

There are two alternative approaches to accessing diamond resources seaward of the low water mark, namely:

- temporary accretion of the beach in the immediate vicinity of the mining target using overburden material available on the beach or from adjacent onland mining sites; or
- the construction of a rock berm or coffer dam using non-native rocks and boulders sourced from rock stockpiles near Koingnaas. Both statistically stable and dynamically stable rock berms are being considered.

Up to six potential sites harbouring surf zone resources have been identified. However, the nature of the specific target area determines which of the alternative approaches is most suitable. For example, the exposed nature of the coastline and high longshore sediment transport rates, in combination with insufficient overburden sands available on the beach to maintain accretion under the resulting high erosion rates, negates the application of beach accretion using sand anywhere but in very sheltered bays.

Using information summarised from WSP (2015) and the Department of Mineral Resources (DMR) Application form, the alternative mining approaches are detailed below.

### 2.2.1 Cofferdams

Along the typically wave exposed coastline of the project area, rock berms or coffer dams are the only feasible alternative to effectively reclaiming a mining area located beyond the low water mark. The procedure for construction of a protective rock berm is described briefly below:

- On both the northern and southern side of the mining target area a rock berm is built by progressively end-tipping rock- and boulder core material from trucks perpendicular to the oncoming waves and shoreline. Dozers and excavators subsequently shape the profile and dress the slope with a suitable armour layer of larger rocks;
- The berms extend from above the storm high water mark into the surf zone until the seaward extent of the mining block is reached and a shore-parallel berm is constructed linking the two shore-perpendicular berms;
- Once the berm is in place and the mining block is enclosed overburden stripping and gravel extraction can be undertaken using conventional open-cast mining approaches;
- Once the area has been mined out, the rock berm would be progressively extended offshore to enclose the next mining block, potentially enabling mining up to 300 m seawards of the low water mark.

The material used to construct such breakwaters typically consists of an underlying core of quarried material, which gets progressively coarser towards the outside and is covered by an outer layer of large armour rock. Geotextile sandbags commonly used for coastal protection works may also be used in areas of low wave energy, as temporary emergency measures or above the high water mark on the wall itself. The seaward extent of the berm and prevailing wave conditions determine the size/mass of the rock required for the armour layer. Berm can be extended in phases as far offshore as conditions allow. Although four phases have been assumed for this project (Figure 3), the material requirements for Stages 3 and 4 would necessitate the use of very large armour rocks that would be difficult to produce, transport and place, thereby

reducing the feasibility of these structures. Possible alternatives for Stage 4 include the use of concrete armour units on the seaward face of the berm, or constructing the berm as a dynamically reshaping profile using smaller rocks (see later). However, this would involve prohibitively high construction and rehabilitation costs and high erosion rates, possibly exceeding material placement rates, respectively. The Stage 4 berm is thus not considered feasible.

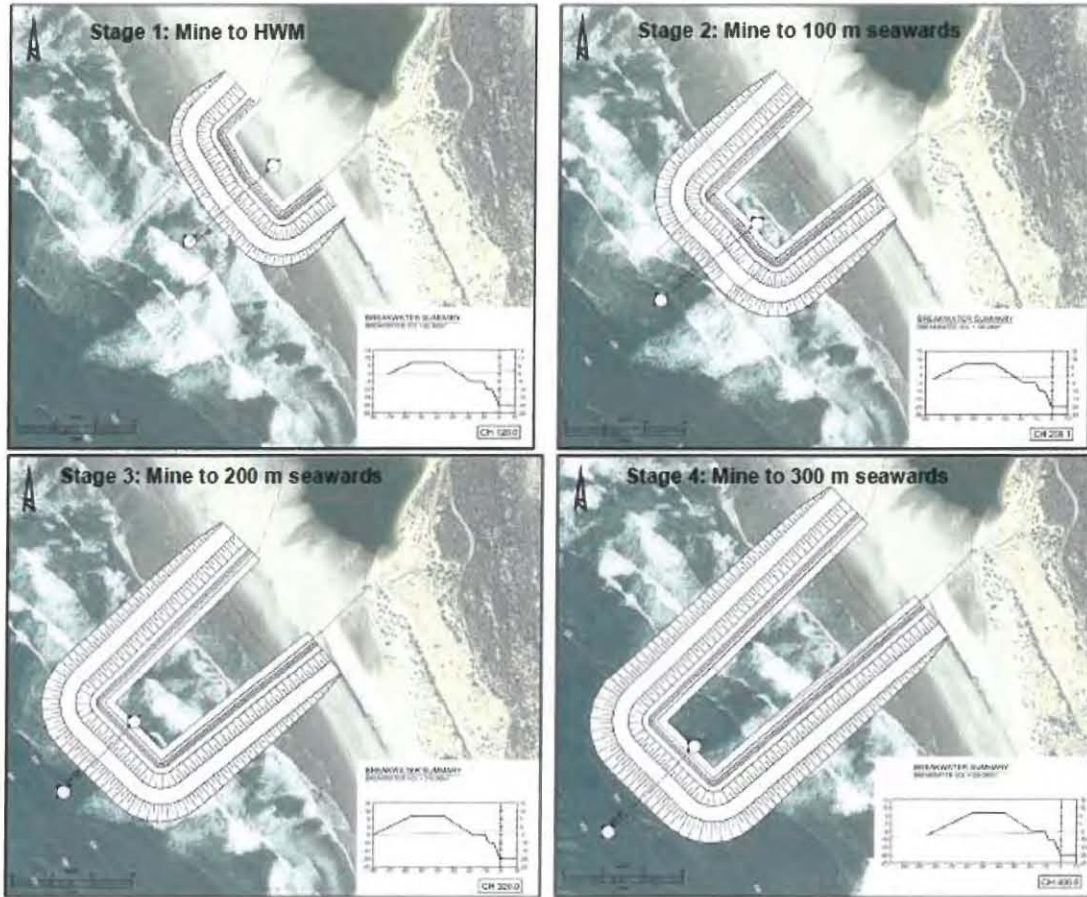


Figure 3: Proposed phased rock berm construction at Koingnaas 68/69, Somnaas and Langklip Central (Source: WSP 2015).

Despite the comparatively high volumes of material required for berm construction (Table 1), the design-life of such berms is typically 1-2 years and they can thus be considered temporary structures.

Table 1: Estimated rock volumes required for the various construction phases

Construction Phase	Material requirements (m <sup>3</sup> )
Stage 1	65,000
Stage 2	135,000
Stage 3	216,000
Stage 4	356,000

Similar beach mining operations have previously been successfully undertaken near the Olifant's River and along the coastline near Alexander Bay. For the current project, WCR is intending to implement this mining approach at the sandy beach target sites known as Koingnaas 68/69,

Somnaas and Langklip Central. The estimated area to be disturbed at each of these sites amounts to ~118,000 m<sup>2</sup>.

### 2.2.2 Accretion of Mitchell's Bay

Mitchell's Bay (Rooiwal Bay) is a small protected bay located north of the Spoeg River in Concession 8a. The mouth of the bay is some 700 m across. The bay hosts a narrow sandy beach backed by steep soil cliff and a shallow reef in the mouth. The seabed is mainly rock - bedrock, boulders, cobble and gravel, although there is limited sand cover at the beach in the eastern side of the bay and at the palaeochannel in the north of the bay. An irregular, deep, channel reaching at least 20 m depth is present in the northern part of the bay, with a second depression occurring in the southern part of the bay.

One of the proposed mining approaches implemented to access the diamond deposits on the seabed and adjacent beaches within Mitchell's Bay, involves using fine overburden sands stripped from a potential mining site in an adjacent on-land dune field to accrete the shoreline of the bay. Mining of the accreted area would liberate further material that can be dumped into the sea to gain additional accretion. Three stages of beach accretion are being considered, with the shoreline moving seawards by 150 m during each successive stage (Figure 4). Sand volumes required for each stage comprised 1.3 million, 2.5 million and 5.9 million cubic metres, respectively for 150 m, 300 m and 450 m accretion. However, as the beach is accreted and the shoreline maintains equilibrium with the wave-driven currents, sand placed on the beach would be redistributed by currents and transported southwards and westwards out of the bay, where it would redeposit on the seabed and adjacent shoreline.

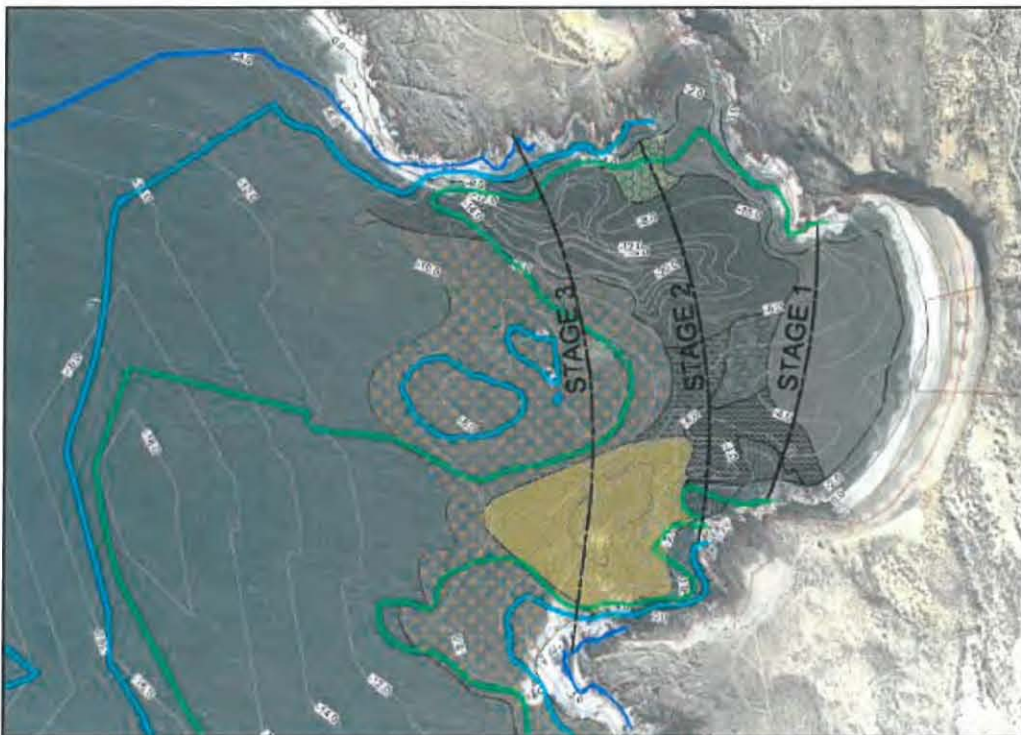


Figure 4: Three phases of proposed shoreline accretion within Mitchell's Bay. The associated deposition of sand for Stage 1 is shown in green, Stage 2 in cyan and Stage 3 in blue (Source: WSP 2015).

While this alternative for Mitchell's Bay is considered feasible from an engineering perspective, it is dependent on the mining of the inland deposits for a source of the accretion material. The estimated area to be disturbed using this approach would be 541,755 m<sup>2</sup>, excluding indirect effects due to redistribution of eroded sediments.

### 2.2.3 Closure of Mitchell's Bay with a Dynamically Stable Rock Berm

The alternative approach proposed for Mitchell's Bay is the construction of a dynamically stable rock berm across the mouth of the bay and perpendicular to the predominant wave action (Figure 5). To avoid erosion of the berm profile during storms, it needs to be relatively wide and therefore requires large volumes of material for construction and covers a larger footprint than a conventional rock berm.

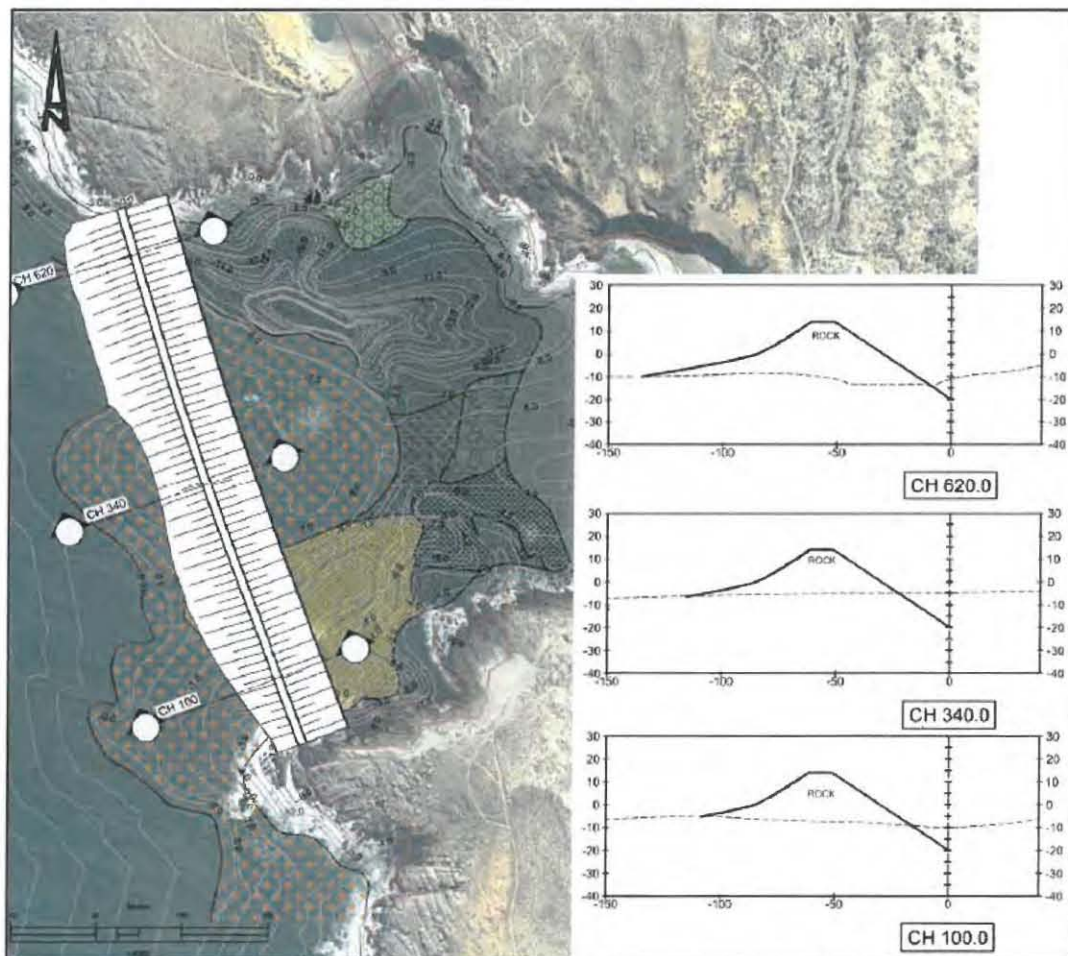


Figure 5: Layout and sections for a proposed dynamically stable rock berm for the closure of Mitchell's Bay (Source: WSP 2015).

To implement this approach in Mitchell's Bay, a berm crest of 14 m in height would be required to protect the mining area from extreme wave conditions. With a berm width of 10 m at the crest and as much as 140 m at the base, at minimum 660,000 m<sup>3</sup> of large cobbles/small boulders would be required. This volume does not cater for wastage through erosion of material during the construction phase, or for ongoing replenishment of eroded material during the life of the structure. While considered technically feasible, this alternative has high costs associated with it

and the high loss rate of material off the partly completed berm during construction may result in the structure being impossible to build. The estimated area to be disturbed using this approach would be 541,755 m<sup>2</sup>, excluding indirect effects due to loss of construction material.

Closure of Mitchell's Bay with a statistically stable rock berm is not considered feasible due to the need for either very large armour rocks or concrete armour units on the seaward side of the berm facing the oncoming waves.

#### 2.2.4 Partial Closure of Mitchell's Bay with a Rock Groyne

A further option considered was to partially close the southern portion of Mitchell's Bay through the construction of a rocky groyne, which would extend some 275 m in a north-westerly direction to the reef in the centre of the bay (Figure 6). The groyne would be positioned over the natural underwater ridge occurring in the south of the bay and would reduce the wave heights inside the bay. The water depth at the tip of the groyne would be approximately 4 m. The volume of rock required for construction amounts to ~90 000 m<sup>3</sup>.

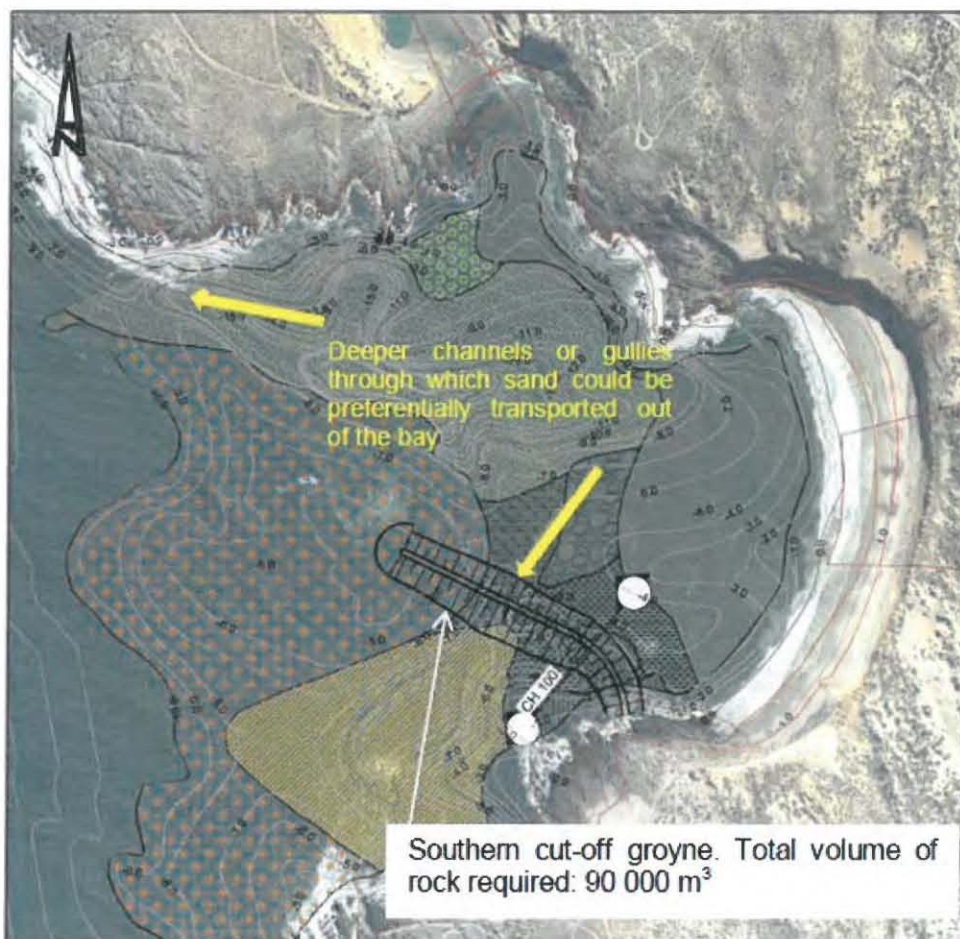


Figure 6: Layout for a proposed rock groyne for the partial closure of Mitchell's Bay (Source: WSP 2016).

### 2.2.5 Generic Protection Design

A more generic design involving either statistically stable rock berms, or these in combination with dynamically stable berms, is being considered for other potential mining sites characterised by either a rocky shoreline or a shoreline of mixed sand and rock. The generic design is proposed for the Noup, Visbeen, Koingnaas, Langklip Central and Langklip target areas.

The generic designs assume an initial mining area of 200 x 200 m, with sequential extension into adjacent blocks as mining progresses and the resource in a block is mined out. The type of design applied is determined largely by the depth of the seabed at the seaward extreme of the shore parallel berm. Two alternative generic designs are being considered, namely:

#### 1) Statistically stable rock berm

In areas of seabed depth up to 2.5 m below mean sea level at the seaward edge of the mining target, a conventional, statistically stable rock berm comprising a core of finer material and an armour layer of larger rocks facing the prevailing waves would be constructed. For protection of the Stage 1 mining block, these berms would comprise a shore-parallel and shore-perpendicular component (grey shading in Figure 7). Extension of operations into subsequent mining blocks would require the construction of a further shore-parallel berm to protect the adjacent area (lighter shading in Figure 7).

#### 2) Alternative combination berm

In areas of seabed depth up to 4 m below mean sea level at the seaward edge of the mining target, a conventional, statistically stable groyne would be built perpendicular to the shore to the required depth. Large armouring would be required at the seaward edge of this groyne to prevent erosion. To protect the Stage 1 mining block, the seaward end of the groyne would connect to a shore-parallel dynamic re-shaping berm (grey shading in Figure 8). An further shore-parallel dynamic re-shaping berm would then be added for the protection of the Stage 2 mining block (lighter shading in Figure 8).

For each site, the most economically and technically viable concept/s will be selected bearing in mind the temporary nature of the mining, the quantity and characteristics of available construction materials (rock, sand and clay), possible phasing of the mining to facilitate recovery of diamonds at an early stage, the need to minimise seepage into the mining area and the costs of protective measures. The potential areas to be disturbed by these proposed operations are provided in Table 2.

Table 2: Potential areas to be disturbed in the mining areas targeted for beach and offshore channel mining.

Mining Zone	Total Area (m <sup>2</sup> )	Disturbed Area	
		(%)	(m <sup>2</sup> )
Noup	1 589 380	25%	397 345
Visbeen	448 457	75%	336 343
Koingnaas	1 340 284	50%	670 142
Langklip Central	391 679	50%	195 839
Langklip	165 443	25%	41 361

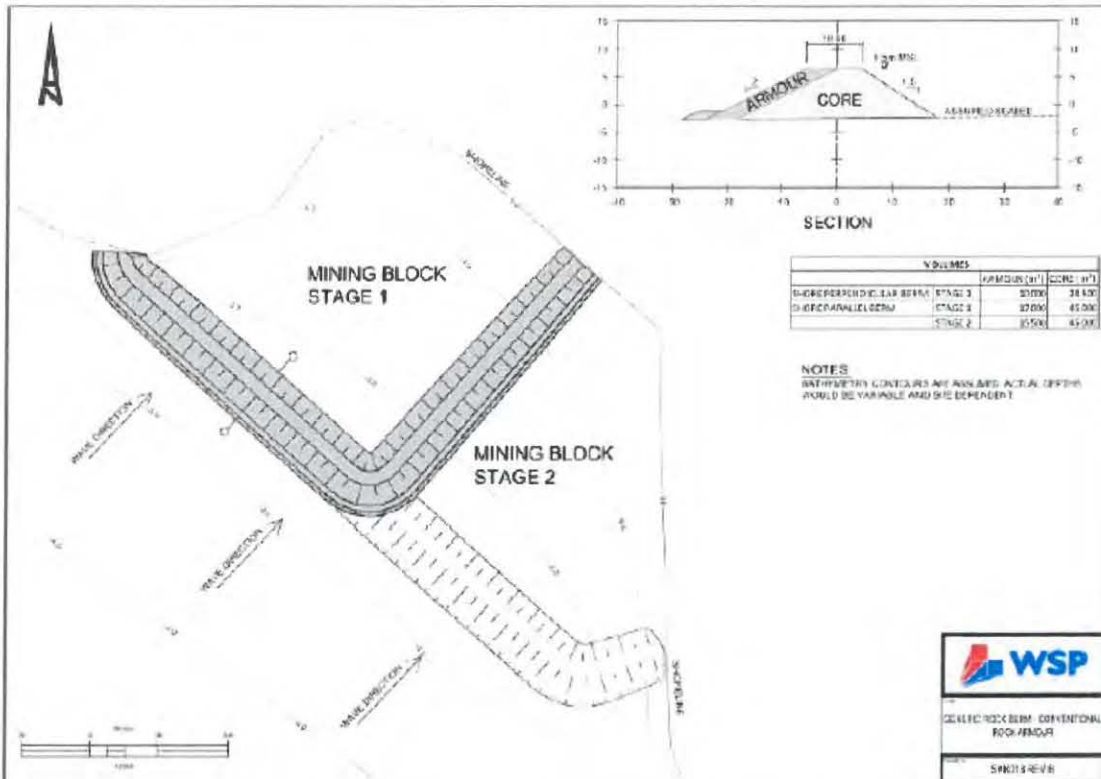


Figure 7: Layout of a generic rock berm with a conventional statistically stable armour slope(Source: WSP 2015).

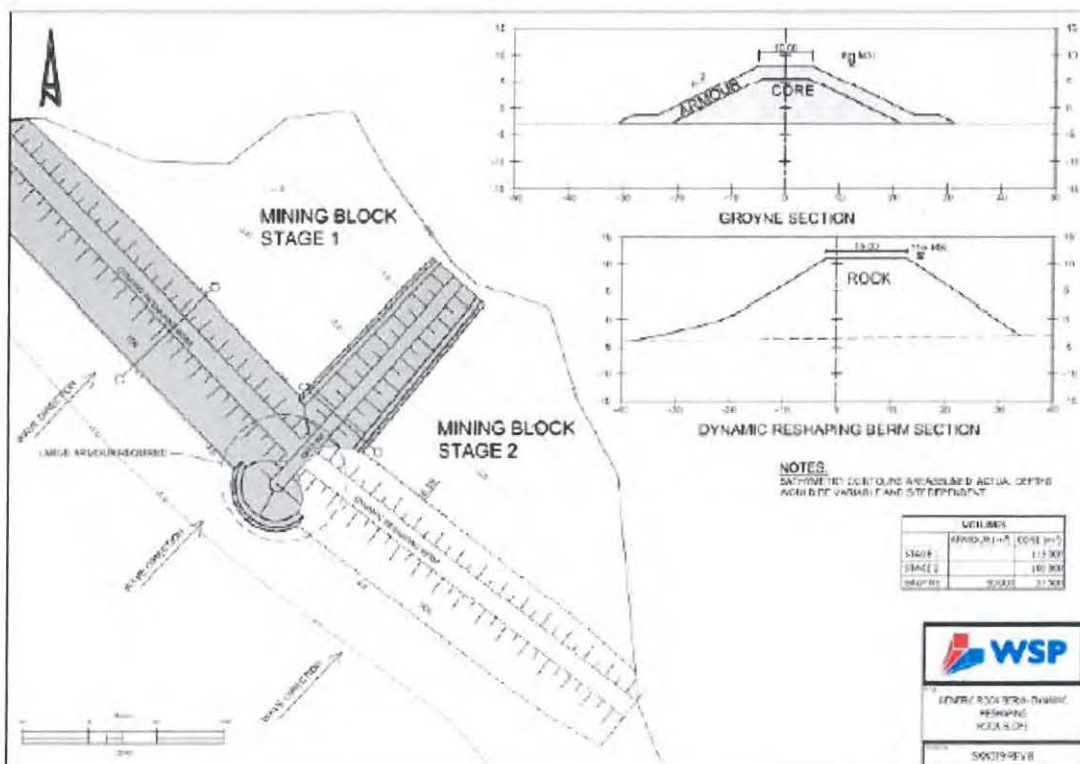


Figure 8: Layout of an alternative generic design using a conventional statistically stable groyne in combination with a dynamic re-shaping shore-parallel berm(Source: WSP 2015).

### 3. DESCRIPTION OF THE AFFECTED MARINE ENVIRONMENT

#### 3.1 Physical Environment

##### 3.1.1 Sea Surface Temperature, Currents and Circulation Patterns

An overview of the water masses, and major coastal and oceanic current and circulation patterns along the South African west coast was presented by Shannon & Nelson (1996). The cool temperate Benguela region (average sea surface temperature 10 - 14°C) is located between two warm current features, namely the Angola Current in the north and the Agulhas current in the south. The southward flowing Angola Current originates from the circular gyre on the Angola Dome, which is a prominent oceanographic feature off the coast of Angola. At the opposite end of the Benguela system, the strong Agulhas Current flows down the eastern South African shelf edge, along the Agulhas Bank past Cape Agulhas, and periodically generates massive, warm 'Agulhas Rings', resulting in substantial heat flux into the central South Atlantic ocean. The Agulhas Current is also capable of rounding Cape Point and generating an episodic, northward-flowing current, which splits near Cape Columbine (33°S) into the offshore Cape Canyon jet, and a northward longshore flow (Figure 9). The surface water of the Agulhas Current is generally >21 C, and its influence west of Cape Agulhas results in average sea surface temperatures in the southern Benguela of 16 - 20°C (Shannon 1985).

The Benguela region, in contrast, is dominated more by wind-driven upwelling and swell events than by consistent current flows. Currents tend to follow major topographic features, with typical current speeds in the region ranging from 10 - 50 cm/s. Over the southern Benguela region (south of Cape Columbine), there is a southward flow of cold water close inshore near the surface, which occurs during periods of barotropic reversals, and during the winter non-upwelling period (Nelson & Hutchings 1983). There is also a significant southerly poleward flow of sub-thermocline water on the continental shelf and at the shelf break, forming a poleward undercurrent, which becomes more consistent to the south (Nelson 1989; Boyd & Oberholster 1994; Shannon & Nelson 1996) (Figure 9).

The project area falls within the nearshore central Benguela region (Cape Columbine to Lüderitz), which is primarily characterised by variable, northward flowing, longshore surface currents, generated by consistent, strong winds and swells from the south and southwest (Shillington et al. 1990; Shannon & Nelson 1996). These nearshore surface currents remain closely aligned with the coastline and the winds, generally flowing in a northerly direction, although periodic reversals can occur. Winds are the main physical driver of the nearshore region, and physical processes are characterised by the average seasonal wind patterns. Substantial episodic changes in these wind patterns can consequently have strong effects on the entire Benguela region.

The prevailing winds along the southern African West Coast are controlled by the South Atlantic subtropical anticyclone, the eastward moving mid-latitude cyclones south of southern Africa, and the seasonal atmospheric pressure field over the subcontinent. The south Atlantic anticyclone is a perennial feature that forms part of a discontinuous belt of high-pressure systems, which encircle the subtropical southern hemisphere. This undergoes seasonal variations, being strongest in the austral summer, when it also attains its southernmost extension, lying south west and south of the subcontinent. In winter, the south Atlantic anticyclone weakens and migrates north-westwards.



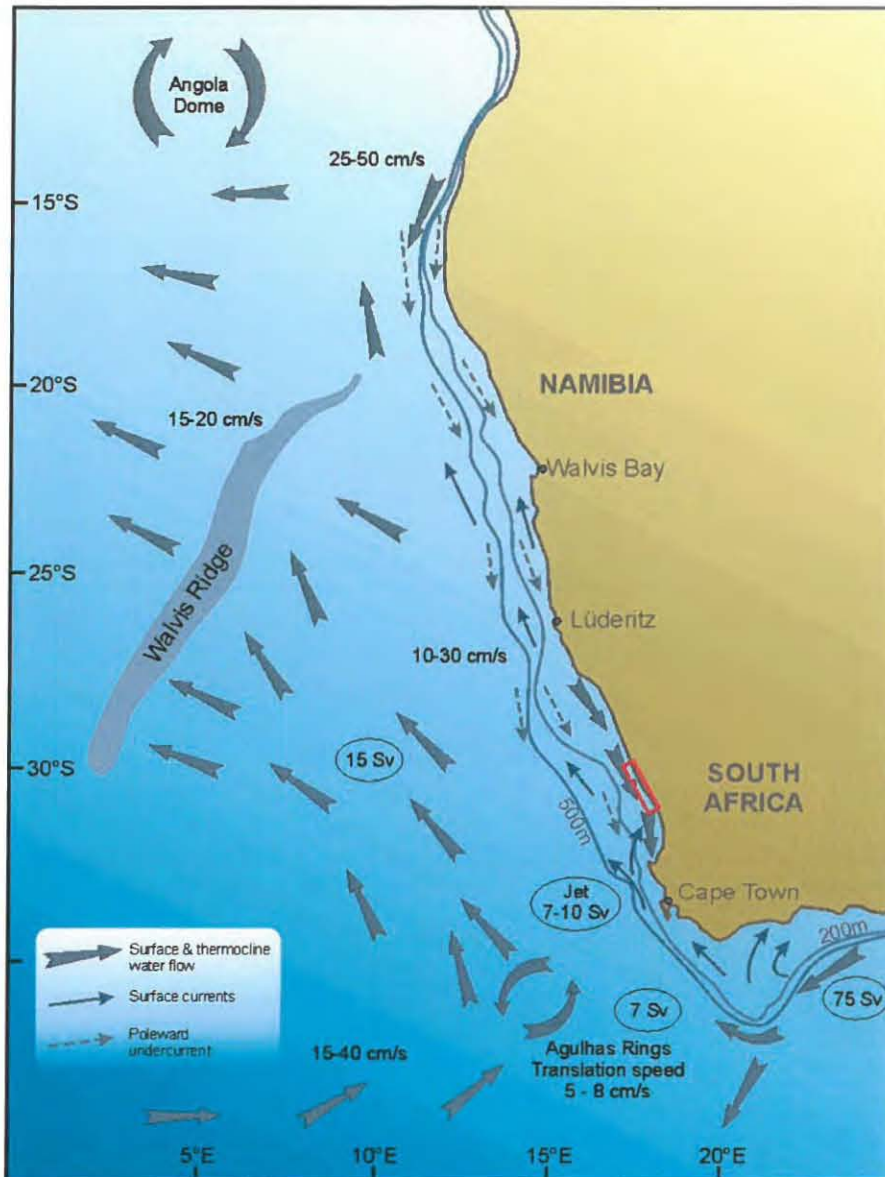


Figure 9: Major features of the predominant circulation patterns and volume flows in the Benguela System, along the southern Namibian and South African west coasts (re-drawn from Shannon & Nelson 1996), in relation to the project area (red polygon).

These seasonal changes result in substantial differences between the typical summer and winter wind patterns in the region, as the southern hemisphere anti-cyclonic high-pressure systems, and the associated series of cold fronts, moves northwards in winter, and southwards in summer (Figure 10). The strongest winds occur in summer, during which winds blow 99% of the time, and gales (winds exceeding 63 km/h or 18 m/s) are frequent. In summer, winds are dominated by southerlies, which occur over 40% of the time, averaging 37 - 55 km/h (10 - 15 m/s) and reaching speeds in excess of 100 km/h. South-easterlies are almost as common, blowing about one-third of the time, and also averaging 37 - 55 km/h. The combination of these southerly/south-easterly winds drives the massive offshore movements of surface water, and the resultant strong upwelling of nutrient-rich bottom waters, which characterise this region in summer.

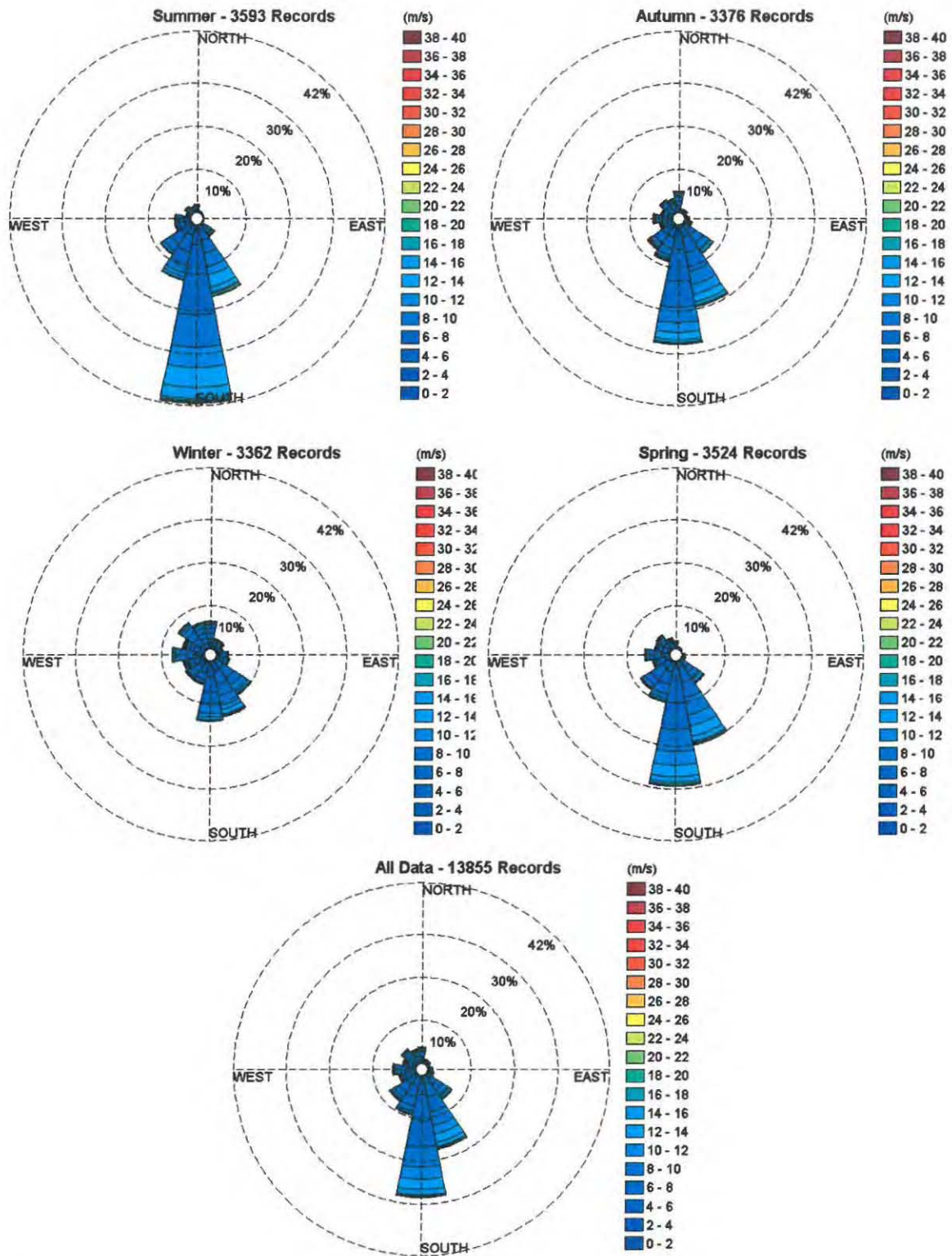


Figure 10: VOS Wind Speed vs. Wind Direction data for the Cape Columbine area 32.0 to 32.9 S and 17.0 to 17.9 E (1903-11-01 to 2011-05-24; 13,855 records) (from CSIR).

Southerly to south-southeasterly winds continue to dominate the wind pattern during winter, but the closer proximity of the winter cold-front systems also results in a significant south-westerly to north-westerly component (Figure 10). This 'reversal' from the summer condition results in cessation of upwelling, movement of warmer mid-Atlantic water shorewards and breakdown of the strong thermoclines, which typically develop during summer. There are also more calms in winter, occurring about 3% of the time, and wind speeds generally do not reach the maximum speeds of summer. The westerly winds blowing in synchrony with the prevailing south-westerly swell direction in winter, however, usually result in far heavier swell conditions.

### 3.1.2 Waves and Tides

Most of the west coast of southern Africa is classified as exposed, experiencing strong wave action, rating between 13 - 17 on the 20 point exposure scale (McLachlan 1980). West- to north-facing embayments are limited and most of the coastline is therefore impacted by heavy south-westerly swells generated in the roaring forties, as well as significant sea waves generated locally by the prevailing moderate to strong southerly winds characteristic of the region. The Namaqualand coastline is particularly exposed, being rated as "exposed" and "extremely exposed" (Steffani 2001).

The wave regime along the southern African west coast shows only moderate seasonal variation in direction, with virtually all swells throughout the year coming from the southwesterly to southerly direction (Figure 11). Winter swells are strongly dominated by those from the southwest to south-southwest, which occur almost 80% of the time, and typically exceeding 2 m in height, averaging about 3 m, and often attaining over 5 m. With wind speeds capable of reaching 100 km/h (during heavy winter south-westerly storms, winter swell heights can exceed 10 m). The dominant peak energy period for waves is ~12 seconds, although longer period swells occur about 30% of the time.

Summer swells tend to be smaller on average, typically around 2 m with a more pronounced southerly swell component. These southerly swells tend to be wind-induced, with shorter wave periods (~8 seconds), and are generally steeper than swell waves. The wind-induced southerly waves are relatively local and work together with the strong summer southerly winds to cause the northward-flowing nearshore surface currents, which results in substantial nearshore sediment mobilisation and northwards transport. In common with the rest of the southern African coast, tides along the Namaqualand coast and in the project area are semi-diurnal, with a total range of some 1.5 m at spring tide, but only 0.6 m during neap tide periods.

### 3.1.3 Water

South Atlantic Central Water (SACW) comprises the bulk of the seawater in the study area, either in its pure form in the deeper regions, or mixed with previously upwelled water of the same origin on the continental shelf (Nelson & Hutchings 1983). Salinities range between 34.5 ‰ and 35.5 ‰ (Shannon 1985).

Seawater temperatures on the continental shelf of the central Benguela typically vary between 6 °C and 16 °C. Well-developed thermal fronts exist, demarcating the seaward boundary of the upwelled water. Upwelling filaments are characteristic of these offshore thermal fronts, occurring as surface streamers of cold water, typically 50 km wide and extending beyond the normal offshore

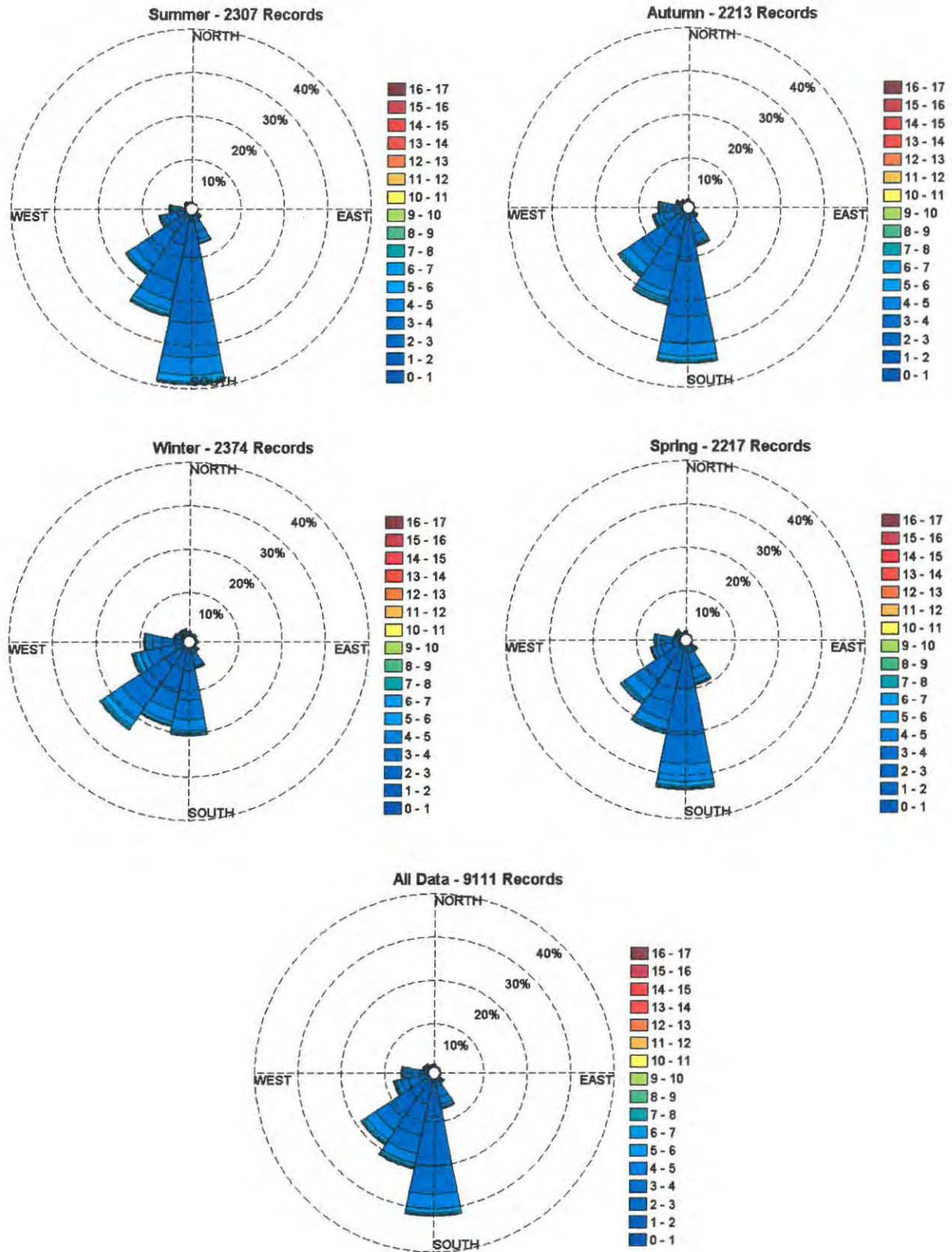


Figure 11: VOS Wave Height vs. Wave Direction data for the Cape Columbine area 32.0 to 32.9 S and 17.0 to 17.9 E (1903-11-01 to 2011-05-24; 9,111 records) (from CSIR).

extent of the upwelling cell. Such fronts typically have a lifespan of a few days to a few weeks, with the filamentous mixing area extending up to 625 km offshore.

The continental shelf waters of the Benguela system are characterised by low oxygen concentrations, especially on the bottom. SACW itself has depressed oxygen concentrations (~80% saturation value), but lower oxygen concentrations (<40% saturation) frequently occur (Bailey *et al.* 1985; Chapman & Shannon 1985).

#### 3.1.4 Upwelling and Plankton Production

Coastal, wind-induced upwelling is the principal physical process that shapes the marine ecology of the Benguela region. The prevailing longshore, equatorward winds move nearshore surface water northwards and offshore. To balance the displaced water, cold, deeper water wells up inshore.

During upwelling the comparatively nutrient-poor surface waters are displaced by enriched deep water, supporting substantial seasonal primary phytoplankton production. The cold, upwelled water is rich in inorganic nutrients, the major contributors being various forms of nitrates, phosphates and silicates (Chapman & Shannon 1985). Nutrient concentrations of upwelled water of the Benguela system attain 20  $\mu\text{M}$  nitrate-nitrogen, 1.5  $\mu\text{M}$  phosphate and 15-20  $\mu\text{M}$  silicate, indicating nutrient enrichment (Chapman & Shannon 1985). This is mediated by nutrient regeneration from biogenic material in the sediments (Bailey *et al.* 1985). Modification of these peak concentrations depends upon phytoplankton uptake which varies according to phytoplankton biomass and production rate. The range of nutrient concentrations can thus be large but, in general, concentrations are high.

High phytoplankton productivity in the upper layers again depletes the nutrients in these surface waters. This results in a wind-related cycle of plankton production, mortality, sinking of plankton detritus and eventual nutrient re-enrichment occurring below the thermocline as the phytoplankton decays. Biological decay of plankton blooms can in turn lead to “black tide” events, as the available dissolved oxygen is stripped from the water during the decomposition process (see below). Subsequent anoxic decomposition by sulphur reducing bacteria can result in the formation and release of hydrogen sulphide (Pitcher & Calder 2000).

Although the rate and intensity of upwelling fluctuates with seasonal variations in wind patterns, the most intense upwelling tends to occur where the shelf is narrowest and the wind strongest. The largest and most intense upwelling cell is in the vicinity of Lüderitz, and upwelling can occur there throughout the year (Shannon & O’Toole 1998; Shillington 2003). Several secondary upwelling cells occur, of which the Namaqua cell is centred around Hondeklip Bay (30°S), and the Cape Columbine (33°S) and Cape Point (34°S) upwelling cells are located further south (Figure 12). Upwelling in these secondary cells is seasonal, with maximum upwelling occurring between September and March. The project area is located within the Hondeklip Bay cell, and is thus likely to be periodically influenced by upwelling-related processes (Figure 12). During the winter months westerly winds result in relaxation of upwelling and often warmer surface water temperatures (Lutjeharms & Meeuwis 1987).

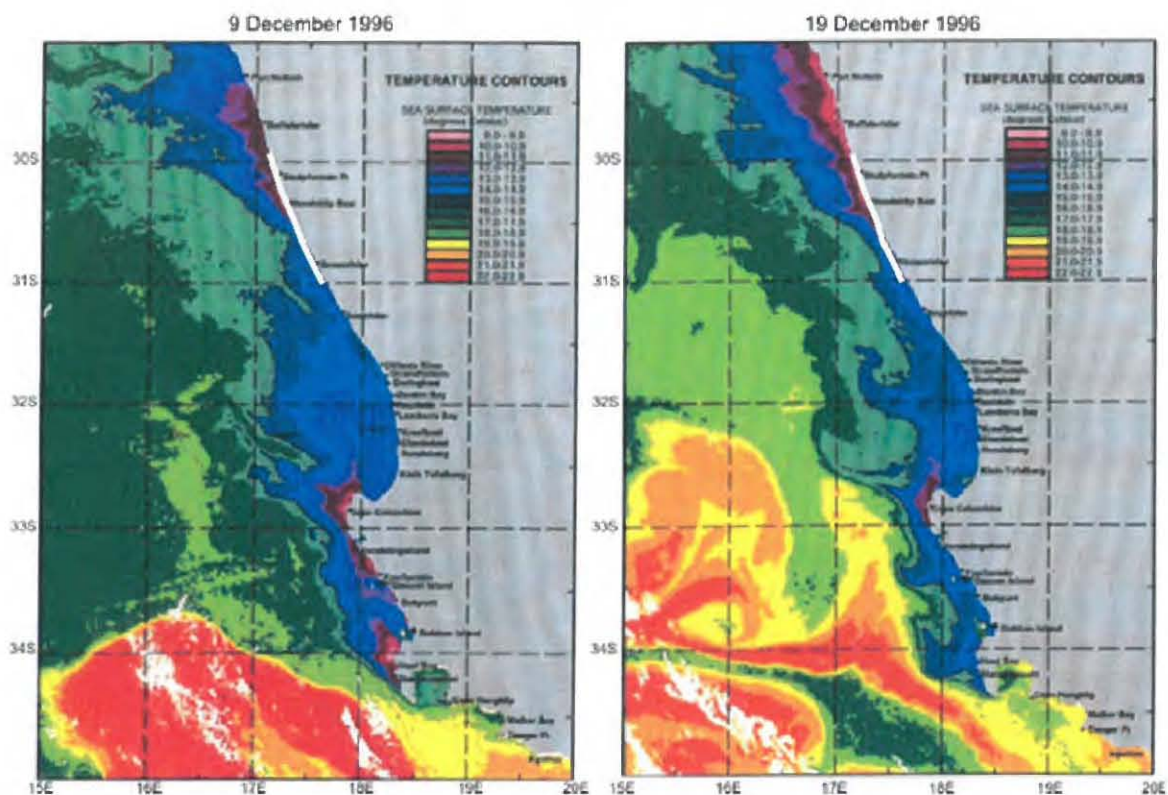


Figure 12: Satellite sea-surface temperature images showing upwelling intensity along the South African west coast and the influence of the Agulhas current on temperatures on the southwest coast (from Lane & Carter 1999). The white line denotes the project area.

### 3.1.5 Organic Inputs

The Benguela upwelling region is an area of particularly high natural productivity, with extremely high seasonal production of phytoplankton and zooplankton. These plankton blooms in turn serve as the basis for a rich food chain up through pelagic baitfish (anchovy, pilchard, round-herring and others), to predatory fish (snoek), mammals (primarily seals and dolphins) and seabirds (jackass penguins, cormorants, pelicans, terns and others). All of these species are subject to natural mortality, and a proportion of the annual production of all these trophic levels, particularly the plankton communities, die naturally and sink to the seabed. Balanced multispecies ecosystem models have estimated that during the 1990s the Benguela region supported biomasses of 76.9 tons/km<sup>2</sup> of phytoplankton and 31.5 tons/km<sup>2</sup> of zooplankton alone (Shannon *et al.* 2003). Thirty six percent of the phytoplankton and 5% of the zooplankton are estimated to be lost to the seabed annually. This natural annual input of millions of tons of organic material onto the seabed off the southern African West Coast has a substantial effect on the ecosystems of the Benguela region. It provides most of the food requirements of the particulate and filter-feeding benthic communities that inhabit the sandy-muds of this area, and results in the high organic content of the muds in the region. As most of the organic detritus is not directly consumed, it enters the seabed decomposition cycle, resulting in subsequent depletion of oxygen in deeper waters.

### 3.1.6 Low Oxygen Events

An associated phenomenon ubiquitous to the Benguela system are red tides (dinoflagellate and/or ciliate blooms) (see Shannon & Pillar 1985; Pitcher 1998). Also referred to as Harmful Algal Blooms (HABs), these red tides can reach very large proportions, extending over several square kilometres of ocean (Figure 13, left). Toxic dinoflagellate species can cause extensive mortalities of fish and shellfish through direct poisoning, while degradation of organic-rich material derived from both toxic and non-toxic blooms results in oxygen depletion of subsurface water (Figure 13, right).



Figure 13: Red tides can reach very large proportions (left, Photo: [www.e-education.psu.edu](http://www.e-education.psu.edu)) and can lead to mass stranding, or 'walk-out' of rock lobsters, such as occurred at Elands Bay in February 2002 (Photo: [www.waterencyclopedia.com](http://www.waterencyclopedia.com)).

The continental shelf waters of the Benguela system are characterised by low oxygen concentrations with <40% saturation occurring frequently (e.g. Visser 1969; Bailey *et al.* 1985). The low oxygen concentrations are attributed to nutrient remineralisation in the bottom waters of the system (Chapman & Shannon 1985). The absolute rate of this is dependent upon the net organic material build-up in the sediments, with the carbon rich mud deposits playing an important role. As the mud on the shelf is distributed in discrete patches (see Figure 14), there are corresponding preferential areas for the formation of oxygen-poor water. The two main areas of low-oxygen water formation in the central Benguela region are in the Orange River Bight and St Helena Bay (Chapman & Shannon 1985; Bailey 1991; Shannon & O'Toole 1998; Bailey 1999; Fossing *et al.* 2000). The spatial distribution of oxygen-poor water in each of the areas is subject to short- and medium-term variability in the volume of hypoxic water that develops. De Decker (1970) showed that the occurrence of low oxygen water off Lambert's Bay is seasonal, with highest development in summer/autumn. Bailey & Chapman (1991), on the other hand, demonstrated that in the St Helena Bay area daily variability exists as a result of downward flux of oxygen through thermoclines and short-term variations in upwelling intensity. Subsequent upwelling processes can move this low-oxygen water up onto the inner shelf, and into nearshore waters, often with devastating effects on marine communities.

Periodic low oxygen events in the nearshore region can have catastrophic effects on the marine communities leading to large-scale stranding of rock lobsters, and mass mortalities of marine biota and fish (Newman & Pollock 1974; Matthews & Pitcher 1996; Pitcher 1998; Cockcroft *et al.* 2000) (see Figure 13, right). The development of anoxic conditions as a result of the decomposition of huge amounts of organic matter generated by phytoplankton blooms is the main cause for these

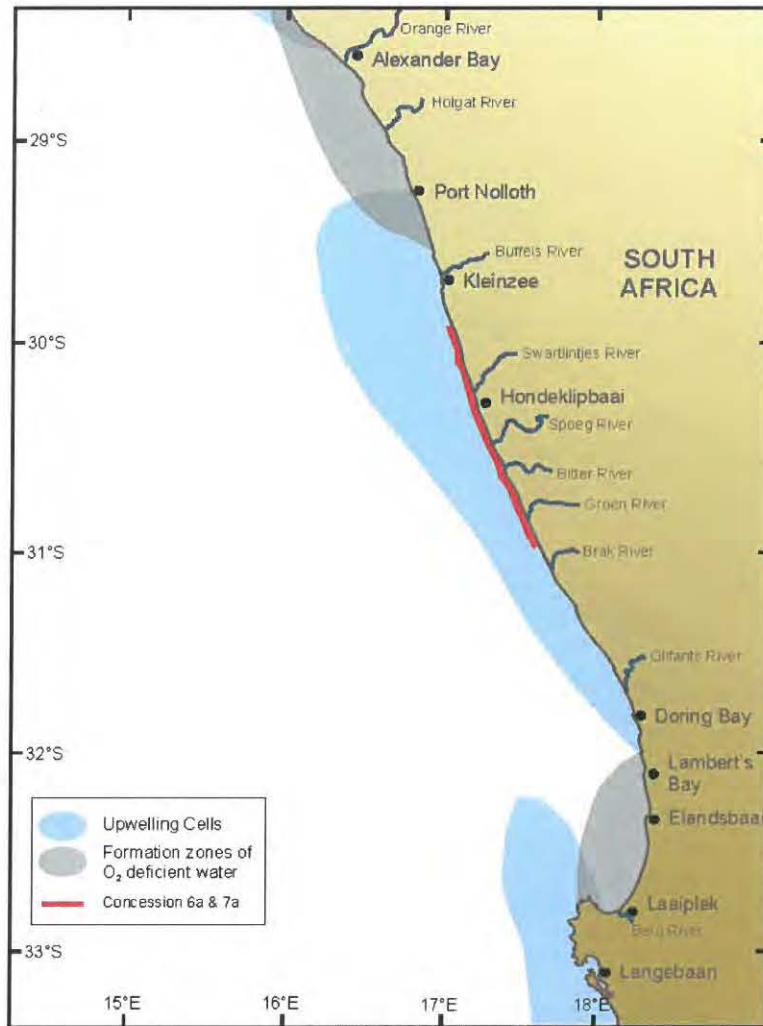


Figure 14: Upwelling centres and formation zones of oxygen deficient water on the West Coast in relation to the project area (red line).

mortalities and walkouts. The blooms develop over a period of unusually calm wind conditions when sea surface temperatures were high. Algal blooms usually occur during summer-autumn (February to April) but can also develop in winter during the ‘berg’ wind periods, when similar warm windless conditions occur for extended periods. Low-oxygen events have, however, not been reported from the region in which the project area is located.

### 3.1.7 Turbidity

Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particulate matter. Total Suspended Particulate Matter (TSPM) can be divided into Particulate Organic Matter (POM) and Particulate Inorganic Matter (PIM), the ratios between them varying considerably. The POM usually consists of detritus, bacteria, phytoplankton and zooplankton, and serves as a source of food for filter-feeders. Seasonal microphyte production associated with upwelling events will play an important role in determining the concentrations of POM in coastal waters. PIM, on the other hand, is primarily of geological origin consisting of fine sands, silts and clays. Off Namaqualand, the PIM loading in nearshore waters is strongly related to



natural inputs from the Orange River or from 'berg' wind events. Although highly variable, annual discharge rates of sediments by the Orange River is estimated to vary from 8 - 26 million tons/yr (Rogers 1979). 'Berg' wind events can potentially contribute the same order of magnitude of sediment input as the annual estimated input of sediment by the Orange River (Shannon & Anderson 1982; Zoutendyk 1992, 1995; Shannon & O'Toole 1998; Lane & Carter 1999). For example, a 'berg' wind event in May 1979 described by Shannon and Anderson (1982) was estimated to have transported in the order of 50 million tons of sand out to sea, affecting an area of 20,000 km<sup>2</sup>.

Concentrations of suspended particulate matter in shallow coastal waters can vary both spatially and temporally, typically ranging from a few mg/ℓ to several tens of mg/ℓ (Bricelj & Malouf 1984; Berg & Newell 1986; Fegley *et al.* 1992). Field measurements of TSPM and PIM concentrations in the Benguela current system have indicated that outside of major flood events, background concentrations of coastal and continental shelf suspended sediments are generally <12 mg/ℓ, showing significant long-shore variation (Zoutendyk 1995). Considerably higher concentrations of PIM have, however, been reported from southern African West Coast waters under stronger wave conditions associated with high tides and storms, or under flood conditions. During storm events, concentrations near the seabed may even reach up to 10,000 mg/ℓ (Miller & Sternberg 1988). In the vicinity of the Orange River mouth, where river outflow strongly influences the turbidity of coastal waters, measured concentrations ranged from 14.3 mg/ℓ at Alexander Bay just south of the mouth (Zoutendyk 1995) to peak values of 7,400 mg/ℓ immediately upstream of the river mouth during the 1988 Orange River flood (Bremner *et al.* 1990).

The major source of turbidity in the swell-influenced nearshore areas off the West Coast is the redistribution of fine inner shelf sediments by long-period Southern Ocean swells. The current velocities typical of the Benguela (10-30 cm/s) are capable of resuspending and transporting considerable quantities of sediment equatorwards. Under relatively calm wind conditions, however, much of the suspended fraction (silt and clay) that remains in suspension for longer periods becomes entrained in the slow poleward undercurrent (Shillington *et al.* 1990; Rogers & Bremner 1991).

Superimposed on the suspended fine fraction, is the northward littoral drift of coarser bedload sediments, parallel to the coastline. This northward, nearshore transport is generated by the predominantly south-westerly swell and wind-induced waves. Longshore sediment transport varies considerably in the shore-perpendicular dimension, being substantially higher in the surf-zone than at depth, due to high turbulence and convective flows associated with breaking waves, which suspend and mobilise sediment (Smith & Mocke 2002).

On the inner and middle continental shelf, the ambient currents are insufficient to transport coarse sediments typical of those depths, and re-suspension and shoreward movement of these by wave-induced currents occur primarily under storm conditions. Data from a Waverider buoy at Port Nolloth have indicated that 2-m waves are capable of re-suspending medium sands (200 µm diameter) at ~10 m depth, whilst 6-m waves achieve this at ~42 m depth. Low-amplitude, long-period waves will, however, penetrate even deeper. Most of the sediment shallower than 90 m can therefore be subject to re-suspension and transport by heavy swells (Lane & Carter 1999).

### 3.2 Biological Environment

The study area lies within the relatively uniform cool Namaqua marine biogeographic region, which extends from Cape Point to Lüderitz in Namibia (Emanuel *et al.* 1992; Lombard *et al.* 2004)(Figure 15). The major force driving the ecology of this region is coastal upwelling, predominantly occurring in the spring/summer period when the south-easterly is the prevailing wind. The upwelling process supplies inorganic nutrients to the euphotic zone supporting high biological productivity (see previous section). This coast is, however, characterized by low marine species richness and low endemism (Awadet *al.* 2002).

The biota of nearshore marine habitats on the West Coast is relatively robust, being naturally adapted to an extremely dynamic environment where biophysical disturbances are commonplace. The benthic communities within this region are largely ubiquitous, particular only to substrate type (i.e. hard vs. soft bottom), exposure to wave action, or water depth. Habitats specific to the study area include:

- Sandy intertidal and subtidal substrates,
- Intertidal rocky shores and subtidal reefs, and
- The water body.

The biological communities consist of many hundreds of species, often displaying considerable temporal and spatial variability - even at small scales. No rare or endangered species have been recorded(Awadet *al.* 2002). Consequently, this review describes 'typical' biological communities, focussing on dominant, commercially important and conspicuous species only.

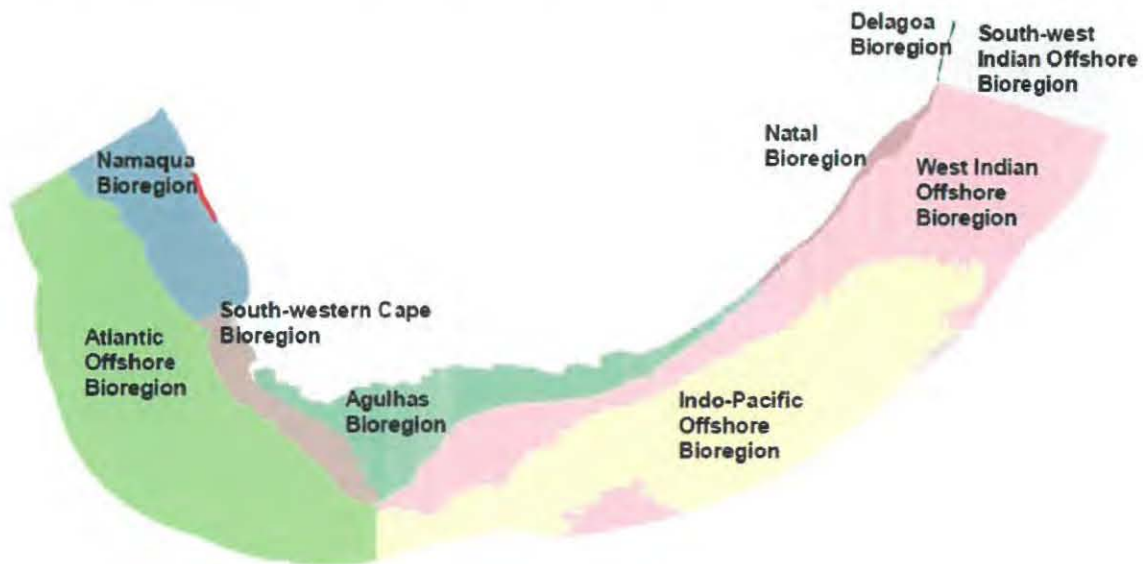


Figure 15: The South African inshore and offshore bioregions in relation to the concession areas (red line) (adapted from Lombard *et al.* 2004).

### 3.2.1 Sandy Substrate Habitats and Biota

Sandy substrates comprise approximately 14.25km of the coast of concession 6a and 7a (Figure 1). Similar spatial data are unfortunately not available for concessions 8a and 9a. The benthic biota of soft bottom substrates constitutes invertebrates that live on, or burrow within, the sediments, and are generally divided into megafauna (>10 cm), macrofauna (animals >1 mm) and meiofauna (<1 mm).

#### *Intertidal Sandy Beaches*

Although the coastline of the study area is highly dominated by rocky shores, there are some isolated pocket beaches between the rocky outcrops. Sandy beaches are one of the most dynamic coastal environments. The composition of their faunal communities is largely dependent on the interaction of wave energy, beach slope and sand particle size, which is termed beach morphodynamics. Three morphodynamic beach types are described: dissipative, reflective and intermediate beaches (McLachlan *et al.* 1993):

**Dissipative beaches** are generally relatively wide and flat with fine sands and high wave energy. Waves start to break far from the shore in a series of spilling breakers that 'dissipate' their energy along a broad surf zone. This generates slow swashes with long periods, resulting in less turbulent conditions on the gently sloping beach face. These beaches usually harbour the richest intertidal faunal communities.

**Reflective beaches** have low wave energy, and are coarse grained (>500 µm sand) with narrow and steep intertidal beach faces. The relative absence of a surf-zone causes the waves to break directly on the shore causing a high turnover of sand. The result is depauperate faunal communities.

**Intermediate beach** conditions exist between these extremes and have a very variable species composition (McLachlan *et al.* 1993, Jaramillo *et al.* 1995, Soares 2003). This variability is mainly attributable to the amount and quality of food available.

Beaches with a high input of e.g. kelp wrack have a rich and diverse drift-line fauna, which is sparse or absent on beaches lacking a drift-line (Branch & Griffiths 1988). As a result of the combination of typical beach characteristics, and the special adaptations of beach fauna to these, beaches act as filters and energy recyclers in the nearshore environment (Brown & McLachlan 1990). Due to the exposed nature of the coastline in the study area, most beaches are of the intermediate to reflective type.

Numerous methods of classifying beach zonation have been proposed, based either on physical or biological criteria. The general scheme proposed by Branch & Griffiths (1988) is used below (Figure 16), supplemented by data from various publications on West Coast sandy beach biota (e.g. Bally 1987; Brown *et al.* 1989; Soares *et al.* 1996, 1997; Nel 2001; Nel *et al.* 2003; Soares 2003; Branch *et al.* 2010; Harris 2012). The macrofaunal communities of sandy beaches are generally ubiquitous throughout the southern African West Coast region, being particular only to substratum type, wave exposure and/or depth zone.

The supralittoral zone is situated above the high water spring (HWS) tide level, and receives water input only from large waves at spring high tides or through sea spray. This zone is characterised by a mixture of air-breathing terrestrial and semi-terrestrial fauna, often associated with and feeding on kelp deposited near or on the driftline. Terrestrial species include a diverse array of beetles

and arachnids and some oligochaetes, while semi-terrestrial fauna include the oniscid isopod *Tylos granulatus*, and amphipods of the genus *Talorchestia* and *Africorchestia*.

The intertidal or mid-littoral zone has a vertical range of about 2 m. This mid-shore region is characterised by the cirrolanid isopods *Pontogeloides latipes*, *Eurydice (longicornis=) kensleyi*, and *Excirolana natalensis*, the polychaetes *Scololepissquamata*, *Orbinia angrapequensis*, *Nepthys hombergii* and *Lumbrineris tetraura*, and amphipods of the families Haustoridae and Phoxocephalidae (Figure 17). In some areas, juvenile and adult sand mussels *Donax serra* may also be present in considerable numbers.

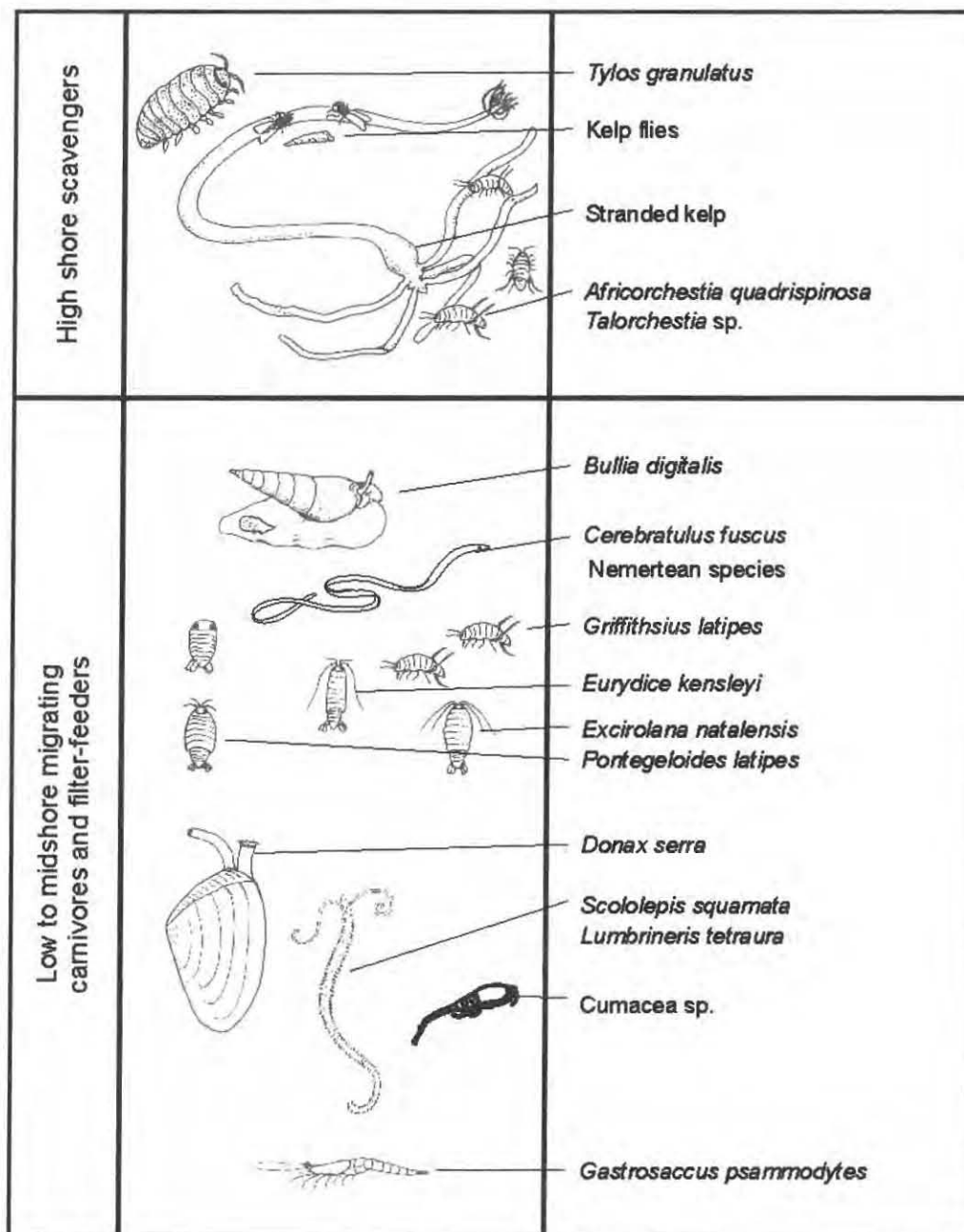


Figure 16: Schematic representation of the West Coast intertidal beach zonation (adapted from Branch & Branch 1981). Species commonly occurring on the Namaqualand beaches are listed.

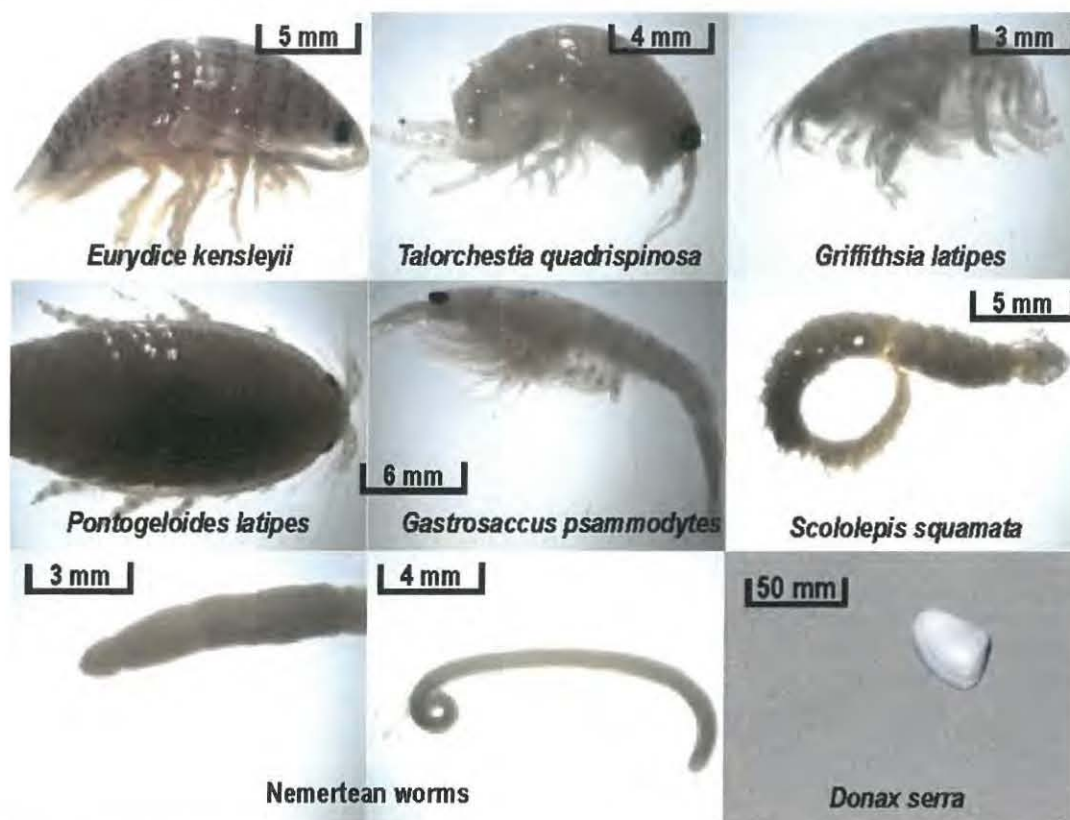


Figure 17: Common beach macrofaunal species occurring on exposed West Coast beaches.

The inner turbulent zone extends from the Low Water Spring mark to about -2 m depth. The mysid *Gastrosaccus psammodytes* (Mysidacea, Crustacea), the ribbon worm *Cerebratulus fuscus* (Nemertea), the cumacean *Cumopsis robusta* (Cumacea) and a variety of polychaetes including *Scololepis squamata* and *Lumbrineris tetraura*, are typical of this zone, although they generally extend partially into the midlittoral above. In areas where a suitable swash climate exists, the gastropod *Bullia digitalis* (Gastropoda, Mollusca) may also be present in considerable numbers, surfing up and down the beach in search of carrion.

The transition zone spans approximately 2-5 m depth beyond the inner turbulent zone. Extreme turbulence is experienced in this zone, and as a consequence this zone typically harbours the lowest diversity on sandy beaches. Typical fauna include amphipods such as *Cunicus profundus* and burrowing polychaetes such as *Cirriiformia tentaculata* and *Lumbrineris tetraura*.

The outer turbulent zone extends below 5 m depth, where turbulence is significantly decreased and species diversity is again much higher. In addition to the polychaetes found in the transition zone, other polychaetes in this zone include *Pectinaria capensis*, and *Sabellides ludertizii*. The sea pen *Virgularia schultzi* (Pennatulacea, Cnidaria) is also common as is a host of amphipod species and the three spot swimming crab *Ovalipes punctatus* (Brachyura, Crustacea).

#### **Nearshore and Offshore unconsolidated habitats**

Numerous studies have been conducted on southern African West Coast continental shelf benthos, mostly focused on mining, pollution or demersal trawling impacts (Christie & Moldan 1977; Moldan

1978; Jackson & McGibbon 1991; Environmental Evaluation Unit 1996; Parkins & Field 1997; 1998; Pulfrich & Penney 1999; Goosen *et al.* 2000; Savage *et al.* 2001; Steffani & Pulfrich 2004a, 2004b; 2007; Steffani 2007a; 2007b; Steffani 2009, 2010; Atkinson *et al.* 2011; Steffani 2012). The description below is drawn from recent surveys by Karenyi (unpublished data), De Beers Marine Ltd surveys in 2008 and 2010 (unpublished data), and Atkinson *et al.* (2011).

Three macro-infauna communities have been identified on the inner- (0-30 m depth) and mid-shelf (30-150m depth, Karenyi unpublished data) off the Namaqualand coast. The inner-shelf community, which is affected by wave action, is characterised by various mobile predators (e.g. the gastropod *Bullia laevissima* and polychaete *Nereis* sp.), sedentary polychaetes and isopods. The mid-shelf community inhabits the mudbelt and is characterised by the mud prawns *Callianassa* sp. and *Calocaris barnardi*. A second mid-shelf sandy community occurring in sandy sediments, is characterised by various polychaetes including deposit-feeding *Spiophanes soederstromi* and *Paraprionospio pinnata*. Polychaetes, crustaceans and molluscs make up the largest proportion of individuals, biomass and species on the west coast (Figure 18). The distribution of species within these communities are inherently patchy reflecting the high natural spatial and temporal variability associated with macro-infauna of unconsolidated sediments (e.g. Kenny *et al.* 1998; Kendall & Widdicombe 1999; van Dalssen *et al.* 2000; Zajac *et al.* 2000; Parry *et al.* 2003), with evidence of mass mortalities and substantial recruitments recorded on the South African West Coast (Steffani & Pulfrich 2004).

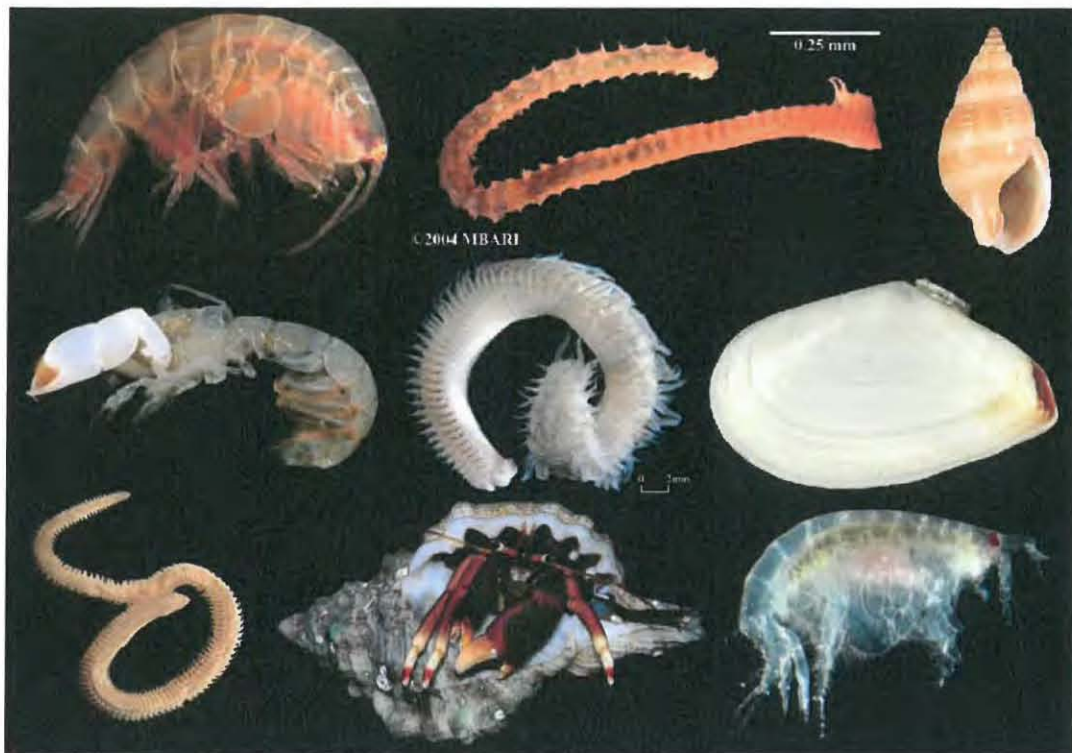


Figure 18: Benthic macrofaunal genera commonly found in nearshore sediments include: (top: left to right) *Ampelisca*, *Prionospio*, *Nassarius*; (middle: left to right) *Callianassa*, *Orbinia*, *Tellina*; (bottom: left to right) *Nephtys*, hermit crab, *Bathyporeia*.

Generally species richness increases from the inner shelf across the mid shelf and is influenced by sediment type (Karenzi unpublished data). The highest total abundance and species diversity was measured in sandy sediments of the mid-shelf. Biomass is highest in the inshore ( $\pm 50 \text{ g/m}^2$  wet weight) and decreases across the mid-shelf averaging around  $30 \text{ g/m}^2$  wet weight. This is contrary to Christie (1974) who found that biomass was greatest in the mudbelt at 80 m depth off Lamberts Bay, where the sediment characteristics and the impact of environmental stressors (such as low oxygen events) are likely to differ from those further offshore.

Benthic communities are structured by the complex interplay of a large array of environmental factors. Water depth and sediment grain size are considered the two major factors that determine benthic community structure and distribution on the South African west coast (Christie 1974, 1976; Steffani & Pulfrich 2004a, 2004b; 2007; Steffani 2007a; 2007b) and elsewhere in the world (e.g. Gray 1981; Ellingsen 2002; Bergen *et al.* 2001; Post *et al.* 2006). However, studies have shown that shear bed stress - a measure of the impact of current velocity on sediment - oxygen concentration (Post *et al.* 2006; Currie *et al.* 2009; Zettler *et al.* 2009), productivity (Escaravage *et al.* 2009), organic carbon and seafloor temperature (Day *et al.* 1971) may also strongly influence the structure of benthic communities. There are clearly other natural processes operating in the deepwater shelf areas of the West Coast that can over-ride the suitability of sediments in determining benthic community structure, and it is likely that periodic intrusion of low oxygen water masses is a major cause of this variability (Monteiro & van der Plas 2006; Pulfrich *et al.* 2006). In areas of frequent oxygen deficiency, benthic communities will be characterised either by species able to survive chronic low oxygen conditions, or colonising and fast-growing species able to rapidly recruit into areas that have suffered oxygen depletion. The combination of local, episodic hydrodynamic conditions and patchy settlement of larvae will tend to generate the observed small-scale variability in benthic community structure.

The invertebrate macrofauna are important in the marine benthic environment as they influence major ecological processes (e.g. remineralisation and flux of organic matter deposited on the sea floor, pollutant metabolism, sediment stability) and serve as important food source for commercially valuable fish species and other higher order consumers. As a result of their comparatively limited mobility and permanence over seasons, these animals provide an indication of historical environmental conditions and provide useful indices with which to measure environmental impacts (Gray 1974; Warwick 1993; Salas *et al.* 2006).

Also associated with soft-bottom substrates are demersal communities that comprise epifauna and bottom-dwelling vertebrate species, many of which are dependent on the invertebrate benthic macrofauna as a food source. According to Lange (2012) the continental shelf on the West Coast between depths of 100 m and 250 m, contained a single epifaunal community characterised by the hermit crabs *Sympagurus dimorphus* and *Parapaguris pilosimanus*, the prawn *Funchalia woodwardi* and the sea urchin *Brisaster capensis*. Atkinson (2009) also reported numerous species of urchins and burrowing anemones beyond 300 m depth off the West Coast.

### 3.2.2 Rocky Substrate Habitats and Biota

Rocky and mixed sand and rock substrates comprise approximately 59.1km of the concession 6a and 7a coastline (Figure 1). Similar spatial data are unfortunately not available for concessions 8a and 9a. The following general description of the intertidal and subtidal habitats for the West Coast is based on Field *et al.* (1980), Branch & Branch (1981), Branch & Griffiths (1988) and Field & Griffiths (1991). It is supplemented by the descriptions of Steffani (2001), Blamey (2003), Pulfrich *et al.* (2003a), and Steffani & Branch (2003a, b, 2005), from the Groen River coastline just south of the project area. The biological communities of rocky intertidal and subtidal reefs are generally ubiquitous throughout the southern African West Coast region, being particular only to wave exposure, turbulence and/or depth zone.

#### *Intertidal Rocky Shores*

Several studies on the west coast of southern Africa have documented the important effects of wave action on the intertidal rocky-shore community. Specifically, wave action enhances filter-feeders by increasing the concentration and turnover of particulate food, leading to an elevation of overall biomass despite low species diversity (McQuaid & Branch 1985, Bustamante & Branch 1995a, 1996a, Bustamante *et al.* 1997). Conversely, sheltered shores are diverse with a relatively low biomass, and only in relatively sheltered embayments does drift kelp accumulate and provide a vital support for very high densities of kelp trapping limpets, such as *Cymbula granatina* that occur exclusively there (Bustamante *et al.* 1995b). In the subtidal, these differences diminish as wave exposure is moderated with depth.

West Coast rocky intertidal shores can be divided into five zones on the basis of their characteristic biological communities: The Littorina, Upper Balanoid, Lower Balanoid, Cochlear/Argenvillei and the Infratidal Zones. These biological zones correspond roughly to zones based on tidal heights (Figure 19 and Figure 20). Tolerance to the physical stresses associated with life on the intertidal, as well as biological interactions such as herbivory, competition and predation interact to produce these five zones.

*Supralittoral fringe or Littorina zone* - The uppermost part of the shore is the supralittoral fringe, which is the part of the shore that is most exposed to air, perhaps having more in common with the terrestrial environment. The supralittoral is characterised by low species diversity, with the tiny periwinkle *Afrolittorina knysnaensis*, and the red alga *Porphyra capensis* constituting the most common macroscopic life.

*Upper Mid-littoral or Upper Balanoid zone* - The upper mid-littoral is characterised by the limpet *Scutellastra granularis*, which is present on all shores. The gastropods *Oxysteles variegata*, *Nucella dubia*, and *Helcion pectunculus* are variably present, as are low densities of the barnacles *Tetraclita serrata*, *Octomeris angulosa* and *Chthamalus dentatus*. Flora is best represented by the green algae *Ulva* spp.

*Lower Mid-littoral or Lower Balanoid zone* - Toward the lower shore, biological communities are determined by exposure to wave action. On sheltered and moderately exposed shores, a diversity of algae abounds with a variable representation of: green algae - *Ulva* spp, *Codium* spp.; brown algae - *Splachnidium rugosum*; and red algae - *Aeodes orbitosa*, *Mazzaella* (= *Iridaea*) *capensis*, *Gigartina polycarpa* (= *radula*), *Sarcothalia* (= *Gigartina*) *stiriata*, and with increasing wave exposure



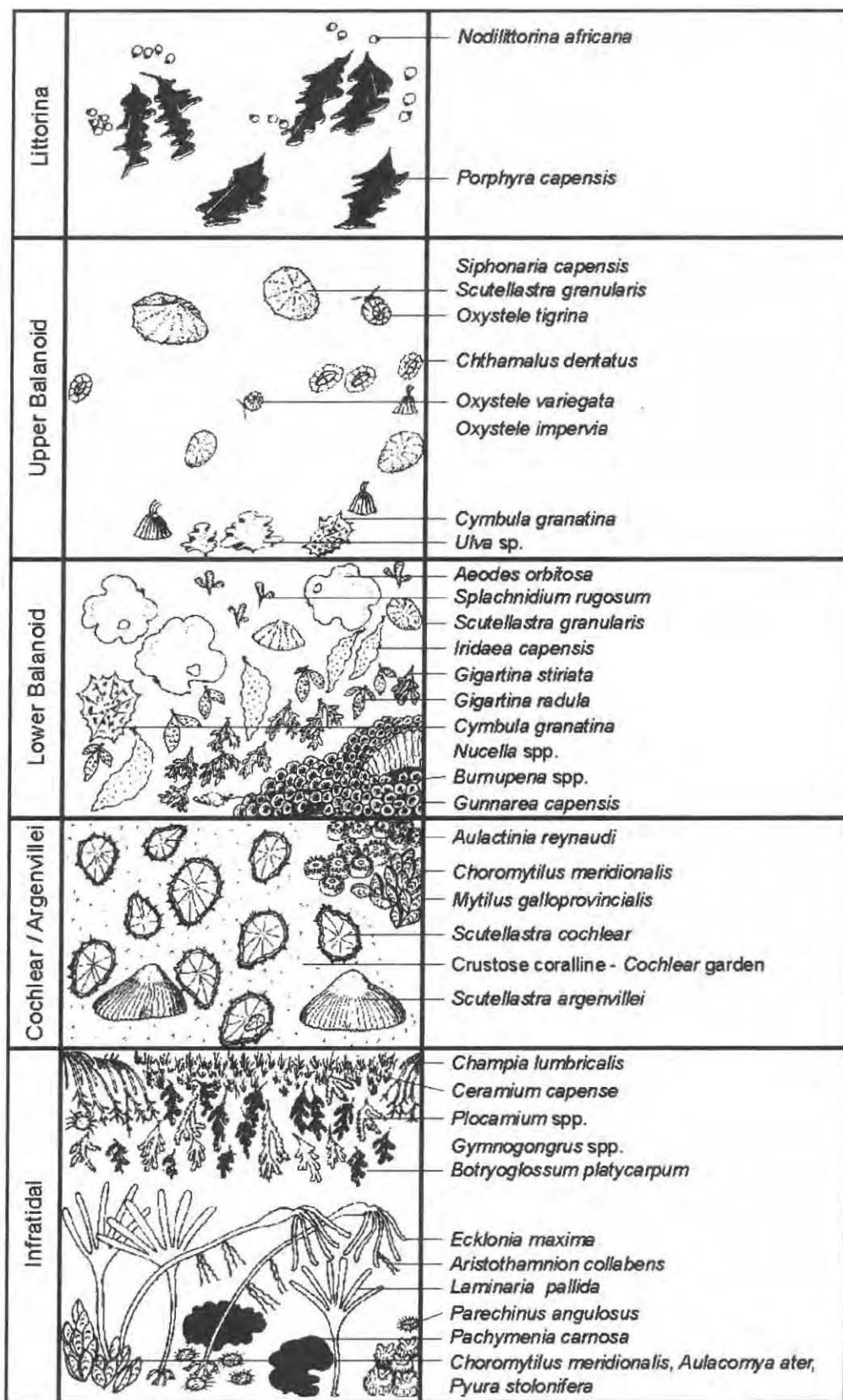


Figure 19: Schematic representation of the West Coast intertidal zonation. Species commonly occurring north of the Olifants River mouth are listed (adapted from Branch & Branch 1981).

*Plocamium rigidum* and *P. cornutum*, and *Champia lumbricalis*. The gastropods *Cymbula granatina* and *Burnupena* spp. are also common, as is the reef building polychaete *Gunnarea capensis*, and the small cushion starfish *Patiriella exigua*. On more exposed shores, almost all of the primary space can be occupied by the dominant alien invasive mussel *Mytilus galloprovincialis*. First recorded in 1979 (although it is likely to have arrived in the late 1960's), it is now the most abundant and widespread invasive marine species spreading along the entire West Coast and parts of the South Coast (Robinson *et al.* 2005). *M. galloprovincialis* has partially displaced the local mussels *Choromytilus meridionalis* and *Aulacomya ater* (Hockey & Van Erkom Schurink 1992), and competes with several indigenous limpet species (Griffiths *et al.* 1992; Steffani & Branch 2003a, b). Recently, another alien invasive has been recorded, the acorn barnacle *Balanus glandula*, which is native to the west coast of North America where it is the most common intertidal barnacle. The presence of *B. glandula* in South Africa was only noticed a few years ago as it had always been confused with the native barnacle *Cthamalus dentatus* (Simon-Blecher *et al.* 2008). There is, however, evidence that it has been in South Africa since at least 1992 (Laird & Griffith 2008). At the time of its discovery, the barnacle was recorded from 400 km of coastline from Elands Bay to Misty Cliffs near Cape Point (Laird & Griffith 2008). As it has been reported on rocky shores south of Lüderitz in Namibia (Pulfrich 2013), it is likely that it occurs in the study area. When present, the barnacle is typically abundant at the mid zones of semi-exposed shores.



Figure 20: Typical rocky intertidal zonation on the southern African west coast.

*Sublittoral fringe or Argenvillei zone* - Along the sublittoral fringe, the large kelp-trapping limpet *Scutellastra argenvillei* dominates forming dense, almost monospecific stands achieving densities of up to 200/m<sup>2</sup> (Bustamante *et al.* 1995). Similarly, *C. granatina* is the dominant grazer on more

sheltered shores, also reaching extremely high densities (Bustamante *et al.* 1995). On more exposed shores *M. galloprovincialis* dominates. There is evidence that the arrival of the alien *M. galloprovincialis* has led to strong competitive interaction with *S. argenvillei* (Steffani & Branch 2003a, b, 2005). The abundance of the mussel changes with wave exposure, and at wave-exposed locations, the mussel can cover almost the entire primary substratum, whereas in semi-exposed situations it is never abundant. As the cover of *M. galloprovincialis* increases, the abundance and size of *S. argenvillei* on rock declines and it becomes confined to patches within a matrix of mussel bed. As a result exposed sites, once dominated by dense populations of the limpet, are now largely covered by the alien mussel. Semi-exposed shores do, however, offer a refuge preventing global extinction of the limpet. In addition to the mussel and limpets, there is variable representation of the flora and fauna described for the lower mid-littoral above, as well as the anemone *Aulactinia reynaudi*, numerous whelk species and the sea urchin *Parechinus angulosus*. Some of these species extend into the subtidal below.

Very recently, the invasion of west coast rocky shores by another mytilid, the small *Semimytilus algosus*, was noted (de Greef *et al.* 2013). It is hypothesized that this species has established itself fairly recently, probably only in the last ten years. Its current range extends from the Groen River mouth in the north to Bloubergstrand in the south. Where present, it occupies the lower intertidal zone, where they completely dominate primary rock space, while *M. galloprovincialis* dominates higher up the shore. Many shores on the West Coast have thus now been effectively partitioned by the three introduced species, with *B. glandula* colonizing the upper intertidal, *M. galloprovincialis* dominating the mid-shore, and now *S. algosus* smothering the low-shore (de Greef *et al.* 2013).

#### **Rocky Subtidal Habitat and Kelp Beds**

Biological communities of the rocky sublittoral can be broadly grouped into an inshore zone from the sublittoral fringe to a depth of about 10 m dominated by flora, and an offshore zone below 10 m depth dominated by fauna. This shift in communities is not knife-edge, and rather represents a continuum of species distributions, merely with changing abundances.

From the sublittoral fringe to a depth of between 5 and 10 m, the benthos is largely dominated by algae, in particular two species of kelp. The canopy forming kelp *Ecklonia maxima* extends seawards to a depth of about 10 m. The smaller *Laminaria pallida* forms a sub-canopy to a height of about 2 m underneath *Ecklonia*, but continues its seaward extent to about 30 m depth, although further north up the west coast increasing turbidity limits growth to shallower waters (10-20 m) (Velimirov *et al.* 1977; Jarman & Carter 1981, Branch 2008). *Ecklonia maxima* is the dominant species in the south forming extensive beds from west of Cape Agulhas to north of Cape Columbine, but decreasing in abundance northwards. *Laminaria* becomes the dominant kelp north of Cape Columbine and thus in the project area, extending from Danger Point east of Cape Agulhas to Rocky Point in northern Namibia (Stegenga *et al.* 1997; Rand 2006).

Kelp beds absorb and dissipate much of the typically high wave energy reaching the shore, thereby providing important partially-sheltered habitats for a high diversity of marine flora and fauna, resulting in diverse and typical kelp-forest communities being established (Figure 21). Through a combination of shelter and provision of food, kelp beds support recruitment and complex trophic food webs of numerous species, including commercially important rock lobster stocks (Branch 2008).

Growing beneath the kelp canopy, and epiphytically on the kelps themselves, are a diversity of understory algae, which provide both food and shelter for predators, grazers and filter-feeders associated with the kelp bed ecosystem. Representative under-storey algae include *Botryocarpa prolifera*, *Neuroglossum binderianum*, *Botryoglossum platycarpum*, *Hymenena venosa* and *Rhodymenia (=Epymenia) obtusa*, various coralline algae, as well as subtidal extensions of some algae occurring primarily in the intertidal zones (Bolton 1986). Epiphytic species include *Polysiphonia virgata*, *Gelidium vittatum (=Suhria vittata)* and *Carpoblepharis flaccida*. In particular, encrusting coralline algae are important in the under-storey flora as they are known as settlement attractors for a diversity of invertebrate species. The presence of coralline crusts is thought to be a key factor in supporting a rich shallow-water community by providing substrate, refuge, and food to a wide variety of infaunal and epifaunal invertebrates (Chenelot *et al.* 2008).



Figure 21: The canopy-forming kelp *Ecklonia maxima* provides an important habitat for a diversity of marine biota (Photo: Geoff Spiby).

The sublittoral invertebrate fauna is dominated by suspension and filter-feeders, such as the mussels *Aulacomya ater* and *Choromytilus meridonalis*, and the Cape reef worm *Gunnarea capensis*, and a variety of sponges and sea cucumbers. Grazers are less common, with most herbivory being restricted to grazing of juvenile algae or debris-feeding on detached macrophytes. The dominant herbivore is the sea urchin *Parechinus angulosus*, with lesser grazing pressure from limpets, the isopod *Paridotea reticulata* and the amphipod *Ampithoe humeralis*. The abalone *Haliotis midae*, an important commercial species present in kelp beds is naturally absent north of Cape Columbine.

Key predators in the sub-littoral include the commercially important West Coast rock lobster *Jasus lalandii* and the octopus *Octopus vulgaris*. The rock lobster acts as a keystone species as it

influences community structure via predation on a wide range of benthic organisms (Mayfield *et al.* 2000). Relatively abundant rock lobsters can lead to a reduction in density, or even elimination, of black mussel *Choromytilus meridionalis*, the preferred prey of the species, and alter the size structure of populations of ribbed mussels *Aulacomya ater*, reducing the proportion of selected size-classes (Griffiths & Seiderer 1980). Their role as predator can thus reshape benthic communities, resulting in large reductions in taxa such as black mussels, urchins, whelks and barnacles, and in the dominance of algae (Barkai & Branch 1988; Mayfield 1998).

Of lesser importance as predators, although numerically significant, are various starfish, feather and brittle stars, and gastropods, including the whelks *Nucella* spp. and *Burnupena* spp. Fish species commonly found in kelp beds off the West Coast include hottentot *Pachymetopon blochii*, two tone finger fin *Chirodactylus brachydactylus*, red fingers *Cheilodactylus fasciatus*, galjoen *Dichistius capensis*, rock suckers *Chorisochismus dentex* and the catshark *Haploblepharus pictus* (Branch *et al.* 2010).

There is substantial spatial and temporal variability in the density and biomass of kelp beds, as storms can remove large numbers of plants and recruitment appears to be stochastic and unpredictable (Levitt *et al.* 2002; Rothman *et al.* 2006). Some kelp beds are dense, whilst others are less so due to differences in seabed topography, and the presence or absence of sand and grazers. Due to their importance as recruitment, nursery, and feeding grounds for numerous species, including the commercially important rock lobster *J. lalandii*, kelp beds are considered a medium sensitivity habitat.

### 3.2.3 The Water Body

The study area is located in the central Benguela ecosystem and, as there are few barriers to water exchange, pelagic communities are typical of those of the region. The pelagic communities are typically divided into plankton, fish, and marine mammals (seals, dolphins and whales).

#### **Plankton**

Plankton is particularly abundant in the shelf waters off the West Coast, being associated with the upwelling characteristic of the area. Plankton range from single-celled bacteria to jellyfish of 2-m diameter, and includes bacterio-plankton, phytoplankton, zooplankton, and ichthyoplankton (Figure 22).

Phytoplankton are the principle primary producers with mean productivity ranging from 2.5 - 3.5 g C/m<sup>2</sup>/day for the midshelf region and decreasing to 1 g C/m<sup>2</sup>/day inshore of 130 m (Shannon & Field 1985; Mitchell-Innes & Walker 1991; Walker & Peterson 1991). The phytoplankton is dominated by large-celled organisms, which are adapted to the turbulent sea conditions. The most common diatom genera are *Chaetoceros*, *Nitzschia*, *Thalassiosira*, *Skeletonema*, *Rhizosolenia*, *Coscinodiscus* and *Asterionella* (Shannon & Pillar 1985). Diatom blooms occur after upwelling events, whereas dinoflagellates (e.g. *Prorocentrum*, *Ceratium* and *Peridinium*) are more common in blooms that occur during quiescent periods, since they can grow rapidly at low nutrient concentrations. In the surf zone, diatoms and dinoflagellates are nearly equally important members of the phytoplankton, and some silicoflagellates are also present.



Figure 22: Phytoplankton (left, photo: hymagazine.com) and zooplankton (right, photo: mysciencebox.org) is associated with upwelling cells.

The phytoplankton includes diatoms, dinoflagellates, coccolithophorids and microflagellates. Phytoplankton biomass in the southern Benguela is generally high in summer during the upwelling season, but also quite extensive in the autumn and spring, with diatoms generally dominating inshore and small flagellates offshore (Barlow *et al.* 2005). Maximum diatom concentrations are found in the upper 10 m and thereafter decrease with an increase in depth. Common and widely distributed diatom species include *Asterionella glacialis*, *Leptocylindrus danicus*, *Minidiscus trioculatus*, *Skeletonema costatum*, *Thalassionema nitzschioides* and a number of *Navicula*, *Nitzschia* and *Thalassiosira* species. The most common member of the microflagellates is a species of *Pyramimonas*. Dinoflagellates are represented by several members of the genus *Gyrodinium*, *Ceratium*, *Protoperdilium* amongst others. Also present in the area are toxic dinoflagellate species such as *Alexandrium catenella* and various members of the genus *Dinophysis*, which can cause mass mortalities of fish, shellfish, marine mammals, seabirds and other animals (Pitcher & Calder 2000).

Zooplankton is characterised by pelagic crustaceans (e.g. copepods, cumaceans, hyperiid amphipods, chaetognaths, mysids, euphausiids), invertebrate larvae (e.g. bivalve, polychaete, etc.), pelagic cnidarians, and ichthyoplankton. Crustacean zooplankters often contribute greatest to the total zooplankton with copepods (e.g. *Calanus* spp., *Centropages* spp., *Metridia* spp.) being the most common organisms in the zooplankton (Verheye & Richardson 1998, Hutchings *et al.* 2006). Ichthyoplankton constitutes the eggs and larvae of fish. Long-term changes in the southern Benguela include a significant increase in zooplankton over the past five decades, with a decline since 1995 linked to a concomitant increase in pelagic fish biomass as the main predators on zooplankton (Hutchings *et al.* 2006).

Red-tides are ubiquitous features of the Benguela system (see Shannon & Pillar 1986). The most common species associated with red tides (dinoflagellate and/or ciliate blooms) are *Noctiluca scintillans*, *Gonyaulax tamarensis*, *G. polygramma* and the ciliate *Mesodinium rubrum*. *Gonyaulax* and *Mesodinium* have been linked with toxic red tides. Most of these red-tide events occur quite close inshore although Hutchings *et al.* (1983) have recorded red-tides 30 km offshore.

The mesozooplankton ( $\geq 200\mu\text{m}$ ) is dominated by copepods, which are overall the most dominant and diverse group in southern African zooplankton. Important species are *Centropagesbrachiatus*, *Calanoidescarinatus*, *Metridialucens*, *Nannocalanusminor*, *Clausocalanus arcuicornis*, *Paracalanus parvus*, *P. crassirostris* and *Ctenocalanus vanus*. All of the above species typically occur in the phytoplankton rich upper mixed layer of the water column, with the exception of *M. lucens* which undertakes considerable vertical migration.

The macrozooplankton ( $\geq 1,600\mu\text{m}$ ) are dominated by euphausiids of which 18 species occur in the area. The dominant species occurring in the nearshore are *Euphausia lucens* and *Nyctiphanes capensis*, although neither species appears to survive well in waters seaward of oceanic fronts over the continental shelf (Pillar *et al.* 1991).

Standing stock estimates of mesozooplankton for the southern Benguela area range from 0.2 - 2.0 g C/m<sup>2</sup>, with maximum values recorded during upwelling periods. Macrozooplankton biomass ranges from 0.1-1.0 g C/m<sup>2</sup>, with production increasing north of Cape Columbine (Pillar 1986). Although it shows no appreciable onshore-offshore gradients, standing stock is highest over the shelf, with accumulation of some mobile zooplanktors (euphausiids) known to occur at oceanographic fronts. Beyond the continental slope biomass decreases markedly. Localised peaks in biomass may, however, occur in the vicinity of Child's Bank and Tripp seamount in response to topographically steered upwelling around such seabed features.

Zooplankton biomass varies with phytoplankton abundance and, accordingly, seasonal minima will exist during non-upwelling periods when primary production is lower (Brown 1984; Brown & Henry 1985), and during winter when predation by recruiting anchovy is high. More intense variation will occur in relation to the upwelling cycle; newly upwelled water supporting low zooplankton biomass due to paucity of food, whilst high biomasses develop in aged upwelled water subsequent to significant development of phytoplankton. Irregular pulsing of the upwelling system, combined with seasonal recruitment of pelagic fish species into West Coast shelf waters during winter, thus results in a highly variable and dynamic balance between plankton replenishment and food availability for pelagic fish species.

Although ichthyoplankton (fish eggs and larvae) comprise a minor component of the overall plankton, it remains significant due to the commercial importance of the overall fishery in the region. Various pelagic and demersal fish species are known to spawn in the inshore regions of the southern Benguela, (including pilchard, round herring, chub mackerel lanternfish and hakes (Crawford *et al.* 1987), and their eggs and larvae form an important contribution to the ichthyoplankton in the region. Ichthyoplankton abundance within the project area is thus expected to be high.

### **Fish**

The structure of the nearshore and surf zone fish community varies greatly with the degree of wave exposure. Species richness and abundance is generally high in sheltered and semi-exposed areas but typically very low off the more exposed beaches (Clark 1997a, 1997b).

The surf-zone and outer turbulent zone habitats of sandy beaches are considered to be important nursery habitats for marine fishes (Modde 1980, Lasiak 1981, Kinoshita & Fujita 1988, Clark *et al.*

1994). However, the composition and abundance of the individual assemblages seems to be heavily dependent on wave exposure (Blaber & Blaber 1980; Potter *et al.* 1990; Clark 1997a, b). Surf-zone fish communities off the South African West Coast have relatively high biomass, but low species diversity. Typical surf-zone fish include harders (*Liza richardsonii*), white stumpnose (*Rhabdosargus globiceps*) (Figure 23), Cape sole (*Heteromycteris capensis*), Cape gurnard (*Chelidonichthys capensis*), False Bay klipfish (*Clinus latipennis*), sandsharks (*Rhinobatosannulatus*), eagle ray (*Myliobatis aquila*), and smooth-hound (*Mustelus mustelus*) (Clark 1997b).

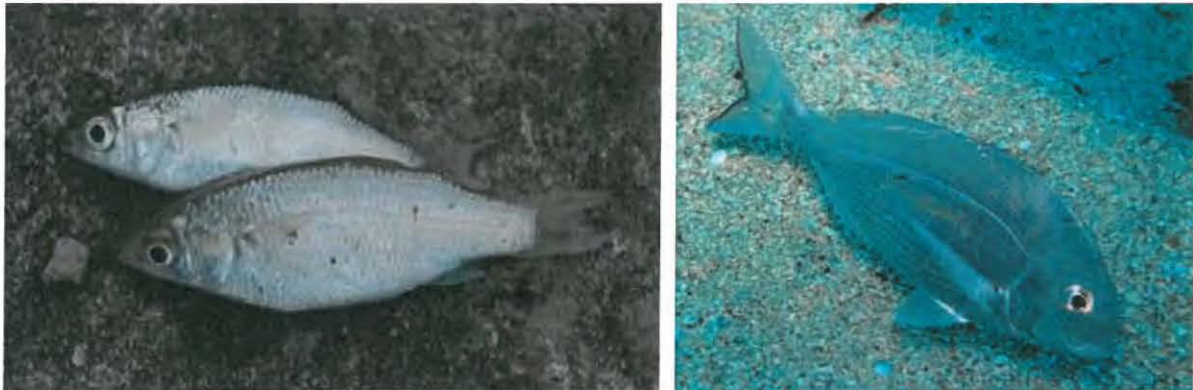


Figure 23: Common surf-zone fish include the harder (left, photo: [aquariophil.org](http://aquariophil.org)) and the white stumpnose (right, photo: [easterncapesclubdiving.co.za](http://easterncapesclubdiving.co.za)).

Fish species commonly found in kelp beds off the West Coast include hottentot *Pachymetopon blochii*, twotone fingerfin *Chirodactylus brachydactylus* (Figure 24), red fingers *Cheilodactylus fasciatus*, galjoen *Dichistius capensis*, rock suckers *Chorisochismus dentex*, maned blennies *Scartella emarginata* and the catshark *Haploblepharus pictus* (Saueret *al.* 1997; Brouwer *et al.* 1997; Branch *et al.* 2010). Several additional species of fish are also commonly caught in gill-nets set over rocky reef areas between the Orange River and Cape Columbine. Species of importance include harder *Liza richardsonii*, pilchard *Sardinops sagax*, strepie *Sarpa salpa*, houndsharks *Mustelus mustelus* and cowsharks *Notorynchus cepedianus* (K. Hutchings, UCT, pers. comm.).



Figure 24: Common fish found in kelp beds include the Hottentot fish (left, photo: [commons.wikimedia.org](https://commons.wikimedia.org)) and the twotone fingerfin (right, photo: [www.parrphotographic.com](http://www.parrphotographic.com)).



Small pelagic species that occur in the area include the sardine (*Sardinops sagax*), anchovy (*Engraulis encrasicolus*), juvenile Cape horse mackerel (*Trachurus trachurus capensis*), and round herring (*Etrumeus whiteheadi*). Although these species generally occur within the 200 m contour, they may often be found very close inshore (Pecquerie *et al.* 2004). Demersal fish include deep water (*Merluccius paradoxus*), shallow water hake (*M. capensis*) and kingklip (*Genypterus capensis*), and St Joseph shark (*Callorhynchus capensis*) in shallow inshore waters. Linefish species include (juvenile) snoek (*Thyrsites atun*), silver kob (*Argyrosomus inodorus*), white steenbras (*Lithognathus lithognathus*), blacktail (*Diplodussargus*), white stumpnose (*Rhabdosargus globiceps*), Hottentot (*Pachymetopon blochii*), geelbek (*Atractoscion aequidens*) and galjoen (*Dichistius capensis*).

### Seabirds

Large numbers of pelagic seabirds exploit the pelagic fish stocks of the Benguela system. Of the 49 species of seabirds that occur in the Benguela region, 14 are defined as resident, 10 are visitors from the northern hemisphere and 25 are migrants from the southern Ocean. The area between Cape Point and the Orange River supports 38% and 33% of the overall population of pelagic seabirds in winter and summer, respectively. 14 species of seabirds breed in southern Africa; Cape Gannet, African Penguin, four species of Cormorant, White Pelican, three Gull and four Tern species. The breeding areas are distributed around the coast with islands being especially important. The number of successfully breeding birds at the particular breeding sites varies with food abundance.

Birds endemic to the region and liable to occur most frequently in the project area include Cape Gannets, Kelp Gulls, African Penguins, African Black Oystercatcher (Figure 25, left), Bank, Cape and Crowned Cormorants (Figure 25, right), and Hartlaub's Gull. Of these the Black Oystercatcher and Bank Cormorant are rare. The breeding success of African Black Oystercatcher is particularly susceptible to disturbance from off-road vehicles as they nest and breed on beaches between the Eastern Cape and southern Namibia. Caspian and Damara terns are likewise rare and breed in the study area, especially in the wetland and saltpan areas associated with the Olifants River estuary. Most of the breeding seabird species forage at sea with most birds being found relatively close inshore (10 - 30 km), although African Penguins and Cape Gannets are known to forage up to 60 km and 140 km offshore, respectively.



Figure 25: The African Black Oystercatcher (Left, photo: [patrickspilsbury.blogspot.com](http://patrickspilsbury.blogspot.com)) and Crowned Cormorant (right, photo: [savoels.za.net](http://savoels.za.net)).

### Marine Mammals

The marine mammal fauna of the West Coast comprises between 28 and 31 species of cetaceans (whales and dolphins) and four species of seals. The Cape fur seal *Arctocephalus pusillus* (Figure 26) is the only species of seal resident along the west coast of Africa, occurring at numerous breeding and non-breeding sites on the mainland and on nearshore islands and reefs. Vagrant records from four other species of seal more usually associated with the subantarctic environment have also been recorded: southern elephant seal (*Mirounga leonina*), subantarctic fur seal (*Arctocephalus tropicalis*), crabeater (*Lobodon carcinophagus*) and leopard seals (*Hydrurga leptonyx*) (David 1989). There are three Cape fur seal breeding colonies within the broader study area: at Kleinzee (incorporating Robeiland), and at Bucchu Twins near Alexander Bay. The colony at Kleinzee has the highest seal population and produces the highest seal pup numbers on the South African Coast (Wickens 1994). The colony at Bucchu Twins, formerly a non-breeding colony, has also attained breeding status (M. Meyer, SFRI, pers. comm.). Non-breeding colonies occur at Strandfontein Point (~5 km north of the Groen River mouth) and on Bird Island at Lamberts Bay. All have important conservation value since they are largely undisturbed at present.

Dusky dolphin (*Lagenorhynchus obscurus*) (Figure 27, right) and Heaviside's dolphin (*Cephalorhynchus heavisidii*) (Figure 27, left) are resident year round throughout the Benguela ecosystem coastal waters (Findlay *et al.* 1992; Elwen 2008; Elwen *et al.* 2010). In water <500m deep, Dusky Dolphins are likely to be the most frequently encountered small cetacean. The species is very boat friendly and will often approach boats to bowride. This species is resident year round throughout the Benguela ecosystem in waters from the coast to at least 500m deep, but may occur as far offshore as 2 000m depth (Findlay *et al.* 1992). Although no information is available on the size of the population, they are regularly encountered in near shore waters between Cape Town and Lamberts Bay, but further north they are usually found further from shore in slightly deeper waters (Elwen *et al.* 2010a; NDP unpubl data). Abundance estimates are being calculated but currently suggest a relatively large population of several thousand at least. Group sizes up to 800 have been reported in southern African waters (Findlay *et al.* 1992). Dusky Dolphins are resident year round in the Benguela, although a hiatus in sightings (or low density area) is reported between -27°S and 30°S, associated with the Lüderitz upwelling cell (Findlay *et al.* 1992).



Figure 26: Colony of Cape fur seals *Arctocephalus pusillus pusillus* (Photo: Dirk Heinrich).

Heaviside's Dolphins are relatively abundant in the Benguela ecosystem (Elwen *et al.* 2009). Individuals show high site fidelity to small home ranges, 50-80km along shore (Elwen *et al.* 2006) and may thus be more vulnerable to threats within their home range. This species occupies waters from the coast to at least 200m depth, (Elwen *et al.* 2006; Best 2007). They may show a diurnal onshore-offshore movement pattern (Elwen *et al.* 2010b), but this varies throughout the species range. Heaviside's dolphins are resident year round.

Whale species that may be sighted in the area include Southern Right Whale (*Balaena glacialis*), Humpback Whale (*Megaptera novaeangliae*), and Killer Whale (*Orcinus orca*), along with Antarctic Minke (*Balaenoptera acutorostrata*) and Bryde's (*B. brydei*) whales (Best 2007). Whales occurring in the nearshore region in the project area will largely be transitory.

All whales and dolphins are given protection under the South African Law. The Marine Living Resources Act, 1998 (No. 18 of 1998) states that no whales or dolphins may be harassed, killed or fished. No vessel or aircraft may, without a permit or exemption, approach closer than 300 m to any whale and a vessel should move to a minimum distance of 300 m from any whales if a whale surfaces closer than 300 m from a vessel or aircraft.



Figure 27: The endemic Heaviside's Dolphin *Cephalorhynchus heavisidii* (left) (Photo: De Beers Marine Namibia), and Dusky dolphin *Lagenorhynchus obscurus* (right) (Photo: scottelowitzphotography.com).

### 3.2.4 Other Uses of the Area

#### **Rock Lobster Fishery**

The West Coast rock lobster *Jasus lalandii* is a valuable resource of the South African West Coast and consequently an important income source for West Coast fishermen. Following the collapse of the rock-lobster resource in the 1970s, fishing has been controlled by a Total Allowable Catch (TAC), a minimum size, restricted gear, a closed season and closed areas (Crawford *et al.* 1987; Melville-Smith & Van Sittert 2005). The West Coast rock lobster fishery is seasonally restricted to the period 15 November to the last day in May. Management of the resource is geographically specific, with the TAC annually allocated by Area. The study area falls within Area 2 of the commercial rock lobster fishing zones that extends from Kleinsee to the mouth of the Brak River. The TAC for the season 2013/14 has been set at 2167.06 tons.

Commercial catches of rock lobster in Area 2 are confined to shallower water (<30 m) with almost all the catch being taken in <15 m depth. Actual rock-lobster fishing, however, takes place only at discrete suitable reef areas along the shore within this broad depth zone. Lobster fishing is conducted from a fleet of small dinghies/bakkies. The majority of these works directly from the shore within a few nautical miles of the harbours, with only 30% of the total numbers of bakkies partaking in the fishery being deployed from larger deck boats. As a result, lobster fishing tends to be concentrated close to the shore within a few nautical miles of Port Nolloth and Hondeklip Bay.

Rock lobster landings for the fishing season 2008/09 to 2012/13 for the sub-areas 1 and 2 of Area 2 are provided in Table 3.

Table 3: Actual rock lobster catch (kg) for subareas 1 and 2 of Area 2 for the 2008/09 to 2012/2013 fishing seasons (Data source: Rock Lobster Section, DAFF).

Area/subarea	Actual Catch 2008/09	Actual Catch 2009/10	Actual Catch 2010/11	Actual Catch 2011/12	Actual Catch 2012/13
2/1	937	1,286	2,246	1,683	--
2/2	--	--	--	--	--

### **Kelp Collecting**

The West Coast is divided into numerous seaweed concession areas (Figure 28). Access to a seaweed concession is granted by means of a permit from the Fisheries Branch of the Department of Agriculture, Forestry and Fisheries to a single party for a period of five years. The seaweed industry was initially based on sun dried beach-cast seaweed, with harvesting of fresh seaweed occurring in small quantities only (Anderson *et al.* 1989). The actual level of beach-cast kelp collection varies substantially through the year, being dependent on storm action to loosen kelp from subtidal reefs.

Permit holders collect beach casts of both *Ecklonia maxima* and *Laminaria pallida* from the driftline of beaches (Table 4). The kelp is initially dried just above the high water mark before being transported to drying beds in the foreland dune area. The dried product is ground before being exported for production of alginic acid (alginate).