APPENDIX 3.4

MARINE FAUNAL ASSESSMENT

PROPOSED EXPLORATION DRILLING IN THE ORANGE BASIN DEEP WATER LICENCE AREA OFF THE WEST COAST OF SOUTH AFRICAN

MARINE FAUNAL ASSESSMENT

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EXECUTIVE SUMMARY

Shell proposes to drill one or possibly two vertical exploration wells to determine whether hydrocarbons are present in commercially viable quantities in the Orange Basin Deep Water Licence Area off the West Coast of South Africa. A 900 km^2 area of interest, located in the northern portion of the licence area at depths of 1,500 – 2,100 m, has been defined for drilling. Drilling operations would be undertaken with either a dynamically positioned semi-submersible drilling rig or a drill ship.

The well would drilled in several sections, using drill bits of different sizes to drill a series of concentric holes from the seabed to the planned well total depth. Drilling would begin with boring of a 36" (91 cm) diameter hole to a depth of 70 m, followed by a 26" (66 cm) diameter hole to 1,000 m below the seabed, using water-based drilling muds (WBMs). The drill cuttings and WBMs would be discharged at the seabed where they would form a cone-shaped cuttings pile affecting an area of <0.045 km^2 around the wellhead. An estimated 350 - 400 m^3 of cuttings will be discharged at the seabed. A casing will be cemented into place to ensure the structural integrity of the well. Excess cement (maximum of 210 m^3) would emerge out of the top of the well and onto the seabed. Subsequent sections would be drilled with synthetic-based drilling muds (SBMs) to a depth of 2,650 m below the seafloor. The SBMs together with the cuttings slurry is circulated back to the rig between the well casing and riser pipe, and subsequently separated and treated on board. The 150 - 200 m^3 of cleaned cuttings are discharged overboard where they will disperse as a plume and settle back onto the seabed within 77 hrs over an area of ~30 km^2.

The Orange Basin Deep Water Licence Area is located in water depths >500 m off the shelf break of the South African West Coast between Port Nolloth and Cape Columbine. The seabed sediments comprise sandy muds and muds. Although influenced by the Benguela Current the licence area is located well offshore of the coastal upwelling cells. Winds come primarily from the southeast, whereas virtually all swells throughout the year come from the S and SSW direction. The bulk of the seawater in the study area is South Atlantic Central Water characterised by low oxygen concentrations, especially at depth. Surface waters in the licence area will primarily be nutrient poor and clear, being beyond the influence of coastal upwelling.

The Orange Basin Deepwater Licence Area falls into the Atlantic Offshore Bioregion. Although there is a lack of knowledge of the community structure and diversity of benthic macrofauna off the shelf edge, the South Atlantic bathyal and abyssal unconsolidated habitat types have been rated as ‘least threatened’, reflecting the great extent of these habitats in the South African Exclusive Economic Zone (EEZ). Two geological features of note in the vicinity of the proposed area of interest are Child’s Bank, situated ~75 km due east of the area of interest at about 31°S, and Tripp Seamount situated at about 29°40’S, ~120 km north-northwest of the area of interest. Features such as banks and seamounts often host deepwater corals and boast an enrichment of bottom-associated communities relative to the otherwise low profile homogenous seabed habitats.

Due to its offshore location, plankton abundance is expected to be low, with the major fish spawning and migration routes occurring further inshore on the shelf. The dominant fish in the area would include the migratory large pelagic species such as tunas, billfish and pelagic sharks. Seabirds will be dominated by the pelagic species such as albatross, petrels and shearwaters. Migrating turtles in the area would include the leatherback and loggerhead turtles. Marine mammals likely to occur offshore include a variety of baleen whales including humpbacks, Antarctic minke, fin and sei whales. Toothed whales will include sperm and killer whales, as well as a variety of beaked whales and dolphins. The licence area lies well offshore of any marine protected areas and offshore biodiversity conservation priority areas.

Using the results of the oil spill modelling undertaken as part of this project (PRDW 2013) the impact assessment identified a high risk to pelagic seabirds of a 5-day and 20-day blow out. As the spill would generally move in a north-westerly direction as a relatively confined plume, a 5-day blow out had no probability of shoreline oiling, whereas the 20-day blow out had <10% probability of shoreline oiling at a point between Oranjemund and Cape Town. Risks to pelagic fish, turtles and mammals, as well as coastal flora and fauna were rated as medium to low. Risks associated with an offshore operational hydraulic or diesel spill were primarily identified as low, with the exception of oiling of pelagic seabirds from an accidental well blow-out.

Potential impacts to the marine environment as a result of the proposed drilling operations include:

- Disturbance and loss of benthic macrofauna as a result of physical disturbance of the seabed and removal of sediments during installation of the well(s);
- Disturbance and loss of benthic communities due to smothering by disposed drill cuttings;
- Reduced physiological functioning of marine organisms due to the biochemical effects on the water column and seabed sediments of discharged cement, cuttings and drill fluids;
- Threats to Benguela ecosystem biodiversity through the introduction of invasive alien species with the drilling units;
- Alteration of the seabed habitat through the physical presence of subsea structures (e.g. completed and abandoned wellhead(s));
- Disturbance of marine biota due to noise and pollution generated by the drilling units, support vessels and aircraft / helicopter; and
- Toxic effects on marine biota from potential spills and leaks during well drilling, testing and operation.

The impacts before and after mitigation on marine habitats and communities associated with the proposed project are summarised below (Note: * indicates that no mitigation is possible and / or considered necessary, thus significance rating remains):

Impact	Probability	Significance (before mitigation)	Significance (after mitigation)
Removal or crushing of benthic macrofauna in unconsolidated sediments during well installation	Definite	Very Low	Very Low
Removal or crushing of benthic macrofauna of deepwater reefs during well installation	Improbable	Medium	Very Low
Smothering of benthic macrofauna by drilling solids discharged directly onto the seabed during well spudding and drilling of the initial section with WBMs	Highly probable	Low	Low
Smothering of soft-sediment benthic macrofauna	Highly probable	Very Low	Very Low

Impact	Probability	Significance (before mitigation)	Significance (after mitigation)
Smothering of vulnerable reef communities by drilling solids discharged at the surface depositing onto the seabed	Improbable	Medium - High	Low
Reduced physiological functioning of marine organisms due to biochemical effects of Water-Based drilling muds	Highly probable	Very Low	Very Low
Reduced physiological functioning of marine organisms due to biochemical effects of Synthetic-Based Drilling muds	Highly probable	Very Low	Very Low
Reduced physiological functioning of marine organisms due to biochemical effects of cementing	Highly probable	Very Low	Very Low
Reduced physiological functioning of marine organisms due to increased water column turbidity due to discharge of cuttings near the surface	Probable	Very Low	Very Low*
Reduced physiological functioning of marine organisms due to increased turbidity near the seabed due to discharge of WBMs and cuttings at the seabed	Improbable	Very Low	Very Low*
Reduced physiological functioning of marine organisms due to the development of anoxic sediments in the cuttings depositional footprint due to biodegradation of the organic constituents of WBMs	Probable	Very Low	Very Low*
Threats to Benguela ecosystem biodiversity through the introduction of invasive species on petroleum infrastructure	Probable	High - Very High	Medium
Impacts on marine biodiversity: wellhead is lifted from the seafloor during abandonment	Improbable	Low	Low*
Impacts on marine biodiversity: wellhead remains on the seafloor during abandonment	Probable	Low	Low*
Disturbance of seabirds, seals, turtles and cetaceans through noise from well-drilling operations	Highly Probable	Very Low	Very Low*
Disturbance of seabirds, seals, turtles and cetaceans through noise generated by support aircraft	Definite	Low	Very Low
Pollution of the marine environment through operational discharges to the sea from drilling units and support vessels	Highly Probable	Very Low	Very Low

Impact	Probability	Significance (before mitigation)	Significance (after mitigation)
Toxic effects on marine organisms of a major spill following a blow out	Improbable	Very High	High
Toxic effects on marine organisms of an operational spill at the well site	Probable	Medium	Low
Toxic effects on marine organisms of an operational spill in nearshore areas	Probable	Medium	Very Low
Toxic effects of hydrocarbon 'drop-out' during flaring on offshore areas	Probable	Very Low	Very Low

With the implementation of appropriate mitigation measures the significance in most cases was reduced to Low or Very Low, exceptions being the introduction of invasive alien species and the effects of a major spill following an accidental blow out, which rates as Medium and High following mitigation, respectively.

Mitigation measures proposed were:

- Use the existing seismic data to conduct a pre-drilling geohazard analysis of the seabed, and near-surface substratum. In doing so, map potentially vulnerable habitats to prevent potential conflict with the well site;
- Use a Remotely Operated Vehicle (ROV) to survey the seafloor prior to drilling, to identify any significant topographic features (e.g. rocky outcrops) or vulnerable habitats (e.g. hard grounds) and species (e.g. cold-water corals, sponges). If detected, adjust the well position accordingly, keeping in mind the smothering effects anticipated as a consequence of seabed and surface cuttings discharges.
- If vulnerable seabed communities were identified in the vicinity of the proposed well locations, implement innovative technologies and operational procedures for drilling solids discharges to minimise the impacts (see for example Jødestøl & Furuholt 2010).
- Use the results of the cuttings dispersal modelling in combination with information from the post-drill ROV survey to assess the magnitude of the impacts of cuttings disposal on seabed communities in the vicinity of the well;
- Ensure regular maintenance of the onboard solids control package;
- Aid dispersion of the discharged cuttings and mud by placing the cuttings chute several metres below the sea surface.
- Maximise the use of water-based drilling muds at all times, using risered SBMs only when necessary;
- Ensure only low-toxicity and partially biodegradable additives are used;
- All recovered SBM should be stored on board and taken to shore for treatment and reuse;
- Avoid excess cement usage by monitoring discharges to the seafloor around the surface casing by ROV survey; and
- De-ballasting of vessels to be undertaken only under strict adherence to International Maritime Organisation (IMO) Guidelines governing discharge of ballast waters at sea.
- Reballasting at sea currently provides the best available measure to reduce the risk of transfer of harmful aquatic organisms, but is subject to ship-safety limits. The IMO note

that vessels using ballast water exchange should whenever possible, conduct such exchange at least 200 nautical miles from the nearest land and in water of at least 200 m depth. Where the ship is unable to conduct ballast water exchange as described, the exchange should be as far from the nearest land as possible, and a minimum of 50 nautical miles from the nearest land and in water at least 200 m in depth.

- Other precautionary guidelines suggested by the IMO include:
  - During the loading of ballast, every effort should be made to avoid the uptake of potentially harmful aquatic organisms, pathogens and sediment that may contain such organisms, through adequate filtration procedures;
  - Where practicable, routine cleaning of the ballast tank to remove sediments should be carried out in mid-ocean or under controlled arrangements in port or dry dock, in accordance with the provisions of the ship's ballast water management plan; and
  - Avoidance of unnecessary discharge of ballast water.
- For crew-change and logistics, flight paths must be pre-planned to ensure that no flying occurs over coastal reserves (MacDougall's Bay), seal colonies (Buchu Twins, Kleinzee and Strandfontein Point), bird colonies (Bird Island at Lambert's Bay) or Important Bird Areas (Orange River Mouth wetlands, Olifants River Estuary, Velorenvlei, Lower Berg River wetlands and the West Coast National Park and Saldanha Bay Islands).
- Extensive low-altitude coastal flights (<2,500 ft and within 1 nautical mile of the shore) should be avoided, particularly during the winter/spring (June to December) whale migration period and during the November to January seal breeding season. The flight path between the onshore logistics base in Kleinzee and drilling unit should be perpendicular to the coast. As no seasonal patterns of abundance are known for odontocetes occupying the proposed exploration area, a precautionary approach to avoiding impacts throughout the year is recommended.
- Aircraft may not, without a permit or an exemption, approach to within 300 m of whales in terms of the Marine Living Resources Act, 1998, without a permit. As this may be both impractical and impossible, an exemption permit must be applied for through the Department of Environmental Affairs.
- The contractor should comply fully with aviation and authority guidelines and rules.
- All pilots must be briefed on ecological risks associated with flying at a low level along the coast or above marine mammals.
- Adhere strictly to best management practices recommended in the relevant EMPr and that of MARPOL 73/78 (International Convention for the Prevention of Pollution from Ships, 1973) for all necessary disposals at sea.
- Ensure that adequate oil spill contingency plans are in place at all times.
- As far as possible, and whenever the sea state permits, attempt to control and contain the spill at sea with suitable recovery techniques to reduce the spatial and temporal impact of the spill.
- Use dispersants cautiously and only with the permission of DEA (Marine Pollution Division) as they are often as toxic to marine life as the spill itself.
- In the case of small operational spills offshore, no mitigatory action would be necessary, unless large numbers of pelagic seabirds are present, in which case consideration should be given to spraying the spill with dispersants, if sea conditions permit and permission has been obtained from DEA.

- Ensure adequate resources are available to collect and transport oiled birds to a cleaning station.
- Should spills of crude oil reach the shore, Shell would need to comply with the approved oil spill contingency plan for the operation.
- Hydrocarbon 'drop-out' during well testing can be minimised by the use of a high efficiency burner for flaring and through accurate control of the mix of hydrocarbons and air going to flare.

ACRONYMS, ABBREVIATIONS and UNITS

BAR	Basic Assessment Report
BCLME	Benguela Current Large Marine Ecosystem
BOP	Blow out preventer
CAPP	Canadian Association of Petroleum Producers
CCA	CCA Environmental (Pty) Ltd
cm	centimetres
cm/s	centimetres per second
CITES	Convention on International Trade in Endangered Species
CMS	Convention on Migratory Species
CMS	Centre for Marine Studies
CSIR	Council for Scientific and Industrial Research
dB	decibell
DEA	Department of Environmental Affairs
DEFRA	UK Department for Environment, Food & Rural Affairs
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EMP	Environmental Management Programme
EPA	Environmental Protection Agency
ERA	Environmental Risk Analysis
FAO	Food and Agricultural Organisation
g/m^2	grams per square metre
$g\ C/m^2/day$	grams Carbon per square metre per day
h	hour
H_2S	hydrogen sulphide
HAB	Harmful Algal Bloom
kHz	Herz
IBA	Important Bird Area
IMO	International Maritime Organisation
IUCN	International Union for the Conservation of Nature
kHz	kiloHerz
km	kilometre
km^2	square kilometre
km/h	kilometres per hour
kts	knots
MPA	Marine Protected Area
m	metres
m^2	square metres
m^3	cubic metre
mm	millimetres
m/s	metres per second
mg/l	milligrams per litre
mT	metric Tons

N	north
NADF	Non-aqueous drilling fluid
NDP	Namibian Dolphin Project
NNW	north-northwest
NMMU	Nelson Mandela Metropolitan University
NW	north-west
OBMs	Oil-based muds
OGP	International Association of Oil and Gas Producers
OSPAR	The Oslo and Paris Convention for the Protection of the marine Environment of the North-East Atlantic
PAH	polycyclic aromatic hydrocarbon
PAM	Passive Acoustic Monitoring
PIM	Particulate Inorganic Matter
POM	Particulate Organic Matter
ppm	parts per million
PRDW	Prestedge Retief Dresner Wijnberg Coastal Engineers
ROV	Remotely Operated Vehicle
S	south
SACW	South Atlantic Central Water
SANBI	South African National Biodiversity Institute
SBM	Synthetic-based mud
SFRI	Sea Fisheries Research Institute, Department of Environmental Affairs
SPRFMA	South Pacific Regional Fisheries Management Authority
SSW	South-southwest
SW	south-west
T	ton(s)
TSPM	Total Suspended Particulate Matter
VMEs	Vulnerable Marine Ecosystems
VOS	Voluntary Observing Ships
WBMs	Water-based muds
WWF	World Wildlife Fund
µg	micrograms
µm	micrometre
µg/l	micrograms per litre
µPa	micro Pascal
°C	degrees Centigrade
%	percent
‰	parts per thousand
~	approximately
<	less than
>	greater than
"	inch

EXPERTISE AND DECLARATION OF INDEPENDENCE

This report was prepared by Dr Andrea Pulfrich of Pisces Environmental Services (Pty) Ltd. Andrea has a PhD in Fisheries Biology from the Institute for Marine Science at the Christian-Albrechts University, Kiel, Germany.

As Director of Pisces since 1998, Andrea has considerable experience in undertaking specialist environmental impact assessments, baseline and monitoring studies, and Environmental Management Programmes relating to marine diamond mining and dredging, hydrocarbon exploration and thermal/hypersaline effluents. She is a registered Environmental Assessment Practitioner and member of the South African Council for Natural Scientific Professions, South African Institute of Ecologists and Environmental Scientists, and International Association of Impact Assessment (South Africa).

This specialist report was compiled for CCA Environmental (Pty) Ltd on behalf of Shell South Africa Upstream B.V. for their use in preparing a Basic Assessment Report and Environmental Management Programme Addendum for the proposed exploration drilling programme in the Orange Basin Deep Water Licence Area off the West Coast of South Africa. I do hereby declare that Pisces Environmental Services (Pty) Ltd is financially and otherwise independent of the Applicant and CCA Environmental.

Dr Andrea Pulfrich

1. GENERAL INTRODUCTION

Shell South Africa Upstream B.V. (hereafter referred to as "Shell") is proposing to drill one or possibly two exploration wells in the northern portion of their Orange Basin Deep Water Licence Area, offshore of the South African West Coast. CCA Environmental (Pty) Ltd (CCA) has been appointed by Shell to undertake a Basic Assessment process and compile an Environmental Management Programme (EMPr) Addendum for the proposed exploration drilling activities. CCA in turn has approached Pisces Environmental Services (Pty) Ltd to provide a specialist report on potential impacts of the proposed drilling operations on marine fauna in the area.

1.1. Scope of Work

This specialist report was compiled as a desktop study on behalf of CCA, for their use in compiling a Basic Assessment Report (BAR) and EMPr Addendum for the proposed exploration drilling off the South African West Coast.

The terms of reference for this study, as specified by CCA, are:

1 Provide a general description of the benthic environment in the Orange Basin Deep Water Licence Area, West Coast, based on current available literature.
2 Compile an Ecological Risk Analysis based on the results of the oil spill modelling to determine the primary risks to the marine and coastal environment in the unlikely event of an accidental leak or spill during well drilling, testing and production.
3 Identify, describe and assess the significance of potential impacts of the proposed exploration drilling programme on the local marine fauna, focussing particularly on the benthic environment, but including generic effects on cetaceans, turtles, seals, fish and pelagic invertebrates; and
4 Identify practicable mitigation measures to reduce the significance of any negative impacts and indicate how these can be implemented in the construction phase and management of the proposed project.

1.2. Approach to the Study

As determined by the terms of reference, this study has adopted a 'desktop' approach. Consequently, the description of the natural baseline environment in the study area is based on a review and collation of existing information and data from the scientific literature, internal reports and the Generic EMPr compiled for oil and gas exploration in South Africa (CCA & CMS 2001). The information for the identification of potential impacts of well-drilling activities on the benthic marine environment was drawn from various scientific publications, the Generic EMPr (CCA & CMS 2001) and Benguela Current Large Marine Ecosystem (BCLME) Thematic Report (CSIR 1999), previous specialist reports (Atkinson 2010; Atkinson & Shipton 2010) and information sourced from the Internet. The sources consulted are listed in the Reference chapter.

All identified marine impacts are summarised, categorised and ranked in appropriate impact assessment tables, to be incorporated in the overall BAR and EMPr Addendum.

2. DESCRIPTION OF THE PROPOSED PROJECT

2.1. Exploration drilling

2.2.1 Well Location and Drilling Programme

Shell proposes to drill one or possibly two vertical exploration wells to determine whether hydrocarbons are present in commercially viable quantities in the Orange Basin Deep Water Licence Area off the West Coast of South Africa. At this stage an area of interest has been defined for the well locations (Figure 1), which is approximately 900 km^2 in extent with water depths ranging between 1,500 m and 2,100 m. The final well location will be based on a number of factors, including further analysis of the 3D seismic data, the geological target and seafloor location obstacles. The area of the proposed drill location would be analysed for hazards on a special high definition seismic dataset, which is a subset of the acquired 3D data.

The expected final depth of the well is between 2,700 m and 3,000 m below the seafloor and is expected to take in the order of three months to drill and complete. For operational reasons, drilling is expected to take place in a future summer window period between November to April.

Depending on the success of the first well, a second well may be drilled to establish the quantity and potential flow rate of the resource. The “appraisal” well would be drilled in a location and to a depth determined by the results of the first well. It is anticipated that the appraisal well would be drilled at least one year after completion of the first well in order to allow sufficient time for data analysis and planning.

2.2.2 Drilling Unit Options

Various types of drilling technology can be used to drill an exploration well depending on, *inter alia*, the water depth and marine operating conditions experienced at the well site, e.g. barges, platform rigs, jack-up rigs, semi-submersible drilling units (rigs), drill ships and tension leg platform rigs. Shell is currently considering two alternative drilling units, either a semi-submersible drilling unit (Figure 2, left) or a drill-ship (Figure 2, right).

2.2.2.1 Semi-submersible drilling unit (rig)

A semi-submersible drilling unit is essentially a drilling rig with auxiliary drilling and marine support equipment located on a floating structure comprised of one or a number of pontoons. A semi-submersible drilling unit typically, but not necessarily, requires a tow vessel or transport barge to transport the unit to its drilling location.

When at the well location, the pontoons are partially flooded (or ballasted), to submerge the pontoons to a pre-determined depth below the sea level where wave motion is minimised. This gives stability to the drilling unit thereby facilitating drilling operations. In deeper water where anchoring is not practical (such as in the area of interest), the drilling unit would be held in position by dynamic positioning thrusters. On-board computers are locked onto the well location and activate bow and stern thrusters to maintain the drilling unit on location with a high degree of precision.

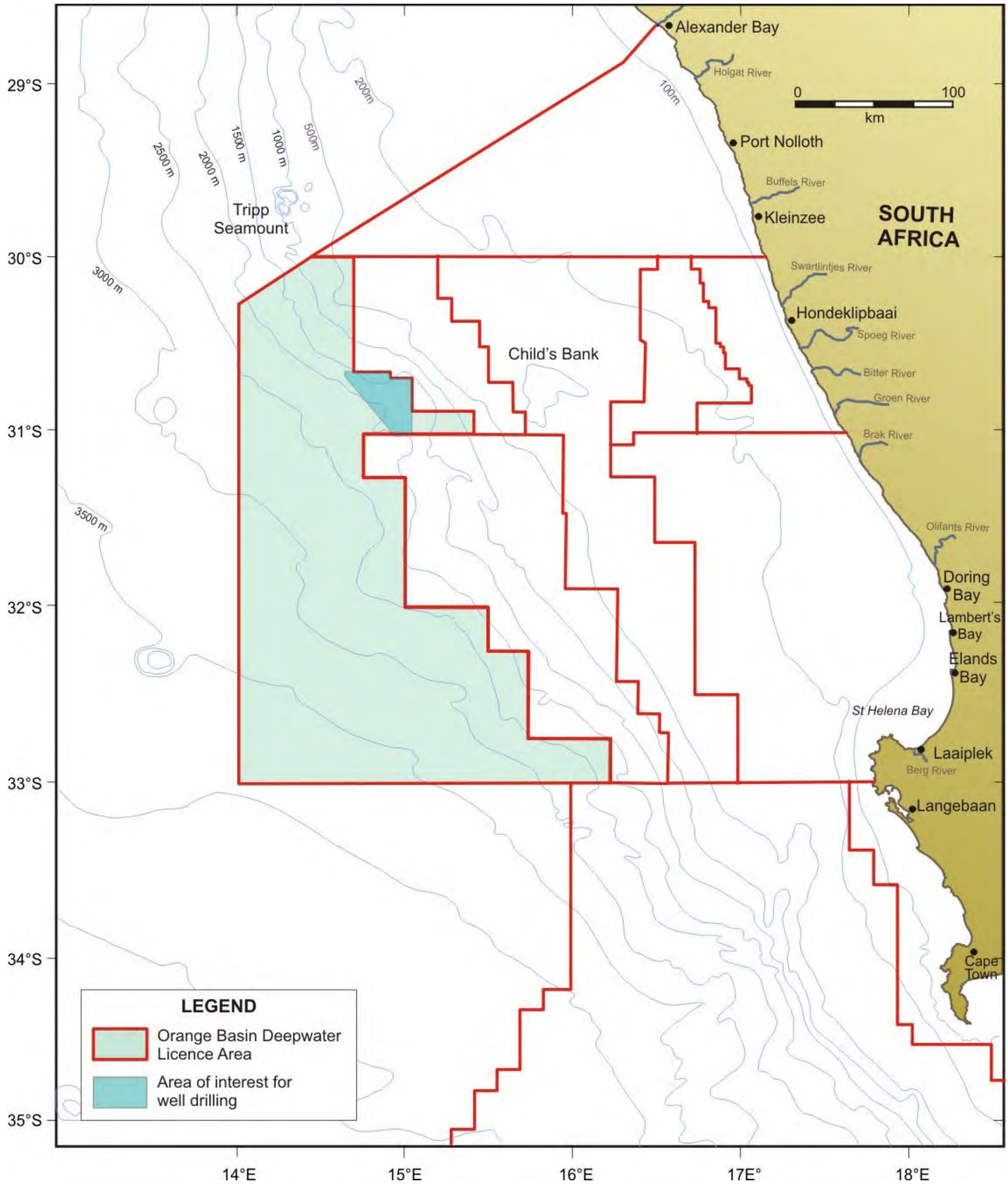


Figure 1: Map indicating location of the Orange Basin Deep Water Licence Area. Places mentioned in the text are also indicated.

Figure 2: Typical semi-submersible drilling rig (left) and drilling vessel (right) (Source: Shell).

A riser pipe on compensated hydraulic tensioners (which keep the tension of the riser pipe constant during wave motion) connects the drilling unit to the seabed during the drilling operation. The riser acts as a conduit through which drilling operations can proceed and drilling fluid can be circulated.

2.2.2.2 Drill ship

A drill-ship is essentially a self-sufficient ship with a drilling rig attached, normally located at the centre of the ship where drilling operations are conducted. The advantages of a drill ship over the majority of semi-submersible units are that the drill ship has much greater storage capacity and is independently mobile, not requiring any towing or transport vessel.

Drill ships may be held in position by anchors in the same way as semi-submersibles. However, in deeper water where anchoring is not practical, they are similarly held in position by dynamic positioning thrusters.

The drill-ship, similar to the semi-submersible drilling unit, uses a riser pipe on compensated hydraulic tensioners to connect the vessel to the seabed and to act as a conduit through which drilling operations can proceed.

2.2.3 Drilling Equipment and Procedure

2.2.3.1 Equipment

The essential elements of a drilling unit are: hoisting, rotating, circulating, power and safety equipment. These are described below (Figure 3).

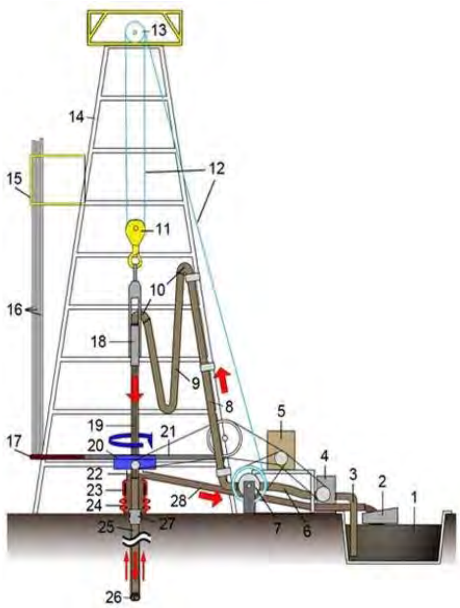
The **hoisting system** is used to raise and lower drill pipe in and out of the hole and to support the drill string to control the weight on the drill bit during drilling. The hoisting system consists of the derrick, traveling and crown blocks, the drilling line and the draw works. The drilling unit uses a derrick, which is a steel tower that is used to support the traveling and crown blocks and the drill bit and pipe (string). The crown and traveling blocks are a set of pulleys that raise and lower the drill string. The crown block is a stationary pulley located at the top of the derrick. The traveling block moves up and down and is used to raise and lower the drill string. These pulleys are connected to the drill string with a large diameter steel cable. The cable is connected to a winch or draw-works. The draw-works contain a large drum around which the drilling cable is wrapped. As the drum rotates one way or the other, the drilling cable spools on or off the drum and raises or lowers the drill string.

The **rotating equipment** turns the drilling bit. This equipment consists of the topdrive, the rotary table, the drill pipe and the drill collars (drill string) and the bit. The topdrive is attached to the bottom of the traveling block and permits the drill string to rotate. The topdrive consists of a strong engine that rotates the drill string. A hose, through which the drilling fluid enters the drill pipe, is connected at the top of the topdrive. The drill pipe is a round pipe about 9 m long with a diameter of from 5 inch (13 cm). Drill collars are heavy thick pipes that are used at the bottom of the drill string to add weight on the bit. The drill pipe has threaded connections on each end that allow the pipe to be joined together to form longer sections as the hole gets deeper. The drilling bit is used to create the hole. Drilling bit sizes typically range from 36 inches (91 cm) to 6 inches (15 cm) in diameter.

The drilling operation uses drilling fluids to reduce friction (lubricate and cool drill bit), remove the drilled rock fragments (cuttings), and to equalise pressure in the wellbore and prevent other fluids from flowing into the wellbore. The **circulation system** of drilling fluid consists of the suction pits, pumps, surface piping (flowlines and standpipe), rotary hose (or kelly hose) and swivel, which is connected to the topdrive.

Figure 3 shows the flow path of the drilling fluid. The circulating system pumps the drilling fluids (or drilling muds) down the hole, out of the nozzles in the drilling bit and returns them to the surface where the cuttings are separated from the drilling fluid.

The cuttings are separated from the mud by vibrating screens called a shale shakers. The cuttings are trapped on the screens and the mud passes through the screens into the mud pits. The circulating pumps pick up this clean mud and pump it back down the hole.



1	-	Mud tank	15	-	Monkey board
2	-	Shale shakers	16	-	Stand (of drill pipe)
3	-	Suction line (mud pump)	17	-	Pipe rack (floor)
4	-	Mud pump	18	-	Swivel
5	-	Motor or power source	19	-	Kelly
6	-	Vibrating hose	20	-	Rotary table
7	-	Draw-works	21	-	Drill floor
8	-	Standpipe	22	-	Bell nipple
9	-	Kelly hose	23	-	Blow-out preventer annular
10	-	Goose-neck	24	-	Blow-out preventers
11	-	Traveling block	25	-	Drill string
12	-	Drill line	26	-	Drill bit

Figure 3: Flow path of the drilling fluid.

Although the probability of a well blow-out is extremely low, it nonetheless provides the greatest environmental concern during drilling operations. The primary safeguard against a blow-out is the drilling fluid. The density of the fluid can be controlled to balance any abnormal formation pressures. Abnormal formation pressures are detected by primary well control equipment, which generally consists of two sets of pit level indicators and return mud-flow indicators with one set manned by the drill crew and the other by the mud logger. The mud logger also has a return mud gas detector, which monitors return mud temperature and changes in shale density for abnormal pressure detection. The drilling fluid is also tested frequently during drilling operations and its composition can be adjusted to account for changing downhole conditions.

The likelihood of a blow-out is further minimised by employing a specially designed item of safety equipment called a blow-out preventer (BOP), which is a secondary control system. The BOP is installed on the wellhead and is designed to close in the well to prevent the uncontrolled flow of hydrocarbons from the reservoir in case the pressure of the reservoir exceeds the pressure of the drilling fluid in the reservoir resulting in hydrocarbons entering the wellbore. If this cannot be controlled hydrocarbons could eventually exit the wellbore into the marine environment / atmosphere. Hence the BOP system plays a key role in preventing potential risks to people, the environment and equipment. The BOP would undergo a thorough inspection prior to installation and subsequently pressure and function tested on a regular basis.

A typical BOP stack is shown in Figure 4. The BOP stack usually consists of the following:

- **Annular preventer**: The annular-type blow-out preventer can close around the drill string, casing or a non-cylindrical object, such as a kelly. Drill pipe including the larger-diameter tool joints (threaded connectors) can be "stripped" (i.e. moved vertically while pressure is contained below) through an annular preventer by careful control of the hydraulic closing pressure. Annular BOPs are typically located at the top of a BOP stack, with one or two annular preventers positioned above a series of several ram preventers.
- **Ram type preventers**: Ram type preventers are similar in operation to gate valves but use a pair of opposing steel plungers or rams. The rams extend toward the centre of the wellbore to restrict flow or retract open in order to permit flow. There are four common types of rams or ram blocks used in a BOP stack (or combination thereof):
  - Pipe rams close around a drill pipe, restricting flow in the annulus (ring-shaped space between concentric objects) between the outside of the drill pipe and the wellbore, but do not obstruct flow within the drill pipe. Variable-bore pipe rams can accommodate tubing in a wider range of outside diameters than standard pipe rams, but typically with some loss of pressure capacity and longevity;
  - Blind rams (also known as sealing rams), which have no openings for tubing, can close off the well when the well does not contain a drill string or other tubing and seal it;
  - Shear rams cut through the drill string or casing with hardened steel shears; and
  - Blind shear rams (also known as shear seal rams or sealing shear rams) are intended to seal a wellbore, even when the bore is occupied by a drill string, by cutting through the drill string as the rams close off the well.

In deeper offshore operations, there are four primary ways in which a BOP can be controlled, including (in order of priority):

- Electrical control signal, which is sent from the surface through a control cable;
- Acoustical control signal, which is sent from the surface based on a modulated / encoded pulse of sound transmitted by an underwater transducer;
- Remotely Operated Vehicle (ROV) intervention, which mechanically controls valves and provides hydraulic pressure to the stack (via "hot stab" panels); and
- Deadman switch / auto shear, which is a fail-safe activation of selected BOPs during an emergency, and if the control, power and hydraulic lines have been severed.

In addition to the above, advanced well intervention and capping equipment is available in Saldanha Bay for deployment in the event of a subsea well control incident. The subsea well intervention system includes four capping stacks to shut-in an uncontrolled subsea well and two hardware kits to clear debris and apply subsea dispersant at a wellhead. This unique piece of equipment is only stored in four international locations, namely Norway, Brazil, Singapore and South Africa, and is maintained ready for immediate mobilisation in the event of an incident.

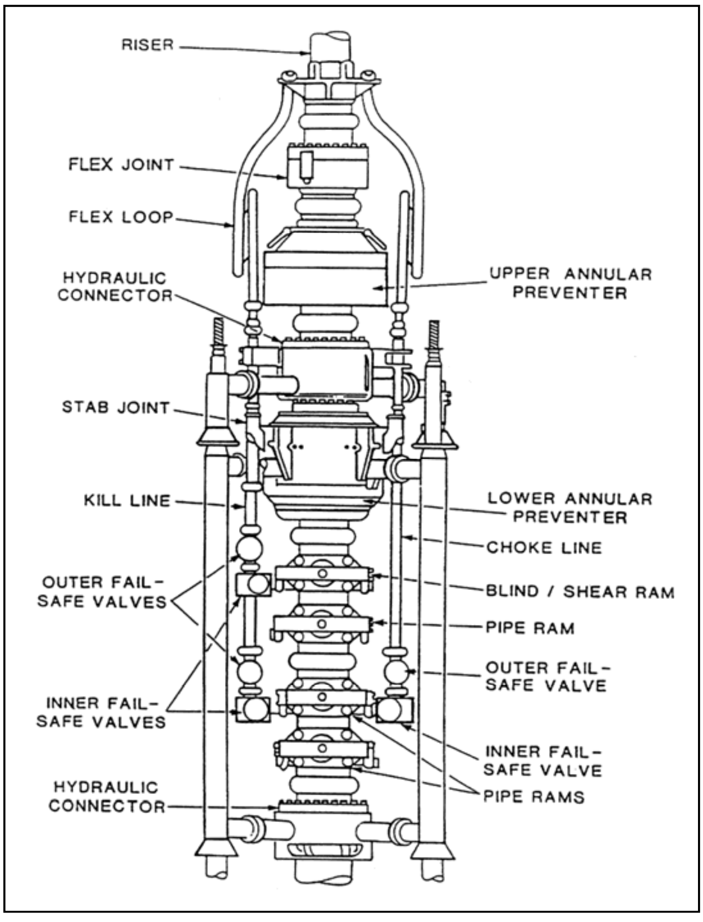


Figure 4: Schematic of a typical subsea BOP stack.

Power System

The drill unit would need power to operate the circulating, rotating and hoisting systems. This power is generated from diesel engines that power generators which transmit electricity to the drilling unit.

Storage Areas

The drilling unit would have dedicated storage for a variety of fluids and chemicals including:

- Fuel (diesel);
- Fresh (potable) water;
- Drilling water;
- Bulk mud and cement;
- Liquid mud;
- Mud chemicals; and
- Cementing chemicals.

2.2.3.2 Drilling method

Two drilling methods can be employed on a drilling unit, namely rotary or downhole motor drilling. The primary drilling method would be rotary drilling, where the whole drill string is rotated to penetrate the formations. However, a downhole motor may be included in the bottom hole assembly to provide additional power to the bit. The downhole motor is driven by the drilling fluid, which is pumped down the drill string.

The downhole motor drilling also allows a well to be directionally drilled to achieve any inclination from vertical to horizontal and to also change the azimuth direction in order to reach the geological target (Figure 5). The direction of the well is changed by holding the drill string stationary and pointing the downhole motor, which has a slight bend in its body, in the direction required and slide drilling ahead.

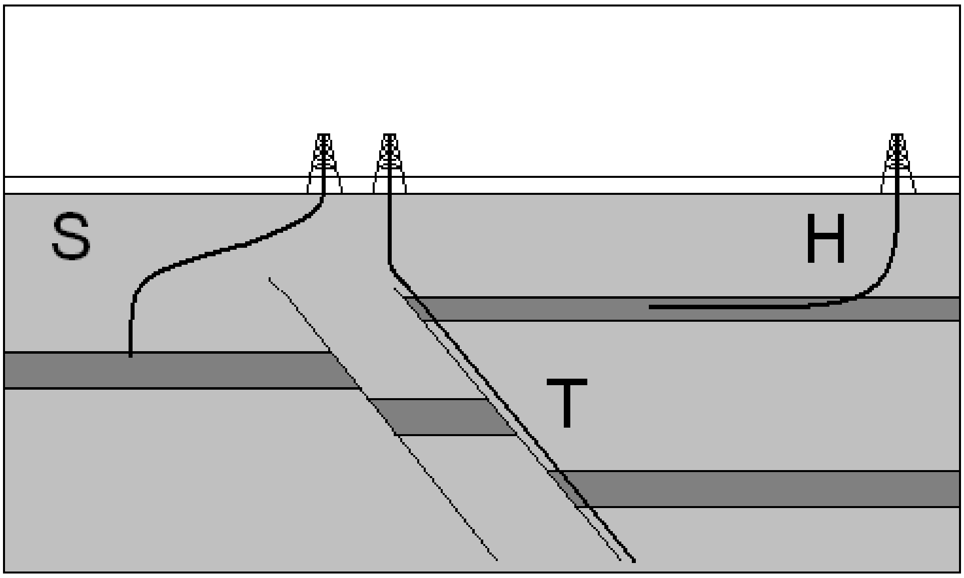


Figure 5: Tangent (T), Horizontal (H) or S shaped (S) drill trajectories.

2.2.3.3 *Drilling sequence or stages*

The well would be created by jetting and drilling a hole into the seafloor with a drilling unit that rotates a drill string with a bit attached. After the hole is drilled, sections of steel pipe (or casings), slightly smaller in diameter than the borehole, are placed in the hole and permanently cemented in place. The hole diameter decreases with increasing depth as progressively smaller diameter casings are inserted into the hole at various stages and cemented into place.

The casing provides structural integrity to the newly drilled wellbore, in addition to isolating potentially dangerous high pressure zones from each other and from the surface. With these zones safely isolated and the formation protected by the casing, the well would be drilled deeper with a smaller bit, and also cased with a smaller size casing (Figure 6). Shell is proposing to have four to nine sets of subsequently smaller hole sizes drilled inside one another, each cemented with casing.

Drilling is essentially undertaken in two stages, namely the riserless and risered drilling stages.

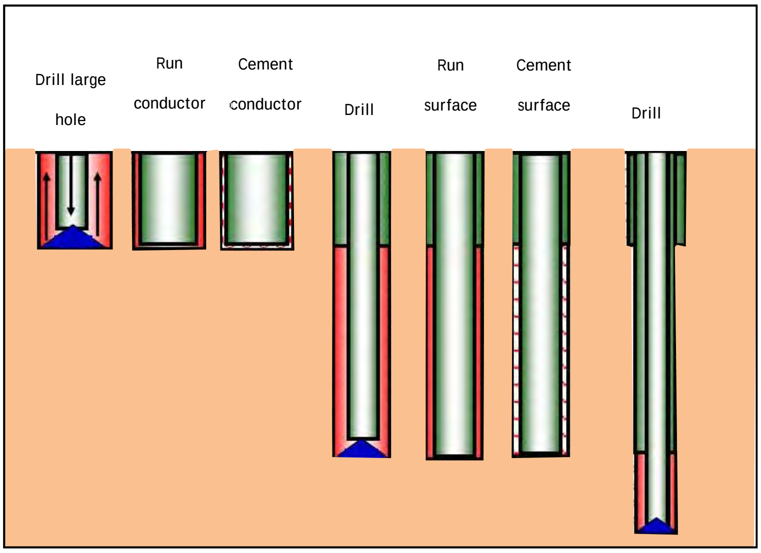


Figure 6: Simplified view of well drilling

Initial (riserless) drilling stage

Sediments just below the seafloor are often very soft and loose, and to keep the well from caving in and to carry the weight of the wellhead a 36 inch (91 cm) diameter structural conductor pipe is jetted and / or drilled and cemented into place depending on the shallow seabed properties.

The conductor pipe is assembled at the drilling unit floor and a drill bit, connected to a drill pipe, is run through the inside to the bottom of the casing. The entire assembly is lowered to the seafloor by the rig hoist. At the seafloor the driller spuds the assembly into the seafloor sediments and then turns on a pump, which uses water or drilling fluid to jet the pipe into place.

When the conductor pipe and wellhead are at the correct depth the drill bit and drill string are released in order to commence with drilling operations. The rotating drill string, causes the drill bit to crush rock into small particles, called "cuttings". While the wellbore is being drilled, drilling fluid is pumped from the surface down through the inside of the drill pipe, the drilling fluid passes through holes in the drill bit and travels back to the seafloor through the space between the drill string and the walls of the hole, thereby removing the cuttings from the hole. At the planned depth the drilling is stopped and the bit and drill string is pulled out of the hole. The conductor pipe would be approximately 75 m deep.

Below the conductor pipe, typically a 26 inch (66 cm) diameter hole would be drilled for a 20 inch (51 cm) surface casing, which would extend to approximately 1,000 m below the seabed. The surface casing would be permanently cemented into place. In the event of technical issues in the riserless section, intermediate liners could be required in order for the surface casing to be installed at a sufficient depth to accommodate the drilling riser and BOP.

These initial hole sections would be drilled using seawater (with viscous sweeps) and water-based mud (WBM). All cuttings and WBM from this initial drilling stage would be discharged directly onto the seafloor adjacent to the wellbore.

Risered drilling stage

Following the initial drilling stage described above, a BOP and marine riser (Figure 7) is run and installed on the wellhead. The riser connects the drilling unit to the well and allows the drilling fluid and rock cuttings to be circulated back to the drilling unit, thereby isolating the drilling fluid and cuttings from the marine environment.

Drilling is continued by lowering the drill string, with a smaller bit, through the riser to the 20 inch (51 cm) diameter casing shoe and rotating the drill string. During the risered drilling stage when WBMs cannot provide the necessary characteristics, a low toxicity synthetic-based mud (SBM), which is a type of non-aqueous drilling fluid, would be used to (a) obtain critical reservoir parameters, b) provide a greater level of lubrication, and (c) provide more tolerance to high temperatures.

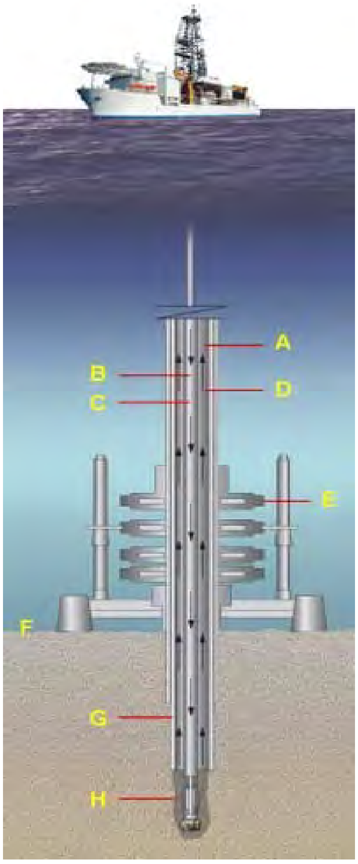
While drilling is in progress, drilling fluid is continuously recirculated to the drilling unit. The returned drilling fluid is treated to remove solids and drill cuttings from the re-circulating mud stream. The cuttings are also treated before being discharged overboard.

The hole diameter decreases in steps with depth as progressively smaller diameter casings are inserted into the hole at various stages and cemented into place. As indicated previously, the expected final depth of the well is between 2,700 m and 3,000 m below the seafloor.

2.2.3.4 Cementing operation

The casings are permanently secured into place by pumping cement slurry, followed by drilling fluid, through the drill pipe and/or cement stinger at the bottom of the hole and back up into the space between the casing and the borehole wall (annulus). To separate the cement from the drilling fluid in order to minimise cement contamination a cementing plug and/or spacer fluids are used. The plug is pushed by the drilling fluid to ensure the cement is placed outside the casing filling the annular space between the casing and the hole wall.

To ensure effective cementing, an excess of cement is often used. Until the marine riser is set, this excess emerges out of the top of the well onto the seafloor. This cement does not set and is slowly dissolved into the seawater.



A - Riser
B - Drill pipe
C - Drilling fluid is pumped down through drill pipe
D - Drilling fluid and cuttings flow up between the drill pipe and the riser
E - Blow-out preventer
F - Seafloor
G - Casing
H - Open hole

Figure 7: Typical drilling operation (Source: http://www.planetseed.com).

Offshore drilling operations typically use Portland cements, defined as pulverised clinkers consisting of hydrated calcium silicates and usually containing one or more forms of calcium sulphate. The raw materials used are lime, silica, alumina and ferric oxide. The cement slurry used is specially designed for the exact well conditions encountered.

Additives can be used to adjust various properties in order to achieve the desired results. There are over 150 cementing additives available. The amount (concentrations) of these additives generally make up only a small portion (<10%) of the overall amount of cement used for a typical well. Usually, there are three main additives used: retarders, fluid loss control agents and friction reducers. These additives are polymers generally made of organic material and are considered non-toxic.

Once the cement has set, a short section of new hole is drilled, then a pressure test is performed to ensure that the cement and formation are able to withstand the higher pressures of fluids from deeper formations.

2.2.3.5 Drilling fluid circulation system and solids control equipment

While drilling is in progress, drilling fluid is continuously pumped down the inside of the hollow drill string. The fluid emerges through ports ("nozzles") in the drill bit and then rises (carrying the rock cuttings with it) up the annular space between the sides of the hole (the casing and riser pipe) and the drill string, to the drilling unit. The returned drill mud is treated to remove the cuttings from the re-circulating mud stream (Figure 3).

The solids control system sequentially applies different technologies to remove the cuttings from the drilling fluid and to recover drilling fluid so that it can be reused. A typical solids control system consists of the following main components:

- Shale shakers (removes large-sized cuttings);
- Degasser (removes entrained gas);
- Desanders (removes sand-sized cuttings);
- Desilters (removes silt-sized cuttings); and
- Centrifuge (recovers fine solids and weighting materials such as barite).

The components of the solids control system depends on the type of drilling fluid used, the formations being drilled, the available equipment on the drilling unit and the specific requirements of the disposal option. Solids control may involve both primary and secondary treatment steps.

2.2.3.6 Anticipated well design

The well design ultimately depends upon factors such as planned depths, expected pore pressures and anticipated hydrocarbon-bearing formations. The various components of the anticipated well design are shown in Table 1.

Table 1: Estimated well design and cutting volumes.

Drill Section	Hole diameter (in)	Pipe diameter (in)	Depth of section (m)	Drilling duration (days)	Type of drilling fluid used	Volume of drilling fluid discharged	Volume of cuttings (m^3)	Drilling fluid and cuttings discharge location
Riserless drilling stage								
1	36	30	70	1	Seawater, viscous sweeps & WBM	69 m^3	46.0	Seabed
2	26	20	1,000	2		480 m^3	342.5	Seabed
Risered drilling stage								
3	17.25	13 5/8	800	4	SBM	223 mT	120.6	Surface
4	12.25	9 7/8	450	4		10 mT	34.2	Surface
5	8.5	-	400	8		2.5 mT	14.6	Surface

2.2.4 Drilling Fluids or Muds

An important component in the drilling operation is the drilling fluid or drilling mud, which is used for:

- Maintaining a stable wellbore and preventing the open hole from collapsing;
- Providing sufficient hydrostatic pressure to control subsurface pressures and prevent kicks or blow-outs;
- Transport of the cuttings to the surface;
- Cooling and lubrication of the drill bit and drill string (reduce friction);
- Powering mud motors / downhole tools during the drilling process;
- Regulation of the chemical and physical characteristics of returned mud slurry on the drilling unit; and
- Displacing cements during the cementing process.

Drilling fluid is a complex mixture of fluids, solids and chemicals that are carefully tailored to provide the correct physical and chemical characteristics required to safely drill the well.

2.2.4.1 Water-based muds

Due to the variability in conditions that can be encountered drilling fluid mixtures vary to some extent. Typically, the major ingredient making up 85 to 90 % of the total volume of a WBM is fresh and / or seawater, with the remaining 10 to 15 % of the volume being barite, potato or corn starch, cellulose-based polymers, xanthan gum, bentonite clay, soda ash, caustic soda and salts (these are usually either potassium chloride [KCl] or sodium chloride [NaCl]).

Barite (barium sulphate) is an inert compound used as a weighting agent. Potato or corn starch and other cellulose-based polymers are used to control the rate of filtration of water in the mud into the formation being drilled by forming a thin filter cake on the borehole wall. Xanthan gum and minor amounts of bentonite clay are used to provide viscosity and impart rheological properties to the mud for cuttings transport, as well as to provide gel strength for cuttings suspension. Caustic soda (sodium hydroxide) is used to maintain the required pH in the drilling fluid. KCl or NaCl are used to reduce the swelling tendencies of clays being drilled and help to maintain a stable wellbore. Other minor additives may be used in special circumstances. A listing of the WBM chemicals used on a typical well, their functions and comments on their ecotoxicity are provided in Table 2.

Table 2: Main components of water-based fluid.

Material	Use	Ecotoxicity
Aluminium stearate	Defoamer	Non-toxic, insoluble
Barite	Weighting agent	Non-toxic, insoluble, non-biodegradable
Bentonite	Viscosifer	Non-toxic, insoluble, non-biodegradable
Calcium carbonate	Bridging, loss of circulation	Non-toxic, insoluble
Caustic soda	pH and alkalinity control	Soluble, corrosive
Cellulose based polymers	Fluid loss control	Insoluble, non-toxic
Citric acid	pH control	Soluble, low toxicity, irritant
Diesel oil pill (< 0.1 % mud volume)	Stuck pipe spotting fluid	Slightly soluble, 96 hr LC_{50} >0.1-1000 ppm
Gilsonite (asphalt based)	Lubricant, fluid loss reducer	Low toxicity, slightly soluble
Gluteraldehyde (0.01% mud vol)	Bactericide (biocide)	Noted for its toxic properties, irritant
Lime	Carbonate and CO_2 control	Slightly soluble, non-toxic, irritant
Organic synthetic polymer blends	Filtrate reducing agent	Non-toxic, 96 hr LC_{50} >500 ppm
Palm oil ester	Lubricant, stuck pipe pills	Slightly soluble, biodegradable
Potassium chloride	Shale / clay inhibitor	Soluble, non-toxic
Soda ash	Alkalinity, calcium reducer	Soluble, non-toxic
Sodium bicarbonate	Alkalinity, calcium reducer	Soluble, non-toxic
Xanthan gum	Viscosity, rheology	Soluble, non-toxic

2.2.4.1 Non-aqueous drilling fluids

Non-aqueous drilling fluids (NADF) are used to:

- Provide optimum wellbore stability and enable a near gauge hole to be drilled;
- Reduce torque and drag in high angle to horizontal wells;
- Minimise damage to reservoirs that contain clays that react adversely to WBM; and
- Obtain irreducible water saturation log data for gas reservoirs.

The main chemicals used in a NADF are presented in Table 3.

Table 3: Main chemicals used in a non-aqueous drilling fluid (adapted from Swan et al. 1994).

Material	Description
Base oil	Non-aqueous drilling fluids use base fluids with significantly reduced aromatics and extremely low polynuclear aromatic compounds. New systems using vegetable oil, polyglycols or esters have been and continue to be used.
Brine phase	$CaCl_2$, NaCl, KCl.
Gelling products	Modified clays reacted with organic amines.
Alkaline chemicals	Lime e.g. $Ca(OH)_2$.
Fluid loss control	Chemicals derived from lignites reacted with long chain or quaternary amines.
Emulsifiers	Fatty acids and derivatives, rosin acids and derivatives, dicarboxylic acids, polyamines.

The disadvantage of using a NADF is that base fluid and other chemicals would result in an increase in toxicity. Drill cuttings that derive from the reservoir section contain residual base fluids, which cannot be removed easily. The trend in the industry has been to move towards low toxicity NADF (Group III NADF) that are biodegradable and will not persist in the long-term. There are three types of NADF that are used for offshore drilling and can be defined as follows:

- **Group I NADF (high aromatic content)**

  These base fluids were used during initial days of oil and gas exploration and include diesel and conventional mineral oil based fluids. They are refined from crude oil and are a non-specific collection of hydrocarbon compounds including paraffins, olefins and aromatic and polycyclic aromatic hydrocarbons (PAHs). Group 1 NADFs are defined by having PAH levels greater than 0.35%.

- **Group II NADF (medium aromatic content)**

  These fluids are sometimes referred to as Low Toxicity Mineral Oil Based Fluids (LTMBF) and were developed to address the rising concern over the potential toxicity of diesel-based fluids. They are also developed from refining crude oil but the distillation process is controlled such that the total aromatic hydrocarbon concentration is less than Group I NADFs (0.5 – 5%) and the PAH content is less than 0.35% but greater than 0.001%.

- **Group III NADF (low to negligible aromatic content)**

  These fluids are characterised by PAH contents less than 0.001% and total aromatic contents less than 0.5%. They include SBM which are produced by chemical reactions of relatively pure compounds and can include synthetic hydrocarbons (olefins, paraffins and esters). Using special refining and/or separation processes, base fluids of Group III can also be derived from highly processed mineral oils (paraffins, enhanced mineral oil based fluid (EMBF)). PAH content is less than 0.001%. Shell is proposing to use a SBM during the risered drilling stage.

2.2.5 Well evaluation

2.2.5.1 Mud logging

Evaluation of the petro-physical properties of the formations that have been penetrated is carried out routinely during the drilling operation. Mud logging involves the examination of the drill cuttings brought to the surface by the drilling fluid.

Mud logging also monitors for hydrocarbon gases that relate to changes in formation pressure and the volume or rate of returning fluid, which is imperative to catch "kicks" early. A "kick" is when the formation pressure at the depth of the bit is more than the hydrostatic head of the mud above, which if not controlled temporarily by closing the BOP and ultimately by increasing the density of the drilling fluid would allow formation fluids and mud to come up through the drill pipe uncontrollably.

2.2.5.2 Downhole formation logging

Electrical logging and measurement while drilling logging are the two most widely used downhole formation evaluation methods. The use of wireline logging tools requires the drill string to be removed from the well so these logs are generally run at casing points. Radioactive sources may be used for certain types of data acquisition (see Section 2.2.5.3).

There are two fundamentally different uses of radioactive devices in wireline logging. In the first, the source is mounted in the wireline tool, where it generates a radioactive field that interacts with the rocks penetrated at the wellbore. The measured response is directly related to the physical properties of the rocks. The other usage is for calibrating wireline tools that measure either natural or induced radioactivity.

2.2.5.3 Radioactive sources

There are two standard types of wireline tools that use radioactive sources and measure formation porosity, namely:

- The density log, which measures the electron density of a formation (this is a function of porosity); and
- The neutron log, which measures the hydrogen ion concentration in a formation.

The radiation levels of the density and neutron tool activity are very low.

2.2.5.4 Radioactive calibration tools

Calibration tools generate a known level of low radioactivity, which is used to calibrate the receiver response for the neutron logging tool and for calibrating tools that measure the natural radiation of formations. The measurements are used for correlating zones between wells and for identifying lithologies, particularly volcanic ashes, organic rich shales, potassium feldspars, micas and glauconite. The radiation from the calibration tools is similar to the natural radiation from rocks.

2.2.5.5 Radiation level

The radioactive sources used in wireline logging would be stored in sealed containers. The radioactive material is encapsulated in ceramic cylinders and then sheathed in several layers of stainless steel. The size of the sealed sources is approximately 4 inches (length) x 1 inch (diameter) for the density tool and 7 inches (length) x 1.5 inches (diameter) for the neutron source.

The radiation levels are very low. The density tool activity can range from 0.1-2 curies (Ci) with a 0.5–200 milliroentgens per hour (mR/hr) maximum radiation level at the source surface. The neutron tool activity can range from 3-20 Ci with a 50-200 mR/hr maximum radiation level at the surface. The neutron tool, however, does not emit any external radiation at the tool surface when it is not energised.

The radiation from the calibration tools is similar to the natural radiation from rocks. Activities range from 0.000002–0.5 mR/hr maximum radiation levels.

Specific safety procedures would be established by the wireline logging contractor to handle the sources (see Section 2.2.5.6). In addition, the contractor has to set up incident and emergency reporting procedures for actual or suspected individual over-exposure, theft or loss, logging tools stuck downhole in wells and release or spillage into the environment. The contractor routinely tests the sources according to industry requirements to document leak levels.

2.2.5.6 Transport, storage and handling of radioactive devices

Radioactive devices are transported from the wireline contractor's base to a drilling unit in specially designed secured (locked) storage containers. The tools are inventoried upon arrival and tested for leaks. A detailed log is kept of any access to the storage container and tools.

Drilling units would have a special storage location designated for radioactive containers. The storage location would be specifically chosen to minimise the danger of fire, explosion and exposure, and are clearly identified by yellow radioactive warning signs.

Only certified wireline logging engineers would be allowed to handle the radioactive devices. Whenever the radioactive sources are used, the area between and around the storage containers and the drill floor would be secured and only key personnel would be allowed in the area. Long handling sticks would be used to transfer the density and neutron sources between the storage containers and the logging tools on the drill floor, but the calibration tools, being very low-level radioactive devices, would be hand-held.

The engineers handling the devices would follow strict approved procedures. They would also wear personal monitoring devices to measure any unusual exposure. The equipment would be handled as little as possible by the engineers and returned immediately to the storage containers upon completion of the logging run.

2.2.6 Well (flow) testing

Should the exploration well encounter hydrocarbons, an “appraisal” well may be drilled, which would be flow-tested (also called production testing) to determine the economic potential of the discovery before the well is either abandoned or suspended for later re-entry and completion.

If flow testing is required, hydrocarbons would be burned at the well site. A high-efficiency flare is used to maximise combustion of the hydrocarbons. The amount of hydrocarbons produced would depend on the quality of the reservoir but is kept to a minimum to avoid wasting potentially marketable oil and/or gas. Thus the final well test programme would be prepared when the detailed geology and fluids are defined.

No produced water is anticipated. However, if water does flow with the hydrocarbons to the surface it would be flared off. Any water remaining would be stored and brought to shore for treatment and disposal in accordance with regulatory requirements.Once total depth is reached the well is logged and tested. This consists of lowering a logging tool(s) to gather data in order to create a petro-physical evaluation of the wellbore.

If the exploration well encounters hydrocarbons, an “appraisal” well would be drilled, which would be flow-tested to determine the economic potential of the discovery before the well is either abandoned or suspended for later re-entry and completion. If flow-testing is required, hydrocarbons would be burned at the well site. A high-efficiency flare is used to maximise combustion of the hydrocarbons.

2.2.7 Well completion and abandonment

Based on the results of the drilling, logging and possible testing of the well, a decision would be made as to whether to the final state of the well, before the drilling unit is moved off location. The options are described below.suspend or abandon the well.

a) Suspended wells: If it is verified that a well is commercially viable, it could be suspended. This would entail the following:
   - Cement plugs would be set inside the well bore and tested for integrity;
   - The blow-out preventer would be removed before the drilling unit is moved off location;
   - The wellhead (total 3 to 4 m high) would remain on the seafloor; and
   - A corrosion cap would be placed over the wellhead to facilitate re-entry.

b) Abandoned wells: If a well is unsuccessful, it would be permanently abandoned. This would entail the following:
   - Cement plugs would be set inside the well bore and tested for integrity;
   - The blow-out preventer would be removed before the drilling unit is moved off location; and
   - The wellhead (total 3 to 4 m high) would either remain on or be removed from the seafloor. The preferred alternative would be to leave the wellhead on the seafloor.

2.2.8 Sea- and land-based support

2.2.8.1 Onshore logistics base

A logistics shore base would be located in either Cape Town or Saldanha Bay. The shore base would provide for the storage of materials (including wellbore materials, diesel, water and drilling fluids) and equipment that would be transported from/to the drilling unit by sea. The shore base would also be used for bunkering vessels.

2.2.8.2 Support and supply vessels

The drilling unit will be supported by at least three vessels, namely one standby and two supply vessels. The standby vessel would provide support for firefighting, oil containment / recovery, rescue and any equipment that may be required in case of an emergency. The standby vessel would also be used to patrol the area to ensure that other vessels adhere to the 500 m safety zone around the drilling unit. The supply vessels would provide equipment and material transport between the drilling unit and the port.

It is envisioned that a supply vessel would call into port every week during the campaign.

The drilling operations would be supported by at least three vessels, which would facilitate equipment and material transport between the drilling unit and port. The standby vessels would also provide support for fire-fighting, oil containment/recovery, rescue and any equipment that may be required in case of an emergency.

The logistics shore base would be located in either Cape Town or Saldanha Bay. This shore base would provide for the storage of materials (including wellbore materials, diesel, water and synthetic-based mud) and equipment that would be transported from/to the drilling unit by sea. The shore base would also be used for bunkering vessels. Transportation of personnel would be provided by helicopter from Kleinzee and fixed-wing flights to and from Cape Town.

2.2.8.3 Crew transfers

Transportation of personnel to and from the drilling unit would be provided by helicopter operations from the Kleinzee airport, which is located approximately 250 km from the proposed area of operation. Transportation to Kleinzee would be provided by fixed-wing flights from Cape Town, which is approximately 500 km to the south.

The drilling unit would accommodate in the order of 100 - 150 personnel. Crews would work in 12-hour shifts in 4-5 week cycles. Crew changes would be staggered, and in combination with ad hoc personnel requirements. Thus helicopter operations to and from the drilling unit and fixed wing operations between Kleinzee and Cape Town would occur on an almost daily basis.

A second helicopter would be kept on standby for rescue operations. This helicopter is kept in a high state of readiness, i.e. fuelled, setting on pad, pilot and crew at base in Kleinzee.

3. DESCRIPTION OF THE BASELINE MARINE ENVIRONMENT

The descriptions of the physical and biological environments along the South African West Coast focus primarily on the study area between the Orange River mouth and St Helena Bay. However, the description has been extended into Namibia, where appropriate, to cater for potential transboundary impacts. The purpose of this environmental description is to provide the marine baseline environmental context within which the proposed exploration drilling will take place. The summaries presented below are based on information gleaned from Lane & Carter (1999), Morant (2006), and Penney *et al*. (2007). The description of benthic macrofaunal communities was provided by Natasha Karenyi of the South African National Biodiversity Institute, and the section on marine mammals was provided by Dr Simon Elwen of the Namibian Dolphin Project and Mammal Research Institute (University of Pretoria).

3.1. Geophysical Characteristics

3.1.1 Bathymetry

The continental shelf along the West Coast is generally wide and deep, although large variations in both depth and width occur. The shelf maintains a general NNW trend, widening north of Cape Columbine and reaching its widest off the Orange River (180 km) (see Figure 1). The nature of the shelf break varies off the South African West Coast. Between Cape Columbine and the Orange River, there is usually a double shelf break, with the distinct inner and outer slopes, separated by a gently sloping ledge. The immediate nearshore area consists mainly of a narrow (about 8 km wide) rugged rocky zone and slopes steeply seawards to a depth of around 80 m. The middle and outer shelf normally lacks relief and slopes gently seawards reaching the shelf break at a depth of ~300 m.

Banks on the continental shelf include the Orange Bank (Shelf or Cone), a shallow (160 - 190 m) zone that reaches maximal widths (180 km) offshore of the Orange River, and Child's Bank, situated ~150 km offshore at about 31°S, and ~75 km due east of the principal project target area. Child's Bank is the only known submarine bank within South Africa's Exclusive Economic Zone (EEZ), rising from a depth of 350 - 400 m water to less than 200 m at its shallowest point. The bank area has been estimated to cover some 1,450 km^2 (Sink *et al*. 2012). Tripp Seamount is a geological feature ~30 km to the north of the Licence Area, which rises from the seabed at ~1,000 m to a depth of 150 m.

3.1.2 Coastal and Inner-shelf Geology and Seabed Geomorphology

Figure 8 illustrates the distribution of seabed surface sediment types off the South African north-western coast. The inner shelf is underlain by Precambrian bedrock (Pre-Mesozoic basement), whilst the middle and outer shelf areas are composed of Cretaceous and Tertiary sediments (Dingle 1973; Dingle *et al*. 1987; Birch *et al*. 1976; Rogers 1977; Rogers & Bremner 1991). As a result of erosion on the continental shelf, the unconsolidated sediment cover is generally thin, often less than 1 m. Sediments are finer seawards, changing from sand on the inner and outer shelves to muddy sand and sandy mud in deeper water. However, this general pattern has been modified considerably by biological deposition (large areas of shelf sediments contain high levels of calcium carbonate) and localised river input. An ~500-km long mud belt (up to 40 km wide, and of 15 m average thickness) is situated over the innershelf shelf between the Orange River and St Helena Bay (Birch *et al*. 1976). Further offshore and within the Licence Area, sediment is dominated by muds and sandy muds. The continental slope, seaward of the shelf break, has a smooth seafloor, underlain by calcareous ooze.

Present day sedimentation is limited to input from the Orange River. This sediment is generally transported northward. Most of the sediment in the area is therefore considered to be relict deposits by now ephemeral rivers active during wetter climates in the past. The Orange River, when in flood, still contributes largely to the mud belt as suspended sediment is carried southward by poleward flow. In this context, the absence of large sediment bodies on the inner shelf reflects on the paucity of terrigenous sediment being introduced by the few rivers that presently drain the South African West Coast coastal plain.

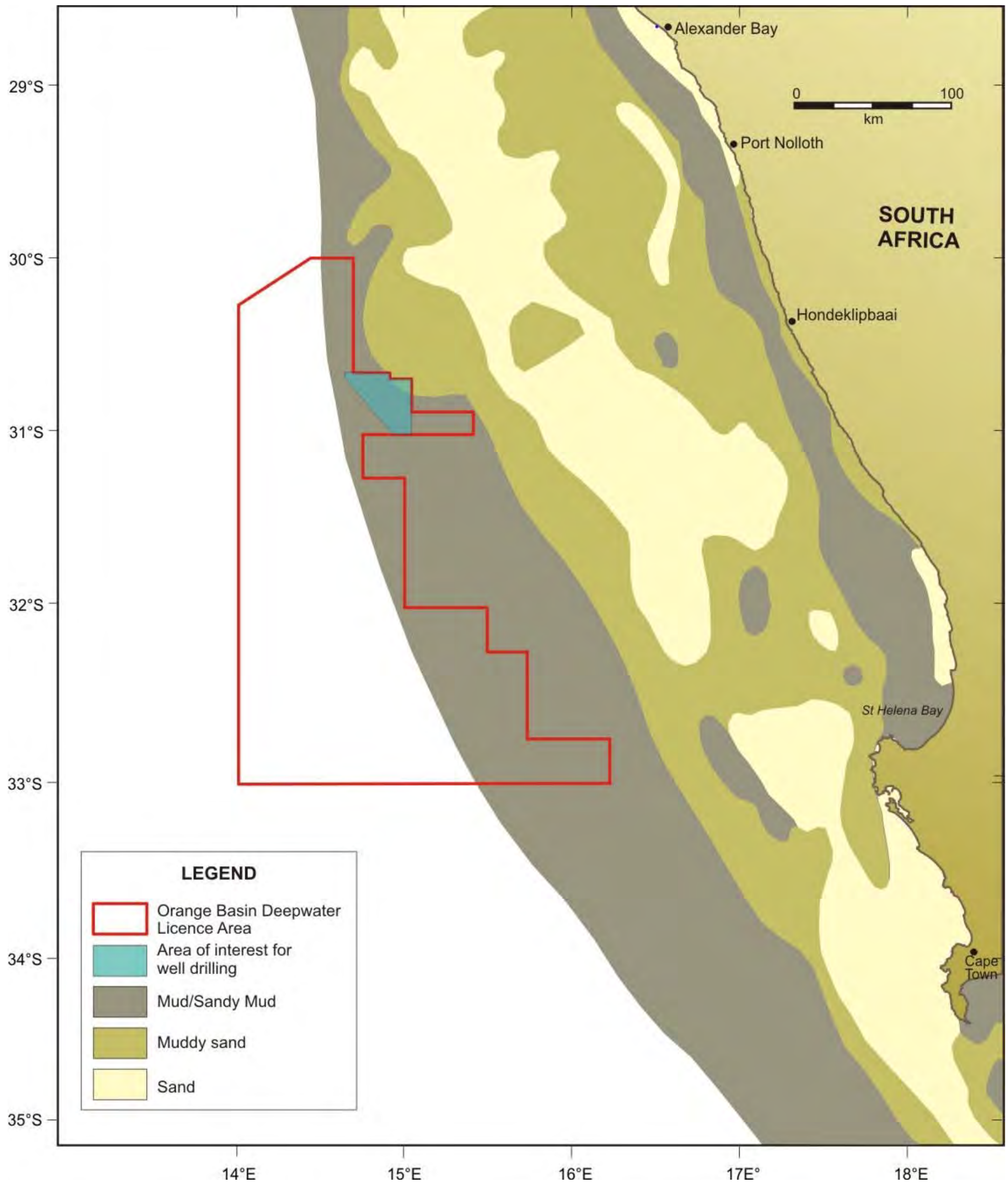


Figure 8: Sediment distribution on the continental shelf of the South African West Coast (Adapted from Rogers 1977).

3.2. Biophysical Characteristics

3.2.1 Wind Patterns

Winds are one of the main physical drivers of the nearshore Benguela region, both on an oceanic scale, generating the heavy and consistent south-westerly swells that impact this coast, and locally, contributing to the northward-flowing longshore currents, and being the prime mover of sediments in the terrestrial environment. Consequently, physical processes are characterised by the average seasonal wind patterns, and substantial episodic changes in these wind patterns have strong effects on the entire Benguela region.

The prevailing winds in the Benguela region 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.

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-pressures system, and the associated series of cold fronts, moves northwards in winter, and southwards in summer. The strongest winds occur in summer (October to March), during which winds blow 98% of the time (PRDW 2013), with a total of 226 gales (winds exceeding 18 m/s or 35 kts) being recorded over the period (CSIR 2006). Virtually all winds in summer come from the south to south-southeast (Figure 9). 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.

Winter remains dominated by southerly to south-easterly winds, but the closer proximity of the winter cold-front systems results in a significant south-westerly to north-westerly component (Figure 7). 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 in summer. There are also more calms in winter, occurring about 4% of the time, and wind speeds generally do not reach the maximum speeds of summer. However, the westerly winds blow in synchrony with the prevailing south-westerly swell direction, resulting in heavier swell conditions in winter.

3.2.2 Large-Scale Circulation and Coastal Currents

The southern African West Coast is strongly influenced by the Benguela Current. Current velocities in continental shelf areas generally range between 10–30 cm/s (Boyd & Oberholster 1994), although localised flows in excess of 50 cm/s occur associated with eddies (PRDW 2013). On its western side, flow is more transient and characterised by large eddies shed from the retroflection of the Agulhas Current. This results in considerable variation in current speed and direction over the domain (PRDW 2013). In the south the Benguela current has a width of 200 km, widening rapidly northwards to 750 km. The surface flows are predominantly wind-forced, barotropic and fluctuate between poleward and equatorward flow

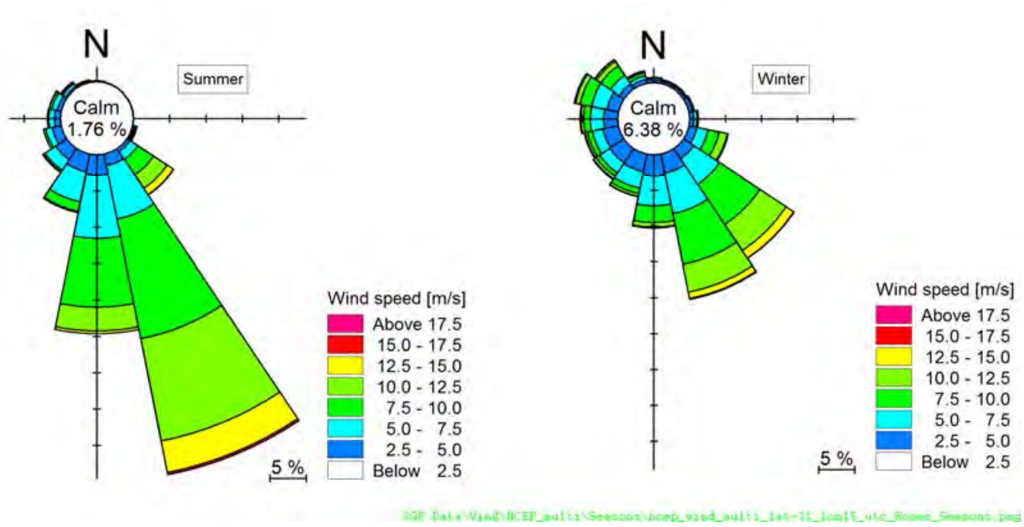


Figure 9: Wind Speed vs. Wind Direction for NCEP hind cast data at location 15°E, 31°S (From PRDW 2013).

(Shillington *et al.* 1990; Nelson & Hutchings 1983) (Figure 10). Fluctuation periods of these flows are 3 - 10 days, although the long-term mean current residual is in an approximate northwest (alongshore) direction. Current speeds decrease with depth, while directions rotate from predominantly north-westerly at the surface to south-easterly near the seabed. Near bottom shelf flow is mainly poleward with low velocities of typically <5 cm/s (Nelson 1989; PRDW 2013).

The major feature of the Benguela Current is coastal upwelling and the consequent high nutrient supply to surface waters leads to high biological production and large fish stocks. The prevailing longshore, equatorward winds move nearshore surface water northwards and offshore. To balance the displaced water, cold, deeper water wells up inshore. 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. There are three upwelling centres in the southern Benguela, namely the Namaqua (30°S), Cape Columbine (33°S) and Cape Point (34°S) upwelling cells (Taunton-Clark 1985) (Figure 11; bottom left). Upwelling in these cells is seasonal, with maximum upwelling occurring between September and March. An example of one such strong upwelling event in December 1996, followed by relaxation of upwelling and intrusion of warm Agulhas waters from the south, is shown in the satellite images in Figure 11. The Orange Basin Deepwater area is located well offshore (>100 km) of these upwelling events.

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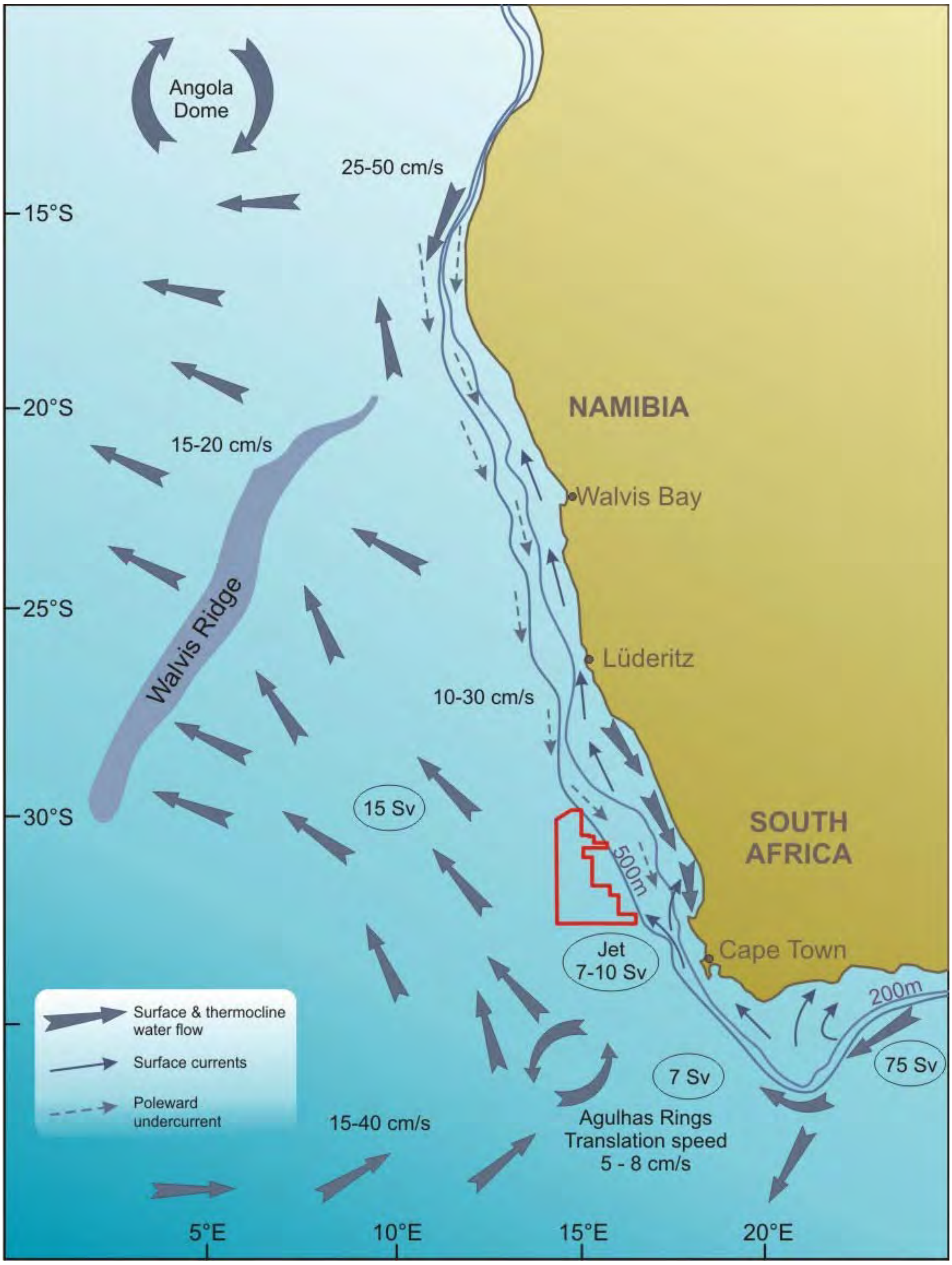


Figure 10: Major features of the predominant circulation patterns and volume flows in the Benguela System, along the southern Namibian and South African west coasts (re-drawn from Shannon & Nelson 1996).

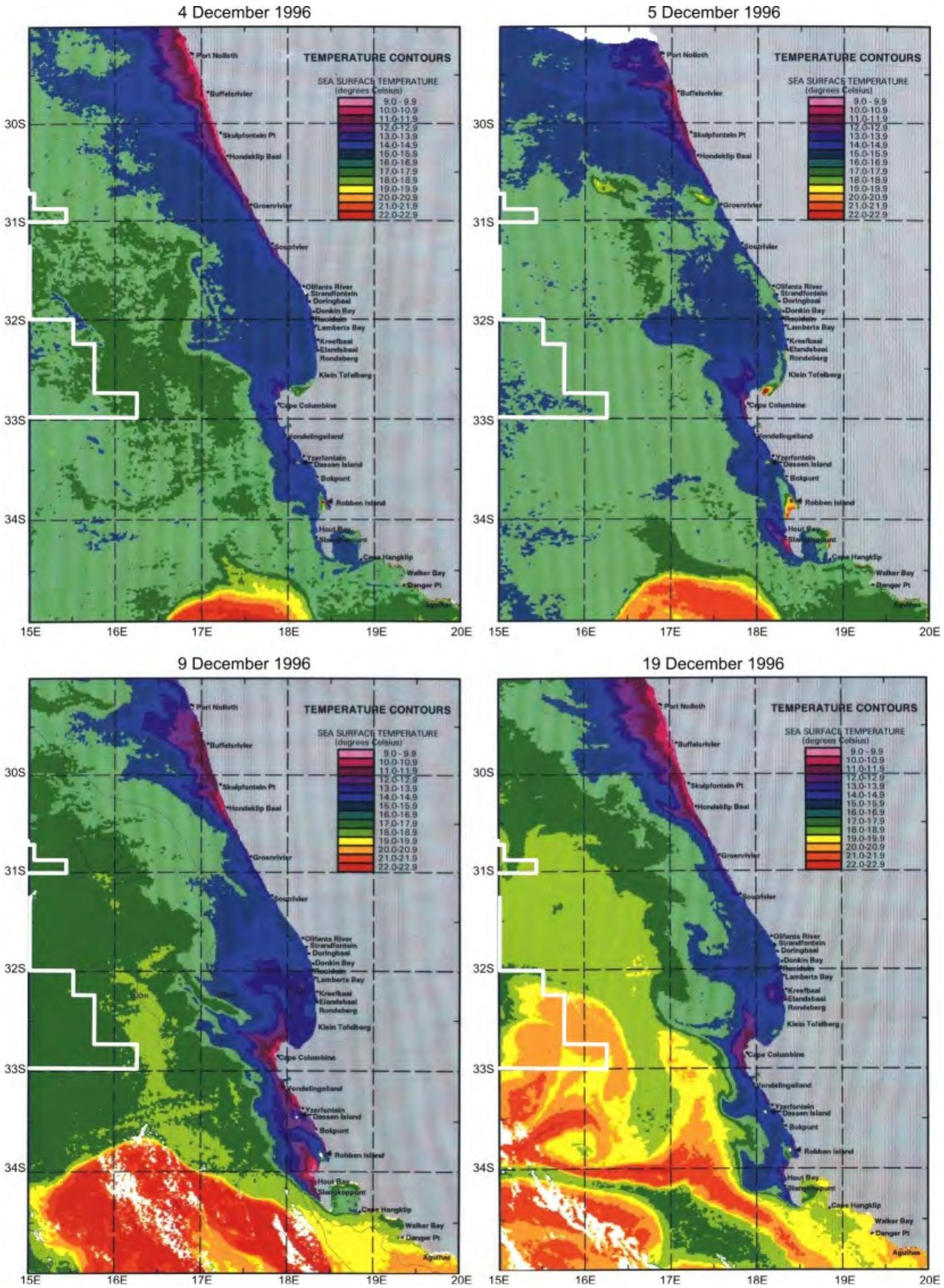


Figure 11: Satellite sea-surface temperature images showing upwelling intensity along the South African west coast on four days in December 1996 (from Lane & Carter 1999), in relation to the Orange Basin Deep Water Licence Area (white polygon).

Where the Agulhas Current passes the southern tip of the Agulhas Bank (Agulhas Retroflection area), it may shed a filament of warm surface water that moves north-westward along the shelf edge towards Cape Point, and Agulhas Rings, which similarly move north-westwards into the South Atlantic Ocean (Figure 11, bottom right). These rings may extend to the seafloor and west of Cape Town may split, disperse or join with other rings. During the process of ring formation, intrusions of cold subantarctic water moves into the South Atlantic. The contrast in warm (nutrient-poor) and cold (nutrient-rich) water is thought to be reflected in the presence of cetaceans and large migratory pelagic fish species (Best 2007).

3.2.3 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). Much 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 peak wave energy periods fall in the range 9.7 – 15.5 seconds.

Typical seasonal swell-height rose-plots, compiled from Voluntary Observing Ship (VOS) data off Oranjemund, are shown in Figure 12 (supplied by CSIR). 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 S and SSW direction. Winter swells are strongly dominated by those from the S and SSW, which occur almost 80% of the time, and typically exceed 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.

In comparison, summer swells tend to be smaller on average, typically around 2 m, not reaching the maximum swell heights of winter. There is also a slightly more pronounced southerly swell component in summer. These southerly swells tend to be wind-induced, with shorter wave periods (~8 seconds), and are generally steeper than swell waves (CSIR 1996). These wind-induced southerly waves are relatively local and, although less powerful, tend to work together with the strong southerly winds of summer to cause the northward-flowing nearshore surface currents, and result in substantial nearshore sediment mobilisation, and northwards transport, by the combined action of currents, wind and waves.

In common with the rest of the southern African coast, tides are semi-diurnal, with a total range of some 1.5 m at spring tide, but only 0.6 m during neap tide periods.

3.2.4 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 southern Benguela typically vary between 6°C and 16°C. Well-developed thermal fronts exist, demarcating the seaward

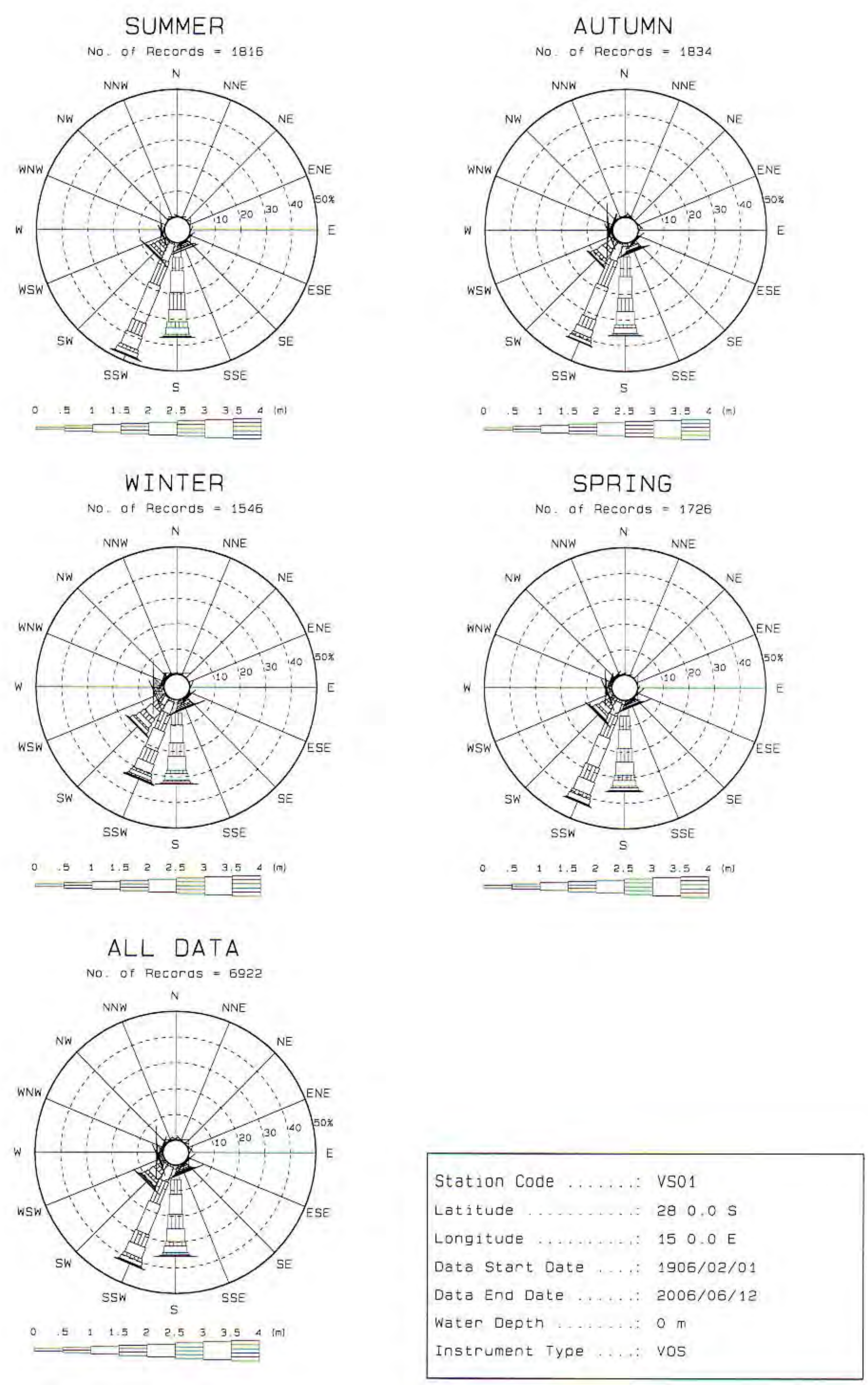


Figure 12: VOS Wave Height vs. Wave Direction data for the offshore area (28°-29°S; 15°-16°E recorded during the period 1 February 1906 and 12 June 2006)) (Source: Voluntary Observing Ship (VOS) data from the Southern African Data Centre for Oceanography (SADCO)).

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 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. South and east of Cape Agulhas, the Agulhas retroflection area is a global "hot spot" in terms of temperature variability and water movements.

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).

Nutrient concentrations of upwelled water of the Benguela system attain 20 µm nitrate-nitrogen, 1.5 µm phosphate and 15-20 µm 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.

3.2.5 Upwelling & Plankton Production

The cold, upwelled water is rich in inorganic nutrients, the major contributors being various forms of nitrates, phosphates and silicates (Chapman & Shannon 1985). During upwelling the comparatively nutrient-poor surface waters are displaced by enriched deep water, supporting substantial seasonal primary phytoplankton production. This, in turn, serves as the basis for a rich food chain up through zooplankton, pelagic baitfish (anchovy, pilchard, round-herring and others), to predatory fish (hake and snoek), mammals (primarily seals and dolphins) and seabirds (jackass penguins, cormorants, pelicans, terns and others). 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.

3.2.6 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^2 of phytoplankton and 31.5 tons/km^2 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.

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) 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)

3.2.7 Low Oxygen Events

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 8), there are corresponding preferential areas for the formation of oxygen-poor water. The two main areas of low-oxygen water formation in the southern 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 mortalities and walkouts. The blooms develop over a period of unusually calm wind conditions when sea surface temperatures where 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.

3.2.8 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^2 (Figure 14).

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).

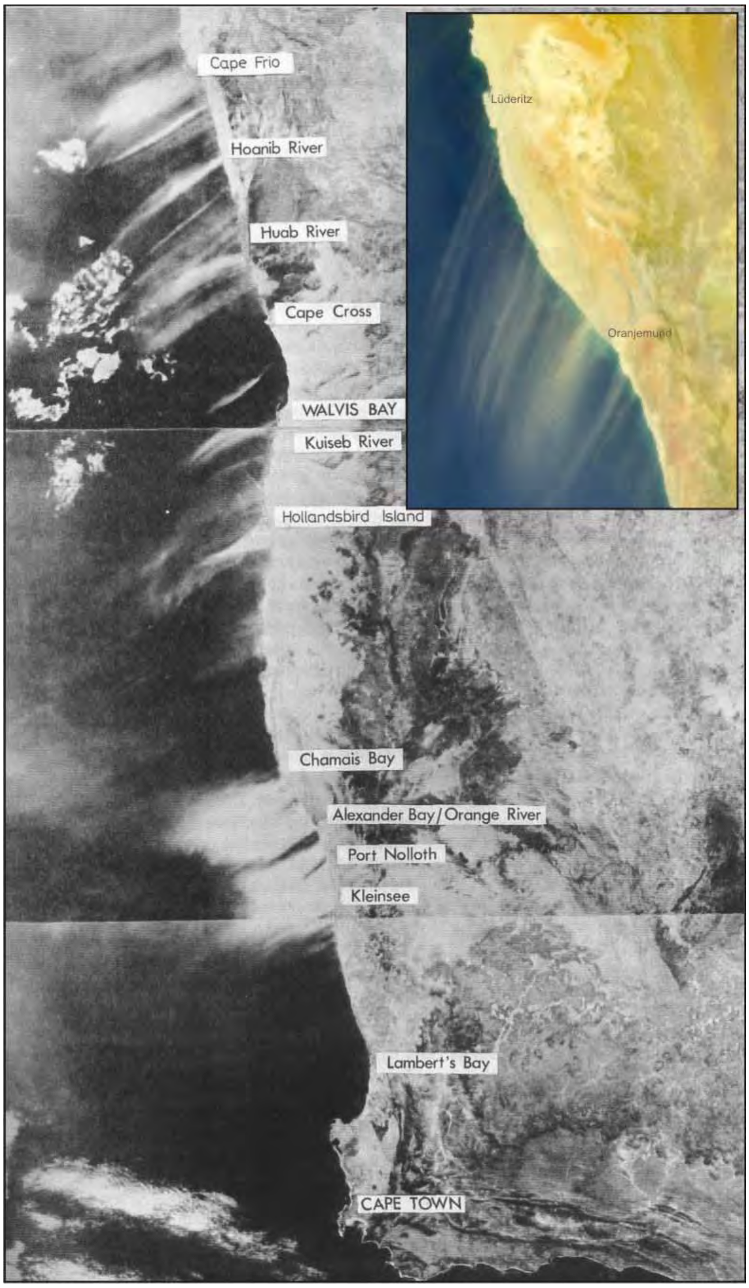


Figure 14: Aerosol plumes of sand and dust due to a 'berg' wind event: NIMBUS 7 CZCS orbit 2726, 9 May 1979 (690 nm) (Shannon & Anderson 1982).

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 (see also Drake *et al*. 1985; Ward 1985). 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).

Mean sediment deposition is naturally higher near the seafloor due to constant re-suspension of coarse and fine PIM by tides and wind-induced waves. Aggregation or flocculation of small particles into larger aggregates occurs as a result of cohesive properties of some fine sediments in saline waters. The combination of re-suspension of seabed sediments by heavy swells, and the faster settling rates of larger inorganic particles, typically causes higher sediment concentrations near the seabed. Significant re-suspension of sediments can also occur up into the water column under stronger wave conditions associated with high tides and storms. Re-suspension can result in dramatic increases in PIM concentrations within a few hours (Sheng *et al.* 1994). Wind speed and direction have also been found to influence the amount of material re-suspended (Ward 1985).

Although natural turbidity of seawater is a global phenomenon, there has been a worldwide increase of water turbidity and sediment load in coastal areas as a consequence of anthropogenic activities. These include dredging associated with the construction of harbours and coastal installations, beach replenishment, accelerated runoff of eroded soils as a result of deforestation or poor agricultural practices, and discharges from terrestrial, coastal and marine mining operations (Airoldi 2003). Such increase of sediment loads has been recognised as a major threat to marine biodiversity at a global scale (UNEP 1995).

Offshore of the continental shelf, the oceanic waters are typically clear as they are beyond the influence of aeolian and riverine inputs. The waters in the Orange Basin Deepwater areas are thus expected to be comparatively clear.

3.3. The Biological Environment

Biogeographically, the study area falls within the following three bioregions: the cold temperate Namaqua, the Atlantic Offshore and the Southwestern Cape Bioregions (Emanuel *et al*. 1992; Lombard *et al.* 2004). The Orange Basin Deepwater Licence Area falls into the Atlantic Offshore Bioregion (Lombard *et al.* 2004) (Figure 15). The coastal, wind-induced upwelling characterising the western Cape coastline, is the principle physical process which shapes the marine ecology of the southern Benguela region. The Benguela system is characterised by the presence of cold surface water, high biological productivity, and highly variable physical, chemical and biological conditions.

Communities within marine habitats are largely ubiquitous throughout the southern African West Coast region, being particular only to substrate type or depth zone. These biological communities consist of many hundreds of species, often displaying considerable temporal and spatial variability (even at small scales). The offshore marine ecosystems comprise a limited range of habitats, namely unconsolidated seabed sediments, deepwater reefs and the water column. The biological communities 'typical' of these habitats are described briefly below, focussing both on dominant, commercially important and conspicuous species, as well as potentially threatened or sensitive species, which may be affected by the proposed exploration drilling operations.

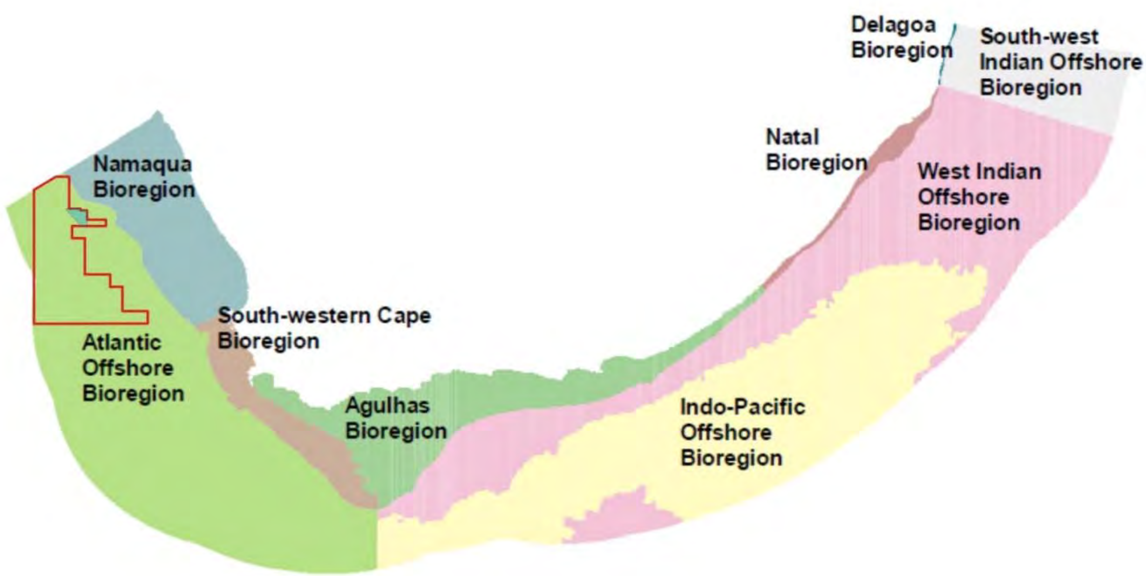


Figure 15: The South African inshore and offshore bioregions in relation to the Orange Basin Deepwater area (red outline) (adapted from Lombard *et al*. 2004).

3.3.1 Demersal Communities

3.3.1.1 Benthic Invertebrate Macrofauna

The benthic biota of unconsolidated marine sediments constitute invertebrates that live on (epifauna) or burrow within (infauna) the sediments, and are generally divided into macrofauna (animals >1 mm) and meiofauna (<1 mm). 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). These studies, however, concentrated on the continental shelf and nearshore regions, and consequently the benthic fauna of the outer shelf and continental slope (beyond ~450 m depth) are very poorly known. This is primarily due to limited opportunities for sampling as well as the lack of access to Remote Operated Vehicles (ROVs) for visual sampling of hard substrata.

To date very few areas on the continental slope off the West Coast have been biologically surveyed. Although sediment distribution studies (Rogers & Bremner 1991) suggest that the outer shelf is characterised by unconsolidated sediments (see Figure 8), recent surveys conducted between 180 m and 480 m depth inshore of the Orange Basin Deep Water Licence Area revealed high proportions of hard ground rather than unconsolidated sediment, although this requires further verification (Karenyi unpublished data).

Due to the lack of information on benthic macrofaunal communities beyond the shelf break, no description can be provided for the Orange Basin Deep Water Licence Area. The description below for areas on the continental shelf, inshore of the project area 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). Although inshore of the Licence Area, they are included here as impacts associated with the proposed well drilling may extend well beyond the target area.

Three macro-infauna communities have been identified on the inner- (0-30 m depth) and mid-shelf (30-150 m depth, Karenyi unpublished data). Polychaetes, crustaceans and molluscs make up the largest proportion of individuals, biomass and species on the west coast. The inner-shelf community, which is affected by wave action, is characterised by various mobile gastropod and polychaete predators and sedentary polychaetes and isopods. The mid-shelf community inhabits the mudbelt and is characterised by mud prawns. A second mid-shelf community occurring in sandy sediments, is characterised by various deposit-feeding polychaetes. 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 Dalfsen *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

Despite the current lack of knowledge of the community structure and endemicity of South African macro-infauna off the edge of the continental shelf, the marine component of the 2011 National Biodiversity Assessment (Sink *et al*. 2012), rated the South Atlantic bathyal and abyssal unconsolidated habitat types that characterise depths beyond 500 m, as 'least threatened' (Figure 16, left). This primarily reflects the great extent of these habitats in the South African EEZ.

Generally species richness increases from the inner-shelf across the mid-shelf and is influenced by sediment type. The highest total abundance and species diversity was measured in sandy sediments of the mid-shelf. Biomass is highest in the inshore (± 50 g/m^2 wet weight) and decreases across the mid-shelf averaging around 30 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 off the northern Namaqualand coast.

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.

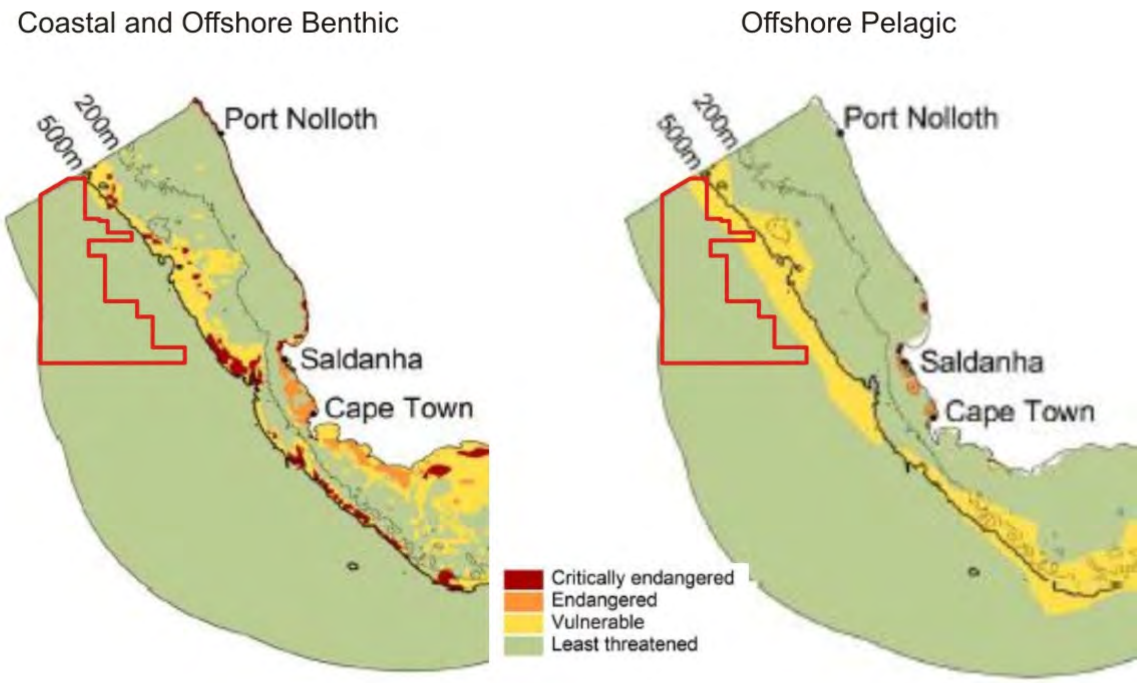


Figure 16: Ecosystem threat status for coastal and offshore benthic habitat types (left), and offshore pelagic habitat types on the South African West Coast in relation to the Orange Basin Deepwater area (red outline) (adapted from Sink *et al*. 2012).

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.

3.3.1.2 Deep-water coral communities

There has been increasing interest in deep-water corals in recent years because of their likely sensitivity to disturbance and their long generation times. These benthic filter-feeders generally occur at depths in below 150 m with some species being recorded from as deep as 3,000 m. Some species form reefs while others are smaller and remain solitary. Corals add structural complexity to otherwise uniform seabed habitats thereby creating areas of high biological diversity (Breeze *et al*. 1997; MacIssac *et al*. 2001). Deep water corals establish themselves below the thermocline where there is a continuous and regular supply of concentrated particulate organic matter, caused by the flow of a relatively strong current over special topographical formations which cause eddies to form. Nutrient seepage from the substratum might also promote a location for settlement (Hovland *et al*. 2002). In the productive Benguela region, substantial areas on and off the edge of the shelf should thus potentially be capable of supporting rich, cold water, benthic, filter-feeding communities.

3.3.1.3 Demersal Fish Species

Demersal fish are those species that live and feed on or near the seabed. As many as 110 species of bony and cartilaginous fish have been identified in the demersal communities on the continental shelf of the West Coast (Roel 1987). Changes in fish communities occur with increasing depth (Roel 1987; Smale *et al*. 1993; Macpherson & Gordoa 1992; Bianchi *et al*. 2001; Atkinson 2009), with the most substantial change in species composition occurring in the shelf break region between 300 m and 400 m depth (Roel 1987; Atkinson 2009). The shelf community (<380 m) is dominated by the Cape hake *M. capensis*, and includes jacopever *Helicolenus dactylopterus*, Izak catshark *Holohalaelurus regain*, soupfin shark *Galeorhinus galeus* and whitespotted houndshark *Mustelus palumbes*. The more diverse deeper water community is dominated by the deepwater hake *Merluccius paradoxus*, monkfish *Lophius vomerinus*, kingklip *Genypterus capensis*, bronze whiptail *Lucigadus ori* and hairy conger *Bassanago albescens* and various squalid shark species. There is some degree of species overlap between the depth zones.

Roel (1987) showed seasonal variations in the distribution ranges shelf communities, with species such as the pelagic goby *Sufflogobius bibarbatus*, and West Coast sole *Austroglossus microlepis* occurring in shallow water north of Cape Point during summer only. The deep-sea community was found to be homogenous both spatially and temporally. In a more recent study, however, Atkinson (2009) identified two long-term community shifts in demersal fish communities; the first (early to mid-1990s) being associated with an overall increase in density of many species, whilst many species decreased in density during the second shift (mid-2000s). These community shifts correspond temporally with regime shifts detected in environmental forcing variables (Sea Surface Temperatures and upwelling anomalies) (Howard *et al*. 2007) and with the eastward shifts observed in small pelagic fish species and rock lobster populations (Coetzee *et al*. 2008, Cockcroft *et al*. 2008).

The diversity and distribution of demersal cartilagenous fishes on the West Coast is discussed by Compagno *et al*. (1991). The species that may occur in the general project area and on the continental shelf inshore thereof, and their approximate depth range, are listed in Table 4.

Table 4: Demersal cartilaginous species found on the continental shelf along the West Coast, with approximate depth range at which the species occurs (Compagno *et al*. 1991).

Common Name	Scientific name	Depth Range (m)
Frilled shark	*Chlamydoselachus anguineus*	200-1,000
Six gill cowshark	*Hexanchus griseus*	150-600
Gulper shark	*Centrophorus granulosus*	480
Leafscale gulper shark	*Centrophorus squamosus*	370-800
Bramble shark	*Echinorhinus brucus*	55-285
Black dogfish	*Centroscyllium fabricii*	>700
Portuguese shark	*Centroscymnus coelolepis*	>700
Longnose velvet dogfish	*Centroscymnus crepidater*	400-700
Birdbeak dogfish	*Deania calcea*	400-800
Arrowhead dogfish	*Deania profundorum*	200-500
Longsnout dogfish	*Deania quadrispinosum*	200-650
Sculpted lanternshark	*Etmopterus brachyurus*	450-900
Brown lanternshark	*Etmopterus compagnoi*	450-925
Giant lanternshark	*Etmopterus granulosus*	>700
Smooth lanternshark	*Etmopterus pusillus*	400-500
Spotted spiny dogfish	*Squalus acanthias*	100-400
Shortnose spiny dogfish	*Squalus megalops*	75-460
Shortspine spiny dogfish	*Squalus mitsukurii*	150-600
Sixgill sawshark	*Pliotrema warreni*	60-500
Goblin shark	*Mitsukurina owstoni*	270-960
Smalleye catshark	*Apristurus microps*	700-1,000
Saldanha catshark	*Apristurus saldanha*	450-765
"grey/black wonder" catsharks	*Apristurus* spp.	670-1,005
Tigar catshark	*Halaelurus natalensis*	50-100
Izak catshark	*Holohalaelurus regani*	100-500
Yellowspotted catshark	*Scyliorhinus capensis*	150-500
Soupfin shark/Vaalhaai	*Galeorhinus galeus*	<10-300
Houndshark	*Mustelus mustelus*	<100
Whitespotted houndshark	*Mustelus palumbes*	>350
Little guitarfish	*Rhinobatos annulatus*	>100
Atlantic electric ray	*Torpedo nobiliana*	120-450
African softnose skate	*Bathyraja smithii*	400-1,020
Smoothnose legskate	*Cruriraja durbanensis*	>1,000
Roughnose legskate	*Crurirajaparcomaculata*	150-620
African dwarf skate	*Neoraja stehmanni*	290-1,025

Common Name	Scientific name	Depth Range (m)
Thorny skate	*Raja radiata*	50-600
Bigmouth skate	*Raja robertsi*	>1,000
Slime skate	*Raja pullopunctatus*	15-460
Rough-belly skate	*Raja springeri*	85-500
Yellowspot skate	*Raja wallacei*	70-500
Roughskin skate	*Raja spinacidermis*	1,000-1,350
Biscuit skate	*Raja clavata*	25-500
Munchkin skate	*Raja caudaspinosa*	300-520
Bigthorn skate	*Raja confundens*	100-800
Ghost skate	*Raja dissimilis*	420-1,005
Leopard skate	*Raja leopardus*	300-1,000
Smoothback skate	*Raja ravidula*	500-1,000
Spearnose skate	*Raja alba*	75-260
St Joseph	*Callorhinchus capensis*	30-380
Cape chimaera	*Chimaera* sp.	680-1,000
Brown chimaera	*Hydrolagus* sp.	420-850
Spearnose chimaera	Rhinochimaera atlantica	650-960

3.3.2 Seamount Communities

Two geological features of note in the vicinity of the proposed area of interest are Child's Bank, situated ~75 km due east of the principal project target area at about 31°S, and Tripp Seamount situated at about 29°40'S, ~120 km north-northwest of the principal project target area. Child's Bank was described by Dingle *et al.* (1987) to be a carbonate mound (bioherm). Composed of sediments and the calcareous deposits from an accumulation of carbonate skeletons of sessile organisms (e.g. cold-water coral, foraminifera or marl), such features typically have topographic relief, forming isolated seabed knolls in otherwise low profile homogenous seabed habitats (Kopaska-Merkel & Haywick 2001; Kenyon *et al*. 2003, Wheeler *et al.* 2005, Colman *et al*. 2005). Features such as banks, knolls and seamounts (referred to collectively here as "seamounts"), which protrude into the water column, are subject to, and interact with, the water currents surrounding them. The effects of such seabed features on the surrounding water masses can include the up-welling of relatively cool, nutrient-rich water into nutrient-poor surface water thereby resulting in higher productivity (Clark *et al.* 1999), which can in turn strongly influences the distribution of organisms on and around seamounts. Evidence of enrichment of bottom-associated communities and high abundances of demersal fishes has been regularly reported over such seabed features.

The enhanced fluxes of detritus and plankton that develop in response to the complex current regimes lead to the development of detritivore-based food-webs, which in turn lead to the presence of seamount scavengers and predators. Seamounts provide an important habitat for commercial deepwater fish stocks such as orange roughy, oreos, alfonsino and Patagonian toothfish, which aggregate around these features for either spawning or feeding (Koslow 1996).

Such complex benthic ecosystems in turn enhance foraging opportunities for many other predators, serving as mid-ocean focal points for a variety of pelagic species with large ranges (turtles, tunas and billfish, pelagic sharks, cetaceans and pelagic seabirds) that may migrate large distances in search of food or may only congregate on seamounts at certain times (Hui 1985; Haney *et al.* 1995). Seamounts thus serve as feeding grounds, spawning and nursery grounds and possibly navigational markers for a large number of species (SPRFMA 2007).

Enhanced currents, steep slopes and volcanic rocky substrata, in combination with locally generated detritus, favour the development of suspension feeders in the benthic communities characterising seamounts (Rogers 1994). Deep- and cold-water corals (including stony corals, black corals and soft corals) (Figure 17, left) are a prominent component of the suspension-feeding fauna of many seamounts, accompanied by barnacles, bryozoans, polychaetes, molluscs, sponges, sea squirts, basket stars, brittle stars and crinoids (reviewed in Rogers 2004). There is also associated mobile benthic fauna that includes echinoderms (sea urchins and sea cucumbers) and crustaceans (crabs and lobsters) (reviewed by Rogers 1994; Kenyon *et al.* 2003). Some of the smaller cnidarians species remain solitary while others form reefs thereby adding structural complexity to otherwise uniform seabed habitats. The coral frameworks offer refugia for a great variety of invertebrates and fish (including commercially important species) within, or in association with, the living and dead coral framework (Figure 17, right) thereby creating spatially fragmented areas of high biological diversity. Compared to the surrounding deep-sea environment, seamounts typically form biological hotspots with a distinct, abundant and diverse fauna, many species of which remain unidentified. Consequently, the fauna of seamounts is usually highly unique and may have a limited distribution restricted to a single geographic region, a seamount chain or even a single seamount location (Rogers *et al.* 2008). Levels of endemism on seamounts are also relatively high compared to the deep sea. As a result of conservative life histories (*i.e.* very slow growing, slow to mature, high longevity, low levels of recruitment) and sensitivity to changes in environmental conditions, such biological communities have been identified as Vulnerable Marine Ecosystems (VMEs). They are recognised as being particularly sensitive to anthropogenic disturbance (primarily deep-water trawl fisheries and mining), and once damaged are very slow to recover, or may never recover (FAO 2008).

It is not always the case that seamount habitats are VMEs, as some seamounts may not host communities of fragile animals or be associated with high levels of endemism. South Africa's seamounts and their associated benthic communities have not been extensively sampled by either geologists or biologists (Sink & Samaai 2009). Evidence from video footage taken on hard-substrate habitats in 100 - 120 m depth off southern Namibia and to the south-east of Child's Bank (De Beers Marine, unpublished data) (Figure 18) suggest that vulnerable communities including gorgonians, octocorals and reef-building sponges do occur on the continental shelf. Whether similar communities may thus be expected in the Orange Basin Deep Water Licence Area is, however, unknown.

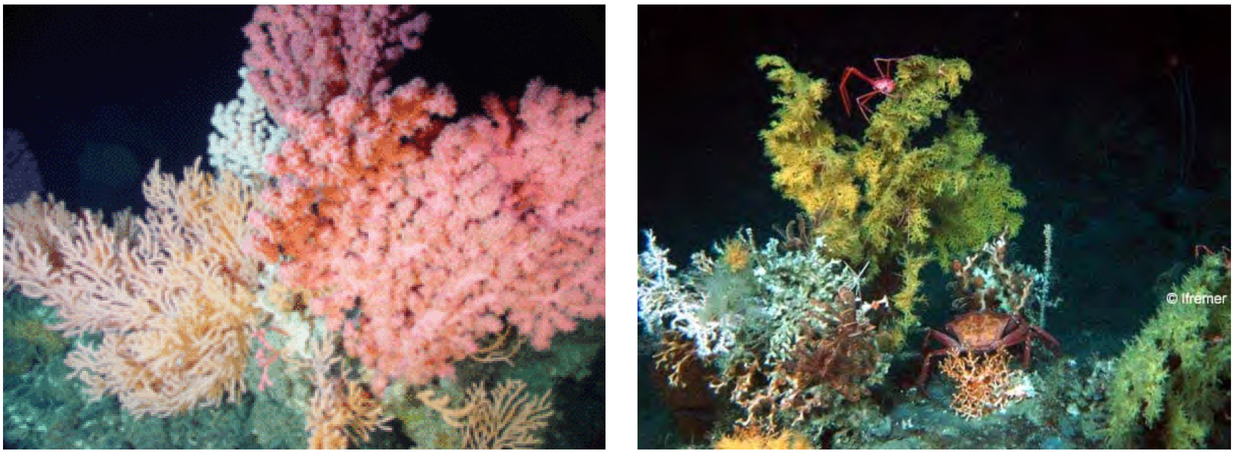


Figure 17: Seamounts are characterised by a diversity of deep-water corals that add structural complexity to seabed habitats and offer refugia for a variety of invertebrates and fish (Photos: www.dfo-mpo.gc.ca/science/Publications/article/2007/21-05-2007-eng.htm, Ifremer & AWI 2003).

Figure 18: Gorgonians and bryozoans communities recorded on deep-water reefs (100-120 m) off the southern African West Coast (Photos: De Beers Marine).

Sediment samples collected at the base of Norwegian cold-water coral reefs revealed high interstitial concentrations of light hydrocarbons (methane, propane, ethane and higher hydrocarbons C4+) (Hovland & Thomsen 1997), which are typically considered indicative of localised light hydrocarbon micro-seepage through the seabed. Bacteria and other micro-organisms thrive on such hydrocarbon pore-water seepages, thereby providing suspension-feeders, including corals and gorgonians, with a substantial nutrient source. Some scientists believe there is a strong correlation between the occurrence of deep-water coral reefs and the relatively high values of light hydrocarbons (methane, ethane, propane and n-butane) in near-surface sediments (Hovland *et al*. 1998, Duncan & Roberts 2001, Hall-Spencer *et al*. 2002, Roberts & Gage 2003).

3.3.3 Pelagic Communities

In contrast to demersal and benthic biota that are associated with the seabed, pelagic species live and feed in the open water column. The pelagic communities are typically divided into plankton and fish, and their main predators, marine mammals (seals, dolphins and whales), seabirds and turtles. These are discussed separately below. Noteworthy is that the marine component of the 2011 National Biodiversity Assessment (Sink *et al*. 2012), rated the majority of the offshore pelagic habitat types that characterise depths beyond 500 m, as 'least threatened' (see Figure 16, right), with only a narrow band along the shelf break of the West Coast being rated as 'vulnerable', primarily due to its importance as a migration pathway for various resource species (e.g. whales, tuna, billfish, turtles).

3.3.3.1 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 include bacterio-plankton, phytoplankton, zooplankton, and ichthyoplankton (Figure 19).

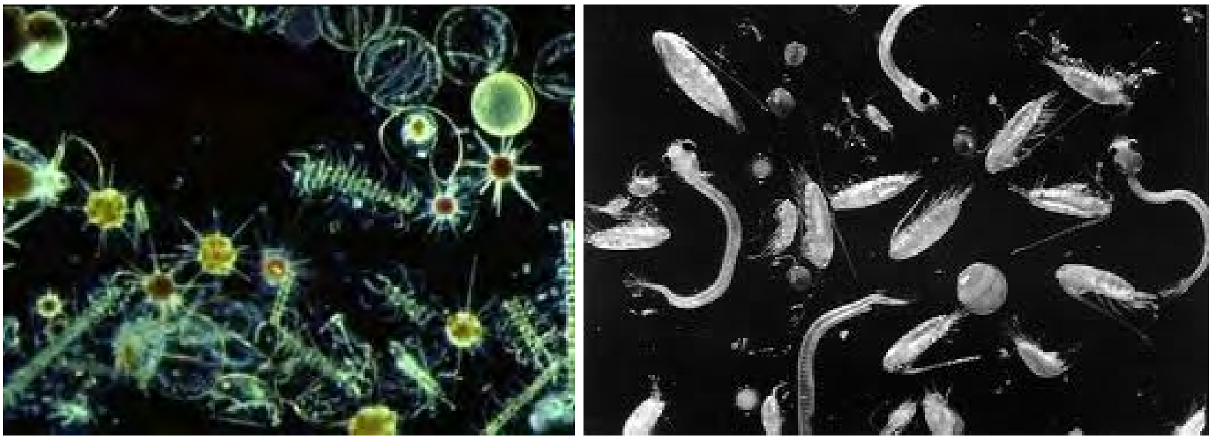


Figure 19: Phytoplankton (left, photo: hymagazine.com) and zooplankton (right, photo: mysciencebox.org) is associated with upwelling cells.

Phytoplankton are the principle primary producers with mean productivity ranging from 2.5 - 3.5 g C/m^2/day for the midshelf region and decreasing to 1 g C/m^2/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*, *Nitschia*, *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.

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. They are unlikely to occur in the offshore regions of the project area.

The mesozooplankton (≥200 µm) is dominated by copepods, which are overall the most dominant and diverse group in southern African zooplankton. Important species are *Centropages brachiatus*, *Calanoides carinatus*, *Metridia lucens*, *Nannocalanus minor*, *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 (≥1,600 µm) 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^2, with maximum values recorded during upwelling periods. Macrozooplankton biomass ranges from 0.1-1.0 g C/m^2, 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) (see Figure 20), and their eggs and larvae form an important contribution to the ichthyoplankton in the region. Ichthyoplankton abundance in the offshore oceanic waters of the proposed area of interest are, however, expected to be low.

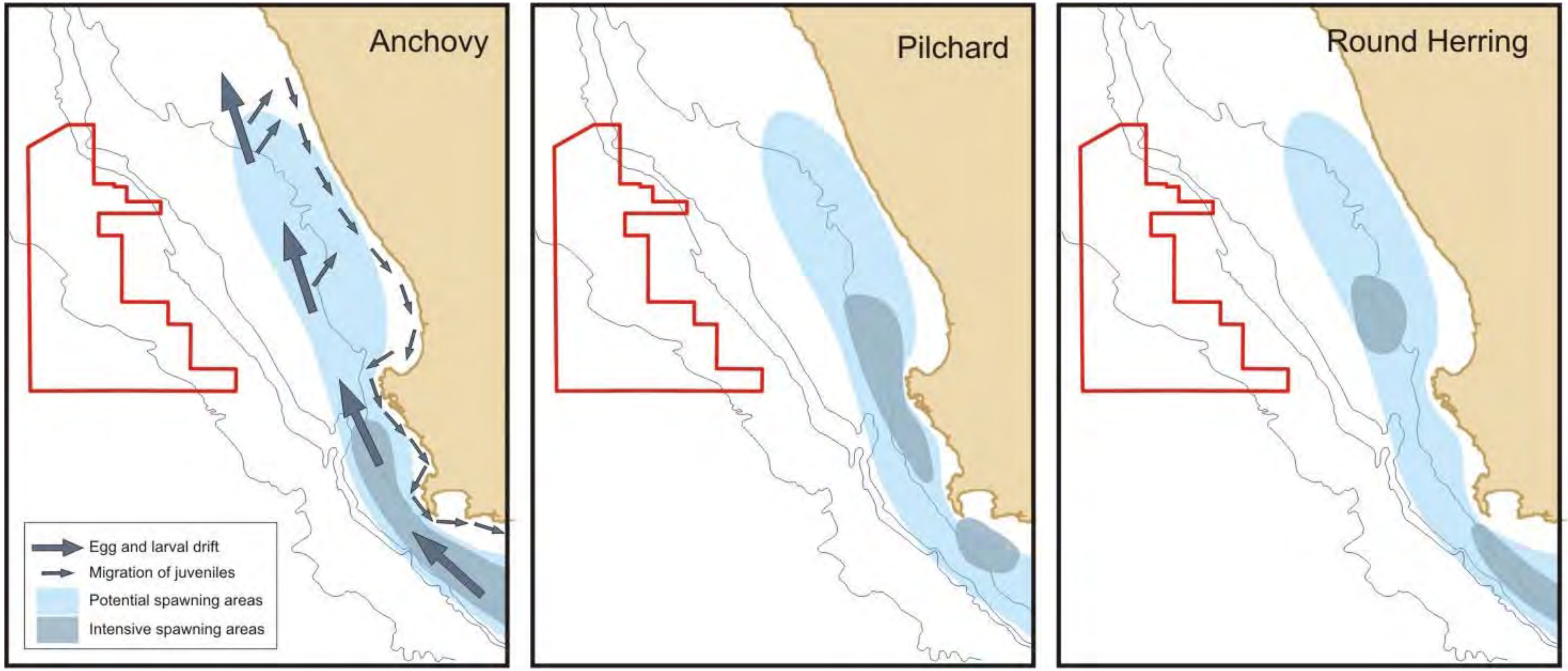


Figure 20: Major spawning areas in the southern Benguela region in relation to the licence area (red polygon) (adapted from Cruikshank 1990).

3.3.3.2 Cephalopods

Fourteen species of cephalopds have been recorded in the southern Benguela, the majority of which are sepiods/cuttlefish (Lipinski 1992; Augustyn *et al.* 1995). Most of the cephalopod resource is distributed on the mid-shelf with *Sepia australis* being most abundant at depths between 60-190 m, whereas *S. hieronis* densities were higher at depths between 110-250 m. *Rossia enigmatica* occurs more commonly on the edge of the shelf to depths of 500 m. Biomass of these species was generally higher in the summer than in winter.

Cuttlefish are largely epi-benthic and occur on mud and fine sediments in association with their major prey item; mantis shrimps (Augustyn *et al.* 1995). They form an important food item for demersal fish.

3.3.3.3 Pelagic Fish

Small pelagic species include the sardine/pilchard (*Sadinops ocellatus*) (Figure 21, left), anchovy (*Engraulis capensis*), chub mackerel (*Scomber japonicus*), horse mackerel (*Trachurus capensis*) (Figure 21, right) and round herring (*Etrumeus whiteheadi*). These species typically occur in mixed shoals of various sizes (Crawford *et al*. 1987), and generally occur within the 200 m contour and thus unlikely to be encountered in the project area (this is confirmed by the CapFish 2013 - Fisheries Specialist Study). Most of the pelagic species exhibit similar life history patterns involving seasonal migrations between the west and south coasts. The spawning areas of the major pelagic species are distributed on the continental shelf and along the shelf edge extending from south of St Helena Bay to Mossel Bay on the South Coast (Shannon & Pillar 1986) (see Figure 15). They spawn downstream of major upwelling centres in spring and summer, and their eggs and larvae are subsequently carried around Cape Point and up the coast in northward flowing surface waters.

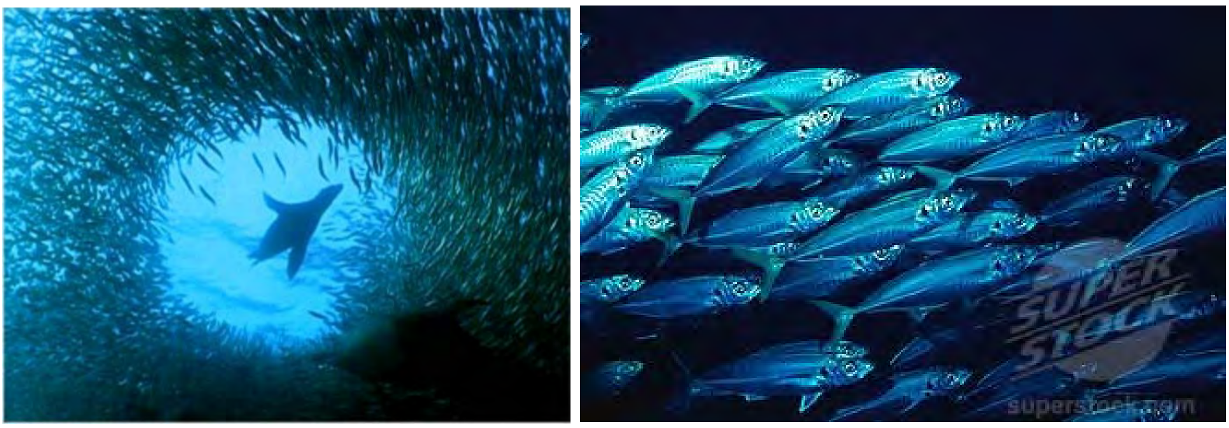


Figure 21: Cape fur seal preying on a shoal of pilchards (left). School of horse mackerel (right) (photos: www.underwatervideo.co.za; www.delivery.superstock.com).

At the start of winter every year, juveniles of most small pelagic shoaling species recruit into coastal waters in large numbers between the Orange River and Cape Columbine. They recruit in the pelagic stage, across broad stretches of the shelf, to utilise the shallow shelf region as nursery grounds before gradually moving southwards in the inshore southerly flowing surface current, towards the major spawning grounds east of Cape Point. Recruitment success relies on the interaction of oceanographic events, and is thus subject to spatial and temporal variability. Consequently, the abundance of adults and juveniles of these small, short-lived (1-3 years) pelagic fish is highly variable both within and between species.

Two species that migrate along the West Coast following the shoals of anchovy and pilchards are snoek *Thyrsites atun* and chub mackerel *Scomber japonicas*. Their appearance along the West and South-West coasts are highly seasonal. Snoek migrating along the southern African West Coast reach the area between St Helena Bay and the Cape Peninsula between May and August. They spawn in these waters between July and October before moving offshore and commencing their return northward migration (Payne & Crawford 1989). They are voracious predators occurring throughout the water column, feeding on both demersal and pelagic invertebrates and fish. Chub mackerel similarly migrate along the southern African West Coast reaching South-Western Cape waters between April and August. They move inshore in June and July to spawn before starting the return northwards offshore migration later in the year. Their abundance and seasonal migrations are thought to be related to the availability of their shoaling prey species (Payne & Crawford 1989).

Large pelagic species include tunas, billfish and pelagic sharks, which migrate throughout the southern oceans, between surface and deep waters (>300 m) and have a highly seasonal abundance in the Benguela. Species occurring off western southern Africa include the albacore/longfin tuna *Thunnus alalunga* (Figure 22, right), yellowfin *T. albacares*, bigeye *T. obesus*, and skipjack *Katsuwonus pelamis tunas*, as well as the Atlantic blue marlin *Makaira nigricans* (Figure 22, left), the white marlin *Tetrapturus albidus* and the broadbill swordfish *Xiphias gladius* (Payne & Crawford 1989). The distributions of these species is dependent on food availability in the mixed boundary layer between the Benguela and warm central Atlantic waters. Concentrations of large pelagic species are also known to occur associated with underwater feature such as canyons and seamounts as well as meteorologically induced oceanic fronts (Penney *et al.* 1992).

Figure 22: Large migratory pelagic fish such as blue marlin (left) and longfin tuna (right) occur in offshore waters (photos: www.samathatours.com; www.osfimages.com).

A number of species of pelagic sharks are also known to occur on the West and South-West Coast, including blue *Prionace glauca*, short-fin mako *Isurus oxyrinchus* and oceanic whitetip sharks *Carcharhinus longimanus*. Occurring throughout the world in warm temperate waters, these species are usually found further offshore on the West Coast. Great whites *Carcharodon carcharias* and whale sharks *Rhincodon typus* may also be encountered in coastal and offshore areas, although the latter occurs more frequently along the South and East coasts. Of these the blue shark is listed as "Near threatened", and the short-fin mako, whitetip, great white and whale sharks as "Vulnerable" on the International Union for Conservation of Nature (IUCN).

3.3.3.4 Turtles

Three species of turtle occur along the West Coast, namely the Leatherback (*Dermochelys coriacea*) (Figure 23, left), and occasionally the Loggerhead (*Caretta caretta*) (Figure 23, right) and the Green (*Chelonia mydas*) turtle. Loggerhead and Green turtles are expected to occur only as occasional visitors along the West Coast.

Figure 23: Leatherback (left) and loggerhead turtles (right) occur along the West Coast of Southern Africa (Photos: Ketos Ecology 2009; www.aquaworld-crete.com).

The Leatherback is the only turtle likely to be encountered in the offshore waters of west South Africa. The Benguela ecosystem, especially the northern Benguela where jelly fish numbers are high, is increasingly being recognized as a potentially important feeding area for leatherback turtles from several globally significant nesting populations in the south Atlantic (Gabon, Brazil) and south east Indian Ocean (South Africa) (Lambardi *et al*. 2008, Elwen & Leeney 2011; SASTN 2011[1]). Leatherback turtles from the east South Africa population have been satellite tracked swimming around the west coast of South Africa and remaining in the warmer waters west of the Benguela ecosystem (Lambardi *et al*. 2008) (Figure 24).

[1] *SASTN Meeting – Second meeting of the South Atlantic Sea Turtle Network, Swakopmund, Namibia, 24-30 July 2011.*

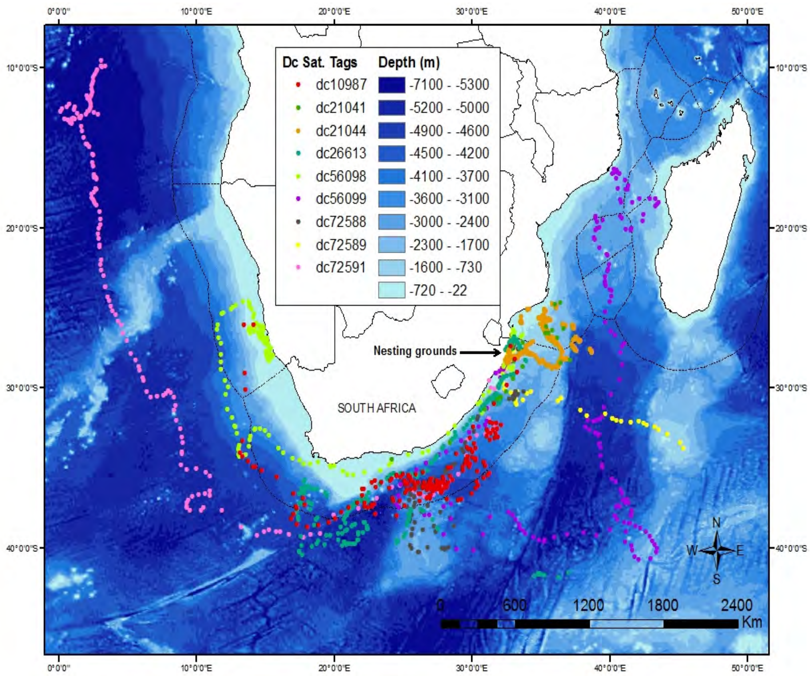


Figure 24: The post-nesting distribution of nine satellite tagged leatherback females (1996 – 2006; Oceans and Coast, unpublished data).

Leatherback turtles inhabit deeper waters and are considered a pelagic species, travelling the ocean currents in search of their prey (primarily jellyfish). While hunting they may dive to over 600 m and remain submerged for up to 54 minutes (Hays *et al*. 2004). Their abundance in the study area is unknown but expected to be low. Leatherbacks feed on jellyfish and are known to have mistaken plastic marine debris for their natural food. Ingesting this can obstruct the gut, lead to absorption of toxins and reduce the absorption of nutrients from their real food. Leatherback Turtles are listed as "Critically Endangered" worldwide by the IUCN and are in the highest categories in terms of need for conservation in CITES (Convention on International Trade in Endangered Species), and CMS (Convention on Migratory Species). Loggerhead and green turtles are listed as "Endangered". As a signatory of CMS, South Africa has endorsed and signed a CMS International Memorandum of Understanding specific to the conservation of marine turtles. South Africa is thus committed to conserve these species at an international level.

3.3.3.5 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 18 species classified as being common in the southern Benguela are listed in Table 5. 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. Most of the species in the region reach highest densities offshore of the shelf break (200 – 500 m depth), well inshore of the proposed area of interest, with highest population levels during their non-breeding season (winter). Pintado petrels and Prion spp. show the most marked variation here.

14 species of seabirds breed in southern Africa; Cape Gannet (Figure 25, left), African Penguin (Figure 25, right), four species of Cormorant, White Pelican, three Gull and four Tern species (Table 6). The breeding areas are distributed around the coast with islands being especially important. The closest breeding islands to the project area are Bird Island at Lambert's Bay, ~370 km southeast of the area of interest, and Sinclair Island ~280 km to the north in Namibia. The number of successfully breeding birds at the particular breeding sites varies with food abundance. Most of the breeding seabird species forage at sea with most birds being found relatively close inshore (10-30 km). Cape Gannets, however, are known to forage up to 140 km offshore (Dundee 2006; Ludynia 2007), and African Penguins have also been recorded as far as 60 km offshore.

Table 5: Pelagic seabirds common in the southern Benguela region (Crawford *et al*. 1991).

Common Name	Species name	Global IUCN
Shy albatross	*Thalassarche cauta*	Near Threatened
Black browed albatross	*Thalassarche melanophrys*	Endangered[1]
Yellow nosed albatross	*Thalassarche chlororhynchos*	Endangered
Giant petrel sp.	*Macronectes halli/giganteus*	Near Threatened
Pintado petrel	*Daption capense*	Least concern
Greatwinged petrel	*Pterodroma macroptera*	Least concern
Soft plumaged petrel	*Pterodroma mollis*	Least concern
Prion spp	*Pachyptila* spp.	Least concern
White chinned petrel	*Procellaria aequinoctialis*	Vulnerable
Cory's shearwater	*Calonectris diomedea*	Least concern
Great shearwater	*Puffinus gravis*	Least concern
Sooty shearwater	*Puffinus griseus*	Near Threatened
European Storm petrel	*Hydrobates pelagicus*	Least concern
Leach's storm petrel	*Oceanodroma leucorhoa*	Least concern
Wilson's storm petrel	*Oceanites oceanicus*	Least concern
Blackbellied storm petrel	*Fregetta tropica*	Least concern
Skua spp.	*Catharacta/Stercorarius* spp.	Least concern
Sabine's gull	*Larus sabini*	Least concern

[1]. May move to Critically Endangered if mortality from long-lining does not decrease.

Figure 25: Cape Gannets *Morus capensis* (left) (Photo: NACOMA) and African Penguins *Spheniscus demersus* (right) (Photo: Klaus Jost) breed primarily on the offshore Islands.

Table 6: Breeding resident seabirds present along the West Coast (CCA & CMS 2001).

Common name	Species name	Global IUCN Status
African Penguin	*Spheniscus demersus*	Vulnerable
Great Cormorant	*Phalacrocorax carbo*	Least Concern
Cape Cormorant	*Phalacrocorax capensis*	Near Threatened
Bank Cormorant	*Phalacrocorax neglectus*	Endangered
Crowned Cormorant	*Phalacrocorax coronatus*	Least Concern
White Pelican	*Pelecanus onocrotalus*	Least Concern
Cape Gannet	*Morus capensis*	Vulnerable
Kelp Gull	*Larus dominicanus*	Least Concern
Greyheaded Gull	*Larus cirrocephalus*	Least Concern
Hartlaub's Gull	*Larus hartlaubii*	Least Concern
Caspian Tern	*Hydroprogne caspia*	Vulnerable
Swift Tern	*Sterna bergii*	Least Concern
Roseate Tern	*Sterna dougallii*	Least Concern
Damara Tern	*Sterna balaenarum*	Near Threatened

3.3.3.6 Marine Mammals

The marine mammal fauna occurring off the southern African coast includes several species of whales and dolphins and one resident seal species. Thirty three species of whales and dolphins are known (based on historic sightings or strandings records) or likely (based on habitat projections of known species parameters) to occur in these waters (Table 7). The offshore areas have been particularly poorly studied with almost all available information from deeper waters (>200 m) arising from historic whaling records prior to 1970. Current information on the distribution, population sizes and trends of most cetacean species occurring on the west coast of southern Africa is lacking. Information on smaller cetaceans in deeper waters is particularly poor and the precautionary principal must be used when considering possible encounters with cetaceans in this area.

Records from stranded specimens show that the area between St Helena Bay (~32° S) and Cape Agulhas (~34° S, 20° E) is an area of transition between Atlantic and Indian Ocean species, as well as those more commonly associated with colder waters of the west coast (e.g. dusky dolphins and long finned pilot whales) and those of the warmer east coast (e.g. striped and Risso's dolphins) (Findlay *et al*. 1992). The project area lies north of this transition zone and can be considered to be truly on the 'west coast'. However, the warmer waters that occur offshore of the Benguela ecosystem (more than ~100 km offshore) provide an entirely different habitat, that despite the relatively high latitude may host some species associated with the more tropical and temperate parts of the Atlantic such as rough toothed dolphins, Pan-tropical spotted dolphins and short finned pilot whales. Owing to the uncertainty of species occurrence offshore, species that may occur there have been included here for the sake of completeness.

The distribution of cetaceans can largely be split into those associated with the continental shelf and those that occur in deep, oceanic water. Importantly, species from both environments may be found on the continental slope (200 – 2,000 m) making this the most species rich area for cetaceans. Cetacean density on the continental shelf is usually higher than in pelagic waters as species associated with the pelagic environment tend to be wide ranging across 1,000s of km. As the project target area is located on the continental slope, cetacean diversity in the area can be expected to be high, although abundances will be low compared to further inshore on the shelf. The most common species within the project area (in terms of likely encounter rate not total population sizes) are likely to be the long-finned pilot whale and humpback whale.

Cetaceans are comprised of two taxonomic groups, the mysticetes (filter feeders with baleen) and the odontocetes (predatory whales and dolphins with teeth). The term 'whale' is used to describe species in both groups and is taxonomically meaningless (e.g. the killer whale and pilot whale are members of the Odontoceti, family Delphinidae and are thus dolphins). Due to differences in sociality, communication abilities, ranging behavior and acoustic behavior, these two groups are considered separately.

Table 7 lists the cetaceans likely to be found within the project area, based on data sourced from: Findlay *et al.* (1992), Best (2007), Weir (2011), Dr J-P. Roux, (MFMR pers. comm.) and unpublished records held by the Namibian Dolphin Project. Of the 33 species listed, three are endangered and one is considered vulnerable (IUCN Red Data list Categories). Altogether 17 species are listed as "data deficient" underlining how little is known about cetaceans, their distributions and population trends. The majority of data available on the seasonality and distribution of large whales in the project area is the result of commercial whaling activities mostly dating from the 1960s. Changes in the timing and distribution of migration may have occurred since these data were collected due to extirpation of populations or behaviours (e.g. migration routes may be learnt behaviours). The large whale species for which there are current data available are the humpback and southern right whale, although almost all data is limited to that collected on the continental shelf close to shore.

Table 7: Cetaceans occurrence off the West Coast of South Africa, their seasonality, likely encounter frequency with proposed exploration drilling operations and IUCN conservation status.

Common Name	Species	Shelf	Offshore	Seasonality	Likely encounter frequency	IUCN Conservation Status
Delphinids						
Dusky dolphin	*Lagenorhynchus obscurus*	Yes (0- 800 m)	No	Year round	Daily	Data Deficient
Heaviside's dolphin	*Cephalorhynchus heavisidii*	Yes (0-200 m)	No	Year round	Daily	Data Deficient
Common bottlenose dolphin	*Tursiops truncatus*	Yes	Yes	Year round	Monthly	Least Concern
Common (short beaked) dolphin	*Delphinus delphis*	Yes	Yes	Year round	Monthly	Least Concern
Southern right whale dolphin	*Lissodelphis peronii*	Yes	Yes	Year round	Occasional	Data Deficient
Striped dolphin	*Stenella coeruleoalba*	No	?	?	Very rare	Least Concern
Pantropical spotted dolphin	*Stenella attenuata*	Edge	Yes	Year round	Very rare	Least Concern
Long-finned pilot whale	*Globicephala melas*	Edge	Yes	Year round	<Weekly	Data Deficient
Short-finned pilot whale	*Globicephala macrorhynchus*	?	?	?	Very rare	Data Deficient
Rough-toothed dolphin	*Steno bredanensis*	?	?	?	Very rare	Least Concern
Killer whale	*Orcinus orca*	Occasional	Yes	Year round	Occasional	Data Deficient
False killer whale	*Pseudorca crassidens*	Occasional	Yes	Year round	Monthly	Data Deficient
Pygmy killer whale	*Feresa attenuata*	?	Yes	?	Occasional	Least Concern
Risso's dolphin	*Grampus griseus*	Yes (edge)	Yes	?	Occasional	Data Deficient
Sperm whales						
Pygmy sperm whale	*Kogia breviceps*	Edge	Yes	Year round	Occasional	Data Deficient
Dwarf sperm whale	*Kogia sima*	Edge	?	?	Very rare	Data Deficient
Sperm whale	*Physeter macrocephalus*	Edge	Yes	Year round	Occasional	Vulnerable

Common Name	Species	Shelf	Offshore	Seasonality	Likely encounter frequency	IUCN Conservation Status
Beaked whales						
Cuvier's	*Ziphius cavirostris*	No	Yes	Year round	Occasional	Least Concern
Arnoux's	*Beradius arnouxii*	No	Yes	Year round	Occasional	Data Deficient
Southern bottlenose	*Hyperoodon planifrons*	No	Yes	Year round	Occasional	Not assessed
Layard's	*Mesoplodon layardii*	No	Yes	Year round	Occasional	Data Deficient
True's	*M. mirus*	No	Yes	Year round		Data Deficient
Gray's	*M. grayi*	No	Yes	Year round	Occasional	Data Deficient
Blainville's	*M. densirostris*	No	Yes	Year round		Data Deficient
Baleen whales						
Antarctic Minke	*Balaenoptera bonaerensis*	Yes	Yes	>Winter	Monthly	Data Deficient
Dwarf minke	*B. acutorostrata*	Yes	Yes	Year round	Occasional	Least Concern
Fin whale	*B. physalus*	Yes	Yes	MJJ & ON, rarely in summer	Occasional	Endangered
Blue whale	*B. musculus*	No	Yes	?	Occasional	Endangered
Sei whale	*B. borealis*	Yes	Yes	MJ & ASO	Occasional	Endangered
Bryde's (offshore)	*B. brydei*	Yes	Yes	Summer (JF)	Occasional	Not assessed
Bryde's (inshore)	*B brydei (subspp)*	Yes	Yes	Year round	Occasional	Data Deficient
Pygmy right	*Caperea marginata*	Yes	?	Year round	Occasional	Least Concern
Humpback	*Megaptera novaeangliae*	Yes	Yes	Year round, higher in SONDJF	Daily*	Least Concern
Southern right	*Eubalaena australis*	Yes	No	Year round, higher in SONDJF	Daily*	Least Concern

A review of the distribution and seasonality of the key cetacean species likely to be found within the project area is provided below.

Mysticete (Baleen) whales

The majority of mysticetes whales fall into the family Balaenopeteridae. Those occurring in the area include the blue, fin, sei, Antarctic minke, dwarf minke, humpback and Bryde's whales. The southern right whale (Family Balaenidae) and pygmy right whale (Family Neobalaenidae) are from taxonomically separate groups. The majority of mysticete species occur in pelagic waters with only occasional visits to shelf waters. All of these species show some degree of migration either to or through the latitudes encompassed by the broader project area when *en route* between higher latitude (Antarctic or Subantarctic) feeding grounds and lower latitude breeding grounds. Depending on the ultimate location of these feeding and breeding grounds, seasonality may be either unimodal, usually in winter months, or bimodal (e.g. May to July and October to November), reflecting a northward and southward migration through the area. Northward and southward migrations may take place at different distances from the coast due to whales following geographic or oceanographic features, thereby influencing the seasonality of occurrence at different locations. Because of the complexities of the migration patterns, each species is discussed separately below.

Two genetically and morphologically distinct populations of Bryde's whales (Figure 26, left) live off the coast of southern Africa (Best 2001; Penry 2010). The "offshore population" lives beyond the shelf (>200 m depth) off west Africa and migrates between wintering grounds off equatorial west Africa (Gabon) and summering grounds off western South Africa. Its seasonality on the west coast is thus opposite to the majority of the balaenopterids with abundance likely to be highest in the broader project area in January - March. The "inshore population" of Bryde's, which lives on the continental shelf and Agulhas Bank, is unique amongst baleen whales in the region by being non-migratory. It may move further north into the Benguela current areas of the west of coast of South Africa and Namibia, especially in the winter months (Best 2007).

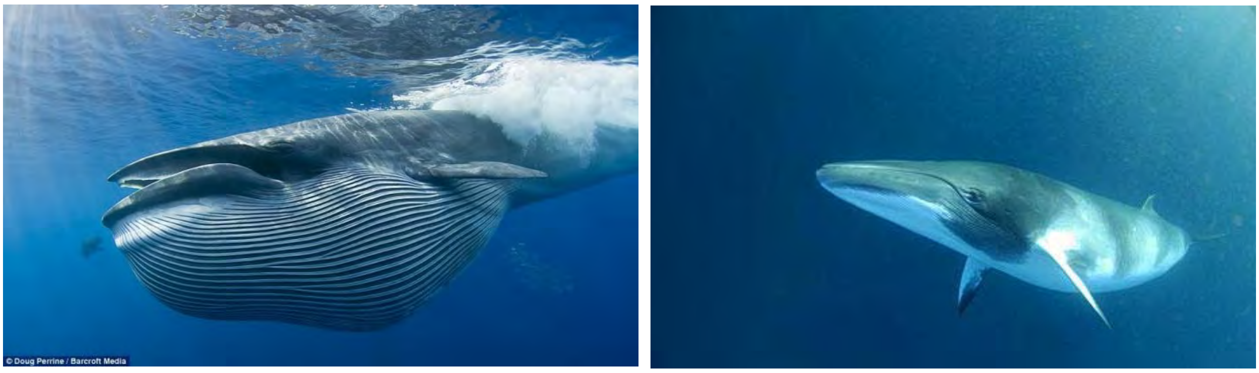


Figure 26: The Bryde's whale *Balaenoptera brydei* (left) and the Minke whale *Balaenoptera bonaerensis* (right) (Photos: www.dailymail.co.uk; www.marinebio.org).

Sei whales migrate through South African waters, where they were historically hunted in relatively high numbers, to unknown breeding grounds further north. Their migration pattern thus shows a bimodal peak with numbers west of Cape Columbine highest in May and June, and again in August, September and October. All whales were caught in waters deeper than 200 m with most deeper than 1,000 m (Best & Lockyer 2002). Almost all information is based on whaling records 1958-1963 and there is no current information on abundance or distribution patterns in the region.

Fin whales were historically caught off the West Coast of South Africa, with a bimodal peak in the catch data suggesting animals were migrating further north during May-June to breed, before returning during August-October *en route* to Antarctic feeding grounds. Some juvenile animals may feed year round in deeper waters off the shelf (Best 2007). There are no recent data on abundance or distribution of fin whales off western South Africa.

Although blue whales were historically caught in high numbers off the South African West Coast, there have been only two confirmed sightings of the species in the area since 1973 (Branch *et al*. 2007), suggesting that the population using the area may have been extirpated by whaling. However, scientific search effort (and thus information) in pelagic waters is very low. The chance of encountering the species in the proposed survey area is considered low.

Two forms of minke whale (Figure 26, right) occur in the southern Hemisphere, the Antarctic minke whale (*Balaenoptera bonaerensis*) and the dwarf minke whale (*B. acutorostrata* subsp.); both species occur in the Benguela (Best 2007). Antarctic minke whales range from the pack ice of Antarctica to tropical waters and are usually seen more than ~50 km offshore. Although adults migrate from the Southern Ocean (summer) to tropical/temperate waters (winter) to breed, some animals, especially juveniles, are known to stay in tropical/temperate waters year round. The dwarf minke whale has a more temperate distribution than the Antarctic minke and they do not range further south than 60-65°S. Dwarf minkes have a similar migration pattern to Antarctic minkes with at least some animals migrating to the Southern Ocean during summer. Dwarf minke whales occur closer to shore than Antarctic minkes. Both species are generally solitary and densities are likely to be low in the project area.

The most abundant baleen whales in the Benguela are southern right whales and humpback whales (Figure 27). In the last decade, both species have been increasingly observed to remain on the west coast of South Africa well after the 'traditional' South African whale season (June – November) into spring and early summer (October – February) where they have been observed feeding in upwelling zones, especially off Saldanha and St Helena Bay (Barendse *et al.* 2011; Mate *et al.* 2011).

Figure 27: The Humpback whale *Megaptera novaeangliae* (left) and the Southern Right whale *Eubalaena australis* (right) are the most abundant large cetaceans occurring along the southern African West Coast (Photos: www.divephotoguide.com; www.aad.gov.au).

The majority of humpback whales passing through the Benguela are migrating to breeding grounds off tropical west Africa, between Angola and the Gulf of Guinea (Rosenbaum *et al.* 2009; Barendse *et al.* 2010). In coastal waters, the northward migration stream is larger than the southward peak (Best & Allison 2010; Elwen *et al.* 2013), suggesting that animals migrating north strike the coast at varying places north of St Helena Bay, resulting in increasing whale density on shelf waters and into deeper pelagic waters as one moves northwards, but no clear migration 'corridor. On the southward migration, many humpbacks follow the Walvis Ridge offshore then head directly to high latitude feeding grounds, while others follow a more coastal route (including the majority of mother-calf pairs) possibly lingering in the feeding grounds off west South Africa in summer (Elwen *et al.* 2013, Rosenbaum *et al.* in press). Recent abundance estimates put the number of animals in the west African breeding population to be in excess of 9,000 individuals in 2005 (IWC 2012) and it is likely to have increased since this time at about 5% per annum (IWC 2012). Humpback whales are thus likely to be the most frequently encountered baleen whale in the project area, ranging from the coast out beyond the shelf, with year round presence but numbers peaking in July – February associated with the breeding migration and subsequent feeding in the Benguela.

The southern African population of southern right whales historically extended from southern Mozambique (Maputo Bay) to southern Angola (Baie dos Tigres) and is considered to be a single population within this range (Roux *et al.* 2011). The most recent abundance estimate for this population is available for 2008 which estimated the population at ~4,600 individuals including all age and sex classes, which is thought to be at least 23% of the original population size (Brandaõ *et al.* 2011). Since the population is still continuing to grow at ~7% per year (Brandaõ *et al.* 2011), the population size in 2013 would number more than 6,000 individuals. When the population numbers crashed, the range contracted down to just the south coast of South Africa, but as the population recovers, it is repopulating its historic grounds including Namibia (Roux *et al.* 2001) and Mozambique (Banks *et al.* 2011). Southern right whales are seen regularly in the nearshore waters of the West Coast (<3 km from shore), extending north into southern Namibia (Roux *et al.* 2001, 2011). Southern right whales have been recorded off the West Coast in all months of the year, but with numbers peaking in winter (June - September).

In the last decade, deviations from the predictable and seasonal migration patterns of these two species have been reported from the Cape Columbine – Yzerfontein area (Best 2007; Barendse *et al*. 2010). High abundances of both Southern Right and Humpback whales in this area during spring and summer (September-February), indicates that the upwelling zones off Saldanha and St Helena Bay may serve as an important summer feeding area (Barendse *et al.* 2011, Mate *et al*. 2011). It was previously thought that whales feed only rarely while migrating (Best *et al.* 1995), but these localised summer concentrations suggest that these whales may in fact have more flexible foraging habits.

Odontocetes (toothed) whales

The Odontoceti are a varied group of animals including the dolphins, porpoises, beaked whales and sperm whales. Species occurring within the broader project area display a diversity of features, for example their ranging patterns vary from extremely coastal and highly site specific to oceanic and wide ranging. Those in the region can range in size from 1.6-m long (Heaviside's dolphin) to 17 m (bull sperm whale).

All information about sperm whales in the southern African sub-region results from data collected during commercial whaling activities prior to 1985 (Best 2007). Sperm whales are the largest of the toothed whales and have a complex, structured social system with adult males behaving differently to younger males and female groups. They live in deep ocean waters, usually greater than 1,000 m depth, although they occasionally come onto the shelf in water 500 - 200 m deep (Best 2007) (Figure 28, left). They are considered to be relatively abundant globally (Whitehead 2002), although no estimates are available for South African waters. Seasonality of catches suggests that medium and large sized males are more abundant in winter months while female groups are more abundant in autumn (March - April), although animals occur year round (Best 2007). Sperm whales are thus likely to be encountered in relatively high numbers in deeper waters (>500 m), predominantly in the winter months (April - October). Sperm whales feed at great depths during dives in excess of 30 minutes making them difficult to detect visually, however the regular echolocation clicks made by the species when diving make them relatively easy to detect acoustically using Passive Acoustic Monitoring (PAM).

Figure 28: Sperm whales *Physeter macrocephalus* (left) and killer whales *Orcinus orca* (right) are toothed whales likely to be encountered in offshore waters (Photos: www.onpoint.wbur.org; www.wikipedia.org).

There are almost no data available on the abundance, distribution or seasonality of the smaller odontocetes (including the beaked whales and dolphins) known to occur in oceanic waters (>200 m) off the shelf of the southern African West Coast. Beaked whales are all considered to be true deep water species usually being seen in waters in excess of 1,000-2,000 m deep (see various species accounts in Best 2007). Presence in the project area may fluctuate seasonally, but insufficient data exist to define this clearly.

The genus *Kogia* currently contains two recognised species, the pygmy (*K. breviceps*) and dwarf (*K. sima*) sperm whales, both of which most frequently occur in pelagic and shelf edge waters, although their seasonality is unknown. The majority of what is known about Kogiidae whales in the southern African subregion results from studies of stranded specimens (e.g. Ross 1979; Findlay *et al.* 1992; Plön 2004; Elwen *et al.* 2013).

Killer whales (Figure 28) have a circum-global distribution being found in all oceans from the equator to the ice edge (Best 2007). Killer whales occur year round in low densities off western South Africa (Best *et al.* 2010), Namibia (Elwen & Leeney 2011) and in the Eastern Tropical Atlantic (Weir *et al.* 2010). Killer whales are found in all depths from the coast to deep open ocean environments and may thus be encountered in the project area at low levels.

The false killer whale has a tropical to temperate distribution and most sightings off southern Africa have occurred in water deeper than 1,000 m, but with a few recorded close to shore (Findlay *et al*. 1992). They usually occur in groups ranging in size from 1 - 100 animals (Best 2007). The strong bonds and matrilineal social structure of this species makes it vulnerable to mass stranding (8 instances of 4 or more animals stranding together have occurred in the western Cape, all between St Helena Bay and Cape Agulhas). There is no information on population numbers or conservation status and no evidence of seasonality in the region (Best 2007).

Long finned pilot whales display a preference for temperate waters and are usually associated with the continental shelf or deep water adjacent to it (Mate *et al.* 2005; Findlay *et al.* 1992; Weir 2011). They are regularly seen associated with the shelf edge by marine mammal observers (MMOs) and fisheries observers and researchers. The distinction between long-finned and short finned pilot whales is difficult to make at sea. As the latter are regarded as more tropical species (Best 2007), it is likely that the vast majority of pilot whales encountered in the project area will be long-finned.

The common dolphin is known to occur offshore in West Coast waters (Findlay *et al.* 1992; Best 2007), although the extent to which they occur in the project area is unknown, but likely to be low. Group sizes of common dolphins can be large, averaging 267 (± *SD* 287) for the South Africa region (Findlay *et al.* 1992). They are more frequently seen in the warmer waters offshore and to the north of the country, seasonality is not known.

In water <500 m deep, dusky dolphins (Figure 29, right) are likely to be the most frequently encountered small cetacean as they are very "boat friendly" and often approach vessels to bowride. The species is resident year round throughout the Benguela ecosystem in waters from the coast to at least 500 m deep (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 (Elwen *et al.* 2010a; NDP unpubl. data) with group sizes of up to 800 having been reported (Findlay *et al.* 1992). 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). Dusky dolphins are resident year round in the Benguela.


Figure 29: The endemic Heaviside's Dolphin *Cephalorhynchus heavisidii* (left) (Photo: De Beers Marine Namibia), and Dusky dolphin *Lagenorhynchus obscurus* (right) (Photo: scottelowitzphotography.com).

Heaviside's dolphins (Figure 29, left) are relatively abundant in the Benguela ecosystem region with 10,000 animals estimated to live in the 400 km of coast between Cape Town and Lamberts Bay (Elwen *et al.* 2009). This species occupies waters from the coast to at least 200 m depth, (Elwen *et al.* 2006; Best 2007), and 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.

Several other species of dolphins that might occur in deeper waters at low levels include the pygmy killer whale, Risso's dolphin, rough toothed dolphin, pan tropical spotted dolphin and striped dolphin (Findlay *et al.* 1992; Best 2007). Nothing is known about the population size or density of these species in the project area but encounters are likely to be rare.

Beaked whales were never targeted commercially and their pelagic distribution makes them the most poorly studied group of cetaceans. With recorded dives of well over an hour and in excess of 2 km deep, beaked whales are amongst the most extreme divers of any air breathing animals (Tyack *et al*. 2011). They also appear to be particularly vulnerable to certain types of anthropogenic noise, although reasons are not yet fully understood. All the beaked whales that may be encountered in the project area are pelagic species that tend to occur in small groups usually less than five, although larger aggregations of some species are known (MacLeod & D'Amico 2006; Best 2007).

In summary, the humpback and southern right whale are likely to be encountered year-round, with numbers in the Cape Columbine area highest between September and February, and not during winter as is common on the South Coast breeding grounds. Several other large whale species are also most abundant on the West Coast during winter: fin whales peak in May-July and October-November; sei whale numbers peak in May-June and again in August-October and offshore Bryde's whale numbers are likely to be highest in January-February. Whale numbers on the shelf and in offshore waters are thus likely to be highest between October and February.

Of the migratory cetaceans, the Blue, Sei and Humpback whales are listed as "Endangered" and the Southern Right and Fin whale as "Vulnerable" in the IUCN Red Data book. 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.

The Cape fur seal (*Arctocephalus pusillus pusillus*) (Figure 30) 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 (see Figure 31). Vagrant records from four other species of seal more usually associated with the subantarctic environment have also been recorded: southern elephant seal (*Mirounga leoninas),* subantarctic fur seal (*Arctocephalus tropicalis),* crabeater *(Lobodon carcinophagus)* and leopard seals (*Hydrurga leptonyx)* (David 1989).

There are a number of Cape fur seal colonies within the study area: at Kleinzee (incorporating Robeiland), at Bucchu Twins near Alexander Bay, and Strandfontein Point (south of Hondeklipbaai). 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 Buchu Twins, formerly a non-breeding colony, has also attained breeding status (M. Meyer, SFRI, pers. comm.). Non-breeding colonies occur south of Hondeklip Bay at Strandfontein Point and on Bird Island at Lamberts Bay, with the McDougall's Bay islands and Wedge Point being haul-out sites only and not permanently occupied by seals. All have important conservation value since they are largely undisturbed at present. Seals are highly mobile animals with a general foraging area covering the continental shelf up to 120 nautical miles offshore (Shaughnessy 1979), with bulls ranging further out to sea than females. The timing of the annual breeding cycle is very regular, occurring between November and January. Breeding success is highly dependent on the local abundance of food, territorial bulls and lactating females being most vulnerable to local fluctuations as they feed in the vicinity of the colonies prior to and after the pupping season (Oosthuizen 1991).

Figure 30: Colony of Cape fur seals *Arctocephalus pusillus pusillus* (Photo: Dirk Heinrich).

3.4. Other Uses of the Area

3.4.1 Beneficial Uses

The Orange Basin Deep Water Licence Area and area of interest are located well offshore beyond the 500 m and 1,500 m depth contour, respectively. Other users of the offshore areas include the commercial fishing industry (see CapFish 2013 – Fisheries Specialist Study), with marine diamond mining concessions being located further inshore on the continental shelf (Figure 32). Recreational use of the area of interest will be negligible due to its location offshore. The coastal area onshore of the Orange Basin Deep Water Licence Area falls within the Alexkor, De Beers Namaqualand and TransHex coastal diamond mining areas and as public access is restricted, recreational activities along the coastline between Hondeklipbaai and Alexander Bay is limited to the area around Port Nolloth.

On the Namaqualand coast marine diamond mining activity is restricted to nearshore, diver-assisted operations from small, converted fishing vessels working in the a-concessions, which extend to 1,000 m offshore of the high water mark. No deep-water diamond mining is currently underway in the South African offshore concession areas. In Namibian waters, deepwater diamond mining by De Beers Marine Namibia is currently operational in the Atlantic 1 Mining Licence Area, ~250 km to the north northeast of the project target area.

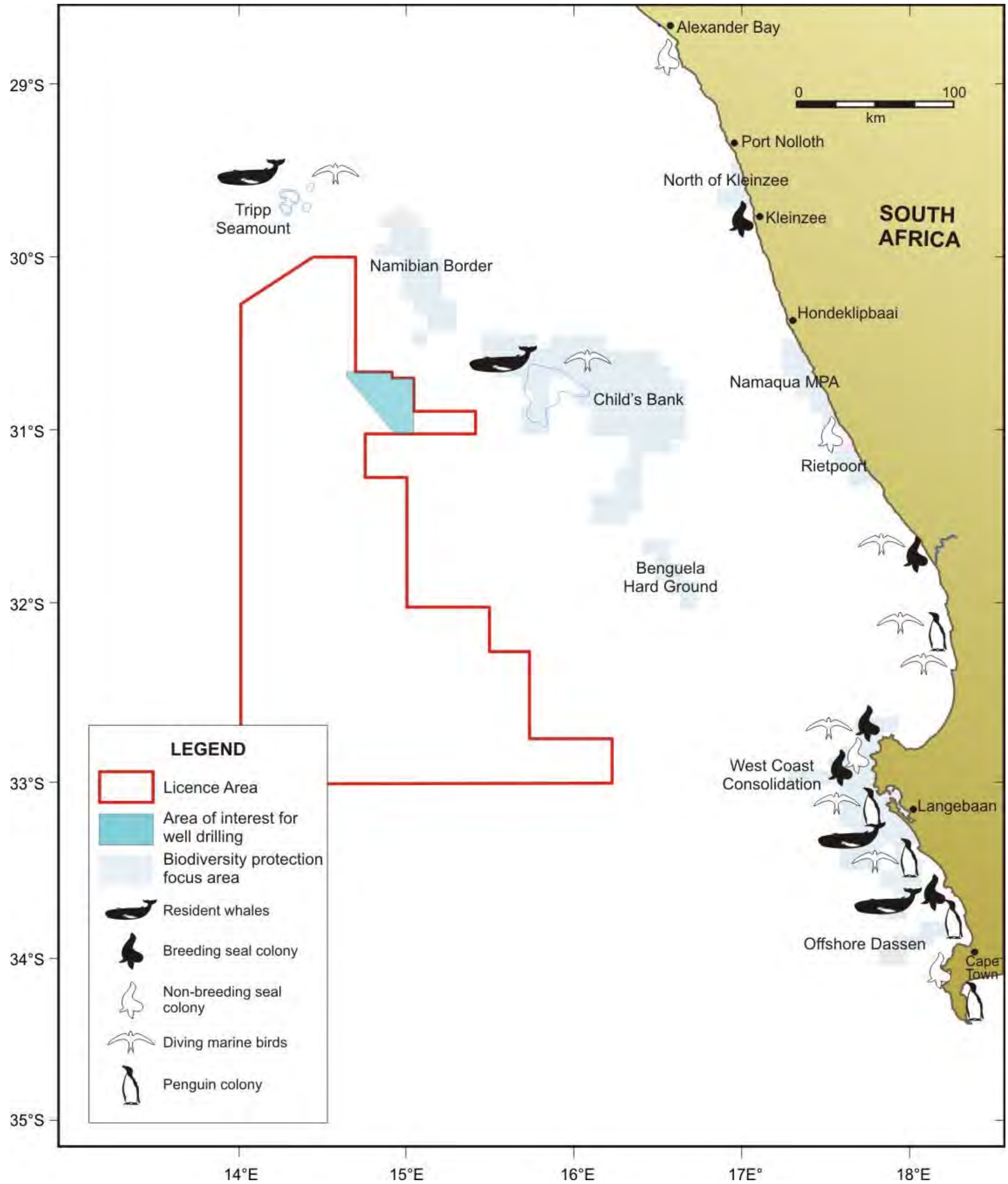


Figure 31: Project - environment interaction points on the West Coast, illustrating the location of seabird and seal colonies and resident whale populations in relation to the Orange Basin Deep Water Licence Area and the proposed area of interest. Areas identified by Majiedt *et al*. (2013) as priority areas for the protection of benthic and pelagic habitats are shaded blue.

These mining operations are typically conducted to depths of 150 m from fully self-contained mining vessels with on board processing facilities, using either large-diameter drill or seabed crawler technology. The vessels operate as semi-mobile mining platforms, anchored by a dynamic positioning system, commonly on a three to four anchor spread (Figure 33). Computer-controlled positioning winches enable the vessels to locate themselves precisely over a mining block of up to 400 m x 400 m. These mining vessels thus have limited manoeuvrability and other vessels should remain at a safe distance.

Other industrial uses of the marine environment include the intake of feed-water for mariculture, or diamond-gravel treatment. None of these activities should in any way be affected by exploration drilling activities offshore.

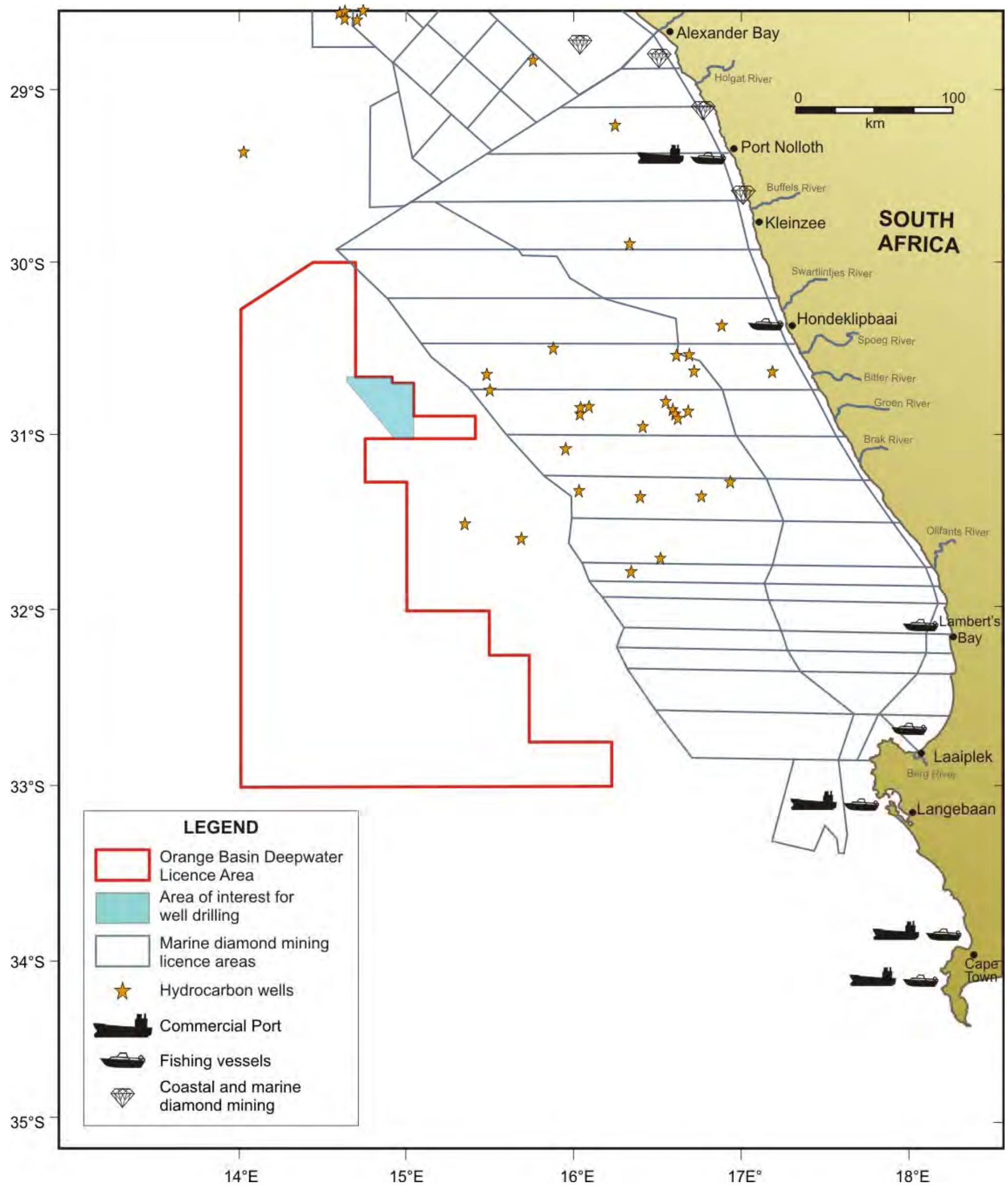


Figure 32: Project - environment interaction points on the West Coast, illustrating the location of existing hydrocarbon wells, marine diamond mining concessions and ports for commercial and fishing vessels.

Figure 33: Typical crawler-vessel (left) and drillship (right) operating in the Atlantic 1 Mining Licence Area (Photos: De Beers Marine).

3.4.2 Conservation Areas and Marine Protected Areas

Numerous conservation areas and a marine protected area (MPA) exist along the coastline of the Western Cape, although none fall within the Orange Basin Deep Water Licence Area. The only conservation area in the vicinity of the project area in which restrictions apply is the McDougall's Bay rock lobster sanctuary near Port Nolloth, which is closed to commercial exploitation of rock lobsters.

'No-take' MPAs offering protection of the Namaqua biozones (sub-photic, deep-photic, shallow-photic, intertidal and supratidal zones) are absent northwards from Cape Columbine (Emanuel *et al*. 1992, Lombard *et al*. 2004). This has resulted in substantial portions of the coastal and shelf-edge marine biodiversity in the area being assigned a threat status of 'critically endangered', 'endangered' or 'vulnerable' (Lombard *et al*. 2004; Sink *et al*. 2012) (see Figure 16). Using biodiversity data mapped for the 2004 and 2011 National Biodiversity Assessments a systematic biodiversity plan has been developed for the West Coast (Majiedt *et al*. 2013) with the objective of identifying both coastal and offshore priority areas for MPA expansion. To this end, nine focus areas have been identified for protection on the West Coast between Cape Agulhas and the South African – Namibian border. Those within the broad project area are shown in Figure 31.

The Orange River Mouth wetland located ~250 km to the northeast of the project target area provides an important habitat for large numbers of a great diversity of wetland birds and is listed as a Global Important Bird Area (IBA) (ZA023/NA 019)(BirdLife International 2005). The area was designated a Ramsar site in June 1991, and processes are underway to declare a jointly-managed transboundary Ramsar reserve. Further IBAs in the general project area include the Olifants River Estuary (ZA078), Verlorenvlei (ZA082), the Lower Berg River wetlands (ZA083) and the West Coast National Park and Saldanha Bay Islands (ZA 084).

There are also various conservation areas in southern Namibia, which need to be considered here, as they fall within the area potentially affected in the event of an unlikely major oil spill (Figure 34). The Sperrgebiet, which covers an area of approximately 26,000 km^2 between the Orange River in the south and latitude 26° in the north, extends inland from the coast for 100 km. The Sperrgebiet was proclaimed in 1908 to prevent public access to the rich surface diamond deposits occurring in the area, and has largely remained closed off to general public access since then. However, as diamond mining has remained confined to the narrow coastal strip and along the banks of the Orange River, most of the area has effectively been preserved as a pristine wilderness. Although large parts of the Sperrgebiet have now reverted to unproclaimed State land, most of the area is not yet formally managed as a conservation area. The southern boundary of the Sperrgebiet is located at Oranjemund ~250 km northeast of the project target area.

The first Namibian MPA was launched on 2 July 2009 under the Namibian Marine Resources Act (No. 29 of 1992 and No. 27 of 2000), with the purpose of protecting sensitive ecosystems and breeding and foraging areas for seabirds and marine mammals, as well as protecting important spawning and nursery grounds for fish and other marine resources (such as rock lobster). The MPA comprises a coastal strip extending from Chamais Bay (27º57'S) in the south to Hollamsbird Island (24º38'S) in the north, has an average width of 30 km and includes 16 specified offshore islands, islets and rocks (Currie *et al.* 2008). The Namibian Islands' MPA spans an area of 9,555 km^2, and includes a rock-lobster sanctuary constituting 478 km^2 between Chameis Bay and Prince of Wales Bay. The offshore islands, whose combined surface area amounts to only 2.35 km^2 have been given priority conservation and highest protection status as they serve as vital breeding grounds for a variety of seabirds that breed in Namibia, most of which are listed Red Data species in Namibia (Currie *et al.* 2009). Of particular importance are the African Penguin, Bank Cormorant and Cape Gannet, which are listed as endangered and near threatened. The proposed area has been further zoned into four degrees of incremental protection. These are detailed in Currie *et al*. (2008). The southern boundary of the MPA is located ~ 300 km north of the project target area.

3.5. Features Specific to the Licence Area

The area of interest defined for the well locations within the Orange Basin Deep Water Licence Area, is approximately 900 km^2 in extent with water depths ranging between 1,500 m and 2,100 m. The area of interest lies ~250 km offshore of Hondeklipbaai. Seabed sediments comprise primarily muds and sandy muds, which are likely to host a range of benthic macrofaunal species. Information on seabed communities specific to the area of interest is, however, lacking. As the area of interest lies well offshore of the influence of coastal upwelling, waters are likely to be comparatively warm and clear with low abundances of phytoplankton, zooplankton and ichthyoplankton. The fish species likely to be encountered comprise primarily the large pelagic species (e.g. tunas, billfish and pelagic sharks), which migrate throughout the southern oceans, between surface and deep waters (>300 m). Migrating leatherback turtles are also likely to occur, as are a variety of pelagic seabirds. Marine mammals likely to be encountered include sperm whales, migrating humpback whales and various baleen and toothed whales known to frequent offshore waters. The area of interest lies well offshore of marine diamond mining concessions, and proposed priority areas for the protection of benthic and pelagic habitats.

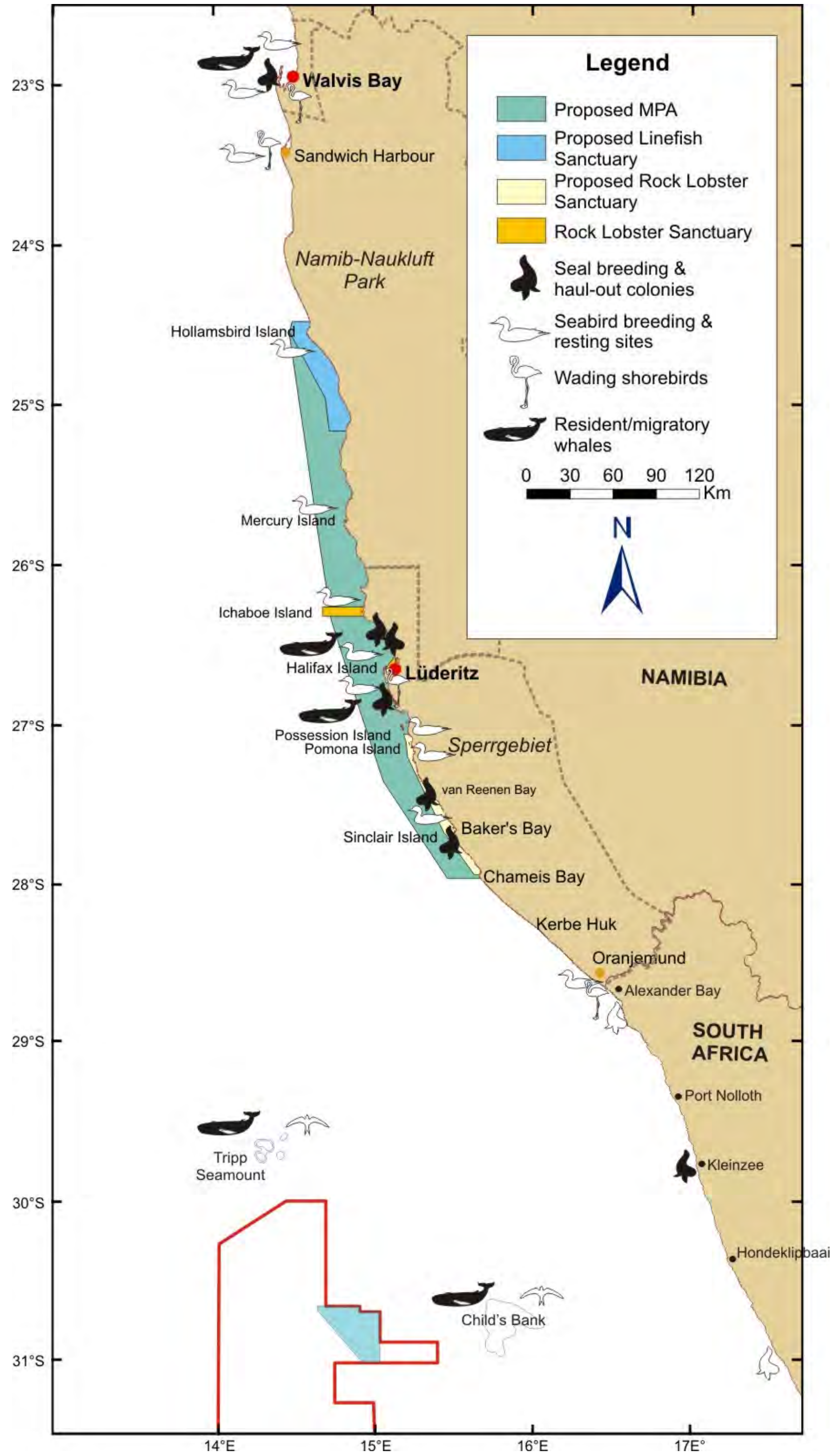


Figure 34: Project - environment interaction points in southern and central Namibia illustrating conservation and marine protected areas, seal colonies and seabird breeding areas in the coastal region in relation to the Orange Basin Deep Water Licence area (red polygon) and the area of interest for exploration drilling (pale blue shading).

4. ASSESSMENT OF IMPACTS OF EXPLORATION WELL DRILLING ON MARINE FAUNA

4.1. Assessment Procedure

The following convention was used to determine significance ratings in the assessment:

Rating	Definition of Rating
Extent – defines the physical extent or spatial scale of the impact	
Local	Extending only as far as the activity, limited to the site and its immediate surroundings
Regional	Limited to the South African West Coast
National	Limited to the coastline of South Africa
International	Extending beyond the borders of South Africa
Duration – the time frame over which the impact will be experienced	
Short-term	0 – 5 years
Medium-term	6 – 15 years
Long-term	Where the impact would cease after the operational life of the activity, either because of natural processes or by human intervention
Permanent	Where mitigation either by natural processes or by human intervention would not occur in such a way or in such time span that the impact can be considered transient
Intensity – establishes whether the magnitude of the impact is destructive or benign in relation to the sensitivity of the receiving environment	
Zero to Very Low	Where the impact affects the environment in such a way that natural, cultural and social functions and processes are not affected.
Low	Where the impact affects the environment in such a way that natural, cultural and social functions and processes continue, albeit in a slightly modified way.
Medium	Where the affected environment is altered, but natural functions and processes continue, albeit in a modified way
High	Where environmental functions and processes are altered to the extent that they temporarily or permanently cease

Using the core criteria above, the significance of the impact is determined:

Significance – attempts to evaluate the importance of a particular impact, and in doing so incorporates extent, duration and intensity	
VERY HIGH	Impacts could be EITHER: of high intensity at a regional level and endure in the long term; OR of high intensity at a national level in the medium term; OR of medium intensity at a national level in the long term.

Significance – attempts to evaluate the importance of a particular impact, and in doing so incorporates extent, duration and intensity	
HIGH	Impacts could be EITHER: of high intensity at a regional level enduring in the medium term; OR of high intensity at a national level in the short term; OR of medium intensity at a national level in the medium term; OR of low intensity at a national level in the long term; OR of high intensity at a local level in the long term; OR of medium intensity at a regional level in the long term.
MEDIUM	Impacts could be EITHER: of high intensity at a local level and endure in the medium term; OR of medium intensity at a regional level in the medium term; OR of high intensity at a regional level in the short term; OR of medium intensity at a national level in the short term; OR of medium intensity at a local level in the long term; OR of low intensity at a national level in the medium term; OR of low intensity at a regional level in the long term.
LOW	Impacts could be EITHER of low intensity at a regional level, enduring in the medium term; OR of low intensity at a national level in the short term; OR of high intensity at a local level and endure in the short term; OR of medium intensity at a regional level in the short term; OR of low intensity at a local level in the long term; OR of medium intensity at a local level, enduring in the medium term.
VERY LOW	Impacts could be EITHER of low intensity at a local level and endure in the medium term; OR of low intensity at a regional level and endure in the short term; OR of low to medium intensity at a local level, enduring in the short term.
INSIGNIFICANT	Impacts with: Zero to very low intensity with any combination of extent and duration.
UNKNOWN	Where it is not possible to determine the significance of an impact.

Status of the Impact – describes whether the impact would have a negative, positive or zero effect on the affected environment	
Positive	The impact benefits the environment
Negative	The impact results in a cost to the environment
Neutral	The impact has no effect
Probability – the likelihood of the impact occurring	
Improbable	Possibility very low either because of design or historic experience
Probable	Distinct possibility
Highly Probable	Most likely
Definite	Impact will occur regardless of preventive measures

Degree of confidence in predictions – in terms of basing the assessment on available information and specialist knowledge	
Low	Less than 35% sure of impact prediction.
Medium	Between 35% and 70% sure of impact prediction.
High	Greater than 70% sure of impact prediction

Additional criteria to be considered, which could "increase" the significance rating are:

- Permanent / irreversible impacts (as distinct from long-term, reversible impacts);
- Potentially substantial cumulative effects; and
- High level of risk or uncertainty, with potentially substantial negative consequences.

Additional criteria to be considered, which could "decrease" the significance rating are:

- Improbable impact, where confidence level in prediction is high.

The relationship between the significance ratings after mitigation and decision-making can be broadly defined as follows:

Significance after Mitigation - considering changes in intensity, extent and duration after mitigation and assuming effective implementation of mitigation measures	
Very Low; Low	Will not have an influence on the decision to proceed with the proposed project, provided that recommended measures to mitigate negative impacts are implemented.
Medium	Should influence the decision to proceed with the proposed project, provided that recommended measures to mitigate negative impacts are implemented.
High; Very High	Would strongly influence the decision to proceed with the proposed project.

4.2. Identification of Impacts

Potential impacts to the marine environment as a result of the proposed drilling operations include:

- Disturbance and loss of benthic macrofauna as a result of physical disturbance of the seabed and removal of sediments during installation of the well(s);
- Disturbance and loss of benthic communities due to smothering by disposed drill cuttings;
- Reduced physiological functioning of marine organisms due to the biochemical effects on the water column and seabed sediments of discharged cement, cuttings and drill fluids;
- Threats to Benguela ecosystem biodiversity through the introduction of invasive alien species with the drilling units;
- Alteration of the seabed habitat through the physical presence of subsea structures (e.g. completed and abandoned wellhead(s));
- Disturbance of marine biota due to noise and pollution generated by the drilling units, support vessels and aircraft / helicopter; and

- Toxic effects on marine biota from potential spills and leaks during well drilling, testing and operation.

4.3. Assessment of Impacts

The impacts of petroleum extraction activities on marine benthic communities in South Africa's Exclusive Economic Zone (EEZ) have to date not been comprehensively investigated (Atkinson & Sink 2008). Several studies have, however, been conducted in other parts of the world, thus providing some indication of impacts to benthic habitats that might be expected during petroleum extraction activities in South Africa. Potential impacts are discussed and assessed below using information from the international literature.

4.3.1 Disturbance and/or Loss of Benthic Macrofauna as a result of physical disturbance of the seabed and removal of sediments during installation of the well(s)

Exploratory drilling in the Orange Basin Deep Water Licence area would result in physical damage to and disturbance of the invertebrate benthic communities through removal of sediments during drilling activities, potential crushing of benthic epifauna by the permanent or temporary placement of wellhead structures on the seabed. Due to the target depths involved, a dynamically positioned drilling unit would be implemented for the project, and seabed disturbance within the Licence Area due to anchor deployments would not happen. However, temporary disturbance of the benthos by anchor deployments may occur should support vessels need to anchor prior to returning to port.

The immediate effect on the benthos depends on their degree of mobility, with sedentary and relatively immobile species likely to be physically damaged or destroyed during the drilling disturbance. The current well-design parameter is to have a wellbore diameter of 36" (91 cm) during spudding. The penetration of the seabed by the drill bit would disturb a surface area of 0.650 m^2, and any benthic fauna present on the seabed and in the top 20 - 30 cm of sediment, would be eliminated. Further loss or disturbance of the benthos due to smothering under the spoil mounds generated by disposal of drilling muds and cuttings are discussed further under Section 4.3.2.

Casing of the hole and installation of the wellhead and BOP is also likely to result in localised disturbance of macrofauna in an area of 3 m^2 around the well site. Considering the available area of similar habitat on and off the edge of the continental shelf in the Atlantic Offshore bioregion, this disturbance of and reduction in benthic biodiversity can be considered negligible, and no cumulative effects on higher order consumers is expected.

The high-intensity negative impact of disturbance of unconsolidated seabed as part of exploration well drilling is unavoidable, but as it would be extremely localised the impact can confidently be rated as being **VERY LOW**, both without and with mitigation. If, however, the proposed well is located on, or in the vicinity of rocky outcrops or hard grounds potentially supporting vulnerable, slow-growing deep-water species (e.g. cold-water corals, sponges), the impact is considered to be of **MEDIUM** significance before mitigation and **VERY LOW** after mitigation.

Mitigation

There are no feasible mitigation measures that can be implemented to avoid or minimise the predicted impact on benthic communities due to well drilling. However, the following mitigation measures are recommended:

- Use the existing seismic data to conduct a pre-drilling geohazard analysis of the seabed, and near-surface substratum. In doing so, map potentially vulnerable habitats to prevent potential conflict with the well site;
- Consider using a Remotely Operated Vehicle (ROV) to survey the seafloor in the immediate vicinity of drilling, to identify any significant topographic features (e.g. rocky outcrops) or vulnerable habitats (e.g. hard grounds) and species (e.g. cold-water corals, sponges). Plan to avoid drilling in the immediate vicinity of these vulnerable habitats.

Impacts on benthic macrofauna of unconsolidated sediments through removal or crushing		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to well site or anchor and chain footprints	Local
Duration	Short-term; recovery expected within 2-5 years	Short-term
Intensity	Medium	Medium
Significance	Very Low	Very Low
Status	Negative	Negative
Probability	Definite	Definite
Confidence	High	High

Impacts on benthic macrofauna of deep-water reefs through removal or crushing		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to well site or anchor and chain footprints	Local
Duration	Medium to Long-term	Short-term
Intensity	High	Medium
Significance	Medium	Very Low
Status	Negative	Negative
Probability	Improbable	Improbable
Confidence	High	High

4.3.2 Disturbance and loss of benthic communities due to smothering by disposed drill cuttings

During the drilling of the well(s), the primary discharge from the drilling unit would be the drill cuttings. For the current project, these are expected to range in size from muds (100 µm) to gravel (~10 mm). The chemistry and mineralogy of the rock particles reflects the types of sedimentary rocks penetrated by the bit. The cuttings from the top-hole sections of the well (drilled with WBMs) are discharged onto the seafloor where they would primarily have smothering effects on benthic macrofauna, or potentially increase turbidity of the near-bottom water layers (see Section 4.3.4 below). Cuttings from lower hole sections (drilled with SBMs) are lifted up the marine riser to the drilling unit and separated from the drilling fluid by the on-board solid control systems. The solids waste stream is fluidised with seawater and discharged overboard through the cutting chute, which is usually located a few metres below the sea surface.

The effects of drilling mud and cuttings discharges on the benthic environment are related to the total mass of drilling solids discharged, whether these are discharged at the seabed or off the drilling unit, and the relative energy of the water column and benthic boundary layer at the discharge site. The total volume of cuttings discharged during the drilling of a well would be dependent upon the well depth and the drilling conditions encountered. With increasing well depth and concomitant decrease in both penetration rate and wellbore diameter, the rate of cuttings discharge decreases.

The cuttings discharged at the seabed during the spudding of a well will form a highly localised spoil mound around the wellbore, thinning outwards. In contrast, the cuttings discharged from the drilling unit form two plumes as they are discharged. The heavier cuttings and flocculated clay/barite particles (>0.2 mm), which typically constitute 83% of the discharge, settle to the seabed near the wellbore while the fine-grained unflocculated solids and dissolved components of the mud (17% of the discharge) are dispersed in the water column at increasing distances from the drill unit (Figure 35). The dispersion pattern and degree of accumulation depends on water depth, current strength and the frequency of storm surges (Buchanan *et al*. 2003).

In high energy environments, accumulation of drilling waste on the seabed is minimal as the drilling solids are rapidly dispersed and redistributed. Under such conditions adverse effects of the discharges on benthic community composition are difficult to detect above the natural variability (Lees & Houghton 1980; Houghton *et al*. 1980a; Bothner *et al.* 1985; Neff *et al*. 1989; Daan & Mulder 1993, 1996). Where changes in abundance and diversity of macrofaunal communities were detected, these were typically restricted to within about 100 m of the discharge, but did not persist much beyond 6 months after drilling operations had ceased (Chapman *et al.* 1991; Carr *et al*. 1996; Currie & Isaacs 2005).

In low-energy, deep-water environments, however, the effects of drilling waste discharges on benthic ecosystems are more severe and long-lasting. Typically, the coarse cuttings accumulate within 200 m of the drilling unit, although depending on the strength of prevailing current, some may disperse as far as 800 m from the drilling unit. Some authors report that cuttings piles near a rig can be 1-2 m high (Hinwood *et al*. 1994; Hartley *et al.* 2003; Neff 2005), but these were usually associated either with the disposal of NADF cuttings, which tend to aggregate once discharged and thus disperse less readily resulting in a smaller area but thicker deposition on the seabed, or with cuttings shunted to and discharged near the seabed. The results of recent international modelling studies and physical sampling exercises have indicated that the majority of discharges would have a maximum accumulated height of less than 8 cm, with a fine cover of less than 2 mm thickness likely to extend to ~0.5 km from the discharge point (Perry 2005).

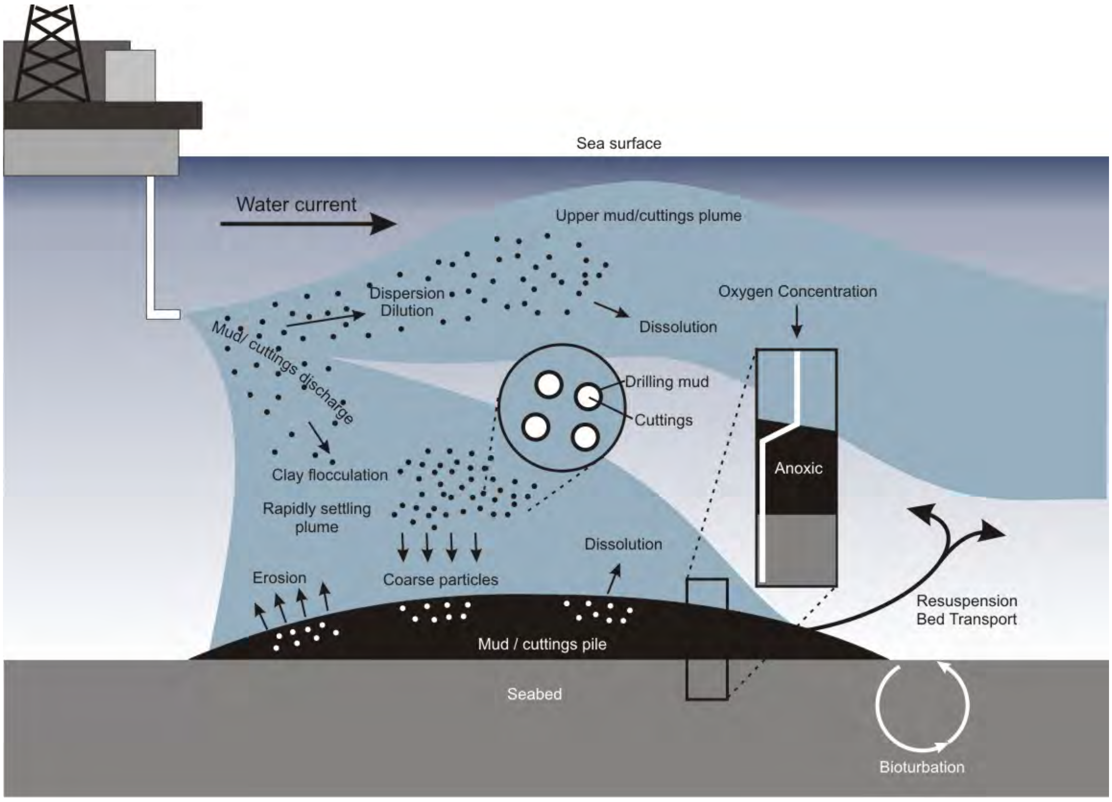


Figure 35: Hypothetical dispersion and fates of cuttings following discharge to the ocean, irrespective of drilling unit used. The solids undergo dispersion, dilution, dissolution, flocculation, and settling in the water column. If the discharge contains a high concentration of organic matter, the cuttings pile may become anaerobic near the surface, before being altered by redox cycling, bioturbation, and bed transport (adapted from Neff 2005).

Studies have found that changes in abundance and diversity of macrofaunal communities in response to depositing cuttings were typically detected within a few 100 m of the discharge (Neff *et al*. 1992; Ranger 1993; Montagna & Harper 1996; Schaanning *et al*. 2008), with recovery of the benthos observed to take from several months to several years (most likely within 1 year) after drilling operations had ceased (Husky 2000, 2001a, 2001b; Buchanan *et al*. 2003; Neff 2005; Currie & Isaacs 2005). The potential environmental effects of drilling solids discharges have been discussed in several studies (Morant 1999; Husky 2000, 2001a; CAPP 2001; Hurley & Ellis 2004), all of which concluded that exploratory drilling has no measureable environmental effect on the marine environment.

The main impacts associated with the disposal of drilling solids would be smothering of sessile benthic fauna, physical alteration of the benthic habitat (changes in sediment properties) in the immediate vicinity (<200 m) of the well. The effects of smothering on the receiving benthic macrofauna are determined by 1) the depth of burial; 2) the nature of the depositing sediments; and 3) the tolerance of species (life habitats, escape potential, tolerance to hypoxia etc.) (Kranz 1974; Maurer *et al*. 1981a, 1981b, 1982, 1986; Bijkerk 1988;

Hall 1994; Baan *et al*. 1998; Harvey *et al*. 1998; Essink 1999; Schratzberger *et al*. 2000b; Baptist *et al*. 2009).

Many benthic infaunal species are able to burrow or move through the sediment matrix, and some infaunal species are able to actively migrate vertically through overlying deposited sediment thereby significantly affecting the recolonisation and subsequent recovery of impacted areas (Maurer *et al*. 1979, 1981a, 1981b, 1982, 1986; Ellis 2000; Schratzberger *et al*. 2000a; but see Harvey *et al*. 1998; Blanchard & Feder 2003). Maurer *et al*. (1979) reported that some animals are capable of migrating upwards through 30 cm of deposited sediment. In contrast, consistent faunal declines were noted during deposition of mine tailings from a copper mine in British Columbia when the thickness of tailings exceeded 15-20 cm (Burd 2002), and Schaffner (1993) recorded a major reduction in benthic macrofaunal densities, biomass, and species richness in shallow areas in lower Chesapeake Bay subjected to heavy disposal (>15 cm) of dredged sediments. Similarly, Roberts *et al*. (1998) and Smith & Rule (2001) found differences in species composition detectable only if the layer of instantaneous applied overburden exceeded 15 cm. In general, mortality tends to increase with increasing depth of deposited sediments, and with speed and frequency of burial.

The survival potential of benthic infauna, however, also depends on the nature of the deposited non-native sediments (Turk & Risk 1981; Chandrasekara & Frid 1998; Schratzberger *et al*. 2000a). Although there is considerable variability in species response to specific sediment characteristics (Smit *et al*. 2006), higher mortalities were typically recorded when the deposited sediments have a different grain-size composition from that of the receiving environment (Cantelmo *et al*. 1979; Maurer *et al*. 1981a, 1981b, 1982, 1986; Smit *et al*. 2006; Smit *et al*. 2008), which would be the case in the discharge of drill cuttings. Migration ability and survival rates of organisms are generally lower in silty sediments than in coarser sediments (Hylleberg *et al.* 1985; Ellis & Heim 1985; Maurer *et al*. 1986; Romey & Leiseboer 1989, cited in Schratzberger *et al*. 2000a; Schratzberger *et al*. 2000a). Some studies indicate that changes to the geomorphology and sediment characteristics may in fact have a greater influence on the recovery rate of invertebrates than direct burial or mortality (USDOI/FWS 2000). The availability of food in the depositional sediment is, however, also influential.

The duration of burial, would also determine the effects on the benthos. Here a distinction must be made between incidental deposition, where species are buried by deposited material within a short period of time (as would occur during drilling solids disposal), and continuous deposition, where species are exposed to an elevated sedimentation rate over a long period of time (e.g. in the vicinity of river mouths). Provided the sedimentation rate of incidental deposition is not higher than the velocity at which the organisms can move or grow upwards, such deposition need not necessarily have negative effects. The sensitivity to short-term incidental deposition is species dependent and also dependent on the sediment type, with deposition of silt being more lethal than a deposition of sand.

The nature of the receiving community is also of importance. In areas where sedimentation is naturally high (e.g. wave-disturbed shallow waters) the ability of taxa to migrate through layers of deposited sediment is likely to be well developed (Roberts *et al*. 1998). The life-strategies of organisms is a further aspect influencing the susceptibility of the fauna to mortality. Benthic and demersal species that spawn, lay eggs or have juvenile life stages dependent on the seafloor habitat (e.g. hake) may be negatively affected by the smothering effects of drill cuttings. Studies on the burrowing habits of 30 species of bivalves showed that mucous-tube feeders and labial palp deposit-feeders were most susceptible to sediment deposition, followed by epifaunal suspension feeders, boring species and deep-burrowing siphonate suspension-feeders, none of which could cope with more than 1 cm of sediment overburden. Infaunal non-siphonate suspension feeders were able to escape 5 cm of burial by their native sediment, but normally no more than 10 cm (Kranz 1972, cited in Hall 1994). The most resistant species were deep-burrowing siphonate suspension-feeders, which could escape from up to 50 cm of overburden. Meiofaunal species appear to be less susceptible to burial than macrofauna (Menn 2002).

There has recently been increasing focus on the potential impacts of drilling solids disposal on vulnerable deep-water coral communities in the Northeast Atlantic (Rogers 1999; Colman *et al*. 2005; www.coralreef.noaa.gov/deepseacorals/threats). As deep-water corals tend to occur in areas with low sedimentation rates (Mortensen *et al*. 2001), these benthic suspension-feeders and their associated faunal communities are likely to show particular sensitivity to increased turbidity and sediment deposition associated with cuttings discharges. Exposure of corals to drilling solids can result in mortality of the colony due to smothering, alteration of feeding behaviour and consequently growth rate, disruption of polyp expansion and retraction, physiological and morphological changes, and disruption of calcification. While tolerances to increased suspended sediment concentrations will be species specific, drilling mud concentrations as low as 100 mg/l have been shown to have noticeable effects on coral function (Roger 1999). Mortensen and Lepland (2008) identified that deep-water corals on the Norwegian shelf, downcurrent of a test well discharge, did not show clear differences in health status, although barite crystals derived from the drilling mud were present among trapped sediments in the skeleton cavities of dead coral polyps older than six years, with highest barite concentration found in a polyp older than 13 years. As high proportions of hard ground have been identified between 180 m and 480 m depth inshore of the proposed well location(s), and video footage from southern Namibia and to the south-east of Child's Bank has identified vulnerable communities including gorgonians, bryozoans and octocorals, the potential occurrence of such sensitive deep-water ecosystems in the Orange Basin Deepwater area cannot be excluded. It is recommended that pre-drilling site surveys be conducted to provide sufficient information on seabed habitats on and in the vicinity of the proposed drill site(s), and that appropriate technologies be implemented to reduce the risks of damage to vulnerable seabed habitats and communities should they occur in the target area (Jødestøl & Furuholt 2010).

The results of the cuttings dispersion modelling studies undertaken as part of this project (PRDW 2013) largely confirm the reports of international studies that predicted that the effects of discharged cuttings are localised (see Perry 2005). For the current project, 450 - 600 m^3 of rock cuttings would be generated, of which 300 - 400 m^3 of uncontaminated cuttings would be discharged at the seafloor (~70% of the total volume of cuttings generated), with the remaining 150 - 200 m^3 discharged off the drill rig to the water column. The cuttings discharged at the seabed were predicted to create a cone in the order of 80 cm thick close to the wellbore, thinning outwards to a thickness of 3 cm at a radius of 120 m. The total predicted area affected by the seabed discharges would thus be in the order of 0.045 km^2.

Assuming drilling would be undertaken during the summer months as proposed, surface cuttings discharges were predicted to cover a maximum area of between 25.9 and 29.8 km^2 (depending on the dispersion rate and the depth at which the well was located), with deposition exceeding 1 mm thickness being confined to an area of only 0.09 km^2 in the immediate vicinity of the well (radius of ~150 m from the drill site). The large depths at the well sites in combination with the moderate to strong current speeds (maximum 0.56 m/s at 200 m depth) therefore result in a high dispersion of the discharged drill cuttings. This is, however, offset by the relatively low deposition thicknesses (<1 mm) predicted for distances beyond ~150 m from the well location. What must also be kept in mind is that cuttings discharge would be intermittent as drilling operations occur for only one third to one half of the total time the drilling unit is on location. Relatively rapid recolonisation of benthic fauna can thus be expected (see for example Kingston 1987, 1992; Trefry *et al*. 2013), with subsequent bioturbation playing an important role in the physical recovery of the seabed (Munro *et al*. 1997).

Due to the high natural variability in benthic communities in the region (Environmental Evaluation Unit 1996; Parkins & Field 1997, 1998; Pulfrich & Penney 1999; Goosen *et al*. 2000; Steffani & Pulfrich 2004, 2007; Steffani 2007a, 2007b 2009a, 2009b, 2010a, 2010b, 2010c), the structure of the recovering communities will likely be highly spatially and temporally variable. The community developing after an impact depends on (1) the nature of the impacted substrate, (2) environmental factors such as bedload transport, near-bottom dissolved oxygen concentrations etc., and (3) differential re-settlement of larvae into the area, migration of mobile species into the area and from burrowing species migrating upwards back to the surface. Indications of significant recruitments and natural mortalities in recovering succession communities on the southern African West Coast following marine diamond mining has provided evidence of natural disturbances (Pulfrich & Penney 1999; see also Savage *et al*. 2001). Short-term physical disturbance resulting from activities such as exploration well drilling, mining or dredging will thus be no more stressful than the regular naturally occurring anoxic events typical of the West Coast continental shelf areas.

The smothering effects resulting from the discharge of drilling solids at the wellbore is thus assessed to have an impact of medium intensity on the benthic macrofauna of unconsolidated sediments in the cuttings footprint, whereas discharges from the drilling unit would have a low intensity impact. In both cases, the impact is highly localised and recovery is expected within a few years (2 – 5 yrs). The impact is considered to be of **LOW** significance for discharges at the wellbore and **VERY LOW** significance for discharges from the drilling unit, both with and without mitigation. However, should the cuttings footprint overlap with vulnerable communities on hard ground, the smothering effects would potentially have an impact of high intensity, and as recovery would only be expected over the medium- to long-term due to their long generation times, the impact would be considered to be of **MEDIUM** to **HIGH** significance before mitigation and **LOW** after mitigation.

Mitigation

The following mitigation measures are recommended:

- Use the results of cuttings dispersal modelling to assess the potential risks to vulnerable seabed communities in the vicinity of the well;
- If vulnerable seabed communities have been identified in the vicinity of the proposed well locations, either adjust the well position accordingly or implement innovative technologies and operational procedures for drilling solids discharges to minimise the impacts (see for example Jødestøl & Furuholt 2010).

- Ensure regular maintenance of the onboard solids control package;
- Aid dispersion of the discharged cuttings and mud by placing the cuttings chute several metres below the sea surface.

Smothering effects of drilling solids discharge onto the seabed		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to within a few 10s of metres of the well site.	Local
Duration	Short-term: recovery is expected within 2 – 5 years	Short-term
Intensity	High	High
Significance	Low	Low
Status	Negative	Negative
Probability	Highly Probable	Highly Probable
Confidence	High	High

Smothering effects of drilling solids discharged at surface on soft sediment macrofauna		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to within a few 100 m of the well site.	Local
Duration	Short-term: recovery is expected within 2 – 5 years	Short-term
Intensity	Medium: some biota will be smothered, but many will be capable of burying up through the deposited drilling solids	Medium
Significance	Very Low	Very Low
Status	Negative	Negative
Probability	Highly Probable	Highly Probable
Confidence	High	High

Smothering effects of drilling solids discharge on vulnerable reef communities		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to within a few 100 m of the well site.	Local
Duration	Medium to Long-term	Short-term
Intensity	High	Medium
Significance	Medium to High	Low
Status	Negative	Negative
Probability	Improbable	Improbable
Confidence	Medium	Medium

4.3.3 Reduced physiological functioning of marine organisms due to direct biochemical effects

The disposal of cuttings at the wellbore and from the drilling unit would have various direct and indirect biochemical effects on the receiving environment. The direct effects are associated with the contaminants contained in the drilling muds and cements used during drilling operations. The indirect effects result from changes to water and sediment quality and are discussed separately in Section 4.3.4 below. The cuttings themselves are generally considered to be relatively inert, but may contribute small amounts of trace metals and/or hydrocarbons to receiving waters (Neff *et al.* 1987). However, most of the metals associated with cuttings are in immobile forms in minerals from the geologic strata, and their composition will thus resemble that of natural marine sediments. The drilling muds on the other hand, are a specially formulated mixture of natural clays, polymers, weighting agents and/or other materials suspended in a fluid medium. The constituents and additives of the discharged muds may potentially have ecotoxicological effects on the water column and sediments. These are assessed below.

Water-Based Muds (WBMs)

WBMs would be used to drill the first 1,000 m section of the well. These would be discharged at the seabed together with the drill cuttings. For the current project, it is estimated that 500 - 600 m^3 of WBMs will be discharged at the seabed affecting an area of some 0.045 km^2 around the wellhead. Typically, the major ingredients that make up over 90% of the total mass of the WBF are fresh or sea water, barium sulphate (barite), bentonite clay, lignite, lignosulphonate, and caustic soda. Others substances are added to gain the desired density and drilling properties.

Synthetic-based Muds (SBMs)

WBMs are, however, not well suited for use in demanding drilling operations, such as highly deviated and horizontal wells, or for drilling the deeper sections of offshore wells. For the current project, the deeper sections of the well would be drilled using a SBM comprising barite, calcium chloride, a synthetic base oil, lime, and a mixture of surfactants, emulsifiers, thinners and viscosifiers. The drilling fluid and cuttings would be isolated from the marine environment by the marine riser and would be circulated back to the drilling unit between the well casing and riser pipe. Although most of the drilling fluids would mechanically separated from the drilling cuttings, some SBM would remain adhered to the cuttings and would therefore reach the ocean. It is estimated that the discharged cuttings may contain up to 6.9 % by weight of drilling fluid solids. During drilling of the deeper sections of the well, in the order of 235 mT of mud may be discharged to the sea with treated cuttings.

The fate of these drilling fluids in the marine environment differs from that of the WBMs used in the initial section of the well. Such cuttings do not clump when discharged, but disperse and settle over a wide area, preventing development of significant cuttings mounds and speeding biodegradation (Getliff *et al*. 1997). The heavier cuttings and particles settle near the wellbore where a localised smothering effect can be expected (see Section 4.3.2 above). The fines generate a plume in the upper water column, which is dispersed away from the drilling unit by prevailing currents, diluting rapidly[2] to background levels at increasing distances from the drill unit. Despite the widespread dispersion of the cuttings, minor toxicity effects may occur in the water column and sediments from the potential solution of the constituents and additives of the discharged muds.

The primary issues related to the discharge of WBMs and SBMs thus include bioaccumulation and toxicity. The disposal of mud into the marine environment and its subsequent fate has been extensively investigated through field and laboratory studies (reviewed by Neff 2005). In general, it has been found that the impacts are insignificant in the open marine environment (Thomson *et al*. 2000; Hurley & Ellis 2004). The results of the studies are summarised below, focussing primarily on the constituents of WBMs as these would form the bulk of the discharge at the seabed (500 - 600 m^3), with anticipated loss of SBMs in the cuttings discharged at the surface amounting to only 200 -250 mT.

Bioaccessibility of Metals

Several metals typically occur in significantly higher concentrations in drilling muds discharges than background concentrations in uncontaminated marine sediments. Barium (from drilling mud barite) is usually the most abundant metal in WBMs, OBMs and SBMs, and is thus used most frequently as an indicator of drilling muds in sediments (Neff 2005). Increased levels of barium in the sediments surrounding wells have been recorded up to 65 km from drill sites (Neff *et al.* 1989), and persisting in the sediments for up to 1.5 years post-drilling (Steinhauer *et al*. 1994). Other metals, most of them associated with barite, often present at substantially higher concentrations in drilling muds than in natural marine sediments are chromium, lead, and zinc (Neff *et al*. 1989; Neff 2005 and references therein), with elevated concentrations of cadmium, arsenic, copper and mercury in near-field sediments (<500 m) also being recorded in some cases (Buchanan *et al*. 2003). However, due to the low solubility of barite in seawater and in anoxic marine sediments, these metals do not dissolve from the barite and leach into sediment pore water and are thus not bioavailable to benthic fauna and do not bioaccumulate in the marine food chain (Neff 2005 and references therein). Lead appears to be the only metal that is bioavailable in some cuttings piles.

Bioaccessibility of Drilling Mud Ingredients

The requirements for toxicity testing differ worldwide, with some countries requiring testing on whole muds, whereas others require testing of the individual mud components. The overall conclusion drawn from these tests is that the majority of WBMs currently used in offshore drilling operations constitute a low risk of chemical toxicity to marine communities.

As the most abundant solid ingredient in both WBMs and SBMs, particulate barite is almost insoluble and non-biodegradable, and thus essentially inert toxicologically to marine organisms. In chronic studies with benthic shrimp *Palaemonetes pugio* barite accumulated in the exoskeleton, hepatopancreas, and muscle tissue, with ingestion damaging the epithelial tissue of the gut (Neff 2005). Tagatz and Tobia (1978) reported that although barite-rich sediments did not prevent recruitment of several planktonic larvae of polychaetes and mussels, fewer individuals and species colonised sediments covered by a thin layer of barite. No adverse

[2] The cuttings dispersion modelling study (PRDW 2013) predicted that fall-out rates would range from 1.4 hrs for 10 mm cuttings to 77 hrs for 0.1 mm cuttings

effects on faecal production, growth, and adults tube production were observed in the polychaete *Mediomastus ambiseta* living in barite-covered sediments, although migration out of patches of 100% barite was observed (Starczak *et al*. 1992). Olsgard and Gray (1995) suggested that the effects of barite are more likely to be detected at a community level than at individual species levels.

Most toxicological studies have determined that sensitivity to barite was related to physical interactions with gills, the gastrointestinal tract, and integument due to elevated concentrations of particulate barite in suspension, rather than to direct chemical toxicity (see for example Barlow & Kingston 2001). Dilute suspensions have been shown to inhibit gonad development (Cranford *et al*. 1999), and food ingestion rates in the scallop *Placopecten magellanicus* leading to reduced growth rates and increased mortality (Muschenheim & Milligan 1996). In contrast, Cranford *et al.* (1998) reported no significant effect on survivorship or growth following acute and chronic exposure of scallops to 100 mg/l water based drilling mud. At concentrations >1,000 mg/l, Barium (as barite) was toxic to embryos of the crab *Cancer anthonyi* (Macdonald *et al*. 1988). Most bioassays have produced effects at median lethal concentrations >7,000 mg/l suspended barite (National Research Council 1983, in Neff 2005).

Bentonite, the second most abundant ingredient of WBMs, is a naturally occurring, insoluble and non-biodegradable clay added to drilling muds to provide viscosity. When in suspension, the clay-sized bentonite solids have smothering effects through burial and clogging of the gills, ultimately leading to mortality (Cabrera 1971; Sprague & Logan 1979). It may cause physical damage through abrasion and erosion (Sprague & Logan 1979), or shading effects reducing photosynthesis in the alga (Neff 2005). In particular, clay additives have been found to induce changes in respiratory and cardiac activities in cod, haddock, salmon and rays exposed to concentrations up to 40 mg/l for 2-5 minutes (Shparkovski *et al* 1989) with reduced survival in cod and flounder at 5 mg/l for exposures of 10-30 days (Kozak & Shparkovski 1991). Dethlefsen *et al*. (1996) also reported some indications of effects of WBMs on fish embryos and larvae. However, once the clay settles to the bottom, no further effects were observed (Carls & Rice 1984). Most 96-hr acute toxicity studies have thus found bentonite to be non-toxic, with LC_{50}s ranging from 22,000 to >100,000 ppm for various organisms.

In modern WBMs, bentonite has been supplemented or replaced by organic polymers (e.g. carboxymethyl cellulose, hydroxyethyl cellulose, guar gum), which are primarily used in shallow parts of a well due to their poor thermal stability. These organic polymers are similarly non-toxic to aquatic organisms, but being highly biodegradable, require a biocide to control bacterial growth. The biocide most frequently used is gluteraldehyde (a liquid derivative of glutaric acid), which is a toxic irritant. However, when discharged to the marine environment, it is rapidly destroyed by biological degradation and reduction by oxidation of organic matter. Gluteraldehyde is moderately toxic to non-toxic to various freshwater and marine animals with LC_{50}s ranging from >6-2,200 ppm for several crustaceans. If used in excess in polymer muds, sufficient gluteraldehyde could persist in the mud/cuttings plume to be toxic to pelagic organisms.

Some of the inorganic salts added to WBM for alkalinity/pH or shale control are slightly toxic to freshwater plants and animals due to their ionic or pH effects. Caustic soda is corrosive. Because of the high ionic strength and buffer capacity of seawater, it is unlikely that these salts would be toxic to marine organisms at the concentrations at which they occur in drilling muds.

Some chrome and ferrochrome lignosulfonate thinners used in WBMs are slightly toxic to marine organisms (Neff 2005). Chronic toxicity testing identified that their effects include alterations in feeding behaviour of lobsters; cessation of swimming by crab and mysid larvae, inhibition of shell formation, reduced rate of shell regeneration, and damage to gills in various molluscs; reduction in calcification, respiration, and growth rates of corals; and a decrease in growth rate, depressed heart rate, developmental abnormalities, and reduced survival of several marine fish species. Whether these effects would be manifested under conditions of exposure to discharged drilling muds and cuttings is uncertain, as field studies have generally failed to find evidence of the long-lasting ecological impacts of lignosulfonate muds near WBM and cuttings discharges. Nonetheless, chrome lignosulfonates have to some extent been replaced with less-toxic chrome-free lignosulfonate salts. Other clay thinners, such as lignites and tannins, are not toxic.

Of the minor additives (based on volumes discharged) sometimes used in WBMs, the most toxic include diesel fuel, corrosion inhibitors, detergents, defoamers, and emulsion breakers. Toxicity of whole drilling mud was attributed primarily to chrome, in cases where chromate and chrome lignosulfonate concentrations in the mud were very high (Conklin *et al*. 1983). Other additives such as zinc-based H_2S scavengers, tributyl phosphate surfactant defoamers, and fatty acid high-temperature lubricants are also toxic, but are usually not present in concentrations high enough to contribute significantly to whole mud toxicity. Where hydrocarbons are added to the mud to aid in lubricating the drill string or to free stuck pipes, the toxicity of WBM to water column and benthic marine animals increases significantly (Breteler *et al*. 1988). Although common in the past, this practice is seldom implemented today. Drilling fluids containing a high-sulfur diesel fuel (Group I NADFs containing 25% total aromatic hydrocarbons) are the most toxic, followed by those containing a low-sulfur diesel (containing 8.7% total aromatics); drilling fluids containing a low-aromatic mineral (Group III NADFs) oil were the least toxic.

Table 8 below provides a summary of acute toxicities of the ingredients of WBMs and SBMs to marine algae and animals, summarized by Neff (2005) from the scientific literature. Neff (2005) notes that the requirements for toxicity testing of drilling mud and drilling mud ingredients differ in different regions of the world. In the U.S., a mysid (crustacean), *Americamysis [Mysidopsis] bahia*, is used for toxicity tests with dispersions of used whole drilling muds. In contrast, the North Sea countries test the individual drilling mud components with at least three organisms from different taxonomic levels: alga, crustacean, fish. In Russia, toxicity testing is undertaken with several species on individual drilling mud components.

In addition to the multitude of ecotoxicological studies undertaken to date, many field monitoring studies have been performed since the 1970s to determine short- and long-term impacts of drilling discharges on the marine environment (e.g. Neff *et al*. 1989; Daan *et al*. 1992; Steinhauer *et al*. 1994; Hyland *et al*. 1994; Olsgard & Gray 1995, amongst others). Most of the monitoring conducted prior to 1993, focused on the impacts of OBMs cuttings discharges. Some of these earlier studies (e.g. Neff *et al*. 1989; Steinhauer *et al*. 1994; Hyland *et al*. 1994) reported no detectable changes in benthic communities that could be attributed to oil and gas extraction, possibly due to dispersal of drilling mud solids over a wide area in the high-energy environment in which the drilling occurred (Neff *et al*. 1989). Many monitoring studies, however, showed a clear chemical contamination gradient of sediment within a few hundred

Table 8: Acute toxicities, measured as median lethal concentration (LC_{50}) after 48 – 96 hours, and expressed as mg/l (ppm) of the ingredient or its suspended particulate phase.

Ingredient	Range of LC_{50} for different species (mg/l)
Weighting Materials	
Barite (barium sulfate: $BaSO_4$)	385[a] - >100,000
Hematite (iron oxide: $Fe2O_3$)	>100,000
Siderite (iron carbonate: $FeCO_3$)	>100,000
Viscosifiers	
Bentonite (montmorillonite clay)	9,600[a] - >100,000
Hydroxyethyl cellulose (HEC) polymer/viscosifier	7,800 – 29,000
Sodium carboxymethyl cellulose (CMC)	500[a] - >100,000
Polyanionic cellulose	60,000 – 100,000
Organic polymers	7,800 - >100,000
Xanthan gum	420
Salts for pH and Shale Control	
Potassium chloride (KCl: muriate of potash)	2,100[b]
Lime (CaO)	70 – 450[b]
Calcite (calcium carbonate: $CaCO_3$)	>100,000
Sodium hydroxide (NaOH: caustic soda)	105 – 110[b]
Lost Circulation Materials	
Mica	>7,500
Jellflake® shredded cellophane	>7,500
Thinners, Clay Dispersants	
Ferrochrome lignosulfonate	12 – 1,500
Chrome lignosulfonate	12,200 – 100,000
Chrome-treated lignosulfonate	465 – 12,200
Chrome-free lignosulfonate	31,000 – 100,000
Iron lignosulfonate	2,100
Modified chrome lignite	20,100
Potassium lignite	>100,000
Carbonox® lignitic material	6,500 - >7,500
Generic lignite	>15,000
Sulfomethylated tannin	33,900 - >100,000

Ingredient	Range of LC_{50} for different species (mg/l)
Sodium acid pyrophosphate ($Na_4P_2O_7$)	870[b] - >100,000
Lubricants	
Diesel fuel	0.1 – 1,112
Fatty acid high pressure lubricant	3,500 - >100,000
Blended organic ester lubricant	10,400 – 49,400
Graphite	86,500
Other Additives	
Corrosion inhibitors (several types)	2.0 – 7,000
Ammonium bisulfite corrosion inhibitor	75,000
H_2S scavengers (zinc salts)	235 – 7,800
Low MW polyacrylate reverse breaker	3,500
Polyacrylate scale inhibitor	77,300
Scale inhibitors	>10,000
Glutaraldehyde (biocide) (25%)	41 – 465
Flocculant WT-40	5,300
Surfactants	40 – 429
Detergents	0.4 – 340
Defoamers	5.4 – 84
Tributyl phosphate surfactant defoamer	5,100
Emulsion breakers	3.6 - 930
Oxygen scavenger (sodium bisulfite)	175 – 185

LC_{50} median lethal concentration; measure of toxicity that will kill 50% of a given population of organisms in a specified period.

[a] microalgal test; effects probably caused by turbidity.

[b] Freshwater species used in test; marine species expected to be more tolerant due to high ionic strength and buffer capacity of seawater

metres of the well, decreasing beyond 750 m (Daan *et al*. 1992; Hernandez Arana *et al.* 2005), but in some cases still being detectable at distances of several kilometres from the well (Olsgard & Gray 1995), and persisting over the long term (>15 years) (OSPAR 2008). These contamination gradients manifested themselves as reduced abundance and biomass of dominant faunal species that serve as food for demersal fish, declines in diversity and loss of sensitive macrofaunal species, with an increase in abundance of opportunistic species (OGP 2003). The effects were shown to be predominantly linked to the presence of total hydrocarbons, barium and strontium. Although taint studies on fish caught near North Sea platforms discharging OBM cuttings where unable to determine an off taste (reviewed in Davies *et al.* 1983), Husky (2001b) reported external lesions (indicative of contaminant stress) in fish in the vicinity of drilling sites. Similarly, cod and haddock from a Norwegian oil field were found to have different lipid content or lipid composition of the cell membranes, possibly due to the fish feeding on old NADF cuttings piles (OSPAR 2008).

Biological effects associated with the use of SBMs are not typically found beyond 250 – 500 m from the drilling unit (Husky 2000, 2001a; Buchanan *et al*. 2003; OGP 2003). The potential for significant bioaccumulation of SBMs in aquatic species is unlikely due to their extremely low water solubility and consequent low bioavailability (OGP 2003), however, certain hydrocarbons are known to have tainting effects on fish and shellfish. Sediment toxicity tests for SBMs have shown that these base fluids have relatively low toxicity to sessile organisms with LC_{50} >1,000 mg/l. Esters are the least toxic and impacts to benthic community structure did not persist beyond 2 years (reviewed by OGP 2003). This was followed by internal olefin and polymerised olefin, where complete recovery of impacted communities was anticipated within 3 – 5 years (Neff *et al*. 2000). The differences in toxicity may be due to differences in molecular size and polarity, which affects water solubility and bioavailability (OGP 2003).

With changes to the use of WBMs and low-toxicity SBMs, field results have clearly indicated "a reduction in environmental contamination and biological impact, compared to effects reported ... for OBM drill cuttings" (Olsgard & Gray 1995). Due to the low acute and chronic toxicities of WBMs and SBMs to marine life, and as a result of the high dilution and wide dispersal of the dissolved and particulate components following discharge, the effects of these muds are restricted primarily to the seabed in the immediate vicinity of the drilling unit and for a short distance downcurrent from the discharge (OSPAR 2008). Rather than direct chemical toxicity, impacts to sessile marine organisms arise primarily through smothering effects (see Section 4.3.2) and oxygen depletion due to rapid biodegradation of the base fluid in the sediment (see Section 4.3.4).

In summary, although several metals typically occur in significantly higher concentrations in drilling muds than in uncontaminated marine sediments, most of these are not bioavailable to benthic fauna and thus do not bioaccumulate in the marine food chain. Toxicity testing of WBMs and SBMs in use today has indicated that they constitute a low risk of chemical toxicity to marine communities. The two most abundant ingredients in WBMs, barite and bentonite, are insoluble and non-biodegradable. Other additives such as gluteraldehyde, inorganic salts and lignosulfonate thinners are only mildly toxic to marine life, but are present in such low concentrations that evidence of long-lasting ecological impacts are lacking. The most toxic additives include diesel fuel, corrosion inhibitors, detergents, defoamers, and emulsion breakers, but are usually not present in concentrations high enough to contribute significantly to whole mud toxicity. Similarly, the potential for significant bioaccumulation of SBMs in the marine environment is unlikely due to their extremely low water solubility and consequent low bioavailability. Due to the high dilution and wide dispersal of the dissolved and particulate components of SBMs, the biological effects associated with their use typically do not extend beyond 250 – 500 m from the drilling unit, with complete recovery of impacted communities being predicted within 3 – 5 years.

For the current project, the total predicted area affected by seabed discharges of WBMs would be in the order of 0.045 km^2, whereas deposition following surface discharges of SBM cuttings were anticipated to cover a maximum area of between 25.9 and 29.8 km^2 (assuming drilling would be undertaken during the summer months as proposed and depending on the dispersion rate and the depth at which the well was located) (PRDW 2013). The larger footprint of the surface-discharged cuttings was, however, offset by the relatively low deposition thicknesses (<1 mm) predicted for distances beyond ~150 m from the well location. Nonetheless, the potential maximum extent of contamination of seabed sediments was in the order of 30 km^2.

Assuming that the WBMs to be used in drilling the initial section of the well do not contain spotting fluids or lubricating hydrocarbons, the impacts of discharges of these drilling fluids to both the water column and the sediments are considered of low intensity. As the area affected by discharged drilling fluids would be localised (0.045 km^2), any potential adverse effects on sessile benthos of WBMs would be of **VERY LOW** significance, both before and after mitigation. In the case of SBMs, the impacts of discharges are considered of medium intensity. However, as the area affected by discharged drilling fluids would be localised (<30 km^2), any potential adverse effects on sessile benthos, or on the feeding, spawning and recruitment of mobile predators, will be very low. The impact for SBMs can similarly be rated as being of **VERY LOW** significance, both before and after mitigation.

Mitigation

The following measures can be implemented to mitigate any negative effects of drilling fluid discharges:

- Maximise the use of water-based drilling muds at all times, using risered SBMs only when necessary;
- Ensure only low-toxicity and partially biodegradable additives are used;
- Ensure regular maintenance of the onboard solids control package;
- All recovered SBM should be stored on board and taken to shore for treatment and reuse;
- Aid dispersion of the discharged cuttings and mud by placing the cuttings chute several metres below the sea surface.

Biochemical Impacts of Water-Based Drilling muds on marine organisms		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to drill site (0.045 km^2)	Local
Duration	Short-term: 2-5 yrs	Short-term
Intensity	Low	Low
Significance	Very Low	Very Low
Status	Negative	Negative
Probability	Highly Probable	Highly Probable
Confidence	Medium	Medium

Biochemical Impacts of Synthetic-Based Drilling muds on marine organisms		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to drill site (<30 km^2)	Local
Duration	Short-term: recovery is expected within 5 years	Short-term
Intensity	Medium	Medium
Significance	Very Low	Very Low
Status	Negative	Negative
Probability	Highly Probable	Highly Probable
Confidence	Medium	Medium

Cementing

After a casing string is set in a well, specially designed cement slurries are pumped into the annular space between the outside of the casing and the borehole wall. Various chemical additives are used in the cementing programme to control its properties, include setting retarders and accelerators, surfactants, stabilisers and defoamers. The formulations are adapted to meet the requirements of a particular well. Their concentrations, however, typically make up <10% of the overall cement used. Furthermore, the additives have a low toxicity to marine life (Ranger 1993; Chevron 1994) and the organic additives are partially biodegradable.

To ensure effective cementing, an excess of cement is usually used. This excess (210 m^3 in the worst case) emerges out of the top of the well onto the cuttings pile, where (depending on its mix) it either does not set and dissolves slowly into the surrounding seawater, or if it remains in a pile, may act as an artificial reef, be colonised by epifauna and attract fish and other mobile predators (Buchanan *et al*. 2003).

The impact of the excess cement around the wellbore and leaching of the additives into the surrounding water column is of low intensity and extremely localised (*i.e*. confined to the wellbore footprint). The biochemical impact can thus confidently be rated as being **VERY LOW** both with and without mitigation.

Mitigation

Although the use of cement is unavoidable, the following measures can be implemented to mitigate any negative effects:

- Avoid excess cement usage by monitoring discharges to the seafloor around the surface casing by ROV survey; and
- Ensure only low-toxicity and partially biodegradable cement additives are used.

Impacts of cementing on marine biota		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to well site	Local
Duration	Short-term: for duration of drilling operation	Short-term
Intensity	Low	Low
Significance	Very Low	Very Low
Status	Negative	Negative
Probability	Highly Probable	Highly Probable
Confidence	Medium	Medium

4.3.4 Reduced physiological functioning of marine organisms due to indirect biochemical effects

The heavier cuttings and particles discharged at the seabed or from the drilling unit would settle near the wellbore where a localised smothering effect can be expected (see Section 4.3.2). The finer components of the surface discharge generate a plume in the upper water column, which is dispersed away from the drilling unit by prevailing currents, diluting rapidly to background levels at increasing distances from the drill unit. Several studies have shown that in areas where current speeds are high, cuttings discharges are diluted rapidly (within an hour) to very low concentrations, within 1,000 – 2,000 m down-current of the drilling unit (see Neff 2005 for references). Morant (1999) reported that a typical near-surface plume is 30-40 m in vertical height, 40-60 m wide and can extend in excess of 10 km from the drilling unit. In contrast, the plume modelling undertaken for the current project (PRDW 2013) identified that due to the great water depth of the proposed wells, the fine particles (0.1 mm) would settle out within 77 hrs within a 50 km radius of the well site. Apart from the main biophysical (smothering and alteration in sediment characteristics) and biochemical (ecotoxicological effects of drilling mud constituents) impacts of the dispersed and settling cuttings on the marine environment, as discussed in Sections 5.3.2 and 5.3.3 respectively, indirect impacts (i.e. impacts arising indirectly from biochemical effects on the water column or sediments) associated with cuttings disposal include changes in water turbidity in the vicinity of the discharge point, and development of hypoxic conditions in the near-surface sediment layers through bacterial decomposition of organic matter. These are assessed separately below.

Turbidity

One of the more apparent effects of increased concentrations of suspended sediments and consequent increase in turbidity, is a reduction in light penetration through the water column with potential adverse effects on the photosynthetic capability of phytoplankton (Poopetch 1982; Kirk 1985; Parsons *et al.* 1986a, 1986b; Monteiro 1998; O'Toole 1997) and the foraging efficiency of visual predators (Simmons 2005; Braby 2009; Peterson *et al*. 2001). However, due to the rapid dilution and widespread dispersion of settling particles, any adverse effects in the water column would be ephemeral and highly localised. Any biological effects on nectonic and planktonic communities would thus be negligible (Aldredge *et al*. 1986). Turbid water is a natural occurrence along the southern African west coast, resulting from aeolian and riverine inputs, resuspension of seabed sediments in the wave-influenced nearshore areas and seasonal phytoplankton production in the upwelling zones. Further offshore where the proposed well(s) would be located, surface waters, however, tend to be clearer and less productive as they are beyond the influence of coastal upwelling (see Figure 11). Consequently, the major spawning areas are all located on the continental shelf, well inshore of the proposed well sites(s) (see Figure 20). Any potential effects of turbid water plumes generated during cutting disposal on phytoplankton and ichthyoplankton production, fish migration routes and spawning areas, or on benthic and demersal species in the area would thus be negligible. Increased turbidity of near-bottom waters through disposal of WBMs and cuttings at the wellbore, may place transient stress on sessile and mobile benthic organisms, by negatively affecting filter-feeding efficiency of suspension feeders or through disorientation due to reduced visibility (reviewed by Clarke & Wilber 2000). However, in most cases sub-lethal or lethal responses occur only at concentrations well in excess of those anticipated at the wellbore. Furthermore, as marine communities in the Benguela are frequently exposed to naturally elevated suspended-sediment levels, they can be expected to have behavioural and physiological mechanisms for coping with this feature of their habitat.

The impact of increased turbidity in the water column and elevated suspended sediment concentrations around the wellbore would thus be of low intensity, persist only over the very short term (days), and would be comparatively localised (<50 km radius of the well site). Any potential adverse effects on sessile benthos, or on the feeding, spawning and recruitment of mobile predators, will be very low. The biochemical impact of reduced water quality through increased turbidity can thus confidently be rated as being **VERY LOW** both with and without mitigation.

Mitigation

No direct mitigation measures for potential impacts on the water column or sediments from the discharge of WBMs cuttings from exploratory well drilling are deemed necessary.

Impacts of drill cuttings discharge on water column biochemistry (turbidity and light)		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to drill site. (<30 km^2)	No mitigation is proposed
Duration	Short-term: intermittently for duration of drilling operations	
Intensity	Low: rapid dispersion and dilution	
Significance	Very Low	
Status	Negative	
Probability	Probable	
Confidence	Medium	

Impacts of drill cuttings discharge on near-bottom water biochemistry		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to drill site (<1 km^2)	No mitigation is proposed
Duration	Short-term: for duration of drilling operation	
Intensity	Low: rapid dispersion and dilution	
Significance	Very Low	
Status	Negative	
Probability	Improbable	
Confidence	Medium	

Oxygen Depletion

Biodegradable organic matter in cuttings piles on the seabed often has a greater effect than sediment texture, deposition rate or, in some cases, chemical toxicity on the structure and function of benthic communities (Hartley *et al.* 2003). Bacterial decomposition of organic matter may deplete oxygen in the near-surface sediment layers, thereby changing the chemical properties of the sediments by generating potentially toxic concentrations of sulfide and ammonia (Wang & Chapman 1999; Gray *et al*. 2002; Wu 2002). The rapid biodegradation of drilling solids (particularly those containing NADFs) may therefore lead indirectly yet rapidly to sediment toxicity, particularly in fine-grained sediments (Munro *et al*. 1998; Jensen *et al*. 1999; Trannum *et al*. 2010). Organically enriched sediments are often hypoxic or anoxic, and consequently harbour markedly different benthic communities to oxygenated sediments (Pearson & Rosenberg 1978; Gray *et al*. 2002). Organic matter concentration in the sediments would decrease in response to microbial degradation, resulting in increases in oxygen concentration in the surface-sediment layers leading to succession in the benthic community structure toward a more stable state.

WBM cuttings piles typically contain low concentrations of biodegradable organic matter and do not support large populations of bacteria (Dow *et al.* 1990). As most of the organic chemicals in WBMs are biodegradable under aerobic conditions, sediments containing WBM cuttings show only slight and short-term reductions in redox potential. However, organic chemicals in settled solids from mineral oil- and diesel fuel-contaminated WBMs have a high chemical and biological oxygen demand (Breteler *et al*. 1988). Therefore, if cuttings piles contain WBMs contaminated with petroleum hydrocarbons, the sediments may experience the ecological effects of organic enrichment, particularly if the cuttings pile is large. Similarly, the synthetic fluids in SBMs typically degrade rapidly and can cause localised hypoxia in underlying sediments (EPA 2000; OGP 2003). In the case of sediments containing OBM cuttings, the anoxic conditions that developed not only persisted over the long term (>1 year), but stimulated production of hydrogen sulphide by anaerobic sulphate-reducing bacteria (Dow *et al.* 1990).

Oxygen depletion in the sediments around a well site may also develop in response to organic enrichment following fall-out of fouling organisms off submerged platform structures.

Marine organisms respond to hypoxia by first attempting to maintain oxygen delivery (e.g. increases in respiration rate, number of red blood cells, or oxygen binding capacity of haemoglobin), then by conserving energy (e.g. metabolic depression, down regulation of protein synthesis and down regulation/modification of certain regulatory enzymes), and upon exposure to prolonged hypoxia, organisms eventually resort to anaerobic respiration (Wu 2002). Hypoxia reduces growth and feeding, which may eventually affect individual fitness. The effects of hypoxia on reproduction and development of marine animals remains almost unknown. Many fish and marine organisms can detect, and actively avoid hypoxia. Some macrobenthos may leave their burrows and move to the sediment surface during hypoxic conditions, rendering them more vulnerable to predation. Hypoxia may eliminate sensitive species, thereby causing changes in species composition of benthic, fish and phytoplankton communities. Decreases in species diversity and species richness are well documented, and changes in trophodynamics and functional groups have also been reported. Under hypoxic conditions, there is a general tendency for suspension feeders to be replaced by deposit feeders, demersal fish by pelagic fish and macrobenthos by meiobenthos (see Wu 2002 for references). Further anaerobic degradation of organic matter by sulphate-reducing bacteria may additionally result in the production of hydrogen sulphide, which is detrimental to marine organisms (Brüchert *et al*. 2003).

The bulk of the seawater in the area comprises South Atlantic Central Water (SACW), which has depressed oxygen concentrations (~80% saturation value), with lower oxygen concentrations (<40% saturation) occurring frequently due to nutrient remineralisation in bottom waters. The benthic communities will therefore be adapted to low oxygen conditions and will be characterised either by species able to survive chronic hypoxia, or colonising and fast-growing species able to rapidly recruit into areas that have suffered oxygen depletion.

Development of anoxic conditions beneath re-deposited cuttings is highly unlikely due to the low deposition thicknesses (<1 mm) predicted in the cuttings fallout footprint for distances beyond ~150 m from the well location. Should anoxic conditions develop, these are likely to be limited to within the 0.045 km^2 footprint of the WBMs cuttings pile deposited on the seabed around the wellbore, where they would have an impact of medium intensity on the benthic macrofauna, with recovery expected within a few months. The impact is thus considered to be of **VERY LOW** significance, both with and without mitigation.

Mitigation

No mitigation measures are possible, or considered necessary.

Indirect Impacts of Cuttings Discharges: development of anoxic sediments		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to well site.	No mitigation is proposed
Duration	Short-term: erosion and dispersal of cuttings and bioturbation of cuttings pile should occur within a few months	
Intensity	Medium: West Coast biota are naturally adapted to low oxygen conditions	
Significance	Very Low	
Status	Negative	
Probability	Probable	
Confidence	Medium	

4.3.6 Threats to Benguela ecosystem biodiversity through the introduction of Invasive Species

Artificial structures deployed at sea serve as a substrate for a wide variety of larvae, cysts, eggs and adult marine organisms. The transportation of equipment from one part of the ocean to another would therefore also facilitate the transfer of the associated marine organisms. Drill units, drilling equipment and support vessels are used and relocated all around the world. The marine invertebrates that colonize the surface of drilling units and vessels can therefore easily be introduced to a new region, where they may become invasive by outcompeting and displacing native species. Similarly, the ballasting and de-ballasting of these vessels may lead to the introduction of exotic species and harmful aquatic pathogens to the marine ecosystems (Bax *et al*. 2003). Marine invasive species are considered primary drivers of ecological change in that they create and modify habitat, consume and outcompete native fauna, act as disease agents or vectors, and threaten biodiversity. Once established, an invasive species is likely to remain in perpetuity (Bax *et al.* 2003).

Numerous studies have investigated the potential for petroleum infrastructure to serve as vectors of potential invasive species (Foster & Willan 1979; Page *et al*. 2006; Hewitt *et al.* 2009). Foster and Willan (1979) identified 12 barnacle species, a grapsid crab (*Plagusia depressa tubuculata*), sergant-major fish (*Abedefduf sexetilis*), a species of hydroid (*Orthopyxis* sp.) and two algal species in the succession community that developed over a two-month period on an oil rig towed from Japan to New Zealand. Of these, six species of barnacles and the sergant-major fish had never previously been recorded in New Zealand. Similarly Page *et al*. (2006) documented three exotic invertebrate species (a bryozoan, anemone and amphipod) inhabiting offshore platforms on the Pacific offshore continental shelf of California, of which the bryozoan and anemone appeared to be outcompeting indigenous organisms for primary space. Underwater footage of existing petroleum infrastructure on the Agulhas Bank has shown dense abundances of an exotic anemone species *Metridium senile* most likely introduced from the North West Atlantic (K. Sink *pers. comm*.). Three non-indigenous marine species are currently known to be *invasive* in South African waters, namely the Mediterranean mussel *Mytilus galloprovincialis*, the European shore crab *Carcinus meanas* and the Pacific barnacle *Balanus glandula*. Although many more non-native species have been documented, the difficulty in detection, identification and the cryptic nature of some species suggests that there may be many more (C.L. Griffiths *pers. comm*.).

The introduction of non-native, potentially invasive species would have an impact of medium intensity on marine biodiversity. As the impact may extend regionally or even nationally, and established species could persist to perpetuity, the impact is considered to be of **HIGH** to **VERY HIGH** significance without mitigation, and of **MEDIUM** significance with mitigation. It must be pointed out, however, that this impact is not unique to the proposed project, but rather a threat common to the Southern African offshore environment from the numerous vessels that pass through South African coastal waters daily.

Mitigation

The following measures can be implemented to mitigate the risk of introducing alien species:

- De-ballasting of vessels to be undertaken only under strict adherence to International Maritime Organisation (IMO) Guidelines governing discharge of ballast waters at sea;

- Reballasting at sea currently provides the best available measure to reduce the risk of transfer of harmful aquatic organisms, but is subject to ship-safety limits. The IMO note that vessels using ballast water exchange should whenever possible, conduct such exchange at least 200 nautical miles from the nearest land and in water of at least 200 m depth. Where the ship is unable to conduct ballast water exchange as described, the exchange should be as far from the nearest land as possible, and a minimum of 50 nautical miles from the nearest land and in water at least 200 m in depth.
- Other precautionary guidelines suggested by the IMO include:
  - During the loading of ballast, every effort should be made to avoid the uptake of potentially harmful aquatic organisms, pathogens and sediment that may contain such organisms, through adequate filtration procedures;
  - Where practicable, routine cleaning of the ballast tank to remove sediments should be carried out in mid-ocean or under controlled arrangements in port or dry dock, in accordance with the provisions of the ship's ballast water management plan; and
  - Avoidance of unnecessary discharge of ballast water.

Introduction of invasive species on petroleum infrastructure		
	Without Mitigation	**Assuming Mitigation**
Extent	Regional to National	Regional
Duration	Long-term: once established an invasive species could remain to perpetuity	Short- to Medium-term
Intensity	Medium	Low
Significance	High to Very High	Medium
Status	Negative	Negative
Probability	Probable	Improbable
Confidence	Medium	Medium

4.3.7 Impact on marine biodiversity due to the alteration of the seabed habitat through the physical presence of sub-sea structures

Hall (2001) introduced the concept that the infrastructure provided by oil platforms may support a rich diversity of marine species, including rare and slow-growing cold water corals. Studies on the effects of platforms on the behaviour and abundance of certain fish species showed that the presence of oil and gas infrastructure appeared to provide a sheltering habitat for fish usually associated with complex reef habitats (Love *et al*. 2005; Love & York 2006). These authors proposed that the increased abundance of species such as bocaccio *Sebastes paucispinis* and cowcod *Sebastes levis* around installed infrastructure off California positively affected larval production, which could subsequently result in increased recruitment success. Some of the platforms investigated hosted larger mature individuals than nearby natural reefs, suggesting that platforms can provide important habitat for adults, particularly in reef fish species that have been heavily exploited.

In a study on exploratory drilling in 120 m depth on the Mid-Atlantic Outer Continental Shelf, the abundance of motile predatory fish, crabs, and starfish species, were found to increase near the rig site during well drilling (EG&G, Environmental Consultants 1982, in Neff 2005). It was assumed that these animals were attracted to the area by the increased bottom-relief afforded by the cuttings pile, or by the clumps of mussels and other biofouling organisms that had fallen off the drilling rig or anchor chains.

Similarly, Ellis *et al*. (1996) compared the abundance and size class structure of macroepifaunal invertebrates (shrimp, crabs, scallops, and starfish) at various distances from three platforms, and concluded that differences in community structure of associated fauna were attributable to the physical presence of the rig, and the unique chemical and physical environment at each platform. Differences in abundance and size of epifaunal invertebrates near the platforms compared to far away may also have been due to differences in food availability and predation. Mobile fish and invertebrates would be attracted by the shelter and food (biofouling organisms) provided by the underwater platform structures (Bull & Kendall 1994; Fechhelm *et al*. 2001). Each platform will have a slightly different reef community, depending primarily on water depth and proximity to nearby natural reefs and topographic features.

The epibenthic populations beneath, and in the area surrounding, an oil platform off California, were investigated by Wolfson *et al*. (1979). The study found an extraordinarily dense population of starfish (*Pisaster* sp.) below the platform, with abundances declining with increasing distance from the platform. Similarly, a tube-dwelling polychaete (*Diopatra ornate*) occurred in greater densities within 100 m from the structure, compared with a control area further away. Other infauna showed variable responses with some species increasing in abundance near the platform, others decreasing and some showing no discernible differences in abundance. The observed changes in benthic communities composition within the immediate vicinity of the structure was primarily attributed to the fall-out of mussels (*Mytilus californianus* and *M. edulis*) from the upper part of the platform.

The presence of subsea infrastructure (namely two wellheads) can therefore alter the community structure in an area, and effectively increase the availability of hard substrate for colonisation by sessile benthic organisms, thereby locally altering and increasing biodiversity and biomass. While this may have positive implications to certain fish species (e.g. kingklip *Genypterus capensis* and jacopever *Helicolenus dactylopterus*, which show a preference for structural seabed features), it may enhance colonisation by non-indigenous species thereby posing a threat to natural biodiversity. It has been suggested that these “reef effects” on community structure may be equal to, or even greater than those caused by contaminants or discharged drilling solids (Montagna *et al*. 2002). Prior to imminent decommissioning of oil and gas fields and complete removal of infrastructure, the potential benefits of the infrastructure should be investigated, and their contribution to enhancing benthic biodiversity should be assessed (Hall 2001).

The presence of physical structure on the seabed would have an impact of low intensity on marine biodiversity. The duration of the impact ultimately depends on whether the wellhead is removed or left on the seafloor during abandonment. If the wellhead is removed the duration would range from short-term (abandoned well) to medium-term (suspended well). However, if the wellhead is abandoned on the seafloor the impact would be permanent. In the case of a wellhead that is removed from the seafloor during abandonment, the impact is considered to be of **VERY LOW** significance both with and without mitigation. In the case of a wellhead that is abandoned on the seafloor the impact is considered to be of **LOW** significance.

Mitigation

No mitigation measures are recommended or deemed necessary.

Impacts of petroleum infrastructure on marine biodiversity: wellhead is lifted from the seafloor during abandonment		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to well site	No mitigation is proposed
Duration	Short-term	
Intensity	Low	
Significance	Very Low	
Status	Neutral	
Probability	Improbable	
Confidence	Medium	

Impacts of petroleum infrastructure on marine biodiversity: wellhead remains on the seafloor during abandonment		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to well site	No mitigation is proposed
Duration	Permanent	
Intensity	Low	
Significance	Low	
Status	Neutral	
Probability	Probable	
Confidence	Medium	

4.3.8 Disturbance of marine biota due to noise

The ocean is a naturally noisy place and marine animals are continually subjected to both physically produced sounds from sources such as wind, rainfall, breaking waves and natural seismic noise, or biologically produced sounds generated during reproductive displays, territorial defence, feeding, or in echolocation (see references in McCauley 1994). Such acoustic cues are thought to be important to many marine animals in the perception of their environment as well as for navigation purposes, predator avoidance, and in mediating social and reproductive behaviour. Anthropogenic sound sources in the ocean can thus be expected to interfere directly or indirectly with such activities thereby affecting the physiology and behaviour of marine organisms (NRC 2003). Of all human-generated sound sources, the most persistent in the ocean is the noise of shipping. Depending on size and speed, the sound levels radiating from vessels range from 160 to 220 dB re 1 µPa at 1 m (NRC 2003). Especially at low frequencies between 5 to 100 Hz, vessel traffic is a major contributor to noise in the world's oceans, and under the right conditions, these sounds can propagate 100s of kilometres thereby affecting very large geographic areas (Coley 1994, 1995; NRC 2003; Pidcock *et al.* 2003). Other forms of anthropogenic noise include 1) aircraft flyovers, 2) multi-beam sonar systems, 3) seismic acquisition, 4) hydrocarbon and mineral exploration and recovery, and 5) noise associated with underwater blasting, pile driving, and construction (Figure 36).

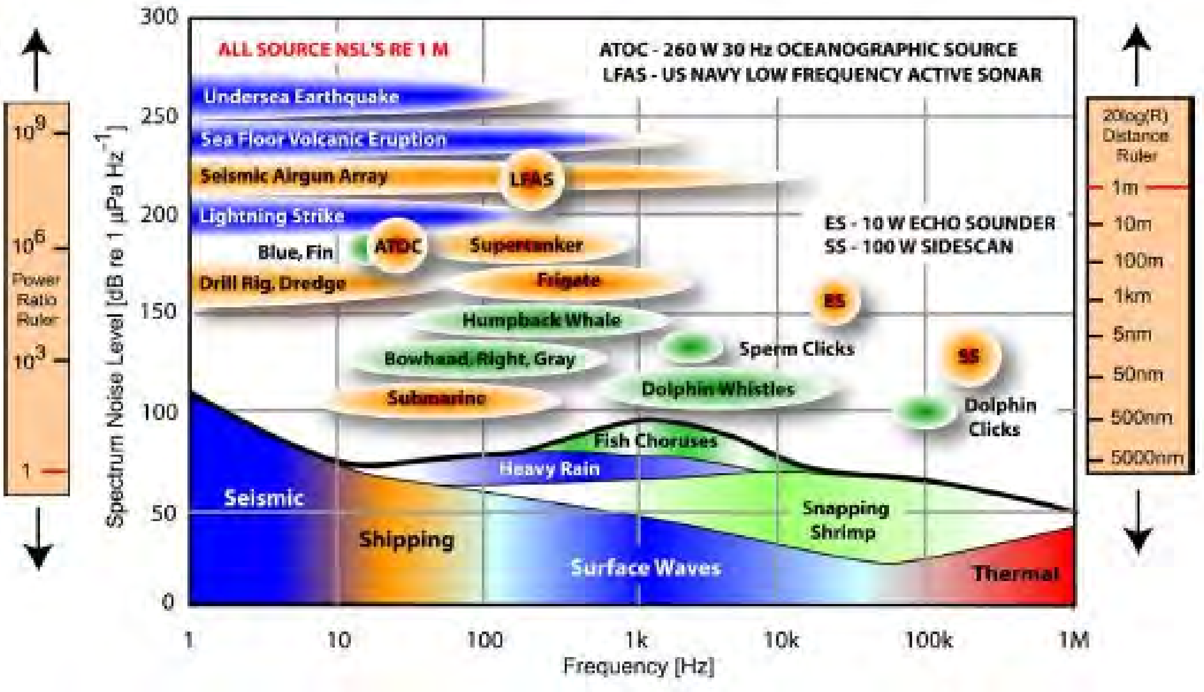


Figure 36: Comparison of noise sources in the ocean (Goold & Coates 2001).

Drilling noise

The cumulative impact of increased background anthropogenic noise levels in the marine environment is an ongoing and widespread issue of concern (Koper & Plön 2012). The sound level generated by drilling operations fall within the 120-190 dB re 1 µPa range at the drilling unit, with main frequencies less than 0.2 kHz. The noise generated by well-drilling operations thus falls within the hearing range of most fish and marine mammals, and would be audible for considerable ranges (in the order of tens of kms) before attenuating to below threshold levels (Table 9).

Unlike the noise generated by airguns during seismic surveys, the emission of underwater noise from drilling operations and associated drill unit and tender vessel activity is thus not considered to be of sufficient amplitude to cause direct harm to marine life. Whereas the underwater noise from well drilling operations may induce localised behavioural changes in some marine mammal, there is no evidence of significant behavioural changes that may impact on the wider ecosystem (Perry 2005). In a study evaluating the potential effects of vessel-based diamond mining on the marine mammals community off the southern African West Coast, Findlay (1996) concluded that the significance of the impact is likely to be minimal based on the assumption that the radius of elevated noise level would be restricted to ~20 km around the mining vessel. The responses of cetaceans to noise sources are often also dependent on the perceived motion of the sound source as well as the nature of the sound itself. For example, many whales are more likely to tolerate a stationary source than they are one that is approaching them (Watkins 1986; Leung-Ng & Leung 2003), or are more likely to respond to a stimulus with a sudden onset than to one that is continuously present (Malme *et al*. 1985).

Table 9: Known hearing frequency and sound production ranges of various marine taxa (koper & Plön 2012).

Taxa	Order	Hearing frequency (kHz)	Sound production (kHz)
Shellfish	Crustaceans	0.1 – 3	
Snapping shrimp	*Alpheus/ Synalpheus* spp.		0.1 - >200
Ghost crabs	*Ocypode* spp.		0.15 – 0.8
Fish	Teleosts		0.4 – 4
Hearing specialists		0.03 - >3	
Hearing generalists		0.03 – 1	
Sea turtles	Chelonia	0.1 – 1	Unknown
Sharks and skates	Elasmobranchs	0.1 – 1.5	Unknown
Seals	Pinnipeds	0.25 – 10	1 – 4
Northern elephant seal	*Mirounga agurostris*	0.075 – 10	
Manatees and dugongs	Sirenians	0.4 – 46	4 – 25
Toothed whales	Odontocetes	0.1 – 180	0.05 – 200
Baleen whales	Mysticetes	0.005 – 30	0.01 – 28

The impact of underwater noise generated during well-drilling and by the drilling unit and support vessels is thus considered to be of low intensity in the drilling area and for the duration of the drilling campaign. The impact of underwater noise is considered of **VERY LOW** significance both with and without mitigation.

Impacts of noise from well-drilling operations		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to well site area	No mitigation is proposed
Duration	Short-term: for duration of drilling operations	
Intensity	Low	
Significance	Very Low	
Status	Negative	
Probability	Highly Probable	
Confidence	High	

Aircraft / helicopter noise

There may, however, be some limited noise impacts to marine mammals and turtles from the helicopters used to support the drilling units. Although reported behavioural reactions by seabirds, turtles and whales to aircraft are highly variable and often anecdotal, it is safe to assume that any observed effects as a result of the helicopter support would be in response to both acoustic and visual cues.

Low altitude flights (especially near the coast) can have a significant disturbance impact on cetaceans during their breeding and mating season. The level of disturbance would depend on the distance and altitude of the aircraft from the animals (particularly the angle of incidence to the water surface) and the prevailing sea conditions. In terms of the Marine Living Resources Act, 1998 (No. 18 of 1998) it is illegal for any vessel, including aircraft, to approach to within 300 m of whales within South African waters.

Likewise seals will experience severe disturbance from low-flying aircraft usually reacting by showing a startle response and moving rapidly into the water. Although, any observed response is usually short-lived, disturbance of breeding seals can lead to pup mortalities through abandonment or injury by fleeing, frightened adults. The seal colony at Kleinzee has the highest population and produces the highest number of pups on the South African Coast (Wickens 1994). If the Kleinzee airfield is used as the logistics base for fixed-wing and rotary-wing operations as part of the proposed well drilling project, flight paths will need to be planned to avoid this colony. The nearest seabird colonies are at Bird Island in Lamberts Bay and Sinclair Island in Namibia, 300 km to the south and 260 km to the north of Kleinzee, respectively. The Orange River RAMSAR site and IBA is located 130 km north of Kleinzee. These are thus located far enough away to not be influenced by aircraft landing at or taking off from the Kleinzee airfield.

Indiscriminate low altitude flights over whales, seals, seabird colonies and turtles could thus have an impact on behaviour and breeding success. Although such impacts would be localised, they may have wider ramifications over the range of the affected species. The National Environmental Management: Protected Areas Act (2003) stipulate that the minimum over-flight height over nature reserves, national parks and world heritage sites is 762 m (2,500 ft). The Marine Living Resources Act (1998) prohibits aircraft to approach within 300 m of a whale. Therefore, except for when the aircraft lands on or takes off from the drilling unit and logistics base, the flight altitude would be >300 m. Assuming that aviation regulations are adhered to at all times, the intensity of overflights is thus deemed to be of low intensity, with the significance of the potential impact considered to be of **LOW** significance without mitigation, and **VERY LOW** significance with mitigation.

Mitigation

The following mitigation measures are recommended:

- Flight paths must be pre-planned to ensure that no flying occurs over coastal reserves (MacDougall's Bay), seal colonies (Buchu Twins, Kleinzee and Strandfontein Point), bird colonies (Bird Island at Lambert's Bay) or Important Bird Areas (Orange River Mouth wetlands, Olifants River Estuary, Velorenvlei, Lower Berg River wetlands and the West Coast National Park and Saldanha Bay Islands).
- Extensive low-altitude coastal flights (<2,500 ft and within 1 nautical mile of the shore) should be avoided, particularly during the winter/spring (June to December) whale migration period and during the November to January seal breeding season. The flight path between the onshore logistics base in Kleinzee and drilling unit should be perpendicular to the coast. As no seasonal patterns of abundance are known for odontocetes occupying the proposed exploration area, a precautionary approach to avoiding impacts throughout the year is recommended.
- Aircraft may not, without a permit or an exemption, approach to within 300 m of whales in terms of the Marine Living Resources Act, 1998, without a permit. As this may be both impractical and impossible, an exemption permit must be applied for through the Department of Environmental Affairs.

- The contractor should comply fully with aviation and authority guidelines and rules.
- All pilots must be briefed on ecological risks associated with flying at a low level along the coast or above marine mammals.

Impacts of support aircraft on seabirds, seals, turtles and cetaceans		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to immediate area around drill unit	Local
Duration	Short-term	Short-term
Intensity	Low to High	Low
Significance	Low	Very Low
Status	Negative	Negative
Probability	Definite	Definite
Confidence	High	High

4.3.9 Pollution of the marine environment through operational Discharges to Water

During the drilling of an exploration well, normal discharges to the sea can come from a variety of sources (from drilling unit and support vessels). These discharges are regulated by onboard waste management plans and shall be MARPOL compliant. For the sake of completeness they are listed and briefly discussed below:

- **Deck drainage**: all deck drainage from work spaces is collected and piped into a sump tank on board the drilling unit to ensure MARPOL compliance (15 ppm oil in water). The fluid would be analysed and any hydrocarbons skimmed off the top prior to discharge. The oily substances would be added to the waste (oil) lubricants and disposed of on land.
- **Sewage**: sewage discharges will be comminuted and disinfected. In accordance with MARPOL Annex IV, the effluent must not produce visible floating solids in, nor causes discolouration of, the surrounding water. The treatment system must provide primary settling, chlorination and dechlorination before the treated effluent can be discharged into the sea. The discharge depth is variable, depending upon the draught of the drilling unit / support vessel at the time, but would not be less than 5 m below the surface.
- **Vessel machinery spaces and ballast water**: the concentration of oil in discharge water from vessel machinery space or ballast tanks may not exceed 15 ppm oil in water. If the vessel intends to discharge bilge or ballast water at sea, this is achieved through use of an oily-water separation system. Oily waste substances must be shipped to land for treatment and disposal.
- **Food (galley) wastes**: food wastes may be discharged after they have been passed through a comminuter or grinder, and when the drilling unit is located more than 3 nautical miles from land. Discharge of food wastes not comminuted is permitted beyond 12 nautical miles. The ground wastes must be capable of passing through a

screen with openings <25 mm. The daily volume of discharge from a standard drilling unit is expected to be <0.5 m^3.

- **Detergents**: detergents used for washing exposed marine deck spaces are discharged overboard. The toxicity of detergents varies greatly depending on their composition, but low-toxicity, biodegradable detergents are preferentially used. Those used on work deck spaces would be collected with the deck drainage and treated as described above.
- **Cooling Water:** electrical generation on drilling units is typically provided by large diesel-fired engines and generators, which are cooled by pumping water through a set of heat exchangers. The cooling water is then discharged overboard. Other equipment is cooled through a closed loop system, which may use chlorine as a disinfectant. Such water would be tested prior to discharge and would comply with relevant Water Quality Guidelines[3].

A further operational discharge is associated with routine well opening and closing operations. As part of these operations, the subsea BOP stack elements will vent ~12,000 litres of hydraulic fluid into the ocean at the seafloor. Concentrated BOP fluids, which are usually mineral oil- or glycol-water mixes are mildly toxic to crustaceans and algae (96 hr LC_{50} 102-117 ppm) but are completely biodegrade within 28 days.

The potential impact on the marine environment of such operational discharges from the drilling unit would be limited to the drilling location over the short-term. For support vessels travelling from Saldanha and/or Cape Town operational discharges would likewise be restricted to the immediate vicinity of the vessel over the short-term. As volumes discharged would be low, they would be of low intensity, and are therefore considered to be of **VERY LOW** significance, both without or with mitigation.

Mitigation

The following mitigation measures are recommended:

- Ensure compliance with MARPOL 73/78 standards,
- Develop a waste management plan using waste hierarchy.

Impacts of operational discharges to the sea from drilling units and support vessels		
	Without Mitigation	**Assuming Mitigation**
Extent	Local: limited to immediate area around drill unit or support vessel	Local
Duration	Short-term	Short-term
Intensity	Low	Low
Significance	Very Low	Very Low
Status	Negative	Negative
Probability	Highly Probable	Highly Probable
Confidence	High	High

[3] No South African guideline exists for residual chlorine in coastal waters. The Australian/New Zealand (ANZECC 2000) guidelines give a value of 3 µg Cl.ℓ^{-1}, wheras the World Bank (1998) guidelines stipulate 0.2 mg.ℓ^{-1} at the point of discharge prior to dilution

4.3.10 Oil Spills

The Fate of Hydrocarbons in the Marine Environment

Any release of liquid hydrocarbons has the potential for direct, indirect and cumulative effects on the marine environment. These effects include physical oiling and toxicity impacts to marine fauna and flora, localised mortality of plankton (particularly copepods), pelagic eggs and fish larvae, and habitat loss or contamination (CSIR 1998; Perry 2005).

Various factors determine the impacts of oil released into the marine environment. The physical properties and chemical composition of the oil, local weather and sea state conditions and currents greatly influence the transport and fate of the released product. The physical properties that affect the behaviour and persistence of an oil spilled at sea are specific gravity, distillation characteristics, viscosity and pour point, all of which are dependent on the oils chemical composition (e.g. the amount of asphaltenes, resins and waxes). Spilled oil undergoes physical and chemical changes (collectively termed 'weathering'), which in combination with its physical transport determine the spatial extent of oil contamination and the degree to which the environment will be exposed to the toxic constituents of the released product.

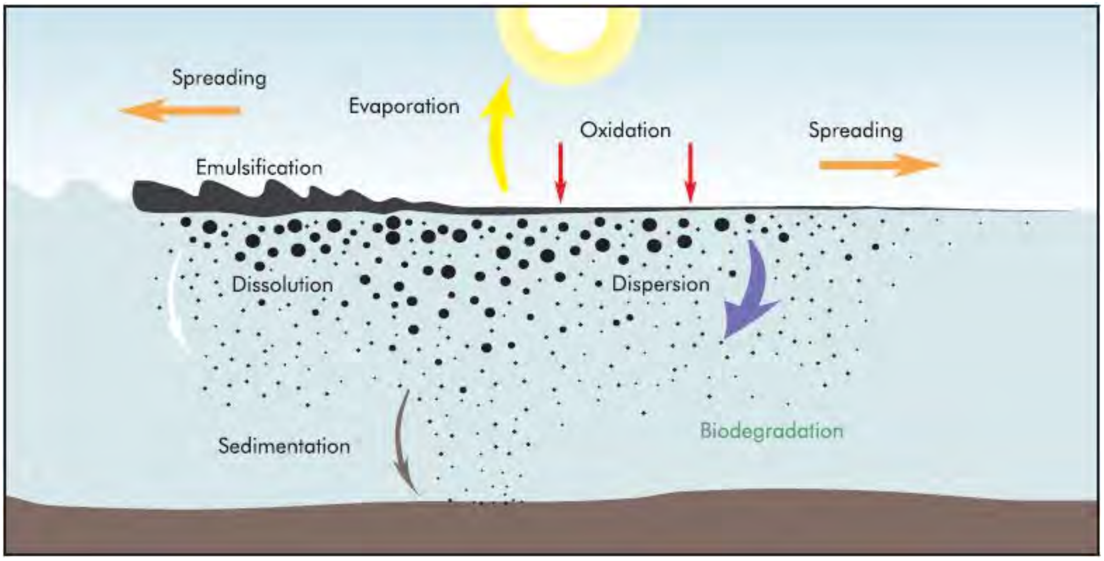
As soon as oil is spilled, various weathering processes (Figure 37A) come into play. Although the individual processes may act simultaneously, their relative importance varies with time (Figure 37B). Whereas spreading, evaporation, dispersion, emulsification and dissolution are most important during the early stages of a spill, the ultimate fate of oil is determined by the longer term processes of oxidation, sedimentation and biodegradation.

As a general rule, oils with a volatile nature, low specific gravity and low viscosity are less persistent and tend to disappear rapidly from the sea surface. In contrast, high viscosity oils containing bituminous, waxy or asphaltenic residues, dissipate more slowly and are more persistent, usually requiring a clean-up response.

Oil spilled in the marine environment will have an immediate detrimental effect on water quality. Most of the toxic effects are associated with the monoaromatic compounds and low molecular weight polycyclic hydrocarbons, as these are the most water-soluble components of the oil. Oil is most toxic in the first few days after the spill, losing some of its toxicity as it begins to weather and emulsify. The time of year during which a large spill takes place will significantly influence the magnitude of the impact on plankton and pelagic fish eggs and larvae. Should the spill coincide with a major spawning peak, it could result in severe mortalities and consequently a reduction in recruitment (Baker *et al.* 1990). However, spawning and recruitment success is temporally variable and environmental conditions are likely to have a far greater impact than a single large spill (Neff 1991). Sensitivity of fish eggs and larvae are primarily associated with exposure to fresh (unweathered) oils (Teal & Howarth 1984), with little mortality attributable to exposure to weathered product (Neff 1991). Because of their mobility and ability to avoid floating oil masses and the associated hydrocarbon contamination, adult pelagic fish are considered less at risk from exposure to oil spills than benthic or inshore species.

Surface spills in the offshore environment are unlikely to have an immediate effect on the seabed. However, oil in sediments as a result of accidental spillage near the coast, or the discharge of oil-contaminated drill cuttings, can result in physical smothering of the benthos and chronic pollution of the sediments. A wide range of effects of oil on benthic invertebrates has been recorded, with much of the research focussing on the various life stages of polychaetes, molluscs and crustaceans (Volkman *et al*. 1994). However, as tolerances and

A)



B)

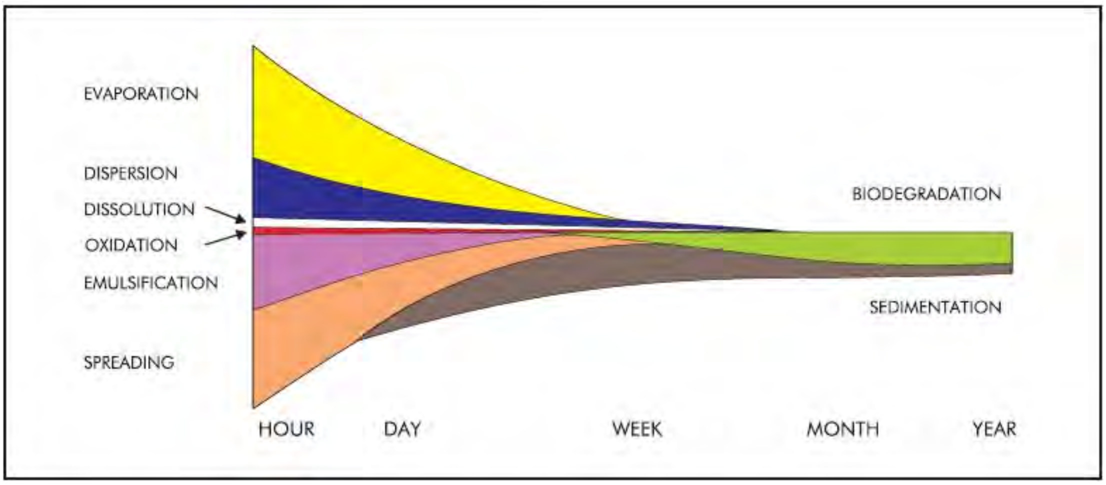


Figure 37: A) The weathering processes acting on spilled crude oil, and B) the fate of a typical medium crude oil under moderate sea conditions showing changes in the relative importance of weathering processes with time - the width of each band indicates the importance of the process (ITOPF 2002).

sensitivities vary greatly, generalisations cannot be confidently made. Some burrowing infauna (e.g. polychaetes and copepods) show high tolerances to oils, as the weathered product serves as a source of organic material that is suitable as a food source. Polychaetes in particular can take advantage of bioturbation and degradation of oiled sediments (Scholtz *et al*. 1992). This results in highly modified benthic communities with (potentially lethal) 'knock-on' effects for higher order consumers (see Section 4.3.3). Bioaccumulation of petroleum hydrocarbons by fish through oil-contaminated prey and sediments is a well-described phenomena (CSIR 2011).

Volkman *et al*. (1994) suggest that some epifauna produce complex responses to oiling and that bioaccumulation of petroleum hydrocarbons can in some cases readily occur. Sessile and motile molluscs (e.g. mussels and crustaceans) are frequent victims of direct oiling or coating. Filter-feeders in particular are susceptible to ingestion of oil in solution, in dispersion or adsorbed on fine particles. Chronic oiling is known to cause a multitude of sub-lethal responses in taxa at different life stages, variously affecting their survival and potential to re-colonise oiled areas. Tolerances to oil vary between life stages, with larvae and juvenile stages generally being more sensitive to the water-soluble fractions of oil than adults (Volkman *et al.* 1994; CSIR 2011).

Impacts of oil on juvenile and adult fish can be lethal, as gills may become coated with oil. Sub-lethal and long-term effects can include disruption of physiological and behavioural mechanisms, reduced tolerance to stress, and incorporation of carcinogens into the food chain (Thomson *et al*. 2000). However, being mobile, fish are likely to be able to avoid a large spill.

Chronic and acute oil pollution is a significant threat to both pelagic and inshore seabirds. Diving sea birds that spend most of their time on the surface of the water are particularly likely to encounter floating oil and will die as a result of even moderate oiling which damages plumage and eyes. The majority of associated deaths are as a result of the properties of the oil and damage to the water repellent properties of the birds' plumage. This allows water to penetrate the plumage, decreasing buoyancy and leading to sinking and drowning. In addition, thermal insulation capacity is reduced requiring greater use of energy to combat cold. Oil is also ingested as the birds preen in an attempt to clear oil from plumage and may furthermore be ingested over the medium to long term as it enters the food chain (Munro 2004). The effects of ingested oil include anaemia, pneumonia, intestinal irritation, kidney damage, altered blood chemistry, decreased growth, impaired osmoregulation, and decreased production and viability of eggs (Scholz *et al.* 1992). Furthermore, even small concentrations of oil transferred from adult birds to the eggs can cause embryo mortalities and significantly reduce hatching rate. Oil spills can thus have an effect on birds that may be some distance from the spill site, which can be attributed to the parent's feeding habits.

Impacts of oil spills on turtles is thought to primarily affect hatchling survival (CSIR & CIME 2011). Turtles encountered in the project area would mainly be migrating adults and vagrants. Similarly, little work has been done on the effect of an oil spill on fur seals, but they are expected to be particularly vulnerable as oil would clog their fur and they would die of hypothermia (or starvation, if they had taken refuge on land).

The effects of oil pollution on marine mammals is poorly understood (White *et al*. 2001), with the most likely immediate impact of an oil spill on cetaceans being the risk of inhalation of volatile, toxic benzene fractions when the oil slick is fresh and unweathered (Geraci & St Aubin 1990, cited in Scholz *et al*. 1992). Common effects attributable to the inhalation of such compounds to include absorption into the circulatory system and mild irritation to permanent damage to sensitive tissues such as membranes of eyes, mouth and respiratory tract. Direct oiling of cetaceans is not considered a serious risk to the thermoregulatory capabilities, as cetacean skin is thought to contain a resistant dermal shield that acts as a barrier to the toxic substances in oil. Baleen whales may experience fouling of the baleen plates, resulting in temporary obstruction of the flow of water between the plates and, consequently, reduce feeding efficiency. Field observations record few, if any, adverse effects among cetaceans from direct contact with oil, and some species have been recorded swimming, feeding and surfacing amongst heavy concentrations of oil (Scholz *et al*. 1992) with no apparent effects.

Brief Summary of Oil Spill Modelling Results

The oils spill modelling undertaken by PRDW (2013) was divided into two main sections, namely:

1) Small instantaneous spills of hydraulic fluid (1 ton) or diesel (10 tons), where the dominant weathering processes are evaporation and dispersion.
2) Large blow out of crude oil at the seabed under 5-day and 20-day blow out scenarios. For crude oil the weathering processes over the short-term (hours to weeks) include evaporation, dispersion, dissolution, photo-oxidation, emulsification and spreading, whereas biodegration and sedimentation dominate the weathering processes over the medium- to long-term (weeks to years).

The spill scenarios were based on historical meteorological and oceanographic data to model the most realistic surface and sub-surface conditions during the summer (October – March) and winter (April – September) seasons. As the small operational spills would typically occur near the sea surface and involve the light volatile fraction of aromatics and other oil components with a low molecular weight, the spills would disperse rapidly from the point source and remain at the sea surface for no more than a few days. In contrast, in the case of a large blow out, the discharge of crude oil would leave the seabed under momentum, which together with the buoyancy of the oil/gas mixture would result in a rapid rise of the plume in the water column. However, gas hydrate formation and the entrainment of ambient water would likely result in the plume being trapped about 60 m above the seabed (Spaulding *et al.* 2000). Thereafter, the oil particles would rise towards the surface as a function of oil droplet diameter and the differences in oil and water density. The larger fractions would reach the surface within 0.3 to 3.3 days, whereas the smaller fractions would take in excess of 30 days to reach the surface.

The model results and consequently the assessment of risks have an element of uncertainty associated with them, namely the unknown characteristics of the crude oil itself and uncertainties regarding the long-term weathering behaviour of oil from a deepwater blow out. To offset these uncertainties, three different weathering rates were modelled: fast, medium and slow weathering. The medium weathering scenario is considered to be the most likely, but as a precautionary approach, the slow weathering scenario was assumed for the impact assessment.

The results of the oil spill modelling exercise are summarised below:

Scenario	Result
1 ton of hydraulic fluid	• travels as a narrow plume up to 150 km north-westwards from the source, • oil remains at the sea surface for a maximum of 2 days before a combination of oil dispersion and spreading reduces the oil thickness below 0.3 µm, • no probability of it reaching the shoreline.
10 tons diesel spill	• moves ~110 km from the source, also as a narrow plume predominantly in a north-westerly direction, • diesel remains on the sea surface for <36 hrs before oil dispersion and spreading reduces the oil thickness below 0.3 µm, • no probability of reaching the coastline.

Scenario	Result
5-day & 20-day blow out	• extensive areas of oiling of both sub-surface and surface waters, • Once the oil surfaces it generally moves in a north-westerly direction as a relatively confined plume due to the prevailing near-surface currents and winds (Figure 38), • probability of shoreline oiling reduced, but oiling may nonetheless occur, particularly for the longer duration blow outs during winter and for the slow oil weathering scenario, • portions of coastline affected would be from Lüderitz to ~150 km south, and a point on the coast between Hondeklipbaai and Lamberts Bay, • minimum time to oiling would be longer than 35 days (Figure 39), • 5-day blow-out has no probability of shoreline oiling (summer drilling, slow weathering), • 20-day blow-out has <10% probability of shoreline oiling at a point between Oranjemund and Cape Town (Figure 40), • Drilling during winter significantly increases the probability of shoreline oiling in the event of a spill.

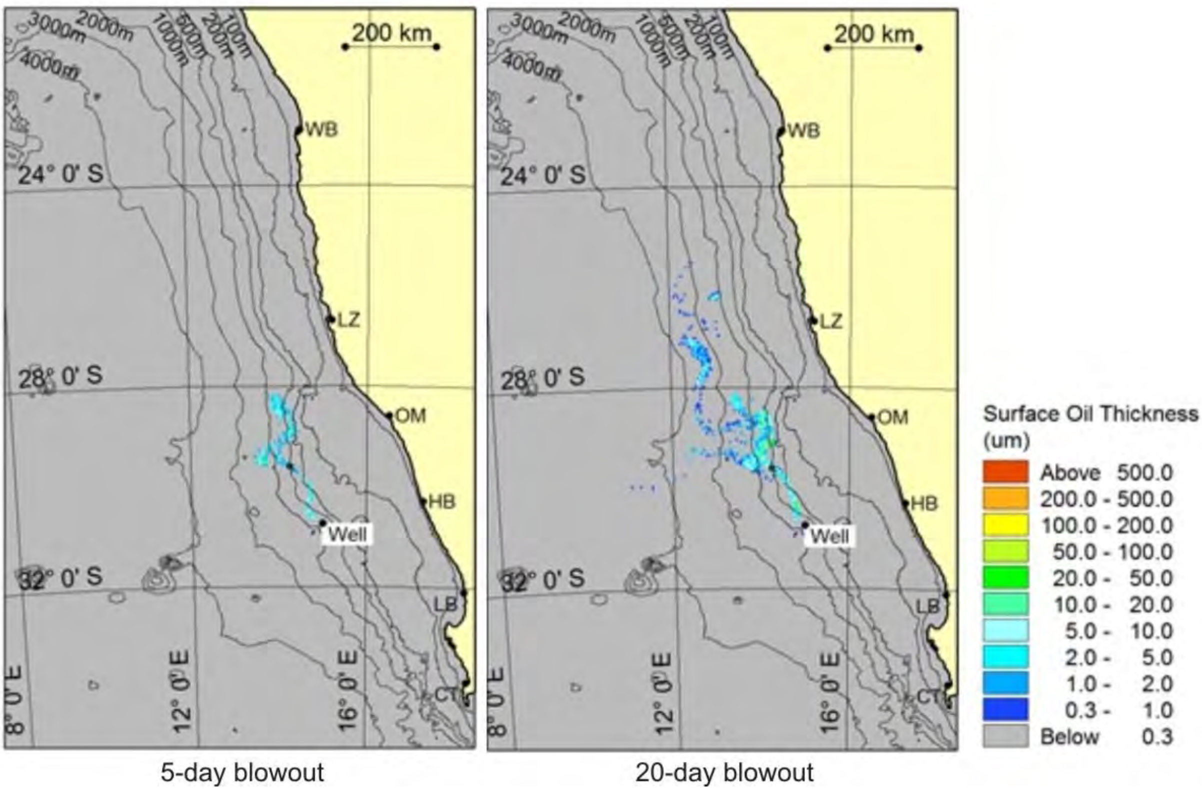


Figure 38: Instantaneous surface oil patches 14 days after the start of 5-day and 20-day blowouts under the slow weathering scenario (adapted from PRDW 2013).

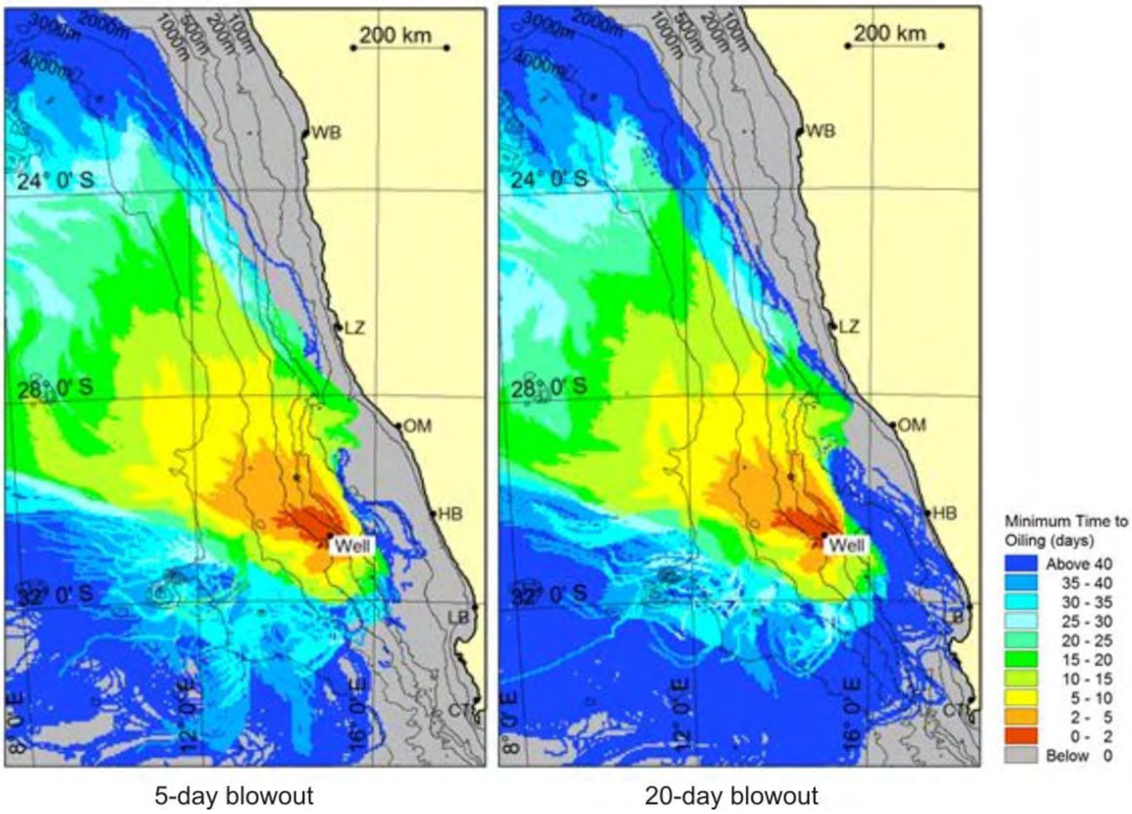


Figure 39: Minimum time to surface oiling (from start of spill) in summer for 5-day and 20-day blowouts under the slow weathering scenario (adapted from PRDW 2013).

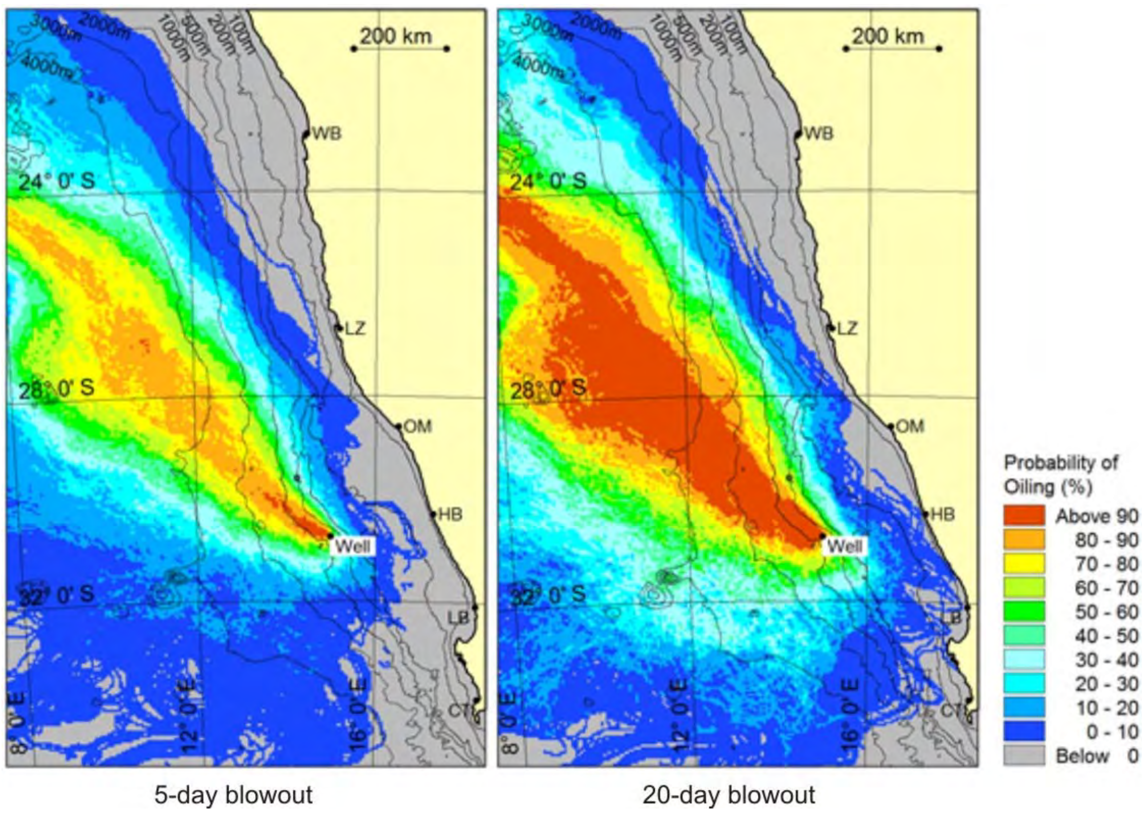


Figure 40: Probability of a surface oiling event in summer for 5-day and 20-day blowouts under the slow weathering scenario (adapted from PRDW 2013).

Based on these results, under the highly unlikely worst-case scenario of a 20-day blow out, there is thus a potential risk of a major spill affecting portions of the central and southern Benguela coastline. Of particular concern here are the Namibian Islands south of Lüderitz, which serve as important breeding habitats to numerous Red listed seabirds. It must be kept in mind though that the modelled scenarios assume that no spill response actions are implemented. The low to medium risk of a beaching incident from the drilling location, and the large spatial extent potentially involved in the case of a spill makes extensive shore-based protection both impractical and unwarranted. Furthermore, as advanced well intervention and capping equipment is available in Saldanha Bay for deployment in the event of a subsea well control incident, the likelihood of oil reaching the shore in the event of a blow out is further reduced. This assessment thus focusses primarily on the risk to offshore marine resources from a potential spill.

The environmental impacts associated with the various oil spill scenarios modelled by PRDW (2013) are assessed below, based on the footprints for the probability of sub-surface and surface oiling from spill events assuming slow weathering of the oil. The assessment has also assumed well drilling would occur during summer. Despite slightly larger footprints for spills occurring during winter, the overall significance rating would not change.

Major Spills

While the probability of a major spill happening is extremely small, the impact nonetheless needs to be considered as it could have devastating effects on the marine environment. Assuming the worst-case scenario of a 20-day blow out of slow-weathering crude oil, the potential impact on the marine environment would be of high intensity and would likely persist over the medium- to long-term. Results of the oil spill modelling study indicated that the spill would spread in a north-westerly direction, extending over 650 km into Namibian waters thus being of international extent. The probability of surface oil reaching the coast is, however, low (<10%), with the area potentially affected being between Hondeklipbaai and Saldanha. In the unlikely event of a spill, the impact is thus considered to be of **VERY HIGH** significance before mitigation, and of **HIGH** significance with mitigation.

Impacts of a major spill following a blow out on deepwater benthic macrofauna		
	Without Mitigation	**Assuming Mitigation**
Extent	Local	Local
Duration	Medium-term	Medium-term
Intensity	Low	Low
Significance	Very Low	Very Low
Status	Negative	Negative
Probability	Improbable	Improbable
Confidence	High	High

Impacts of a major spill following a blow out on pelagic fish and larvae		
	Without Mitigation	**Assuming Mitigation**
Extent	International	Regional
Duration	Short-term	Short-term
Intensity	Medium	Medium
Significance	Medium	Low
Status	Negative	Negative
Probability	Improbable	Improbable
Confidence	High	High

Impacts of a major spill following a blow out on seabirds		
	Without Mitigation	**Assuming Mitigation**
Extent	International	Regional
Duration	Medium to Long-term	Medium-term
Intensity	High	Medium
Significance	Very High	Medium
Status	Negative	Negative
Probability	Improbable	Improbable
Confidence	High	High

Impacts of a major spill following a blow out on marine mammals and turtles		
	Without Mitigation	**Assuming Mitigation**
Extent	International	Regional
Duration	Medium to Long-term	Medium-term
Intensity	Low	Low
Significance	Medium	Low
Status	Negative	Negative
Probability	Improbable	Improbable
Confidence	High	High

Operational Spills

There is a far greater probability of a minor spill of hydrocarbons, chemicals or drilling mud than of a blow out and major spill. Operational spills may arise from bunkering of fuel oil (offshore or in port), the storage and handling of oil drums or faults in the oil/water separator and the rig drainage system. Smaller scale spills from vessel movements and loading/unloading operations in port pose a far greater risk to the nearshore environment than a major spill at the offshore drilling site. Operational spills from vessels would involve either fuel or lube oils rather than crude. Evaporation of lighter fuel oil fractions would be far quicker than for a crude spill, removing a proportion of the volatile component of the spill to the atmosphere. Despite the lower quantities and greater evaporation potential, the environmental consequences of a nearshore spill are potentially far greater than a major offshore spill, although the severity will depend on where the spill takes place. If a spill occurs in port while bunkering/loading the impact would most likely be easily managed and the risk / impact would be low. If the spill occurs at the drilling unit, it may be more difficult to contain and would more readily disperse, but would be unlikely to reach the shore due to the offshore location of the drill site. A spill *en route* to the drilling site would only occur in the unlikely event of a vessel collision. The use of standby vessels with spill response capability (both booms and dispersant spraying equipment) would ensure that a first tier response is available at both the well site and port area at all times.

The potential impact on the marine environment would be of high intensity but would likely only persist over the short-term. Results of the oil spill modelling study indicated that an offshore spill would spread in a north-westerly direction and will not reach the shore. Areas experiencing a >30% probability of oiling would extend ~20 km from the source of the spill within 8 hrs. Unless contained and managed within a port, a nearshore spill is likely to reach the shore though wave action and tidal currents. The significance of the impact of an operational spill at the well site or near the coast is dependent on the biota likely to be affected. In most cases the impacts can be considered of **VERY LOW** significance both before and after mitigation, with the exception of seabirds, where the impact is considered to be of **MEDIUM** significance before mitigation, and of **LOW** significance with mitigation.

Offshore Operational Spill

Impacts of an operational spill at the well site on deepwater benthic macrofauna		
	Without Mitigation	**Assuming Mitigation**
Extent	Regional	Local
Duration	Short-term	Short-term
Intensity	Zero	Zero
Significance	Insignificant	Insignificant
Status	Negative	Negative
Probability	Improbable	Improbable
Confidence	High	High

Impacts of an operational spill at the well site on pelagic fish and larvae		
	Without Mitigation	**Assuming Mitigation**
Extent	Regional	Local
Duration	Short-term	Short-term
Intensity	Low	Low
Significance	Very Low	Very Low
Status	Negative	Negative
Probability	Probable	Probable
Confidence	High	High

Impacts of an operational spill at the well site on seabirds		
	Without Mitigation	**Assuming Mitigation**
Extent	Regional	Regional
Duration	Short-term	Short-term
Intensity	High	Medium
Significance	Medium	Low
Status	Negative	Negative
Probability	Probable	Probable
Confidence	High	High

Impacts of an operational spill at the well site on marine mammals and turtles		
	Without Mitigation	**Assuming Mitigation**
Extent	Regional	Local
Duration	Short-term	Short-term
Intensity	Low	Low
Significance	Very Low	Very Low
Status	Negative	Negative
Probability	Probable	Probable
Confidence	High	High

Nearshore Operational Spill

Impacts of an operational spill near the shore on intertidal and subtidal fauna and flora		
	Without Mitigation	**Assuming Mitigation**
Extent	Regional	Local
Duration	Short-term	Short-term
Intensity	High	High
Significance	Medium	Low
Status	Negative	Negative
Probability	Probable	Probable
Confidence	High	High

Impacts of an operational spill near the shore on pelagic fish and larvae		
	Without Mitigation	**Assuming Mitigation**
Extent	Regional	Local
Duration	Short-term	Short-term
Intensity	Medium	Low
Significance	Very Low	Very Low
Status	Negative	Negative
Probability	Probable	Probable
Confidence	High	High

Impacts of an operational spill near the shore on seabirds		
	Without Mitigation	**Assuming Mitigation**
Extent	Regional	Regional
Duration	Short-term	Short-term
Intensity	High	Medium
Significance	Medium	Low
Status	Negative	Negative
Probability	Probable	Probable
Confidence	High	High

Impacts of an operational spill near the shore on marine mammals and turtles		
	Without Mitigation	**Assuming Mitigation**
Extent	Regional	Local
Duration	Short-term	Short-term
Intensity	Low	Low
Significance	Very Low	Very Low
Status	Negative	Negative
Probability	Probable	Probable
Confidence	High	High

Well Tests

Following well tests the rig is unable to contain the resultant hydrocarbons and these are necessarily sent to the burner boom for disposal by flaring. Inefficient combustion of hydrocarbons can result in the release of unburnt hydrocarbons, which 'drop-out' onto the sea surface and may form a visible slick of oil, where they can result in localised impacts to seabirds and other marine animals.

The impact of hydrocarbon 'drop-out' during flaring is considered to be of **VERY LOW** significance both without and with mitigation.

Impacts of hydrocarbon 'drop-out' during flaring on offshore areas		
	Without Mitigation	**Assuming Mitigation**
Extent	Local	Local
Duration	Short-term	Short-term
Intensity	Low	Low
Significance	Very Low	Very Low
Status	Negative	Negative
Probability	Probable	Probable
Confidence	High	High

Mitigation

The following mitigation measures are recommended for major oil spills, operational spills and well tests:

- Ensure that adequate oil spill contingency plans are in place at all times to ensure that spills can be effectively handled.
- As far as possible, and whenever the sea state permits, attempt to control and contain the spill at sea with suitable recovery techniques to reduce the spatial and temporal impact of the spill.
- Use dispersants cautiously and only with the permission of DEA (Marine Pollution Division) as they are often as toxic to marine life as the spill itself.
- In the case of small operational spills offshore, no mitigatory action would be necessary, unless large numbers of pelagic seabirds are present, in which case consideration should be given to spraying the spill with dispersants, if sea conditions permit and permission has been obtained from DEA.
- Ensure adequate resources are available to collect and transport oiled birds to a cleaning station.
- Should spills of crude oil reach the shore, Shell would need to comply with the approved oil spill contingency plan for the operation.
- Hydrocarbon 'drop-out' during well testing can be minimised by the use of a high efficiency burner for flaring and through accurate control of the mix of hydrocarbons and air going to flare.

4.3.11 Cumulative impacts

The primary impacts associated with the drilling of an exploration well in the Atlantic Offshore Bioregion on the West Coast of South Africa, relate to physical disturbance of the seabed, discharges of drilling solids to the benthic environment, the presence of infrastructure remaining on the seabed and associated vessel or oil rig presence. The development of the proposed exploration well(s) in this assessment would impact an area of ~0.09 km^2 (per well) in the Atlantic Offshore Bioregion, which can be considered an insignificant percentage of the bioregion as a whole. Cumulative impacts from other hydrocarbon exploration ventures in the area are likely to be limited. Although no wells have been drilled in this Bioregion to date, further exploratory drilling is being proposed for Block 1, to the north and inshore of the Orange Deep Water Licence area and within the Namaqua Bioregion. In the Namaqua Bioregion ~40 wells have been drilled since 1976. The majority of these occur in the Ibhubesi gas field in Block 2A. Prior to 1983, technology was not available to remove wellheads from the seafloor. Of the approximately 40 wells drilled on the West Coast, 35 wellheads remain on the seabed. The total area impacted by 40 petroleum exploration wells is estimated at around 10 km^2, or ~0.038 % of the Namaqua bioregion.

Other activities that may have contributed to cumulative impacts to the benthic environment in the licence area include limited historical deep water trawling (see CapFish 2013 - Fisheries Specialist Study), and the installation of the subsea telecommunications cables SAT1, SAT2 and SAT3, which traverse the Orange Deep Water Licence area in a NW-SE direction beyond the 2,000 m contour. The subsea cables, however, lie offshore of the area of interest for exploratory drilling.

5. CONCLUSIONS AND RECOMMENDATIONS

The potential environmental effects of drilling solids discharges have been discussed in several studies (Morant 1999; Husky 2000, 2001; CAPP 2001; Hurley & Ellis 2004; Trefy *et al*. 2013), all of which concluded that exploratory drilling of a single well within a large spatial area has no measureable effect on the marine environment.

The few studies investigating benthic communities, habitats or ecosystems in the offshore environments of South Africa's West Coast have focussed primarily on the impacts of offshore diamond mining activities at depths not exceeding 150 m. Knowledge of seabed communities at the depths of the proposed wells is lacking.

The impacts on marine habitats and communities associated with the proposed drilling of 1-2 exploratory wells in the Orange Basin Deep Water area are summarised in the Table below (Note: * indicates that no mitigation is possible and / or considered necessary, thus significance rating remains). The total area to be impacted by the proposed exploration drilling can be considered negligible with respect to the total area of the Atlantic Offshore bioregion.

Impact	Probability	Significance (before mitigation)	Significance (after mitigation)
Removal or crushing of benthic macrofauna in unconsolidated sediments during well installation	Definite	Very Low	Very Low
Removal or crushing of benthic macrofauna of deepwater reefs during well installation	Improbable	Medium	Very Low
Smothering of benthic macrofauna by drilling solids discharged directly onto the seabed during well spudding and drilling of the initial section with WBMs	Highly probable	Low	Low
Smothering of soft-sediment benthic macrofauna	Highly probable	Very Low	Very Low
Smothering of vulnerable reef communities by drilling solids discharged at the surface depositing onto the seabed	Improbable	Medium - High	Low
Reduced physiological functioning of marine organisms due to biochemical effects of Water-Based drilling muds	Highly probable	Very Low	Very Low
Reduced physiological functioning of marine organisms due to biochemical effects of Synthetic-Based Drilling muds	Highly probable	Very Low	Very Low
Reduced physiological functioning of marine organisms due to biochemical effects of cementing	Highly probable	Very Low	Very Low
Reduced physiological functioning of marine organisms due to increased water column turbidity due to discharge of cuttings near the surface	Probable	Very Low	Very Low*

Impact	Probability	Significance (before mitigation)	Significance (after mitigation)
Reduced physiological functioning of marine organisms due to increased turbidity near the seabed due to discharge of WBMs and cuttings at the seabed	Improbable	Very Low	Very Low*
Reduced physiological functioning of marine organisms due to the development of anoxic sediments in the cuttings depositional footprint due to biodegradation of the organic constituents of WBMs	Probable	Very Low	Very Low*
Threats to Benguela ecosystem biodiversity through the introduction of invasive species on petroleum infrastructure	Probable	High - Very High	Medium
Impacts on marine biodiversity: wellhead is lifted from the seafloor during abandonment	Improbable	Low	Low*
Impacts on marine biodiversity: wellhead remains on the seafloor during abandonment	Probable	Low	Low*
Disturbance of seabirds, seals, turtles and cetaceans through noise from well-drilling operations	Highly Probable	Very Low	Very Low*
Disturbance of seabirds, seals, turtles and cetaceans through noise generated by support aircraft	Definite	Low	Very Low
Pollution of the marine environment through operational discharges to the sea from drilling units and support vessels	Highly Probable	Very Low	Very Low
Toxic effects on marine organisms of a major spill following a blow out	Improbable	Very High	High
Toxic effects on marine organisms of an operational spill at the well site	Probable	Medium	Low
Toxic effects on marine organisms of an operational spill in nearshore areas	Probable	Medium	Very Low
Toxic effects of hydrocarbon ‘drop-out’ during flaring on offshore areas	Probable	Very Low	Very Low

If all environmental guidelines, and appropriate mitigation measures advanced in this report, and the EMP for the proposed exploration drilling project as a whole, are implemented, there is no reason why the proposed well drilling should not proceed.

5.1. Recommended Mitigation Measures

The mitigation measures proposed below are based largely on the guidelines currently accepted for exploratory well drilling in South Africa, but have been revised to include salient points from international guidelines discussed in the documents cited above.

- Use the existing seismic data to conduct a pre-drilling geohazard analysis of the seabed, and near-surface substratum. In doing so, map potentially vulnerable habitats to prevent potential conflict with the well site;
- Consider pre- and post-drilling site surveys using a Remotely Operated Vehicle (ROV) to survey the seafloor, to identify any significant topographic features (e.g. rocky outcrops) or vulnerable habitats (e.g. hard grounds) and species (e.g. cold-water corals, sponges). If detected, adjust the well position accordingly, keeping in mind the smothering effects anticipated as a consequence of seabed and surface cuttings discharges.
- If vulnerable seabed communities were identified in the vicinity of the proposed well locations, implement innovative technologies and operational procedures for drilling solids discharges to minimise the impacts (see for example Jødestøl & Furuholt 2010).
- Use the results of cuttings dispersal modelling in combination with information from the post-drill ROV survey to assess the magnitude of the impacts of cuttings disposal on seabed communities in the vicinity of the well;
- Ensure regular maintenance of the onboard solids control package;
- Aid dispersion of the discharged cuttings and mud by placing the cuttings chute several metres below the sea surface.
- Maximise the use of water-based drilling muds at all times, using risered SBMs only when necessary;
- Ensure only low-toxicity and partially biodegradable additives are used;
- All recovered SBM should be stored on board and taken to shore for treatment and reuse;
- Avoid excess cement usage by monitoring discharges to the seafloor around the surface casing by ROV survey; and
- Ensure only low-toxicity and partially biodegradable cement additives are used.
- De-ballasting of vessels to be undertaken only under strict adherence to International Maritime Organisation (IMO) Guidelines governing discharge of ballast waters at sea.
- Reballasting at sea currently provides the best available measure to reduce the risk of transfer of harmful aquatic organisms, but is subject to ship-safety limits. The IMO note that vessels using ballast water exchange should whenever possible, conduct such exchange at least 200 nautical miles from the nearest land and in water of at least 200 m depth. Where the ship is unable to conduct ballast water exchange as described, the exchange should be as far from the nearest land as possible, and a minimum of 50 nautical miles from the nearest land and in water at least 200 m in depth.
- Other precautionary guidelines suggested by the IMO include:
    - During the loading of ballast, every effort should be made to avoid the uptake of potentially harmful aquatic organisms, pathogens and sediment that may contain such organisms, through adequate filtration procedures;

- Where practicable, routine cleaning of the ballast tank to remove sediments should be carried out in mid-ocean or under controlled arrangements in port or dry dock, in accordance with the provisions of the ship's ballast water management plan; and
- Avoidance of unnecessary discharge of ballast water.

- Flight paths must be pre-planned to ensure that no flying occurs over coastal reserves (MacDougall's Bay), seal colonies (Buchu Twins, Kleinzee and Strandfontein Point), bird colonies (Bird Island at Lambert's Bay) or Important Bird Areas (Orange River Mouth wetlands, Olifants River Estuary, Velorenvlei, Lower Berg River wetlands and the West Coast National Park and Saldanha Bay Islands).
- Extensive low-altitude coastal flights (<2,500 ft and within 1 nautical mile of the shore) should be avoided, particularly during the winter/spring (June to December) whale migration period and during the November to January seal breeding season. The flight path between the onshore logistics base in Kleinzee and drilling unit should be perpendicular to the coast. As no seasonal patterns of abundance are known for odontocetes occupying the proposed exploration area, a precautionary approach to avoiding impacts throughout the year is recommended.
- Aircraft may not, without a permit or an exemption, approach to within 300 m of whales in terms of the Marine Living Resources Act, 1998, without a permit. As this may be both impractical and impossible, an exemption permit must be applied for through the Department of Environmental Affairs.
- The contractor should comply fully with aviation and authority guidelines and rules.
- All pilots must be briefed on ecological risks associated with flying at a low level along the coast or above marine mammals.
- Adhere strictly to best management practices recommended in the relevant EMPr and that of MARPOL 73/78 (International Convention for the Prevention of Pollution from Ships, 1973) for all necessary disposals at sea.
- Ensure that adequate oil spill contingency plans are in place at all times.
- As far as possible, and whenever the sea state permits, attempt to control and contain the spill at sea with suitable recovery techniques to reduce the spatial and temporal impact of the spill.
- Use dispersants cautiously and only with the permission of DEA (Marine Pollution Division) as they are often as toxic to marine life as the spill itself.
- In the case of small operational spills offshore, no mitigatory action would be necessary, unless large numbers of pelagic seabirds are present, in which case consideration should be given to spraying the spill with dispersants, if sea conditions permit and permission has been obtained from DEA.
- Ensure adequate resources are available to collect and transport oiled birds to a cleaning station.
- Should spills of crude oil reach the shore, Shell would need to comply with the approved oil spill contingency plan for the operation.
- Hydrocarbon 'drop-out' during well testing can be minimised by the use of a high efficiency burner for flaring and through accurate control of the mix of hydrocarbons and air going to flare.

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