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OCEANS AND COASTS
AROUND SOUTH AFRICA 2014

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Cover: Two species of turtle breed in KwaZulu-Natal and several other species visit South Africa's waters (source: www.istock.com)

Executive summary

1. The physical oceanography of waters around South Africa is predominantly driven by the warm, fast-flowing Agulhas Current along the East Coast and wind-driven upwelling of the Benguela Current system in the west. Both the Agulhas Current and upwelling influence the Agulhas Bank in the south. The Agulhas Current is driven by the wind field over the Indian Ocean and has strengthened recently. Changes to the locations of the oceanic high pressure systems over the South Atlantic and South Indian oceans will affect the strength and location of upwelling along the west coast and over the Agulhas Bank and the productivity of these two systems.

2. The chemistry of the global oceans is undergoing fundamental changes, in response to climate change, rising atmospheric carbon dioxide, excess nutrient inputs from land and many forms of pollution. Major global trends observed include a shift in the acid-base chemistry of seawater, reduced subsurface oxygen in both nearshore and open ocean water masses, rising coastal nitrogen levels and widespread increases in mercury and persistent organic pollutants. An Ocean Acidification Indicator (ACID-I) developed for South Africa's west coast showed that acidification is most severe in the north and inshore. An ocean oxygen indicator (O2-I) for the same region suggests that water depths of approximately 30 to 120 m, and average dissolved oxygen concentrations for the bottom 10 m of the water column, are ideal criteria for establishing the extent of bottom water hypoxia in the southern Benguela upwelling system.

3. Plankton form the basis of marine food webs, and many animals higher up the food web are dependent on plankton as a food source. Satellite remote sensing is an ideal tool to monitor large-scale spatial and temporal changes in the concentration of chlorophyll at the ocean surface, which is an index of phytoplankton biomass. Along the West Coast, chlorophyll index values are generally higher than along the South Coast, and there is a strong seasonality related to the annual upwelling cycle. Despite considerable spatial variability, chlorophyll levels have on average remained fairly high over the past few years. Zooplankton are the link between phytoplankton and higher foodweb levels including pelagic forage fish. The abundance of copepods, a proxy for zooplankton, on the West Coast is much higher now than it was 5–6 decades ago, although abundances started declining around the mid-1990s. At the same time, there was a shift towards smaller species dominance, which is indicative of ocean warming. Similar changes in copepod abundance and size composition occurred on the South Coast. Whether these changes are mainly driven from the bottom up (e.g. ocean warming) or from the top down (e.g. increased predation by pelagic fish), or a combination of the two, remains unclear but they have fundamental impacts on biogeochemical processes, food web structure and ecosystem functioning.

4. The role of top predators as indicators of marine ecosystems is widely acknowledged and monitoring of top predators assists the Department of Environmental Affairs (DEA) in its unique role of attempting to identify and monitor those potential areas of accumulation (over time) and aggregation (over space) of negative impacts on the environment. Large recent changes in the populations and distributions of some seabirds in southern Africa reflect shifts to the south and east in the distributions of their prey. Seabirds are also indicating change at South Africa's sub-Antarctic Prince Edward Islands (PEIs). Monitoring of marine top predators has additionally proved useful in identifying thresholds of impact, beyond which the integrity of ecosystems is or maybe significantly altered. Ecotourism activities targeting marine top predators

expanded rapidly in the 21st century and generate substantial revenue for South Africa. However, whereas some opportunistic, adaptable predators, e.g. seals, have a healthy conservation status, the overall conservation status of seabirds in South Africa has deteriorated. Abundant predators, such as seals, may have impacts on other species. Many of South Africa's marine top predators travel extensive distances and hence require management at regional or international levels.

5. It is recognised that South Africa's existing marine protected area (MPA) network falls well short of representing the full diversity of the country's ocean systems. At present, less than 0.5% of the ocean space within the mainland's EEZ (i.e. excluding the PEIs) occurs in MPAs, while 40% of the 136 marine and coastal ecosystem types, which have been classified, are not represented in the MPA network and offshore habitat is scarcely protected. This is being addressed by the Operation Phakisa, in terms of which 18 new MPAs and expansions to three existing MPAs have been proposed. If implemented, these will increase MPA coverage within the EEZ to more than 5% and advance habitat representation from 60% to 94%, with 46 of the 54 ecosystem types, which currently have no protection, being included. Systematic conservation planning with an emphasis on habitat representativeness, and descriptions of ecologically or biologically significant areas (EBSAs) and vulnerable marine ecosystems (VMEs), have all informed the prioritisation of marine or coastal areas for protection in South Africa. To date, single species conservation concerns have received far less consideration. Given the ongoing declines in Endangered seabird populations (e.g. African penguin), spatial protection for such species warrants much greater emphasis in future MPA planning.

A northern giant petrel at Salisbury Plain, South Georgia. The species breeds at South Africa's Prince Edward Islands (photo Arthur Morris).

1. Introduction

Marine ecosystems are being affected by climate change worldwide. Often such change is pronounced at high latitudes, where its impact on associated fauna is readily apparent. For example, *in the* West Antarctic Peninsula, there have been poleward shifts in ice extent and local declines of ice-dependent Adélie penguins, which contrast with increases and a southward range extension of Gentoo penguins that do not depend on ice[1, 2]. At lower latitudes changes in distributions of marine fauna also may be pronounced[3], but sometimes the reasons for these and altered population trends are not as clearly understood. In many instances, this remains the case for South Africa's complex and variable marine ecosystems[4]. However, progress is being made in understanding some of the drivers of change[5]. This has been aided by monitoring and research of South Africa's marine and coastal environments that has been undertaken by the Department of Environmental Affairs (DEA).

In the *State of the Oceans and Coasts around South Africa Report 2014*, aspects of this monitoring and research are briefly elaborated upon. It is hoped that these few examples will illustrate how South Africa is attempting to enhance its knowledge base for management of its ocean space and associated resources. The report considers some features of the physical and chemical oceanography of South Africa's marine environment and then the plankton of its oceans, which form the basis of the marine food webs. Top predators, such as large sharks, turtles, seabirds and marine mammals are managed by DEA and are most useful indicators of the health and functioning of marine ecosystems, as well as targets for marine ecotourism. These and other aspects of research and monitoring are discussed. Finally, the present status of protection of South Africa's marine habitats is described.

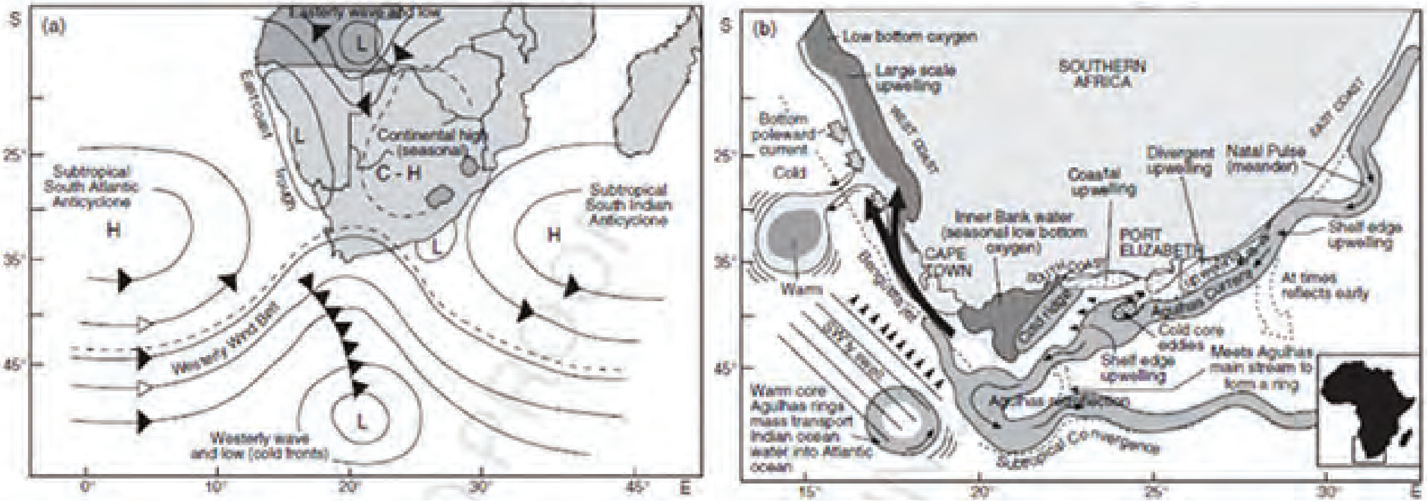
2. Physical oceanography around southern Africa

Michael J Roberts

The marine environment around southern Africa is one of the most diverse, complex and variable anywhere in the world[6] (Figure 2.1).

2.1. Agulhas Current and Agulhas Bank

The oceanography of South Africa's east coast and outer Agulhas Bank (south coast) is strongly influenced by the warm, fast-flowing (2 m s^{-1}) Agulhas Current. This is a well-defined western boundary current with origins in the Moçambique Channel[6], which transports some 100 Sv (1 Sv=1 million m^3 s^{-1}). At the southern tip of the Agulhas Bank, the Agulhas Current undergoes a number of configurations, which include retroflection eastwards along the Subtropical Convergence into the South Indian Ocean, the formation of anticyclonic rings shed into the South Atlantic[7] or continuous flow along the shelf edge of the western Bank[8]. On the outer Agulhas Bank, the oceanography is dominated by associated shear boundary processes, such as meanders, eddies, and break-away filaments[9]. Large-scale upwelling is common east of Port Elizabeth, as a result of the divergence between the shelf edge (and Agulhas Current) and the coast[10]. Intense thermoclines induced by shelf-edge upwelling and insolation are characteristic of the eastern and central Bank[11]. The inner shelf is influenced by wind-driven coastal upwelling, particularly during summer[12]. Upward doming of the thermocline in an elongated formation is often found on the central Agulhas Bank. This feature, referred to as a 'cold ridge' (Figure 2.1b), is commonly associated with high levels of primary and secondary production[13]. Large, solitary, transient meanders in the Agulhas Current, referred to sometimes as a 'Natal Pulse', are at times found on South Africa's east coast[14]. These have profound influences on the shelf oceanography there, as well as on the trajectory of the Agulhas Current. Ring formation has been associated with the Natal Pulse[15].



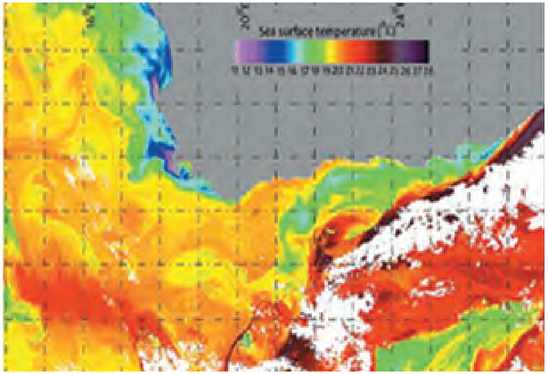


Figure 2.1: (a) The complexity and variability of the marine environment around southern Africa is partly due to the latitude and associated weather. In summer, the oceanic high-pressure cells either side of southern Africa dominate the wind field, causing south-easterly winds on the West Coast and north-easterly winds on the eastern Agulhas Bank and East Coast. In winter, the westerly wind belt migrates north, moving cold fronts and strong westerly winds onto southern Africa. (b) The oceanography is also dominated by the warm Agulhas and cold Benguela currents. These drive many of the physical processes and key features on the shelf. (c) An SST image highlighting the difference in temperatures between the East and West coasts. ((a) and (b) from[26], (c) courtesy of Marine Remote Sensing Unit, CSIR, Rosebank).

2.2. Benguela upwelling system

The West Coast is completely different, being dominated by the cold Benguela upwelling system[16], one of the largest eastern boundary upwelling systems in the world and primarily driven by the South Atlantic High Pressure (anticyclone) and associated south-easterly winds (Figure 2.1a). Consequently, the region has abundant primary and secondary production, the decay of which frequently leads to low levels of dissolved oxygen in the bottom layer, and at times almost anoxic conditions[17] (chapter 3). Off South Africa's west coast, the outer shelf is influenced by the north-flowing, cool and relatively slow (0.25–0.50 m s^{-1}) Benguela Current[18]. This eastern boundary current is less defined than the Agulhas Current, and essentially is the eastern component of the South Atlantic gyre. A narrow frontal jet, referred to as the Benguela jet, is common along the shelf edge between the Cape Peninsula and Cape Columbine (Figure 2.1b). Compared with the Agulhas Current, the Benguela jet is small, with maximum velocities of about 0.75 m s^{-1} and a flow of 7 Sv. North of Cape Columbine the jet undergoes bifurcation, moving onto the wider shelf and into the South Atlantic towards the Walvis Ridge. The northern boundary of the Benguela is where the continental margin narrows at 16 °S, and is marked by the permanent warm Angola-Benguela Front, the location of which may vary over several degrees of latitude[19]. Agulhas rings[20], other eddy features[21], and filaments[22] interact with the West Coast's shelf causing water to be drawn offshore (Figure 2.1b). A poleward undercurrent on the shelf and slope varies in strength and seasonal dependence[23]. Much of the variability on the shelf around South Africa is consequently caused by the dynamics of the Agulhas Current, the Benguela Current (and jet), and the north-south seasonal migration of the atmospheric high-pressure cell situated over the SE Atlantic and SW Indian oceans[24] (Figure 2.1a). In winter, the westerly belt expands to the latitudes of southern Africa, causing strong westerly winds to dominate, with large swells. In summer, the westerly belt contracts southwards, and the wind field is then largely driven by the two anticyclones (South Atlantic and South Indian, see Figure 2.1a), causing coastal upwelling on the west coast and the Agulhas Bank.

2.3. Present and future change

The Agulhas Current is observed to be undergoing changes, which are likely to have a profound effect on the local climate and marine and coastal ecosystems of South Africa. The Current is driven by the wind field over the Indian Ocean. Since the 1980s, the sea surface temperature of the Agulhas Current system has increased significantly[25]. This is due to an increase of its transport in response to an intensification in wind stress curl in the South Indian Ocean. In turn, this causes an intensification of the Agulhas Current system and leads to an increased flux of salt and heat into the Atlantic Ocean. There is also an augmentation in the transfer of energy from the Agulhas Current to the atmosphere due to increased evaporation. These observed changes could have far-reaching consequences over and above their potential regional impacts on ecosystems and climate.

3. Chemical oceanography

Stephanie de Villiers and Mutshutshu Tsanwani

The chemistry of the global coastal and open ocean is undergoing fundamental changes, in response to climate change, rising atmospheric carbon dioxide (CO_2), excess nutrient inputs from land, and many forms of pollution. Major global trends observed include a shift in the acid-base chemistry of seawater, reduced subsurface oxygen in both near-shore and open ocean water masses, rising coastal nitrogen levels, and widespread increases in mercury and persistent organic pollutants. Most of these perturbations are projected to grow in coming decades and negatively to impact on ocean biota, marine resources and the industries and communities dependent on these resources.

Two chemical indicators of ecosystem health are introduced here for the South African marine environment for the first time, (i) the Ocean Acidification Indicator (ACID-I) and (ii) the Ocean Oxygen Indicator (O2-I). For the purpose of this report, the status of these indicators is assessed for South Africa's west coast only, i.e. the southern Benguela upwelling system. This choice of geographic area is based on the data available: the southern Benguela area has been the focus of most offshore ship-based monitoring efforts of the Department of Environmental Affairs (DEA) in the recent past. This, in turn, has been motivated by the elevated levels of productivity characteristic of this upwelling area, which are the highest in South Africa's EEZ, from a marine living resource perspective. Future reports will include assessment of these indicators in other geographic areas, for example variability in ACID-I in South Africa's coastal waters, as well as the introduction of other indicators, which are currently under development, such as indicators of coastal eutrophication and levels of mercury pollution.

3.1. Ocean acidification indicator (ACID-I)

Ocean uptake of anthropogenic CO_2 alters ocean chemistry, leading to more acidic conditions (lower pH) and lower chemical saturation states (Ω) for the calcium carbonate ($CaCO_3$) minerals used by many plants, animals and microorganisms to make shells and skeletons. The critical chemical reaction for organisms is the reduction of carbonate ion (CO_3^{2-}) concentrations through the reaction:

$$H^+ + CO_3^{2-} \rightarrow HCO_3^-$$

Although this reaction increases the total amount of dissolved inorganic carbon (DIC) in seawater, declining CO_3^{2-} concentrations lower the $CaCO_3$ saturation state,

$$\Omega = [Ca^{2+}].[CO_3^{2-}]/K_{sp}$$

where K_{sp} is the thermodynamic solubility product of the mineral $CaCO_3$. Marine organisms form two major forms of the mineral $CaCO_3$, aragonite (corals, pteropods and many molluscs) and calcite (coccolithophores, foraminiferans, and some molluscs). Aragonite is more soluble in seawater than calcite. If seawater becomes under-saturated with respect to $CaCO_3$ ($\Omega < 1$), unprotected shells and skeletons of marine organisms begin to dissolve. Increased ocean acidification can, therefore, have massive implications for ecosystem health and function.

For the purpose of this report, the Ocean Acidification Indicator (ACID-I) is defined as the aragonite saturation state, $\Omega_{aragonite}$. An ACID-I value above 1.0 indicates seawater that is saturated with respect to aragonite (and therefore also calcite); values below 1.0 indicate seawater conditions favourable to aragonite dissolution. An ACID-I (or $\Omega_{aragonite}$) value of 0.63 is equivalent to calcite saturation, and values below 0.63 will therefore favour the dissolution of both aragonite and calcite mineral phases. Published results, however, show that both aragonite and calcite are suspect to dissolution above their respective thermodynamic dissolution horizons. Therefore, in order to define critical ACID-I boundary values, thresholds values of 1.2 and 0.8 are assumed instead for ACID-I, to represent potential *in situ* conditions that may induce dissolution of aragonite and calcite, respectively.

Water in upwelling areas, such as the Benguela upwelling system, have a naturally low pH and may be naturally under-saturated with respect to the carbonate mineral phases. At present, our knowledge of the $CaCO_3$ saturation state of South Africa's coastal and offshore waters is poor and needs to be improved on. This will provide baseline data for long-term monitoring of ocean acidification related to anthropogenic factors, such as increasing atmospheric CO_2 absorption by the ocean. Figure 3.1 shows the offshore depth profiles for ACID-I (or $\Omega_{aragonite}$) along DEA's three Integrated Ecosystem Programme (IEP) monitoring lines off the west coast of South Africa, for the April 2014 cruise. Values for ACID-I are calculated from combined measurements of the carbonate system parameters DIC and Alkalinity, on discrete water samples collected at hydrographic (CTD) stations.

From Figure 3.1 it can be seen that aragonite under-saturation is widespread on South Africa's west coast, particularly in bottom water along the inshore stations. Small pockets of water also occasionally experience calcite under-saturation. These results have important implications for marine calcifying organisms in the southern Benguela upwelling system, and continued study and monitoring is required.

Figure 3.2 shows the ACID-I scorecards for selected locations at the surface (Figure 3.2a) and in bottom waters (Figure 3.2b) along the three IEP monitoring lines, surveyed in September 2013 (1st indicator box), April 2014 (2nd box) and August 2014 (3rd box).

The scorecard results for ACID-I show that at the ocean surface, ocean acidification is most severe at the inshoremost stations along the northern monitoring line (off Kleinsee). In bottom waters, the most persistent under-saturation with respect to aragonite is observed along the same line at the same inshore locations. However, the most pronounced evidence for ocean acidification, i.e. under-saturation with respect to both aragonite and calcite, is episodically found along the inshore stations of the southernmost line (off St Helena Bay).

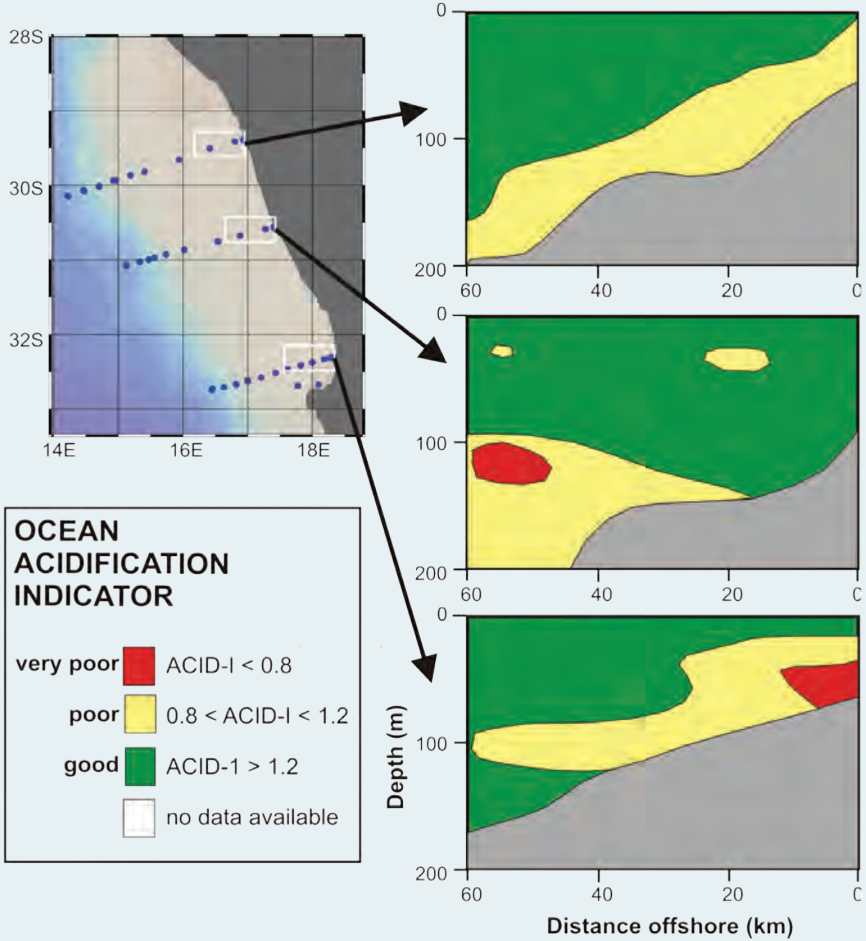


Figure 3.1: Spatial variability in ACID-I along three West Coast monitoring lines, for the April 2014 monitoring cruise on R/V *Algoa*.

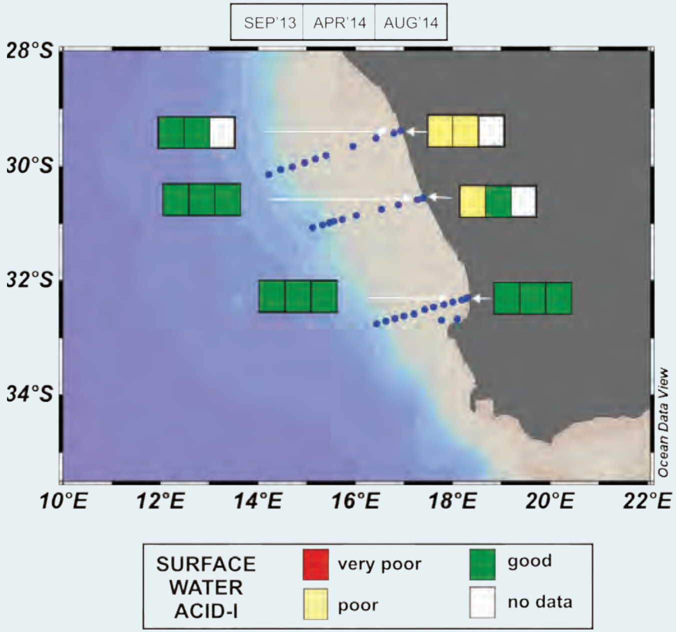


Figure 3.2a: SCORECARD: surface water ACID-I on South Africa's west coast.

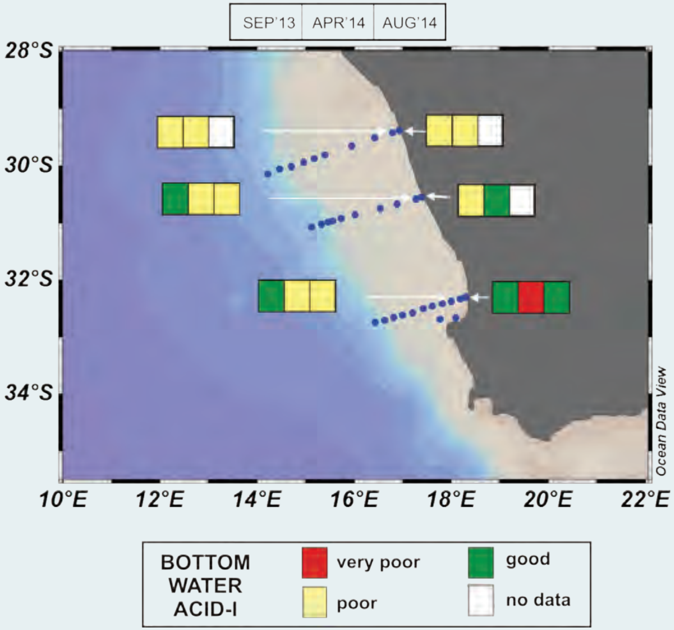


Figure 3.2b: SCORECARD: bottom water ACID-I on South Africa's west coast.

3.2. Ocean oxygen indicator (O2-I)

Dissolved oxygen concentrations in the global ocean have been routinely measured for more than 100 years. The near-surface water, which extends down to 100 m, is typically saturated with oxygen by the supply from the atmosphere and photosynthesizing primary producers. In the deeper ocean, however, oxygen concentrations are determined by a complicated interplay of water circulation and consumption due to biological respiration. Changes in either physical or biological processes can lead to changes in the ocean's oxygen content. Dissolved oxygen can, in fact, be viewed as a sensitive early-warning system for global (climate) change in the ocean. Research efforts in recent years have recorded decreasing oxygen concentrations for almost all of the ocean basins. These trends are, however, fairly weak and mainly limited to water masses in the upper 2000 m of the ocean.

In the global ocean, the lowest oxygen concentrations are found at mid-latitudes, especially on the west coasts of continents, associated with upwelling systems. These large oceanic oxygen-minimum zones are natural dead zones for higher organisms, and are not caused by humans. Marine organisms have a wide range of tolerance levels to oxygen-poor conditions. If dissolved oxygen levels fall below certain threshold values, the water becomes unsuitable to sustain life of higher organisms. Sessile, attached organisms die, while mobile organisms will attempt to swim or walk away. Crustaceans and fish generally require higher oxygen concentrations than mussels and snails. At dissolved oxygen levels below 2 mg L^{-1}, benthic fauna typically starts to show aberrant behaviour. Anoxic conditions, i.e. when dissolved oxygen levels are below 0.5 mg L^{-1}, result in mass mortality and the formation of 'dead zones'. This may negatively impact on fisheries resources, with socio-economic repercussions. For example, the February 2015 DEA survey took place two weeks after the detection of a harmful algal bloom, which was responsible for the killing of more than 300 tons of rock lobster, 7 tons of fish and 10 tons of molluscs in Elands Bay, Dwarskersbos and Donkin Bay on the west coast of South Africa. The bloom stretched from Dwarskersbos in the south to the Orange River in the north and as far as 80 km offshore in some areas.

Changes in wind-driven upwelling, induced by climate-change-related alterations in wind pattern or upper ocean stratification may exacerbate the extent of these natural oxygen-minimum zones in coastal zones. There is conflicting evidence on how coastal upwelling may respond to climate change, and impacts may vary regionally. The status of water-column dissolved oxygen levels along three monitoring lines during the April 2014 ship-based monitoring survey off South Africa's west coast is illustrated in Figure 3.3. From the combined monitoring surveys it can be seen that hypoxic conditions ($O_2 < 2$ mg L^{-1}) are typically restricted to bottom waters in the inshore zone. These data, combined with longer-term monitoring information, suggest that water depths of approximately 30 to 120 m, and average dissolved oxygen concentrations for the bottom 10 m of the water column, are ideal criteria for establishing the extent of bottom water hypoxia in the southern Benguela upwelling system. These location criteria capture both the movement of hypoxic waters towards shallower areas and its offshore extent.

Figure 3.3 also summarizes the dissolved oxygen threshold levels that define the status of the Ocean Oxygen Indicator (O2-I), from > 4 mg L^{-1} for 'good conditions' to < 0.5 mg L^{-1} for anoxic or 'very poor' conditions. Based on these levels, and the choice of sampling depths along each of the three monitoring lines, the scorecard for the Ocean Oxygen Indicator for the west coast of South Africa, determined from the four surveys conducted between September 2013 and February 2015, is shown in Figure 3.4.

3.3. The Harmful Algal Bloom event of February 2015: variability of partial pressure of carbon dioxide (pCO_2) and dissolved oxygen (O_2)

Harmful Algal Blooms (HABs), also known as 'red tides', occur when toxic or otherwise harmful microscopic algae grow to excessively high cell concentrations well beyond normal conditions. HABs are capable of killing marine organisms such as fish, shellfish and birds and can also cause health problems to humans. During a HAB event along South Africa's west coast in February 2015, which caused mass mortalities of rock lobster, fish and molluscs, there were clear patterns of co-variation of nearshore sea surface pCO_2, temperature and O_2, despite significantly high spatial and temporal variability of each variable (Figure 3.5). A maximum pCO_2 value of 1600 µatm was measured near the shore, indicating that pCO_2 on the West Coast during the summer upwelling season is already exceeding 880 µatm, the projected value for 2100.

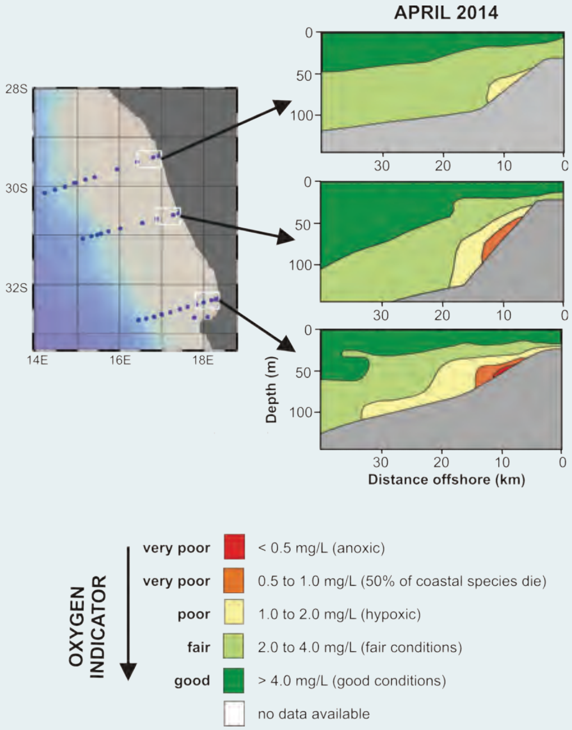


Figure 3.3: Water column dissolved oxygen profiles in April 2014 along three West Coast monitoring lines that are sampled 3–4 times a year as part of DEA's Integrated Ecosystem Programme (IEP).

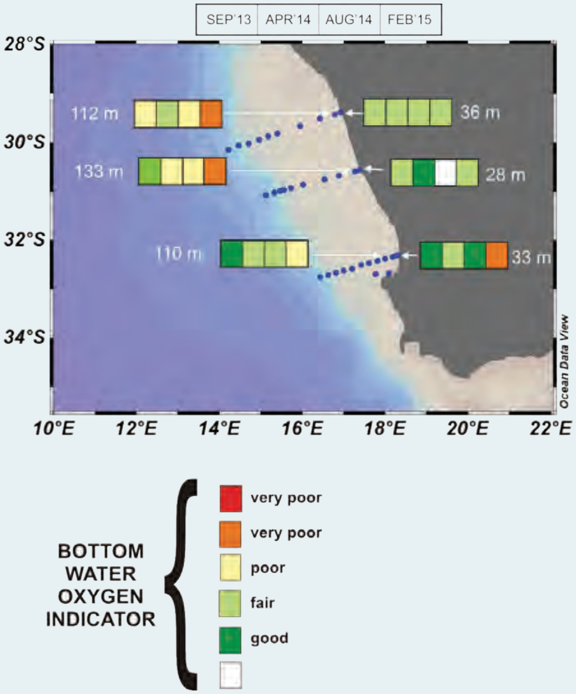


Figure 3.4: SCORECARD: bottom water O2-I status (Sept. 2013 – Feb. 2015).

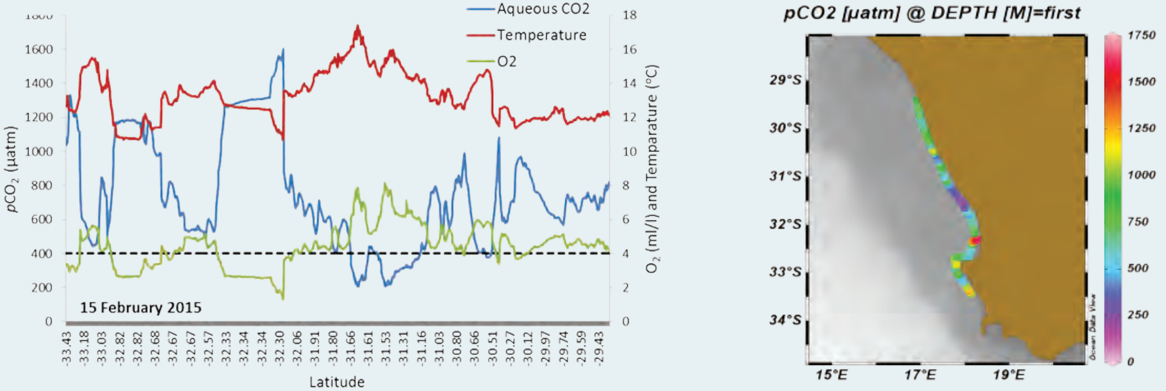


Figure 3.5: Relationship between ocean surface pCO_2, temperature and O_2 in the near-shore zone of the southern Benguela between Cape Town (on the left of the X-axis) and the Orange River (on the right) during the Harmful Algal Bloom in February 2015. The dotted line represents the estimated contemporary pCO_2 levels of about 400 μatm.

The CO_2-rich waters found inshore were characterized by low temperature and low O_2 concentration, suggesting that upwelling is a major driver of the observed variability. These cold, CO_2-rich, low-oxygen waters found during the February 2015 survey were locally formed by respiring organic matter below the surface layer. Hypoxic conditions in this region are known to develop in late summer as a result of remineralisation coupled with decreased ventilation.

The pCO_2 of the surface waters observed inshore during the survey in February 2015 was highly variable, ranging between 200 μatm and about 1600 μatm. There was a clear inverse relationship between pCO_2 and O_2, with the maximum pCO_2 value of 1600 μatm coinciding with the lowest O_2 value of 1.34 mg L^{-1} and the minimum pCO_2 of 200 μatm coinciding with the highest O_2 value of 8.16 mg L^{-1}. It is concluded that biological drawdown of CO_2 and production of oxygen took place simultaneously, which suggests that the observed variability is the result of upwelling of cold, CO_2-rich waters depleted in oxygen.

4. Plankton: life adrift in the ocean

Hans M Verheye, Jenny A Huggett and Tarron Lamont

The term ‘plankton’ was coined in 1887 by Victor Hensen (1835–1924), the German founder of quantitative plankton and fishery research, and more critically defined in 1890 by another German, Ernst Haeckel (1834–1919). It is derived from the Greek word πλαναο (planao), meaning ‘to wander’ or ‘to drift’, and it has the same etymological root as ‘planet’. It comprises all those organisms that drift in the water whose abilities of locomotion are not sufficient to withstand currents, as opposed to ‘nekton’, the community of actively swimming organisms such as larger crustaceans, cephalopods, fishes and aquatic birds and mammals. Plankton comprise two major groups, phytoplankton and zooplankton (Figure 4.1), which are important because they form the basis of most aquatic food webs, with fish, corals, shellfish and larger animals such as baleen whales and basking sharks feeding on them.

4.1. Phytoplankton

Phytoplankton are the planktic aquatic plants, or unicellular algae, having tiny silica or cellulose cells packed full of chlorophyll. Phytoplankton may be distinguished from zooplankton (the planktic aquatic animals), the next level up in the food web, based on mode of nutrition: phytoplankton are autotrophic, globally accounting for almost half of the photosynthesis, while zooplankton are heterotrophic.

One proxy measure of phytoplankton biomass is the concentration of chlorophyll in the water. Shipboard sampling does not allow a comprehensive picture of phytoplankton biomass in the entire ecosystem and is also not representative of the complete annual primary production cycle. Therefore, the use of remotely-sensed ocean colour provides much greater spatial and temporal coverage than shipboard measurements.

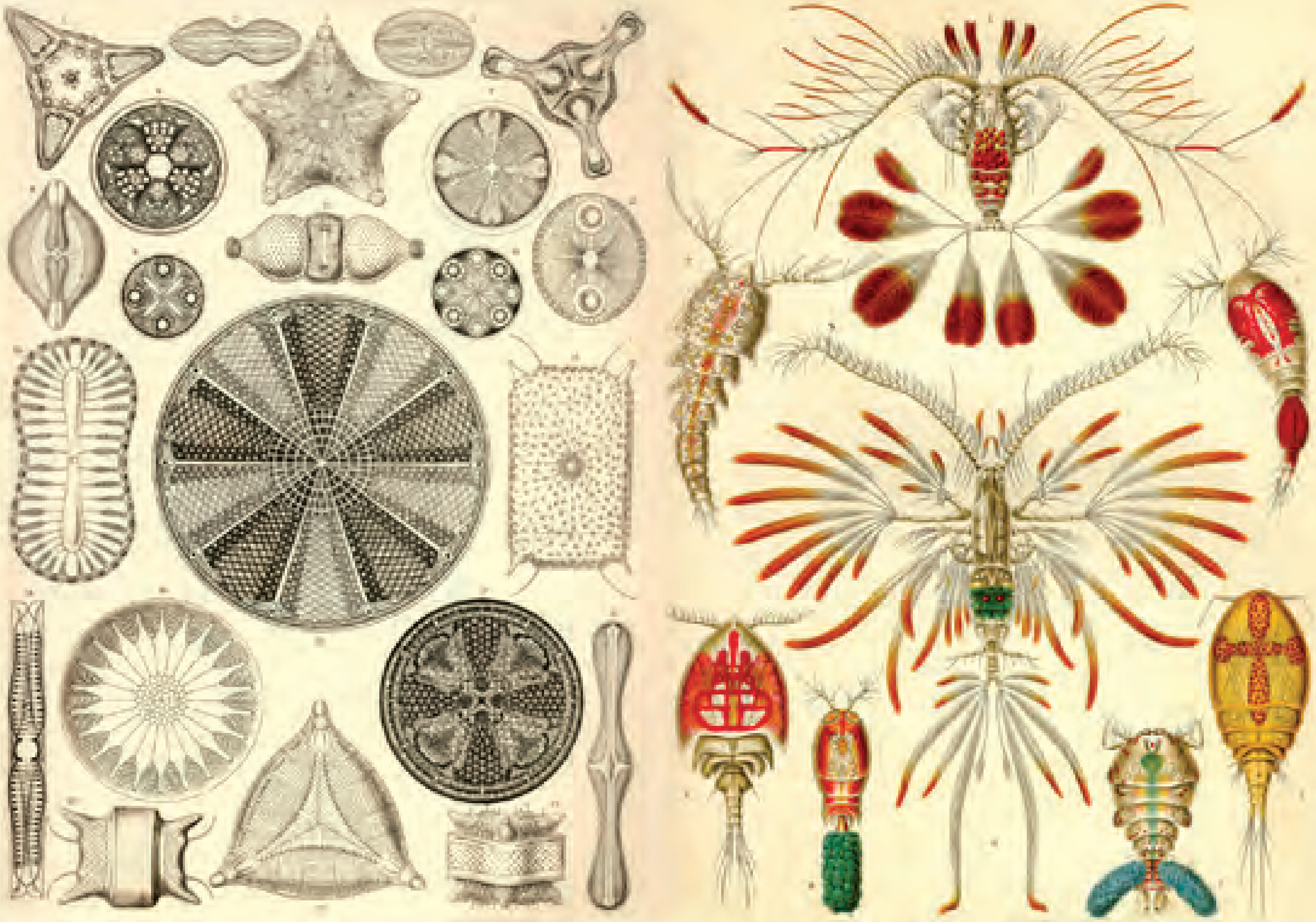


Figure 4.1: Plankton: a collection of (left) diatoms (phytoplankton) and (right) copepods (zooplankton), hand-drawn by Ernst Haeckel (1900) (source: www.BioLib.de).

4.1.1. Surface chlorophyll concentration along the St Helena Bay Monitoring Line

St Helena Bay, on the west coast of South Africa, is one of the most productive regions of the Benguela Current Large Marine Ecosystem (BCLME), and has been the focus of environmental research and monitoring for many decades. In April 2000, a monthly monitoring line was implemented in St Helena Bay, comprising of 14 stations from the coast to 187 km offshore (Figure 4.2).

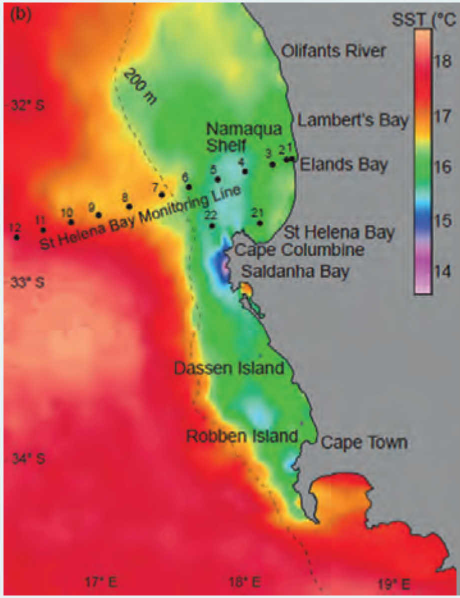
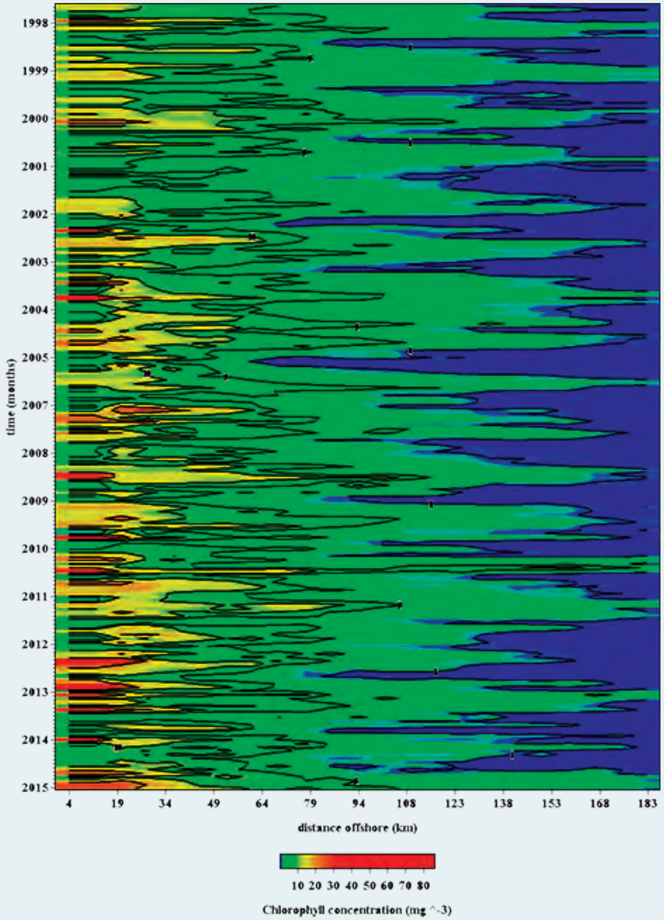


Figure 4.2: Monthly averaged thermal image of the South-West Cape shelf during active upwelling. Station positions along the St Helena Bay Monitoring Line are indicated (from Hutchings L et al. (2012). St Helena Bay (southern Benguela) then and now: muted climate signals, large human impact. African Journal of Marine Science 34(4): pages 559-583. Reproduced from *African Journal of Marine Science* (2012) volume 34 (4) with permission from © NISC (Pty) Ltd and L. Hutchings).



Whereas monthly in situ sampling of hydrological and plankton parameters along this St Helena Bay Monitoring Line (SHBML) was discontinued in March 2012, satellite-derived near-surface data are continually collected and processed. Variations, in space and time, of satellite-derived surface chlorophyll concentrations along the SHBML are illustrated in Figure 4.3. Data were obtained from SeaWiFS for the period September 1997 to June 2002, and from MODIS Aqua thereafter. At the spatial and temporal scales used in this report, there does not seem to be any difference between the SeaWiFS and MODIS Aqua data sets.

Figure 4.3: A space-time plot showing the spatial and temporal variation of surface chlorophyll concentration along the St Helena Bay Monitoring Line for the period September 1997 to February 2015.

A clear seasonal signal in chlorophyll concentration can be observed, with maxima in spring/early summer and late summer/autumn. Generally, higher concentrations always occur close to the coast and diminish with distance from the shore. Concentrations exceeding 5 mg m^{-3} are, on average, found up to 86 km offshore, but occurred up to 120 km offshore during the late summers of 2000, 2006 and 2008. During the summer/autumn seasons of 2008/2009 and 2009/2010, nearshore concentrations were fairly low, but in March 2010, chlorophyll concentrations of 5–10 mg m^{-3} extended beyond 170 km offshore. This is the furthest offshore extension of elevated chlorophyll seen throughout the time-series, and resulted in the high index values seen in Figure 4.3. Nearshore chlorophyll concentrations were high during the early part of the 2010/2011 summer, but stayed low throughout the remainder of 2011 and most of 2012. Elevated concentrations (> 20 mg m^{-3}) were only observed during April/May and October/November 2012.

During 2013, elevated concentrations were evident during the first six months, with the highest values (> 20 mg m^{-3}) only notable during January and May. Seasonal differences seem to be more evident during 2013 than preceding years, with clearly lower values during winter. Elevated chlorophyll concentrations during September and October marked the onset of the spring phytoplankton bloom. During the first six months of 2014, chlorophyll concentrations were lower than preceding years, but consistently high values were observed after the onset of the spring bloom in October 2014.

4.1.2. Chlorophyll variability on the West and South coasts

An index of chlorophyll concentration along the coast of southern Africa was computed by integrating surface chlorophyll *a*, obtained from satellite sensors, from the coast to the 1 mg m^{-3} level (Figure 4.4). For the West Coast (Figure 4.5), the integration was performed in a zonal direction (east to west) and for the South Coast (Figure 4.6), it was computed in a meridional direction (north to south). SeaWiFS data were used from September 1997 to June 2002, and MODIS Aqua data thereafter. The most prominent features of the West Coast chlorophyll index in Figure 4.5 are summarised here.

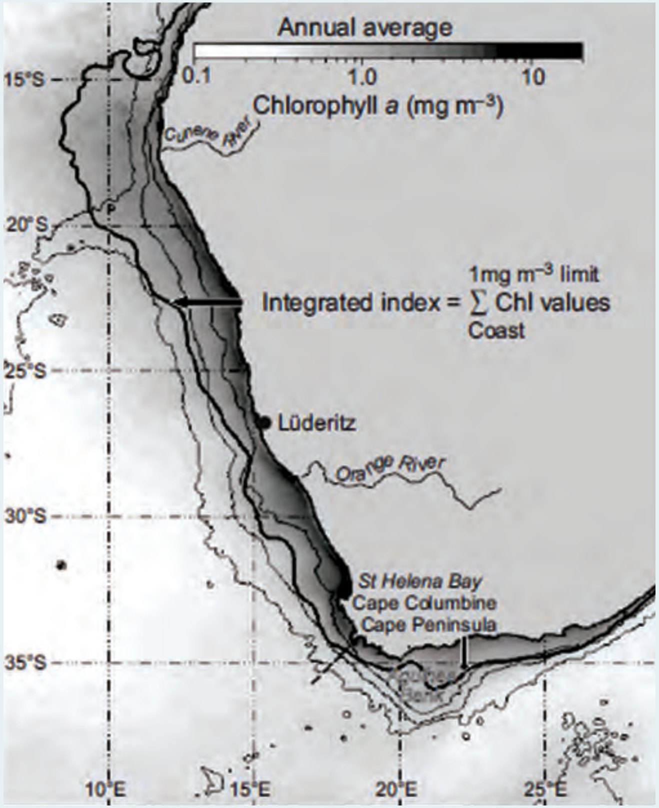


Figure 4.4: Annual average of chlorophyll *a* concentration. The dark solid line indicates the location of the 1 mg m^{-3} isopleth. Bathymetry contours (200 m, 1000 m, 3000 m) are shown. The dashed line off the Cape Peninsula indicates the divide between the West and South coasts (from Demarcq H et al. (2007). Application of a chlorophyll index derived from satellite data to investigate the variability of phytoplankton in the Benguela ecosystem. *African Journal of Marine Science* 29(2): 271-282. Reproduced from *African Journal of Marine Science* (2007) volume 29 (2) with permission from © NISC (Pty) Ltd and H Demarcq).

The highest index values are found off Namibia (16–26 °S), indicating that the highest phytoplankton biomass occurs in this part of the Benguela ecosystem. Upwelling over most of this region is at a maximum during winter and this leads to a tendency for chlorophyll maxima to occur near the middle of the year. However, this is not the case in all years. In 2010, the mid-year maximum was very conspicuous in the region north of 22 °S, with the highest values seen throughout the time-series. By contrast, the index values in this region during 2011 were the lowest on record since 2003. Consistently elevated values were observed throughout this region from January to July 2012. During 2013, the highest index was confined to a small area between 19 and 21 °S. While high index values were observed in a similar latitudinal range in 2014, they were consistently high for 10 months of the year, three months longer than during the previous year.

Low chlorophyll concentration is a consistent feature of the coastal region directly south of the Lüderitz upwelling cell (26–28 °S). Chlorophyll concentrations along this part of the coast seem to have been increasing gradually since the start of the time-series. Highest index values for this region were observed during 2010 and 2011, with a subsequent decrease in 2012 and 2013. During 2014, elevated values were observed throughout this region during spring.

Elevated chlorophyll index values normally occur in the region affected by upwelling in the Namaqualand, Cape Columbine and Cape Peninsula upwelling cells (28–33 °S), usually with a maximum between 31 and 32.5 °S (Doring Bay to Cape Columbine). In the northern part of this region, the chlorophyll concentration maximum tends to occur in spring, while in the southern part it occurs in late summer. During 2010, concentrations were moderate in the Orange River to Hondeklip Bay region (28–30 °S) in late summer, but further south concentrations were high. The 2011 and 2012 index values suggest low chlorophyll concentrations in the north and high concentrations in the southern part of the region. During 2013, there appeared to be a further decrease in chlorophyll concentrations in this region, while higher values were observed for most of 2014.

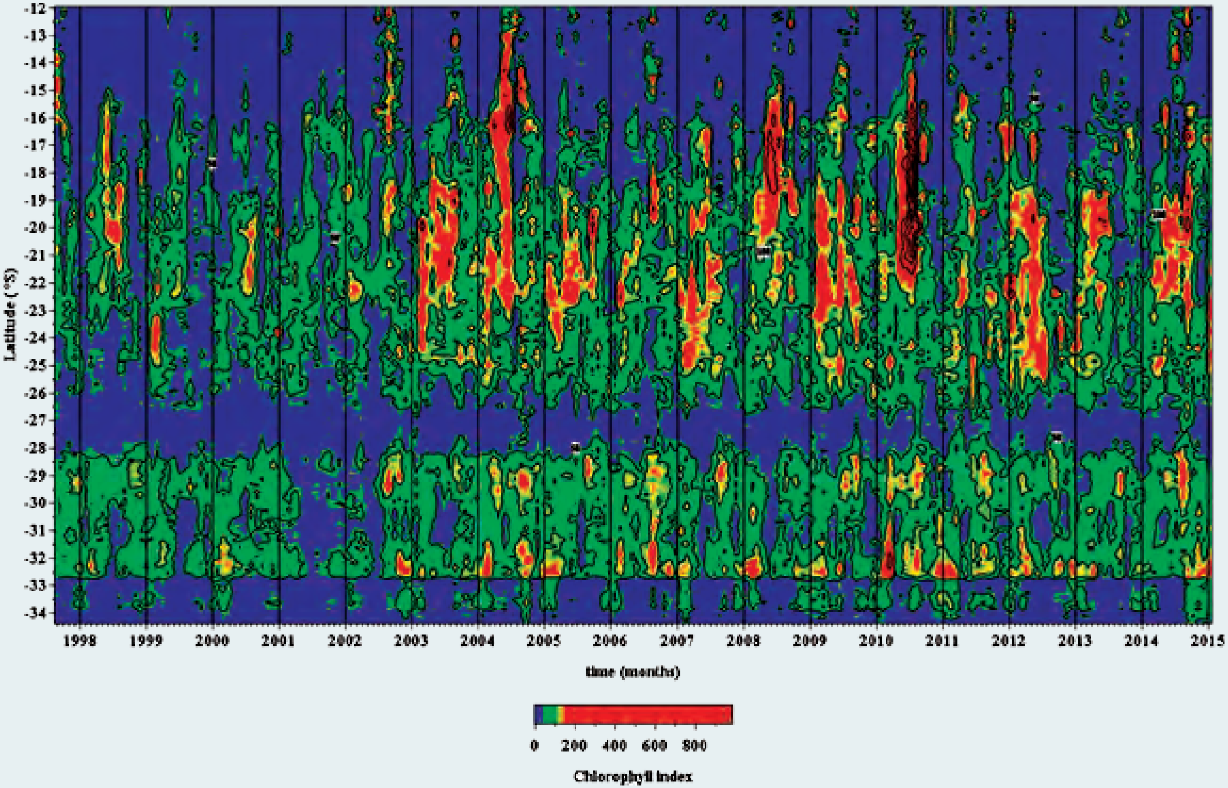


Figure 4.5: A space-time plot of the chlorophyll index for the West Coast (12–34 °S) from September 1997 to February 2015. Note: the solid vertical lines indicate January of each year.

The area between 33 and 34 °S is characterized by low chlorophyll index values, but with a clear seasonal signal of summer maxima and winter minima. Chlorophyll concentrations in this area were moderately high during the 2010/2011 summer, but low during the rest of the year. Elevated concentrations were observed during the first four months of 2012, but very low values were noted during the remainder of the year. The 2012/2013 and the 2013/2014 summer seasons were characterized by elevated concentrations. While 2013 had low values throughout the rest of the year, consistently elevated values were observed from September 2014 to February 2015.

Along the South Coast (Figure 4.6), the chlorophyll index values are generally lower than along the West Coast. Well-defined chlorophyll maxima are observed in March/April and October. These maxima are normally most prominent between Mossel Bay and Port Alfred.

During the 2009/2010 and 2010/2011 summers, moderately high chlorophyll concentrations were only indicated in the extreme western part of the south coast. During the winters of 2010 and 2011, the index values were more or less at average level. While elevated concentrations were evident throughout most of the region from 2008 to 2011, seasonal chlorophyll minima and maxima were more marked during 2012 and 2013. During 2014, consistently high values were observed during spring and summer (September 2014 to February 2015) in the extreme western part of the region. In the central part of the region, high index values occupied a small area off Mossel Bay during January and February 2014, but covered most of south coast between Mossel Bay and Port Elizabeth during September 2014.

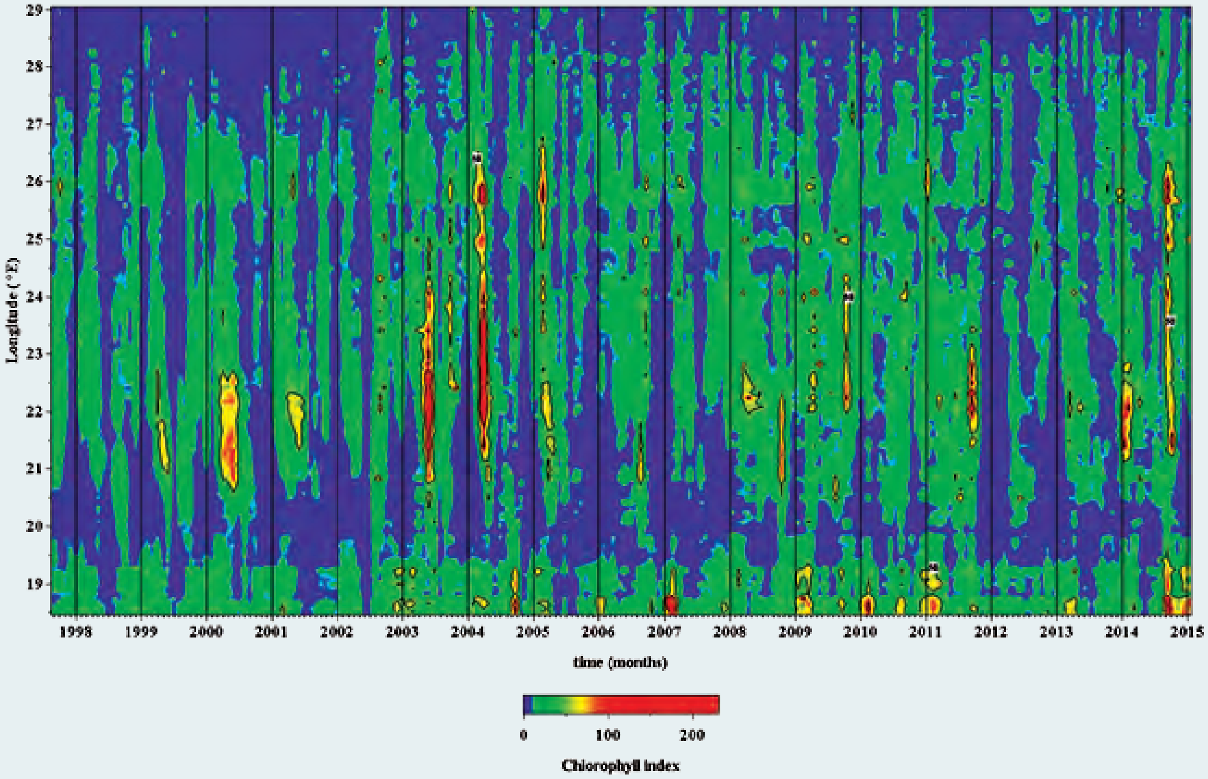


Figure 4.6: A space-time plot of the chlorophyll index for the South Coast (18.4–29 °E) from September 1997 to February 2015. Note: the solid vertical lines indicate January of each year.

4.2. Zooplankton

Zooplankton embrace the diverse, delicate and often very beautiful assemblage of animals that drift in the waters of the world's oceans. They include some of the most abundant multicellular animals on the planet – the copepods (Figure 4.1). Zooplankton occupy a key position in the pelagic food web transferring the organic energy produced by phytoplankton through photosynthesis via three main pathways. Some energy is transported directly from the water column to the ocean floor, fuelling the benthic community; this pathway also contributes to the removal of surplus anthropogenic CO_2 from the atmosphere through sedimentation and burial of organic and inorganic carbon compounds. A second route of energy produced by phytoplankton is remineralisation by bacteria and microzooplankton – the so called 'microbial loop' – with some of the energy remaining in this loop, while some sinks to the benthos or is consumed by zooplankton. The third pathway of energy from primary production is consumption by zooplankton.

In addition to their pivotal role in controlling phytoplankton production in pelagic food webs, zooplankton play a critical role as a food source for larval and juvenile stages of most fishes. The dynamics of zooplankton populations, their reproductive cycles, and their rates of growth, reproduction and survival are all important factors influencing recruitment to fish stocks that are exploited by man. Zooplankton also play an important role in shaping the extent and pace of climate change.

4.2.1. West Coast zooplankton: up and down

Changes in zooplankton communities on the west coast of South Africa have been monitored since the early 1950s, coincident with the development of the pelagic fishery there. Zooplankton samples collected since 1951 in St Helena Bay (Figure 4.7), specifically during autumn (April–June), when peak recruitment of anchovy and sardine occurs, were analysed in terms of abundance, species and size composition of the copepod community. The St Helena Bay time-series of total copepod abundance covers six decades of data (Figure 4.7), with a gap in the dataset during the 1970s and early 1980s while there was also no autumn sampling after 2010 due to either sampling gear failure or the unavailability of a suitable sampling platform.

There is clear evidence of an initial multi-decadal trend of increasing abundance since the 1950s, reversing around the mid-1990s and declining thereafter, with possibly another turning point around the mid-2000s. Similar patterns of alternating increases and decreases in abundance were also observed in the dominant species albeit to varying extents dependent on body size. The decline in copepods in St Helena Bay since the mid-1990s coincided with a marked increase in biomass of pelagic fish recruits during autumn, suggesting that increased predation pressure was the primary forcing mechanism controlling zooplankton populations in this fish-recruitment area.

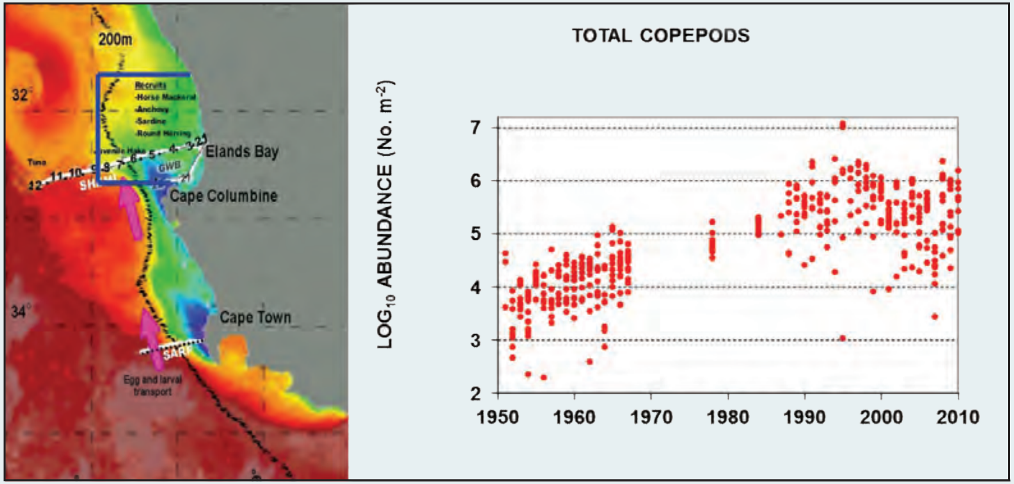


Figure 4.7: Time-series of numerical abundance (Log$_{10}$[No. m^{-2} +1]) of total copepods in net samples (200 µm mesh) collected at station positions within a 1° x 1° box grid in St Helena Bay (see map – adapted from E. Koch, University of Cape Town, unpublished manuscript) in autumn (April–June) during a variety of plankton monitoring programmes over the period 1951–2010.

In addition to changes in numerical abundance, there was also a marked shift in copepod species composition during autumn (Figure 4.8). Medium to large copepods such as *Centropages brachiatus*, *Calanoides carinatus s.l.* and *Rhincalanus nasutus*, which are the preferred prey of anchovy, were more prominent during the 1950s–1960s than later, whereas smaller copepods such as *Oithona* spp., small calanoid species, and *Metridia lucens*, preferred by sardine, became more prominent from the late 1980s onward compared with the 1950s and 1960s.

These changes in copepod abundance and species and size composition are clearly illustrated when expressing the data as an index of Average Copepod Community Size (ACCS) (Figure 4.9). The ACCS index shows a change from high values (around 1.5 mm) in the 1950s and 1960s, representing a community generally dominated by larger species, to lower values (< 1.0 mm) in the 1990s and 2000s, when smaller species were more prevalent. Such a shift from larger to smaller species is indicative of ocean warming, although there is evidence to suggest a cooling trend (by up to 0.5°C per decade) in the southern Benguela from the 1980s onward due to an increase in upwelling-favourable south-easterly winds.

As mentioned earlier, the decline in zooplankton autumn abundance since the mid-1990s may be attributed to predation pressure by very abundant pelagic fish recruiting there at that time. However, what the cause(s) is/are for the observed coincident shift from large to small zooplankton species dominance remains unclear, but it could be linked to the preference of anchovy, which were very abundant at the time, for larger species, in contrast to sardine, which were less abundant and prefer smaller species.

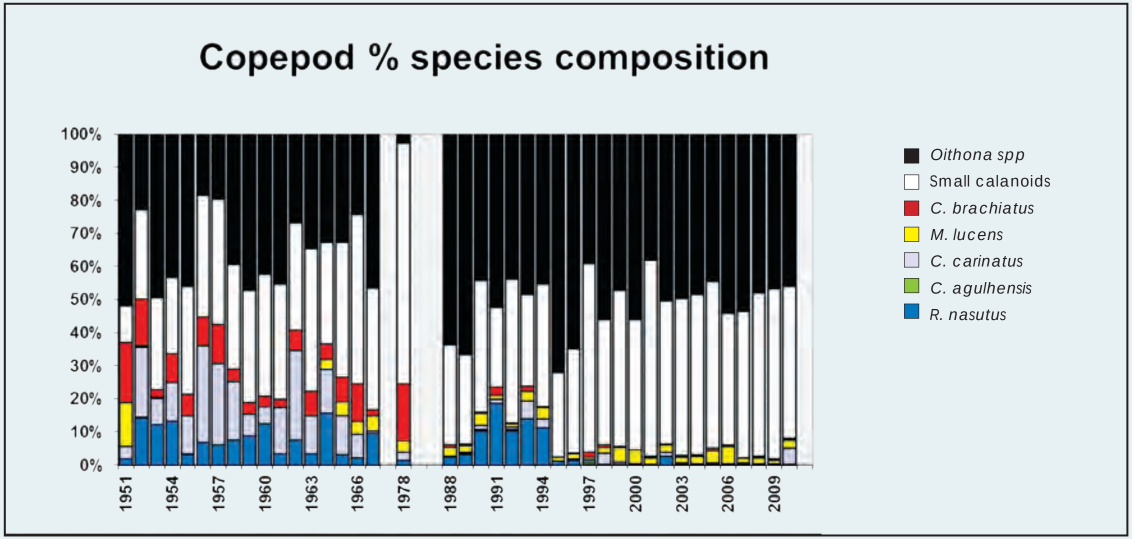


Figure 4.8: Time-series of change in percentage composition of the seven most dominant copepod taxa in St Helena Bay during autumns of 1951–2010; the species listed in the key are arranged from top to bottom in ascending order of body size.

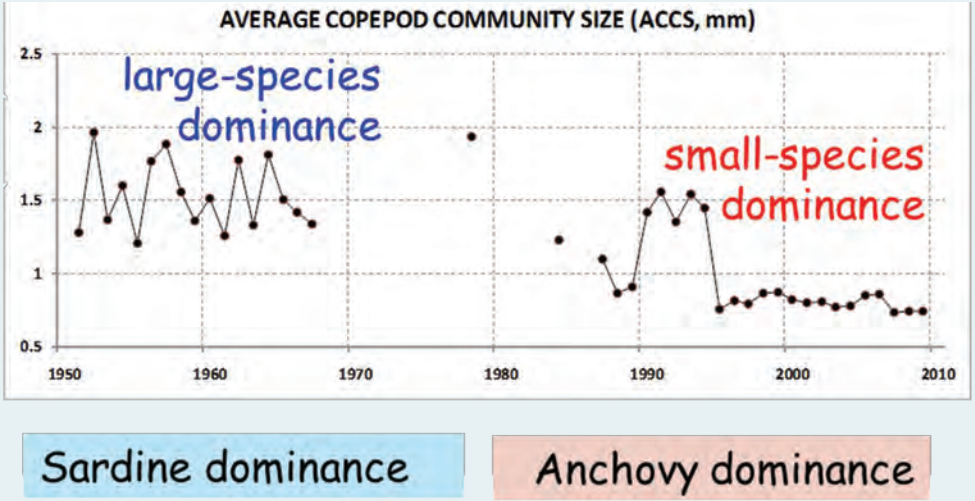


Figure 4.9: Time-series of Average Copepod Community Size (ACCS) index in St Helena Bay during autumns of 1951–2010; the ACCS index is calculated as adult female body length of each species, multiplied by its abundance, summed over all species and divided by their total abundance. Periods of pelagic fish species dominance are also indicated.

In conclusion, the abundance of zooplankton, proxied by copepods, in St Helena Bay on the West Coast is much higher now than it was five to six decades ago, although there was a turning point around the mid-1990s, after which abundances declined. Concomitantly, a shift towards a dominance of smaller copepod species has occurred. It remains unclear whether these changes are mainly due to bottom-up (e.g. physical forcing) or top-down (predation) effects, or a combination of both, but they certainly have a fundamental effect on biogeochemical processes, food web structure and ecosystem functioning.

4.2.2. Declining plankton on the South Coast

The vast continental shelf off the South Coast is known as the Agulhas Bank, which spans an area of 116,000 km² and extends up to 250 km south of the African continent. An ecologically relevant feature of the Bank is that it serves as a spawning ground for many commercially important fish, including sardine, round herring and anchovy. Copepods, which comprise 90% of zooplankton carbon on the Agulhas Bank, provide an important food source for these pelagic fish as well as juvenile squid. A single, large (~3 mm) species of copepod, *Calanus agulhensis*, dominates this copepod community in terms of biomass, and has a centre of distribution associated with the semi-permanent ridge of cool, upwelled water south of Mossel Bay (see chapter 2). Zooplankton abundance and species composition on the Agulhas Bank have been monitored annually in austral spring since 1988, during routine acoustic surveys of pelagic fish, providing a time-series of over two decades. Spring coincides with peak spawning by anchovy. To investigate interannual and long-term zooplankton variability on the Agulhas Bank, mean copepod biomass was calculated using data from stations sampled across the shelf in the vicinity of Walker Bay (western Agulhas Bank, WAB) and Mossel Bay (central Agulhas Bank, CAB; Figure 4.10). Relationships were explored between copepod biomass and data on sea surface temperature and chlorophyll (satellite derived) and pelagic fish biomass collected from the same areas.

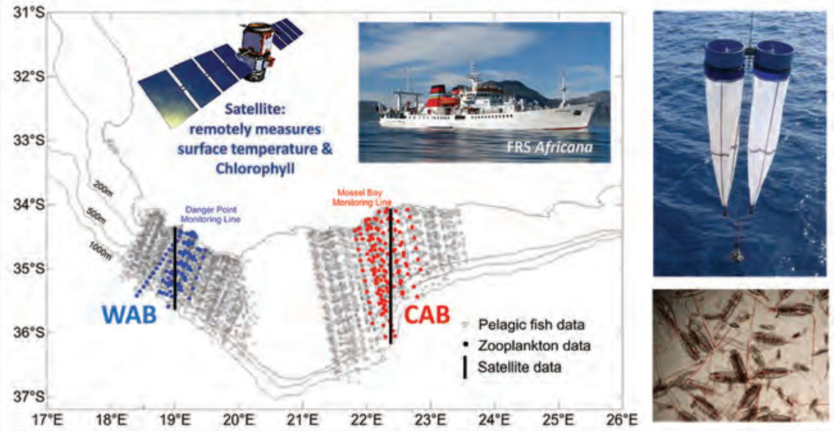


Figure 4.10: Map showing sampling locations on the western (WAB) and central (CAB) Agulhas Bank for satellite (top left – image source: calipsooutreach.hamptonu.edu) data, and zooplankton and pelagic fish during annual hydro-acoustic stock assessment surveys in October/November from 1988 to 2010 aboard FRS *Africana* (top centre – image source: www.nda.agric.za). Also shown are a Bongo net (top right – image source: 2007: *Exploring the Inner Space of the Celebes Sea)* used to collect zooplankton and a selection of copepods (bottom right – image courtesy of Chris Linder, WHOI, USA), which dominate the zooplankton.

A comparison of the data from the latter part of the time-series (1997 onwards) with those prior to 1997 shows that there has been a marked decline in copepod biomass on the Agulhas Bank over the past two decades, in particular that of the large, dominant species *C. agulhensis*. This has been most pronounced in the region off Mossel Bay on the CAB (Figure 4.11a), where overall copepod biomass has declined by 57% and *C. agulhensis* biomass has declined by 68%, compared to 22% and 44% respectively on the WAB (Table 4.1). This has resulted in a gradual shift towards a smaller-copepod-dominated community (Figure 4.11b).

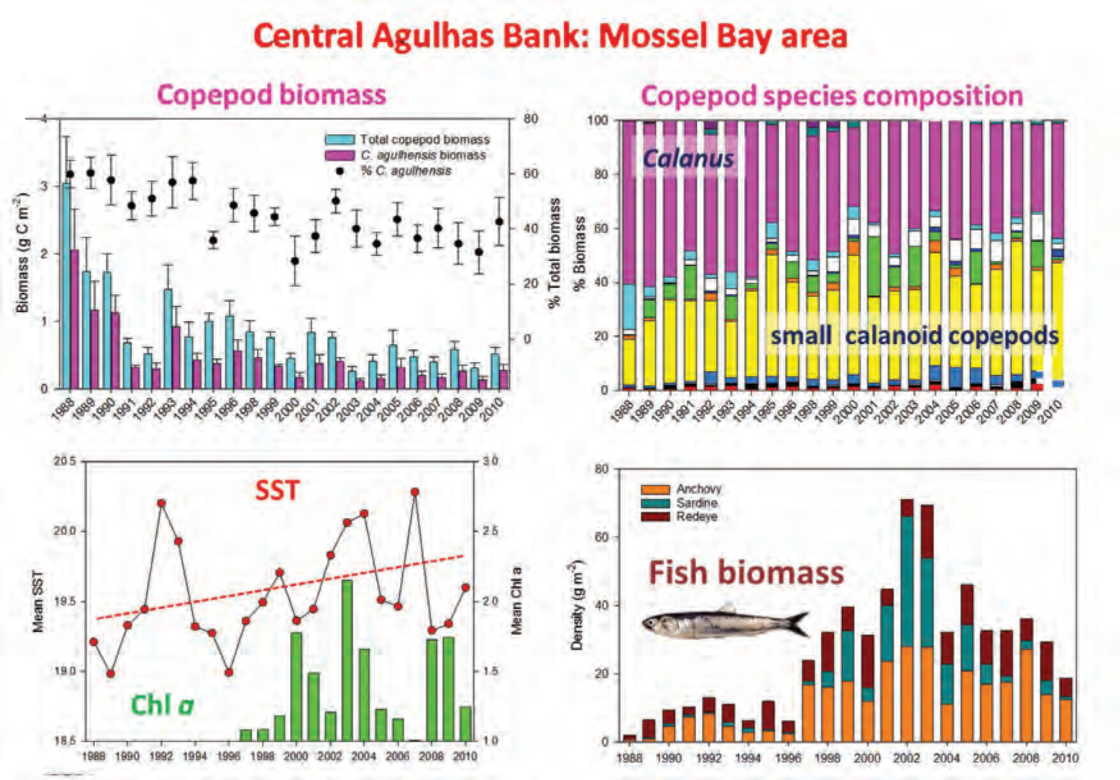


Figure 4.11: (a) Mean annual total copepod and *Calanus agulhensis* biomass (± SE, g C m^{-2}), as well as the percentage of copepod biomass comprised of *C. agulhensis*, over the Agulhas Bank in the vicinity of Mossel Bay (central Agulhas Bank) during the November spawner biomass surveys from 1988 to 2010; (b) copepod species composition as a percentage of total copepod biomass off Mossel Bay between 1988 and 2010; (c) annual (Jan–Dec) averages of Sea Surface Temperature (SST) and Chlorophyll *a* (Chl *a*) along a representative transect from the Mossel Bay area; (d) mean density of pelagic fish (g m^{-2}) on the central Agulhas Bank as determined during hydro-acoustic surveys in October/November each year from 1988 to 2010 (image source: www.fooduniversity.com) (from poster by Huggett JA et al. 2012 at chapman.agu.org).

Investigation of environmental trends indicates that there has been a concomitant increase in sea surface temperature in both areas, of 0.36°C for the WAB and 0.23°C for the CAB (Figure 4.11c). There has also been a significant increase in pelagic fish biomass on the Agulhas Bank since 1997, with roughly 5- and 16-fold increases in anchovy and sardine density respectively on the CAB (Figure 4.11d). Statistical analyses reveal that the changes in the copepod community have been largely driven by predation from the increased densities of pelagic fish (top-down control), but that environmental influences such as ocean warming (bottom-up control) have also played a role, especially on the CAB. Further warming is likely to enhance the shift to a smaller copepod-dominated community, but further monitoring (suspended since 2011) will be required to test this.

Comparison of post-1997 with pre-1997 means		
Danger Point	**Parameter**	**Mossel Bay**
↓ 22%	Mean copepod biomass	↓ 57%
↓ 44%	Mean *Calanus* biomass	↓ 68%
↓ 31%	% *Calanus* biomass	↓ 20%
↑ 0.36°C	Mean SST	↑ 0.23°C
↑ 2.5 x	Mean Anchovy density	↑ 4.8 x
↑ 2.8 x	Mean Sardine density	↑ 16.0 x
↑ 3.0 x	Mean Redeye density	↑ 2.4 x

Table 4.1: Comparison of mean data from 1997 onwards (1997–2010) with those prior to 1997 (1988–1996) – a downward arrow indicates a decline, and an upward arrow indicates an increase (from Huggett JA et al. 2012. http://chapman.agu.org/agulhas/files/2012/11/Huggett-et-al-poster-for-Chapman-Conference-2012.pdf).

5. Top predators

Robert JM Crawford, Darrell Anders, Alan J Boyd, Azwianewi Makhado, Mdu Seakamela and Sarika Singh

Marine top predators are frequently conspicuous animals, particularly those that are big (such as whales and sharks) and those that breed on land in large colonies (such as seals, seabirds and turtles), and they attract widespread attention for several reasons. These include: they are often good indicators of ecosystem functioning, health and change; their being foci for burgeoning marine ecotourism operations, which attract foreign revenue, stimulate the economy and provide jobs for local communities; their often unfavourable conservation status; their impact on ecosystems and on the human use of ecosystems; many range widely across international boundaries and on the high seas and hence are regarded as shared resources; and their use in advising on ecosystem management. Formerly many marine top predators were harvested for food and other products. In some countries such harvesting persists, whereas in others, including South Africa, a deteriorating conservation status of several predators and their greater value as targets for ecotourism led to cessation of extractive harvesting.

South Africa, by virtue of its location at the junction of the Indian and Atlantic Oceans and its possession of the Prince Edward Islands (PEIs) in the southwest Indian Ocean, has a wide variety of marine habitats, which range from cold in the west to warm and tropical in the east and sub-Antarctic at the PEIs. It similarly has a high diversity of marine top predators. About 100 species of sharks, five of turtles, 90 of seabirds and more than 40 of marine mammals (seals and cetaceans) occur in South African waters, excluding those around the PEIs. Two of the turtles, 15 seabirds and one seal breed in South Africa and 28 seabirds and three seals at its PEIs. Of the seabirds that breed in South Africa, seven species are endemic to the Benguela upwelling system. These include the African penguin and Cape gannet, which together with large whales and sharks combine with South Africa’s terrestrial fauna to give tourists a remarkable mix of animal viewing opportunities that should be preserved.

5.1. Indicator value

The role of marine top predators as potential indicators of marine conditions is widely acknowledged[27, 28, 29, 30] and monitoring of such predators has been employed in programmes aimed at understanding marine ecosystem functioning and change, both off southern Africa[31] and in the southern ocean[32]. Change in the functioning of marine ecosystems can affect the services provided by these ecosystems (such as food obtained from fisheries), adversely influence biodiversity conservation and prove extremely difficult to reverse[33, 34]. For example, large changes have been observed in the functioning of the northern Benguela system off Namibia[34]. In this system, sardine was the main link between plankton and fisheries between 1950 and the early 1970s but then collapsed, probably as a result of overfishing. Subsequently, most of the energy flow was diverted to jellyfish, detritus, the bearded goby (a bottom-dwelling fish) and benthic recycling (Figure 5.1). There was substantial loss of jobs in the sardine fishery, formerly one of the largest in the world, which has now been depressed for more than 40 years.

Seabirds provided early warning of changes in the functioning of the northern Benguela system[35] and have also suggested recent changes in the marine ecosystems off northwest South Africa[36] and at the Prince Edward Islands[37]. Off northwest South Africa, similarly to Namibia, there were substantial decreases in numbers of five seabirds that compete with fisheries for prey. Two of these species maintained their overall populations by increased breeding in the south and east but three endemic species suffered large overall decreases and are now considered Endangered. At the Prince Edward Islands there were congruent decreases over 20 years of two inshore, benthic-feeding seabirds. Therefore, marine top predators assist DEA in its unique role of attempting to identify and monitor those potential areas of accumulation (over time) and aggregation (over space) of negative impacts on the environment, a function that is not undertaken by any of the sector departments such as transport or fishing.

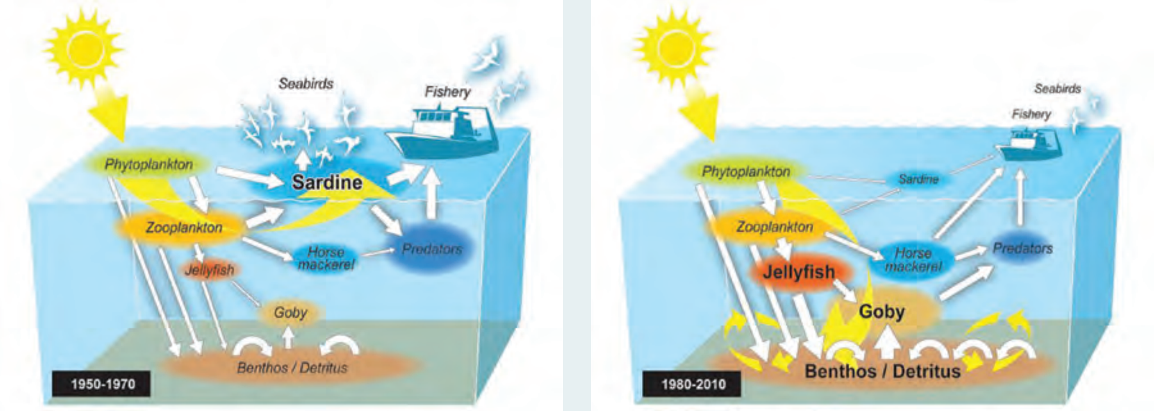


Figure 5.1: Conceptual sketches of the main energy flows towards fish production and fisheries in the northern Benguela ecosystem during two periods. From 1950–1970, sardine was the main link between plankton and fisheries and predators (top). After the collapse of the sardine in the early 1970s, most of the energy flow (yellow arrows) was diverted through jellyfish, detritus, benthic recycling and bearded goby (bottom, from Roux J-P et al. 2013. Jellyfication of marine ecosystems as a likely consequence of overfishing small pelagic fishes: lessons from the Benguela. *Bulletin of Marine Science* 89: 249–284. Reprinted with permission from *Bulletin of Marine Science* and J-P Roux).

5.2. Marine ecotourism

One of the world's fastest growing areas of economic opportunity is tourism. It is getting easier for people to travel globally and for tour operators and establishments to advertise their product through the internet. A key component of marine tourism is the non-consumptive use of marine resources, e.g. viewing of marine mammals, birds, turtles and sharks (Figure 5.2). Furthermore because non-consumptive use does not remove the resource from the system it can be repeated over and over again, if it is managed so as not adversely to influence the population sizes and behaviours of target species.

The non-consumptive use of marine resources in South Africa expanded rapidly after 2000, its value growing two-to-threefold by 2013. In that year the direct value of this sector to the South African economy was estimated at ZAR 400 million and its indirect value (based on an approximate multiplier of five) as more than ZAR 2 billion[38] (Table 5.1). There is scope for further growth of this tourism sector, if it is managed properly.

Table 5.1: The estimated value of different sectors of the marine ecotourism industry to South Africa's economy in 2013[38].

Ecotourism sector	Number of permits	Estimated number of persons employed	Number of tourists	Estimated average price per person (ZAR)	Estimated direct value of sector (million ZAR)	Estimated overall value to economy (million ZAR)
Land-based whale watching					80	400
Boat-based whale watching	23 (16 active)	184	42,812	500	21	105
Seals – viewing and diving	2 main sites	30			5	25
White shark cage diving	12 (active)	120	61,404	1,500	92	460
Tiger sharks at Aliwal Shoal	13	39	946–1,198	1,651	1–2	11–14
Other shark diving	18	90	20,000	400–1,200	20	100
Seabird watching	3 main sites		750,000	55	25	125
Turtle viewing	1 main site	12			3	15
SCUBA diving	90	540			60	300
Eco Filming	40 (in 2011)	400			120	600
Total					**428**	**2,130**

Figure 5.2: One-third of tourists to Cape Town listed African penguins at Boulders on the Cape Peninsula as one of their reasons for visiting the mother city[39] (photograph RJM Crawford).

5.3. Conservation status

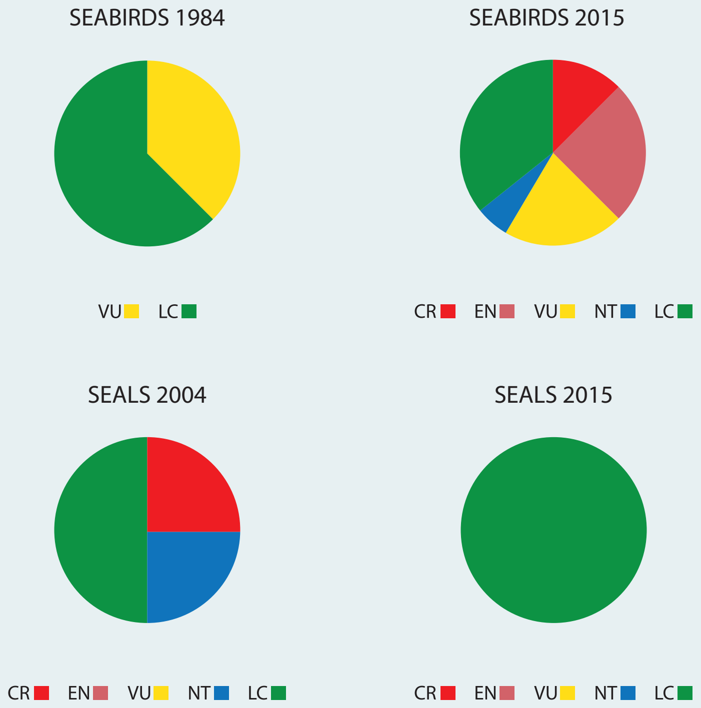
In 2015, updated national assessments of the Red List status of South Africa's seabirds were finalised and those for its marine mammals were progressed. Preliminary results are available for the one seal that breeds in South Africa and for the three that breed at its Prince Edward Islands. The results show a considerable worsening in the status of seabirds breeding in South

Africa between 1984 and 2015, but an improvement in that of the four seals since 2004 (Figure 5.3). Globally, seabirds are more threatened, and in recent decades their status has deteriorated faster, than all other groups of birds having comparable numbers of species[40]. The four families of seabirds that have the worst overall global conservation status are albatrosses (Diomedeidae), penguins (Spheniscidae), petrels/shearwaters (Procellariidae) and cormorants (Phalacrocoracidae)[40]. Each of these families occurs in South Africa or at its Prince Edward Islands. Amongst factors influencing their conservation status are interactions with fisheries and climate change as will be discussed briefly below. Seals are often opportunistic animals that are able to adjust to changing conditions.

5.4. Impact on ecosystems and humans

When abundant, marine top predators may have an impact on marine ecosystems or on human operations in these systems, for example through interfering with fishing operations. Examples of their impact on ecosystems have been the recolonization by Cape fur seals of several islands off southern Africa. At these islands they have displaced seabirds from nesting sites, thereby contributing to the worsening conservation status of several seabirds. It is thought that accumulated deposits of seabird guano at islands may previously have lessened such competition for space, for example by allowing penguins to nest in burrows where they would not have been disturbed by seals. However, guano deposits at most southern African islands were cleared in the 1800s for use as fertiliser.

The recent recolonization by seals of Vondeling Island, near Saldanha Bay, has been well monitored. Seals were observed at the west of the island in 1999 and by 2012 had covered the entire island. In 2006, about 1,200 pups were born at the island, which increased to more than 18,000 pups in 2013 when the colony appeared to be reaching an asymptote. By contrast, numbers of African penguins and Cape, bank and crowned cormorants breeding at Vondeling Island decreased after 2006 (Figure 5.4). Although it is likely that some of the reductions in numbers of seabirds breeding resulted from displacement by seals, not all of the decreases are necessarily attributable to seals because other seabird colonies off northwest South Africa, which do not have seals, have also been decreasing. It may be possible to mitigate the displacements to some extent by providing artificial habitat for seabirds, such as platforms that will not allow access by seals.



SEABIRDS 1984

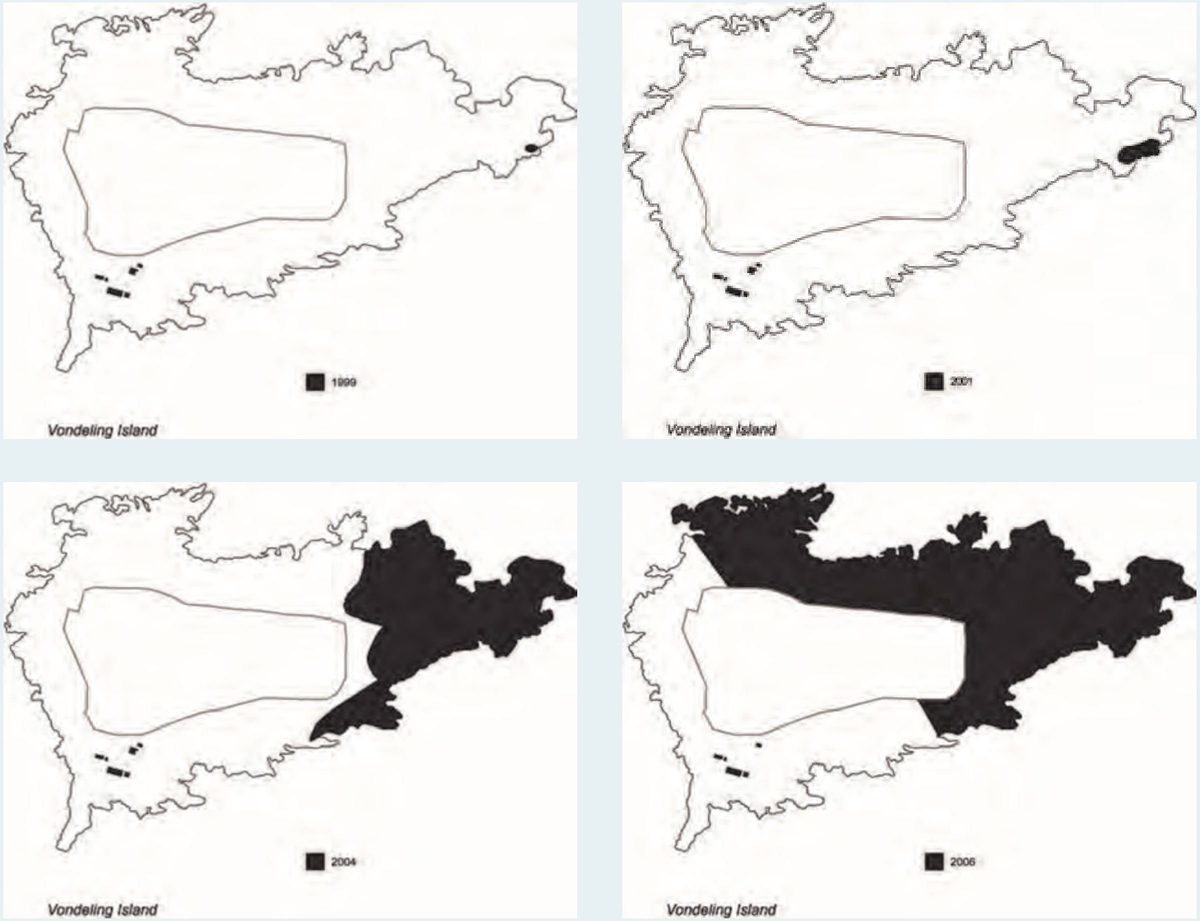
SEABIRDS 2015

SEALS 2004

SEALS 2015

Figure 5.3: Trends in the conservation status of seabirds breeding in South Africa[41] and seals breeding in South Africa and at its Prince Edward Islands[42]. Whereas the conservation status of seabirds worsened between 1984 and 2015, that of seals improved between 2004 and 2015.

CR = Critically Endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened, LC = Least Concern.


1999
Vondeling Island
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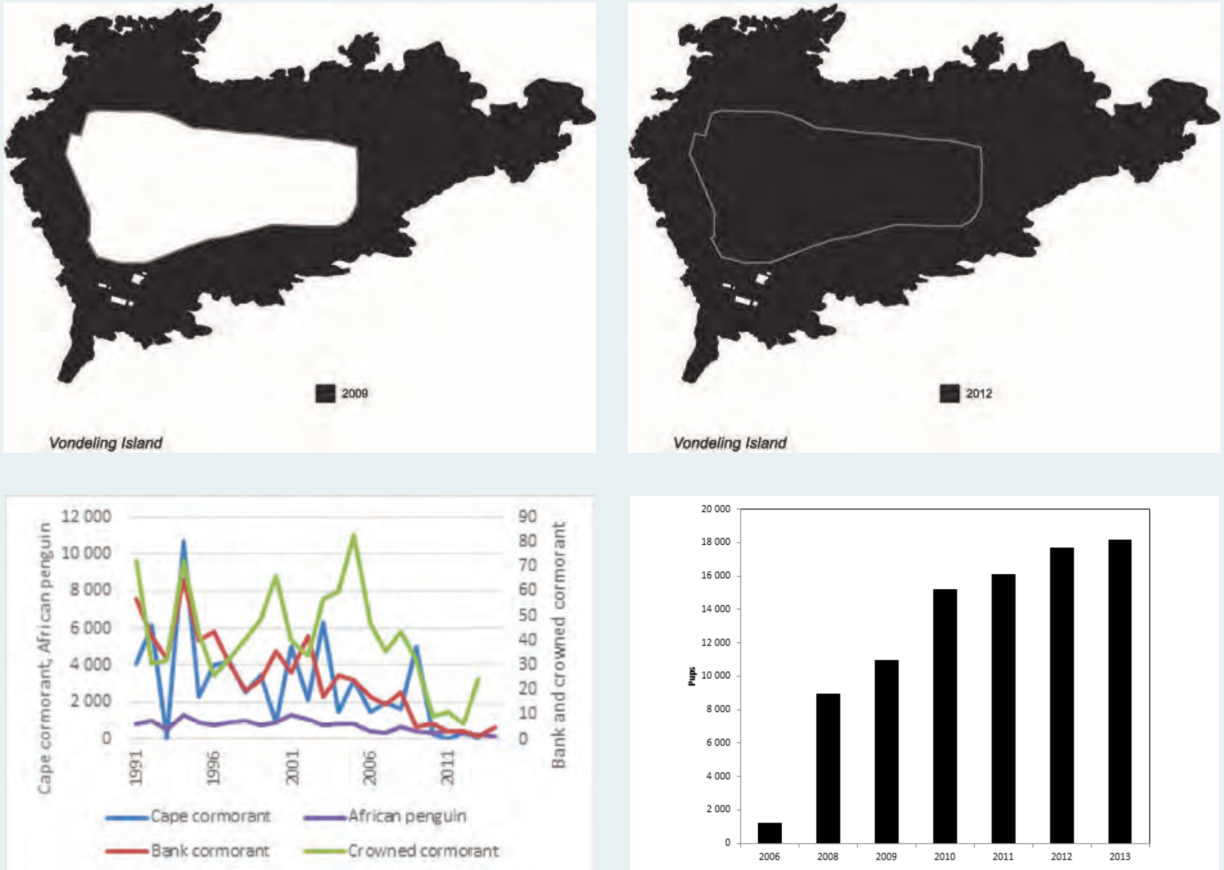

Figure 5.4: Area of Vondeling Island occupied by Cape fur seals in selected years 1999–2012. In 1999 seals were present in small numbers at the east of the island, but in 2012 they occupied the entire island. Also shown are counts of seal pups since 2006 and seabird nests since 1991.

5.5. Migrations and movements

Tracking studies undertaken by the Department of Environmental Affairs (DEA) have confirmed wide-scale movement of several of South Africa's marine top predators. Some examples are shown in Figure 5.5. On account of the trans-boundary movements of species, international cooperation in their management and conservation is necessary. South Africa contributes information to several marine environmental agreements to which it is a party, including Agreement on the Conservation of Albatrosses and Petrels (ACAP), African Eurasian Waterbird Agreement (AEWA), Benguela Current Commission (BCC), Convention on Migratory Species (CMS) and associated memoranda of understanding on turtles, and International Whaling Commission (IWC).

5.6. Ecosystem management

Long-term monitoring of marine top predators facilitates the identification of thresholds of impact, beyond which the integrity of ecosystems is or may be significantly altered. For example, in seven of the world's marine ecosystems breeding success of 18 seabird populations was reduced and became more variable when forage biomass decreased below its mean value[43] (Figure 5.6). Monitoring can also be used to suggest a precautionary level of impact, e.g. a maximum allowable level of by-catch in fisheries. Tracking of marine predators may be used to identify ecologically and biologically significant areas (EBSAs).

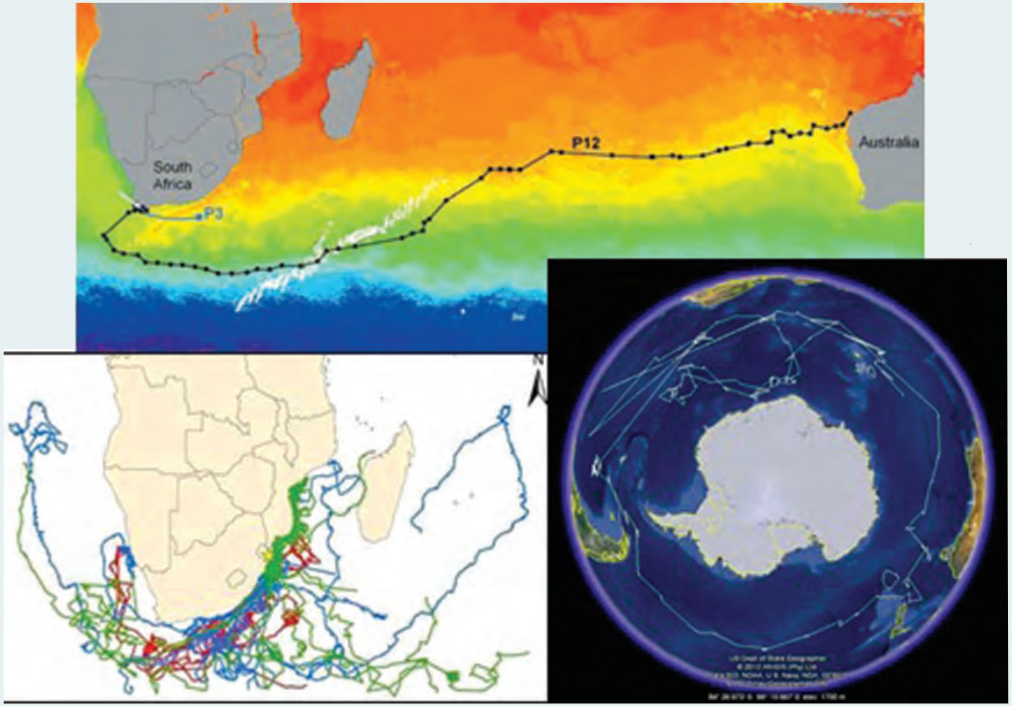

Figure 5.5: Tracking studies have shown wide-ranging movements by several of South Africa's marine top predators. A great white shark travelled from South Africa to northwest Australia (top, from Bonfil R et al. 2005. Transoceanic migration, spatial dynamics and population linkages of white sharks. *Science* 310: 100–103. Reprinted with permission from AAAS), leather back turtles breeding in KwaZulu-Natal moved all around southern Africa (bottom left) and a light-mantled albatross from the Prince Edward Islands circumnavigated the globe (bottom right).

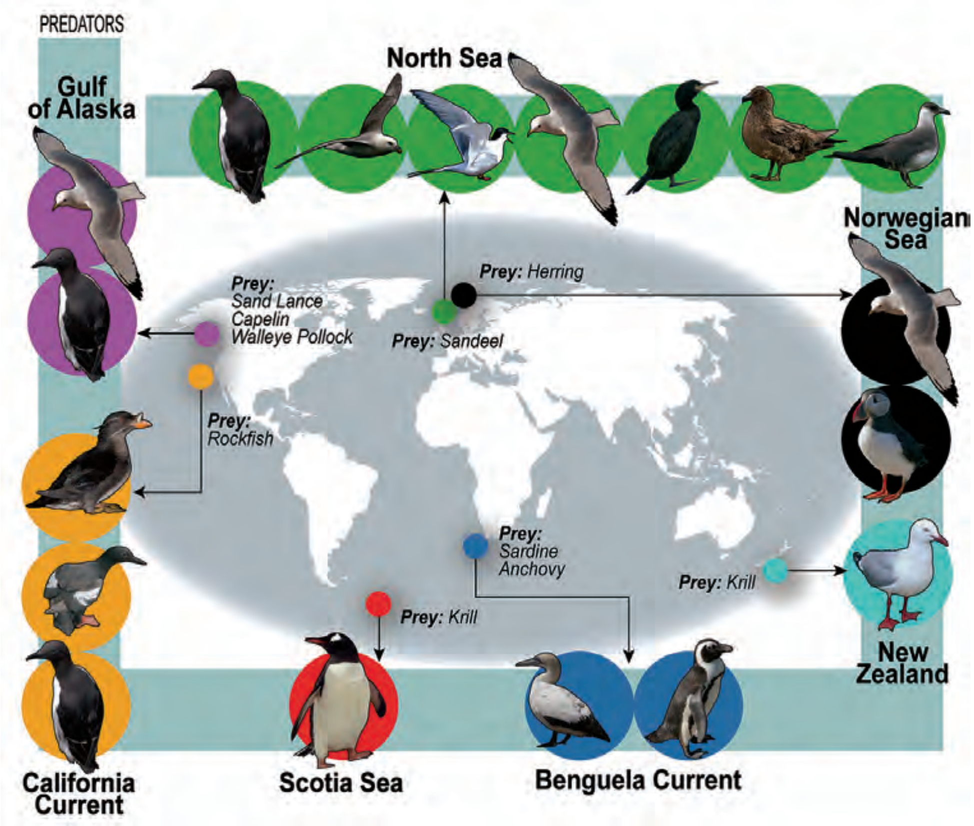

Figure 5.6: The seabirds for which breeding success was reduced and became more variable when forage biomass was reduced below its mean value. The ecosystems and prey species in each system are indicated (from Cury PM et al. 2011. Global seabird response to forage fish depletion – one-third for the birds. *Science* 334: 1703–1706. Reprinted with permission from AAAS).

6. Spatial protection of marine habitat and biodiversity in South Africa

Stephen P Kirkman and Toufiek Samaai

6.1. Marine Protected Areas (MPAs)

At the leading edge of marine conservation in many countries is the spatial management tool of Marine Protected Areas (MPAs). In addition to conserving natural marine ecosystems and biodiversity, MPAs are advocated as a means to rebuild depleted fish stocks, improve fishery yields and provide insurance against stock collapse[44, 45]. For these reasons South Africa has committed to a representative MPA network[46] and to date 23 MPAs have been declared within the exclusive economic zone (EEZ) of mainland South Africa[47], i.e. excluding the Prince Edward Islands. However, the existing MPA network falls well short of representing the full diversity of South Africa’s ocean systems (Figure 6.1). All 23 existing MPAs are coastal MPAs and while about 23% of the coastline falls under their protection, this protection is not evenly distributed between ecoregions and is therefore not representative of the country’s coastal marine biodiversity, e.g. none occur in the Namaqua Ecoregion on the West Coast. Moreover, because the MPAs mostly extend only 2–3 nautical miles out to sea, less than 0.5% of the entire EEZ is protected, while 40% of the 136 marine and coastal ecosystem types, which have been classified, are currently not represented in the MPA network and offshore habitat is scarcely protected[46, 48]. All this is cause for concern especially because the majority (61%) of South Africa’s living marine resources are overexploited and 47% of South Africa’s marine and coastal habitats are threatened according to the threat status assessment conducted under the most recent National Biodiversity Assessment[47].

Considering the above, and the potential implications that a lack of protection of habitats hold for sustainable economic growth and long-term benefits, the need to address the offshore and other gaps in South Africa’s MPA network have been long recognised[44, 46, 47, 49]. Therefore, following workshops and consultations under Operation Phakisa, which is the government’s initiative to unlock the oceans’ economic potential, 18 new MPAs and expansions to three existing MPAs were proposed to “advance habitat representation, protection of threatened and vulnerable ecosystems and species, support fisheries management and ecotourism and provide for research and monitoring in South Africa’s ocean environment”[50]. The proposed MPAs must still be gazetted but if they are implemented as proposed, not only would they nearly double the number of MPAs in the MPA network but they would increase MPA coverage in the EEZ from less than 0.5% to more than 5%. They would also advance habitat representation from 60% to 94%, with 46 of the 54 ecosystem types, which currently have no protection, being included. This would significantly advance representation of benthic (Figure 6.1A) as well as pelagic ecosystem types. Also, the proposed MPAs include the first protection for ten of the ecosystem types that have been classified as critically endangered[47] but are currently not represented in the MPA network, with a key focus on protecting the last remaining areas of these threatened ecosystem types that are in good condition (Figure 6.1B).

6.2. Ecologically or Biologically Significant Areas (EBSAs)

The proposed new MPAs and expansions to MPAs were mostly developed from priority areas identified by national or regional biodiversity assessments or systematic conservation plans (SCPs)[47, 51], which generally was not the case for the existing MPAs. Exceptions include two new areas, the Namaqua Fossil Forest and Agulhas Front that were proposed as part of management measures for areas that meet the criteria for Ecologically or Biologically Significant Areas (EBSAs)[52, 53]. EBSAs are areas that are identified to be in need of protection on the basis of meeting scientific criteria prescribed by the Conference of the Parties to the Convention on Biological Diversity in 2008 (COP9), uniqueness or rarity, special importance for life history stages of species, biological diversity, biological productivity, and others. Several EBSAs that have been described and proposed for South Africa (Figure 6.1C) have been endorsed by the Convention on Biological Diversity. While not a general strategy for protecting all marine habitats and communities, EBSAs are a tool for calling attention to areas that have particularly high ecological or biological importance and that should be considered by decision makers working towards ecosystem objectives, e.g. they could be treated with a higher than usual degree of risk-averseness.

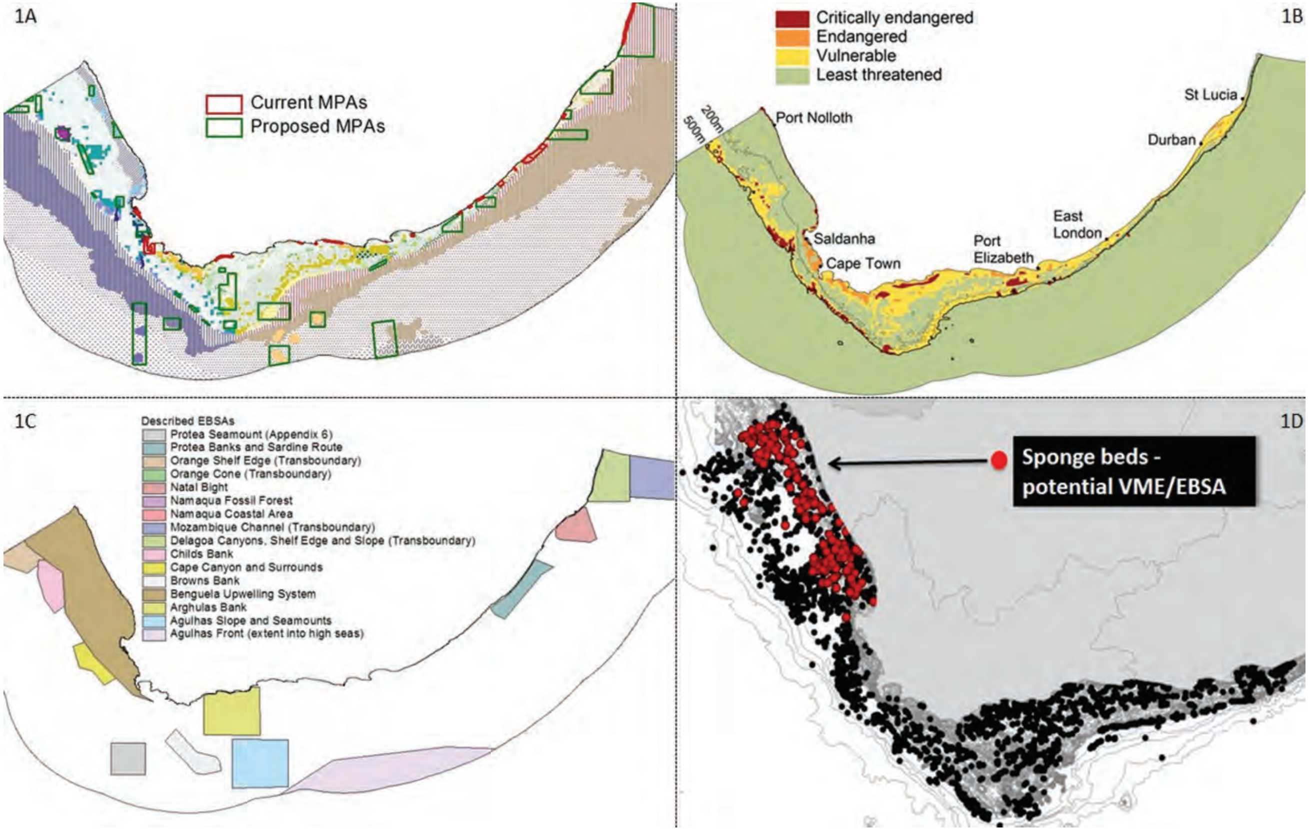

Figure 6.1: Locations of current and proposed MPAs in relation to benthic habitat types (A), ecosystem threat status for coastal and offshore habitat (B, from[47]), locations of Ecologically or Biologically Significant Areas (EBSAs), which have been described to date (C, from [52, 53]), and locations of sponge beds on the west coast that should be considered for Vulnerable Marine Ecosystem (VME) or EBSA status.

6.3. Vulnerable Marine Ecosystems (VMEs)

There is a large degree of overlap between criteria for EBSAs, MPAs and Vulnerable Marine Ecosystems (VMEs), which are identified by Regional Fisheries Management Organisations and include habitat types that are easily disturbed by humans and are slow to recover, or which will never recover[54]. VMEs may include seamounts, canyons, cold-water coral reefs, octo-coral gardens and deep-sea sponge beds. Sponge beds featuring the lob-shaped Suberites sponges, which grow up to 80 cm high, occur in the 100–500 m depth range throughout the southern Benguela region (Figure 6.1D). Submersible footage taken in the Cape Canyon off Cape Columbine showed a high diversity and abundance of sponges, many of which are habitat-forming, and which may be considered as potential VMEs (Figure 6.2A). During a recent survey on the east coast of South Africa, another potential VME, consisting of abundant individuals of the glass sponge *Pheronema* sp., was discovered within canyons in the Isimangaliso Wetland Park (Figure 6.2B,C), which formed a distinct zone at depths between 130 and 160 m.

6.4. Species Protection Areas (SPAs)

Descriptions of both VMEs and EBSAs can be, and have been, used as input guides for MPA planning in South Africa. However, it is noteworthy that while VMEs, EBSAs and in particular habitat representativeness (with emphasis on threatened habitat in good condition) have been influential in the process of defining priority areas for MPAs, single-species conservation concerns have received far less consideration. Thus, several key areas that are considered key for the conservation of threatened or protected species are presently not within the current or proposed MPA network. Examples are important island breeding habitats for Endangered seabirds such as African penguins, Cape cormorants and bank cormorants, e.g. Dassen and Dyer Islands and their associated foraging areas, and areas around localities where it is proposed to try to establish new colonies of these seabirds close to the present distribution of their food, in attempts to mitigate their ongoing decreases off western South Africa. The exigency of such Species Protection Areas (SPAs) in the ongoing declines of seabirds is recognised and, considering the positive benefits of no-take areas around African penguin breeding colonies that have been indicated by early results of an ongoing experiment[55], spatial protection for such species warrants much greater emphasis in future MPA planning.

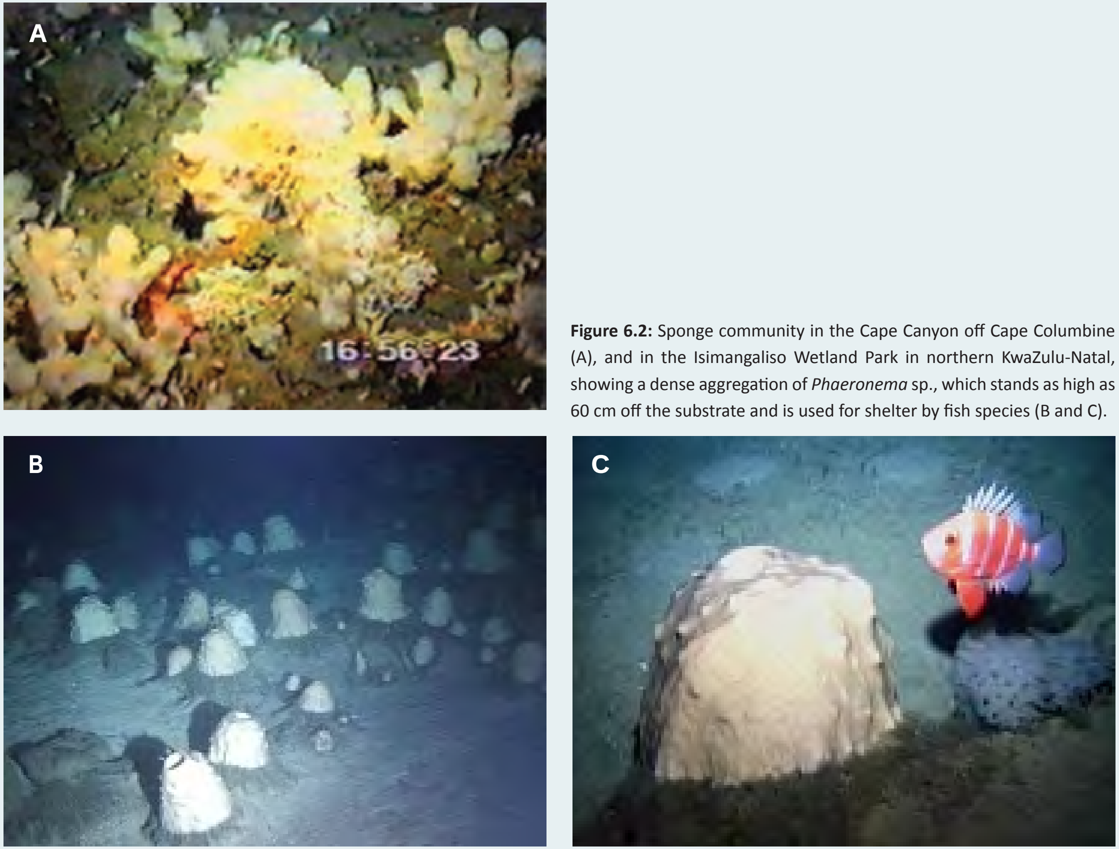

Figure 6.2: Sponge community in the Cape Canyon off Cape Columbine (A), and in the Isimangaliso Wetland Park in northern KwaZulu-Natal, showing a dense aggregation of *Phaeronema* sp., which stands as high as 60 cm off the substrate and is used for shelter by fish species (B and C).

Jellyfish are part of the zooplankton community (source: www.dreamstime.com)

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