APPENDIX 1D

NAMIBIAN MARINE PHOSPHATE (PTY) LTD

JELLYFISH

Sandpiper Project

Proposed recovery of phosphate enriched sediments from the Marine Mining Licence Area No.170 off Walvis Bay Namibia.

Environmental Impact Assessment Report for the Marine Component

Prepared by:
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In association with:
Enviro Dynamics
The CSIR

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ENVIRO DYNAMICS

March 2012

Prof. M Gibbons: Jellyfish

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SPECIALIST STUDY NO. 1D:

Specialist Study of Jellyfish in the environs of the proposed dredging of Phosphate Deposits in the Sandpiper Phosphate Mining Licence Area off the coast of Central Namibia

Project:

The Dredging of marine phosphate enriched sediments from Mining Licence Area No. 170

Date:

March 2012

Namibian Marine Phosphate (Pty) Ltd.

Declaration:

I, *Professor Mark J. Gibbons* of the University of the Western Cape, do not have and will not have any vested interest (either business, financial, personal or other) in the proposed activity proceeding other than remuneration for work performed in terms of the South African Environmental Impact Assessment Regulations, 2010

summary

Two species of large jellyfish are common off Namibia, *Chrysaora fulgida* (Scyphozoa) and *Aequorea forskalea* (Hydrozoa), both of which have metagenic life-cycles (an alteration between a small, benthic polyp phase that reproduces asexually to produce new medusae, and a large, free-swimming medusa phase, responsible for sexual reproduction and the eventual generation of polyps). Our understanding of the polyp-phase is non-existent, whilst our knowledge of the medusae is poor.

Jellyfish are members of the plankton, and as such their distribution in space and time reflects, to a large degree, the physical milieu. The biomass of these medusae is currently estimated to exceed that of fin-fish in the region. Medusae can be found along the coastline but are most common in the central area, inshore of the 200 m isobath. Whilst they occur throughout the water column, most of the biomass is concentrated in the upper 50 m: there is no clear evidence that populations display diel vertical migration. They are to be found throughout the year, but appear to peak in abundance during late winter/early spring. In other words, jellyfish occur at highest abundance in the same place and at the same time as many commercial fishes spawn, and are likely therefore to be having an indirect (as well as a direct, operational) impact on commercial fisheries.

There is strong, if circumstantial, evidence to suggest that the biomass of jellyfish has increased since the collapse of the pelagic fisheries off Namibia at the end of the 1960s and early 1970s. This is likely to reflect the formerly efficient predation by fish on newly released, and juvenile, medusae, as well as to changes in the fish populations that might feed on the polyps. In the absence of this predation pressure, jellyfish populations have increased, to the point that they can now control fish recruitment through their voracious predation on fish eggs and larvae. Although large medusae have few direct predators (sunfish and turtles), they are not the trophic-dead ends previously considered, and they form a significant part of the diet of the bearded goby (*Sufflogobius bibarbatus*) – which in turn are important fodder for hake (*Merluccius* spp), horse-mackerel (*Trachurus trachurus capensis*) and assorted other higher predators.

Jellyfish do not occur commonly at depth thus there should be few problems of clogging at the drag-head. However, at the surface, where water will be drawn into the vessel for cooling (etc), they could cause a large problem for vessel activities. There are no “off-the-shelf” solutions to this and engineers will need to draw up their own strategies of dealing with the problem: indeed, the anti-jellyfish measures that have been devised elsewhere in the world have all been drawn-up for shallow operations. Large jellyfish aggregations, sub-surface, can be detected using multi-frequency hydro-acoustic techniques (surface swarms should be detectable from the bridge) and so an early warning system could be developed but these would again need to be tailored to the vessel’s operational specifications.

Jellyfish have no special tolerance of hydrogen sulphide and are likely to be killed if exposed to it for prolonged periods of time. They do, however, have a remarkable tolerance to low concentrations of dissolved oxygen (as medusae and polyps) and thus are likely to survive short periods of exposure to hypoxic waters.

Because there are so many unknowns regarding jellyfish off Namibia (and elsewhere for that matter), any information that can be collected would be useful from a scientific point of view, and a number of suggestions in this regard are made (see Section 6.2).

glossary of terms and abbreviations

Benthic – bottom-living
Congenerics – species from the same genus
Diel vertical migration (DVM) – movement up and down in the water column from depth to the surface and back again, on a daily basis.
Ephyra (ephyrae, pl) – early stage medusa
Medusa (medusae, pl) – adult, free-swimming jellyfish
Meroplankton – temporary member of the plankton
Metagenic – alteration between a benthic (polyp) and pelagic (jellyfish) life history phase
Pelagic – in the water column
Plankton – organisms (animals, zooplankton; "plants", phytoplankton) drifting in the water and lacking an ability to move against horizontal water flow
Polyp – sessile, attached life-history phase, resembling a sea-anemone
Strobilation – process of asexual reproduction whereby a scyphozoan polyp buds off ephyrae

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1 INTRODUCTION

Detailed descriptions of the regional bathymetry, geology, and oceanographic and physical processes as well as the benthic invertebrate and demersal and pelagic fish communities off the central Namibian coast are presented in the EIA report and/or other specialist studies. Here we provide a brief overview of the distribution, ecology and biology of the dominant species of jellyfish that are likely to occur in the mining license area, we discuss changes in abundance and the role that they play within the wider ecosystem and we comment on the likely impacts of mining activities on same.

2 DESCRIPTION OF THE ENVIRONMENT

2.1 NAMIBIAN JELLYFISH

The primary species of jellyfish considered here are *Aequorea forskalea* Péron & Lesueur 1810 and *Chrysaora fulgida* (Reynaud, 1830) (Figure 1), which belong to the medusozoan classes Hydrozoa and Scyphozoa, respectively. Although more than 85 species of planktic Hydrozoa (Gibbons *et al*., 2010) and less than 10 species of Scyphozoa (http://sajellywatch.uwc.ac.za) have been reported off Namibia, it is these two aforementioned taxa that attain greatest biomass in the region (Lynam *et al*., 2006), and which likely play the most important ecological role within the system.

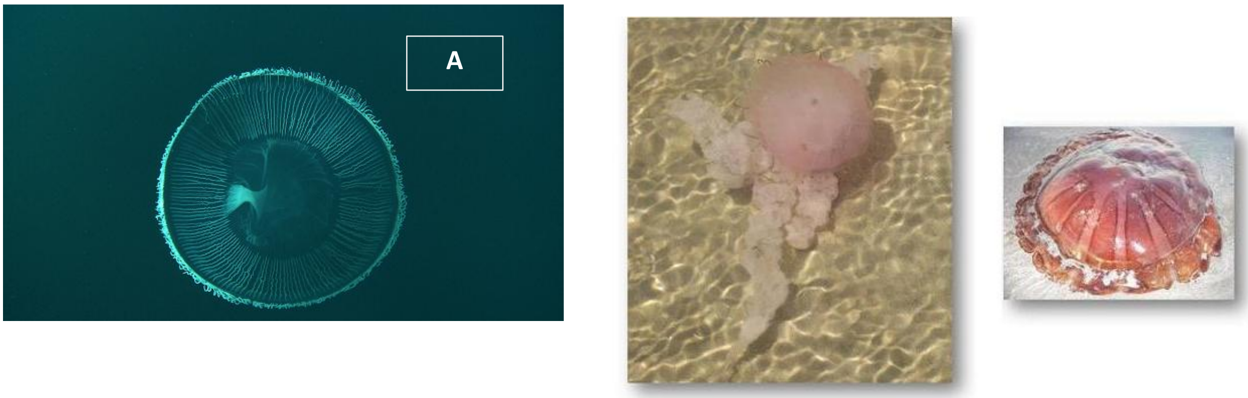
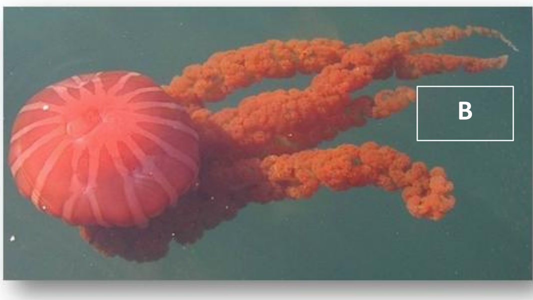


Figure 1: The two common species of jellyfish encountered off Namibia.

A) Aequorea forskalea (above) and
B) *Chrysaora fulgida*
(from http://sajellywatch.uwc.ac.za)



Although the two species belong to different classes of Cnidaria, they both have metagenic life-histories (Figure 2). That is, there is an alteration of generations between a large, conspicuous and pelagic medusa phase that is responsible for sexual reproduction and dispersal, and a minute, cryptic and benthic polyp phase that produces new medusae by asexual reproduction. Our understanding of the biology and ecology of the adult medusa locally (and elsewhere, for that matter) is generally weak, but our knowledge of the "juvenile" polyp is non-existent, though we do understand them to prefer hard substrata (rocks, harbour pilings etc).

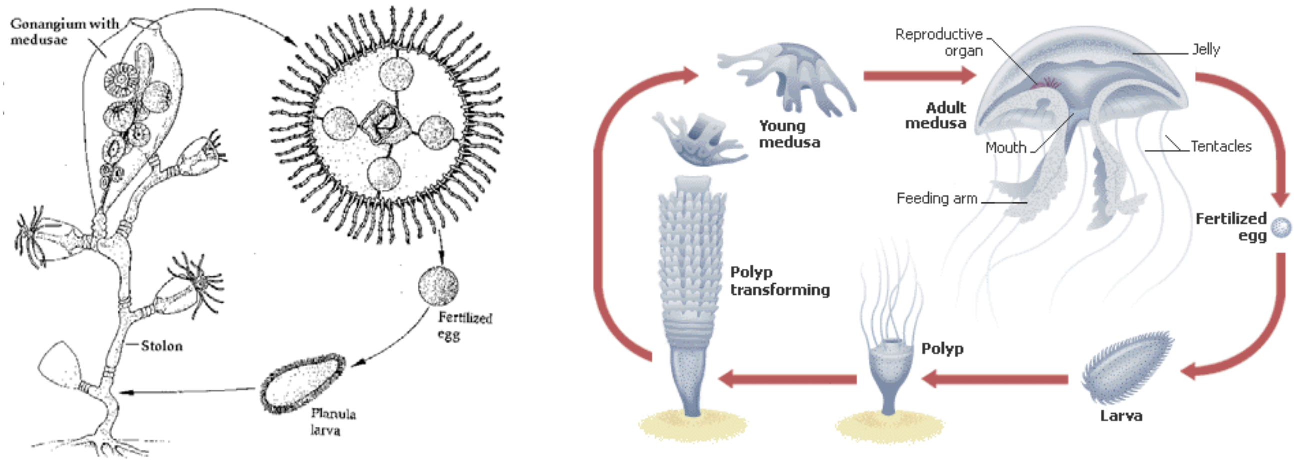


Figure 2: ***Life cycle of Hydrozoan (left hand panel) and Sycphozoan (right hand panel), showing the alteration of life history phases. Taken from: http://9e.devbio.com/preview_article.php?ch=2&id=6 (Hydrozoa), http://sharon-taxonomy2009-p3.wikispaces.com/Cnidaria (Scyphozoa).***

2.2 THE DISTRIBUTION OF NAMIBIAN JELLYFISH IN SPACE AND TIME

Before summarizing what we know about the temporal and spatial patterns of jellyfish distribution off Namibia, it is important to remember that jellyfish are members of the plankton. Indeed, they are the largest members of the plankton. That means jellyfish lack the ability to move horizontally against prevailing water flows, though they can (and do), move vertically in the water column. This latter ability allows jellyfish to take advantage of depth-linked water flows, which gives them a measure of control over their horizontal position. Just like other plankton, therefore, jellyfish tend to have a patchy distribution that is influenced by a suite of physical and (perhaps to a lesser extent) biological factors. They can be common in embayments and at physical discontinuities, and can be concentrated by features such as fronts and Langmuir circulation cells (Graham *et al*., 2001).

Owing to the general problems associated with estimating jellyfish abundance (they are more than 96% water), information on exactly how many jellyfish there are off Namibia is strictly limited. Computer models of energy flow within the northern Benguela indicate that jellyfish biomass may be ~ 5 million tonnes (Shannon and Jarre-Teichmann, 1999), which is in broad agreement with the conclusions reached by Sparks *et al*. (2001) from trawl estimates. More recent estimates derived using multi-beam hydroacoustics from a synoptic survey of the entire Namibian shelf indicate, however, that there may be as much as 12 million tonnes of jellyfish (or at least, there were during spring 2003 when the survey was conducted: Lynam *et al*., 2006). This biomass exceeded that of all fishes at the time by a factor of 4!

The medusae of both species can be found along the length of the Namibian shelf (Figure 3), which suggests that the benthic polyps of both species can be found on appropriate substrata along the coast (Flynn *et al*., in press). In the case of *Chrysaora fulgida*, this is certainly in accordance with personal observations, as ephyrae have been recovered in nearshore plankton samples from the two locations we have investigated to date (Lüderitz and Swakopmund), and they have been observed by others off northern Namibia (Pagès and Gili, 1992). Whilst animals can be found along the entire coast, they appear to be encountered most frequently between 20-24 °S (Flynn *et al*., in press). In other words, they are most common off central Namibia. This is in the same general area as the greatest zooplankton biomass occurs (Olivar and Barange, 1990) and reflects the topographic and hydrographic features of the area (Shannon and Pillar, 1986; Barange and Boyd, 1992)).

Both species occur across the width of the shelf, but tend to be more common at depths less than 200 m (Flynn *et al*., in press). This is again no surprise owing to their meroplanktic nature and agrees with observations on the distribution of con-generics elsewhere in the world (e.g. Brodeur *et al.*, 2002; Suchman and Brodeur, 2005; Il'inskii and Zavolokin, 2007). There is some evidence to suggest that the two species have different centres of cross-shelf distribution, with *Chrysaora fulgida* being found inshore of *Aequorea forskalea* (Brierley *et al*., 2001; Sparks *et al*., 2001), although the reasons for this are unknown, as are the mechanisms by which it is achieved and maintained.

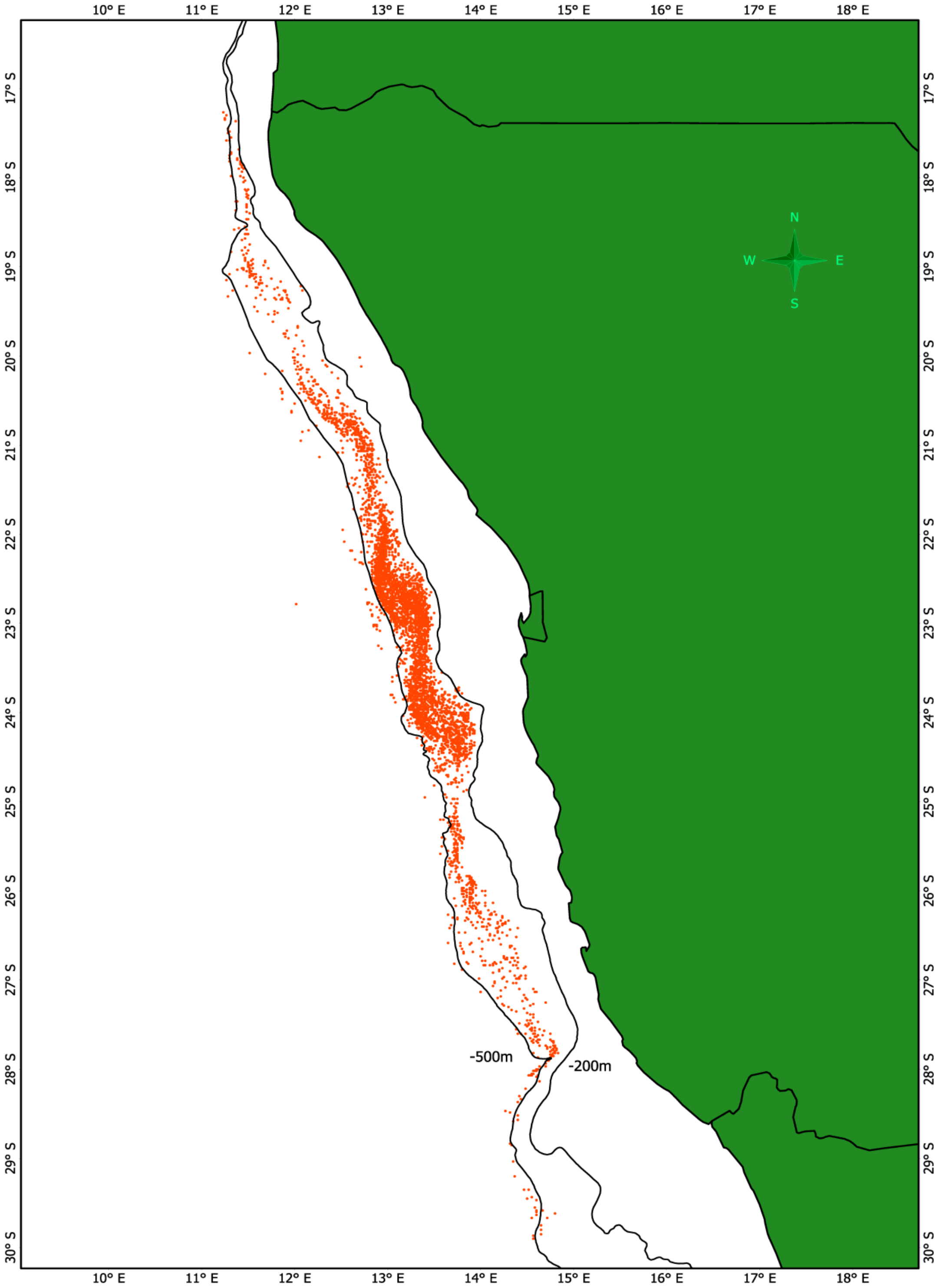


***Figure 3:** Distribution of jellyfish (both species combined) off Namibia, as positive catches from fishery-dependent, demersal trawls (1997-2006, > 200 m only).*

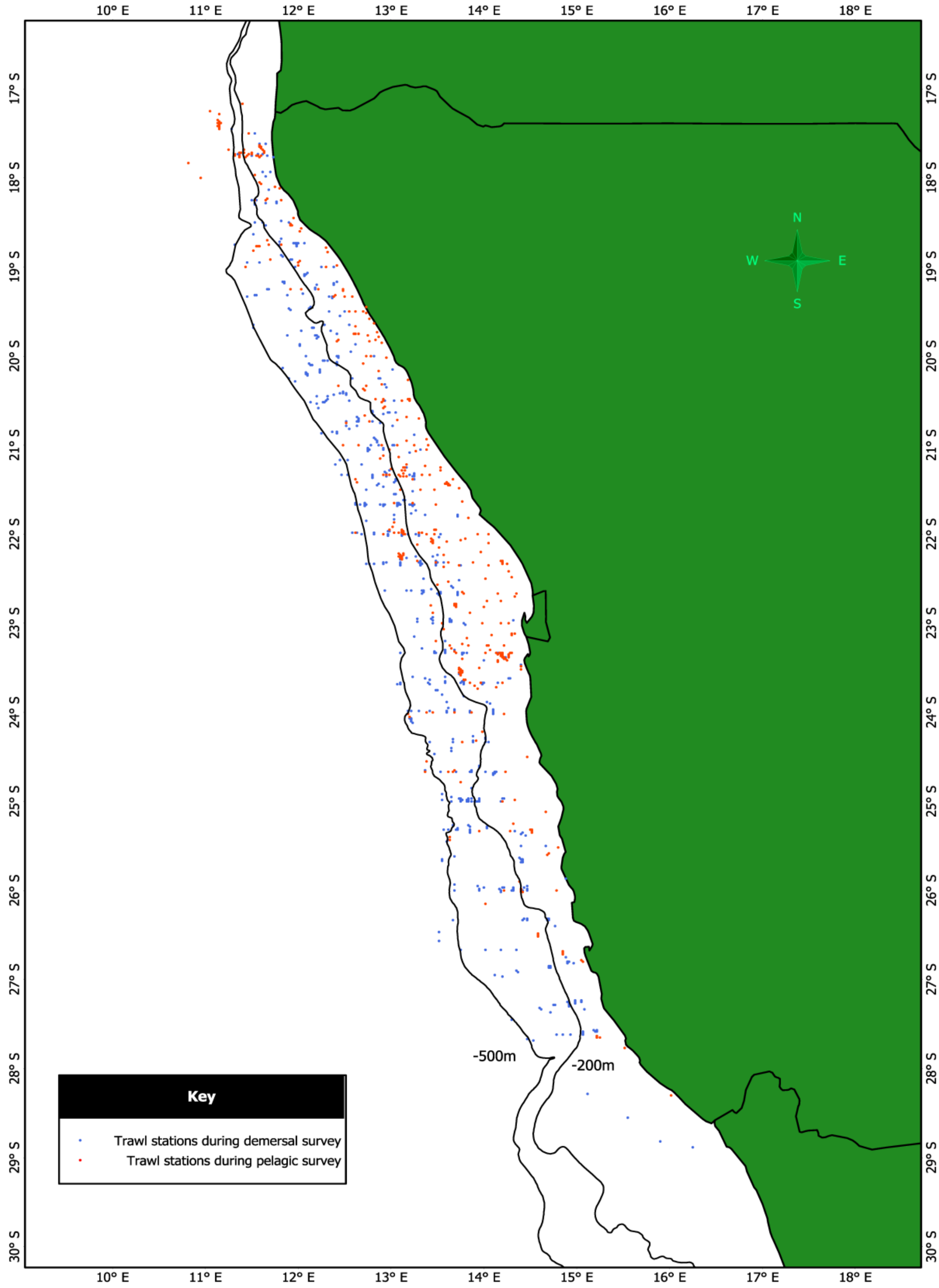


Figure 4: ***Distribution of jellyfish (both species combined) off Nambia as fishery-independent samples collected using both demersal and pelagic nets by the RV Dr Fridtjof Nansen (1990-2006).***

Both species are found throughout the water column, though more than 80% of their biomass appears to be located in the upper 50 m (Flynn *et al*., in press). The evidence to suggest that either species displays clear diel vertical migration (DVM) is missing (but see Brierley *et al*., 2001; Sparks *et al*., 2001), which is perhaps no surprise given the absence of any abundant visual predators (e.g. sunfish and turtles), and the fact that that their zooplankton prey similarly fail to display pronounced DVM (Olivar and Barange, 1990) and are also largely concentrated in the upper water layers.

Jellyfish are present in the waters off Namibia throughout the year (Flynn *et al*., in press), a fact that likely reflects the near persistent nature of upwelling throughout much of the year – or rather, the lack of any clear seasonal signal to upwelling. Whilst the cues responsible for medusa release by polyps of *Aequorea* are unknown, work elsewhere indicates that strobilation in scyphozoan polyps is cued by a drop in temperature (Arai, 1997; di Camillio *et al*., 2010), though light, salinity and food can also be important. Our work on strobilation by *Chrysaora fulgida* is at an early stage, but it already suggests that the release of ephyrae by polyps takes place when ambient water temperature drops to ~14 °C. That means that new medusa are likely added to the population on an ongoing basis, from somewhere along the Namibian coast, and these are then distributed across the shelf by local circulation. Individual *A. forskalea* may grow to a diameter of 12 cm (central disk width), whilst medusae of *C. fulgida* can attain a size in excess of 80 cm diameter (> 20 kg mass). The growth rates of local species are unknown, but elsewhere they are thought to be rapid when individuals are small, and to decline with increasing size: Palaomares and Pauly (2009) have suggested that species of *Chrysaora* may have growth rates similar to those of small pelagic fishes.

But the abundance of jellyfish is not only dependent on additions to the population, but also on losses through mortality. Unambiguous information on what causes the latter is missing, and it probably varies with environment. In temperate systems it can be a result of senescence following reproduction (Arai, 1997) as well as mortality following a change in temperature/salinity to above/below lethal limits (Sexton *et al*., 2010). Otherwise the declining pulsation rates associated with (for example) a decrease in temperature could mean that individuals sink (Sexton *et al*., 2010) and are then more prone to starvation, disease, parasitism and predation, as well as physical processes of removal such as advection (Albert, 2005). What is clear, however, is that under the right conditions, large jellyfish can survive for a relatively long period of time. Albert (2005) has indicated that up to 40% of the *Aurelia labiata* population in Roscoe Bay (Canada) may live to >2 years of age, and *Chrysaora fulgida* can survive for >20 months in the laboratory (MJG unpublished data). This longevity provides a buffer to population fluctuations and complicates unambiguous interpretation of the data, particularly so if Gröndahl (1988) and Brewer and Feingold (1991) are correct, that the mortality of planulae/polyps is more important in influencing the medusa population size than is the mortality of ephyrae/medusa.

2.3 CHANGES IN THE ABUNDANCE OF NAMIBIAN JELLYFISH

We need to understand that there is no direct evidence suggesting that there has been an increase in jellyfish biomass off Namibia over the past 40-odd years, and the subject is a matter of some debate. For example, Mills (2001) has suggested that the routine, undocumented exclusion of jellyfish from historic plankton samples has resulted in an erroneous interpretation of recent data. While on the one hand this is not an unreasonable suggestion, it is not supported by the facts. Unterüberbacher (1964), who was one of the first scientists to study zooplankton in the Benguela system in a quantitative way, clearly notes that "salps, fish larvae and eggs, big ctenophores and medusa" were removed from samples before analysis. He goes on, however, and notes that "in some samples the salps occurred in such vast quantities…." but he makes no further reference to medusa – suggesting that they were not common at that time.

A large number of plankton samples were collected and examined for pelagic cnidarians off the SW coast of Africa prior to the mid-1900s, including those from the *Dana* (Kramp, 1959), *Discovery I* and *II*, *William Scoresby* (Kramp, 1957), Deutschen Südpolar (Vanhöffen, 1908, 1912; Moser, 1925), Deutschen Tiefsee (*Valdivia*, Vanhöffen, 1902a,b, 1911) and *Meteor* (Leloup, 1934) expeditions. While numerous (small and large) pelagic cnidarians were described from all the collections, neither *Aequorea forskalea* nor *Chrysaora fulgida* were recorded at that time. Indeed, they were only described from the region during the mid-late 20th Century: *A. forskalea* was first officially recorded off Namibia during the *Discovery* Expeditions in the 1950s (Kramp, 1957) and *C. fulgida* (as *C. hysoscella*) was first formally described from the region during the 1990s (Pagès *et al*., 1992). Large jellyfish have undoubtedly always been found off Namibia, and the species in question are indigenous, but if the jellyfish were a "problem" (i.e. occurring at such abundances to have a noticeable impact on fishing or recreation) then they would inevitably have been reported. That it was not further indicates that large jellyfish were "relatively" uncommon prior to the 1970s. From the mid-1970s onwards, however, high concentrations of large jellyfish became routinely apparent off Namibia (King and O'Toole, 1973; Cram and Visser, 1973; Venter, 1988; Fearon *et al*., 1992).

The early 1970s are significant, because they mark the time when pelagic fish populations crashed off Namibia. The shelf waters off Namibia are subject to coastal upwelling, and pelagic fish communities were dominated by sardine (*Sardinops sagax*) and (to a lesser extent) anchovy (*Engraulis encrasicolis*) prior to the mid 1970s. These small pelagic fish are considered wasp-waist species (Cury *et al.* 2000) that use the high primary production relatively efficiently, and they were the subject of industrial fisheries that date back to the mid-20th century (Boyer *et al.*, 2000). Annual sardine catches were around 200 000 tonnes for much of the 1950s, then increased throughout the 1960s to more than 1.5 million tonnes in 1968 after good recruitment in the late 1950s and early 1960s (reviewed by Cury and Shannon, 2004). Following heavy targeted fishing throughout the 1960s, sardine stocks suffered several crashes (Heymans *et al.*, 2004), from which they have failed to recover for a variety of possible reasons (Boyer *et al*. 2001, Boyer and Hampton 2001, Bakun and Weeks, 2006). Interestingly, and unlike many other coastal upwelling systems (see Bakun and Weeks, 2008), there has been no classical regime shift off Namibia (Cury *et al.,* 2000; Cury and Shannon, 2004). This is perhaps in part because the system has always been considered a sardine-dominated one even in pre-industrial times (Shackleton, 1987; Rau, 1988) and in part because anchovy, the possible replacement species, was also subject to heavy exploitation (Butterworth 1983). Instead, a number of opportunistic species (including horse mackerel *Trachurus trachurus capensis*, jellyfish and bearded goby *Sufflogobius bibarbatus*) have replaced the dominant group (Cury and Shannon, 2004).

The suggestion that jellyfish have increased after the collapse of the large sardine fishery is not new, as Venter (1988) had noted that the abundance and distribution of jellyfish had increased "…after the dramatic decrease in pelagic fishing in 1972…" and that, by the latter half of the 1980s they had "…become an increasingly irritating nuisance…" to regional fishers (Venter, 1988; page 56).

Quite why jellyfish may have increased is also open to debate, as a number of factors have been invoked to explain increases in jellyfish blooms elsewhere in the world (Mills, 2001; Purcell *et al.*, 2007; Richardson *et al.*, 2009; Brotz *et al.*, in review). A number of anthropogenic factors have been implicated in these increases, and it is likely that these act synergistically (Purcell *et al.*, 2007; Richardson *et al.*, 2009). These factors include overfishing, eutrophication, climate change, and a proliferation of hard substrata (all reviewed in Purcell *et al.*, 2007; Richardson *et al.*, 2009), and may involve introduced species (Graham and Bayha, 2007). In the Namibian case, overfishing is likely to be the main "causative factor", as the liberation of niche-space and the reduction in predation pressure (on ephyrae and juvenile medusa, as well as on polyps) inevitably will have allowed populations of both life-history phases to increase.

The role that jellyfish play within the northern Benguela ecosystem is largely unknown. Until very recently, large medusa were considered to represent trophic dead ends, both locally and globally, and they are generally considered to have a small reach (Brodeur *et al.*, 2011). But, off Namibia it is now understood that jellyfish can form a significant source of food (up to 70%) for the bearded goby, *Sufflogobius bibarbatus* (van der Bank *et al.*, 2011). This is another species that has proliferated locally since the demise of the commercial pelagic fishery (Staby and Krakstad, 2006), and although it is not directly exploited at present, it plays a significant role within the system because it, in turn, is an important food source for higher trophic levels. This includes piscivorous fishes such as hake, as well as seabirds and seals. Indeed, were it not for the bearded goby, populations of these other species probably would be substantially lower than they are at present – despite its poor nutritional value (Ludynia *et al.*, 2010). But jellyfish not only provide food for gobies (hake etc), they also provide a refuge for the goby from piscivorous predators, when it migrates into the water column at night (Utne-Palm *et al.*, 2010).

2.4 DIRECT AND INDIRECT EFFECTS OF JELLYFISH ON FISHERIES

Unfortunately, we are not in a position to assess the scale, impact or significance that jellyfish may be having on the fishing industry – directly or indirectly – as data are totally lacking in a local context.

Flynn *et al*. (in press) have reviewed the jellyfish information contained within the (pelagic and demersal) commercial catch records from Namibia for the period 1997 – 2006 (Flynn *et al.*, in press). These data suggest that, on average, jellyfish are caught in <2% of demersal trawls (N>350 000) and only in about 20% of pelagic purse seine sets (N>11 000 samples). These values are significantly lower than those obtained from fishery-independent sources (Flynn *et al.*, in press), and this suggests either that commercial fishers avoid catching jellyfish, or that they fail to fully report on catches. In the case of pelagic fishers, who process their catch in bulk (for canning (high value) or reduction to fishmeal (low value)), a skipper is unlikely to set a net if there is a risk of significant catch contamination by jellyfish. Such contamination could, at best, result in the catch being reduced to fishmeal with a subsequent reduction in remaining quota (not entirely trivial, Quiñones *et al.*, in review), or (at worst) result in costly additional damage to gear and other equipment (e.g. the refrigerated seawater cooling system). Excessively contaminated catches could be illegally dumped at sea. The financial penalties incurred by demersal fishers from trawl contamination by jellyfish , by contrast, are likely to be small, as the catch is individually processed, and the net is only open in the pelagos (where jellyfish are most common) for a relatively short duration of time.

Indirect effects (through consumption of eggs/larvae) may be significant, however, as the spatial (latitudinal, longitudinal and vertical) and temporal (seasonal) distribution of jellyfish off Namibia broadly overlaps with that of many of the commercial fishes (Flynn *et al*., in press). When the sardine biomass was much higher than it is today, fish spawned throughout much of the year, albeit with two seasonal maxima: August/September (late winter-spring) and January/February (late summer-autumn) (O'Toole, 1977). There were two principal spawning areas, one between 19° – 22 °S and one off central Namibia near Walvis Bay (O'Toole, 1977). Sardine spawning occurs just below the upper mixed layer and eggs ascend rapidly to the surface owing to their buoyancy (Stenevik *et al*., 2001). Whilst there is a tendency for eggs and larvae to be displaced offshore, larvae can be retained inshore by a combination of behavior and vertical mixing (Stenevik *et al*., 2001). Namibian hake too tend to reproduce for much of the year, with peak spawning during October-December (O'Toole, 1978; Olivar *et al*., 1988). Spawning occurs along the length of the Namibian shelf (Olivar and Shelton, 1993), mostly in offshore waters and at depth (Sundby *et al*., 2001). Eggs ascend slowly and early larvae are moved onshore and concentrated by a combination of physical and behavioural processes (Sundby *et al*., 2001), often in the vicinity of Walvis Bay (Sundby *et al*., 2001).

Given the ability of jellyfish to consume large numbers of ichthyoplankton, as both eggs and larvae (e.g. Purcell and Arai, 2001; Brodeur *et al*., 2002), jellyfish could have the potential to limit recruitment (as Möller, 1984, Lynam *et al*., 2005). Direct evidence of jellyfish predation on fish eggs and larvae off Namibia is presently missing, but Olivar and Barange (1990) noted that large jellyfish off Namibia were most common in areas where fish larvae were least abundant and these authors attributed this near mutually exclusive distribution, in part, to predation. What is most interesting about this particular observation is that it was made during April, which corresponds to the second peak in sardine spawning activity.

3 LEGISLATION / STANDARDS OF RELEVANCE

The Marine Resources Act 27 of 2000: The act is administered by the Ministry of Fisheries and Marine Resources (MFMR). The Ministry has a large capacity. The ministry is the principal responsible controlling / regulatory authority for all activities below the high water mark that may affect the marine ecological environment.

This Act provides for the conservation of the marine ecosystem; for the responsible utilization, conservation, protection and promotion of marine resources on a sustainable basis. [The Act replaces the Sea Fisheries Act 29 of 1992, which dealt with: Dumping at sea, discharge of wastes into marine reserves, disturbance of rock lobsters, marine invertebrates or aquatic plants, areas in which the catching/disturbing of fish or aquatic plants or disturbing/damaging the seabed are prohibited.

Section 52 states: *"Any person who discharges in or allows to enter or permits to be discharged in Namibian waters anything which is or may be injurious to marine resources or which may disturb* *or change the ecological balance in – any area of the sea, or which may detrimentally affect the marketability of marine resources, or may hinder their harvesting, shall be guilty of an offence and liable on conviction to a fine not exceeding N$500 000."*

Section 52 (3) (f) states: "*Any person who kills or disables any marine animal by means of any explosive, poison or noxious substance, or by means of a firearm except as may be prescribed, shall be guilty of an offence and liable on conviction to a fine not exceeding N$ 500 000."*

Part 10 of the Marine Resources Act empowers the Minister to prescribe specific conditions and restrictions regarding closed areas and exclusion zones, applicable to commercial fishing rights, quotas and licenses granted under the Act. In this regard, trawling and longlining is prohibited in waters shallower than 200 m. The Act also provides for the declaration of Marine Protected Areas and fishing areas.

4 SOURCES OF POTENTIAL ENVIRONMENTAL IMPACT / RISK

4.1 HYDROGEN SULPHIDE

The liberation of large quantities of hydrogen sulphide by dredging activities has the potential to kill off any jellyfish present in the affected water column, as these organisms possess no special tolerance to this metabolic toxin, although both medusa and polyps are remarkably tolerant of hypoxic water (Purcell *et al*., 2001; Condon *et al*., 2001). Affected individuals would then sink to the seafloor, though whether or not they settle in the operational area depends on local patterns of water circulation. The magnitude of settlement will obviously depend on local (patchy) abundances and the extent and intensity of the affected area. Although dead jellyfish could be concentrated by bottom water movements in depressions left on the seafloor by dredging activities, such aggregations are unlikely to persist for very long (days rather than weeks) owing to their high water and low organic matter content (reviewed in Arai, 1997). Our understanding of the decomposition (rates and processes) of jellyfish is presently weak (e.g. Titelman *et al*., 2006; West *et al*., 2009). The mesocosm study of West *et al*. (2009) suggested that the rates of nutrient efflux from jellyfish carcasses, and the associated sediment oxygen demand, were initially high, but that systems had returned to control levels after 120 hours. Two things need to be borne in mind when interpreting these results in the present context – 1) the temperature of the West *et al*. (2009) study site was 30 °C, and 2) there was no scavenging of moribund/dead jellyfish. Whilst the lower water temperatures off Namibia would result in a potentially longer decomposition time, the presence of potential scavengers (such as gobies, *Sufflogobius bibarbatus:* van der Bank *et al*., 2011) could reduce this time. The latter is not insignificant (potentially), because elsewhere in the world scavengers have been shown to reduce jellyfish carcass mass by 40% within 24 hours (Yamamoto *et al*., 2008). This, again, highlights the limited information available on most aspects of jellyfish ecology in the Benguela.

4.2 TAILINGS PLUME

The plume of fine sediment that will be generated in the water column during dredging operations has a limited potential to be deleterious to individual jellyfish, with population level impacts being dependent on the numbers of animals moving through the licence areas. That said.

it must be stressed that no research has been conducted in this area. The "fines" could settle out on individual jellyfish, but as the organisms have no specialized respiratory surfaces that could be blocked, they should be able to continue swimming, and through swimming they should be able to rid themselves of settled particles. Whilst it could be argued that jellyfish might ingest particles in the tailing plume, this is considered unlikely. Firstly, the mechanism of prey capture is such that nematocysts will only discharge if stimulated by physical contact, and a "fines" particle is unlikely to so stimulate, though if it does the oral arm / tentacle is unlikely to transfer the particle to the mouth for subsequent digestion without further stimulation by the particle itself. And even if the "fines" particle does get ingested, its organic nature is such that it is likely to be digested.

4.3 ALTERATION TO THE SEABED HABITAT

The removal of surficial sediments from the benthic environment, as a result of dredging, will alter the nature of the seabed environment. Whilst this has no impact on jellyfish in the water column, it could increase the area suitable for polyp attachment should large areas of hard substrata be exposed. That said, polyps of other species seem to require a sediment-free surface for persistent establishment. This is unlikely to be realized given the immediate fallout from the tailings plume, from the persistent sedimentation of photic zone production and from the sluggish nature of bottom circulation.

4.4 PHYSICAL ENTRAINMENT

Although jellyfish can be found throughout the water column, more than 80% of biomass is found in the upper 50 m (Flynn *et al.,* in press). This means that jellyfish are unlikely to be entrained in large quantities in dredged sediments. However, it does mean that jellyfish could block seawater cooling intakes on the dredging vessel itself, which could pose a significant technical risk. More details are provided under mitigation measures (below).

5 ASSESSMENT OF POTENTIAL IMPACTS

The following methods have been used to determine the significance rating of impacts identified in this benthic specialist study:

1. Description of impact - reviews the type of effect that a proposed activity will have on the environment;
2. What will be affected; and
3. How will it be affected.

Points 1 to 3 above are to be considered / evaluated in the context of the following impact criteria:

- *Extent*;
- *Duration*;
- *Probability*; and
- *Intensity*.

These impact criteria are to be applied as prescribed in the table below:

Impact Criteria:						
Extent	**Dredge Area** Per vessel cycle i.e. ~66,000m² or 6.6 ha	**Annual Mining Area** Up to 3 km²	**Specific Mine Site** (SP1 or SP2) each is 22x8 km or 176km²	**Local** 25-50 km or 2,000km²-8,000km²	**Regional** 50-100 km or 8,000km² – 30,000km²	**National** 100 km to EEZ (200 nautical miles)[1] 100 to 370 km, or >30,000km²

Duration	**Very Short Term** 3 days	**Short term** 3 days – 1 year	**Medium term** 1 - 5 years	**Long term** 5 – 20 years	**Permanent** > 20 years (life of mine)

Intensity/ Magnitude	**No lasting effect** No environmental functions and processes are affected	**Minor effects** The environment functions, but in a modified manner	**Moderate effects** Environmental functions and processes are altered to such extent that they temporarily cease	**Serious effects** Environmental functions and processes are altered to such extent that they permanently cease

Probability	**Improbable**	**Possible**	**Probable**	**Highly Probable/ Definite**

The status of the impacts and degree of confidence with respect to the assessment of the significance are stated as follows:

Status of the impact: A description as to whether the impact is positive (a benefit), negative (a cost), or neutral.

Degree of confidence in predictions: The degree of confidence in the predictions, based on the availability of information and specialist knowledge. This had been assessed as high, medium or low.

Based on the above considerations, the specialist provides an overall evaluation of the significance of the potential impact, which is described as follows:

	None	Low	Medium	High
Impact Significance	A concern or potential impact that, upon evaluation, is found to have no significant impact at all.	Any magnitude, impacts will be localised and temporary Accordingly the impact is not expected to require amendment to the project design	Impacts of moderate magnitude locally to regionally in the short term Accordingly the impact is expected to require modification of the project design or alternative mitigation	Impacts of high magnitude locally and in the long term and/or regionally and beyond Accordingly the impact could have a ‘no go’ implication for the project unless mitigation or re-design is practically achievable

[1] 1 nautical mile = 1,85 kilometres

Furthermore, the following are being considered:

- Impacts are described both **before** and **after** the proposed **mitigation** and management measures have been implemented;
- All impacts are evaluated for all project phases: **initiation, operations and decommissioning;**
- The impact evaluation takes into consideration the **cumulative effects** associated with this and other facilities which are either developed or in the process of being developed in the region, if relevant. Cumulative impacts are impacts that result from the incremental impact of the proposed activity on a common resource when added to the impacts of other past, present or reasonably foreseeable future activities. Cumulative impacts can occur from the collective impacts of individual minor actions over a period of time and can include both direct and indirect impacts;
- **Mitigation / management actions:** Where negative impacts were identified, the specialists specified practical mitigation measures (i.e. ways of avoiding or reducing negative impacts). Where no mitigation is feasible, this is stated and the reasons given. Where positive impacts were identified, management actions to enhance the benefit are recommended. The specialists have set quantifiable standards for measuring the effectiveness of mitigation and enhancement; and
- **Monitoring (forms part of mitigation):** Specialists recommend monitoring requirements to assess the effectiveness of mitigation actions, indicating what actions are required, by whom, and the timing and frequency thereof.

5.1 ASSESSMENT OF IMPACTS

Impacts on jellyfish from the proposed Sandpiper Phosphate Project are only expected during the operational phase of the project (but may extend beyond the closure of the project). Impacts are thus assessed for the operational phase only, and not for the initiation and decommissioning phases.

5.2 DETERMINING THE LEVELS OF SIGNIFICANCE OF THE POTENTIAL IMPACTS

Nature of the impact	Blocking of vessel seawater intake system by dense surface aggregations of jellyfish. Dense surface volumes of jellyfish have been known to block the seawater intakes. This incoming seawater is used to cool the vessel's engines and any blockage of the intake system could cause the engines to overheat and fail, if remedial action is not taken.
Extent	***Dredge Event:*** The extent is limited to immediately adjacent to the vessel during all operations.
Duration	***Extremely short term:*** The duration is limited to the period of time when dense aggregations of jellyfish are around the vessel: probably no more than a few hours in duration
Intensity	***No lasting effect.*** This impact would involve a relatively limited number of jellyfish and is more likely to have adverse impact to the vessel if not mitigated.
Probability	**Highly probable**: Although it is not possible to predict exactly when dense jellyfish aggregations may appear around the vessel, they do tend to occur more commonly during late winter / early spring: it is inconceivable, given how many jellyfish there

	are off Namibia, that this threat will not arise.
Status (+ of -)	***Negative to individual jellyfish, possibly positive for fisheries***
Significance (no mitigation)	***Low***
Mitigation	• In the case of blockage, jellyfish will have to be physically removed or flushed from the system. • Sailing the vessel to areas with less dense aggregations of jellyfish • Forward looking sonar could be installed on the vessel to identify dense masses of sub-surface jellyfish during operations. A "jellyfish observer" on deck should be able to identify jellyfish aggregations at the surface.
Significance (with mitigation)	***Very Low***
Confidence level	***High***

Nature of the impact	Hydrogen sulphide released from dredge sediments causing mortalities to jellyfish. The mining operation is located seaward of the mud belt where high levels of hydrogen sulphide are known to be associated with soft sediments. Hydrogen sulphide releases from the sediments in the Mining Licence Area (which is adjacent to, but not in the mud belt) are thus envisaged to be significantly less frequent and intense.
Extent	***Dredge Event***
Duration	***Extremely short term:*** The duration is short (hours), related to the pulsed release of hydrogen sulphide.
Intensity	***Minor effects.***
Probability	***Probable.*** In the event that the combination of adverse factors comes together at any one time, jellyfish moralities will occur.
Status (+ of -)	***Negative to individual jellyfish, possibly positive for fisheries***
Significance (no mitigation)	***Low***
Mitigation	No mitigation is presented
Significance (with mitigation)	***Low***
Confidence level	***High:*** Although there is no information on the tolerance of jellyfish to hydrogen sulphide, they are unlikely to have special adaptations thereto. More research on this is needed.

Nature of the impact	Lean water overflow from the vessel generates a tailings plume of fine sediments which settle out through and are dispersed in the water column. These fine sediments if present in sufficient quantities may cause mortalities to jellyfish, though this is considered unlikely
Extent	***Mine site: < 25 km.*** It is understood that whilst dredging a sediment plume of ~1500 m long and 800 m wide will be generated over the cut length of up to 22 km. This plume is determined to sink to the seabed over a distance of 500-1500m from the point of discharge. The maximum concentrations of sediments in the sediment plume are envisaged to be <50 mg/l but most of the plume area will have total suspended sediment concentrations <10 mg/l above background (1-4 mg/l), these are regarded as low.
Duration	***Extremely short term***
Intensity	***Minor effects***
Probability	***Rare.***

Status (+ of -)	***Negative to individual jellyfish, possibly positive for fisheries***
Significance (no mitigation)	***Very Low***
Mitigation	No mitigation is presented
Significance (with mitigation)	***Very Low***
Confidence level	***Low** – research on this is needed*

Nature of the impact	Removal of seabed sediments will change the nature of the sediment surface. Jellyfish populations are known to increase in areas where there is an increase of hard substrate. Typically this occurs where rock, concrete or iron structures are erected. The removal of the upper relative soft layers of sediment, leaving a relative hard clay footwall surface may provide such a hard surface.
Extent	***Annual Mining Area.***
Duration	***Very Short term:***
Intensity	***Minor effects***
Probability	***Rare***
Status (+ of -)	***Positive for jellyfish, negative for fisheries***
Significance (no mitigation)	***Low***
Mitigation	None: If between 10 - 15 % of the original thickness of the sediment is not recovered, there will sufficient soft-substrata to preclude polyp settlement.
Significance (with mitigation)	***Very Low***
Confidence level	***High***

6 MITIGATION AND MONITORING RECOMMENDATIONS

6.1 MITIGATION

Mitigation in this context refers to the mitigation of risks to the operational activities, and not to jellyfish *per se*. Although a number of techniques exist to "repel" jellyfish, the exact techniques employed vary with the type of operational activity and none is 100% effective. It is **important** to note that the techniques described briefly below have been deployed in shallow, near-shore areas and may not be appropriate at the operational depths considered here. And it should also be realized that almost all have been tailor-made to the particular situation by engineers: there is no *off-the-shelf* method that fits all situations. It should also be mentioned that published information on this topic is hard to find, and that most sources consulted are from the internet (Internet (1) and (2)).

Vertical nets, in conjunction with booms may be deployed around resort beaches, or parts thereof, to exclude jellyfish from entering bathing areas. Nets and booms are also used at the entrance to power-plant ponds and the offshore intakes for desalination plants (Azis *et al*. 2000), as well as around naval vessels (internet 1) to prevent jellyfish from clogging pumps etc. Typically, two sets of nets (an outer coarse mesh net system and an inner fine mesh system: internet 2) are either suspended from surface floats and extend to close to the seafloor, or they are fastened to pilings sunk into the seafloor (e.g. Marks and Cargo 1974). The problem with nets, as highlighted by the latter authors, is that they tend to clog and are subject to bio-fouling, which means that without regular, routine maintenance (cleaning and repair) they will eventually either sink, or the hydrodynamic load on them will become so great that they will be ripped away. Regardless, in addition to catching jellyfish, nets tend to damage them too, which means that “bits” of jellyfish can still pass through (Marks and Cargo 1974).

Further offshore, hydro-acoustic techniques can be used to alert operations’ managers of the presence of large numbers of jellyfish sub-surface. Multi-frequency hydro-acoustics (18 kHz, 38 kHz, 120 kHz) have been used to detect jellyfish at high abundances, and algorithms for the discrimination of both local species have been developed: fuller details can be found in Brierley *et al*. (2001, 2004, 2005). Although these techniques have been employed during specialized research cruises on the *Dr Fridtjof Nansen*, they are not routinely performed by the Namibian Ministry of Fisheries and Marine Resources as their research vessels lack the necessary equipment. In the case of the *Dr Fridtjof Nansen*, the transducers are fixed to the keel (38 kHz, 120 kHz) and hull (18 kHz) and acoustic backscatter is detected vertically. Whilst such an orientation may be useful for the detection of large numbers of jellyfish close to the drag head site on the seafloor, this would perhaps not be appropriate for the detection of sub-surface blooms close to water-inflow points on the vessel. Further work is clearly needed in this regard.

Although clogging can be minimized if there are effective prevention measures in place, this is unlikely to be materially achieved at the operational depths considered here. However, a number of techniques do exist that can be used to limit intake and to deal with caught material. All the techniques, however, have been developed largely by the energy sector (in shallow environments), which requires clean water for cooling (and other) purposes in coastal power-plants. As a consequence, they may not be applicable for operations either in deep-water or, more likely, that wish to include (rather than exclude) sediments.

6.2 MONITORING

It is very hard to propose a monitoring programme for jellyfish that is aimed at minimizing the potential impact of jellyfish on dredging operations, because at this stage we don’t know what the operational impacts and risks are. That said, it would be useful to collect the following routine types of information on jellyfish - but always in association with other environmental measures.

a) Daily observations on the presence/abundance/type of jellyfish at the surface, in conjunction with similarly captured data on SST and surface currents.
b) If jellyfish are caught on screens (?) from pumping operations at depth, these should be logged on an ongoing basis in conjunction with operational data (pump flow-rates), bottom temperature and currents, and the concentration of dissolved oxygen and hydrogen sulphide.
c) If operations are going to be monitored using ROVs, depth stratified data should be collected on the presence/abundance/type of jellyfish, throughout 24 h periods, in conjunction with appropriate environmental data.
d) If opportunities exist for detailed studies on the fate/decomposition (rates and processes) of jellyfish on the seafloor, and if those opportunities can be exploited without undue trouble, they too should be exploited.

Activities a-c (above) can be undertaken routinely by appropriately trained operational staff. Should NMP be prepared to allow its operational platform to be used for research, activity d (above) could be conducted by university-based scientists.

7 CONCLUSION

Off Namibia, jellyfish can be found across the shelf and along the shelf, and they are abundant all year-round. It is thought that their numbers have increased markedly since the collapse of the pelagic fisheries in the early 1970s, where they presently pose a problem for fishery operations. It is possible that they are having a negative impact on the sustainability of regional fisheries.

The proposed mining activities are not considered to have a significant and lasting impact on the abundance and distribution of jellyfish populations: the tailings plume is limited in areal/temporal extent and jellyfish have no specialized respiratory surfaces that could get clogged; alterations to the benthos are unlikely to increase the habitat for polyp establishment if a layer of soft sediment is not recovered, and whilst hydrogen sulphide could kill individuals in the affected water column, this is likely to be on a very limited scale since dredging will take place seawards of the mud belt which is the main source of H_2S. More serious impacts are likely to be effected by jellyfish on mining operations, though not though clogging at the drag-head as jellyfish are uncommon at depth. However, at the surface, where water will be drawn into the vessel for cooling (etc), they could cause a major problem for vessel activities. There are no "off-the-shelf" solutions to this and engineers will need to draw up their own strategies of dealing with the problem. Large jellyfish aggregations, sub-surface, could be detected using multi-frequency hydro-acoustic techniques (surface swarms should be detectable from the bridge) and so an early warning system could be developed but these would again need to be tailored to the vessel's operational specifications.

Because there are so many unknowns regarding jellyfish off Namibia (and elsewhere for that matter), any information that can be collected would be useful from a scientific point of view, and a number of suggestions in this regard are made.

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