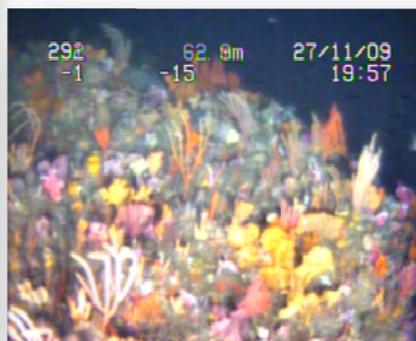




Assessment of offshore benthic biodiversity on the Agulhas Bank and the potential role of petroleum infrastructure in offshore spatial management



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EXECUTIVE SUMMARY

South African offshore benthic biodiversity is generally poorly known. Benthic communities on petroleum infrastructure have not been studied, species lists have not been compiled, impacts on biodiversity have never been assessed and the potential role of this infrastructure in spatial management has not been examined. The Agulhas Bank is an important region for offshore biodiversity, fisheries and petroleum activities. The lack of information on benthic biodiversity and the poor knowledge of the effect of activities such as trawling and petroleum production impair decision making in this area. This collaborative project aimed to improve the knowledge of offshore benthic biodiversity on the Agulhas Bank and assess the implications of existing petroleum infrastructure on selected components of benthic biodiversity.

This project drew from international published literature, historical reports from research conducted at the FA-platform between 1992 and 1999 and existing Remotely Operated Vehicle (ROV) footage obtained by PetroSA from surveys undertaken in 2005, 2006 and 2008. Dedicated sampling was conducted in 2009 using ROV surveys, fish traps, saturation (SAT) diver collections and benthic grabs. As benthic macrofauna provide a good indicator of ecosystem status, the project included research on benthic infauna and sediment characteristics to assess potential petroleum impacts inside and outside of a petroleum exclusion zone. The project also facilitated the first ROV surveys of deep reef and adjacent sandy habitats on the Agulhas Bank to allow comparison with fauna on infrastructure and to assess the relative importance of these areas for offshore biodiversity protection.

Historical reports from the shallower sections of the FA platform revealed 48 invertebrate species, only four of which were observed during more recent surveys. A total of 54 invertebrate and 6 fish species were documented at the FA platform on existing ROV footage whereas 51 invertebrates and 17 fish species (5 close to the surface and 12 at the seabed) were documented in the Oribi/Oryx area. Dedicated sampling by SAT divers in the vicinity of Oribi/Oryx yielded 38 macro-invertebrate species. A total of 22 fish species were documented in dedicated ROV surveys at deep reefs and sandy areas, with important commercial linefish species observed at all deep reef complexes outside the exclusion zone. A total of 100 benthic infaunal species were identified from unconsolidated (sandy) habitats in the Oribi/Oryx area.

Existing ROV footage showed that the FA platform supports a well developed invertebrate assemblage that is structured with depth with the fouling community being more developed in 2008 than in 2005. At the Oribi/Oryx field, surveys of different infrastructure components allowed assessment of types of fauna, including introduced species, on different types of infrastructure. This will help to support decommissioning decisions about these different components. Shallow water (0 - 30 m) fouling assemblages examined in this study were mostly representative of intertidal and shallow subtidal assemblages in the Agulhas region. In deeper water, assemblages on infrastructure showed little similarity with the invertebrate fauna found on deeper reefs, although high variability between reef sites was noted. It seems that existing infrastructure has limited value in protecting representative benthic assemblages and no vulnerable marine ecosystems or reef building cold water coral species were documented in association with infrastructure during our surveys.

The sandy habitats surveyed by ROV on the Agulhas Bank revealed at least three different epifaunal assemblages. The untrawled areas (i.e. within the Sable exclusion zone and adjacent to a deep reef) hosted a greater diversity of structure-forming epifaunal species and there was considerable variation between sites i.e. two distinct communities. The two trawled areas surveyed (i.e. within The Blues) hosted similar species and were largely colonized by two dominant epifaunal species, a burrowing urchin and a burrowing tube anemone.

The overlap between the benthic fish fauna associated with petroleum infrastructure and that of deep reefs was confined to four species and no commercially important sparid species were encountered on any of the infrastructure footage deeper than 10 m. This suggests that the installations do not support ichthyofauna representative of deep reef areas on the Agulhas Bank but more dedicated work

is required for more conclusive information. These preliminary results suggest that the installations provide limited value as a refuge for vulnerable, reef-associated linefish species. Kingklip *Genypterus capensis* was the only commercially important fish species that was encountered at petroleum installations on the sea bed. Jacopever *Helicolenus dactylopterus* also occurred in relatively high densities on seabed infrastructure at both the FA platform and Oribi/Oryx fields. Due to the limited dive time and fishing effort the results are far from conclusive, but we found no evidence of a positive effect of the exclusion zone for fish associated with unconsolidated sediment. Although hake *Merluccius sp* was encountered on both dives in trawl areas adjacent to the petroleum area, no hake were observed in any of the footage inside petroleum areas. Hake exhibit neutral behavior towards the ROV and flight reaction can be excluded as an explanation for the low hake density. Trawl sampling within exclusion areas is needed if further insight into potential benefits for hake are to be assessed.

The deep reef footage acquired through this project provided the first images of this inaccessible and poorly studied habitat, advancing science and providing important information to support planning for the protection of threatened fish species and vulnerable seabed ecosystems.

The documentation of at least 5 introduced species, the expansion of two cryptogenic species into deep water and the presence of at least 3 unidentified possibly introduced species is cause for concern. South Africa's most significant marine invasive, the European mussel *Mytilus galloprovincialis*, two introduced, invasive anemones and two introduced ascidians were documented during the very limited sampling. The most severe infestations of the introduced anemone *Metridium senile* were recorded on the six inch oil export pipeline in the Oribi/Oryx field whereas *Sagartia elegans*, a probable new introduction, was common at both the FA platform and on infrastructure in the Oribi/Oryx field. The invasive status of the two ascidian species is unknown but neither of these indistinct taxa were observed in any ROV footage. A further anemone, an unidentified octocoral or colonial ascidian and a tunicate were conspicuous, unidentified species that were identified as priority taxa for collection and identification in the near future as these may also represent introduced taxa.

Benthic infaunal assemblages sampled closest to the wellhead were significantly different to those sampled more than 250 m away, suggesting some degree of petroleum impact within a 250 m radius of the sampled wellhead. Untrawled sites sampled up to 10 km away from the wellhead also hosted significantly different infaunal assemblages to all other sites sampled. No significant differences were detected among infaunal assemblages at all remaining sites sampled, whether they were within or outside of the exclusion zone, suggesting that both trawling and petroleum activities result in similar impact effects on infaunal assemblages. Changes detected in benthic fauna in this study (i.e. within 250 m radius of the wellhead) were most likely a result of physical disturbance rather than petrochemical effects. Potential benthic pollution impacts from petroleum activities were assessed for the first time in South Africa. Sediment properties measured (particle size, organic carbon, trace metals and hydrocarbons) showed no significant differences among any sites. The continued use of water based drilling fluids is recommended and we suggest further collaboration with the petroleum sector to ensure that where other types of drilling fluids are necessary, appropriate environmental practice and monitoring is implemented.

We recommend that the results of this project be factored into the environmental, safety, economic and technical considerations that contribute to the decommissioning process and that this work is taken forward to improve environmental management within the petroleum sector. The risk of introducing or spreading non-indigenous species should be carefully considered in environmental management and decommissioning for this sector as introduced and invasive species can have serious biodiversity and economic impacts. There is a need for focused research on introduced taxa, risk assessments to understand the potential spread and impact of introduced species and the formulation of management recommendations to minimise the spread of introduced taxa.

This project has improved the understanding of this important economic sector, its activities, consequences for species and ecosystems affected and has advanced our knowledge of offshore biodiversity in a nationally important area. The expanded knowledge base will support;

- environmental management in the petroleum, fisheries and biodiversity sectors,
- decisions about decommissioning options for oil and gas infrastructure,
- offshore Marine Protected Area planning and
- integrated spatial management of South Africa's Exclusive Economic Zone.

ACRONYMS

CSIR	Council for Scientific and Industrial Research
EEZ	Exclusive Economic Zone
MENZ	Ministry of Environment New Zealand
MPA	Marine Protected Area
OGP	Oil and Gas Producers
Petro-SA	The Petroleum Oil & Gas Corporation of South Africa (Pty) Ltd
ROV	Remotely Operated Vehicle
SAEON	South African Environmental Observation Network
SANBI	South African National Biodiversity Institute
SAT	Saturation
SDU	
SUTA	
TOC	Total Organic Carbon
WWF	World Wildlife Fund

STATISTICAL ACRONYMS

SIMPROF	Similarity Profile
MANOVA	Multivariate analysis of variance
PERMANOVA	Permutational Multivariate analysis of variance
DISTLM	Distance-based Linear Model
AIC	Akaike's Information Criterion
MDS	Multi-dimensional Scaling

INTRODUCTION

The offshore environment of South Africa is poorly protected with less than 1% of the mainland Exclusive Economic Zone (EEZ) protected under any type of spatial management. Most offshore habitats are not represented within South Africa's Marine Protected Area (MPA) network and the identification of a potential offshore MPA network is a conservation priority (Lombard *et al.* 2004). The poor status of offshore benthic biodiversity knowledge in South Africa has limited progress in identifying priority areas for offshore MPAs. This lack of information is attributed to the financial, logistical and technological constraints of sampling deep water habitats and the taxonomic challenges involved (Gibbons *et al.* 1999, Sink *et al.* 2006). The effect of offshore industries on the biodiversity of deep water habitats and ecosystems has also received little attention in South Africa (Attwood *et al.* 2000, Lombard *et al.* 2004, Atkinson and Sink 2008). This is of increasing concern considering that offshore industrial activities including petroleum exploration and production, diamond mining and demersal trawling are expanding into deeper water without a concomitant increase in scientific information about deep water ecosystems or the setting aside of representative protected areas (Atkinson and Sink 2008).

The Offshore Biodiversity Initiative, housed within the South African National Biodiversity Institute (SANBI) and funded principally by the Greentrust (a partnership between WWF and Nedbank), aims to collaboratively establish MPAs that include offshore habitats to ensure a more representative MPA network for the EEZ. This initiative is the first of its kind to consult with several government departments and industry stakeholders, representing commercial fishing, mining, petroleum and other maritime industries that utilize South Africa's offshore marine areas. The Offshore Biodiversity Initiative identified co-operative research with offshore industries as a potential approach to improve the status of offshore biodiversity information and increase the level of spatial protection in representative offshore environments. This project falls under the umbrella of this initiative and will feed into the spatial planning for offshore MPAs.

The Agulhas Bank on the South African south coast is one of the most economically important offshore areas supporting petroleum production and several commercial fisheries. The demersal communities are poorly studied with sampling being conducted by trawl or line fishing and focused primarily on fish (Smale *et al.* 1993). The Agulhas bioregion hosts both warm and cool temperate species but also has the greatest number of South African endemics including sparid reef fish, octocorals, other invertebrates and algae (Smith and Heemstra 1986, Dai 1998, Lombard *et al.* 2004, Branch *et al.* 2010). Offshore oil and gas exploration in South Africa commenced in 1965 with production beginning on the Agulhas Bank in the 1980s. Over 300 wells have been drilled in the South African Exclusive Economic Zone (EEZ) but the Bredasdorp Basin on the Agulhas Bank has been the focus of most activity. Commercial production has taken place with the development of the Oribi/Oryx and Sable oil fields and the FA gas fields and satellites (Figure 1).

The Agulhas Bank is a significant area for South African fisheries, supporting inshore and offshore demersal trawl fisheries targeting sole, hakes and other species, demersal longlining, a midwater trawl fishery, a squid fishery, a fishery for small pelagics and a commercial linefishery (Japp *et al.* 1994, Atkinson and Sink 2008). Foreign fleets targeted panga *Pterogymnus laniarius* and other redfish by trawling with rockhopper gear prior to the introduction of the EEZ (Japp *et al.* 1994) and there is concern that this resulted in severe benthic habitat damage from trawl impacts. Petroleum activities overlap with fisheries on the South African south coast and there is an urgent need for information about the potential interactive effects and cumulative impacts of oil and gas activities in concert with fisheries, in particular demersal trawling. Oil and gas structures, particularly on the Agulhas Bank, have prevented demersal trawling in specific areas and the petroleum sector has proposed that this protection may benefit both biodiversity and fisheries. Some of these areas were previously trawled by the inshore trawl fleet (Japp *et al.* 1994).

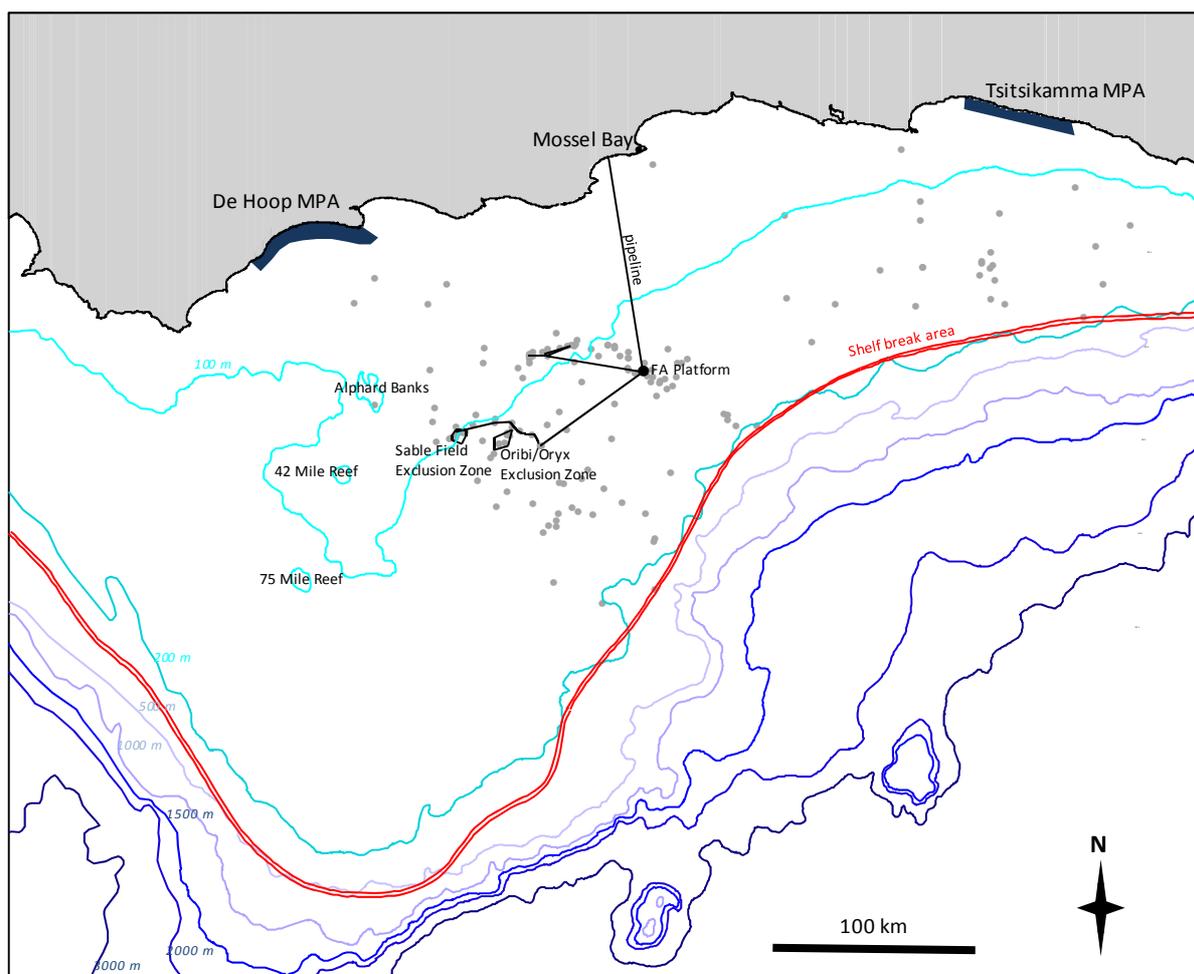


Figure 1. South coast Agulhas Bank region showing bathymetry, deep reefs, petroleum activity areas and Marine Protected Areas. Grey circles represent petroleum wells.

Benthic fauna (species living on or in seabed sediments) has been shown to play important ecological roles in both structuring marine unconsolidated sediment habitat and as prey for commercially valuable species (Gray 1974). Benthic assemblages are considered to effectively integrate historical environmental conditions as a result of their comparatively limited mobility and permanence over seasons (Warwick 1993, Salas *et al.* 2006) and provide useful indices to evaluate the status of marine ecosystems in monitoring for long-term responses and site-specific impacts (Salas *et al.* 2006). Benthic infauna and epifauna are therefore considered good indicator species to measure the status of biological ecosystem functioning (Gray *et al.* 1974, Salas *et al.* 2006, Bremner *et al.* 2006a). Benthic organisms living within sediments significantly influence major ecological processes contributing to regulation of carbon, nitrogen and sulphur cycling, transport, burial and metabolism of pollutants, secondary production, bioturbation and stability of sediments (Snelgrove *et al.* 1997, Snelgrove 1998, Hutchings 1998). Benthic environmental surveys typically do not quantify the larger epibenthic megafaunal component (those organisms living on or rooted in the surface of the sediment, Jones *et al.* 2008), however, these organisms play an important role in benthic processes, specifically in dispersing and redistributing organic matter and sediment (Widdicombe and Austen 1998). Monitoring epifaunal assemblages can provide valuable information on the recovery of benthic systems from disturbance effects (Jennings and Kaiser 1998).

Elsewhere petroleum infrastructure has been shown to alter and sometimes increase habitat diversity and host species of conservation concern. It is sometimes argued that infrastructure may benefit fished species or habitats through the exclusion of fishing (Rice and Owen 1999 in Hall 2001, Hall 2001 Love *et al.* 2005). Infrastructure can form artificial reefs, the value of which is controversial (Bohnsack 1989, 1994, Baine 2002, Ponti *et al.* 2002, Powers 2003, Fabi *et al.* 2004, Kaiser 2006,

Neves dos Santos 2010). More recent concerns have centered on the potential role of this industry in the introduction, hosting and spread of alien species (Page *et al.* 2006, Coutts *et al.* 2007, Wanless *et al.* 2009, Sheehy and Vik 2010). To date, there are no published research outputs that examine the impact of petroleum activities in South Africa. International studies have shown that offshore drilling can result in various impacts that include pollution, sediment disturbance and habitat change (Cranmer 1988, Newell 1988, Neff *et al.* 1987, 1989, Daan *et al.* 1992, Davies and Kingston 1992, Hyland *et al.* 1994, Olsgard and Gray 1995, Daan and Mulder 1996, Cranford *et al.* 1999, MENZ 2005). A review of offshore activities in South Africa and their implications for biodiversity highlighted the lack of research on the effect of petroleum activities on offshore biodiversity in South Africa (Atkinson and Sink 2008). The lack of understanding of these effects limits decision making. This is concerning because important decisions are currently being made about the decommissioning options for petroleum infrastructure on the Agulhas Bank and petroleum production is soon to begin on the South African west coast.

Little is known about benthic communities associated with petroleum infrastructure in South Africa. Potential impacts on biodiversity have not been assessed and there is little knowledge about species colonizing infrastructure. Preliminary screening of remotely operated vehicle (ROV) footage of concrete mattresses and flow lines on the Agulhas Bank showed that infrastructure has been colonized by several species of benthic invertebrates including the distinctive introduced invasive anemone *Metridium senile*. The extent of colonization by introduced taxa, particularly invasive species, warrants assessment. It is not known whether the structures and the surrounding exclusion zones support representative assemblages or any vulnerable cold water coral communities or other biogenic habitats. Hard ground areas on the Agulhas Bank were reported to be damaged by bottom trawlers with heavy steel bobbins in the 1970s and 1980s. To date, no studies have examined these deep rough ground areas and their vulnerability to trawl damage, specifically that induced by rock-hopper gear, and the extent of suspected damage by foreign trawl fleets remains unknown.

The exclusion of fishing within petroleum areas is asserted to possibly provide benefits for fished species such as hake, kingklip, other trawled species, line-caught sparids (seabreams) and south coast rock lobster. In South Africa, this aspect has not been considered and the presence or abundance of such species within the exclusion areas has never been investigated.

Exclusion zones associated with offshore oil and gas production are not only advocated as sites that may offer protection to commercially fished species but are also argued to provide protection and refuge for habitats and benthic macrofaunal assemblages that may be impacted by activities such as demersal trawling. The trawl exclusion zones around pipelines may offer an opportunity to assess the impact of demersal trawling on benthic macrofauna with comparisons between trawled and untrawled areas. However, if petroleum activities have already altered benthic assemblages, such exclusion areas may not provide suitable reference areas. Pilot work is required to assess whether untrawled areas within petroleum exclusion zones can serve as reference areas for benthic assemblages.

The lack of information on benthic biodiversity on the Agulhas Bank and the poor knowledge of the effect of activities such as trawling and petroleum production impair decision making in this important area. This project represents a co-operative research project that intends to improve the status of knowledge of offshore benthic biodiversity on the Agulhas Bank and assess the potential implications of existing petroleum infrastructure on selected components of the benthic biodiversity. The project is a pilot study that will be able to improve knowledge needed to support environmental management in this sector, decisions about decommissioning options and help guide wise spatial management on the Agulhas Bank.

Aims

This collaborative project aimed to assess the potential role of petroleum infrastructure in offshore spatial management on the Agulhas Bank. The project set out to improve knowledge of offshore biodiversity on the south coast, examine the potential impacts and benefits of offshore petroleum activities on biodiversity and investigate the potential role of petroleum infrastructure in the spatial management of the EEZ. Specific objectives and key questions are detailed in Table.1.

Table 1. The project objectives and associated key questions.

OBJECTIVE	KEY QUESTION
Colonization of existing petroleum infrastructure	
Provide baseline information on colonization of existing petroleum infrastructure by benthic invertebrates and fish on the Agulhas Bank	What species (macro-invertebrates and fish) are associated with the petroleum infrastructure?
Representivity of benthic communities on infrastructure	
Assess whether benthic communities are representative of offshore benthic biodiversity of the Agulhas bank	Do the infrastructure and trawl exclusion zones include representative benthic communities from the Agulhas Bank?
Vulnerable habitats and species	
Identify vulnerable habitats and species such as cold water coral reefs, sponge beds and other biogenic communities	Are there vulnerable habitats or species that warrant spatial protection within or adjacent to existing petroleum infrastructure?
Fisheries exclusion effects	
Undertake a pilot study to investigate potential benefits of fisheries exclusion associated with petroleum infrastructure	Is there evidence of differences in fish assemblages (such as differences in fish species, abundance or size) that may be linked to the exclusion of fishing?
Introduced species	
Detect introduced species associated with petroleum infrastructure and assess the extent of any invasive taxa	Are there introduced and/or invasive species colonizing petroleum infrastructure on the Agulhas Bank? Have invasives spread onto areas of adjacent natural habitat?
Unconsolidated sediment fauna	
Assess whether untrawled soft sediment exclusion areas can serve as reference areas for understanding demersal trawl impacts in unconsolidated habitats	Are the benthic faunal assemblages in the trawl exclusion zone different from those in trawled areas?

An additional objective was originally proposed to assess trawling impacts on hard ground communities, however, limited availability of the ROV and ship time, prevented the investigation of this and it was subsequently eliminated from the project. This objective would have involved surveys inside and outside of De Hoop and Tsitsikamma MPAs.

METHODS

The sampling area identified in consultation with PetroSA was defined to focus within the Oribi/Oryx exclusion zone and FA Platform on the Agulhas Bank but also includes areas of infrastructure (such as wellheads and pipelines) outside of current exclusion areas (Figure 1). The FA platform, a fixed structure, was constructed at sea in its current position in 1991 and is in shallower water (105 m at deepest) than the ORCA infrastructure observed (117 m at deepest). The 39-year old ORCA was originally a drilling rig that underwent conversion to a floating production platform in 1997 and is towed into harbour every five years for inspection, re-certification, repairs and cleaning. This was last done in 2007 with the ORCA being re-deployed at the Oribi/Oryx field in December 2008.

This project drew from international published literature, historical reports from research conducted at the FA-platform from 1992 to 1999 and existing Remotely Operated Vehicle (ROV) footage obtained by PetroSA during standard infrastructure surveys within the defined study area. Dedicated sampling was conducted during this project using ROV surveys, fish traps, saturation (SAT) diver collections and benthic grab sampling (Figure 2 and Plate 1). These sampling methods are detailed below:

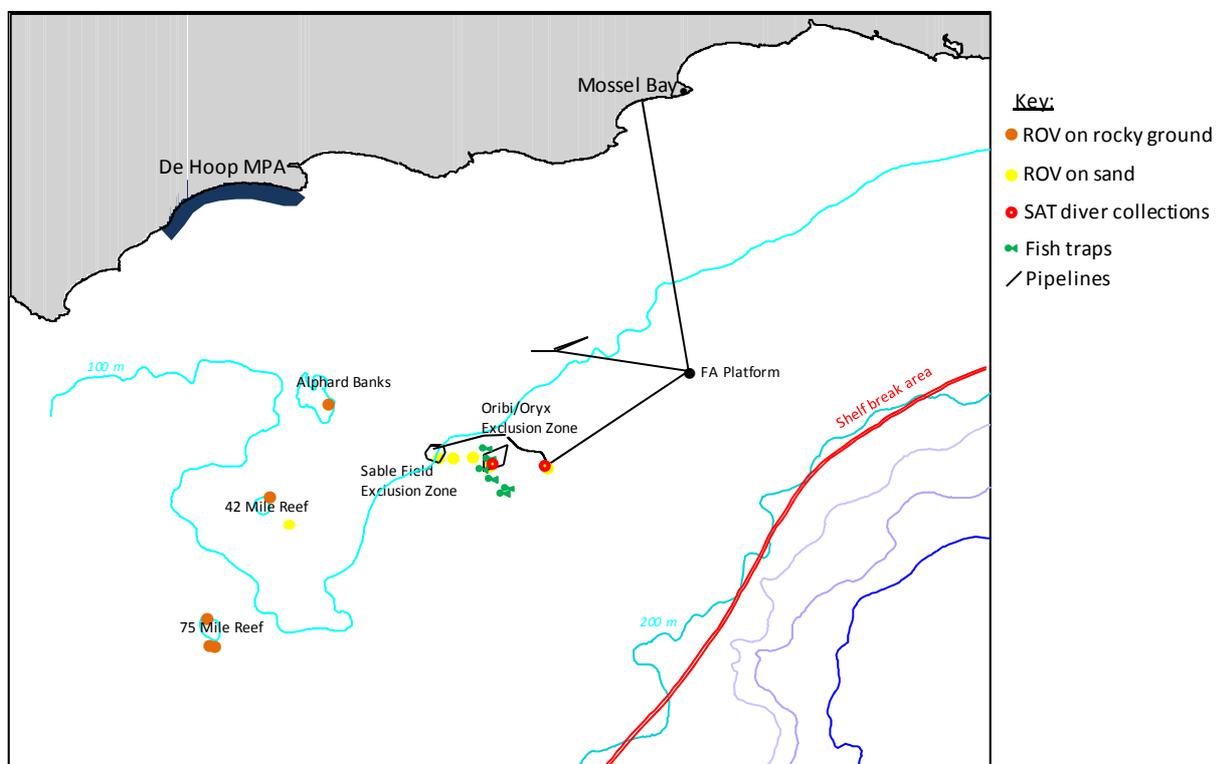


Figure 2. Positions of ROV surveys, SAT diver collections and fish traps conducted on the Agulhas Bank during the project. The current exclusion zones and pipelines are demarcated. ROV surveys took place within areas of current or previous exploration and production activities as well as in reference areas on deep reef and adjacent sandy habitats away from petroleum activities. SAT diver collections were only conducted around infrastructure.

Literature review

A review of published international literature about biodiversity and petroleum infrastructure and activities was undertaken with a focus on the primary objectives in this report. Key aspects examined included the colonization of petroleum infrastructure, rigs as artificial reefs, the effects of fisheries exclusion, species introductions and the known impacts of petroleum activities.

Historical reports

Four reports (Cooke 1995, 1996, 1997, 1999) that document previous research on the fouling community of the FA platform were made available by PetroSA. A species list was compiled and a summary of pertinent information produced. The fouling community on the FA Platform was sampled in the surface to 60 m depth range on at least 7 occasions in the 1990s with reports available for 4 years (Table 2).

Table 2. Sampling periods and species richness at the FA Platform in the 1990's.

Sampling period	Number of species	References
November 1992	15	Cooke 1995
March / April 1993	23	Cooke 1995
January/February 1994	36	Cooke 1995
December 1994 (18 sites)	31	Cooke 1995
March 1996 (7 sites)	27	Cooke 1996
January 1997 (7 sites)	26	Cooke 1997
March 1999 (10 sites)	26	Cooke 1999

Existing ROV footage

Footage of the FA Platform was available from 2005 and 2008 and footage from the Oribi/Oryx field was provided from 2007. The primary purpose of this footage was to inspect infrastructure, with a focus on state of infrastructure, identification of damage and collection of measurements. Examination of marine growth was therefore opportunistic and pilots or divers did not attempt to obtain suitable footage to facilitate identification. It was therefore difficult to identify any algae or invertebrates from the footage available but some macrofauna were identified with certainty. Within the Oribi/Oryx field some species identifications were confirmed by collections. More than 20 hours of footage was examined for the purpose of identifying marine biota associated with the FA Platform and more than 17 hours of ROV footage was examined from the Oribi/Oryx field. The Oribi/Oryx footage included general visual inspections of wellheads, the SUTA, the SDU frame, cross piece connections, the chains and anchors of calm buoys and the floating ORCA platform, umbilicals, risers, flowlines and pipelines.

Due to the unsystematic survey approach of the ROV inspections it was not possible to gather quantitative estimates from existing footage. Invertebrate and fish species lists were compiled and patterns associated with depth and the type of infrastructure were noted.

Dedicated ROV surveys

Two ROV surveys took place on infrastructure in March 2009 and bait bags were deployed during a component of these surveys to attract and document fish fauna. ROV footage was collected from during nine dedicated dives in November 2009 (Table 3). Hard ground reference areas that were examined included the deep reefs on the 45 – and 72-Mile Banks on the central Agulhas Bank which are prominent targets for the commercial linefishing fleet as well as the Alphard Banks, a formation of tertiary volcanic rocks that extrude from the sandy seabed from a depth of 90 m, rising to 17 m below the surface. Unconsolidated sediment areas were inspected in the vicinity of 45 Mile Bank, inside “The Blues”, a prominent trawling area and inside the Sable Exclusion Zone. The dedicated ROV surveys usually included a reconnaissance period during which the ROV was slowly flying above the seabed, covering a distance of 50 to 100 m, depending on sea conditions and seabed profile. A bait-bag experiment to attract fish was usually conducted at the end of an ROV survey during which the ROV was kept in one position to observe a weighted, mesh bag filled with bait (sardines), which was lowered to the seabed. The reconnaissance period varied between 45 min and 2 hours, depending on the variety of habitats and biological assemblages. The bait bag experiment was kept to a standard duration of 10 min. The bait bag experiments were conducted using the same methodology from a related scientific project in the same area to yield comparable results.

Table 3. ROV and collection SAT dive details of dedicated sampling conducted in March and November 2009.

Date	Sample type	Longitude	Latitude	Time	Habitat type	Maximum depth
25 Mar 2009	ROV 1	21.492	-35.234	12h50	Sand & infrastructure WNW of ORCA	117 m
25 Mar 2009	ROV 2	21.694	-35.237	19h00	Wellhead, mattress & sand	118 m
25 Mar 2009	SAT diver	21.497	-35.233	10h00	On infrastructure	117 m
25 Mar 2009	SAT diver	21.694	-35.237	19h10	Outside exclusion zone	118 m
26 Nov 2009	ROV 1	20.535	-35.739	14h40	72 Mile Bank rocky reef	110 m
26 Nov 2009	ROV 2	20.550	-35.743	17h35	72 Mile Bank rocky reef	84 m
27 Nov 2009	ROV 3	20.524	-35.664	07h05	72 Mile Bank rocky reef	134 m
27 Nov 2009	ROV 4	20.803	-35.391	11h50	Sand adjacent to 45 Mile Bank	81 m
27 Nov 2009	ROV 5	20.743	-35.329	13h40	45 Mile Bank rocky reef	68 m
27 Nov 2009	ROV 6	20.941	-35.062	19h02	Alphard Bank rocky reef	74 m
28 Nov 2009	ROV 7	21.317	-35.213	07h09	Sand in Sable excl zone	103 m
28 Nov 2009	ROV 8	21.368	-35.212	09h51	Sand in Blues trawl area 1	110 m
28 Nov 2009	ROV 9	21.432	-35.208	13h21	Sand in Blues trawl area 2	116 m

Different methodologies were applied to analyze ROV footage with regard to invertebrate fauna associated with reefs, invertebrate fauna associated with soft sediment and ichthyofauna assemblages.

Dedicated ROV surveys: Epifauna in reef habitat

All large, well known invertebrate species that could be identified from the ROV footage were recorded, with emphasis on invertebrate species previously recorded at the FA platform and on infrastructure at the Oribi/Oryx field as well as slow growing, fragile, three dimensional species that characterize vulnerable marine ecosystems. As these deep reefs areas were recently sampled by divers and benthic sled in shallower and deeper areas respectively as part of a more comprehensive study on deep reef ecosystems, the images acquired during ROV surveys will be analyzed as part of this broader project. Specimens are needed to accurately identify benthic invertebrates from these poorly studied habitats (Sink *et al.* 2006).

Dedicated ROV surveys: Epifauna in unconsolidated habitat

A total of six ROV surveys were conducted on unconsolidated sediments including untrawled areas inside petroleum exclusion zones, trawled areas outside of exclusion zones and near rocky reefs (untrawled and unmined, Table 3). The total area covered by each ROV transect varied as a result of the influence of current speed and direction on progress of the ROV. All benthic epifauna visible along the ROV transect were recorded and dominant species (urchin *Brissopsis lyrifera capensis* and burrowing tube anemone *Cerianthus* sp.), when present, were counted during four randomly selected 10 minute sections per ROV transect.

Dedicated ROV surveys: Fish

All ROV footage from both reef and sand habitat was analysed to assess ichthyofauna composition using standardized methods so as to be comparable with other scientific studies in the area. Species lists were compiled for each survey. Because fishes were encountered either in aggregations around the bait bag or as individuals, and because area coverage could not be standardized, the maximum number of individuals within a single frame per species per dive was selected as a measure of comparison between sites. Each time an aggregation of fish was encountered; still images were captured and the individuals were then counted and the highest number taken as the measure of maximum abundance (Nmax).

SAT diver collections

On two occasions deep-sea divers were deployed to collect benthic specimens occurring on adjacent to infrastructure within and outside of the current Oribi/Oryx exclusion zone (Fig. 2). Both collections took place around infrastructure. The primary focus of these opportunities was to collect invertebrate specimens on infrastructure for accurate identification by taxonomists. Some specimens occurring on sand were also collected. Several attempts were made to collect a specimen of a burrowing tube anemone *Cerianthus* sp. however, this genus is notoriously difficult to collect and all attempts were only able to retrieve the *Cerianthus* sp. tube. Footage from SAT diver collections were also examined for species records within the area.

Trap sampling

Conical shaped, baited commercial crab traps were deployed within the FA Platform exclusion zone during pilot sampling attempts in November 2008. Variations in soak time and deployment methods (i.e. attached to a tether or freely deployed) for 5 crab trap deployments failed to yield any fish specimens and only one crab (*Plagusia chabrus*) was retained from one trap set. After this unsuccessful trial with crab traps, baited rectangular fish traps (Plate 1) were used to sample the ichthyofauna inside and outside the exclusion zone. The traps used in this experiment have been successful in sampling fish assemblages associated with soft sediment (Grey *et al.* 2005) and are currently used on a related Department of Fisheries project to assess the deep reef fish fauna on the Agulhas bank. A total of 10 fish trap deployments were executed in soft sediment habitat inside and outside of the Oribi/Oryx petroleum exclusion zone (Fig. 2). Traps were baited with sardine and deployed individually in depths of approximately 120 m. Soak times varied from two to five hours. The use of fish traps to assess fish communities in sandy habitat proved limited with only 3 species of fish represented from fish trap sampling. ROV transects provided evidence that several more species of fish do indeed occur in the areas, but are simply not appropriately sampled by means of trap. Results from these sampling events are further reported on below.

Infauna (grab samples)

Effects of anthropogenic disturbance on the benthic environment, such as those arising from petroleum extraction activities, can be detected by sampling a component of the benthic fauna (usually the macrofauna i.e. species greater than 1 mm in size) and a range of chemical parameters from the source of the impact at geometrically increasing distances, along four radiating transects (Gray *et al.* 1990; Kingston 1992). Changes in species numbers, individuals or diversity (univariate measures) are frequently monitored to detect impacts, however, these measures are often considered insufficiently sensitive to detect changes in faunal communities as a result of an impact or disturbance (Kaiser *et al.* 1998, Thrush *et al.* 1998, Gray *et al.* 1990, Atkinson 2010). Multivariate analyses more effectively detect disturbance effects when monitoring benthic faunal assemblages (Gray *et al.* 1990, Warwick and Clarke 1993).

Conventional methods of sampling epifauna include benthic dredge, sled or scientific trawl net, however, these methods further impact the habitat during sampling. Employing the use of imaging techniques (i.e. camera or remotely operated vehicle) allows fine-scale in situ surveys of megabenthic abundance, diversity and distribution and can have greater spatial coverage than is possible with conventional macrofaunal sampling (Jones *et al.* 2008). Imaging techniques allow assessment of epifauna at larger scales relevant to community patterns and the area of disturbance, without introducing additional disturbance as a result of sampling (Jones *et al.* 2008).

A total of 80 grab samples, representing 16 sites (5 replicate grabs per site) were collected from inside and outside the Oribi/Oryx exclusion zone. Sample sites were positioned in geometrically increasing distances up to 4 km from the central point of wellhead E-BT01P, with two sites, considered to represent reference conditions, located 10 km south-east of the wellhead (Fig. 3). Sampling stations were positioned at distances of 250 m (1), 500 m (2), 2 km (3) and 4 km (4) from the wellhead and along four axes (A to D) each 90 degrees from the adjacent axis (Fig. 3). Four additional proposed grab sites 250 m and 500 m from the wellhead in the north-east (axis C) and

south-east (axis B) directions, were not permitted to be collected as these locations were deemed too close to petroleum infrastructure. The lack of data from these four sites weakens the statistical analysis of the sample design to some extent. An average of 16 litres of sediment was collected from each grab, sieved through 1 mm mesh to retain all organisms greater than 1 mm in size (classified as infauna) with subsamples of the sediment being retained to determine particle size, percentage total organic carbon (TOC), trace metal and hydrocarbon content. All infauna were preserved in 10 % buffered formalin, identified, counted and weighed yielding a species list with abundance and biomass data for further statistical analysis.

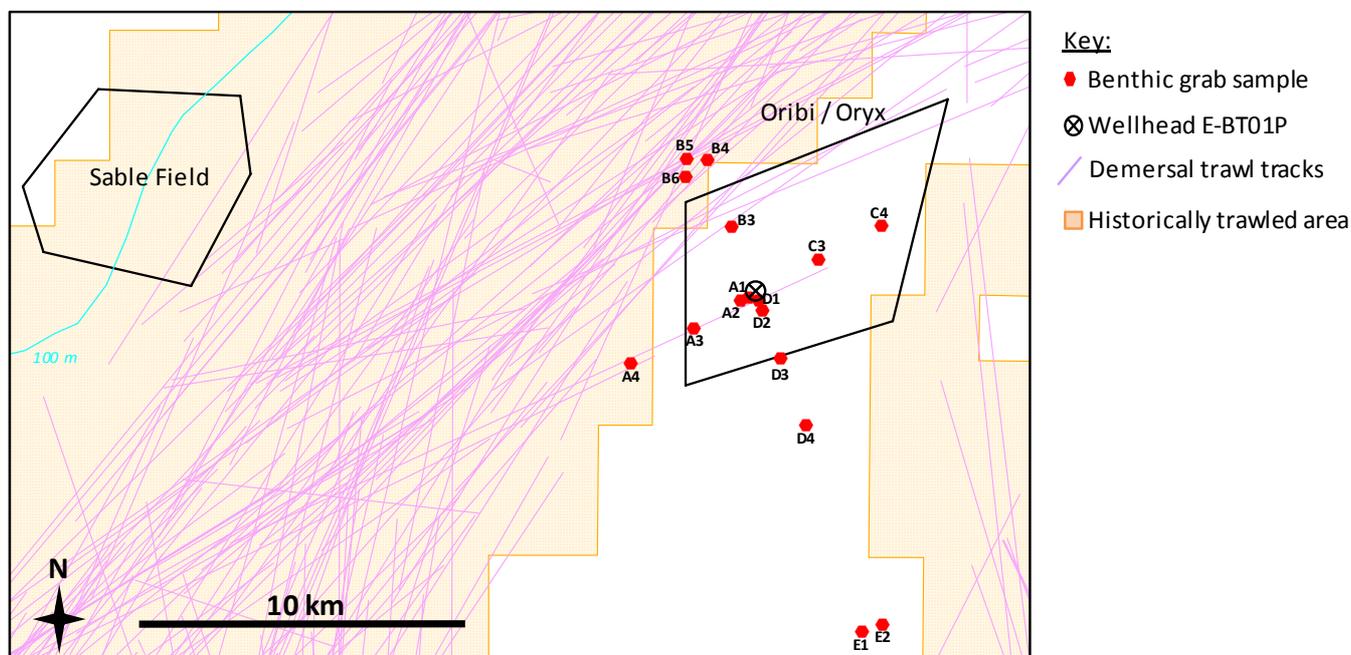


Figure 3. Benthic grab sampling locations and demersal trawled areas in relation to petroleum exclusion zones South coast.

Sediment sample analysis

Particle size analysis

In addition to monitoring the biological component of benthic habitats, the physical attributes of the sediment are equally important in assessing potential factors contributing to any changes observed. Sediment particle size can be influenced by large volumes of discharged sediment emanating from drilling a wellhead or as a result of fine sediment being discharged near the surface during petroleum activities. A change in sediment grain size can significantly alter the benthic faunal community composition.

The particle size distribution of sediment samples collected from each grab sample was determined using the hydrometer method by BemLab Pty LTD. Sodium hexameta-phosphate and sodium carbonate were used as dispersing agents to measure the proportions of clay and silt in suspension while the coarser sand and gravel proportions were measured by sieving dried sediment.

Total Organic Carbon percentage

The total organic carbon content provides a measure of the amount of organic matter present in sediment. In regions not influenced by anthropogenic activities the organic matter is made up of decaying plant and animal remains. Such organic matter provides an important source of food for benthic fauna, however, organic matter can also provide a surface for contaminants (especially organic contaminants like polycyclic aromatic hydrocarbons) to absorb onto. In polluted areas, there is frequently a strong positive correlation between the total organic content of sediment and the concentrations of organic contaminants.

The Walkley-Black method (Walkley and Black 1934) was used to measure the organic carbon content of sediment samples from each grab sample (BemLab Pty LTD). The method extracts approximately 85.6% of the total organic carbon necessitating the use of a standard recovery factor of 1.17 when calculating the final organic carbon content.

Trace metal content

Evaluating sediment for metal contamination is confounded by the fact that metals are a ubiquitous, naturally occurring component of all sediments. Metal concentrations in uncontaminated sediment can vary by orders of magnitude over relatively small spatial scales and are influenced by, inter alia, mineralogy, granulometry and organic content (Loring & Rantala 1992, Thomas & Bendell-Young 1999, Kersten & Smedes 2002). High metal concentrations do not necessarily indicate a contaminated status and may simply reflect the natural sediment composition. To account for natural metals occurring in sediments, baseline metal concentrations are differentiated from anthropogenically introduced metal concentrations with the procedure of geochemical normalization (mathematically normalizing the metal concentration recorded to a co-occurring conservative element, see Appendix 4 for further details). No baseline metal measures were available from sites in similar depth ranges on the South Coast and it was thus necessary to use metal concentrations measured in sediment from St Helena Bay (Monteiro & Roychoudhury 2005) to develop baseline models for the metals. It was however not possible to develop baseline models for barium and strontium as these metals have not previously been measured in the region.

Trace metals in sediment samples were extracted using 0.1M hydrochloric acid and processing with ICP programme software to determine the acid extractable metals (mg/kg). The trace metals determined for this study were Barium (Ba), Lead (Pb), Iron (Fe), Zinc (Zn), Copper (Cu), Strontium (Sr), Cadmium (Cd) and Mercury (Hg). The contamination status of metal concentrations measured in sediment was interpreted using baseline metal concentration models. Details relevant to the development and use of baseline metal concentration models for interpreting metal concentrations measured in sediment are reported in Appendix 4.

Hydrocarbon content (Polycyclic aromatic hydrocarbons)

Polycyclic aromatic hydrocarbons (PAHs) comprise all aromatic hydrocarbon molecules containing three or more benzene rings and are ubiquitous in the natural environment. In general, the two main contributors to PAHs in the environment are fossil fuels and the incomplete combustion of organic material, such as wood, coal and oil. Anthropogenic activities are generally accepted as the most important source of PAHs released into the environment. PAHs have low solubility in water and rapidly absorb onto particles with the result that sediments are the most important reservoir of PAHs in the natural marine environment.

Freeze-dried sediment from each sample was digested using 50% hexane and dichloromethane, filtered, concentrated through evaporation and cleaned using silica gel and aluminium oxide. Various polycyclic aromatic hydrocarbons and total hydrocarbons were detected and quantified using an ion trap mass spectrometer coupled to a gas chromatograph. Method blanks and certified reference material (NIST 1941b) were analysed with each batch of ten samples.

Unconsolidated sediment data and infaunal statistical analysis

Abundance and biomass measures of infaunal assemblages were 4th root transformed (to down-weight the dominance of abundant species, Field *et al.* 1982) and resemblance matrices calculated using the Bray-Curtis measure of (dis)similarity. These results were summarized in cluster dendrograms, including similarity profile test (SIMPROF) analysis and multi-dimensional scaling (MDS) plots. SIMPROF is a permutation test of the null hypothesis that a specified set of samples, not *a priori* divided into groups, do not differ from each other in multivariate structure (Clarke & Gorley 2006). The multivariate analytical technique, Permutational MANOVA (PERMANOVA) was used to test for significant differences in averaged replicate assemblages among different sites and between areas within and outside of the exclusion zone. PERMANOVA tests the dissimilarity values generated

by the resemblance matrix on which permutations are based, generating a test statistic value of pseudo-F (Anderson *et al.* 2008). To assess which species contribute most to differences between groups, similarity of percentages (SIMPER) analyses were conducted.

The relationships between biotic (infaunal abundance and biomass) data and all measured sediment properties were investigated using a distance-based linear model (DISTLM, Anderson *et al.* 2008). DISTLM partitions the variation in data distribution according to a multiple regression model (based on predictor variables), as selected by the user. The “Best” (best fit) procedure and AIC (Akaike’s Information Criterion) options (Anderson *et al.* 2008) were used for this analysis. The sediment properties measured in this study included in the DISTLM model analysis were % sand and % TOC (arcsine transformed), trace metals and hydrocarbon content. All multivariate and diversity analyses were performed using PRIMER-E and its add-on package PERMANOVA+ (Clarke & Warwick 2001, Clarke & Gorley 2006, Anderson *et al.* 2008).



A) Conical crab traps



B) Rectangular fish traps



C) ROV *Seaeye Falcon* deployment



D) Deploying the benthic grab



E) SAT diver collecting a *Toraster* sp. starfish



F) SAT diver collecting *Cerianthus* sp.

Plate 1. Dedicated sampling methods employed during this project.

RESULTS

Literature review

Colonisation of petroleum infrastructure

Artificial structures on the seabed and in the water column may alter and increase the diversity of habitats available to organisms, offering attachment sites for sessile organisms and vertical relief favoured by some species (Foster & Wilan 1979, Wolfson *et al.* 1979, Forteath *et al.* 1982, Seaman *et al.* 1989, Fabi *et al.* 2004, Ponti *et al.* 2002, Sammarco *et al.* 2004, Love *et al.* 2005, Love and York 2006). This can have implications for both native and introduced non-indigenous species of invertebrates and fish (Page *et al.* 2006, Sheehy and Vik 2010) (see section on introduced species below). Faunal assembles occurring on the submerged portions of oil and gas infrastructure are often typical of those found on shallow natural reefs and pier pilings (Foster & Wilan 1979, Fabi *et al.* 2004, Page *et al.* 2006). These are largely dominated by mussels, barnacles and anemones but may support species which are rarer in the nearshore environment (Foster & Wilan 1979, Wolfson *et al.* 1979, Kaiser 2006). It is important to recognize that the species colonizing infrastructure usually represent a different type of biodiversity from the unconsolidated habitats where drilling usually takes place (Forteath *et al.* 1982). Petroleum infrastructure can therefore serve as an artificial reef, the value of which is controversial (see below).

There is some evidence that petroleum infrastructure may host vulnerable marine species such as fragile, slow growing cold water corals. Recently, extensive colonies of the slow-growing cold water coral *Lophelia pertusa* have been recorded on North Sea platforms (Bell & Smith 1999, Hall 2001). This finding is of conservation importance as this species is a reef building coral species that has been impacted by trawling in many areas. There is widespread concern for these slow growing, fragile habitat-forming taxa and unimpacted colonies outside of trawling areas may be important for conservation of cold water coral ecosystems. As a result of this discovery it has been suggested that prior to decommissioning and complete removal of infrastructure, the contribution of these structures to enhancing benthic biodiversity and protecting threatened species should be investigated (Hall 2001). From the above it is clear that oil and gas infrastructure has the potential to alter and in some cases increase marine biodiversity, although only in the immediate vicinity of the structure.

Additionally, the complex form of offshore infrastructure can offer habitat complexity that supports high densities of many species of fishes, although species compositions vary with depth (Love *et al.* 1999 a, b). This elevated abundance is thought to reflect the provision of sheltered habitat for fish species usually associated with hard bottom, complex reef-type habitat (Love *et al.* 1999 a, b, Love *et al.* 2005, Love & York 2006).

Rigs as artificial reefs

Elsewhere, oil and gas infrastructure has been colonized by reef biota representing a different type of biodiversity from unconsolidated habitats where drilling usually takes place (Forteath *et al.* 1982). Petroleum infrastructure can therefore serve as an artificial reef, increasing biodiversity by providing hard substrate, however, the value of this is controversial. In California, oil and gas infrastructures were shown to provide habitat for commercially important fishes such as rockfish and lingcod, some of which are overexploited (Love *et al.* 2005). Where cold water coral communities have been heavily impacted by bottom trawling, it has been advocated that untrawled artificial reefs may provide habitat for healthy coral colonies (Hall 2001).

The wreck of the “Paguro” drilling platform, which sank in the Adriatic Sea as a result of an accident in 1965, offered a unique opportunity to investigate its effectiveness as an artificial reef (Ponti *et al.* 2002). Results from this study using destructive and photographic sampling, showed that platform wrecks may allow the settlement of rich faunal assemblages. Mussels and oysters were the dominant species in this shallow rig (maximum depth 24 m). Surface orientation was noted as a key factor influencing the composition of and abundance patterns within the macrobenthic community, with

species richness greatest at those sites facing prevailing currents. The results of this study have assisted the Italian government in decisions around sinking of further platforms in the Paguro area.

A study on two gas platforms in the northern Adriatic Sea, with different depths, water circulation conditions and bottom types was aimed at evaluating the changes induced by the installation of these structures on fish assemblages of this semi-enclosed basin (Fabi *et al.* 2004). Higher species richness, diversity and catch rates were recorded at the platforms than at the control sites in the open sea, indicating that, as reported for the Gulf of Mexico, California and the North Sea, in the Adriatic Sea these structures act as artificial reefs, attracting aggregations of fish species and leading to diversification of the local fish assemblage. Due to the open, flat and sandy nature of the Adriatic Sea, these gas platforms have been advocated as small protected areas where various fish species, at different stages of their life, may have greater survival opportunities.

Outcomes from surveys on the Tenneco II submerged oil platforms in the Gulf of Mexico (Seaman *et al.* 1989) suggest that platform surface and structure play an important role in ichthyofaunal composition, with a grated structure housing higher fish abundance and diversity. They recommend that amounts of both surface area of a structure exposed to current flow; and vertical substratum each be maximized to promote growth of sessile benthic organisms.

An examination by Shinn and Wicklund (1989) on sixteen artificial reefs off Southeast Florida from a manned submersible showed that the two oil rigs provided vertical structure that penetrated the thermocline and formed artificial reefs. They concluded that water depth and low temperatures below the thermocline had more of an effect on reef communities than did substrate. Seaman *et al.* (1989) observed higher abundance of microfauna and diversity of reef-dwelling fish species around those platforms with grated decks than those with solid sheet decking. Baine (2001) undertook a literature review about global artificial reefs and concluded that intensive prior planning and ongoing management is needed for artificial reefs to fulfill the many objectives for which they are promoted. Soldal *et al.* (2002) describes an experiment using hydroacoustic quantification and trawling methods intended to estimate the extent to which decommissioned platforms in the North Sea attract fish. They observed large differences in fish density, depending on the side of the platform concerned, time of day, and season and conclude that these platforms might be used effectively as artificial reefs.

The Louisiana artificial reef program is the largest rigs-to-reef program in the world, and has created more than 83 artificial reef sites using over 120 decommissioned platforms (Kaiser and Pulsipher 2005, Kaiser 2006). Rigs-to-reefs programs are controversial (Baine 2002, Kaiser and Pulsipher 2005, Kaiser 2006). Generally, scientific research has shown that fish are attracted to platforms, but biomass estimates, when attempted, are cautiously mooted (Soldal *et al.* 1999 in Baine 2002; Picken *et al.*, 2000). Scientific research to assess the effectiveness of reefing programs are extremely expensive and extensive data is needed to allow informed robust assessments. Baine (2002) cite research issues that have not been adequately addressed in this field, including accurate estimates of fish aggregation and distribution; interaction between reef aggregations and stocks; the presence of juvenile fish populations; fish residency and other behavioural traits; fish contamination; effects on the physical, biological, and chemical environment; the fate of drill cuttings piles; and reef life expectancy. Some authors contend that artificial reefs that act primarily by attraction may promote overfishing under heavy fishing pressure by increasing fish catchability (the proportion of the population removed by one unit of effort). Fishes normally dispersed over a wide area would be concentrated and possibly depleted more rapidly (Bohnsack 1989).

Fisheries exclusion effects and fisheries considerations

Mandatory exclusion zones around offshore oil infrastructure precludes fishing within the designated area and these areas have been argued to provide potential benefits for fished species that are targeted outside of petroleum areas. It has been suggested that these potential conservation services should be considered prior to the removal of rigs as part of decommissioning (Hall 2001).

Interactions between fishers and petroleum infrastructure vary between sectors and places. Petroleum infrastructure is often a risk to trawl fishers as gear can snag on abandoned infrastructure. Some prawn trawlers report higher productivity close to platforms in the Gulf of Mexico and drag close to infrastructure (with 0.4 km) (Schroeder and Love 2004). Complex habitat associated with the Rincon Oil Island in California is reported to provide excellent lobster fishing grounds and trap fishers are opposed to the removal of this habitat (Schroeder and Love 2004). Recreational fishers often express strong opinions about platform decommissioning with many fishers favouring reefing programs because catch per unit effort is often high at offshore platforms for targeted fish species (Love and Westphal 1990). In the Gulf of Mexico, it has been estimated that 70% of Louisiana fishing excursions target oil platform habitats (Schroeder and Love 2004). Fishers are less in favour of reefing programs where fishing is prohibited from the reef (Schroeder and Love 2004).

Studies off the Californian coast have demonstrated increased abundance of species like bocaccio, *Sebastes paucispinis* and cowcod *Sebastes levis* around oil and gas infrastructure. They argue that this may have implications for increased larval production as rigs host larger mature individuals than nearby natural reefs (Love *et al.* 2005, Love & York 2006). In addition, platforms may offer a settlement substrate to juveniles of these species which may otherwise be lost offshore (Emery *et al.* 2006). As platforms can provide such important habitat for fish, particularly reef species that are heavily exploited, it is recommended that the potential benefits of infrastructure should be investigated on a case by case basis, prior to decommissioning and removal.

Introduced species

The fouling of rigs is an acknowledged vector for marine invasive alien species (Bax *et al.* 2003). Offshore oil and gas infrastructure may facilitate the range expansion of native species and the introduction of non-indigenous or alien species into new geographic areas by serving as 'stepping stones' of vertical relief and hard substrate across an unconsolidated seafloor environment (Sammarco *et al.* 2004, Page *et al.* 2006). This is of serious concern as introduced species are considered a key threat to biodiversity (Everett 2000, Pimentel *et al.* 2000).

Platforms may initially be colonised by organisms during construction and while being towed to their final position (Foster & Wilan 1979), larvae originating from coastal waters and then carried by regional water movement, may colonise throughout the life span of the rig. Additionally, semi-submersible exploratory drilling vessels, support boats and barges are likely to be important vectors in the transfer of alien species to and from platforms (Carlton 1987, Lewis *et al.* 2006). These vessels often support significant assemblages of invasive species which establish on their hulls during slow voyages or long periods spent in port (Foster & Wilan 1979). In addition to serving as a potential source of exotic species to surrounding natural habitats, the presence of alien species on offshore infrastructure has implications for the assessment of the 'habitat value' of these structures and the degree to which they provide ecological services that are normally derived from natural inshore reefs (Page *et al.* 2006). For example, a high density of an alien species may negatively affect native species through competition for shared resources or through predation pressure (Trussell 2000, Robinson *et al.* 2007). Less often, non-indigenous species may offer a new source of prey to local organisms (Jensen *et al.* 2007).

Despite the strong theoretical basis for concern regarding the role of offshore oil and gas infrastructure in the spread of alien species surprisingly few studies have considered the topic. The earliest report of alien species occurring on an oil infrastructure originates from 1979, when Foster & Wilan (1979) recorded six non-indigenous barnacle species and a single species of sergeant-major fish on an oil rig towed from Japan to New Zealand over 68 days. Introduced species were documented in association with petroleum infrastructure in the Gulf of Mexico where the exotic coral, *Tubastraea coccinea*, was reported to be abundant along with indigenous coral species, on platforms within 15 km of the coral populations of the Flower Garden Banks (Sammarco *et al.* 2004). Page *et al.* (2006) documented exotic invertebrate species inhabiting offshore oil and gas platforms on the Pacific offshore continental shelf of central and southern California. This study recorded three alien species, a bryozoan, an anemone and an amphipod. The distribution and abundance the bryozoan and anemone suggested that these species may out-compete indigenous organisms for primary space.

A recent publication provided alarming evidence for the potential role of some components of petroleum infrastructure in spreading alien marine species (Wanless *et al.* 2009). A decommissioned, semi-submersible petrochemical production platform became stranded on the remote island of Tristan da Cunha in the southern Atlantic ocean after towing problems were encountered en route to Brazil. The rig transported an entire subtropical reef community including 62 non-native taxa into the nearshore environment of a sensitive island ecosystem. Wanless *et al.* (2009) suggest that it is not common practice to remove biofouling organisms before infrastructure is towed and as such these organisms pose considerable risks for the spread of alien species. In this case, the rig was salvaged (disposed of in abyssal depths) purely because of the risk posed by the invasive species in the Tristan Island ecosystem. Wanless *et al.* (2009) make the point that the costs of removing the biofouling community prior to transport would have been trivial compared with the US\$20 million costs of the salvage operation. They recommend that biofouling organisms should be physically removed or otherwise killed (e.g. by prolonged immersion in freshwater or exposure to air) to minimize or prevent the spread of invasive alien species associated with the movement of petroleum infrastructure. The costs of this should be outweighed by savings from reduced fouling drag which can add 20-30% duration to a towing.

The presence of alien species has implications for decommissioning of offshore infrastructure as the fate of these structures has consequences for the further spread of these exotic species. The spread of marine alien species may be facilitated by any options involving the movement of infrastructure if biological communities are not removed prior to transport. Deployment of the structure as a reef needs careful consideration of the risks for the spreading of introduced species into adjacent areas. Similarly, the transformation of oil platforms into large-scale mariculture operations will result in an elevated risk of spread of alien species. Such spread may relate to the target species but also to associated species which are unintentionally translocated. The role of mariculture as an important vector for alien species is well established (Carriker 1992, Naylor *et al.* 2001).

In South Africa, there has been limited work on invasive biology within the marine environment but several researchers have attempted to quantify numbers of introduced and cryptogenic species (Griffiths 2000, Griffiths *et al.* 1992, 2009, Robinson *et al.* 2005, Mead *et al.* in prep). Robinson *et al.* (2005) defined introduced species as those known to be introduced to the region and which presently support extant populations. Species within a region that do not appear to be native, but cannot be proven to be introduced are classified as cryptogenic (Carlton 1995). Mead *et al.* (in prep) have compiled a list of 85 introduced and 40 cryptogenic species, more than tripling the number of known introductions and cryptogens in South Africa's marine environment within the period of a year (2009 to 2010).

According to Sheehy and Vik (2010), the number and size of constructed reefs and petroleum platforms in the Gulf of Mexico have altered offshore habitat and as a result, certain fisheries. These structures provide hard substrate and vertical profile where none previously existed thereby potentially changing the distribution of both indigenous and non-indigenous marine species (also referred to as introduced species), which are transported to a new region through two processes: natural range expansions, and deliberate or accidental human introductions. Range expansions can occur naturally, but may be influenced by habitat alterations. Where numerous or in reasonable proximity, as is common in the Gulf of Mexico, these reefs can also function as corridors for further range expansion. Although most reported non-indigenous marine species are molluscs and crustaceans, other groups ranging from microorganisms to fish are also represented. Increasing the availability of food resources and providing spawning sites may alter local distributions of larger fish species and potentially contribute to further range expansions.

Impacts of petroleum activities

Development of offshore oil usually starts with seismic surveys and is followed by exploratory drilling and eventually, establishment of wells. The general impacts of exploration and exploitation include noise and vibration, solid and liquid production wastes, increased water column turbidity from

dredging and disturbance of the sea bed. These impacts translate into a variety of biological and ecological responses. There are no known published studies on the actual physical or chemical impacts of oil and gas exploration and development activities in South Africa.

Seismic surveys

Although this aspect of petroleum activities are not a focus of this project, potential impacts of seismic surveys were briefly reviewed. The ecological impacts of the seismic activities typically employed during the initial phases of petroleum activities are not fully understood. Initial studies have focused on cetaceans and have demonstrated a variety of responses to seismic activity. These include a startle response, avoidance of the vibration source, attraction to the source, and changes in calling and behaviour (McCauley *et al.* 2000, O'Brien *et al.* 2002). In particular whales are considered more sensitive to seismic activity when suckling, resting or socialising than when migrating or feeding (O'Brien *et al.* 2002). As such appropriate timing of seismic surveys could reduce negative impacts on these animals.

There is very little known about the sensitivity of other organisms such as penguins, seals, turtles, squid and fish to underwater sound. However, it has been suggested that penguins and seals are relatively insensitive to acoustic disturbance, while turtles and squid demonstrate avoidance behaviour (McCauley *et al.* 2000, O'Brien *et al.* 2002). In contrast fish appear more negatively affected by seismic activity and show the general responses of swimming faster, swimming to greater depths and tightening school structure (McCauley *et al.* 2000). Additionally, fish catches may temporarily decline following seismic surveying (Kloff & Wicks 2004).

Physical damage to the seabed and associated organisms

During exploration for and exploitation of oil and gas resources physical disturbance of the seabed occurs. Anchoring, pipeline trenching and production activities can result in a range of effects on the benthic environment, some of which have been considered comparable to natural processes associated with sediment mobilisation through wave action, tidal and surge currents. Additionally, anchor deployment, tensioning and retrieval, as well as pipeline trenching result in impact depressions, scars, spoil mounds, and displacement of fine sediments. The duration of these effects varies depending on the nature of the affected sediments (Dunaway and Schroeder 1988).

The physical changes to the benthic environment described above have the potential to affect benthic communities both directly and indirectly. Firstly sedentary species or those exhibiting low mobility are likely to sustain physical damage, while the loss of benthic prey items for mobile bottom feeding species will have further indirect effects. In areas where benthic communities are dominated by short lived productive species, recovery from disturbance may take place more rapidly, while areas dominated by slow growing species are expected to take longer to recover. In the North Sea and off the southeast coast of England recovery rates have been found to range between 2 to 10 years (Jennings and Kaiser 1998, Boyd & Rees 2003, Cooper *et al.* 2007).

Besides the disturbance of soft sediments, physical damage may also take the form of the inversion of boulders on the seabed. This is likely to cause damage or even death of epifauna living on the boulder surface, especially those with fragile body structures. In addition, physical damage to rocky outcrops may occur during anchoring or as a result of anchor cables dragging across the rock surface. Such rocky habitats are generally considered more sensitive than surrounding soft sediments as they support very slow growing species such as black corals and gorgonians (Jennings and Kaiser 1998).

Smothering and burial of organisms

Disturbance of sediments and habitats can impact benthic faunal assemblages by displacement, burial, smothering and sedimentation (Newell 1998, Hyland *et al.* 1994, Olsgard & Gray 1995, MENZ 2005). The sediment plume associated with drilling operations may result in smothering of mobile or sedentary benthic species if the depth to which they are buried prevents their escape. Some of the observed impacts on benthic communities may be due to physical smothering by drill cuttings which

accumulate in distinct 'cuttings piles' and contain rock fragments contaminated with drilling muds and other substances. The largest volume pile in the North Sea is estimated to contain 66 816 m³ of material, and the tallest reaches 26 m above the sea bed (Grant and Briggs 2002). Disturbance of sediments may impact other species, like fish, that are dependent on infauna and epifauna as prey items, however, these types of impacts are likely to be restricted to a radius of within 1000 m of drilling operations (Ferbrache 1983). In Norway, studies showed that ecologically important prey species (brittle stars) for commercially important fish species (e.g. cod), were reduced by initial pollution impacts and replaced by smaller opportunistic species, believed to be less valuable as a food source (Olsgard & Gray 1995).

Studies from the North Sea indicate that the impacts on infaunal composition are intense but tend to be short lived and are similar to those from severe storms and dredge spoil disposal. Under these conditions recovery of communities within a year has been documented, but slow growing, long lived groups such as corals and gorgonians may take much longer to re-establish.

Changes in benthic assemblages associated with chemical toxicity

Assessing the biological impacts resulting from offshore oil and gas operations has largely focused on unconsolidated macrofaunal assemblages. In general, reduced species diversity and changes in relative abundance have been recorded close to wellheads and platforms, while further away communities are less impacted and unimpacted assemblages are found furthest from infrastructure (Grant & Briggs 2002, Terlizzi *et al.* 2008). Most studies show that drilling impacts are relatively localized (Ferbrache 1983) but can affect the environment more than 6 km from platforms with evidence that impacts are more localized in higher energy and more dynamic environments (Neff *et al.* 1989, Olsgard and Gray 1995). In the North Sea impacts have been detected up to 6 km from platforms (Olsgard & Gray 1995), while changes in community structure have generally been observed within 3000 m, with the most severe effects occurring within 500 m of the platform (Gray *et al.* 1999). In contrast, biological impacts in the Gulf of Mexico appear to be contained within a 200-800 m radius around platforms (Montagna & Harper 1996). The differences in area of detectable impact between these regions may be indicative of the role of local oceanographic conditions in dispersing contaminants which are responsible for changes in community composition. Similarly, petroleum activities at George's Bank on the American east coast were considered to have minimal, if any, impacts on benthic infauna communities compared to the more extensive impacts at mid-Atlantic rig sites (Neff *et al.* 1989). The lower impact was believed to be attributed to the higher energy environment and fewer accumulations of drilling mud cuttings and solids at George's Bank.

Changes in benthic assemblages have been strongly linked to increased total concentrations of hydrocarbons and trace metals (barium, strontium, zinc, copper, cadmium and lead) originating from drilling fluids or muds used in the drilling process (Neff *et al.* 1989, Daan *et al.* 1992, Hyland *et al.* 1994, Steinhauer *et al.* 1994, Olsgard & Gray 1995, Grant & Briggs 2002). Drilling fluids are typically composed of a high density mineral such as barite or ilmenite and various additives suspended in water (water-based muds) or an organic phase fluid. The organic fluid may be petrogenic (oil-based muds) or synthetic (synthetic-based muds). Prior to the mid 1990s oil-based muds were extensively used by the global oil and gas industry, but changes in international legislation has since resulted in them being largely replaced by water-based or synthetic drilling fluids (Gray *et al.* 1999). The move away from using oil-based drilling muds to water based drilling fluids has resulted in reduced environmental contamination and impacts associated with petroleum activities (Olsgard & Gray 1995, Gray *et al.* 1999). South African petroleum exploration and extraction have similarly reduced the extent of oil-based mud use and since the mid-1990s largely make use of water-based muds. Information provided by PetroSA indicates that only water-based drilling muds have been used for drilling and oil extraction at the wellhead surveyed in this study (E-BT01P) and for all wells drilled within the Oribi/Oryx exclusion zone. Eight PetroSA wells located in either the EM gas field or surrounding the FA Platform are reported to have made use of oil-based drilling mud between 1971 and 1994. Due to the lack of oil-based mud use in the Oribi/Oryx exclusion zone it is unlikely that elevated levels of hydrocarbons will be detected in this area.

Discharges of contaminated drill cuttings (mainly oil-based muds) have in the past caused changes in community composition of the benthos surrounding many oil and gas platforms in the North Sea (Davies *et al.* 1981, Gray *et al.* 1990, Kingston 1992, Olsgard & Gray 1995). Close to platforms benthic fauna show low diversity and are dominated by opportunistic species (Schaanning *et al.* 2008). With increasing distance from the platform, faunal diversity begins to return to representative levels, however, species composition is often represented by opportunistic species with more sensitive species no longer being present. Such changes in community structure have been linked to elevated hydrocarbon contents in sediments contaminated with oil-based mud cuttings (Grant & Briggs 2002). Synthetic based drilling muds are also reported to have some degree of impact on the environment although these are considered substantially less than oil-based muds (OGP 2003). Data from around platforms where only synthetic based muds have been used have indicated that the effects on the benthic fauna are less pronounced than around platforms where oil-based muds have been used (Jensen *et al.* 1999 in Schaanning *et al.* 2008). Studies have shown that within one year of synthetic based mud discharges, benthic communities had started to show signs of recovery but the area within 200 m of the discharge point were still impacted (OGP 2003). Within 3 to 5 years after the use of synthetic based muds, it is proposed that toxins in sediments are likely to have reduced to sufficiently low levels that full recovery is a possibility (OGP 2003). The process of biodegradation of the synthetic components of the mud by sulphate reducing bacteria in the sediments can result in sulphide toxicity and anoxic conditions. (Schaanning & Bakke 1997 in Schaanning *et al.* 2008).

Water-based drilling fluids consist largely of approximately 76 % water, 15 % barite and 7 % bentonite making their biodegradation less harmful to the environment. Quantitative studies of the effects of water-based drilling fluids are rare, but a few studies indicate that effects are restricted to a distance of less than 100 m from the platforms (Daan & Mulder 1996, Trannum *et al.* 2004 in Schaanning *et al.* 2008, Currie & Isaacs 2005). The major concern with regard to discharge of water-based fluids is the potential toxicity of trace metal impurities in the weight material, physical stress related to smothering and differences in size or shape of cuttings particles to the surrounding sediment habitat (Hyland *et al.* 1994, Holdway 2002, Schaanning *et al.* 2008).

Although most impact studies focus on infauna from unconsolidated habitats, pollution and disturbance from petroleum activities can also impact hard-bottom fauna (Hyland *et al.* 1994). On deep reef habitats, Hyland *et al.* (1994) found that the abundance some (4 of 22) invertebrate taxa were significantly reduced at sites of heavy petroleum activity. Analyses of chemical contaminants showed concentrations to be below toxic levels and the observed impacts were thus believed to be linked to physical impacts of increased sedimentation such as disruption of feeding or respiration and burial of settled larvae.

Changes in water quality

The largest aqueous discharge emanating from offshore oil and gas extraction structures is that of production water. Released on a continuous basis, volumes vary considerably throughout the lifetime of an oil field (typical volumes of a North Sea field range from 2 400 m³/day to 40 000 m³/day (Kloff & Wicks 2004). Production water consists primarily of relatively warm water from the oil reservoir, containing dissolved and dispersed oils, high salt concentrations, heavy metals, polycyclic aromatic hydrocarbons, no oxygen and on occasions naturally occurring radioactive material (Kloff & Wicks 2004). Although no research has been conducted on the impacts of production water on marine organisms, it is thought to have the potential to have adverse effects, particularly on larval stages (Grundlingh *et al.* 2006).

During construction of offshore infrastructure and drilling activities sediment plumes develop within the water column. This can affect biological communities by limiting light penetration and hence reducing photosynthesis, as well as by clogging the feeding mechanisms of filter-feeders (Newell *et al.* 1998).

Oil pollution

Oil spills associated with offshore production platforms can be classified into three groups. Firstly, those associated with terminal operations. These are usually small accidental oil spills arising during

routine operations when oil is loaded and discharged. While this normally occurs in harbours it may also take place at offshore production platforms. Secondly, large spills arising after incidents such as the grounding of an oil tanker or collisions with other vessels. Lastly, offshore production accidents such as 'blowouts' of wells and pipeline ruptures. A blowout or "loss of well control" can occur if a drilling rig encounters a pocket of sub sea oil under excessive geological pressure or due to technical failures. Under such conditions an extensive oil spill is likely to develop which is generally considered the greatest possible environmental threat in exploratory drilling. The probability of this occurring is generally considered to be low, although the environmental consequences of oil spills are severe and gas blowouts have significant safety considerations. The oil spill event resulting from the blowout at the *Deepwater Horizon* rig in the Gulf of Mexico on 20th April 2010 and the concomitant impacts on various marine and coastal environmental parameters serves to illustrate the extensive devastating effects such an event could cause (Kerr *et al.* 2010). The possibility of an oil spill is perceived as the greatest threat posed by this industry to marine biodiversity in South Africa (Attwood *et al.* 2000). Several studies have assessed the impact of oil spills under different spill volume scenarios using OILMAP, a numerical oil spill trajectory model (CSIR 1995, Crowther Campbell & Associates and CSIR 1998). These studies indicate that the environmental impact of an oil spill event would be considered high, however, the likelihood of occurrence is considered low.

The biological impacts of oil pollution on fisheries resources and marine communities have generally been well documented (see Dauvin 1998, Gomez-Gesteira & Dauvin 2000, Peterson *et al.* 2001, 2003, Junoy *et al.* 2005) and is not a focus of this project. There is, however, a paucity of information available of possible offshore effects on deep shelf and bathyal communities. Most examples of offshore oil spill incidents documented in the scientific literature relate to the sinking of tankers (e.g. The *Prestige* off the northwestern Iberian peninsula (Sanchez *et al.* 2006, Serrano *et al.* 2006) and the *Tsesis* in the Baltic Sea (Elmgren *et al.* 1983), nonetheless, the biological impacts are likely to be similar for a blowout.

In most cases spilt oil will disperse and sink, with the heavier fractions reaching the bottom by dropping from the water column as tar aggregates with low bioavailability or in the form of small toxic particles in sea snow (Sanchez *et al.* 2006). The shelf taxa initially affected by sedimented oil components are thought to be secondary producers, suspension feeders and detritivorous organisms, followed by planktophagous and benthophagous species (Serrano *et al.* 2006). Imbalances in the relative abundance of these lower level trophic groups are likely to result in cascading bottom-up ecosystem effects (Peterson *et al.* 2003). These changes may affect benthic taxa in different ways. Species of slow growth and with slow recovery capability (such as gastropods, crustaceans and echinoderms) show a high sensitivity to oil exposure (Feder & Blanchard 1998, Gomez Gesteira & Dauvin 2000), while initial mortalities of stress-tolerant or opportunistic groups such as polychaetes may be followed by extreme population fluctuations (Suchanek 1993). The effects of oil have been reported to diminish with increasing depth (Serrano *et al.* 2006) and Nounou (1980) reported that offshore oil incidents have less impact on bird and fish populations, however, the recent (20 March 2010) Gulf of Mexico oil spill emanating from a source at a depth of 1600 m has resulted in serious and similar impacts to oil spills in shallower waters (Kerr *et al.* 2010). The period required for deep sea benthic communities to fully recover following oil pollution is believed to be variable and highly dependent on the location of the oil spill and prevailing weather conditions (Nounou 1980, Sanchez *et al.* 2006).

Decommissioning options

Hamzah (2003) provides an overview of international law and practice for the decommissioning of offshore installations and reports on various global and regional instruments that attempt to regulate decommissioning. Although "decommissioning" is not defined by law (Hamzah 2003), it is recognized that this term refers to the process of dealing with petroleum infrastructure once platforms or wellheads are no longer operative. The distinction between decommissioning and dumping is not clear and Hamzah (2003) provides context in terms of the London convention. Various decommissioning alternatives for petroleum infrastructure, and platforms in particular, exist, ranging from total removal to allowing some or all of platform structure to remain in the ocean (Schroeder and

Love 2004, Kaiser 2006). Four broad types of decommissioning options were recognized although there are several iterations for various components of infrastructure (Figure 4). The first option involves the total or partial removal of infrastructure which is then scrapped on land. In many instances, platforms are transported to other locations and deployed as artificial reefs (McGinnis *et al.* 2001, Kaiser 2006). A further suggestion has been the use of platforms in situ for open water mariculture (Reggio 1996).

Operators that donate a platform as an artificial reef can often lower the cost of decommissioning below the cost to bring the platform to shore for disposal. The 'rigs to reefs' approach is used extensively off the coast of the United States of America (McGinnis *et al.* 2001). The major benefits associated with this approach in this area are reduced decommissioning costs to oil and gas companies and reported elevated fish densities around reefs compared to open water which is attractive to the recreational line fishery (when fishing is permitted) and scuba divers. Kaiser (2006) provides detailed information about the Louisiana rigs to reef program including infrastructure descriptions, decommissioning considerations and options, policy and legislation and the economics of rig donation.

Schroeder and Love (2004) discuss the potential ecological response to four general platform decommissioning alternatives: total removal, partial removal, toppling, and leave in-place. Decommissioning of deepwater structures is reported to be more controversial than other decommissioning situations because of greater uncertainties regarding environmental consequences of disposal/reefing in deepwater, and because of the considerably reduced cost to the oil industry in the decommissioning process (Schroeder and Love 2004).

Decommissioning of platforms is considered a process (as opposed to a project) because the owner and the engineer/contractors do not make all of the decisions leading to the completion of the work. Decommissioning decisions are complex and involve many considerations including legislation and regulations, costs, safety, site conditions, other stakeholder interests and environmental and ecological considerations (McGinnis *et al.* 2001, Schroeder and Love 2004, Kaiser 2006). Regulatory agencies, key stakeholders (including the fishing industry) and the public should be involved in the decision-making process (Schroeder and Love 2004). There are several phases to the decommissioning process including an assessment phases, an authorization phases and an implementation phase. In many countries an Environmental Impact assessment is mandatory prior to decommissioning and the environmental authorization component of the process can be challenging taking 3-6 years to complete (Hamzah 2003). Hamzah (2003) further subdivides the implementation component of the process into "three practical phases":

- A first phase consists of rendering the redundant structure hydrocarbon and chemical free by, where appropriate, abandoning the wells, removing conductors/ risers, flushing and cleaning the process/ utility systems, ensuring all the vessels and pipe work are gas and oil free and preparing the components for the lifting/removal operations.
- A second phase involves the deconstruction and removal of the installation and associated components.
- A third phase involves site restoration and regular monitoring and inspection of the site."

The literature is clear that from both ecological and political perspectives, decommissioning decisions should be made on a case-by-case basis (Hamzar 2003, Schroeder and Love 2004, Kaiser 2006).

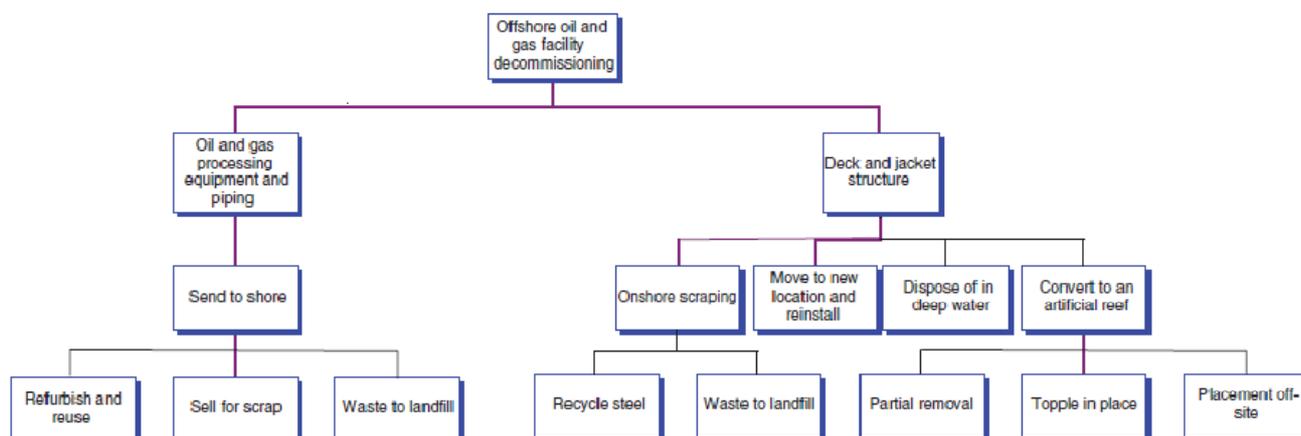


Figure 4. A decommissioning decision tree (Kaiser 2006).

Historical reports: FA Platform

Species previously reported from the FA platform were documented in historical reports (Cook 1995, 1996, 1997 and 1999) and summarized in Table 1. A total of 48 taxa were identified to species or genus level in the 0 – 60 m depth range.

Table 4. Taxa recorded in the fouling community at 0 – 60 m depths on the FA Platform by University Of Cape Town staff during the period 1992-1999. Species that were also observed in footage in 2005 and 2008 are shown in bold.

Scientific Name	Common Name	Depth Range in m per year (Cook)			
		1994	1996	1997	1999
<i>Actinia equina</i>	Plum anemone		5 - 30	15 - 60	
<i>Amphipholis squamata</i>	Scaly-armed brittlestar				
<i>Amphipod spp.</i>	Unidentified amphipods			15 - 50	
<i>Amphiura capensis</i>	Equal-tailed brittlestar				14 - 31
<i>Anomia sp.</i>	Saddle oyster	8 - 21			14 - 35
<i>Anthothoe stimpsoni</i>	Striped anemone			25 - 60	
<i>Arca sp.</i>	Unidentified arc shell			15 - 60	
<i>Arcuatula capensis</i>	Estuarine mussel		30		
<i>Atergatis roseus</i>	Chocolate crab		20		
<i>Austromegabalanus cylindricus</i>	Giant Barnacle	8 - 50	5 - 30	15 - 60	14 - 39
<i>Balanus amphitrite</i>	Striped barnacle	8 - 50		15 - 60	14 - 39
<i>Balanus trigonus</i>	Barnacle	8 - 50		15 - 60	14 - 39
<i>Balanus venustus</i>	Barnacle		5 - 15	15 - 35	
<i>Calyptrea chinensis</i>	Chinese hat (slipper limpet)				
<i>Caprella equilibra</i>	Skeleton shrimp (amphipod)				14 - 35
<i>Chaetopterus varieopedatus</i>	Polychaete	31			31
<i>Chlamys tincta</i>	Dwarf fan shell	31	15		14 - 31
<i>Choromytilus meridionalis</i>	Black mussel	21 - 50			14 - 39
<i>Dosinia hepatica</i>	Heart clam		15		
<i>Elasmopus pecteniscus</i>	Amphipod	8 - 21	15 - 30		14 - 39
<i>Eudendrium spp.</i>	Bushy hydroids		15		

Scientific Name	Common Name	Depth Range in m per year (Cook)			
		1994	1996	1997	1999
<i>Glyceria tridactyla</i>	Glycerine worm			10 - 35	
<i>Golfingia capensis</i>	Common peanut worm		30	15 - 60	
<i>Lepas sp.</i>	Goose barnacle			25 - 40	
<i>Lepidonatus durbanensis</i>	Durban scaleworm		5 - 30	15 - 60	
<i>Lepidonotus semisectus</i>	Common scaleworm	21 - 31			14 - 39
<i>Lithothamnion sp.</i>	encrusting coralline algae	21 - 50			14 - 39
<i>Mactra glabrata</i>	Smooth trough shell	31 - 50	5 - 30	25 - 50	14 - 39
<i>Montipora spp.</i>	Warty coral				
<i>Mytilus galloprovincialis</i>	Mediterranean mussel		5 - 30		
<i>Nephtys spp.</i>	Nephtys' sand-worms (polychaete)	8 - 50			
<i>Ophiarachnella capensis</i>	Banded brittlestar		5 - 30	15 - 50	
<i>Ophiocoma valenciae</i>	Spiny snake-like brittlestar				
<i>Ostrea algoensis</i>	Weed oyster				20
<i>Ostrea atherstonei</i>	Oyster	8 - 31			20
<i>Parachinus angulosus</i>	Cape urchin		5 - 30	35	
<i>Perna perna</i>	Brown mussel	8 - 50	5 - 30		20 - 39
<i>Pinctada capensis</i>	Cape pearl oyster	31	20	40	14
<i>Plagusia chabrus</i>	Cape rock crab	8 - 21	5 - 30	25	
<i>Plagusia depressa</i>	Crab	31			35 - 39
<i>Plumularia spp.</i>	Plumed hydroid		5 - 30	15 - 60	
<i>Polynoe scolopendrina</i>	Scale worm	8 - 21	20		
<i>Saxicava sp.</i>	Bivalve				14 - 39
<i>Spirorbis sp.</i>	Spiral fanworm	31	20	25 - 60	
<i>Syllis armillaris</i>	Beadworm (Polychaete)				14 - 39
<i>Syllis porifera</i>	Beadworm (Polychaete)		5 - 30		
<i>Syllis sp.</i>	Beadworm (Polychaete)			15 - 60	
<i>Syllis variegata</i>	Beadworm (Polychaete)				14 - 39
	Unidentified juvenile bivalve sp.		30	15 - 60	
	Unidentified isopod				14 - 39
	Unidentified nudibranchs				14 - 31
	Unidentified anemones				27
	Unidentified bryozoans		5 - 30	15 - 60	
	Unidentified hydrozoans	8 - 50			14 - 39
	Unidentified sponges	8 - 50	5 - 30	15 - 60	14 - 39

The introduced mussel *Mytilus galloprovincialis* was first recorded in 1996 although this species was not found in 1997 or 1999. No other non-indigenous species were documented. Mussels and barnacles were the key species of concern from a fouling perspective with particular concern about the giant barnacle *Austromegabalanus cylindricus* and the appearance of goose barnacles *Lepas sp.* in 1997. The former was evenly distributed across depths and was nowhere abundant but the recommendation was to monitor this species because of its size, potential to add significant mass to fouling communities and removal difficulty. Goose barnacles were not recorded in 1999 but it was recommended that this species is monitored because of its potential to cause serious fouling problems (Cooke 1999). The most important settlement time for mussels was October/November but a late summer settlement season in March/April was reported in some years. The greatest fouling was

recorded in January 1997 at a depth of 35 m (61.7 kg.m^{-1}). The next greatest was recorded in 1994 at a depth of 5m (54.4 kg.m^{-1}) with reports that wave action and stormy seas remove fouling at shallower sites on occasion. There was less fouling at greater depths in general with only 0.98 kg. m^{-1} recorded at 60 m in December 1994 (Cooke 1995, 1999).

Existing ROV footage: FA platform

The assemblages colonizing the FA platform were well developed and higher diversity and cover of living organisms was noted in 2008 compared to 2005 reflecting changes in succession and maturation of the invertebrate community with time. The invertebrate community was structured with depth as expected.

Structuring with depth

Mussels, barnacles, bryozoans, ascidians, sponges and anemones dominating the epifauna in the first 30 m. Mussels were usually dominated at 20 m and barnacles were usually dominant between 30 and 70 m. Few individual species could be identified (but see Table 5) but anemones, sponges and/or ascidians were recognized. Cape rock crabs *Plagusia chabrus* were abundant in this depth range with as many as 8 crabs recorded in a single frame (approximately 0.5 m^2). Marine growth was much denser closer to the surface with mussels and barnacles dominating the most extensive fouling communities. There is evidence of mussels and barnacles that have fallen from the surface and collected within suitable crevices within infrastructure as well as on the seabed. Crabs and lobsters were observed in association with these dislodged molluscs and barnacles in the 40-90 m depth range as well as seastars *Marthasterias glacialis* feeding on mussels on the seabed.

There was substantial footage reflecting communities in the 40 – 70 m depth range where barnacles, anemones, sponges and hydroids dominate. Ascidians may also be an important component of communities in this depth range but could not be distinguished. Barnacles could not be further identified and the most common anemone was an unidentified pink species that could be an introduced species and requires collection for proper identification. *Plagusia chabrus* was abundant in this zone and west coast rock lobster *Jasus lalandii* were also observed in this zone.

In the 70-100 m depth range, the biofouling community was less well developed. Communities in this depth range were dominated by anemones, small pink polyps and another species, most likely *Sagartia elegans*. Lower densities of barnacles were observed than in shallower depths. Hydroids and other filamentous growth were commonly observed and suspected bryozoans were seen on occasion but not well enough to capture stills or identify further with any certainty.

Algae

No definite algae were observed but it appears as though filamentous algal and fine algal turf are important components of the biofouling community up to 90 m in depth. On occasion, it seems as though encrusting algae is present but this could never be confirmed. ROV footage is annotated and it was recorded that algae extend to a depth of 100 m but this is anecdotal. In the 1990's, Cook (1995, 1999) reported the encrusting coralline algae *Lithothamnion* sp. from the 14 – 50 m depth range.

Sponges, ascidians and bryozoans

Numerous potential sponges, ascidians or other encrusting epifauna were observed on all infrastructure surveyed at the FA platform. In shallow water, bright yellow and orange encrusting sponges were conspicuous but in deeper water sponges were mostly white or orange. Four characteristic types of deep water sponges were observed in the 2008 footage but only encrusting sponges (that could also be ascidians) were seen in 2005. The most common sponges in 2008 were white tubular sponges, probably *Biemna anisotoxa* (Plate 2F) but dome-shaped sponges with large oscula and cup sponges were infrequently observed. No tubular sponges were observed in the 2005 footage although these were relatively common in the 2008 footage. More species were noted in 2008 than 2005 with a denser more complex fouling community documented in 2008.

Anemones

Strawberry anemones *Corynactis annulata* were common in shallow water. Bright purple anemones (possibly *Aulactinia reynaudi*) were also seen in the 10-15m depth range but confirmation of identification was not possible. Fine pink polyps that resemble anemones (see Plate 3) covered extensive areas of infrastructure but these are only visible upon close inspection when the ROV or divers were obtaining measurements from the surface of the infrastructure. This probable anemone is unidentified but has small (approximately 0.5-1.2 cm diameter) polyps, short tentacles and a pink column. It is distinct from the strawberry anemone *Corynactis annulata* that was seen in the 10-18 m depth range. Colonies were not tightly packed with spaces between individuals. The pink “anemone” was most abundant in the 70-90 m depth range but was also common in the 40–70 m zone. The extensive cover of this species suggests that it may also be a non-indigenous species and it is a priority for collection and identification.

There were extensive patches of anemones, probably the non-indigenous *Sagartia elegans* species (also collected by SAT divers from the ORCA in 2009) in the 70 – 105 m depth range. These occurred in orange, brown and white colonies and emit white stringy acontia (white thread-like defensive organs) when disturbed during ROV measurements (see Plate 3). These anemones were common on caissons, horizontals, piles and risers. Only three specimens that are most likely the introduced anemone *Metridium senile* were observed in one place at 105 m in 2005. In 2008, two potential occurrences of *Metridium* sp. were observed in two places on a horizontal in 70 m of water. One patch consisted of approximately 15 individuals and only two individuals were documented in an adjacent area. Their identification cannot be confirmed and it is possible that these were not *Metridium* sp. and it is also possible that other white polyps observed were actually *Metridium* sp. but poor footage quality did not facilitate confirmation of their identification.

Soft corals

A suspected octocoral (that could also be an ascidian) was observed growing in large colonies on infrastructure in the 2008 footage (Plate 5E, F). It is possibly the magenta-purple *Alcyonium fauri* but was distinct in general appearance from those specimens known from reef habitats. It was relatively common in the 40-70 m depth range and occurred in lower abundance above this depth. The deepest record was 90 m. This species formed extensive sheets in some areas and grew over mussels and other fauna and covered conductors, pipes and other structures, leading to concerns that it may also be an introduced and potentially invasive species. One gorgonian was observed in 2008 but it is not possible to confirm identification. It appeared most like the nipples seafan *Eunicella papillosa*.

Hard corals

One solitary hard coral was observed and there were two other observations of potential scleractinia on infrastructure. A further dislodged invertebrate colony was observed on the seabed and reported as a clump of coral in the ROV footage annotation but these are considered to be more likely to be the tubes of a polychaete worm or even bryozoa (see Plate 2C). Poor footage quality and taxonomic challenges may have resulted in mis-identification of corals but no obvious large colonies of scleractinian corals such as *Lophelia pertusa* were seen.

Hydroids

Hydroids could not be identified but several varieties were observed including black, brown, grey and yellow specimens. The yellow hydroids may be *Sertularella arbuscula*.

Worms

During close-up measurements the ROV obtained images of tube worms in both years but these cannot be further identified. Cook (1995, 1996, 1997, 1999) collected several species of *Syllis* sp. beadworms, the polychaete *Chaetopterus varieopedatus*, glycercerine worms *Glyceria tridactyla*, spiral fanworms *Spirorbis* sp., *Nephtys* sp. polychaetes, scale worms *Polynoe scolopendrina* and peanut worms *Golfingia capensis* in the 0-60 m depth range (Table 4).

Molluscs

Mussels were a dominant member of the fouling community, as was observed in footage from the 5-30 m depth range in 2005 and 2008. Species identification was challenging from footage but the introduced mussel *Mytilus galloprovincialis* was tentatively identified. Cook first recorded this species at the FA platform in 1996 although this species was not found in 1997 or 1999. In the 1990s, the fouling community in shallow water was dominated by the brown mussel *Perna perna* in terms of biomass (Cook 1995, 1996, 1997, 1999).

Crustaceans (Barnacles, crabs and lobsters)

Several species of barnacles were evident in the footage throughout the FA platform depth range. The Giant Barnacle *Austromegabalanus cylindricus* was clearly recognized but other barnacles could not be identified. Cook (1995, 1996, 1997, 1999) collected 5 species of barnacles including the giant barnacle. Barnacles formed an important dominant component of the fouling community in shallow water (5-20m) and dominated communities in the 30-70 m depth range. Barnacles dislodged and accumulated on the seabed as well as in crevices or cavities within the infrastructure.

The Cape rock crab *Plagusia chabrus* and the west coast rock lobster *Jasus lalandii* were frequently observed at the FA Platform. The rock crab is abundant throughout the depth range and is the most commonly observed mobile invertebrate. The lobster was observed between 40 and 101 m and was never seen on the seabed but rather on pipes or within hiding places in infrastructure. More than 50 lobsters were observed in the three hours of footage examined from 2005 and similar densities were observed in the more than 15 hours of 2008 footage examined. In 2008, highest densities were observed in association with skirt plates and in the sleeves or guides of conductors. Lobsters were more abundant on horizontal structures than vertical structures and were more abundant closer to potential hiding places. No south coast rock lobster, *Palinurus gilchristi* were seen on any of the FA footage although this species was observed within the ORCA area.

Echinoderms (seastars, brittlestars and urchins)

The seastar *Marthasterias glacialis* was frequently observed close to or on the seabed in both 2005 and 2008, usually associated with accumulated mussels that appear to have fallen from shallower water. One specimen of the seastar *Toraster tuberculatus* was observed in 2008. This species was also collected by SAT divers on tinrastructure associated with the ORCA (Plate 1E). A further two distinct but unidentified seastars were observed. No urchins were observed in the 2005 footage but a few specimens (<15) of *Echinus gilchristi* and *Parechinus angulosus* (about 10) were observed near or on the seabed in 2008. Brittlestars were seen on occasion when sediment was suspended or growth knocked off infrastructure.

Ascidians

Various ascidians were tentatively identified but these cannot readily be distinguished from other encrusting taxa. None of the potential introduced red ascidians with two distinct siphons that were seen on the ORCA footage were observed on the FA infrastructure in either year.

Table 5. Tentative identification of macro-invertebrates observed on footage from the FA Platform. Specimens identified with certainty are indicated with an asterix.

Common name	Scientific name	Year	Notes
Unidentified tubular sponge (white)		2008	Most common between 70-101 m
Unidentified dome-shaped white-grey sponge (large oscula)		2008	Seen between 48 and 101m
Hydriods	Not possible to identify	2005, 2008	Important component of shallow and deep communities, particularly in the 40-90 m depth range
White anemone	<i>Metridium senile</i>	2005	Introduced invasive
Striped anemone	<i>Sagartia elegans</i>	2005, 2008	Introduced invasive, Abundant 70-100 m

Common name	Scientific name	Year	Notes
Unidentified pink anemone			Possible invasive. Abundant in the 40-90 m depth range
Unidentified "flytrap" anemone		2008	Observed in the 70 – 101 m depth range
Tube worms	Not possible to identify	2005, 2008	
Mussels	Probably several species including <i>*Mytilus galloprovincialis</i>	2005, 2008	Observed in the 5 – 30 m depth range. Dominant at 20 m.
Cape rock crab	<i>*Plagusia chabrus</i>	2005, 2008	Highest abundance in 40 – 60 m but fairly common throughout depth range.
West coast rock lobster	<i>*Jasus lalandii</i>	2005, 2008	Highest abundance associated with skirt plates, sleeves and conductor guides in the 50-90 m depth range.
Barnacles 1 (large pink)	<i>*Austromegabalanus cylindricus</i>	2005, 2008	
Barnacles 2	<i>Balanus trigonus</i>	2005, 2008	
Bryozoans	Not possible to identify	2005	
White urchins	<i>*Echinus gilchristi</i>	2008	Always on or within 2 m of the seabed
Purple urchins	<i>*Parechinus angulosus</i>	2008	Seen on the seabed, usually with fallen mussels and the seastar <i>Marthasterias glacialis</i>
Starfish (spiky)	<i>*Marthasterias glacialis</i>	2005, 2008	Common but only seen close to seabed (98-106 m). Often where mussels have fallen onto the seabed.
Starfish	<i>*Toraster tuberculatus</i>	2008	Close to seabed, 104 m
Ascidians, many potential species	Not possible to identify		

Fishes

Only three species of fish were observed in the 2005 FA platform footage; the goldie *Callanthias legras*, the jacobever *Helicolenus dactylopterus* and most commonly, the barred fingerfin *Cheilodactylus pixi* (Plate 6). In 2008, six species were observed; three species of fingerfin, *C. pixi*, *C. fasciatus* (redfingers) and the twotone fingerfin *C. brachydactylus* as well as goldies, many jacobever and one unidentified fish. Barred fingerfins were common in the 20-80 m depth range and redfingers were only observed in association with the seabed at approximately 100 m. Only 1 specimen of twotone fingerfin was observed in all footage and this was at a depth of 40 m. Goldies were observed at the seabed, usually associated with tyres or hard infrastructure with habitat complexity. Jacobever were common on the seabed under infrastructure and were seen in high densities during scour surveys (Plate 6A and D). An unidentified dark rockcod-like fish was also observed during one of the scour surveys. No kingklip *Genypterus capensis* or hake *Merluccius* spp. were seen. In addition, no sparids were observed throughout the FA platform depth range. Very little footage was available in less than 5 m of water and no surface dwelling fish were observed. This is in contrast to the extensive shoals of yellowtail and several sparids observed close to the surface in footage from the ORCA.



A) Barnacles and mussels in shallow water



B) Cape rock crab *Plagusia chabrus*



C) Dislodged reef building invertebrate



D) Gorgonian *Leptogorgia palma*



E) West coast rock lobster *Jasus lalandii*



F) Tubular sponges possibly *Biemna anisotoxa*

Plate 2. Fauna from the FA Platform as captured in ROV footage filmed in 2005 and 2008. The dislodged colony in image C could be worms, coral or bryozoans.



A) Unidentified pink anemone



B) Pink anemone & cf *Sagartia elegans*



C) cf *Sagartia elegans* with 'acontia' threads



D) cf *Sagartia elegans*

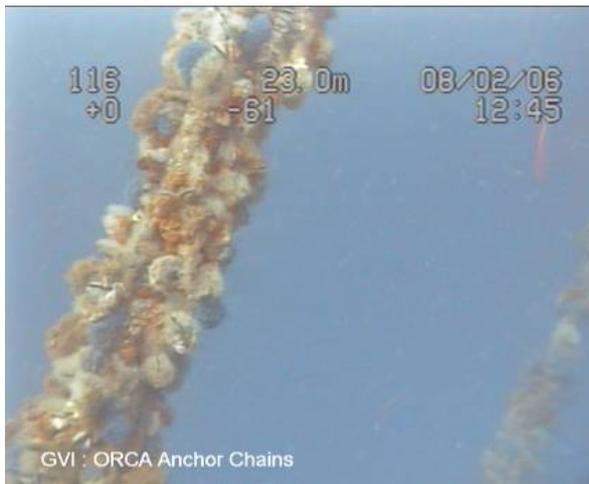


E) cf *Sagartia elegans*



F) cf *Sagartia elegans*

Plate 3. Anemones colonizing the FA platform as captured in ROV or diver footage filmed in 2005 and 2008. Unidentified pink anemones were abundant in the 70-100 m depth range (A, B). These smaller polyps occurred in lower densities than the anemone thought to be the introduced species *Sagartia elegans* (B-F). This species readily emits 'acontia' (fine white threads seen in C), one characteristic feature. Orange and white colonies were observed in both the 2005 and 2008 footage (E, F).



A) Mussels, sponges and soft corals



B) *Plagusia chabrus*



C) *Marthasterias glacialis* & *Parechinus angulosus*



D) Rock lobster and kinglip (encircled)



E) Colonies of branching invertebrate



F) Basket star on mattress

Plate 4. Fauna from the Oribi/Oryx region below the ORCA as captured in ROV footage filmed in 2007. Spherical or bushy colonies of a branching invertebrate (E) are most likely worm colonies of the species *Filograna implexa* but could be a hard coral or bryozoans.



A) Anemone *Metridium senile*



B) Anemone of *Sagartia elegans*



C) Ascidian *Diplosoma splisterianum*



D) Unidentified ascidian (red tunicate)



E) Unidentified magenta octocoral or ascidian



F) Unidentified magenta invertebrate

Plate 5. Introduced and unidentified species that may be introduced species associated with petroleum infrastructure on the Agulhas Bank.



A) Jacopever *Helicolenus dactylopterus*



B) Jacopever *Helicolenus dactylopterus*



C) Barred fingerfin *Cheilodactylus pixi*



D) Redfingers *C.fasciatus* & jacopever



E) Horsefish *Congiopodus* sp. At wellhead



F) Yellowtail *Seriola lalandi* near surface

Plate 6. Fish species colonizing the FA platform and infrastructure in the Oribi/Oryx field. The barred fingerfin *Cheilodactylus pixi* (C) was the most frequently documented species followed by jacopever (A, B, D) in both years at the FA platform.

Existing ROV footage: Oribi/Oryx

Infrastructure within the Oribi/Oryx area was generally covered with less growth than that observed in 2005 and 2008 ROV footage from the FA platform. The exception was growth on chains and umbilicals close to the surface. Similar coverage and densities of growth were observed close to the surface (0-50 m) but in deeper water, and particularly on infrastructure on the seabed, diversity and density of marine growth was far less on ORCA infrastructure than at the FA platform.

Algae

No confirmed algae were observed but it appears as though filamentous algae and fine algal turf are important components of the biofouling community in shallow water (0-50 m).

Sponges

Sponges were not common and a low diversity was observed in the footage examined. It is difficult to distinguish among sponges, ascidians, bryozoans and even encrusting soft corals from underwater footage (i.e. without specimens). Colourful sponges were observed in shallow water on umbilicals, risers, buoyancy moderators and anchor chains. One distinct sponge was seen on the umbilical between the ORCA and the SUTA. None of the deep water sponges (>70 m depth) observed at the FA platform were documented in any of the Oribi/Oryx footage. No sponges were seen or collected during SAT diver collections. Specimens that were thought to be sponges growing on wellheads were actually ascidians, highlighting the importance of collections in examining biodiversity associated with petroleum infrastructure.

Anemones

Strawberry anemones *Corynactis annulata* were only seen in shallow water (< 20 m). In deeper water, there were extensive patches of anemones, the non-indigenous invasive species *Metridium senile* and *Sagartia elegans*. The identification of both these taxa was confirmed through collections by SAT divers. *Metridium senile* was documented between 100 and 117 m and was found on wellheads, umbilicals, flowlines and pipelines. Densest aggregations of *M. senile* were seen on the six inch oil export pipeline (Plate 3). Two *Sagartia elegans* specimens were collected by SAT diver at a wellhead (Plate 3). These were assumed to be the same species that was observed in very dense assemblages on umbilicals, risers and other infrastructure from a depth of 38 m to 114 m. The two specimens that were collected were growing as isolated specimens (the second specimen collected was found in a group of three individuals). Dense aggregations of this suspected invasive anemone were seldom observed on wellheads and such colonies were never observed during SAT diver collections. For the purpose of this report, it is assumed that the dense colonies of anemones are *Sagartia elegans* but it is recommended that further samples from within dense aggregations are collected for confirmation. This species was densest on pipelines, flowlines and umbilicals, particularly in the 70-100 m depth range.

Corals, hydroids and bryozoans

White octocoral polyps were observed during close up ROV inspections and these polyps closely resemble the specimens of *Alcyonarium muricatum* in the Iziko South African museum invertebrate collection. A suspected blue soft coral (resembles *Sansibia* sp. but could also be the bryozoan *Bugula dentata*) is distinct and abundant on umbilicals and chains from the surface to approximately 50 m (Plate 4A). One colony of *Eleutherobia variabile* was collected from a wellhead and further specimens were observed in footage in the 70 to 119 m depth range. One gorgonian *Leptogorgia palma* was documented at 97 m on the 6 inch oil export pipeline. No gorgonians were observed in any infrastructure close to the seabed such as wellheads, pipelines or mattresses.

Solitary hard corals (*Caryophyllia* c.f. *grandis*) were observed and collected by SAT diver. Large colonies of branching invertebrates that may be potential reef building corals (such as *Lophelia pertusa*) were seen on an umbilical and associated buoyancy modules in the 80 – 110 m depth range (See Appendix 2 Plate 3 from video clip 200612112319054). Footage quality and visibility is poor and

further identification is not feasible but we believe these reef building invertebrates are most likely tubes made by annelid worms (see below under Worms) but could also be bryozoans.

Hydroids were commonly observed but further identification was not feasible. One distinct species, the tubular hydroid *Ectopleura crocea* was observed on infrastructure between 112 and 117 m. SAT divers collected bushy hydroids but the taxonomy of this group is challenging and no identifications have been made.

Some bryozoans were collected by SAT diver although distinct bryozoans were not observed on footage. The bryozoans *Bugula dentata* may occur in shallow water on chains and umbilicals.

Worms

During close-up measurements the ROV obtained images of tube worms on wellheads, umbilicals, the SDU frame, flowlines and anchor chains but these cannot be further identified. SAT divers collected worm tubes that are most likely the hosts of *Serpula vermicularis*. The spherical colonies observed on buoyancy moderators on umbilicals could be the tubes of coral worms such as *Filograna implexa* (Plate 4E).

Molluscs

Mussels were a dominant member of the fouling community, as was observed in footage from the 5-60 m depth range. Species identification from footage was not possible and only the alien mussel *Mytilus galloprovincialis* was clearly identified from samples. Mussels occurred from the surface to approximately 60 m on umbilicals and chains. An octopus and unidentified horse mussels were documented on the seabed by the SAT diver at 118 m.

Crustaceans (Barnacles, crabs and lobsters)

Barnacles formed a dominant component of the fouling community in shallow water (0-50 m). Several species of barnacles were evident in the footage but only the pink giant barnacle *Austromegabalanus cylindricus* was clearly recognized. Dislodged specimens of this species were also collected by SAT divers from the seabed, as were the barnacles *Balanus trigonus* and *Amphibalanus* sp.

The Cape rock crab *Plagusia chabrus* and the south coast rock lobster *Palinurus gilchristi* (Plate 3) were frequently observed. The rock crab was abundant throughout the depth range and was collected by SAT diver. This crab occurred on all types of infrastructure ranging from umbilicals to wellheads and was also observed on the adjacent seabed. The crab *Goneplax rhomboides* was collected and observed and the crab *Mursia christimanus* was also documented in sandy habitat adjacent to infrastructure. The lobster was only observed on wellheads or close to or on infrastructure at the seabed (surveys of chains and anchors). One specimen was observed in open sandy habitat by the SAT diver at night. No west coast rock lobster *Jasus lalandii* were seen on any of the ORCA footage although this species was observed on infrastructure at the FA platform. Small shrimps (cf *Plesionika* sp.) were frequently observed on seabed infrastructure including pipelines, flowlines and mattresses. Several shrimps were collected by SAT diver but these could not be identified.

Echinoderms (seastars, basketstars and urchins)

Several species of starfish, urchins and one basket star was observed in footage examined (Plate 3). The seastar *Marthasterias glacialis* (Plate 4C) was frequently observed close to or on the seabed, often associated with accumulated mussels that appear to have fallen from shallower water. The seastar *Toraster turbuculatus* was observed and collected by SAT divers (Plate 1E). Other starfish were seen but identification was not possible. A basketstar *Astrocladus euryale* (Plate 4F) was observed on a concrete mattress during a dedicated ROV survey in March 2009. Two species of urchins were commonly observed at wellheads or on umbilicals or mattresses, *Echinus gilchristi* and *Parechinus angulosus*. The identification of both these species was confirmed by specimens collected by SAT divers. The starfish *Astropecten irregularis pontoporeus* was observed in sandy habitat and this species was also collected by SAT diver (Table 6).

Ascidians

One potential introduced ascidian (red-orange, 2 siphons) was seen on the Orca footage but was not found during collections made by SAT divers (Plate 5D). No other ascidians were observed on 2006 footage but it suspected that some taxa thought to be sponges may actually be ascidians. Many ascidians are cryptic as indicated by the ten specimens collected from wellheads by SAT diver. Two of the ascidian species that were collected have been identified as non-indigenous (*Cnemidocarpa humilis* and *Diplosoma c.f. listerianum*), however, their invasive status is unconfirmed. These species were not observed on 2006 footage but this is not surprising as they are not distinct or easily visible.

Table 6. Tentative identification of macro-invertebrates observed on footage from the ORCA. Specimens identified with certainty are indicated with an asterisk and those that were also collected by SAT diver are indicated with a double asterisk (**)

Common name	Scientific name	Depth	Notes
Unidentified tubular sponge (white)		117m	One specimen observed on an umbilical (suta to ORCA)
Strawberry anemone	* <i>Corynactis annulata</i>	0-20 m	Common on umbilicals and chains.
White anemone	** <i>Metridium senile</i>	100-117 m	Introduced invasive, Abundant on the 6 inch export pipeline, also on wellheads, mattresses and umbilicals
Striped anemone	** <i>Sagartia elegans</i>	38-114 m	Introduced invasive, Abundant on the 6 inch export pipeline, the Oryx and other umbilicals
Unidentified pink anemone		112-118 m	Observed only during close-up inspections on infrastructure at the seabed.
Tube anemones	* <i>Cerianthus sp.</i>	115-119 m	Buried in sand.
Solitary hard corals	Possibly several species including ** <i>Carophyllia grandis</i> (collected by SAT Diver)	114– 118 m	Observed only during close-up inspections, particularly in SAT diver footage.
White soft coral	* <i>Alcyonarium cf muricatum</i>	117 m	Observed only during close-up inspections, particularly in SAT diver footage.
Orange colonial soft coral	** <i>Eleutherobia variabile</i>	70-119 m	Observed on hard structures.
Blue soft coral or bryozoan	Unidentified or possibly <i>Bugula dentata</i>	0-50 m	Abundant in 0-50 m on umbilicals and chains.
Palmate seafan	* <i>Leptogorgia palma</i>	98 m	One specimen on the oil export pipeline.
Hydroids (bushy)	Unidentified	12 – 118 m	Umbilicals and chains particularly in the 30 – 90 m depth range.
Tubular hydroid	* <i>Ectopleura crocea</i>	112-117 m	On wellheads, only observed during close-up inspections.
Bryozoans	Not possible to identify	113-117 m	Bryozoans were infrequently observed on wellheads and conductor guides.
Tube worms	Not possible to identify		Small tubeworms visible throughout depth range
Mussels	Probably several species including ** <i>Mytilus galloprovincialis</i>	0-60 m	Noted in shallow water on calm buoy chains and umbilicals. Dislodged specimens common on seabed.
Barnacles 1 (large pink)	** <i>Austromegabalanus cylindricus</i>		Noted in shallow water on calm buoy chains and umbilicals. Dislodged specimens common on seabed.

Common name	Scientific name	Depth	Notes
Barnacles other	** <i>Balanus trigonus</i> and <i>Amphibalanus</i> sp.		Dislodged specimens collected by SAT divers.
Cape rock crab	** <i>Plagusia chabrus</i>	Surface – 117m	Very common on all infrastructure
Angular crab	** <i>Goneplax rhomboides</i>	117m	Recorded on sandy seabed
Masked crab	* <i>Mursia cristiata</i>	118 m	Recorded on sandy seabed
South coast rock lobster	* <i>Palinurus gilchristi</i>		Only seen close to the seabed, particularly on wellheads.
Unidentified shrimps (cerise markings)	cf <i>Plesionika</i> sp.	115-117 m	Common on infrastructure at the seabed, particularly mattresses and flowlines
Shrimp	** Not possible to identify	unknown	Incidentally collected during SAT dive
White urchins	** <i>Echinus gilchristi</i>	110-117 m	On wellheads, flowlines, export pipelines and the seabed
Purple urchins	** <i>Parechinus angulosus</i>		Seen on the seabed, usually with fallen mussels and the seastar <i>Marthasterias glacialis</i>
Burrowing urchin	* <i>Brissopsis lyrifera capensis</i>		Recorded on sandy seabed in the day. Appear to burrow at night
Starfish (spiky)	** <i>Marthasterias glacialis</i>		Common but only seen close to seabed (98-106 m). Often where mussels have fallen onto the seabed.
Maroon starfish	** <i>Toraster</i> sp.	116-118 m	Infrequently observed on hard infrastructure
Basketstar	<i>Austrocladus euryale</i>		Three specimens observed on concrete mattress
Red ascidian	Not possible to identify		Potential invasive species, Common on wellheads and pipelines

Fishes

Extensive shoals of yellowtail *Seriola lalandi* (Plate 6F) and some common sparids (seabreams) were observed close to the surface of the ORCA, particularly in association with calm buoys, anchor chains and ORCA chains. Sparid identification from footage was difficult but steentjie *Spondyliosoma emarginatum*, hottentot *Pachymetopon* sp., blacktail *Diplodus capensis* and fransmadam *Boopsoidea inornata* were tentatively recognized in the 0-8 m depth range.

Several species of fish were observed sheltering on or within infrastructure at the seabed. The most commonly documented species was Jacopever *Helicolenus dactylopterus* (Plate 6A, B) with as many as 27 individuals recorded at a single wellhead. Kingklip *Genypterus capensis* were most often observed sheltering under concrete mattresses but also within wellheads and even associated with anchors. Three individual horsefish *Congiopodus* sp. were observed, one at a wellhead (Plate 6E), another near a cross-piece and one by SAT diver at an old conductor guide. Several dory *Zeus* sp. were observed close to pipelines or other infrastructure (SDU frame, wellhead). The goldie *Callanthias legras* was seen associated with complex artificial habitat. One species of fingerfin *Cheilodactylus pixi* was observed. No sparids, rockcods or gurnards were ever observed in association with deeper infrastructure (>10 m). No hake *Merluccius* spp were observed close to infrastructure. An unidentified sole, several rat tails (identification impossible), Cape dories *Zeus capensis* and several sygnathids were briefly observed in sandy habitat adjacent to infrastructure. One individual and a shoal of slender snipefish *Macroramphosus scolopax* was observed adjacent to the 6 inch flowline.

Mammals

One South African fur seal (*Arctocephalus pusillus*) was observed at 115 m.

Marine biodiversity associated with different types of infrastructure

Flowlines and mattresses

The 6 inch water injection flowline was colonized with outbreaks of the introduced, invasive *Sagartia elegans* anemones as well as a potentially introduced red ascidian (Plate 5). The urchin *Echinus gilchristi* was observed. Concrete mattresses in the vicinity were colonized by patches of the introduced, invasive anemone *Metridium senile* and these structures were poorly colonized by sessile invertebrates with very little marine growth. Unidentified shrimp species were documented on the mattresses and kingklip and jacopecover were observed hiding underneath mattresses.

Pipelines

In shallow water the oil export pipeline was colonized by a typical fouling community including mussels, barnacles and encrusting colonial invertebrates. Crabs *Plagusia chabrus* were observed over the entire depth range of the pipelines. Dense growth occurred on the flexible riser diminishing after 30 m to some extent. In deeper water, the 6 inch oil export pipeline had outbreaks of invasive *Metridium* and *Sagartia* anemones as well as the potentially introduced red ascidian. Serious infestations of *Sagartia* were seen between 60 and 100 m whereas *Metridium* occurred close to the seabed. Several other interesting anemones that could not be identified were documented. Seastars *Marthasterias glacialis* were frequently observed close to or on pipelines, often associated with dense accumulations of dislodged mussels. They were also seen with mussels on buoyancy moderators in shallow water. One specimen of the gorgonian *Leptogorgia palma* was observed at 97 m. Cape dory *Zeus capensis* and slender snipefish *Macroramphosus scolopax* were observed adjacent to pipelines.

Wellheads

Wellheads were not heavily colonized by invertebrates with much less biofouling than infrastructure close to the seabed at the FA platform. Introduced species on wellheads included the non-indigenous anemones *Metridium* sp. and *Sagartia* sp. and the unidentified red ascidian. Approximately 500 individuals of this ascidian were seen on wellhead E-BT01P. Other unidentified anemones were observed on wellheads as were solitary hard corals. Hard corals were collected for identification. Two species of urchins were commonly observed at wellheads, *Echinus gilchristi* and *Parechinus angulosus*. *Plagusia chabrus* and south coast rock lobsters *Palinurus gilchristi* were also frequently recorded. Crab densities were high with a maximum of approximately 100 individuals observed on a wellhead. Lobster numbers ranged between zero and seven at wellheads although accurate numerical assessment from footage is difficult. Seastars *Marthasterias glacialis* were frequently observed close to or on the wellheads, often associated with dense accumulations of mussels and barnacles that appear to have fallen from shallower water. The seastar *Toraster* sp. was collected and observed at wellheads. Giant barnacles were documented loose on the seabed at 114 m on wellhead E-BT01P. The most commonly observed fish associated with wellheads were Jacopever *Helicolenus dactylopterus* and kingklip *Genypterus capensis*. Jacopever densities ranged from zero to an estimate of about 30 fish at a single wellhead. One large horsefish *Congiopodus* sp. was seen sheltering within wellhead EAR0P2. Other fish observed include goldies *Callanthias legras* and a fingerfin *Cheilodactylus* sp.

Isolated individuals or small patches of *Metridium* sp. were observed close to wellheads in sandy seabed areas.

SDU Frame, SUTA and cross-piece connections

There is little sessile marine life on the SDU structure but high densities of crabs were observed, Starfish *Marthasterias glacialis* and the urchins *Parechinus angulosus* and *Echinus gilchristi* were present. Mussel shells and barnacles (debris) covered the top of the structure. Worms were common on jumper cables. Jacopever, john dory and goldies were observed.

Little marine growth was observed at the SUTA. *Sagartia elegans* and *Metridium senile* anemones and the crab, *Plagusia chabrus* were present. Fairly dense *Metridium* colonies were noted on the jumper cables. Several jacopecover were observed at the SUTA. Adjacent mattresses were covered

with a fine layer of detritus and or sediment and had high densities of shrimps. *Metridium senile* was observed on mattresses.

Bioturbation, fanworms, sygnathid pipefish, rattails and isolated individuals or small patches of *Metridium* sp. were observed in sandy seabed areas adjacent to the SUTA.

Limited footage of cross-piece connections were available but close-up images showed calcareous worm tubes and small pink polyps, probably anemones, on infrastructure at the T-piece. These pink polyps look like the unidentified anemones observed at the FA platform.

Umbilicals

In shallow water, umbilicals are covered in soft marine growth. A blue soft coral (or could be the bryozoan *Bugula dentata*) is distinct and abundant from the surface to approximately 50 m (Plate 4A) Dense aggregations of introduced *Sagartia* sp. anemones were observed on several umbilicals (e.g. umbilical E-BT01P and umbilical suta to ORCA) and *Metridium* sp. outbreaks were also noted on umbilicals, particularly closer to the SUTA. The red unidentified ascidian was also observed in high densities on umbilicals between the SUTA and wellheads. Seastars *Marthasterias glacialis* were commonly observed.

The midwater arch had surprisingly little marine growth and unidentified small red anemones not seen elsewhere were observed during close up inspection.

Unidentified rattails, Cape Dory *Zeus capensis* and cerianthids were observed in soft sediment areas adjacent to umbilicals (113 m). Bioturbation was evident in such habitats.

Calm buoy and Orca Chains

Chains had extensive marine fouling with dense communities in shallow water dominated by mussels, barnacles, sponges, soft corals, hydroids and bryozoans. Growth was structured with depth. Extensive marine growth occurred to almost 60 m with mussels extending to this depth. A blue colonial invertebrate, possibly a soft coral or the bryozoan *Bugula dentata* is distinct and abundant from the surface to approximately 50 m. *Plagusia chabrus* were observed on both calm buoy and ORCA chains. Between 70 m and seabed, chain links were able to be observed as marine growth diminished. Fine filamentous growth (algae and hydroids) was evident in this depth range. *Echinus gilchristi* was observed on some chains in the 110-70 m depth range. The non-indigenous anemone *Metridium senile* was observed on chains in the 117 – 100 m depth range but infestations were localized and densities were much lower than on pipelines. One juvenile *Palinurus gilchristi* was observed on the seabed next to calm buoy chain 2.

SAT diver collections

A total of 38 benthic specimens (Table 7) were collected by SAT divers from infrastructure and adjacent sandy habitat within and outside of the Oribi/Oryx exclusion zone (Fig. 2).

Table 7. Macro-invertebrate specimens collected by SAT diver from infrastructure or the surrounding seabed within the Oribi/Oryx area, March 2009. Collection depths range from 115 to 119 m.

Cryptogenic species (*) and Introduced species (**) are indicated.

Common name	Scientific name	Collected from	Identified by:
White anemone	<i>Metridium senile</i> **	seabed, wellhead	Megan Laird
Striped anemone	<i>Sagartia elegans</i> **	wellhead	Megan Laird
Cerianthid	<i>Cerianthus</i> sp.	seabed	Kerry Sink
Hard corals	<i>Carophyllia grandis</i>	wellhead	Kerry Sink
Orange colonial soft coral	<i>Eleutherobia variabile</i>	wellhead	Kerry Sink
Hydriods	unidentified	wellhead	
Bryozoan 1 (staghorn)	<i>Turbicellepora valligera</i>	Wellhead	Wayne Florence
Bryozoan 2 (lacey)	<i>Schizoretepora tessellata</i>		Wayne Florence
Bryozoan 3 (growing on label)	<i>Klugeflustra jonesii</i>		Wayne Florence
Tube worms	<i>Serpula vermicularis</i>	wellhead	Lara Atkinson
Polychaete	<i>Nereis gilchristi</i>	wellhead, seabed	Lara Atkinson
Mussel	** <i>Mytilus galloprovincialis</i>		Charlie Griffiths
Scallop	<i>Talochlamys cf multistriata</i>		Lara Atkinson
Sea slugs (opisthobranch)	<i>Pleurobrachaea bubala</i> (tbc)	wellhead	Lara Atkinson
Barnacles 1 (large pink)	<i>Austromegabalanus cylindricus</i>	seabed (debris)	Aiden Biccard
Barnacles 2	<i>Balanus trigonus</i>	seabed (debris)	Aiden Biccard
Barnacles 3	<i>Amphibalanus</i> sp.	seabed (debris)	Aiden Biccard
Cape rock crab	<i>Plagusia chabrus</i>	Wellhead	Charles Griffiths
Waveline crab	<i>Goneplax angulata</i>	seabed	Lara Atkinson
Crab (with ascidian on back)	<i>Pseudodromidae</i> sp.	incidental	Marc Ruis
Chocolate tip crab	<i>Eucrater sulcatifrons</i>	incidental	Lara Atkinson
Shrimp	<i>Leptochela pugnax</i>		Lara Atkinson
White urchins	<i>Echinus gilchristi</i>	seabed, wellhead	Lara Atkinson
Purple urchins	<i>Parechinus angulosus</i>	seabed, wellhead	George Branch
Astropecten sea star	<i>Astropecten irregularis pontoporeus</i>	seabed	Lara Atkinson
Starfish (spiky)	<i>Marthasterias glacialis</i> *	seabed, wellhead	Lara Atkinson
Starfish	<i>Toraster</i> sp.	pipeline, wellhead	Lara Atkinson
Brittle star	<i>Ophiothrix aristulata</i>	Incidental	Lara Atkinson
Ascidian (attached to crab)	<i>Distaplia domuncula</i>	incidental	Marc Ruis
Ascidian A	<i>Ascidia multitentaculata</i>	wellhead	Marc Ruis
Ascidian B	<i>Ascidia incrassata</i>	wellhead	Marc Ruis
Ascidian C	<i>Molgula scutata</i>	wellhead	Marc Ruis
Ascidian D	<i>Halocynthia spinosa</i>	wellhead	Marc Ruis
Ascidian E	<i>Tridemnum</i> sp. (cerebriforme)	wellhead	Marc Ruis
Ascidian F	<i>Aplidium tubeiferus</i>	wellhead	Marc Ruis
Ascidian G	<i>Aplidium</i> sp.	wellhead	Marc Ruis
Ascidian H	<i>Cnemidocarpa humilis</i> **	wellhead	Marc Ruis
Ascidian large	<i>Diplosoma</i> sp. (c.f. <i>listerianum</i>)**	wellhead	Marc Ruis

Trap sampling

Only four individual fish representing three species were caught in fish traps; kingklip *Genypterus capensis*, soupfin shark *Galeorhinus galeus* and smooth houndshark *Squalus megalops*. The soupfin shark was captured inside the exclusion zone, the kingklip and two spiny dogsharks were caught in the fished area (Table 8).

Table 8. Fishtrap catches inside and outside the Oribi/Oryx exclusion zone. Traps were placed on sandy seabed away from infrastructure to reduce the risk of entanglement.

Date	Longitude	Latitude	Time of set	Duration	Depth (m)	Species caught
27.03.2009	21 28,669 E	35 14496 S	08h20	2hrs	120	NIL
27.03.2009	21 28,684 E	35 14,501 S	08h40	2hrs	120	NIL
27.03.2009	21 29,847 E	35 15,989 S	11h50	3hrs	199	1 x <i>Galeorhinus galeus</i>
27.03.2009	21 29,740 E	35 14,004 S	12h05	3hrs	119	NIL
28.03.2009	21 28,580 E	35 12,210 S	02h50	3hrs	119	NIL
28.03.2009	21 28,59 E	35 12,21 S	03h05	3hrs	119	NIL
28.03.2009	21 30,021 E	35 14,090 S	09h15	3hrs	119	NIL
28.03.2009	21 29,988 E	35 14,126 S	09h20	3hrs	118	NIL
28.03.2009	21 32,208 E	35 18,966 S	16h10	4hrs	123	1 x <i>Genypterus capensis</i>
28.03.2009	21 32,256 E	35 19,041 S	16h20	5hrs	123	2 x <i>Squalus megalops</i>

Dedicated ROV surveys

Dedicated ROV surveys: Benthic epifauna on deep reefs

Comprehensive lists of invertebrate fauna on the deep reef systems have not been compiled but complex, diverse assemblages were documented. Further work is being undertaken in analyzing invertebrate communities and footage will be analysed once deep reef invertebrate collections from a related more comprehensive study (led by the Department of Environmental Affairs) have been processed. Due to the high diversity and taxonomic and identification challenges, species lists and descriptions of invertebrate communities will take another year to advance.

The Alphard Bank ranges from 16 to 90 m (our survey ranges from 36 – 70 m) and supports very diverse and dense assemblages with clear depth zonation patterns. In shallower portions of the reef a kelp community dominated by *Ecklonia radiata* was documented. In deeper water, diverse emergent invertebrate fauna were recorded including many sponge species, fragile bryozoans, the slow growing hydrocorals *Allopora nobilis* and *A. subviolacea*. Sponges included *Antho kellyae*, *Biemna anisotoxa*, *Clathria* spp., *Isodictya elastica* and *I. frondosa* and *Polymastia* sp. Gorgonians included *Eunicella albicans*, *Eunicella tricorona*, *Leptogorgia palma* and *Homophyton verrucosum*. Gorgonian whip corals (resembling *Ctenocella* sp.) and black corals were also observed.

At the 45 Mile Bank, diverse invertebrate and fish assemblages were documented in the 68 – 75 m depth range (total depth range is approximately between 60 and 100 m). Conspicuous invertebrate fauna that was documented included large cup and vase shaped sponges such as *Hemiasterella vasiformis*, *Suberites* sp. and *Axinella* spp. Two *Geodia* species were recorded, one of which hosts the yellow encrusting *Aplysina* sp. An unidentified *Erylus* sp. and *Isodictya palmata* was also noted. Black corals cf. *Antipathes* sp., gorgonians, alcyonarian soft corals such as *Eleutherobia variabile* and the slow growing hydrocorals *Allopora nobilis* and *A.*

subviolacea were documented. There was substantial variability within the reef in terms of the diversity and abundance of invertebrates.

The sections of 72 Mile Bank explored ranged from 110 to 140 m in depth and showed high variability within the reef complex. Conspicuous taxa included the “mass occurrence” of the tubular sponge *Biemna anisotoxa* which appears to be similar in appearance to the club-shape yellow sponge documented at the FA Platform in 2008. Other sponge species include *Geodia* sp. *Geodia megastar*, *Pachastrella* sp., *Stelletta trisclera* and *Erylus* sp. Hard corals of the genus *Balanophyllia* and *Caryophyllia*, black corals cf. *Antipathes* sp., hydrocorals *Allopora nobilis* and *A. subviolacea*, and the gorgonian *Eunicella papillosa* were also documented. One specimen of the urchin *Echinus gilchristi* was observed. This species was also documented in association with the petroleum infrastructure, as was the Cape urchin, *Parechinus angulosus*, which was not observed in any of the deep reef ecosystems. An unidentified conspicuous orange starfish was also noted. Broken bryozoans and solitary hard corals within the genera *Reteporella* and *Caryophyllia* respectively, were observed within the deeper depths of this reef.



A) Vulnerable biota at Alphard Bank



B) Kelp *Ecklonia radiata* at Alphard Bank



C) Diverse fish & invertebrates at 45 Mile Bank



D) Hydrocoral *Allopora* sp. at 45 Mile Bank



E) Benthic assemblage at 72 Mile Bank



F) Black coral tree at 72 Mile Bank

Plate 7. Still images from the ROV footage of deep reef habitats outside of the exclusion area

Dedicated ROV surveys: Benthic epifauna in unconsolidated sandy habitat

Benthic epifaunal assemblages observed by ROV on unconsolidated sand near the 45-Mile Bank reef were dominated by spiral whelk shells (it was not possible to accurately identify to species level or to determine whether these were alive) and sponges of various types. Overall epifauna were scarce along this transect with a few large, individual specimens of sponge, bryozoans and/or soft corals being observed (Plate 8A). Such species generally require solid substrate on which to attach and the proximity of this transect to the 45-Mile Bank reef leads to the plausible likelihood that this unconsolidated sediment habitat is actually a low profile reef inundated with a layer of sand.

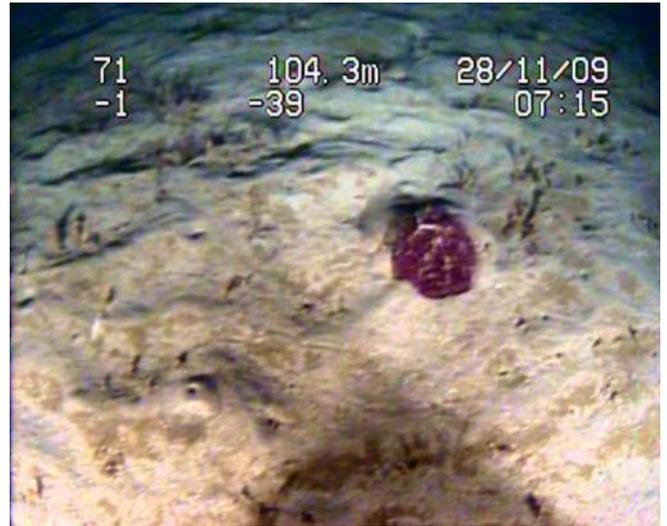
The ROV transect conducted on sand within the Sable petroleum exclusion zone recorded the purple burrowing heart urchin, *Spatangus capensis*, as the most dominant epifaunal species in this area (Plate 8B). Densities of *S. capensis* were estimated to be 28 individuals per 10 minutes, covering an estimated distance of 32 m. Various other species of epifauna were observed, including starfish, sponges, spiral whelk shells, horsemussels, crabs, urchins *Echinus gilchristi* and several burrowing tube anemones, *Cerianthus* sp. Interestingly no burrowing urchins of the species *Brissopsis lyrifera capensis* were observed in this area.

The dominant epifaunal species present in the first of two ROV transects conducted in an area frequently trawled called "The Blues" was the burrowing tube anemone, *Cerianthus* sp. (Plate 8C), which was recorded at densities of 128 individuals per 10 minutes, covering an estimated distance of 35 m. The burrowing urchin, *Brissopsis lyrifera capensis*, were the second most abundant species along this transect at densities of 5 individuals per 10 minutes. Other epifaunal species observed include starfish (e. g. *Marthasterias glacialis*, *Toraster* sp.), crabs (e.g. *Mursia cristiata*, *Gonoplax angulatus*), horsemussels, seapens and urchins (*Echinus gilchristi*).

The second ROV transect in the trawled "Blues" area recorded *B. lyrifera capensis* as the dominant epifaunal species (Plate 8 D) with estimated densities of 217 individuals per 10 minutes, covering a distance of 40 m while lower densities of the burrowing tube anemone, *Cerianthus* sp. were recorded (approximately 3 individuals per 10 minutes). Other species recorded include starfish, crabs and a soft coral species possibly *Alcyonarium variable*. No *Spatangus capensis* individuals were observed in ROV transects within trawled areas.



A) Sandy habitat near 45 Mile Banks



B) Sable Exclusion Zone



C) ROV transect 1 in The Blues trawl lane



D) ROV transect 2 in The Blues trawl lane



E) Hake *Merluccius* sp.



F) Spiny gurnard *Chelidonichthys queketti*

Plate 8. Typical ROV imagery obtained from surveys in unconsolidated sandy habitat within the Sable exclusion zone, adjacent to natural reef and inside trawl lanes.

Dedicated ROV surveys: Fish

No fish were observed during the two ROV dives conducted in infrastructure in the Oribi/Oryx field in March 2009 (Table 3). Bait bags were deployed to attract fish in both cases but no fish were documented. Observation times ranged from 30 – 60 minutes.

A total of 22 fish species was documented in the dedicated ROV surveys at deep reef and sandy areas in November 2009. Species associated with soft sediment such as hake and gurnard were infrequently encountered during the dives and did not seem to be attracted to the bait. Commercially caught, reef associated species such as carpenter *Argyrozona argyrozona*, roman *Chrysoblephus laticeps* and red stumpnose *Chrysoblephus gibbiceps* were observed at all three reef complexes outside the exclusion zone. Other commonly caught sparids such as Steentjie *Spondylosoma emarginatum*, blue hottentot *Pachymetopon aeneum* and Panga *Pterogymnus lanarius* were observed at two of the three reefs.

Table 9. Fish species encountered during ROV dives on soft sediment inside and outside the exclusion zone and from deep reefs on the central Agulhas Bank.

Dive	Species	Nmax (Ntotal for Merlucciidae)	Sampling type	Area
1	<i>Argyrozona argyrozona</i>	5	Reconnaissance	72 Mile Banks, low profile reef with sand inundation, little benthic growth, possibly trawled.
1	<i>Scorpionidae sp 1</i>	1		
1	<i>Cheilodactylus fasciatus</i>	1		
1	<i>Polyprion americanus</i>	1		
3	<i>Helicolenus dactylopterus</i>	1		
3	<i>Scorpionidae sp 1</i>	1		
3	<i>Congiopodus sp 1</i>	1		
3	<i>Cheilodactylus fasciatus</i>	1		
3	<i>Pterogymnus lanarius</i>	2		
3	<i>Callanthias legras</i>	3		
3	<i>Argyrozona argyrozona</i>	9	Bait bag	72 mile banks, low profile reef with sand inundation, little benthic growth, possibly trawled.
3	<i>Pterogymnus lanarius</i>	7		
3	<i>Chrysoblephus gibbiceps</i>	1		
2	<i>Argyrozona argyrozona</i>	6	Reconnaissance	72 mile banks, low profile reef with sand inundation, moderate benthic growth.
2	<i>Chrysoblephus laticeps</i>	1		
2	<i>Chrysoblephus gibbiceps</i>	1		
2	<i>Callanthias legras</i>	2		
2	<i>Argyrozona argyrozona</i>	38	Bait bag	72 mile banks, low profile reef with sand inundation, moderate benthic growth.
2	<i>Pachymetopon aeneum</i>	5		
2	<i>Chrysoblephus laticeps</i>	1		
2	<i>Spondylosoma emarginatum</i>	3		
2	<i>Pterogymnus lanarius</i>	4		
2	<i>Notorhynchus cepedianus</i>	1		
5	<i>Petrus rupestris</i>	33	Reconnaissance	45 mile banks, low profile low rugosity reef with moderate benthic growth and some sand inundation.
5	<i>Chrysoblephus gibbiceps</i>	2		
5	<i>Seriola lalandi</i>	6		
5	<i>Argyrozona argyrozona</i>	2		
5	<i>Chrysoblephus laticeps</i>	1		
5	<i>Spondylosoma emarginatum</i>	3	Bait bag	45 mile banks, low profile low rugosity reef with moderate benthic growth and some sand inundation.
5	<i>Chrysoblephus laticeps</i>	2		
5	<i>Petrus rupestris</i>	2		
5	<i>Chrysoblephus gibbiceps</i>	1		

Dive	Species	Nmax (Ntotal for Merlucciidae)	Sampling type	Area
5	<i>Pachymetopon aeneum</i>	3		
5	<i>Pterogymnus laniarius</i>	37		
5	<i>Chrysoblephus laticeps</i>	2		
5	<i>Galeorhinus galeus</i>	1		
4	None		Reconnaissance	Sandy seabed close to 45 mile banks.
6	<i>Clupeidae unidentified species</i>	>100	Reconnaissance	Alphard Banks sandy seabed, close to reef.
6	<i>Merluccius sp</i>	1		Alphard Banks high profile high rugosity reef with abundant benthic growth.
6	<i>Chrysoblephus laticeps</i>	2		
6	<i>Chrysoblephus gibbiceps</i>	1		
6	<i>Spondylosoma emarginatum</i>	3		
6	<i>Argyrozona argyrozona</i>	1		
6	<i>Callanthias legras</i>	2		
6	<i>Sparidae unidentified sp 1</i>	1		
8	<i>Merluccius sp</i>	1(3)	Reconnaissance	Blues trawl lane
8	<i>Merluccius sp</i>	1		Sandy flat seabed.
8	<i>Chelidonichtys queketti</i>	2	Bait bag	Blues trawl lane
8	<i>Pterogymnus laniarius</i>	2		Sandy flat seabed.
9		1 (1)	Reconnaissance	Blues trawl lane
9	<i>Merluccius sp</i>	1		Sandy flat seabed.
9	<i>Chelidonichtys queketti</i>	1		
9	<i>Unidentified sp 2</i>	1		
7		1	Reconnaissance	Sable exclusion zone
				Sandy flat seabed.
7	<i>Chelidonichtys queketti</i>	1	Bait bag	Sable exclusion zone
				Sandy flat seabed.

Benthic infauna (from grab samples)

The species composition of benthic infauna at the sites sampled comprised predominantly crustaceans (mostly small-bodied amphipods, 46 %) and annelids (polychaete worms, 45 %) (Fig. 5) while echinoderms (largely burrowing urchins and brittle stars) contributed a much lower proportion of the assemblage (3 %). Burrowing urchins, however, have a large body size in comparison to other infaunal species and thus contribute as much as 86 % to the biomass of benthic infaunal assemblages sampled (Fig. 5).

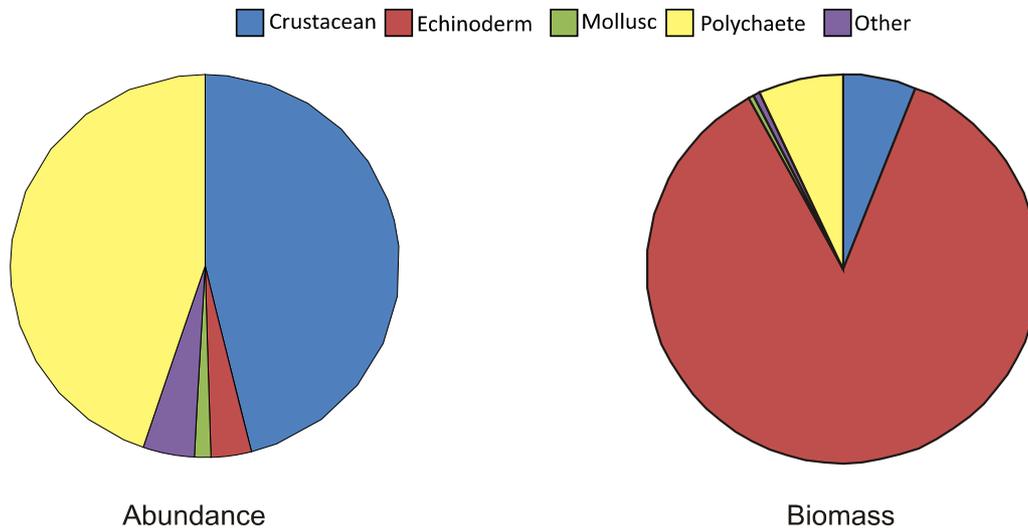


Fig. 5. Composition of benthic infaunal assemblage abundance and biomass sampled from all sites in this study.

A total of 100 infaunal species were identified from all sites with a minimum of 31 species occurring at site E1 and a maximum of 50 species at site B6. The greatest abundance of infauna occurred at site A4 ($n = 291$) and the lowest at A1 ($n = 124$), a site closest to the wellhead. The Shannon-Wiener species diversity index (H') varied very little among sites, being within the range of 2.3 and 2.7 at all sites.

The average abundance and biomass measures for each site, group into three clusters, shown by the MDS plots and dendrograms which are significantly different from each other, as indicated by the SIMPROF analysis (black solid line indicates significant differences, Fig. 6). The two sites closest to the wellhead, A1 and D1, separate from the others first in the cluster dendrogram (group one), followed by the two control sites E1 and E2 (group two). The remaining sites together form the third group with no significant differences among them indicated by SIMPROF tests.

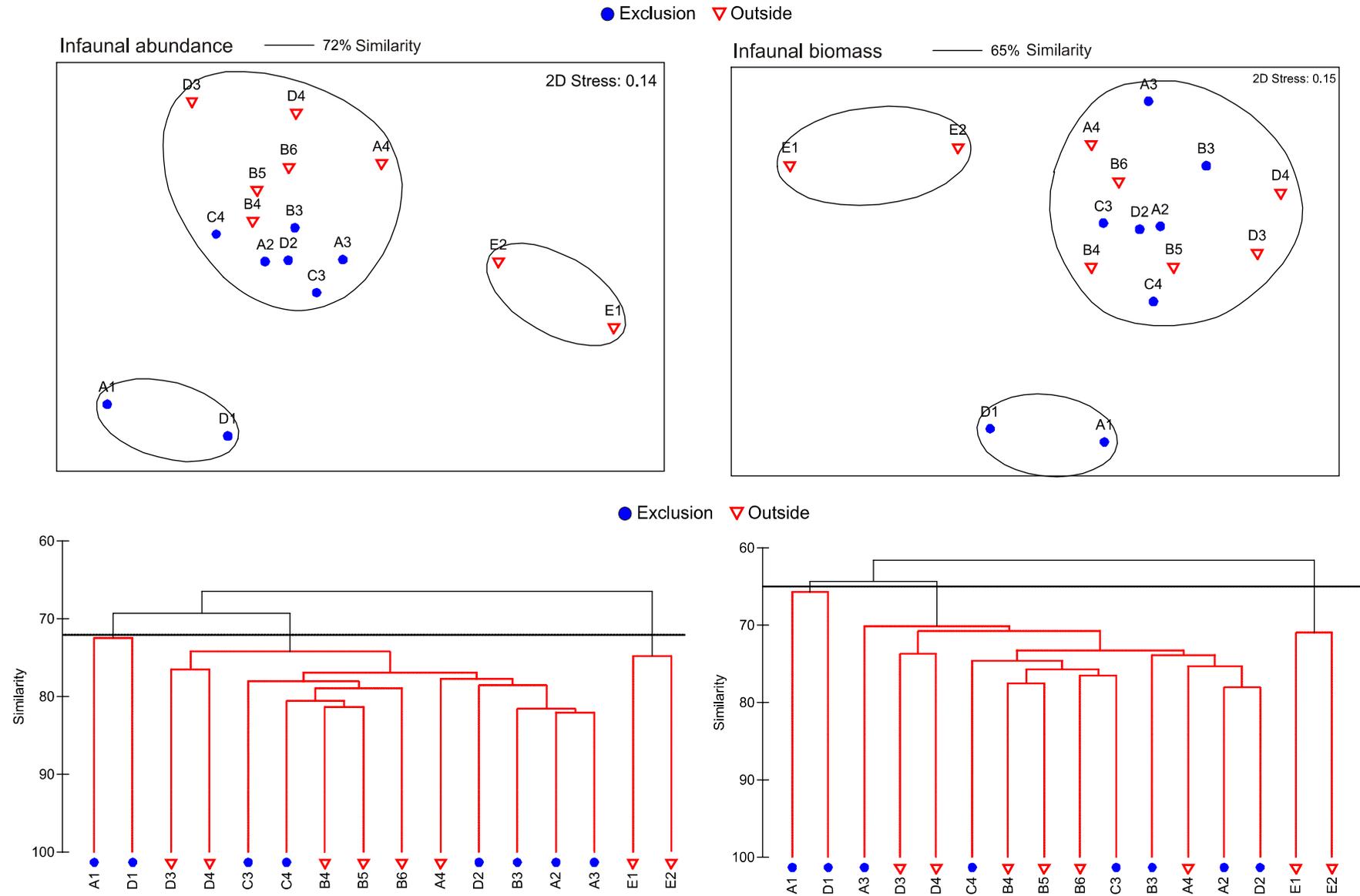


Fig. 6 Multi-dimensional scaling plots and cluster dendrograms (with SIMPROF) of infaunal assemblage abundance and biomass at sites within (blue circles) and outside (red triangles) the Oribi/Oryx petroleum exclusion zone, Agulhas Bank.

A PERMANOVA analysis testing for differences among averaged infaunal abundance and biomass at all sites showed the sites closest to the wellhead (A1 and D1) to be significantly different to all other sites ($p = 0.0003$ to 0.0416), and significantly different to each other (Pseudo-t = 1.6303, $p = 0.0394$). Reference sites 10 km from the wellhead (E1 and E2) were also significantly different to all other sites ($p = 0.0003$ to 0.0128) and to each other (Pseudo-t = 1.8616, $p = 0.0128$). All other sites were not significantly different to at least two or more other sites, these results similarly being reflected in the grouping of the MDS plots and dendrograms.

The SIMPER analysis (indicating which species contribute most to differences occurring) shows that the absence of the amphipod *Eriopisella capensis* and the polychaete *Brada villosa capensis* from site A1 and the low abundance of these species at site D1 contribute most to these sites being significantly different to other sites. The greater abundance and biomass of the burrowing urchins *Echinocardium cordatum* and *Brissopsis lyrifera capensis*, brittle star *Ophiuroidea* and a small polychaete species *Poecilochaetus* sp. at site A1 in comparison to D1, results in these two sites being significantly different from each other. The greater abundance of the bivalve *Tellina* sp. and fewer burrowing urchins and brittle stars at sites E1 and E2 distinguish these sites as being significantly different to others.

In comparing infaunal abundance and biomass between sites that are trawled vs. those that are not trawled, neither the MDS nor dendrogram show clear grouping of sites according to these factors (Fig 6). However, excluding the outlier sites of A1, D1, E1 and E2, PERMANOVA analyses showed significant differences between infaunal assemblage abundance (Pseudo-F = 3.0889, $p = 0.0009$) and biomass (Pseudo-F = 2.8475, $p = 0.0016$) at trawled vs. untrawled sites. PERMANOVA analyses comparing infaunal assemblages from sites within the Oribi/Oryx exclusion zone vs. outside the exclusion zone also showed significant differences in abundance and biomass between these areas (abundance: Pseudo-F = 5.828, $p = 0.0001$; biomass: Pseudo-F = 4.573, $p = 0.0001$).

SIMPER analyses showed high similarity between species occurring at trawled and untrawled sites (70 %) and between sites within the Oribi/Oryx exclusion zone and those outside (61 - 65 %). Some species contributing to infaunal differences detected were similar for trawled vs. untrawled and inside vs. outside the exclusion zone as summarized in Table 10. The burrowing urchin *Echinocardium cordatum* occurred in greater biomass at untrawled sites and within the exclusion zone while the larger burrowing urchin, *Brissopsis lyrifera capensis*, occurred in slightly greater biomass outside the exclusion zone and at trawled sites. *Eriopisella capensis*, *B. villosa capensis* and *Tellina* sp. occurred in greater abundance at trawled sites and outside the exclusion zone while the amphipod *Processa austroafricana* occurred in greater abundance at untrawled sites and within the exclusion zone suggesting some degree of sensitivity to the effects of trawling and petroleum activities. Brittle stars, *Ophiuroidea* sp. and the polychaete species *Spionidae* sp. occur in greater abundance in trawled areas and within the exclusion zone (Table 10).



A) Amphipod species *Eriopisella capensis*



B) Polychaete species *Brada villosa capensis*



C) Burrowing urchin *Brissopsis lyrifera capensis*



D) Burrowing urchin *Echinocardium cordatum*



E) Brittle star *Ophiura* sp.



F) Crustacean *Processa austroafricana*

Plate 9. Benthic infaunal species featuring in assemblages sampled at sites of varying distance from wellhead E-BT01P, Oribi/Oryx field, Agulhas Bank. See text for further details on species.

Table 10. Key infaunal species influencing significant differences among different unconsolidated sediment habitats sampled on the Agulhas Bank. – represents lower biomass, + represents greater biomass.

Species	Trawled	Untrawled	Exclusion zone	Outside exclusion
<i>Echinocardium cordatum</i>	–	+	+	–
<i>Brissopsis lyrifera capensis</i>	+	–	–	+
<i>Eriopisella capensis</i>	+	–	–	+
<i>Brada villosa capensis</i>	+	–	–	+
<i>Tellina</i> sp.	+	–	–	+
<i>Processa austroafricana</i>	–	+	+	–
<i>Ophiuroidea</i>	+	–	+	–
<i>Spionidae</i> sp.	+	–	+	–

The distance-based linear model (DISTLM) analysis (Legendre & Anderson 1999, McArdle & Anderson 2001) of infaunal assemblages at all sites with environmental variables distance from wellhead, sand, TOC, trace metals, sum of polycyclic aromatic hydrocarbons (PAHs) and total hydrocarbons show that the variable “distance from wellhead” contributes the most to influencing the distribution of sites in an ordination plot. However, the variable “distance from wellhead” only contributes 19 % to the total variation of the data cloud with all other measured variables contributing less than 10 % variation each, indicating a weak relationship between the variables measured and the patterns detected in the infaunal assemblages.

Sediment analysis

Sediment from all sites was dominated by sand (average of 97.1%, see Appendix 3) which is sediment classified as having particle sizes of between 0.02 mm to 2 mm with an average particle size of 1.01 mm. Silt and clay (collectively referred to as mud) only contributed an average of 1.8 % and 1 % of the sediment composition respectively. The overall low silt and clay fractions suggest that there is theoretically little propensity for the accumulation of particle reactive contaminants in the sediments from the sites sampled.

The total organic carbon (TOC) content of sediment from the sites sampled in this study was low, ranging from 0.9 % to 1.39 % (average 1.1 %) of the bulk sediment. Organic carbon levels in this range are typical for sand dominated marine sediment. These results confer with the sediment particle size classification as TOC content is frequently positively correlated with fine-grained mud fractions, which were in very low proportions in the study area.

Concentrations of trace metals plotted against co-occurring iron concentrations (see Appendix 3) show the majority of concentrations occur within the proposed two standard deviations of the linear model (Appendix 3 Fig. 2), however, in some instances clusters or single replicate samples did exceed the model prediction limits e.g. copper, lead, zinc and cadmium. Only individual concentrations of copper, lead and zinc were sufficiently high to conclude that these were possibly enhanced by anthropogenic influence. Furthermore the elevated concentrations of these metals originated from site A1, located closest to and downstream from the wellhead E-BT01P. Although chromium and barium are important constituents of drilling fluids, no spatial trend of enrichment of either these two metals were detected in modeled projections. It is however noted that barium and lead were detected in substantially greater concentrations at site A1 than at any other site sampled (Fig. 7.). All samples from site A1 had enriched levels of zinc and there is a possibility that sediment from this site was mildly contaminated by zinc. In general the sediments from the sampled sites only

showed possible contamination at one site, A1.1, where concentrations of copper, lead and zinc were higher than at other sites. All concentrations of all trace metals measured, however, were well below metal concentrations at which adverse effects to benthic invertebrates can be expected, in accordance with the comparison of concentrations to sediment quality guidelines.

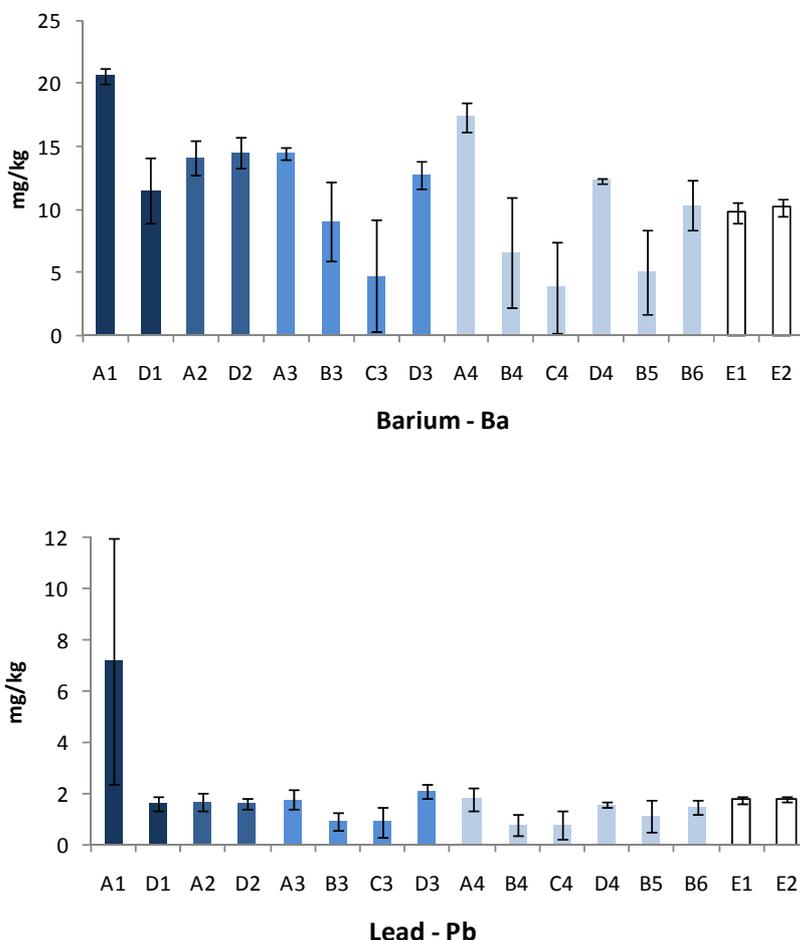


Fig. 7. Concentrations of Barium (Ba) and Lead (Pb) measured at the sites of increasing distance along the x-axis from the wellhead E-BT01P.

Seventeen PAH isomers were measured in sediments from the survey area. Results showed no particularly pronounced spatial trends for concentrations of these isomers, nor for the sum of low and high molecular weight isomers, total PAHs or total hydrocarbons (see Appendix 3 for details). Only one isomer (benzo[k]fluoranthene) concentration correlated to the sand fraction and total organic content of the sediment suggesting that neither these two factors controlled the accumulation of PAHs. Four acenaphthene isomer concentrations marginally exceeded the “Low Effects Range” of the sediment quality guidelines (Long *et al.* 1995), however, no other isomer concentrations, nor the sum of low or high molecular or total PAHs exceeded sediment quality guidelines. There is little probability that the PAH concentrations measured in sediments within the survey area are associated with adverse effects on benthic invertebrate communities.

DISCUSSION

Colonization of existing petroleum infrastructure

Historical reports of research at the FA platform revealed a total of 48 taxa at genus or species level and several unidentified invertebrate taxa were also reported. Only four of these species were clearly observed on footage from the FA platform taken in 2005 and 2008 (Table 5) highlighting the importance of actual sampling versus review of existing ROV footage. The species composition from historical reports and existing ROV footage showed many representative species from intertidal and shallow subtidal habitats on the south coast but in many cases shallow water species extended into deeper water. It was interesting to note that two mollusc species that are reported as exclusively estuarine, *Arcuatula capensis* and *Dosinia hepatica* and the zooxanthellate coral *Montipora* were also recorded at this deep, offshore location.

Mussels and barnacles were documented as key species of concern from a fouling perspective and benthic communities dominated by dislodged mussels and barnacles were observed around the FA and Oribi/Oryx infrastructure in existing footage and during some sampling opportunities. During planning meetings with PetroSA the project team was informed that no steps are taken to address fouling of infrastructure at present or in the past. Cooke (1997) however reported that cleaning operations did take place at shallow sites and that conductor 3 was fitted with a “marine growth clearing hoop”. It appears that dislodged marine growth has altered benthic communities in the immediate vicinity of infrastructure with an entire community characterized by mussels, the cryptogenic starfish, *Marthasterias glacialis* and urchins usually colonizing shallower subtidal habitats. It appears as though the infrastructure supports the extension of the depth range of several shallow water species including mussels, barnacles, the crab *Plagusia chabrus* and the urchin *Parechinus angulosus*, reported to occur at depths of up to 30 m (Branch *et al.* 2010) but documented at 117 m in this project.

Existing ROV footage from the FA platform (2005 and 2008) and Oribi/Oryx (2006) revealed a total of 54 invertebrate and 6 fish species at the FA platform and 51 invertebrates and 17 fish species (5 at the surface and 12 at the seabed) in the Oribi/Oryx area. Dedicated ROV dives on infrastructure at the Oribi/Oryx field added further species of invertebrates to the species list documented in the field. No further fish species were observed. We were surprised by the low fish diversity. Dedicated sampling by SAT diver in the vicinity of Oribi/Oryx yielded 38 macro-invertebrate species.

The FA platform supports a well developed invertebrate assemblage that is structured with depth and fouling community was more developed in 2008 than in 2005. Other studies have also found diverse invertebrate communities colonising oil and gas platforms (Foster & Wilan 1979, Wolfson *et al.* 1979, Forteath *et al.* 1982, Pont *et al.* 2002, Fabi *et al.* 2004, Sammarco *et al.* 2004) and have shown structuring with depth (Forteath *et al.* 1982, Seaman *et al.* 1989, Love *et al.* 1999 a,b, Ponti *et al.* 2002). It would be expected that infrastructure within the Oribi/Oryx area would have less invertebrate growth than at the FA platform as a result of their respective deployment durations.

At the Oribi/Oryx field, detailed surveys of different infrastructure components allowed assessment of types of fauna on different types of structures including wellheads, umbilicals, risers, flowlines, pipelines, mattresses, calm buoys, anchor chains, the SD frame, SUTA and other components. This will help to support decommissioning decisions about various components of infrastructure.

This project has provided important baseline information on the colonization of existing petroleum infrastructure by benthic invertebrates and fish on the Agulhas Bank. This information is important for consideration in environmental management and decommissioning. Future work can build on the results of this study. Such studies may include further research on species composition and abundance (collections should be a key component), tracking of species introductions and monitoring of the development of fouling assemblages.

Representivity of benthic communities on infrastructure

Benthic invertebrate communities at both the FA platform and on petroleum infrastructure in the Oribi/Oryx area were generally distinct from those inhabiting deep reefs. The fouling assemblage of the FA platform was structured with depth and invertebrate communities in shallower water (0 - 30 m) hosted similar assemblages to rocky intertidal and shallow subtidal ecosystems in the region although some fouling species were more abundant. This is a similar result to other studies (Foster & Wilan 1979, Wolfson *et al.* 1979, Forteath *et al.* 1982, Fabi *et al.* 2004, Kaiser 2006, Page *et al.* 2006).

In deeper water, the invertebrate species had little overlap with deep reef species documented in ROV surveys although invertebrate species lists for deep reef ecosystems are far from complete. Few species seen on deeper sections of the petroleum infrastructure were noted at the Alphard Banks, the 45 Mile Banks and the 72 Mile reef system. One species of sponge *Biemna anisotoxa*, one species of soft coral *Euletherobia variabile* and one species of gorgonian, most likely *Eunicella papillosa* was documented on both the FA Platform and deep reefs on the Agulhas Bank. In the Oribi/Oryx area, one specimen of one gorgonian *Leptogorgia palma* was documented on infrastructure and solitary hard corals such as *Carophyllia* sp. were observed and collected. These represent the only recorded species of invertebrates that were documented by ROV surveys on the deep reefs. Other sponges, soft corals, anemone and bryozoan fauna associated with petroleum infrastructure were distinct from those observed on the deep reef ecosystems. None of the hydrocoral, other gorgonians and black corals documented on deep reef ecosystems were observed in ROV footage or collected by SAT divers. None of the introduced or unidentified species documented on petroleum infrastructure were seen in any ROV footage of deep reef ecosystems. Several areas of infrastructure were dominated by introduced taxa that are clearly not representative of the indigenous biodiversity of the region. Overall, existing infrastructure does not seem to offer any opportunities for the protection of representative reef biodiversity.

The overlap between the benthic fish fauna associated with petroleum infrastructure and that of deep reefs was confined to four species; Jacopever *Helicolenus dactylopterus*, Fingerfin *Cheilodactylus fasciatus*, Horsefish, *Congiopodus* spp. and the Goldie *Callanthias legras*. No sparid species were encountered on any of the footage of the infrastructure below 10 m. On the other hand, commonly caught species such as steentlie, carpenter, roman, red stumpnose, blue hottentot and panga were observed in two or all three of the examined reefs outside the exclusion zone. This suggests that the installations do not support ichthyofauna representative of deep reef areas on the Agulhas bank but more dedicated ROV work around sea bed installations is needed to gain more conclusive information. These results are contrary to what has been found in the Mediterranean (Fabi *et al.* 2004), where gas platforms have attracted high densities of reef associated sparids. The presence of jacopever in association with infrastructure is similar to results from California where related rockfish occur in association with oil and gas platforms there (Love *et al.* 2005, Love and York 2006).

Vulnerable habitats and species

No vulnerable marine ecosystems (Rogers *et al.* 2008) and few potentially vulnerable marine species were found associated with existing petroleum infrastructure during this project. Available footage at both the FA Platform and in the Oribi-Oryx field failed to provide evidence of any vulnerable habitats or significant colonies of vulnerable species that could be important for offshore biodiversity conservation within these areas. One specimen of one species of gorgonian (most likely *Eunicella papillosa*) was observed on the FA platform and similarly one specimen of the slow growing gorgonian *Leptogorgia palma* was documented on an oil export pipeline in the Oribi-Oryx field. Two specimens of solitary hard corals, *Carophyllia* sp. were collected by SAT divers from wellheads in the Oribi/Oryx field and this genus is also collected in trawl samples in the region. The conservation status and impact of activities such as trawling on solitary corals is not known. Small isolated colonies (<50 cm²) of framework-building invertebrates that could be polychaetes worm tubes, scleractinia (cold-water corals) or bryozoa were observed and a clump of dislodged "coral" was reported by a ROV pilot working at the FA platform. The identification of these taxa was not feasible and a dedicated survey or collection is advised. Similarly, spherical invertebrate colonies were seen on buoyancy moderators on

umbilicals of the ORCA and these were deemed most likely to be worm tubes of a species similar to *Filograna implexa*. These could however also be hard corals or bryozoans and this warrants further research.

Although this project relied on opportunistic sampling and ROV coverage was very limited, we did not find any evidence to support the assertion that existing petroleum infrastructure may be important for vulnerable marine ecosystems or species. This contrasts with the results from North Sea platforms where the slow-growing cold water coral *Lophelia pertusa* has been documented (Bell & Smith 1999, Hall 2001). The infrastructure examined in this study may not have been in place long enough to support such species.

This project also initially aimed to identify potential vulnerable ecosystems offshore of existing MPAs but as we were not able to survey offshore of existing coastal MPAs, this component of the objective was not achieved. ROV surveys are needed offshore of Tsitsikamma and De Hoop MPAs to identify biota colonizing “hard grounds” in these areas. The area off Tsitsikamma is known as “the razorblades” because of the damage incurred to trawl nets in this region and “lace corals” are reported to be responsible for this damage. Concern for the integrity of this reported ecosystem remains and it is a conservation priority to assess or close this area as a precaution if assessment is not possible in the near future.

This project provided an opportunity to survey deep reef and unconsolidated habitats by ROV acquiring the first images of deep reef ecosystems outside of the petroleum areas. The footage acquired will support decision making for these important vulnerable marine ecosystems that host hard, soft and black corals and play a key role in the lifecycle of threatened linefish species. The Alphard Bank reef appears to be in a pristine condition and can clearly be classified as a vulnerable marine ecosystem (Rogers *et al.* 2008). This reef warrants protection for the benthic communities that create this diverse and complex habitat.

Introduced species

This project raises serious concerns about introduced and invasive species due to the numbers and high densities of non-indigenous, cryptogenic, invasive and unidentified but potentially introduced species found by the limited sampling undertaken during this project.

The introduced European mussel *Mytilus galloprovincialis* was first recorded at the FA platform in 1996 although this species was not found in 1997 or 1999. No other alien species were documented in 1996. Our project, based on existing ROV footage and a single day of SAT diver collecting, found at least 5 conspicuous introduced species associated with petroleum infrastructure on the Agulhas Bank. We found *Mytilus galloprovincialis*, two introduced anemone species, one of which is assumed to be a new introduction (i.e. not previously documented) and two introduced ascidians. We also noted further potentially introduced and possibly invasive species that are a priority to sample for identification. A small pink anemone that also forms dense aggregations at both the FA and Orca infrastructure, an unidentified ascidian and an unidentified probable octocoral that was observed in large sheets at the FA platform should be collected for identification as these may be introduced species. We found 3 cryptogenic species including the first known deep water records of the spiny seastar and the cryptogenic ascidian *Ascidia multitentaculata*.

The introduced Mediterranean mussel *Mytilus galloprovincialis* is considered the most significant marine introduction on rocky intertidal shores, ranging from central Namibia (west coast) to East London on the south-east coast (Robinson *et al.* 2005) This species usually forms dense beds in the mid to low intertidal zone and is now globally distributed as a result of ship fouling and ballast water (Mead *et al.* in prep). It was first collected in Saldanha Bay, South Africa in 1979 with genetic confirmation of the identification published five years later (Grant & Cherry 1984). There have been several studies examining ecological impacts of this species which include competitive interactions, provision of habitat for infaunal species and provision of additional food for predators (Robinson *et al.* 2005, 2007, Mead *et al.* in prep).

An anemone identified as the non-indigenous anemone *Sagartia elegans* was collected from a wellhead in the Oribi/Oryx field (Table 7) and it is believed that this species is the anemone observed in dense aggregations in the 70-105 m depth range in ROV footage from the FA platform captured in both 2005 and 2008. At the FA platform this species was found on caissons, horizontals, piles and risers. Dense aggregations of anemones, most likely to be *Sagartia elegans* were recorded on umbilicals, risers and other infrastructure in the 38 – 114 m depth range within the Oribi/Oryx field. The taxonomist that identified this specimen requested further samples for genetic analyses. This species may represent a new introduction as it has not previously been documented in South Africa. *Metridium senile* and *S. elegans* commonly occur together in Britain and it is suspected that these may have been simultaneously introduced.

The large white non-indigenous anemone *M. senile* was collected within the Oribi/Oryx area and formed dense aggregations in the 100 – 117 m depth range, particularly on the 6 inch oil export pipeline. This species was also observed on wellheads, umbilicals, flowlines, mattresses and areas of adjacent sediment in the close (<2 m) vicinity of infrastructure. At the FA platform, only two possible occurrences of this species were observed in low numbers (2 and about 15 individuals). The identity of the observed white anemones requires confirmation by *in situ* sampling at the FA platform as identification cannot be confirmed using existing ROV footage. The dense aggregations on the oil export pipeline may be related to higher temperatures associated with the transport of oil or could be related to the provision of hard substrate in that area. This distinctive Northern Hemisphere sea anemone was first detected in Table Bay Harbour, Cape Town in 1995 where it is reported from a diversity of substrata in the 6 –12 m depth range (Griffiths *et al.* 1996). To our knowledge, the specimens collected through our project represent the first evidence of this species in deeper water although footage of infestations of this species prior to the initiation of this project were a key motivating factor for this study.

Fine pink polyps that resemble anemones were observed at both the FA platform (40-90 m) and on infrastructure in the Oribi-Oryx field. These are a priority for collection and identification as their abundance in some areas suggests that they could be introduced and even invasive species. A further unidentified magenta invertebrate that is a suspected octocoral or ascidian is also a suspected introduced species. This brightly coloured, distinct species formed large sheets that covered large areas of infrastructure and was overgrowing mussels, barnacles and other organisms.

Introduced anemones were documented on offshore oil and gas platforms on the Pacific offshore continental shelf of central and southern California (Page *et al.* 2006) where their distribution and abundance suggested that these species may outcompete indigenous organisms for primary space.

Two introduced ascidian species *Cnemidocarpa humilis* and *Diplosoma cf. listerianum* were collected by SAT divers although these fairly cryptic species were not recognized on any existing ROV footage. The solitary ascidian *C. humilis* is common in New Zealand, Australia and South America and in South Africa is reported from floating pontoons and harbour ropes in Alexander Bay and Table Bay harbour (Monniot *et al.* 2001, Mead *et al.* in prep). *D. listerianum* is a European species that is now reported to have a worldwide distribution (Mead *et al.* in prep and references therein). In South Africa it was first documented in 1949 in Langebaan lagoon but is now reported to be common in harbours from Alexander Bay to Durban, where it overgrows other sessile invertebrates (Mead *et al.* in prep). The invasive status of these species is unconfirmed. A further potentially introduced and possibly invasive ascidian species (red tunicate, two distinct siphons) was frequently observed, sometimes in dense aggregations on wellheads, the suta and the oil export pipeline in the Oribi-Oryx field but was not encountered and therefore collected during the two SAT dives.

The introduced bryozoan *Bugula dentata*, was documented by previous work on the fouling community of the FA platform and was also observed during ROV surveys examined during our study. It was first collected and reported from South Africa by Busk in 1852 and is likely to have been a very early introduction in ship fouling (Mead *et al.* in prep).

Our study also documented the cryptogenic spiny seastar *Marthasterias glacialis* associated with the

fouling community (particularly attached and dislodged mussels) in shallow water and on the seabed at both the FA platform and in the Oribi/Oryx area. This species originated in Europe and the Mediterranean but was first documented from the 'Cape of Good Hope' in 1842. South African populations are a different colour and have different spination (several spines on some plates) than European populations and Mead *et al.* (in prep) recommend genetic work on this species. The South African *M. glacialis* population is reported to be confined to the South Western Cape, where it is a conspicuous predator in near-shore habitats, feeding on mussels, gastropods, barnacles and ascidians (Penney & Griffiths 1984). To our knowledge, our study represents the first offshore documentation of this species and it was not documented by previous researchers studying the fouling community at the FA platform (Cook 1994, 1996, 1997, 1999). We did not observe this species on the deep reef habitats of the Agulhas Bank.

The results from our study support other research results that have documented introduced and invasive species associated with infrastructure (Sammarco *et al.* 2004, Page *et al.* 2006) and highlight the role of petroleum infrastructure as a potential vector of introduced taxa (Wanless *et al.* 2009, Sheehy and Vik 2010). In the Gulf of Mexico, the most commonly introduced species included a cup coral *Tubastrea* sp., mussels, a diademnid ascidian, a jellyfish and a blenny. The mussels had the greatest impact through fouling, clogging, competition with indigenous species and disease transfer whereas as the jellyfish were reported to have impacted on fisheries through egg and larval predation, food competition with larval fish and by clogging shrimp nets (Sheehy and Vik 2010). The ascidian was aggressively invasive and smothered and overgrew other species.

The potential of the introduced species identified in this study to invade natural habitats is not known but this risk warrants assessment. Assessment of the risk of spread of these taxa is beyond the scope of this project but key considerations include type of reproduction and larvae, the invasive potential of species, habitat vulnerabilities and local oceanographic conditions (Sheehy and Vik 2010). In addition to propagule supply and circulation, biotic processes such as competition and predation may also play a role in limiting invasions into natural habitats (Page *et al.* 2006).

The presence of introduced species on offshore petroleum infrastructure has implications for assessing the 'habitat value' of these structures and the extent to which these structures support biodiversity, provide habitat and other ecological services. The prevalence of non-indigenous species and particularly invasive anemones in association with petroleum infrastructure in South Africa also has important implications for the disposal or transport of these types of infrastructure. Transport or towing of infrastructure colonized with introduced species should not be considered because of the potential risk in spreading introduced and invasive species. This area of work requires further attention in environmental management for this sector in South Africa. Steps should be taken to avoid and minimize the risk of introduction and spread of introduced species.

Our results align with the recent work of Sheehy and Vik (2010) which highlight the role of artificial reefs in contributing to non-indigenous species introductions or range expansions. Potential artificial reef materials that retain developed fouling communities such as decommissioned petroleum platforms, are potential introduced species vectors and habitat provided by reefs placed in areas devoid of natural hard ground or structure may be colonized by introduced species propagules dispersed from anthropogenic or natural sources. A network of such structures may also create corridors that may link previously unconnected areas, furthering range expansions (Sheehy and Vik 2010). Further knowledge of the identity of introduced species associated with petroleum infrastructure, their potential for dispersal and interaction with native species will improve our understanding of the potential impacts of this industry on the ecological functioning of marine ecosystems (Page *et al.* 2006). Sheehy and Vik (2010) outline approaches for anticipating, assessing, and controlling introductions so that planners can begin to evaluate unintended consequences and incorporate risk management measures to reduce future introductions. Prevention is the most effective risk reduction approach because controlling introduced marine species is extremely costly and offers limited probability for success (Sheehy and Vik 2010).

Fisheries exclusion effects

In this study, we used visual techniques (ROV and SAT diver footage) and passive fishing methods (traps) to examine the fish fauna inside the exclusion zone and to compare it to reference areas of soft sediment and reefs in the vicinity. Low sample numbers prevented any assessment of size structure and the existing ROV footage was not suitable for either abundance or size estimates. Due to the limited dive time and fishing effort the results are far from conclusive, but we found no evidence of a positive effect of the exclusion zone for non-attractable benthic and nekton-benthic species associated with soft sediment. Although hake *Merluccius sp* was encountered on both dives in the heavily trawled “Blues” area and on soft sediment next to the Alphonse banks, no hake were observed in any of the footage inside petroleum areas. Hake exhibit neutral behavior towards the ROV and flight reaction can be excluded as explanation for the low hake density. Hake are not usually caught in traps and therefore trawl sampling within exclusion areas is needed if further insight into potential benefits for hake are to be assessed. Trawl sampling within exclusion areas prior to decommissioning is recommended for the research opportunity that this represents. Demersal research trawls should cover areas that were previously sampled in surveys to allow comparison with data from before the exclusion of fishing (i.e. prior to the establishment of the petroleum exclusion zone).

Fish traps deployed on soft sediment seabed had limited success in sampling fish with only 4 fish representing 3 species caught in 10 deployments totaling 31 hours of soak time. Kingklip is a regular by-catch of deep-set rock lobster traps in the vicinity of reef and the two shark species are often caught with fishtraps used to sample the deep reef ichthyofauna on the central Agulhas bank. Similar fishtraps were used by Grey *et al.* (2005) to target soft sediment communities off St Francis bay. Although catch rates are usually highly variable, similar numbers of deployment in the same depth usually yielded a moderate catch of panga *Pterogymnus laniarus*, a species that was also observed during the visual assessment of the soft sediment in the trawled area nearby. The absence of this species from our traps lends further support to the evidence suggesting that this species is absent from the sampled petroleum area.

We found limited evidence of attraction or aggregation of commercially important, benthic or nekto-benthic, reef-associated species around the petroleum infrastructure on the sea bed. Of particular importance is the absence of sparids (seabreams) from footage of the infrastructure below 10 m. Seabreams are an important component of South Africa’s linefishery, although many reef associated sparids are severely overexploited and in need of recovery. We found no evidence of the presence and therefore *any* benefit associated with the exclusion of fishing for these species. This result is different from studies undertaken in the Mediterranean, where gas platforms have attracted sparids associated with deep reefs (Fabi *et al.* 2004).

Kingklip *Genypterus capensis* was the only commercially important fish species that was encountered at petroleum installations on the sea bed. In South Africa, kingklip are caught as a bycatch of the hake directed trawl fishery as well as a demersal longline fishery and are considered the most sought after of the demersal fishes in deep water (Heemstra and Heemstra 2004, Atkinson and Sink 2008). Their primary habitat is rocky areas of the continental shelf and upper slope. Kingklip were overexploited and are being managed in a manner that aims to rebuild stocks after a failed directed fishery was closed due to declining catches (Atkinson and Sink 2008). The jacobever *Helicolenus dactylopterus* also occurred in association with infrastructure (particularly skirt plates and well heads). This scorpionfish is recorded from rocky and unconsolidated habitats and is related to the rockfish, *Sebastes* spp. which has been documented in association with petroleum infrastructure in California (Love and York 2006). This family of fish is susceptible to overexploitation and are considered overfished in the United States (Love *et al.* 2005). Studies off the Californian coast have demonstrated increased abundance of species like bocaccio, *Sebastes paucispinis* and cowcod *Sebastes levis* around oil and gas infrastructure. They argue that this may have implications for increased larval production as rigs host larger mature individuals than nearby natural reefs (Love *et al.* 2005, Love & York 2006).

Invertebrate species of commercial importance associated with infrastructure include the west coast rock lobster *Jasus lalandii* at the FA platform, the south coast rock lobster *Palinurus gilchristi* at the Oribi/Oryx field. The densities of these species would require dedicated sampling for proper quantification but numbers are probably similar to fished areas outside of petroleum exclusion areas. It is likely that rock lobster occurring in association with petroleum infrastructure constitute very small populations colonizing isolated patches of artificial hard ground in an otherwise unconsolidated sandy habitat. There would be little incentive for rock lobster fishers to target such areas due to the limited suitable habitat and associated low numbers of target species. Further surveys and monitoring of rock lobster numbers on the Agulhas Bank may, however, contribute towards better documenting and understanding the observed eastward shift in *J. lalandii* (Cockcroft *et al.* 2008).

Unconsolidated sediment fauna

Benthic epifauna

Untrawled areas, including the ROV transect within the Sable Exclusion Zone, hosted a greater diversity of structure-forming epifaunal species e.g. sponges, bryozoans etc. This observation follows predictions of reduced benthic diversity with increasing disturbance levels (Pianka 1970, Jennings and Kaiser 1998, Atkinson 2010). Some parts of the area within the Sable and Oribi/Oryx Exclusion Zones are reported to have been trawled prior to the petroleum exclusion zones being established (see Figure 3). The presence of the burrowing urchin, *Spatangus capensis* in the Sable Exclusion Zone specifically, and not at any other surveyed sandy area, might be as a result of this historic disturbance followed by elimination of trawl disturbance with enforcement of the exclusion zone boundaries. Urchin species in general are reported to be susceptible to damage by passing trawl gear (Jennings *et al.* 2001, Widdicombe *et al.* 2004, Atkinson 2010) and *S. capensis* was indeed only present in samples collected in lightly trawled areas on the west coast of South Africa (Atkinson 2010) reflecting their sensitivity to disturbance. Other urchin species, like *Brissopsis lyrifera capensis*, are known to occur in trawled areas in southern Africa (Atkinson 2010) and it is suggested that this species (and possibly other similar species) are able to escape damage from trawl gear if they are sufficiently buried beneath the sediment (Bergman and Hup 1992, Thrush *et al.* 1998).

The burrowing tube anemone, *Cerianthus* sp. and burrowing urchin, *Brissopsis lyrifera capensis*, dominated the epifaunal assemblages in the trawled areas surveyed. The dominance of *Cerianthus* sp. in the first transect vs. *B. lyrifera capensis* in the second transect ~ 6 km away, illustrates the well documented patchiness of benthic communities (Jennings and Kaiser 1998, Hall *et al.* 1994). These results suggest that unconsolidated habitats on the Agulhas Bank, where there is some level of disturbance such as that induced by trawling, are colonized by two dominant epifaunal species, namely *Cerianthus* sp. and *B. lyrifera capensis*. Furthermore, these habitats appear to be dominated by one of these two species while the other is present in low abundance, however, further studies are necessary to investigate this. The burrowing behaviour of both these species dominating disturbed areas is likely to play a role in their prevalence in such areas.

Of the four unconsolidated habitats observed during ROV surveys, only the two trawled areas are considered to host similar epifaunal assemblages. The areas surveyed therefore appear to represent at least three different types of epifaunal assemblages occurring in unconsolidated habitats. The diverse nature of epifaunal assemblages occurring in unconsolidated habitat, as illustrated in this study, highlights the need for further investigations of such habitat types to build and refine knowledge of these ecosystems.

Benthic infauna

As with many other unconsolidated sediment habitats sampled within South Africa's marine environment, the infaunal assemblages dominating the habitats sampled in this study were crustaceans (mostly amphipods) and annelids (polychaete or bristle worms). As expected, larger bodied echinoderm species (urchins, starfish and brittle stars) contribute substantially to the overall biomass of infaunal assemblages, however, occur in lower abundance. The site closest to the wellhead (A1), hosted the least infaunal species in the area suggesting that this site represents the

most disturbed state and is thus unable to host the expected average number of species. This site is within 250 m of the wellhead and downstream of the Agulhas Current and would thus be expected to represent the most impacted site of those sampled in this study.

The multivariate analyses of infaunal assemblages in the study area suggest the occurrence of three different 'types' of assemblages as revealed in the MDS and dendrogram plots. The first 'type' of assemblage are those species occurring at sites A1 and D1, which are also the sites closest to the wellhead and thus expected to incur the highest disturbance from petroleum activities. Additional sites sampled within the 250 m radius of the wellhead would have provided further insight as to whether the entire area within the 250 m radius yields similar infaunal species assemblages to those at A1 and D1, which most likely reflect a disturbed community, or if the disturbance is only reflected along the downstream current direction. Sampling at additional sites between 250 m and 500 m from the wellhead was not possible during the sampling trip due to potential gear entanglement with petroleum infrastructure. Options for additional sampling of this nature should be investigated to further validate the proposed petroleum footprint area with respect to infaunal assemblages around a wellhead.

The second 'type' of infaunal assemblage detected in this study represents those species occurring at the reference sites E1 and E2. These sites are located up to 10 km away from the wellhead outside of the petroleum exclusion zone and are also outside of the historical trawl footprint area and therefore are expected to represent unconsolidated habitat unimpacted by petroleum or trawling activities. The infaunal assemblages occurring at E1 and E2 are indeed significantly different to those occurring at all other sites, suggesting that infauna at all other sites reflect some degree of disturbance, either as a result of petroleum or trawling activities. The lack of trawling activity in the area of the reference sites E1 and E2 is likely to be as a result of this area being unsuitable for trawling or not suitable hake habitat due to different prevailing physical variables (e.g. temperature). Sediment properties measured from the grab samples, however, indicate these sites (E1 and E2) consist of similar unconsolidated sediment properties to those sites nearby which are trawled (e.g. The Blues). Further investigations of the physical and biological composition of these sites are required for validation of their suitability as reference sites in this study is required.

The third 'type' of infaunal assemblage detected comprises all remaining 12 sites sampled in this study, half of which are located within the Oribi/Oryx exclusion zone and half outside of the exclusion zone. This indicates that similar species occur at many of the sites within and outside of this exclusion zone and can thus be considered species that are able to colonize physically or chemically disturbed areas.

PERMANOVA analyses revealed significant differences among many of the sites sampled illustrating the high spatial variability among benthic infaunal assemblages on the Agulhas Bank, as has been reported from many other such studies in unconsolidated sediments (de Wolf and Mulder 1985, Drabsch *et al.* 2001, Neumann *et al.* 2008). Nonetheless PERMANOVA results also show that site A1 and D1 are significantly different to all other sites sampled but are also significantly different to each other. Two infaunal species, *Eriopisella capensis* and *Brada villosa capensis* did not occur at site A1 and only in very low numbers at site D1 (the two sites closest to the wellhead). Both these species were present at all other sites sampled. This suggests that these species are likely to be particularly vulnerable to impacts from petroleum activities and are less able to tolerate the conditions within 250 m radius of the wellhead. Burrowing urchins, brittle stars and a small polychaete species (*Poecilochaetus* sp.) occurred in slightly greater abundance and biomass at site A1 in comparison to D1, suggesting that these species may capitalize on impacted areas and are able to tolerate the disturbance downstream of the wellhead more readily than other species. Fewer burrowing urchins and brittle stars at sites E1 and E2 (unimpacted sites ~ 10 km from the wellhead) support this hypothesis. Natural patchiness and high spatial variability of infaunal assemblages may however also contribute to differences detected. High natural variability of unconsolidated sediment assemblages is well documented on spatial scales of hundreds of meters to meters (Kendall and Widdicombe 1999, Zajac *et al.* 2000, Parry *et al.* 2003) and over time (e.g. Kenny *et al.* 1998, van Dalftsen *et al.* 2000). This characteristic of benthic assemblages has recently resulted in recommendations that an

increased number of replicates at each site (i.e. from the standard 5 replicates to 8) are necessary to overcome the confounding effect of high natural variability (Steffani and Pulfrich 2004). Furthermore, sampling at additional sites representing similar conditions (i.e. 250 m from the wellhead) may have assisted in resolving the confounding effect of natural variability vs. disturbance impacts within the immediate vicinity of the wellhead.

PERMANOVA analysis showed a significant difference between sites that are trawled vs. untrawled and between sites within the exclusion zone and sites outside the exclusion zone. However, at least 60 % of the species occurring inside the exclusion zone, also occur outside the exclusion zone, suggesting that a few species contribute to the differences detected by PERMANOVA analysis, indicated in Table 10. Results suggest that the smaller burrowing urchin *Echinocardium cordatum* is most likely unable to withstand the disturbance levels experienced in trawled areas but can tolerate the extent of disturbance (either physical or chemical) as a result of petroleum activities within the exclusion zone. The larger urchin, *B. lyrifera capensis*, appears able to tolerate trawling disturbance levels but might be more sensitive to chemical toxicity, as suggested by its reduced abundance within the petroleum exclusion zone. *Eriopisella capensis*, *B. villosa capensis* and the bivalve *Tellina* sp. occurred in greater abundance at trawled sites and outside the exclusion zone suggesting that these species are not negatively affected by trawling or petroleum activities but rather appear to proliferate under such disturbance conditions. The amphipod *Processa austroafricana* occurred in greater abundance at untrawled sites and within the exclusion zone suggesting some degree of sensitivity to the effects of trawling and petroleum activities. Brittle stars, *Ophiuroidea* sp. and the polychaete species *Spionidae* sp. appear to exhibit a tolerance for disturbance as a result of both trawling and petroleum extraction activities as they occur at both trawled sites and sites within the exclusion zone.

Certain species appear to exhibit some sensitivity to either trawling or petroleum impacts while other species are able to proliferate under disturbed conditions. Results from this study show that some benthic infaunal species were not detected in areas impacted by petroleum activities within 250 m of the wellhead while other areas, further from the wellhead, subjected to either petroleum or trawling activities did not host significantly different infauna.

Sediment properties

The distance-based linear model (DISTLM) analysis (Legendre & Anderson 1999, McArdle & Anderson 2001) results show that none of the environmental variables measured significantly influenced benthic infaunal assemblage composition at the sites sampled. This is further supported by the results from the sediment analysis that did not detect any raised levels of trace metals or hydrocarbons likely to negatively impact on benthic fauna at the sites sampled (Appendix 4).

Conclusions and recommendations

This project has improved the understanding of this important economic sector, its activities, consequences for species and ecosystems affected and has advanced our knowledge of offshore biodiversity in a nationally important region. It has also capacitated the project team in deep water scientific sampling techniques and provided practical and technical lessons to sample by means of SAT divers and undertake ROVs surveys. This experience will be useful for future planned research of deep water habitats. Key lessons include discoveries about biodiversity, the potential role of the South African petroleum industry in the introduction and spread of potentially invasive taxa and the need for improved environmental monitoring and management in this sector. An appreciation of the complexity of environmental management issues for the sector, in particular around the decommissioning of offshore petroleum structures, emerged through this work.

The project provided the first invertebrate and fish species lists for petroleum infrastructure in the 5 – 120 m depth range on the Agulhas Bank. Shallow water (0 - 30 m) fouling assemblages examined in this study were mostly representative of intertidal and shallow subtidal assemblages in the Agulhas region. In deeper water, assemblages on infrastructure showed little similarity with the invertebrate fauna found on deeper reefs, although high variability between reef sites was noted. Results from this study suggest that existing infrastructure has limited value in protecting representative benthic assemblages and no vulnerable marine ecosystems or reef building cold water coral species were documented in the exclusion areas during these surveys. The low levels of fish diversity associated with both the FA platform and Oribi-Oryx field was unexpected as were the absence of important sparids (seabreams) from the adjacent benthic habitats around the platforms and other infrastructure. This result may suggest that the installations provide limited value as a refuge for vulnerable, reef-associated linefish species.

The deep reefs on the Agulhas shelf host a number of vulnerable linefish species that are targeted by the commercial linefishery and therefore open to exploitation. The ROV footage provided important information for assessing the relative conservation value of different deep reefs and this work needs to be taken forward in the context of offshore MPA planning.

Commercially important species such as hake were absent from the ROV surveys taken on unconsolidated sediments inside the exclusion zone but present, albeit in low numbers, in the trawled area. This observation suggests that the exclusion zone has limited value in providing fisheries benefits for commercially important fishes associated with soft substratum (e.g. hake and panga). Further investigations, possibly including standardized research trawls, are needed to substantiate this observation. Kingklip and jacobever occurred in association with petroleum infrastructure on the seabed but dedicated sampling would be needed for further assessment of potential fishery benefits.

The documentation of at least 5 introduced species, the expansion of one cryptogenic species into deep water and the presence of at least 3 unidentified, possibly introduced species has raised concerns about introduced and invasive species colonising existing infrastructure.

This project provided the first known quantitative assessment of benthic faunal communities in deep sandy habitats of the Agulhas Bank and associated sediment pollution levels within petroleum exclusion zones in South Africa. Epifaunal assemblages showed clear differences in species composition in trawled areas compared to untrawled areas near natural reef and within the Sable exclusion zone, which themselves also host different epifaunal species assemblages. Infaunal assemblages sampled closest to the wellhead were significantly different to those sampled more than 250 m away suggesting some degree of petroleum impact within a 250 m radius of the wellhead E-BT01P. Reportedly untrawled sites sampled up to 10 km away from the wellhead also hosted significantly different infaunal assemblages to all other sites sampled. Infaunal assemblages at all remaining sites sampled (i.e. sites more than 250 m from the wellhead except reference sites 10 km away) were not significantly different, whether they were within or outside of the exclusion zone. This suggests that both trawling and petroleum activities impact on benthic infauna and, apart from the area of 250 m radius around the wellhead, disturbance levels from the two activities appear to have

similar end effects on infaunal assemblages. No consistent differences in the sediment grain size, total organic carbon, trace metals or hydrocarbons were detected among sites sampled, suggesting that differences detected in benthic infauna in this study are most likely as a result of physical disturbance (i.e. smothering or sediment plumes) rather than petro-chemical effects.

A key recommendation emanating from this project is the need for further work to support environmental management of this sector. Engagement with PetroSA, the Department of Mineral Regulation and the Petroleum Agency South Africa is required to communicate the findings of this project and to discuss the way forward. The threat of introduced and potentially invasive species must be addressed. There is a need for focused research on introduced taxa, risk assessments to understand the impact of introduced species and the formulation of management recommendations to minimise the spread of introduced taxa. It is proposed that the Generic Environmental Management Program for the sector be updated to incorporate information from this project and to ensure that the risk of species introductions is considered.

The continued use of water based drilling fluids is recommended and we recommend further collaboration with the petroleum sector to ensure that where other types of drilling fluids are necessary, appropriate environmental practice and monitoring is implemented.

Engagement with the industry sector and license holders is also recommended. Industry participants need to be informed about the results of this project and capacitated to further contribute to offshore biodiversity information and to minimise environmental impacts of their activities. We recommend that the results of this project be factored into the numerous environmental, safety, economic and technical considerations that contribute to the decommissioning process and suggest further engagement in this regard. Decommissioning decisions should particularly consider the risk of further non-indigenous species introductions and the risk of spreading introduced and invasive taxa. As invasive species can have serious biodiversity and economic impacts, these risks need to be carefully considered for all decommissioning options under consideration and should be a key aspect of decision making.

SANBI and the project team does not intend to make recommendations about the decommissioning of current infrastructure in this report, as the ultimate aim of this project was to build the knowledge base upon which such decisions depend. This project has significantly expanded this knowledge base and this new information will support;

- environmental management in the petroleum, fisheries and biodiversity sectors,
- decisions about decommissioning options for oil and gas infrastructure,
- offshore Marine Protected Area planning and
- integrated spatial management of South Africa's Exclusive Economic Zone.

APPENDICES (available upon request)

- 1. FA Platform species assemblage report**
- 2. ORCA Platform species assemblage report**
- 3. Sediment properties analysis report by CSIR Brent Newman (particle size, organic carbon, trace metals and hydrocarbons)**

REFERENCES

- Anderson MJ, Gorley RN, Clarke KR. 2008. *PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods*. Plymouth, U.K.: PRIMER-E.
- Atkinson LJ, Sink KJ. 2008. Offshore Marine Protected Areas: User Profiles Support Document. Pretoria: South African National Biodiversity Institute.
- Atkinson LJ. 2010. Effects of demersal trawling on marine infaunal, epifaunal and fish assemblages: studies in the southern Benguela and Oslofjord. PhD thesis, University of Cape Town, South Africa.
- Attwood C, Moloney CL, Stenton-Dozey J, Jackson LF, Heydorn AEF, Probyn TA. 2000. Conservation of Marine Biodiversity in South Africa. In: Durham BD, Pauw J C (eds.), *Summary Marine Biodiversity Status Report*. National Research Foundation, South Africa. pp 68-83.
- Baine M. 2001. Artificial reefs: a review of their design, application, management and performance. *Ocean and Coastal Management* 44: 241-259.
- Baine M. 2002. The North Sea rigs-to-reefs debate. *ICES Journal of Marine Science* 59: S277-S280.
- Bax N, Williamson A, Agüero M, Gonzalez E, Geeves W. 2003. Marine invasive alien species: a threat to global biodiversity. *Marine Policy* 27:313–323.
- Bell N, Smith J. 1999. Coral growing on North Sea rigs. *Nature* 402: 601.
- Bergman MJN, Hup M. 1992. Direct effects of beamtrawling on macrofauna in a sandy sediment in the southern North Sea. *ICES Journal of Marine Science* 49: 5-13.
- Bohnsack J, Harper D, McClellan D, Hulsbeck M. 1994. Effects of reef size on colonization and assemblage structure of fishes at artificial reefs off Southeastern Florida, U.S.A. *Bulletin of Marine Science* 55.
- Bohnsack J. 1989. Are high densities of fishes at artificial reefs the result of habitat limitation or behavioural preference? *Bulletin of Marine Science* 44: 631-645.
- Boyd SE, Rees HL. 2003. An examination of the spatial scale of impact on the marine benthos arising from marine aggregate extraction in the Central English Channel. *Estuarine, Coastal and Shelf Science* 57: 1-16.
- Branch GM, Griffiths CL, Branch ML, Beckley L. 2010. *Two Oceans - a guide to the marine life in Southern Africa*. Cape Town: Struik Nature.
- Bremner J, Rogers SI, Frid CLJ. 2006. Methods for describing ecological functioning of marine benthic assemblages using biological traits analysis (BTA). *Ecological Indicators* 6/7: 609-622.
- Carlton JT, Hodder J. 1995. Biogeography and dispersal of coastal marine organisms: experimental studies on a replica of a 16th-century sailing vessel. *Marine Biology* 121: 721-730.
- Carlton JT. 1987. Patterns of transoceanic marine biological invasions in the Pacific Ocean. *Bulletin of Marine Science* 41: 452-465.
- Carriker MR. 1992. Introductions and transfers of molluscs: risk considerations and implications. *Journal of Shellfish Research* 11: 507-510.
- Clarke KR, Gorley RN. 2006. *PRIMER v6: User Manual/Tutorial*. Plymouth, U.K.: PRIMER-E.

- Clarke KR, Warwick RM. 2001. *Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition*. Plymouth, U.K.: PRIMER-E.
- Cockcroft AC, van Zyl D, Hutchings L. 2008. Large-scale changes in the spatial distribution of South African West Coast rock lobsters: An overview. *African Journal of Marine Science* 30(1): 149-159.
- Cook PA. 1995. Report on marine fouling on the Mossgas FA Platform December 1994. Unpublished Report, University of Cape Town, South Africa.
- Cook PA. 1996. Report on marine fouling on the Mossgas FA Platform March 1996. Unpublished Report, University of Cape Town, South Africa.
- Cook PA. 1997. Report on marine fouling on the Mossgas FA Platform January 1997. Unpublished Report, University of Cape Town, South Africa.
- Cook PA. 1999. Report on marine fouling on the Mossgas FA Platform Sampled in March 1999. Unpublished Report, University of Cape Town, South Africa.
- Cooper K, Boyd S, Eggelton J, Limpenny D, Rees H, Vanstaen K. 2007. Recovery of the seabed following marine aggregate dredging on the Hastings Shingle Bank off the southeast coast of England. *Estuarine, Coastal and Shelf Science* 75: 547-558.
- Coutts A, Taylor M and Hewitt C. 2007. Novel method for assessing the en route survivorship of biofouling organisms on various vessel types. *Marine Pollution Bulletin* 54: 97-116.
- Cranford PJ, Gordon DC, Lee K, Armsworth SL, Tremblay GH. 1999. Chronic toxicity and physical disturbance effects of water- and oil-based drilling fluids and some major constituents on adult sea scallops (*Placopecten magellanicus*). *Marine Environmental Research* 48: 225-256.
- Cranmer G. 1988. Environmental survey of the benthic sediments around three exploration well sites. Aberdeen University Marine Studies Ltd, United Kingdom Offshore Operators Association, United Kingdom. Report No. 88/02.
- Crowther, Campbell and Associates and CSIR. 1998. Environmental impact assessment for the proposed extension of the ORIBI oil production facility and hydrocarbon exploration off the southern Cape Coast. Report No. SOEO1OE/2.
- CSIR. 1995. Environmental Impact Assessment for Gas Exploration Drilling in Licence Area 2814A on the continental shelf of Namibia (*EMAS-C95053b*). Stellenbosch: CSIR - Environmental Services.
- Currie DR, Isaacs LR. 2005. Impact of exploratory offshore drilling on benthic communities in the Minerva gas field, port Campbell, Australia. *Marine Environmental Research* 59: 217-233.
- Daan R, Mulder M. 1996. On the short-term and long-term impact of drilling activities in the Dutch sector of the North Sea. *ICES Journal of Marine Science* 53: 1036-1044.
- Daan R, Mulder M. and van Leeuwen A. 1994. Differential sensitivity of macrozoobenthic species to discharges of oil-contaminated drill cuttings in the North Sea. *Netherlands Journal of Sea Research* 33, 113-127.
- Daan R, van het Groenewoud H, de Jong SA, Mulder M. 1992. Physico-chemical and biological features of a drilling site in the North Sea, 1 year after discharges of oil contaminated drill cuttings. *Marine Ecology Progress Series* 91: 37-45.
- Dai DG. 1998. Molluscan conservation in South Africa: Diversity, issues and priorities. *Journal of Conchology Special Publication No. 2*: 61-76.

Dauvin JC. 1998. The fine sand *Abra alba* community of the Bay of Morlaix twenty years after the Amoco Cadiz oil spill. *Marine Pollution Bulletin* 39: 669-676.

Davies JM, Hardy R, McIntyre AD. 1981. Environmental effects of North Sea oil operations. *Marine Pollution Bulletin* 12: 412-416.

Davies JM, Kingston PF. 1992. Sources of environmental disturbance associated with offshore oil and gas developments. In: Cairns WJ (ed), *North Sea oil and the environment: developing oil and gas resources, environmental impacts and responses*. United Kingdom: Cambridge University Press.

de Wolf P, Mulder M. 1985. Spatial variation of macrobenthos in the southern North Sea. *Estuaries* 8: 64A.

Drabsch SL, Tanner JE, Connell SD. 2001. Limited infaunal response to experimental trawling in previously untrawled areas. *ICES Journal of Marine Science* 58: 1261-1271.

Dunaway ME, Schroeder P. 1988. Minimising anchoring impacts during construction of offshore oil and gas facilities. Oceans '88 Conference and Exhibition, Baltimore.

Elmgren R, Hansson S, Larsson U, Sundelin B, Boehm PD. 1983. The *Tsesis* oil spill: acute and long-term impact on benthos. *Marine Biology* 73: 51-65.

Emery BM, Washburn L, Love M, Nishimoto MM, Ohlmann JC. 2006. Do oil and gas platforms off California reduce recruitment of bocaccio (*Sebastes paucispinis*) to natural habitat? An analysis based on trajectories derived from high frequency radar. *Fisheries Bulletin* 104: 391-400.

Everett RA. 2000. Patterns and pathways of biological invasions. *Trends in Ecology and Evolution* 15: 177-178.

Fabi G, Grati F, Puletti M, Scarcella G. 2004. Effects on fish community induced by installation of two gas platforms in the Adriatic Sea. *Marine Ecology Progress Series* 273: 187-197.

Feder HM, Blanchard A. 1998. The deep benthos of Prince William Sound, Alaska, 16 months after *Exxon Valdez* oil spill. *Marine Pollution Bulletin* 36: 118-130.

Ferbrache J. 1983. A review of the available literature on the marine benthic effects resulting from discharges of water based mud and cuttings. Report prepared for UKOOA oil Base Mud Workgroup, Great Britain.

Field JG, Clarke KR, Warwick RM. 1982. A practical strategy for analyzing multispecies distribution patterns. *Marine Ecological Progress Series* 8: 37-52.

Forteath GNR, Picken GB, Ralph R, Williams J. 1982. Marine growth studies on the North Sea oil platform Montrose Alpha. *Marine Ecology Progress Series* 8: 61-68.

Foster BA, Willan RC. 1979. Foreign barnacles transported to New Zealand on an oil platform. *New Zealand Journal of Marine and Freshwater Research* 13: 143-149.

Gibbons MJ, Abiahy BB, Angel M, Assuncao CML, Bartsch I, Best P, Biseswar R, Bouillon J, Bradford-Grieve JM, Branch W, Burreson E, Cannon L, Casanova J-P, Channing A, Child CA, Compagno L, Cornelius PFS, Dadon JR, David JHM, JD, Della Croce N, Emschermann P, Erseus C, Esnal G, Gibson R, Griffiths CL, Hayward PJ, Heard R, Heemstra PC, Herbert D, Hessler R, Higgins R, Hiller N, Hirano YM, Kensley B, Kilburn R, Kornicker L, Lamshead J, Manning R, Marshall D, Mianzan H, Monniot C, Monniot F, Newman W, Nielsen C, Patterson G, Pugh P, Roeleveld M, Ross A, Ryan P, Ryland JS, Samaai T, Schleyer M, Schockaert E, Seapy R, Shiel R, Sluys R, Southward EC, Sulaiman A, Thandar A, van der Land J, van der Spoel S, van Soest R, Vetter E, Vinogradov G, Williams G and Wooldridge T. 1999. The taxonomic richness of South Africa's marine fauna: crisis at hand. *South African Journal of Science* 95: 8-12.

- Gomez-Gesteira JL, Dauvin JC. 2000. Amphipods are good bioindicators of the impact of oil spills on soft-bottom macrobenthic communities. *Marine Pollution Bulletin* 40: 1017-1027
- Grant JS, Briggs AD. 2002. Toxicity of sediments from around a North Sea oil platform: are metals or hydrocarbons responsible for ecological impacts? *Marine Environmental Research* 53: 95-116.
- Grant WS, Cherry MI, Lombard AT. 1984. A cryptic species of *Mytilus* (Mollusca: Bivalvia) on the west coast of South Africa. *South African Journal of Marine Science* 2: 149-162.
- Gray J, Clarke KR, Warwick RM, Hobbs G. 1990. Detection of initial effects of pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, North Sea. *Marine Ecology Progress Series* 66: 285-299.
- Gray JS. 1974. Animal-sediment relationships. *Oceanography and Marine Biology Annual Reviews* 12: 223-261.
- Griffiths CL, Kruger LM, Smith EC. 1996. First record of the sea anemone *Metridium senile* from South Africa. *South African Journal of Zoology* 31: 157-158.
- Griffiths CL, Robinson TB, Mead A. 2009. The status and distribution of marine alien species in South Africa. In: Rilov G, Crooks JA (eds), *Biological Invasions in Marine Ecosystems*. Heidelberg: Springer-Verlag. pp 393-408.
- Griffiths CL, Robinson TB, Mead A. 2009. The status and distribution of marine alien species in South Africa. In: Rilov G, Crooks JA (eds), *Biological Invasions in Marine Ecosystems*. Heidelberg: Springer-Verlag, Berlin. pp 393-408.
- Griffiths CL. 2000. Overview of current problems and future risks. In: Preston G, Brown G, van Wyk E (eds), *Best Management Practices for Preventing and Controlling Invasive Alien Species*. Cape Town: Working for Water Programme. pp 235-241.
- Grundlingh ML, Morant PD, Van Ballegooyen RC, Badenhorst A, Gomes E, Greyling L, Guddal J, Hunter IT, Japp DW, Maartens L, Peard KR, Smith GG, Wainman CK. 2006. Environmental data requirements of maritime operations in the Benguela coastal ocean. *Large Marine Ecosystems* 14: 357-380.
- Hall SJ, Raffaelli DG, Thrush SF. 1994. Patchiness and disturbance in shallow water benthic assemblages. In Giller PS, Hildrew AG, Raffaelli DG (eds.), *Aquatic Ecology*. Oxford: Blackwell Science. pp 333-375.
- Hall SJ. 2001. Is offshore oil exploration good for benthic conservation? *Trends in Ecology & Evolution* 16(1): 58.
- Hamzah B. 2003. International rules on decommissioning of offshore installations: some observations. *Marine Policy* 27: 339-348.
- Holdway DA. 2002. The acute and chronic effects of wastes associated with offshore oil and gas production on temperate and tropical marine ecological processes. *Marine Pollution Bulletin* 44: 185-203.
- Hutchings P. 1998. Biodiversity and functioning of polychaetes in marine sediments. *Biodiversity and Conservation* 7: 1133-1145.
- Hyland J, Hardin D, Steinhauer M, Coats D, Green R, Neff J. 1994. Environmental impact of offshore oil development on the outer continental shelf and slope off Point Arguello, California. *Marine Environmental Research* 37: 195-229.
- Hyland J, Hardin D, Steinhauer M, Coats D, Green RH, Neff J. 1994. Environmental impact of offshore oil development on the outer continental shelf and slope off Point Arguello, California. *Marine Environmental Research*, 37: 195-229.

- Japp DW, Sims P, Smale M. 1994. A review of the fish resources of the Agulhas Bank. *South African Journal of Science* 90: 123-135.
- Jennings S, Kaiser MJ. 1998. The effects of fishing on marine ecosystems. *Advances in Marine Biology* 34: 210-352.
- Jennings S, Pinnegar JK, Polunin NVC, Warr K J. 2001. Impact of trawling disturbance on the trophic structure of benthic invertebrate communities. *Marine Ecology Progress Series* 213:127–142.
- Jensen GC, McDonald PS, Armstrong DA. 2007. Biotic resistance to green crab, *Carcinus maenas*, in California bays. *Marine Biology* 151: 2231-2243.
- Jones DOB, Parks IFJ, Gates AR. 2008 Techniques for Monitoring the Recovery of Deep, Cold-Water Habitats Following Physical Disturbance From Drilling Discharges. SPE International Conference on Health, Safety, and Environment in Oil and Gas Exploration and Production, 15-17 April 2008. Nice, France.
- Junoy J, Castellanos C, Vieitez JM, De la Huz MR, Lastra M. 2005. The macroinfauna of the Galician sandy beaches (NWSpain) affected by the Prestige oil-spill. *Marine Pollution Bulletin* 50: 526–536.
- Kaiser M , Pulsipher A. 2005. Rigs-to-Reef Programs in the Gulf of Mexico. *Ocean Development and International Law* 36: 119-134.
- Kaiser M. 2006. The Louisiana artificial reef program. *Marine Policy* 30: 605-623
- Kaiser MJ, Edwards DB, Armstrong PJ, Radford K, Lough NEL, Flatt RP, Jones HD. 1998. Changes in megafaunal benthic communities in different habitats after trawling disturbance. *ICES Journal of Marine Science* 55: 353-361.
- Kendall MA, Widdicombe S. 1999. Small scale patterns in the structure of macrofaunal assemblages of shallow soft sediments. *Journal of Experimental Marine Biology and Ecology* 237:127-140.
- Kenny AJ, Rees HL, Greening J, Campbell S. 1998. The effects of marine gravel extraction on the macrobenthos at an experimental dredge site off north Norfolk, U.K. (Results 3 years post-dredging). *ICES CM 1998/V:14*. pp 1-8.
- Kerr RA, Kintisch E, Schenkman L, Stokstad E. 2010. Five questions on the spill. *Science* 328 (8601): 962-963.
- Kersten M, Smedes F. 2002. Normalization procedures for sediment contaminants in spatial and temporal trend monitoring. *Journal of Environmental Monitoring* 4: 109-115.
- Kingston PF. 1992. Impact of offshore oil production installations on the benthos of the North Sea. *ICES Journal of Marine Science* 49: 45-53.
- Kloff S, Wicks C. 2004. Environmental management of offshore oil development and maritime oil transport. A background document for stakeholders of the West African Marine Eco Region. IUCN Commission on Environmental, Economic and Social Policy. 73 pp.
- Legendre P, Anderson MJ. 1999. Distance-based redundancy analysis: testing multispecies responses in multifactorial ecological experiments. *Ecological Monographs* 69:1-24.
- Lewis PN, Bergstorm DM, Whinam J. 2006. Barging in: a temperate marine community travels to the subantarctic. *Biological Invasions* 8: 787-795.
- Lindberg W. 1997. Can Science Resolve the Attraction - Production Issue? *Fisheries* 22: 10-13.

- Lombard AT, Strauss T, Harris J, Sink K, Attwood C, Hutchings L. 2004. South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 4: Marine Component. Pretoria: South African National Biodiversity Institute.
- Long E, MacDonald D, Smith S and Calder F. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management* 19: 81-97.
- Loring DH, Rantala RTT. 1992. Manual for the geochemical analyses of marine sediments and suspended particulate matter. *Earth-Science Review* 32, 235-283.
- Love MS, Caselle J, Snook L. 1999a. Fish assemblages around seven oil platforms in the Santa Barbara Channel area. *Fisheries Bulletin* 98: 96-117.
- Love MS, Caselle J, Snook L. 1999b. Fish assemblages on mussel mounds surrounding seven oil platforms in the Santa Barbara Channel and Santa Maria Basin. *Bulletin of Marine Science* 65: 497-513.
- Love MS, Schroeder DM, Lenarz WH. 2005. Distribution of Bocaccio (*Sebastes paucispinis*) and Cowcod (*Sebastes levis*) around oil platforms and natural outcrops off California with implications for larval production. *Bulletin of Marine Science* 77(3): 397-408.
- Love MS, Westphal W. 1990. Comparison of fishes taken by a sportfishing party vessel around oil platforms and adjacent natural reefs near Santa Barbara, California. *Fisheries Bulletin* 88: 599-605.
- Love MS, York A. 2006. The relationships between fish assemblages and the amount of bottom horizontal beam exposed at California oil platforms: fish habitat preferences at man-made platforms and (by inference) at natural reefs. *Fisheries Bulletin* 104: 542-549.
- McArdle BH, Anderson MJ. 2001. Fitting multivariate models to community data: a comment on distance-based redundancy analysis. *Ecology* 82: 290-297.
- McCauley RD, Fewtrell J, Duncan AJ, Jenner C, Jenner MN, Penrose JD, Prince RIT, Adhitya A, Murdoch J, McCabe K. 2000. Marine seismic surveys – A study of environmental implications. *APPEA Journal*: 692-780.
- McGinnis MV, Fernandez L, Pomeroy C. 2001. The Politics, Economics, and Ecology of Decommissioning Offshore Oil and Gas Structures, MMS OCS Study 2001-006. Unpublished report, Coastal Research Center - Marine Science Institute, California. MMS Cooperative Agreement Number 14-35-0001-30761.
- Mead A, Carlton J, Griffiths CL, Rius M. In Prep. Revealing the scale of marine bioinvasions: The South African example.
- MENZ. 2005. Ministry for the Environment Offshore options: Managing Environmental effects in New Zealand's Exclusive economic zone. Ministry of the Environment, New Zealand. pp 49.
- Monnoit C, Monnoit F, Griffiths CL, Schleyer M. 2001. South African ascidians. *Annals of the South African Museum* 108(1): 141.
- Montagna PA, Harper DE. 1996. Benthic infaunal long term response to offshore production platforms in the Gulf of Mexico. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 2567-2588
- Monteiro PMS, Roychoudhury AN. 2005. Spatial characteristics of sediment trace metals in an eastern boundary upwelling retention area (St. Helena Bay, South Africa): A hydrodynamic-biological pump hypothesis. *Estuarine Coastal and Shelf Science* 65, 123-134.
- Naylor RL, Williams SL, Strong DR. 2001. Aquaculture - A gateway for exotic species. *Science* 294: 1655-1656.

- Neff JM, Bothner MH, Maciolek NJ, Grassle JF. 1989. Impacts of exploratory drilling for oil and gas on the benthic environment of Georges Bank. *Marine Environmental Research* 27: 77-114.
- Neff JM, Rabalais NN, Boesch DF. 1987. Offshore oil and gas development activities potentially causing long-term environmental effects. In: Boesch DF, Rabalais NN (eds), *Long-term Environmental Effects of Offshore Oil and Gas Development*. London and New York: Elsevier Applied Science. pp 149-174.
- Neumann H, Ehrich S, Kröncke I. 2008. Spatial variability of epifaunal communities in the North Sea in relation to sampling effort. *Helgoland Marine Research* 62: 215-225.
- Neves Dos Santos L, Shimada Brotto D and Rosental Zalmon I. 2010. Fish responses to increasing distance from artificial reefs on the Southeastern Brazilian Coast. *Journal of Experimental Marine Biology and Ecology* 386: 54-60.
- Newell RC, Seiderer LJ, Hitchcock DR. 1998. The impact of dredging works in coastal waters: A review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. *Oceanography and Marine Biology: An Annual Review* 36: 127-178.
- Nounou P. 1980. The Oil Spill Age: Fate and Effects of Oil in the Marine Environment. *Ambio* 9: 297-302.
- O'Brien PE, Arnt W, Everson I, Gohl K, Gordon JCD, Goss C, Kremser U, Laws R, Martin T, Ploetz J, Rodhouse PG, Rogers T, Thompson D, Sexton M, Wilson R, Woehler E. 2002. Impacts of marine acoustic technology on the Antarctic environment. Unpublished report, SCAR Ad Hoc Group on marine acoustic technology and the environment.
- OGP. 2003. Environmental aspects of the use and disposal of non aqueous drilling fluids associated with offshore oil and gas operations. International Association of Oil and Gas Producers, United Kingdom. Report No. 342. pp 103.
- Olsgard F, Gray JS. 1995. A comprehensive analysis of the effects of offshore oil and gas exploration and production on the benthic communities of the Norwegian continental shelf. *Marine Ecology Progress Series* 122: 277-306.
- Page HM, Dugan JE, Culver CS, Hoesterey JC. 2006. Exotic invertebrate species on offshore oil platforms. *Marine Ecology Progress Series* 325: 101-107.
- Parry DM, Kendall MA, Pilgrim DA, Jones MB. 2003. Identification of patch structure within marine benthic landscapes using a remotely operated vehicle. *Journal of Experimental Marine Biology and Ecology* 285–286: 497–511.
- Penney AJ, Griffiths CL 1984. Prey selection and the impacts of the starfish *Marthasterias glacialis* (L.) and other predators on the mussel, *Choromytilus meridionalis*, (Krauss). *Journal of Experimental Marine Biology and Ecology* 75: 19-36.
- Peterson CH, McDonal L, Green RH, Erickson W. 2001. Sampling design begets conclusions: the statistical basis for detection of injury to and recovery of shoreline communities after the “Exxon Valdez” oil spill. *Marine Ecology Progress Series* 210: 255–283.
- Peterson CH, Rice SD, Short JW, Esler D, Bodkin JL, Ballachey BE, Irons DB. 2003. Long-term ecosystem response to the Exxon Valdez oil spill. *Science* 302: 2082–2086.
- Pianka ER. 1970. On r- and K-selection. *The American Naturalist* 104(940): 592-597.

- Picken G, Baine M, Heaps L, Side J. 2000. Rigs to reefs in the North Sea. In: Jensen A, Collins KJ, Lockwood APM (eds), *Artificial Reefs in European Seas*. The Netherlands, Kluwer Academic Publishers. pp 331–342.
- Pimentel D, Lach L, Zuniga R, Morrison D. 2000. Environmental and economic costs of nonindigenous species in the United States. *BioScience* 50: 53-65.
- Polovina J. 1989. Artificial reefs: Nothing more than benthic fish aggregators. *CalCAFI Report* 30: 37-39.
- Ponti M, Abbiati M and Ugo Ceccherelli V. 2002. Drilling platforms as artificial reefs: distribution of macrobenthic assemblages of the “Paguro” wreck (northern Adriatic Sea). *ICES Journal of Marine Science* 59: S316-S323.
- Powers S, Grabowski J, Peterson C, Lindberg W. 2003. Estimating enhancement of fish production by offshore artificial reefs: uncertainty exhibited by divergent scenarios. *Marine Ecology Progress Series* 264: 265-277.
- Reggio VC. 1996. Mariculture associated with oil and gas structures: a compendium. In: Proceedings: Rice, Owen. 1999. Fourteenth Information Transfer Meeting, November 17, 1994, New Orleans, La. OCS Study MMS 96-0050. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, La. 32 pp
- Robinson TA, Griffiths CL, McQuaid CD, Rius M. 2005. Marine alien species of South Africa – status and impacts. *African Journal of Marine Science* 27: 297-306.
- Robinson TB, Branch GM, Griffiths CL, Govender A, Hockey PAR. 2007. Effects of the invasive mussel *Mytilus galloprovincialis* on rocky intertidal community structure in South Africa. *Marine Ecology Progress Series* 340: 163-171.
- Rogers AD, Clark MR, Hall-Spencer KM and Gjerde KM 2008. The Science behind the Guidelines: A Scientific Guide to the FAO Draft International Guidelines (December 2007) For the Management of Deep-Sea Fisheries in the High Seas and Examples of How the Guidelines May Be Practically Implemented. IUCN, Switzerland, 2008.
- Salas F, Marcos C, Neto JM, Patricio J, Pérez-Ruzafa A, Marques JC. 2006. User-friendly guide for using benthic ecological indicators in coastal and marine quality assessment. *Ocean and Coastal management* 49: 308-331.
- Sammarco PW, Atchison AD, Boland GS. 2004. Expansion of coral communities within the Northern Gulf of Mexico via offshore oil and gas platforms. *Marine Ecology Progress Series* 280: 129-143.
- Sanchez F, Velasco F, Cartes JE, Olaso I, Preciado I, Fanelli E, Serrano A, Gutierrez-Zabala JL. 2006. Monitoring the Prestige oil spill impacts on some key species of the northern Iberian shelf. *Marine Pollution Bulletin* 53: 332-349.
- Schaanning MT, Trannum HC, Oxnevad S, Carroll J, Bakke T. 2008. Effects of drill cuttings on biogeochemical fluxes and macrobenthos of marine sediments. *Journal of Experimental Marine Biology and Ecology* 361: 49-57.
- Schroeder D, Love M. 2004. Ecological and political issues surrounding decommissioning of offshore oil facilities in the Southern California Bight. *Ocean and Coastal Management* 47: 21-48.
- Seaman W, Lindberg W, Gilbert C, Frazer T. 1989. Fish habitat provided by obsolete petroleum platforms off Southern California. *Bulletin of Marine Science* 44: 1014-1022.
- Serrano A, Sanchez F, Preciado I, Parra S, Frutos I. 2006. Spatial and temporal changes in benthic communities of the Galician continental shelf after the *Prestige* oil spill. *Marine Pollution Bulletin* 53: 315-331.

- Sheehy D, Vik S. 2010. The role of constructed reefs in non-indigenous species introductions and range expansions. *Ecological Engineering* 36: 1-11.
- Shinn E, Wicklund R. 1989. Artificial reef observations from a manned submersible off Southeast Florida. *Bulletin of Marine Science* 44: 1041-1050.
- Sink KJ, Boshoff W, Samaai T, Timm PG, Kerwath SE. 2006. Observations of the habitats and biodiversity of the submarine canyons at Sodwana Bay. *South African Journal of Science* 102(9): 466-474.
- Smale MJ, Roel BA, Badenhorst A, Field JG. 1993. Analysis of demersal community of fish and cephalopods on the Agulhas Bank, South Africa. *Journal of Fisheries Biology* 43:169-191.
- Smith MM, Heemstra PC (eds). 1986. *Smith's Sea Fishes*. Cape Town: Struik Publishers.
- Snelgrove PVR, Blackburn TH, Hutchings PA, Alongi DM, Grassle JF, Hummel H, King G, Koike I, Lambshead PJD, Ramsing NB, Solis-Weiss V. 1997. The importance of marine sediment biodiversity in ecosystem processes. *Ambio* 26(8): 578-583.
- Snelgrove PVR. 1998. The biodiversity of macrofaunal organisms in marine sediments. *Biodiversity Conservation* 7:1123–1132.
- Soldal A , Svellingen I , Jørgensen T and Løkkeborg S. 2002. Rigs-to-reefs in the North Sea: hydroacoustic quantification of fish in the vicinity of a "semi-cold" platform. *ICES Journal of Marine Science* 59: S281-S287.
- Steffani CN, Pulfrich A. 2004. Environmental Baseline Survey of the Macrofaunal Benthic Communities in the De Beers ML3/2003 Mining Licence Area. Contract Report prepared by Pisces Environmental Services (Pty) Ltd for De Beers Marine (Pty) Ltd. South Africa
- Steinhauer M, Crecelius E, Steinhauer W. 1994. Temporal and spatial changes in the concentrations of hydrocarbons and trace metals in the vicinity of an offshore oil-production platform. *Marine Environmental Research* 37: 129-163.
- Suchanek TH. 1993. Oil impacts on marine invertebrate populations and communities. *American Zoology* 33: 510-523.
- Terlizzi A, Bevilacqua S, Scuderi D, Fiorentino D, Guarnieri G, Giangrande A, Licciano M, Felling S, Fraschetti G. 2008. Effects of offshore platforms on soft-bottom macro-benthic assemblage: A case study in a Mediterranean gas field. *Marine Pollution Bulletin* 56: 1303-1309.
- Thomas CA, Bendell-Young LI. 1999. The significance of diagenesis versus riverine input in contributions to the sediment geochemical matrix of iron and manganese in an intertidal region. *Estuarine Coastal and Shelf Science* 48: 635-647.
- Thrush SF, Hewitt JE, Cumings VJ, Dayton PK, Cryer M, Turner SJ, Funnell GA, Budd RG, Milburn CJ, Wilkinson MR. 1998. Disturbance of the marine benthic habitat by commercial fishing: Impacts at the scale of the fishery. *Ecological Applications* 8(3): 866-879
- Trussell GC. 2000. Predator-induced plasticity and morphological trade-offs in latitudinally separated populations of *Littorina obtusata*. *Evolution and Ecology Research* 2: 803-822.
- Van Dalsen JA, Essink K, Toxvig Madsen H, Briklund J, Romero J, Manzanera M. 2000. Differential response of macrozoobenthos to marine sand extraction in the North Sea and the Western Mediterranean. *ICES Journal of Marine Science* 57: 1439–1445.

- Walkley A, Black IA. 1934. An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and inorganic soil constituents. *Soil Science* 63: 251-263.
- Wanless RM, Scott S, Sauer WH H, Andrew TG, Glass JP, Godfrey B, Griffiths C, Yeld E. 2009. Semi-submersible rigs: a vector transporting entire marine communities around the world. *Biological Invasions*: DOI 10.1007/s10530-009-9666-2.
- Warwick RM, Clarke KR. 1993. Comparing the severity of disturbance: a meta-analysis of marine macrobenthic community data. *Marine Ecology Progress Series* 92: 221-231.
- Warwick RM. 1993. Environmental impact studies on marine communities: pragmatical considerations. *Australian Journal of Ecology* 18: 63-80.
- Widdicombe S, Austen M. 1998. Experimental evidence for the role of *Brissopsis lyrifera* (Forbes, 1841) as a critical species in the maintenance of benthic diversity and the modification of sediment chemistry. *Journal of Experimental Marine Biology and Ecology* 288: 241-255.
- Widdicombe S, Austen MCV, Kendall MA, Olsgard F, Schaanning MT, Dashfield SL, Needham HR. 2004. Importance of bioturbators for biodiversity maintenance: indirect effects of fishing disturbance. *Marine Ecology Progress Series* 275: 1-10.
- Wilhelmsson D, Yahya S and Ohman M. 2006. Effects of high-relief structures on cold temperate fish assemblages: A field experiment. *Marine Biology Research* 2: 136-147.
- Wolfson A, Van Blaricom G, Davis N, Lewbe GS. 1979. The marine life of an offshore oil platform. *Marine Ecology Progress Series* 1: 81-89.
- Zajac RN, Lewis RS, Poppe LJ, Twichell DC, Vozarik J, DiGiacomo-Cohen ML. 2000. Relationships among sea-floor structure and benthic communities in Long Island Sound at regional and benthoscape scales. *Journal of Coastal Research* 16: 627– 640.