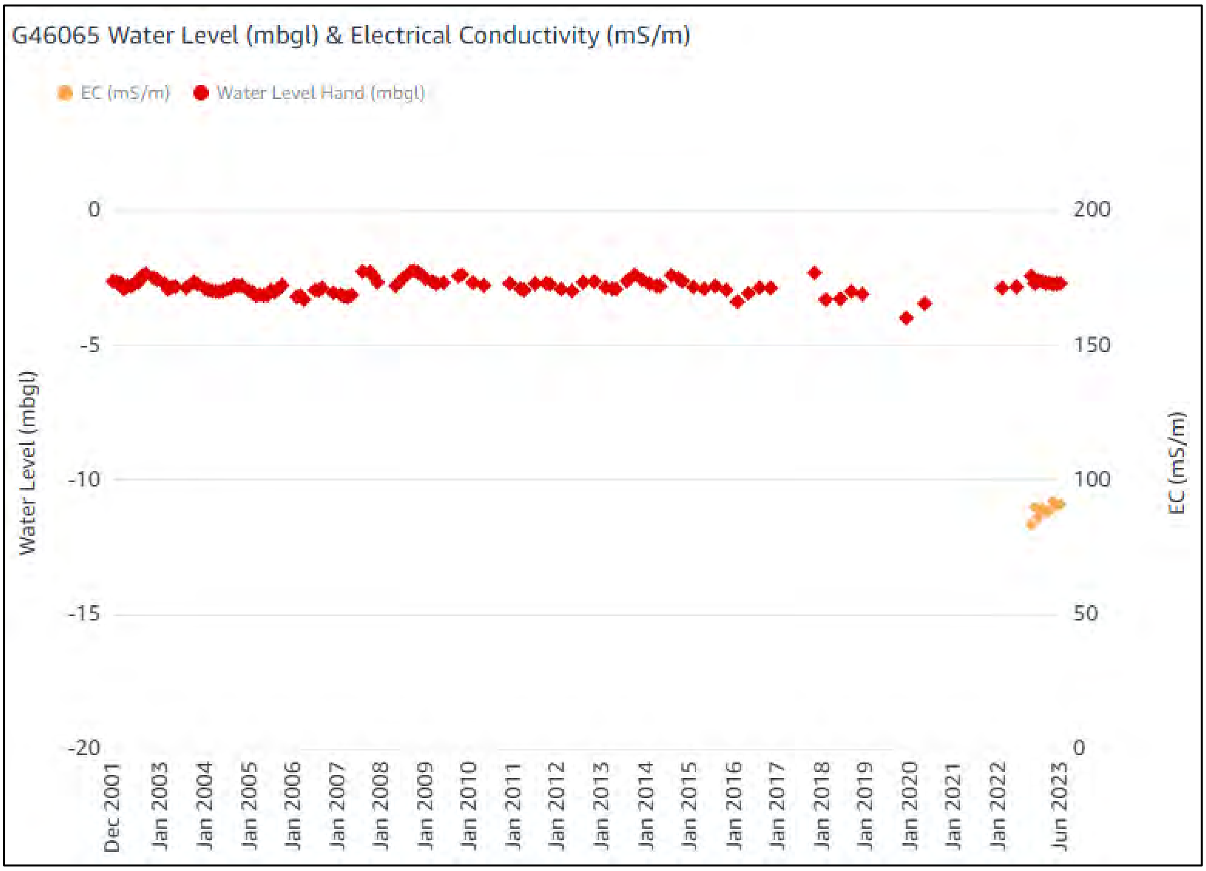

Figure 16.12 G46065 long-term water level graph.

16.2 Appendix 2: The marine alien and invasive species recorded along the coastline of South Africa.

Table 16.1. The marine alien and invasive species recorded along the coastline of South Africa, according to SANBI (South African National Biodiversity Institute), updated with additional species from Robinson et al. (2020).

Kingdom	Phylum	Class	Species	Common name	Status	Natural Range
Animalia	Annelida	Polychaeta	*Alitta succinea*	Pile/clam worm	Invasive	Atlantic Coast
			Boccardia proboscidea	Shell worm	Invasive	Northern Pacific
			Dodecaceria pacifica	Colonial tubeworm	Alien	Pacific Northern America
			Ficopomatus enigmaticus	Estuarine tubeworm	Invasive	Australia
			Janua heterostropha	-	Alien	Europe
			Neodexiospira brasiliensis	-	Invasive	West Indies, Brazil
			Polydora hoplura	-	Invasive	Europe, Mediterranean
			Polydora websteri	Oyster mudworm	Alien	-
			Simplaria pseudomilitaris	-	Alien	Europe
	Arthropoda	Copepoda	*Acartia (Odontacartia) spinicauda*	-	Alien	Southeast Asia
		Hexapoda	*Anisolabis maritima*	Maritime Earwig	Alien	-
			Cafius xantholoma	-	Invasive	Europe
		Malacostraca	*Apocorophium acutum*	-	Alien	Northern Atlantic
			Caprella mutica	Japanese skeleton shrimp	Invasive	Japan
			Carcinus maenas	European shore-crab	Invasive	Europe, Mediterranean
			Cerapus tubularis	Tubular amphipod	Invasive	-
			Chelura terebrans	Wood-boring amphipod	Invasive	Northern Atlantic
			Dynamene bidentata	-	Invasive	Europe
			Ericthonius brasiliensis	-	Invasive	Northern Atlantic
			Ericthonius difformis	Tube-dwelling amphipod	Alien	-
			Homalaspis plana	Chilean Stone Crab	Alien	Chile
			Ischyrocerus anguipes	-	Invasive	Northern Atlantic
			Jassa marmorata	Tube amphipod	Alien	Northern Atlantic

Kingdom	Phylum	Class	Species	Common name	Status	Natural Range
			Jassa morinoi	-	Invasive	-
			Jassa slatteryi	-	Invasive	Pacific Northern America
			Ligia (Megaligia) exotica	Wharf Roach	Alien	North Atlantic
			Limnoria quadripunctata	Quadripunctate gribble	Alien	-
			Limnoria tripunctata	Tripunctate gribble	Alien	-
			Monocorophium acherusicum	Fat-feeler amphipod	Alien	Northern Atlantic
			Orchestia gammarellus	Shore-hopper	Invasive	Europe, Mediterranean
			Paracerceis sculpta	Sponge isopod	Alien	North-east Pacific
			Platorchestia platensis	Beach flea	Invasive	-
			Porcellana africana	Porcelain crab	Invasive	North-west Africa
			Rathbunixa occidentalis	Western pea crab	Invasive	Pacific Northern America
			Sphaeroma serratum	Sea slater	Alien	Europe
			Sphaeroma walkeri	Fouling isopod	Alien	Northern Indian Ocean
			Xantho hydrophilus	Variable xanthid	Alien	Europe, Mediterranean
		Pycnogonida	*Ammothella appendiculata*	-	Alien	Pacific
		Thecostraca	*Amphibalanus venustus*	Striped barnacle	Invasive	Tropical Northern Atlantic
			Austrominius modestus	Modest barnacle	Alien	Australasia
			Balanus glandula	Pacific barnacle	Invasive	Northern American Pacific
			Perforatus perforatus	Perforated barnacle	Alien	Atlantic Ocean
	Brachiopoda	Lingulata	*Discinisca tenuis*	Disc lamp shell	Invasive	Namibian Coast
	Bryozoa	Gymnolaemata	*Bugula neritina*	Fouling moss animal	Invasive	-
			Bugulina flabellata	Fan-shaped moss animal	Invasive	-
			Conopeum seurati	-	Invasive	Europe
			Cryptosula pallasiana	Red crust	Invasive	Europe
			Virididentula dentata	Dentate moss animal	Invasive	Indo-Pacific
			Watersipora subtorquata	Red-rust bryozoan	Invasive	Caribbean
	Chordata	Ascidiacea	*Ascidia sydneiensis*	Yellow-green sea squirt	Invasive	Asia
			Ascidiella aspersa	Dirty sea squirt	Invasive	North Sea

Kingdom	Phylum	Class	Species	Common name	Status	Natural Range
			Asterocarpa humilis	-	Invasive	-
			Botryllus schlosseri	Golden star ascidian	Invasive	Northeastern Atlantic
			Ciona robusta	Sea vase	Invasive	Europe
			Clavelina lepadiformis	Bell ascidian	Invasive	Europe
			Diplosoma listerianum	Gossamer ascidian	Invasive	Europe
			Microcosmus squamiger	Microcosmus	Invasive	Australia
			Styela plicata	Pleated sea squirt	Invasive	West Pacific
		Teleostei	*Cyprinus carpio*	Common carp	Invasive	Asia
	Cnidaria	Anthozoa	*Cylista ornata*	Rooted anemone	Alien	Europe, Mediterranean
			Metridium senile	Plumose anemone	Alien	North Atlantic
		Hydrozoa	*Coryne eximia*	-	Invasive	North Atlantic, Pacific
			Ectopleura crocea	Pinkmouth hydroid	Alien	North Atlantic
			Ectopleura larynx	Ringed tubularia	Alien	North Atlantic
			Gonothyraea loveni	-	Alien	North Atlantic
			Laomedea calceolifera	-	Alien	North Atlantic
			Obelia bidentata	Doubletoothed hydroid	Alien	-
			Obelia dichotoma	Thin-walled obelia	Alien	-
			Obelia geniculata	Zigzag wineglass hydroid	Alien	Europe, Mediterranean
			Odessia maeotica	-	Invasive	Black Sea Region
			Pachycordyle michaeli	Brackish hydroid	Alien	Europe, Mediterranean
			Pennaria disticha	Sea-fern hydroid	Invasive	-
	Echinodermata	Asteroidea	*Heliaster helianthus*	South American Sunstar	Alien	South America
		Ophiuroidea	*Ophiactis savignyi*	Savigny's brittle star	Alien	North Indian and Pacific Oceans
	Mollusca	Bivalvia	*Lyrodus pedicellatus*	Blacktip shipworm	Alien	-
			Magallana gigas	Pacific oyster	Invasive	Japan, Northwestern Pacific
			Mytilus galloprovincialis	Mediterranean mussel	Invasive	Mediterranean, Northeastern Atlantic
			Perna viridis	Asian green mussel	Alien	Southeast Asia
			Semimytilus patagonicus	Bisexual mussel	Invasive	Pacific South America

Kingdom	Phylum	Class	Species	Common name	Status	Natural Range
			Teredo navalis	Naval shipworm	Invasive	Europe, Mediterranean
		Gastropoda	*Catriona columbiana*	British Columbia aeolid	Alien	North Pacific
			Indothais blanfordi	-	Invasive	Tropical Indo-Pacific
			Littorina saxatilis	British periwinkle	Invasive	Europe, Mediterranean, Western Atlantic
			Semiricinula tissoti	Tissot's rock shell	Invasive	Tropical Indo-Pacific
			Tarebia granifera	Quilted melania	Invasive	Southeast Asia
	Porifera	Demospongiae	*Suberites ficus*	Sea orange/fig sponge	Invasive	Northeastern Atlantic and Mediterranean
Chromista	Ciliophora	Heterotrichea	*Mirofolliculina limnoriae*	-	Alien	-
	Myzozoa	Dinophyceae	*Alexandrium minutum*	Red tide phytoplankton/dinoflagellate	Alien	-
			Alexandrium tamarense-complex	Alexandrium	Alien	-
			Dinophysis acuminata	-	Alien	-
Plantae	Chlorophyta	Ulvophyceae	*Cladophora prolifera*	Rough cladophora	Invasive	-
			Codium fragile	Fragile upright codium	Invasive	Korea
	Rhodophyta	Florideophyceae	*Antithamnionella spirographidis*	-	Invasive	-
			Asparagopsis armata	Harpoon weed	Invasive	Southern Australia and New Zealand
			Asparagopsis taxiformis	Supreme limu	Invasive	-
			Schimmelmannia elegans	-	Alien	Atlantic Island of Tristan da Cunha and Venezuela

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