Brief Overview of Potential Ecosystem Impacts of Marine Phosphate Mining in the Western Cape, South Africa

Prepared for WWF South Africa

by

Jock Currie
Introduction

In this report, the potential effects of marine phosphate (or any similar bulk sediment) mining operations on marine ecosystems in the Western Cape province of South Africa are outlined. The report was prompted by the application of Green Flash Trading (Pty) Ltd for a licence to prospect for phosphates and other minerals in extensive areas off the west and south coasts of the Western Cape.

The prospecting phase as laid out by Green Flash Trading (GFT) in their Environmental Management Plans (EMPs; Green Flash Trading 2012a, 2012b) lacks necessary detail to assess the potential extent and severity of their impacts on the marine ecosystem. This report does not attempt to address the impacts of those prospecting activities, but rather focuses on the scenario of full-scale mining of offshore sediments, which could follow prospecting stages. However to provide a geographical context, which is important in consideration of the types of habitats and priority conservation areas that could be impacted, the prospecting licence areas as indicated in the GFT EMPs are employed. This report is restricted to the potential impacts of the mining process offshore and does not include the impacts resulting from the transfer of dredged material onshore and their processing or beneficiation. The onshore processing will likely result in large volumes of waste products, which could contain toxic chemicals and concentrated contaminants (Gecko 2011). During consideration of any proposed marine mining projects, the ecological and socio-economic implications of these processes and waste products would require rigorous assessments, in addition to those of the offshore impacts outlined below.

Phosphate and other bulk sediments have not been mined on a commercial scale from the deep sea floor anywhere in the world. As a result, potential ecosystem impacts can at best be inferred from other types of mining operations that have taken place in similar biogeographic regions, at comparable depths and using similar tools, together with our understanding of the mining strategy and the local oceanography and ecology. The most comparable existing mining operations would be the deep water diamond mining activities offshore of the west coast of Namibia (Penney et al. 2007). During its relatively short history, this vessel-based remote mining strategy has concentrated on locating and recovering localised sediments containing concentrated diamond deposits. However new methods and technologies have led to exponential increases in the achievable mining rate of the sea floor (Figure 5.2b in Penney et al. 2007), culminating in technologies such as the Trailing Suction Hopper-Dredge (TSHD), which allows large volumes of sediments to be dredged, stored in hopper compartments on board, and transferred to another vessel or onshore for further processing. TSHD vessels have the ability to dredge sea floor sediments at a rate of > 100 000 m$^2$/day (Penney et al. 2007) or 4500 m$^3$/hour (NMP 2012) from depths exceeding 130 m. Such new technologies are overcoming the economical restraints that have prevented exploitation of deep sea bulk minerals and if these are to be mined off the Western Cape within the near future, the method used will very likely involve a TSHD or similar high-volume dredging vessel.

The 223-m TSHD, Cristobal Colon, which Namibian Marine Phosphate (Pty) Ltd proposes to use for their
planned phosphate mining off the Namibian coast, has a dredging speed of 1-2 knots and drags an 11-m wide’ dredge head over the sea floor, cutting a trench that is up to 0.75 m deep (NMP 2012). The dredge heads typically have cutting ‘teeth’ and powerful water jets to break up hard or consolidated sediments before they enter the suction tube (Penney et al. 2007). Excess water and fines are released back into the water column at 10-15 m depth, from a hopper overflow funnel. The 46 000 m³ hopper capacity of the Cristobal Colon will allow transfer of 64 175 tonnes of sediment to shore per 36-hour dredging cycle in the Namibian project (NMP 2012). The company plans to eventually mine 5.5 million tonnes of sediment during 47 weeks at sea annually, removing sediments up to 3 m in depth and over areas of ~2.4 km². For greater detail on the various dredging, trenching and drilling mechanisms employed in the marine diamond mining industry, see Penney et al. (2007).

As bulk mining of the sea floor and large-scale dredging at these substantial depths has not taken place before, there is an urgent requirement to understand the impacts of such proposed activities on the surrounding ecosystems, which encompass unique biodiversity and sustain valuable natural resources. The following sections outline the potential threats to these ecosystems, as identified from literature covering the effects of deep water diamond mining and dredging.

**Impacts on Demersal and Pelagic Organisms**

*Flight from Disturbance, Noise and/or Degraded Water Quality*

Heemstra (1994) recorded some fish being sucked into large dredges. However, it is assumed that the majority of mobile organisms that can out-swim the approaching dredge head will escape. Most larger organisms that are able to actively propel themselves will likely move out of the immediate vicinity, while those sensitive to sound would avoid a larger area (potentially on the order of several km for certain fish and mammals; Engås et al. 1996, Southall et al. 2008, Slabbeekoorn et al. 2010) around the noise pollution caused by the surface vessel, the dredging tool on the sea floor and the underwater positioning (sonar) system.

Assuming bulk mining plans would be similar to those of the NMP project in Namibia (NMP 2012), the dredging vessel will focus on a target mining area for several years and will be at sea for the majority of that time, creating a semi-permanent source of acoustic disturbance. As large volumes of dredged sediment have to be transferred ashore frequently (every 37 hours in the Namibian example), a significant increase in shipping traffic will develop between the mining site and the selected port, creating persistent disturbance along the transfer route for species sensitive to sound. The scale and implications of acoustic impacts would require careful investigation for certain species, taking into account their sensitivity, the duration and intensity of noise disturbances and its locality in relation to the animal's habitat use and migration patterns. Pulfrich (2010) provides a useful overview of the literature pertaining to acoustic trauma on marine fauna, with a focus on deep water seismic exploration on the west coast of Namibia.

*This width will likely be reduced to increase the operational depth.*
Raised Turbidity and Reduction of Light Levels

Both within and below the fines plume, light penetration will be reduced, lowering photosynthetic rates and visibility. Greatly enhanced concentrations of sediment particles in the water column can also affect biological processes such as hatching, larval survival and foraging behaviour (Westerberg et al. 1996, Clarke et al. 2000). Penney et al. (2007) judged the tailings plumes in offshore diamond mining areas of Namibia not to pose a significant threat to pelagic fauna, arguing that the sediment loads are below lethal concentrations and that the effects are localised around the mining vessel. Environmental Evaluation Unit (1996) conclude that the photosynthetic inhibition will be limited to an area < 1 km$^2$ around the vessel and is of little consequence. As dense phytoplankton blooms frequently reduce visibility in the Benguela region, the loss of light will likely be of little consequence to other marine organisms.

Biogeochemical Impacts

The chemical composition of sediments and the water-column, as well as bottom water and stratified surface waters, differ substantially due to differences in biogeochemical rates and processes within them. Therefore the disturbed benthic plume and the release of fines and bottom water from the surface vessel will alter water-column chemistry, impacting pelagic, demersal and benthic organisms. Sediments underlying upwelling ecosystems such as the Benguela are typically enriched with organic matter that has settled from the productive waters above (Chapman and Shannon 1985). High re-mineralization rates within and on the surface of the sediments will commonly result in elevated inorganic nutrient concentrations, in many instances well beyond the concentrations seen in upwelling South Atlantic Central Water (Bailey and Chapman 1991). The re-mineralization consumes oxygen, frequently causing hypoxic (or anoxic) sediments and depleted oxygen levels in overlying bottom waters (Brüchert et al. 2009).

Thus a disturbed benthic plume would be expected to impact surrounding oxygen content: Depleted oxygen concentrations from disturbed interstitial (sediment) water will mix with surrounding bottom water, reducing oxygen levels in the latter. In addition, re-suspended anoxic sediments would strip oxygen from surrounding bottom water (Brüchert et al. 2003), while the re-mineralization of re-suspended organic material would provide a further sink for oxygen. Environmental Evaluation Unit (1996) estimate that lowered oxygen impacts due to the benthic plume could potentially extend for several km during continuous diamond mining, although they point out that the severity and resultant ecosystem implications are difficult to predict.

The fines overspill released from the surface vessel will equally contain an elevated organic matter load, originating from the dredged sediments and from destroyed benthic fauna that is sucked up by the dredge (Newell et al. 1999). The decomposition of this organic load will increase oxygen demand, potentially decreasing oxygen concentrations within the water column and on the sediment surfaces where it settles. Over prolonged time-periods, this continual enrichment could lead to reduced oxygen concentrations below the thermocline and might aggravate naturally-occurring bottom-water hypoxia. Penney et al. (2007) cite a study by CSIR (2006) that did not find significantly lowered oxygen concentrations within surveyed
sediment plumes in the Atlantic 1 Mining Licence Area offshore of southern Namibia, and argue that organic enrichment from the overspill of diamond mining vessels is likely negligible compared to the scale of natural organic loads and bottom-water hypoxia in such highly productive regions. Environmental Evaluation Unit (1996) estimate that the high sediment load releases from diamond mining vessels would have a low intensity impact on a spatial scale of about five km$^2$. The volume, persistence (over time) and relative concentration of organic enrichment in the discarded fines/water, compared to background particulate organic matter loads should be carefully considered before this impact is considered negligible to the surrounding ecosystem.

High inorganic nutrient loads from sediments and bottom water will be released near the surface in the fines overspill. The current designs of TSHDs release these at a depth of 10-15 m, which would typically be within the surface mixed layer in offshore Benguela waters (Shannon 1985). The high nutrient loads could provide a point source of eutrophication, fuelling elevated phytoplankton blooms and microbial productivity downstream of the mining vessel. The severity of this impact will depend on the volume of waters released and the scale of mixing within surface waters before the more-dense bottom water sinks down to a level of neutral buoyancy (Environmental Evaluation Unit 1996). Within the productive upwelled waters of the Benguela, this point source of eutrophication is likely to have little impact on surrounding ecosystems. In nutrient-impoverished offshore waters, the ecosystem impact of eutrophication might be more significant.

**Re-suspension of Metals**

Early studies suggested that Benguela shelf sediments could be associated with harmful concentrations of heavy metals (Calvert and Price 1970, Chapman and Shannon 1985) and elevated levels of several metals have been found in sediment samples from the Atlantic 1 Mining area in southern Namibia (Environmental Evaluation Unit 1996, CSIR 2006). Metal uptake by marine organisms can take place by direct absorption or via food intake and the effects may include acute toxicity from short-term elevated exposures, or via long-term bioaccumulation (Penney et al. 2007). Investigating the concentrations of trace elements and pesticides in sediments and overspill plumes in the Atlantic 1 Mining area, Environmental Evaluation Unit (1996) estimated that in some areas, plume concentrations of cadmium (Cd), chromium (Cr), copper (Cu), and zinc (Zn) could exceed the maximum concentrations recommended for the coastal zone by (Lusher 1984). Penney et al. (2007) argue that the dilution by surrounding waters, scale of the transient diamond mining activities and dynamic nature of plumes would make chemical contamination of the ecosystem unlikely. Considering the larger scale and greater persistence at a site of foreseen phosphate mining operations (Coles et al. 2002, NMP 2012), together with the potential threat of bio-magnification leading to contamination of fishery resources, site-specific investigations of trace metal concentrations and other contaminants should be investigated prior to bulk mining activity. If the sediments are found to contain elevated levels of toxic contaminants, a detailed study should assess the severity, scale and bio-availability of the re-suspended contaminants in benthic plumes and the fines overspill.
**Impacts on Benthic Organisms**

*Physical Destruction of Benthic Organisms and Habitat*

From the scale of the heavy machinery involved, the violence of a mechanical 'cutter' and the depth of sediment removal (on the order of 0.5 m), it is clear that bulk dredging will result in effective destruction and removal of the benthic ecosystem from within a mined area (Desprez et al. 2000, Penney et al. 2007). Having reviewed the literature, Penney et al. (2007) conclude that the recovery time of sea bed communities increases with depth and provide a schematic indicating that areas at 200 m depth can take roughly 20 years to reach a 'recovered' state. Their definition of a 'recovered state', however, does not necessarily imply a community statistically similar to pre-disturbance, but one which has reached a mature 'equilibrium' with similar biomass and diversity indices. Whether such a 'recovered', but altered, community would provide the same ecosystem functions as the original assemblage, is very hard to assess.

The removal of benthic habitat has implications for the surrounding ecosystem beyond the destruction of benthic (and slow-moving demersal) organisms from the dredged area. The physical structure created by organisms such as sponges, gorgonians and deep water corals, as well as the food source provided by the benthic community, play an essential role in various life-stages of demersal fish and macro-invertebrates (Auster et al. 1997, Rogers et al. 2008, Baillon et al. 2012, Baker et al. 2012). The animals which were directly dependent on the destroyed habitat will perish, unless they are able to relocate into similar habitat nearby that is able to absorb their abundances (i.e. is below carrying capacity).

*Changes in Benthic Substrate/Sediment Size*

The physical sediment composition is an important determinant of the biological assemblage that inhabits it (Hall 1994, Rees et al. 1999, Schratzberger et al. 2004). If the remaining sediment is identical to that which was removed, community composition and structure should have the potential to recover to match non-dredged reference areas (e.g. Simonini et al. 2007). Frequently however, the depth or particle size of remaining sediment is different from the pre-disturbed sea floor and the benthic community that re-establishes afterwards is therefore different to that which occurred prior to dredging (Parkins and Field 1998, Boyd et al. 2003, Penney et al. 2007). Sediments surrounding the dredged area can also be altered by settling fines, tailings and benthic plumes, thereby driving a different community structure once dredging ceases and the fauna recover (Boyd and Rees 2003). In the Atlantic 1 Mining Licence Area in southern Namibia, Parkins and Field (1998) attributed differences in the sediment composition and its organic content as the drivers of observed differences in community assemblages between mined and un-mined sites.

Local hydrodynamics and sediment particle size play a large role in the recovery potential of dredged areas (Boyd et al. 2005), making it difficult to provide blanket estimates of recovery rates. In areas that are naturally subjected to high deposition rates or high energy environments, the recovery of soft sediments towards a pre-disturbed state is relatively rapid (Rees et al. 1999, Boyd et al. 2005). Penney et al. (2007) point out that benthic communities dredged in the Atlantic 1 Mining Licence Area were significantly...
different to un-dredged areas 9-10 years after dredging stopped, whereas sites further south, perhaps because they were subject to higher deposition rates from the Orange river, had developed benthic communities similar to un-mined sites within 5-6 years. Boyd et al. (2005) show that sites dredged in a depth of 22 m and in a 'moderate' energy environment had communities that were significantly different from non-dredged reference sites after six years of recovery and conclude that re-establishment of benthic assemblages in low-energy environments would likely take many years, possibly decades. The depth/location of the GFT licence areas precludes substantial wave influence or river depositional input and strong currents are not common at these greater depths.

Considering that remaining sediments will frequently have a different structure to their pre-disturbed state (Parkins and Field 1998, Boyd et al. 2003, Penney et al. 2007), habitat and resultant ecosystem changes in such mined areas could be considered permanent, as recovery to pre-disturbed sediment structures (and hence similar habitat) would occur on geological time scales. If the local hydrodynamics and/or source of those sediments has changed since they were formed, they may never recover to the pre-disturbed physical structure (and hence ecological assemblage). This argument would be especially relevant to consolidated or hard grounds if they were to be mined, unless the remaining post-mined sea floor were to provide the same physical structure than in its pre-mined state.

**Burial and Smothering**

There are two different mechanisms by which surrounding (non-dredged) habitats could be impacted by burial and smothering disturbance. Disturbance of sediments that are not sucked up by the dredge will create a benthic mining plume, causing a certain amount of burial and smothering adjacent to the dredged trenches/lanes. The spatial scale of such affected areas would partly depend on the dredging method (apparatus) and the dredging pattern, besides the local hydrodynamics and sediment characteristics (Boyd and Rees 2003). Environmental Evaluation Unit (1996) assumed a surrounding area equal to the dredged area in their estimates of benthic communities impacted by the benthic plume.

The second mechanism would be a result of the fines plume released at or near the surface. There are many variables which potentially affect the intensity and the geographical scale of such an impact, including the grain size and density of fines released, water depth, and the vertical water structure and currents (at different depths). Relatively intricate and site-specific ocean circulation models would have to be employed to gain a realistic estimate of the intensity and extent of the fines plume and its settling rate on the benthos. Studying plumes from deep water diamond mining vessels off Namibia, Carter and Midgley (2000) showed that plume lengths varied between 700 – 5 500 m, with widths of 700 – 3 500 m and that average sediment concentrations neared background levels about 2 000 m downstream from the vessel. Penney et al. (2007) rate the impact of diamond mining tailings deposition on benthic organisms as a regional-scale effect of high environmental significance, especially in deep water habitats that are not naturally subject to high sedimentation rates. The proportion of discarded sediments in phosphate (or other bulk) mining operations
may be lower than that for diamond mining, as the latter is likely more selective of sediment size. However the overall scale and temporal persistence of dredging activity is likely to be greater for the bulk mining operations (Coles et al. 2002). Investigating the impacts of marine aggregate extraction on the south coast of the UK, where no on-board screening takes place and release of fines is minimal, Boyd and Rees (2003) showed a gradient in macrofaunal community composition with increasing distance (beyond 2 km) from the point of dredging activity.

**Increased Organic Fallout**

Both the benthic plume and the fines plume will likely be enriched in organic particles from disturbed or dredged sediments respectively, which could provide an increased food source for organisms that filter these particles from the water-column (Boyd et al. 2000, Boyd and Rees 2003). The population or community impacts within the water-column would likely be negligible, as the majority of filter feeders are planktonic and would be surrounded by the heightened food concentrations only briefly before it is diluted by surrounding waters downstream. However benthic filter feeders could gain increased amounts of settling particulate organic matter (POM) in the area surrounding the mining operation. Boyd and Rees (2003) did find increased densities of filter-feeders between 500 and 1000 m from a site of intense dredging. If the same deposit is mined consistently for a period of months to years, a persistent enrichment of settling POM might alter the benthic community composition.

**Biogeochemical Impacts**

The biogeochemical impacts for benthic organisms will consist mainly of the reduced oxygen levels in surface sediments and bottom waters, as outlined in the 'Impacts on Demersal and Pelagic Organisms' section, hence their description is not repeated here.

**Microbial Impacts**

Microbial life, including bacteria, fungi and viruses, plays a dominant role in the regulation of biogeochemical cycles throughout the biosphere, including the deep ocean (e.g. Raghukumar et al. 2001, Brüchert et al. 2003, Damare et al. 2006, Danovaro et al. 2008). It is unknown how the microbial communities will recover and what the implications are to the broader ecosystem of their removal or disruption in mined areas. This question requires urgent attention in future field and impact studies.

**Spatial Considerations of Habitat, Conservation Priority and Fisheries**

To provide a brief synopsis of the geographical context of the potential impacts discussed above, the GFT prospecting licence areas have been overlaid onto maps of benthic habitats, conservation focus areas and fishery footprints.

The GFT prospecting licence areas cover 26 recognized benthic habitat types, which fall within several broader ecozones (Sink et al. 2011b). Some of these habitats fall predominantly within or are restricted entirely to within the licence area and exist nowhere else. Several of these habitat types are rocky or
consolidated habitat types that may support fragile three-dimensional habitats such as reef-building cold water corals (Rogers et al. 2008, FAO 2009). Such habitat types are considered especially sensitive to activities that impact the seabed (Rogers et al. 2008).

Figure 1. Map indicating benthic habitat types (Sink et al. 2011b) occurring within the GFT 251 and 257 prospecting licence areas.

The potential threat to unique habitat types within these licence areas, is perhaps better illustrated by Figure 2, where the habitat types, together with existing anthropogenic pressures and biodiversity thresholds were used to calculate the ecosystem threat status of benthic habitats (see Sink et al. 2011b). A notable concentration of vulnerable and critically endangered benthic ecosystems are clustered on the edge of the shelf, between the 200 and 500 m isobath. The priority focus areas for prospecting, as identified by GFT (Green Flash Trading 2012a, 2012b) and illustrated by positions of their proposed drill sites (Figure 3), coincide with much of these same threatened ecosystem areas.
Figure 2. Map illustrating the ecosystem threat status for benthic habitats (Sink et al. 2011a), overlaid by the GFT 251 and 257 prospecting licence areas.

Figure 3 shows that the great majority of benthic habitats within the prospecting licence areas are without protection in current marine protected area networks. Figure 3 also illustrates that the licence areas overlay significant parts of identified priority regions for offshore conservation and spatial management (Sink et al. 2011a, 2011b) and overlaps with a section of the Table Mountain National Park Marine Protected Area. The offshore focus areas affected are Child's Bank, Cape Canyon, Brown's Bank and Agulhas Bank.

To illustrate the spatial coincidence between the GFT prospecting licence areas and a major South African fishery sector, Figure 4 overlays the area ring-fenced from commercial trawl effort data collected from the 1970s to 2007 (Wilkinson and Japp 2008) with the licence areas. The licence area overlays a large proportion of the South African offshore trawl footprint and proposed focus prospecting areas (as illustrated by drill sites) coincide to a large degree with fishery areas. Multiple other fishery sectors not shown here similarly use areas within the prospecting licence areas (see e.g. Sink et al. 2011b). Thus understanding the impact of proposed mining activity on local ecosystems and their fish resources will be critical to avoid conflict between launching mining operations and established fishing industries.
Figure 3. Map illustrating current marine protected areas, focus areas for offshore conservation (Sink et al. 2011a) and the level of protection currently afforded benthic habitats (Driver et al. 2012), overlaid by the GFT 251 and 257 prospecting licence areas.

Figure 4. Map indicating the ring-fenced commercial trawl areas (Wilkinson and Japp 2008), overlaid by the GFT 251 and 257 prospecting licence areas.
Conclusions and Recommendations

Drawing on the literature discussed above, bulk sediment mining of the deep sea floor in the GFT prospecting licence areas 251 and 257 will have severe impacts on the benthic habitats that are dredged. Benthic and demersal organisms in adjacent areas will suffer direct and knock-on effects, the extent, intensity and duration of which will depend on many factors related to the mining strategy and site-specific sediment, biogeochemical and ecosystem properties. While pelagic waters will be affected locally, dilution with downstream waters will likely reduce the direct ecological impact to a large degree. The most likely identified impacts of foreseen mining methods in these deep ecosystems are briefly touched on above. Whether there are synergistic effects, what the cumulative and knock-on effects might be, and the overall implications to biodiversity, ecosystem functioning and fishery resources, will require far more attention. In-depth and site-specific studies with detailed input on the mining methods and tools, resource target, local geology, oceanography, biogeochemistry, ecosystems and life-cycles of fishery resources, will be required to estimate the ecological and economic impacts from specific mining projects. Certain of these impacts could be partly mitigated, although the destruction, and in many instances, permanent alteration of sea floor habitat seems inevitable with dredging of deep sea environments.

The implications of such mining activities for biodiversity conservation will depend to a large degree on the extent of the habitat type in question. Certain unique habitats are extremely restricted in their spatial extent and may already be threatened by other ocean uses. A bulk sediment mining operation in or near such a habitat could provide a real threat to its survival. Other benthic habitats may be more ubiquitous and widespread and hence mining in such habitats might threaten only a small fraction of the total area covered by similar assemblages of species. It is imperative to carefully consider the location of mining relative to threatened ecosystems and priority conservation targets. As the mining can result in a permanently altered community, conservation of unique habitat types and their assemblage of biodiversity is not compatible with bulk sediment mining of the same area.

Due to extraction of a renewable resource, fisheries are by their nature sustainable if managed correctly. Mining of valuable minerals or other geological materials is generally not sustainable, as the formation rate of target minerals (and surrounding disturbed sediments) is far outpaced by the rate of resource extraction. South Africa is a signatory to the Reykjavik Declaration, prescribing an Ecosystem Approach to Fisheries management, which requires the holistic approach of maintaining a healthy ecosystem in support of managing fishery resources sustainably. The damage to benthic habitats and surrounding ecosystems has the potential to impact on fishery resources, hence the location of proposed mining activity should be assessed with careful consideration of existing fishery footprints, as well as habitats or ecosystems that are critical to various life-stages of the fishery species. Baillon et al. (2012) have recently showed close association between the larvae of commercially harvested redfish (*Sebastes* spp) and cold-water corals in the north Atlantic. Such relationships, many of which are yet to be discovered, are the reason researchers and fishery
managers support the ecosystem approach to fisheries.

If bulk mining of the sea floor is to be considered, the financial gains and job creation for local communities need to be weighed up against the economic, social and ethical implications of permanent alteration of mined habitats, loss of biodiversity, and potential ecological knock-on effects and disturbance to fishery resources. There is growing recognition globally that the loss of ecosystem services and costs to future resource users need to be taken into consideration, and compensated by the proponents, prior to development of industries that impact on the 'natural capital' of biodiversity and ecosystems (Costanza et al. 1997, Turner et al. 2001, Sukhdev 2011).

References


Green Flash Trading. 2012b. Environmental Management Plan in the ocean off Adam Se Baai and the area to the south towards Table Bay, Western Cape Province. Green Flash Trading 251 (Pty) Ltd.


Heemstra PC. 1994. Assessment of deep-sea mining effects in the fish fauna off the south coast of Namibia and west coast of South Africa from Lüderitz, Namibia to the mouth of the Olifants River at depths of 85 to 200 metres, *Report by the J. L. B. Smith Institutes of Ichthyology*.


Assessment of Cumulative Effects of Marine Diamond Mining Activities on the BCLME Region. Project: BEHP/CEA/03/02. Final Report to the BCLME mining and petroleum activities task group.


