SPECIALIST STUDY # 10

THE IMPACT OF DIAMOND MINING NOISE ON MARINE MAMMAL FAUNA OFF SOUTHERN NAMIBIA

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CONTENTS

1 AIMS

This report aims to evaluate measured noise levels of diamond mining operations of De Beers Marine on the marine mammal fauna of the southern Namibian region.

2 BACKGROUND

The marine mammal fauna of southern African waters comprises 37 cetacean (whale and dolphin) species and one otariid seal species, the Cape fur seal. The cetacean fauna is remarkably diverse, with the high diversity arising from the wide range of oceanographic conditions found within the southern African region. Findlay (1989MS) analysed and described the distribution of these 37 species.

The region of mining interest lies within the west coast inshore cetacean distributional region, described by Findlay (1989MS) as extending from approximately 17° S to 32° S and inshore of the 200 m isobath. Due to the highly mobile nature of the cetacean species concerned, and their often substantial distribution ranges, this review will include species found offshore of the continental shelf off the Namibian coast. Findlay (1989MS) defined cetacean fauna in this region as migratory, resident and semi-resident species (those in which different components of the population (age or sex classes) show resident and migratory habits). The Cape fur seal is distributed from northern Namibia (approximately 18° S) to Algoa Bay, South Africa.

3 DISTRIBUTION PATTERNS

3.1 Resident Cetacean Species

The dusky dolphin (*Lagenorhynchus obscurus*) and the Heaviside's dolphin (*Cephalorhynchus heavisidii*) are found in the extreme nearshore region between the northern Namibian border and Cape Point. The bottlenose dolphin (*Tursiops truncatus*) is found in two habitats, a) in the extreme nearshore region between Walvis Bay and Cape Cross and b) offshore of the 200 m isobath along the Namibian coastline. Southern right-whale dolphins (*Lissodelphis peronii*) have an extremely localised year-round distribution associated with the continental shelf and the shelf-edge in the region between 24° and 28° S. Eleven further species are resident within the offshore area of the Namibian coastline in water depths of over 500 m. These include the long-finned pilot whale (*Globicephala melaena*), Grays beaked whale (*Mesoplodon grayii*), Layard's beaked whale (*Mesoplodon layardii*), the pelagic forms of common dolphin (*Delphinus delphis*) and Bryde's whale (*Balaenoptera edeni*), false killer whale (*Pseudorca crassidens*), Risso's dolphin (*Grampus griseus*), sperm whale (*Physeter macrocephalus*), Cuvier's beaked whale (*Ziphius *cavirostris*), Pygmy killer whale (*Feresa attenuata*) and pygmy sperm whale (*Kogia breviceps*). Killer whales (*Orcinus orca*) are found throughout Namibian waters.

Little is known of the sizes of the home ranges of these resident species. One tagged Heaviside's dolphin was recorded as travelling approximately 85 nautical miles in 18 months, while repeated sightings of three recognisable albino Heavisides dolphins in Table Bay suggest small home ranges for this species.

3.2 Migratory Cetacean Species

All of the large southern hemisphere balaenopterid whale species, namely blue whales (*Balaenoptera musculus*), fin whales (*B. physalus*), sei whales (*B borealis*), minke whales (*B. acutorostrata*), Bryde's whale (*B. edeni*) and humpback whales (*Megaptera novaeangliae*) and two species of balaenid whale the southern right whale (*Eubalaena australis*) and the pygmy right whale (*Caperea marginata*) have been recorded from the Namibian coastline. Blue, fin sei, minke and right whales are highly migratory species and are found in Namibian waters in winter. Although humpback whales are migratory species with a summer distribution in polar waters and a winter distribution in lower latitudes, Townsend (1935) and Keeler (in Best and Shaughnessy 1979) found humpback whales off the Namibian coast in summer. Olsen (1914-15, in Hinton 1925) stated that humpback whales could be taken off the south-western Cape coast in summer months. Consequently humpback whales have been considered semi-resident in this review. Little is known of the migratory patterns of pygmy right whales.

Two species, the humpback whale and the southern right whale would be found in continental shelf waters of Namibia in winter months although as stated there are historical records of humpback whales summering in Namibian waters. Limited numbers of southern right whales are found in the extreme coastal waters, while humpback whales utilise the coastal waters as a migratory corridor between Antarctic feeding grounds and tropical breeding grounds. The distribution patterns of southern right whales appears to have undergone considerable attenuation in range since the peak of historical whaling in the region (1790-1805), in that the species does not appear to be making the recovery in Namibian waters that is recorded on the southern Cape coast. Migrations of the other baleen whale species would occur off the continental shelf.

3.3 The Cape Fur Seal (*Arctocephalus pusillus*)

The Cape fur seal breeds at 24 colonies along the southern African coast between Cape Cross, northern Namibia, and Algoa Bay. A further 10 non-breeding haul out sites occur along the west coast. Six of theses breeding colones occur on the mainland, the remainder being found on offshore rocks or islands. Over 90 % of the population occurs on the west coast, and 14 breeding colonies are found between 24° S and the Orange River Mouth.

4 PREVIOUS STUDIES

There have been no previous studies carried out to assess the impacts of marine diamond mining on the marine mammal fauna of the southern African coast. Coley (1994, 1995) measured and analysed underwater noise radiated by offshore mining operations. **Figures 1 & 2** show the locations where noise measurements were taken. These measurements have been utilised as source spectra in assessing the impacts of noise on marine mammal fauna off the Namibian coast in this review. Krige (1995) analysed the effects of vessel noise on whales in South African waters.

5 IMPACT DESCRIPTION

5.1 Source-Path-Receiver Model

In assessing the impacts of such mining noise on the marine mammal fauna a simple source-path-receiver model has been adopted. The source component of this model includes the characteristics of the sound at the source. The path component includes the transmission of the sound between source and receiver and includes transmission loss. The receiver component of the model includes the detection capabilities of the animals, and includes aspects such as ambient noise which may mask the received sound. This model is shown in **Figure 3** (after Richardson *et al.* 1995).

5.1.1 Source

The spectra and noise amplitude of two type of mining processes used by De Beers Marine namely drill and crawler, have been measured and reported on by Coley (1994 and 1995). Although this report measured and analysed the noise, the assessment of the impact of the noise was not within the scope of that study. Coley (1994) aimed to record noise of two mining vessels (the *Louis G Murray* and the *Grand Banks*) at four cardinal points at distances of 100, 500 and 1000 metres from the vessels while they were involved in mining. However inclement weather conditions precluded the full range of measurements being made and acceptable recordings were only made by deploying the hydrophone 100 metres from leeward side of the bow of each vessel and drifting to 300 metres. No recordings of ambient noise levels were recorded due to the poor weather conditions. Coley (1995) measured additional noise levels (particularly low and high frequency noise levels) of two vessels, the *Coral Sea* and the *Louis G Murray*.

Louis G Murray
Recordings of the *Louis G Murray* were made over two days with and without the crawler operating. Coley (1994) found no difference in the source levels produced by the two scenarios within the low frequency 100 Hz band. Over and above the wide variation in recorded noise levels (resulting from the poor measurement conditions) a basic tonal

structure (peak at 15 Hz and harmonics at 30, 45, 60 and 75 Hz) was recorded. Within the 1000 Hz spectrum the spectrum was dominated by a combined tonal structure where the vessel and the crawler were indistinguishable between 0 and 400 Hz. Above 500 Hz a gradual increase in the broadband level was caused by the crawler operation. Between 1 and 10 kHz there was a marked increase in the level (between 20 and 25 dB) resulting from the crawler operation. This broadband noise level increase was constant in the 25 kHz spectrum (or at least to 22.5 kHz - the limitation of the recording instrumentation).

Coley (1994) noted that the approximate band level produced by the crawler is 167 dB re 1 µPa (ref 1 m) in the 25 kHz band. This increase is produced as a result of the movement of air and rocks up the suction pipes.

Grand Banks
Measurements made on noises from the *Grand Banks* were of the vessel operating and of the vessel and the drill operating. In the low frequency band the spectrum was dominated by tonal sounds produced by rotating machinery and the drill and vessel operating noise levels could not be differentiated. A large variation in the source level at 10 kHz was recorded and Coley (1994) notes that this is worth further investigation. As with the crawler the noise from the drill was only distinguishable above 400 Hz. An increase in the broadband noise above the vessel noise of 20-25 dB was recorded up to the limitation of the recording instrumentation at 22.5 kHz.

Both the mining methods produce elevated (above the vessel noise) broadband noise levels of 20 to 25 dB from 500 Hz to 22.5 kHz. The *Grand Banks* was however found to be 6 dB quieter than the *Louis G Murray*.

The mining operation also makes use of a Sonardyn transponder which can be operated at low, medium and high frequency ranges. The source levels of at these frequency ranges are approximately 192 dB re 1 µPa. However mining operations utilise only the medium frequency range and Coley (1995) notes that the audible range of this frequency would be approximately 8 km.

5.1.2 Path component

The propagation of sound through sea water is dependent on a number of factors with water depth probably having the greatest influence. In deep waters, variations in water properties affect sound propagation, while in shallow waters the sea surface, and the bottom topography and composition have strong influences. As the mining area of interest falls within the 200 metre isobath the path component will be treated as for shallow water transmission. However, sound transmission in shallow water is highly variable and site specific and these factors compound the development of adequate theoretical models.

Coley (1994) compared the mining noise of the *Grand Banks* (source level at 1 m and range attenuated levels at 100, 500 and 1000 m distances) to the ambient noise level expected from a sea state 3 and concluded at the worst case the mining operations could be

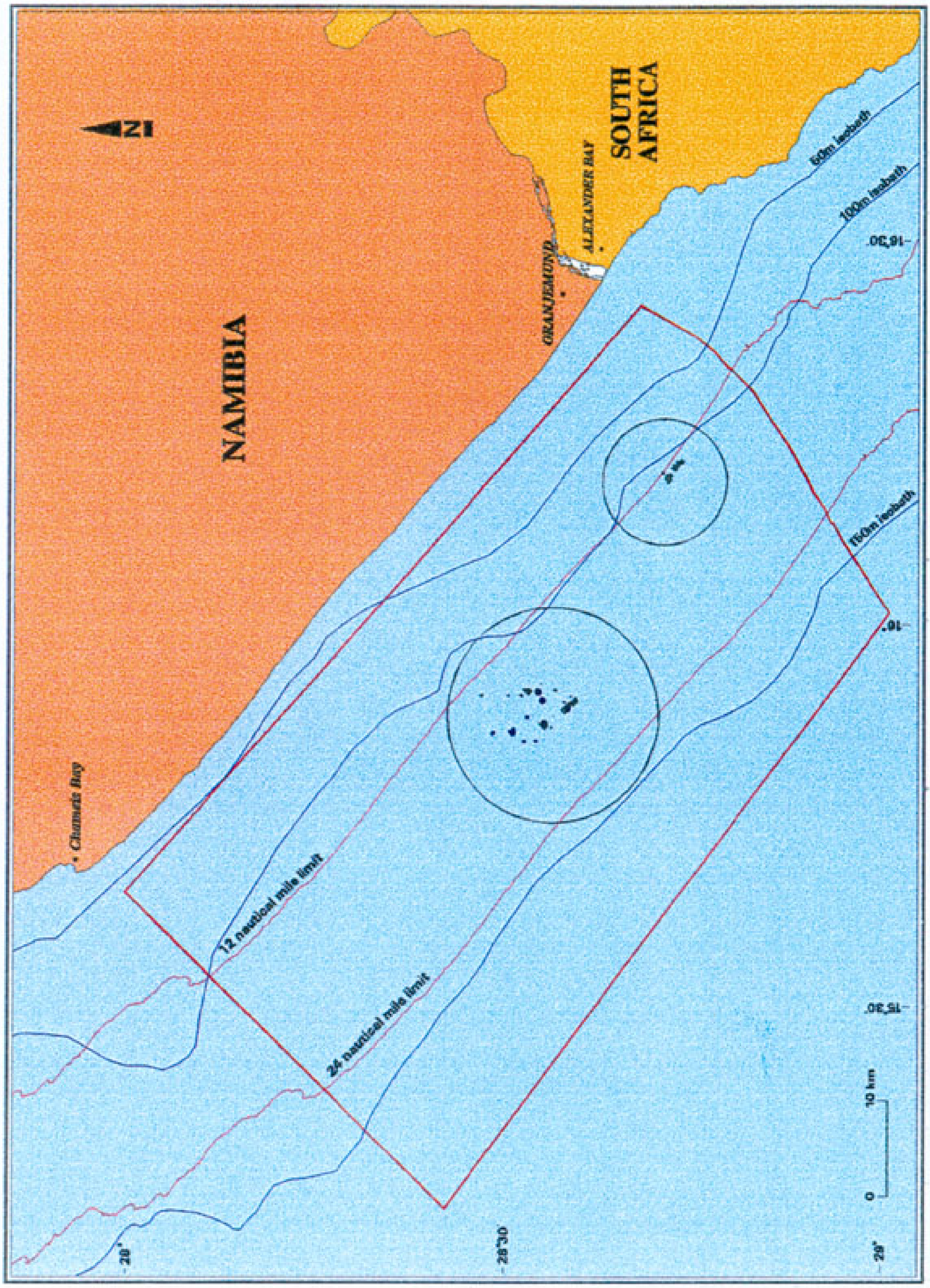

FIGURE 1 : The positions at which noise measurements were taken taken in Atlantic 1 Mining Licence Area (red outline) showing the mining areas of interest (black outlines) and the mined-out areas (shaded black).

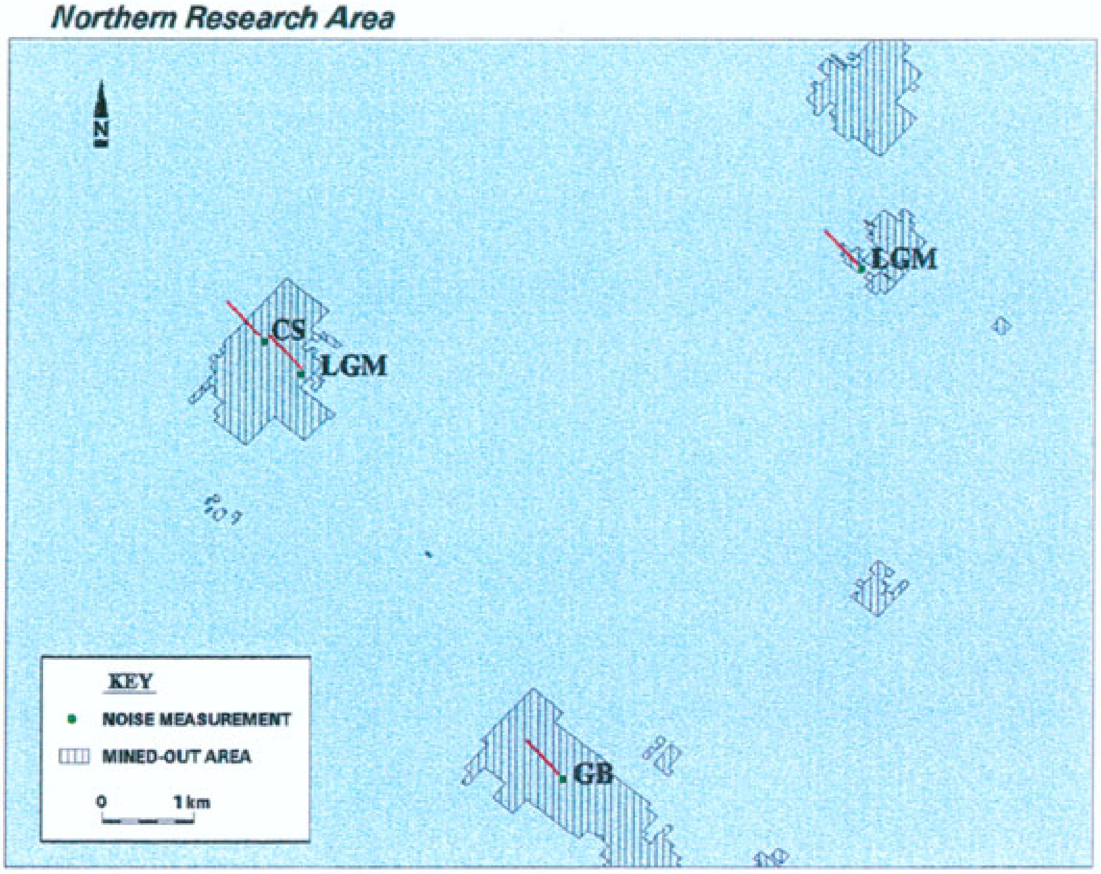

FIGURE 2 : Map of the northern research area showing the positions from which noise measurements were taken.

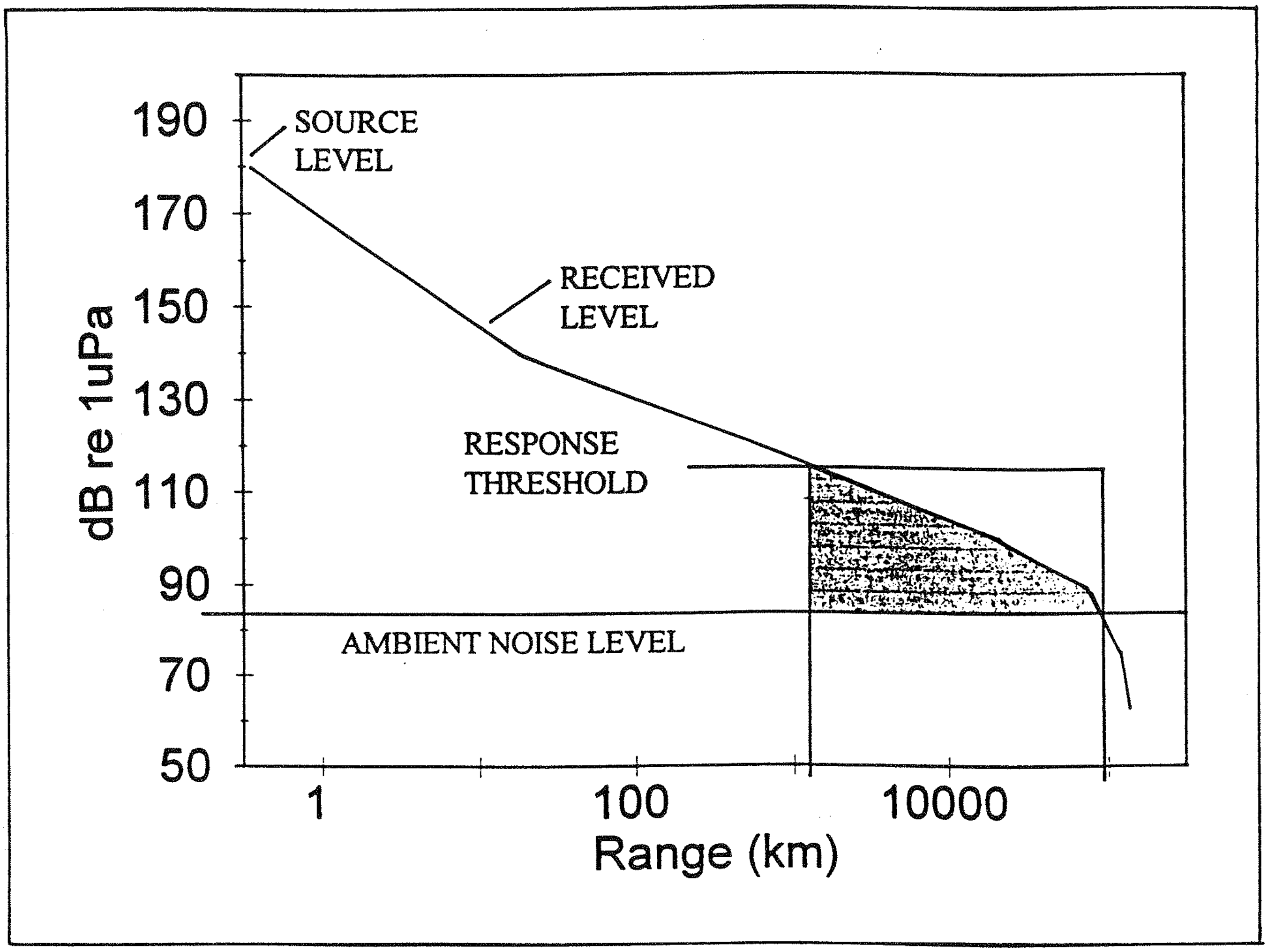

Figure 3 Theoretical components of the source - path - receiver model used in the assesment of mining noise on marine mammal fauna in this review. (After Richardson *et al* 1995).

heard above ambient noise level for well over 1000 metres from the operation. This comparison was carried out using a simple spherical spreading model.

Coley (1995) produced source density spectrum levels for mining operations using both drilling and the crawler operations and noise levels for the sonardyne transponder. These have been compared to ambient noise levels expected under various sea states in Appendix 1. Results show that noise levels at the worst case scenario (low sea state) would generally not be above ambient at distances of over 20 km from the source.

5.1.3 Receiver component

Richardson *et al.* (1995) noted that the hearing ability of any mammal is dependent on a number of factors including :-

i) absolute hearing threshold.
This threshold varies with frequency and the relationship between the two provides an audiogram of the species ability to hear sound levels of different frequencies. Audiograms of marine mammals have in most cases come from behavioural tests on captive trained animals (behavioural audiograms). Audiograms may also be obtained from electrophysical or auditory evoked potential (AEP) methods which measure relative sensitivity of the nervous system to various sounds. Hearing abilities have been measured in some toothed whales and seals. However no measurements have been undertaken on the hearing sensitivity of baleen whales. Furthermore little of the auditory research carried out on marine mammals has been with frequencies of under 1 kHz where most of the anthropogenic noise frequencies occur.

ii) individual variation
The measured audiograms or examples of hearing sensitivity of species come from an extremely limited sample size of individuals. Variations in hearing sensitivity will occur between individuals in a population.

iii) motivation
Hearing sensitivities depend on motivation of the particular individual animal and thresholds are consequently defined as the lowest sound level detected during a specified percentage of trials.

iv) masking
Although audiograms provide information on the lowest levels of sound that can be detected in a quiet environment, ambient noise may mask the ability of an animal to hear a sound source. Animals have varying abilities to detect sound signals over ambient noise. The amount that a pure tone signal must exceed the background noise (measured as a spectrum level) for it to be detected is termed the critical ratio and is dependent on frequency.

v) localisation abilities
Sound localisation, the ability to pin-point the direction of the sound source is critical to hearing and responding to sound sources. Different species and individuals may have different localisation abilities. Furthermore the localisation ability is important in the detection of signal to background noise if the two sources have a different position.

vi) frequency and intensity discrimination.

5.2 Marine Mammal Hearing

5.2.1 Toothed whales

Full behavioural underwater audiograms have been measured for seven species and a further partial audiogram has been measured for one species of small toothed whales (Appendix 1, **Figure A-4**). Generally these show poor sensitivity to low frequency sounds and good sensitivity to high frequency sounds in the 10 to 100 kHz range, with sound levels as low as 30 dB re 1 μPa being identified. Above 100 kHz the sensitivity declines rapidly. However frequencies below 1-10 kHz the threshold levels may be too high as a result of small test tanks. Furthermore, the lack of measurements made in the under 1 kHz frequency range must be noted, particularly as it is in this range that the majority of man-made noises occur. Auditory evoked potential techniques have been used to measure audiograms of certain further species including the dolphins *Stenella* and *Sotalia* and a sperm whale calf. Generally those obtained through AEP's were similar to those obtained behaviourally, although the highest sensitivity obtained for the harbour porpoise by AEP was considerably higher (~ 100 kHz) than by behavioural measurement.

Critical ratios have been measured for few cetacean species. Johnson (1968) found that for a bottlenose dolphin, pure tone signals at 6 kHz and 70 kHz must exceed the spectrum noise level by 22 dB and approximately 40 dB respectively. Below 2 kHz the critical ratios of beluga was found to be constant at approximately 18 dB, but that this increased with frequency above 2 kHz. Both killer whales and false killer whale showed lower critical ratios than bottlenose dolphins in the 10 - 80 kHz and 8 - 24 kHz bands respectively.

5.2.2 Pinnipeds

Underwater behavioural audiograms have been measured for four species of phocid seals (monk, harbour, ringed and harp seals), and two species of otariid seals (the Californian sea lion and the northern fur seal). These are presented in Appendix 1, **Figure A-4**. A further phocid seal (gray seal) has been studied using AEP's.

Critical ratios have been measured for the northern fur seal and range from 19 dB at 4 kHz to 27 dB at 32 kHz.

5.2.3 Baleen whale hearing

As stated no complete behavioural audiograms have been determined for baleen whale species. Dahlheim and Ljungblad (1990) presented a partial "audiogram" for a gray whale in the 800 hz to 1800 Hz range based on behavioural responses to a pure tone source. This "audiogram" includes the level above minimum threshold to illicit a response and as such is a measure of responsiveness as opposed to audibility. It does however give the "shape" of the audiogram in this frequency range. Much of the information on the audiograms of baleen whales arise from indirect sources including

a) anatomical evidence suggesting that baleen whales are adapted to hear low frequencies (Fleischer 1976, 1978, Norris and Leatherwood 1981, in Richardson *et al.* 1985).

b) reactions to anthropogenic noise
Richardson *et al.* (1995) reviewed the reactions of baleen whales to anthropogenic noise and concluded that gray, humpback and bowhead whales hear sounds with dominant components in the 50 to 500 Hz range.

c) reactions to other individual whales
Frankel (1995) found that humpback whales reacted to sounds of other humpbacks (400-550 hz) at received levels of 102 dB re 1μPa and Watkins (1981) found that fin whales react to 20 Hz calls from other fin whales.

d) frequency range of whale vocalisations
Some of the best evidence for low frequency auditory sensitivity in baleen whales is based on the assumption that the acute hearing of baleen whales includes the frequencies at which the animals themselves vocalise. A brief review of the frequency range of baleen whale vocalisations has been attached in Appendix II.

It appears that the hearing sensitivities of baleen whales are at lower frequencies than those of the toothed whales or the pinnipeds. The indirect evidence suggests that baleen whales are acutely sensitive to sounds below 1 kHz but can detect frequencies very much higher than this. The upper limit of the sensitivity is unknown.

5.3 Radii Of Expected Effects

Richardson *et al.* (1995) state that it is important to estimate radii of expected effects when assessing the impacts of anthropogenic noise on marine mammals. They define four radii including :-

5.3.1 The zone of audibility

The maximum distance of audibility of man-made noise on a marine mammal (assuming constant transmission loss) is determined by either the hearing sensitivity of the animal, the

background ambient noise level and the critical ratios. As many of the anthropogenic sounds are of low frequencies where toothed whale and seal sensitivities are poorer, the influence distance will be determined by the low sensitivity rather than the background noise. In the higher frequency range (over 5 kHz) where sensitivity of these species is higher the limit of influence will be determined by ambient noise.
In contrast in baleen whales having good hearing in the low frequency range the maximum radius of audibility will most likely be determined by ambient conditions rather than sensitivity.

5.3.2 The zone of responsiveness

The zone of responsiveness or the area around a marine mammal inside which it responds to man-made noise varies markedly for different noises and species. Reviews of responses to human activity are given by Richardson *et al.* (1995), however it must be noted that few examples referred to give received noise levels which elicited responses. These authors suggest that zones of responsiveness will be expected to be considerably smaller than the zone of audibility.

Both cetacean and seal species show a wide range of responses to anthropogenic noise. Variation results from both physical and biological factors within the source-path-receiver model, including :-

Physical factors
Sound propagation conditions can have varying influences in determining the received component of the sound source through variation in transmission loss rates. Furthermore background noise variation can cause major changes in the distances at which signal noises can be heard.

Biological factors
A number of factors will influence the responsiveness of the animal, including *activity of the animal* (Resting baleen whales are more prone to disturbance than those actively feeding, or involved in social activity or mating (Payne *et al.* 1983, Richardson *et al.* 1985)), *age or sex class* (Ljungblad *et al.* (1983, in Richardson *et al.* 1985) found mother calf gray whale pairs to be more responsive to aircraft than single adults), *habitat* (bowhead whales in waters restricted by depth appear more responsive to noise (Richardson *et al.* 1985) or *past conditioning to that noise source* (eg. habituation, sensitisation and tolerance). Habituation can be defined as a "gradual waning of responses when a repeated or ongoing stimulus lacks any significant consequences for the animal" (Thorpe 1963). Richardson *et al.* (1995) notes that although rigorous testing of habituation has seldom been carried out in marine mammals, apparent habituation to anthropogenic influences has often been reported. In contrast to habituation, sensitization or increasing responsiveness to human activities over time, has been reported in certain cases. Of the sensitisation examples noted by Richardson *et al.* (1995) many involved herding or hunting. Animals may tolerate anthropogenic noise despite physiological stress, due to the importance of the region in the ecological or physiological requirements of the animal. Richardson (*op cit.*) noted that tolerance has rarely been studied specifically, although many anecdotal reports occur in the literature.

5.3.3 The zone of masking

Detection of sound (communicative, echolocation or environmental stimuli) can be affected by anthropogenic noise. A sound signal will be masked if undetectable above the background noise. Within the zone of audibility the background noise will increase due to the anthropogenic component added to the ambient component. Zones of masking will be highly variable, depending on many factors including path distances and transmission loss, relative levels of the two sources and directional hearing abilities of the receiving animal. There is little information on the effects of masking. Generally low frequency man-made noise are more likely to affect communication calls of baleen whales, although sonar may affect echolocation in odontocetes.

5.3.4 The zone of hearing loss, impairment or injury or discomfort.

Continued or repeated exposure to high level sounds produces gradual deterioration of hearing. This may be a permanent threshold shift (PTS) or temporary threshold shift (TTS) which may last anything from a few minutes to a number of days. There is no published information on PTS or TTS in marine mammals. Richardson *et al.* (1995) speculates that continued exposure to levels of above 120 dB re 1μPa could result in PTS in toothed whales and seals. He doubts however that animals would remain in the zone of discomfort for long enough for impairment to occur. No literature is available on the distances at which sounds produce non-auditory injury or discomfort to marine mammals. Human divers report discomfort when exposed to intense underwater noise (eg 190 dB re 1 μPa)

Given the limited range of the noise output from the mining and the mobility of cetacean and pinniped species it is probable that species will move away from the source prior to discomfort occurring. *However powerful sonars may damage marine mammal hearing, especially those which operate at frequencies at which marine mammals are most sensitive.*

5.4 Potential Impacts of Diamond Mining

5.4.1 Resident cetacean species

Potential scenario's of impacts on resident marine mammal species include

1. The noise levels cause permanent or temporary injury to the marine mammal fauna.
The probability of this scenario occurring is assumed to be low given that permanent injury to hearing usually results from prolonged exposure to high noise levels. It is doubtful that marine mammals would tolerate continued exposure to high levels for prolonged periods. The greatest risk of hearing damage would occur if a powerful source including a sonar source was suddenly discharged at maximum volume in the vicinity of animals. As stated in Appendix I the sonardyne transponder produces very high sound levels in the frequency

ranges at which both small odontocete cetaceans and seals have the lowest auditory threshold, and may be a potential acoustic threat to both groups of marine mammals.

2. The noise levels result in permanent or temporary influences which may be direct (as an influence on the marine mammal species) or indirect (as an influence on prey distribution). Direct influences would include avoidance, interruption of feeding (echolocation) or social (communicative) behaviour and would probably result in a movement outside of the zone of influence.

5.4.2 Migratory cetacean species

The impact on migratory cetacean species would be considered minimal as apart from limited numbers of southern right whales in the extreme nearshore region, the only other species utilising the region would be humpback whales. Humpback whales migrating southward in the months of August to November (inclusive) may still be involved in breeding behaviour, including vocalisation of songs at between 20 Hz and 4 KHz (see Appendix II).

Few of the migratory whale species are feeding in southern African waters, with the majority of feeding occurring in polar latitudes. An exception to this would be the probably small component of the humpback whale population which does not make the polar migration, but remains in the west coast region in summer to feed (Findlay and Best 1995).

5.5 Spatial Influence of Negative Impacts.

The spatial influence of the negative impact will largely depend on the radii of the four zones discussed above. The zones of audibility of De Beers marine mining operations have been estimated in Appendix I. In assessing the range of noise effects, it is assumed that the Sonardyne transponder is utilised within the medium frequency range. Use of the transponder in the low frequency range will result in a considerable extension of the zone of audibility (from 11 km to almost 50 km). However, the variability in the physical and biological factors in the SPR model and the paucity of information on response, masking or discomfort threshold levels and critical ratios of marine mammals makes the definition of zonal limits highly speculative. Furthermore there is little information on the received levels of noise at which responses, masking or injury occur and thus the spatial influence of negative impacts is speculative. Consequently, for the purposes of this report (under a worst case scenario) zones of responsiveness have been assumed as the same as zones of audibility. However it must be stressed that in doing so the zones of responsiveness are probably considerably over-estimated.

5.5.1 Resident species

Heaviside's dolphin, dusky dolphin and Cape fur seals are distributed directly in the region of mining influence. However, the influence of mining operations is difficult to determine due to the lack of information on sizes of home ranges (in dolphin species) and foraging range (of the fur seal) and on home range shift in dolphin species. On the assumption of limited home range sizes (based on the one tagged Heavisides dolphin) it appears that the the area of mining noise influence could impact individuals resident in the area.

The majority of foraging by adult fur seals is carried out within continental shelf waters (Rand 1959) and in water depths of less than 200 m (Kooyman and Gentry 1986) and feeding grounds overlap with the mining area.

5.5.2 Migratory species

Of these species it is probably only the humpback whale which migrates through the mining area itself in any numbers, although limited numbers of southern right whales may occur in the inshore region of the mining area during the winter and the spring. Based on recorded migration speeds of approximately 5 km/h (Findlay 1994), humpback whales would migrate through the region of mining influence in less than 48 hours and disturbance could be considered minimal at present or even increased mining levels. The spatial influence of mining noise directly on feeding humpback whales in the area is considered minimal given the area (the entire Benguela upwelling system) over which these animals feed.

5.6 Duration of Impact

The duration of potential impacts are generally assumed to be temporary over the duration of the mining operation. This is based on the assumption that once mining ceases, noise ceases and any noise related influence will abate and that drill and crawler operation will not cause pathological injury to the species. The use of the sonardyne transponder at full level (192 dB re 1μPa at 1 m) at the frequencies of maximum hearing sensitivities of both odontocete cetacean and seal species could be within the ranges of permanent or temporary threshold shifts of these species. Unfortunately there is little information on the noise levels at which these occur in marine mammal species, so that the extent of this threat is unknown.

5.7 Quantified Intensity of Impact

For the majority of cetacean species the intensity of the impact would be assumed to be low, given the mobility of the species and the limited area of impact. However impacts would be larger for those species whose home ranges co-incide with the localised mining region. These would be limited to three species (Heavisides dolphin, dusky dolphin, and Cape fur seal). Although killer whales utilise the continental shelf waters of southern Namibia, there are no records of resident populations in the mining region. As all three species have distribution patterns extending over an area much larger than the mining region, it is assumed that mining will have a low intensity impact on the populations of these species.

Permanent hearing injury to individuals is likely to be minimal, although there is potential for injury from the high sonardyne transponder noise levels if marine mammal species are in close proximity to the region of operation when signals commence.

5.8 Cumulative Effects

The noise may have cumulative effects through impacting distribution of prey of seals or resident cetacean species. Only three (possibly four) species of cetacean (the killer whale, the Heaviside's dolphin, the dusky dolphin and possibly the southern right-whale dolphin) feed within the continental shelf region of Namibia.

Heavisides dolphin appear to feed on bottom-dwelling organisms, species that undertake vertical migrations (at night) and pelagic species. Demersal fish formed 49% of recorded stomach contents identified by Best and Abernethy (1994), while octopods comprised 22%. Gobies and squid also form important components of the diet. Sekiguchi et al (1992) note that two different feeding habitats have been recorded for dusky dolphins, namely on anchovies in the upper water column in Argentina and on mesopelagic prey in New Zealand waters. They note that local dusky dolphins probably feed in both habitats. There is no information on feeding of southern right whale dolphins in southern African waters.

Over 75% of seal diet is fish, while cephalopods make up 20% of the diet, although there are regional differences to the diet. Off the coast of Namibia a large percentage of the diet comprises bearded goby, with smaller percentages of horse mackerel and snoek.

Response of fish to underwater noise is briefly discussed in Appendix III.

5.9 Degree of Confidence in Predictions

The confidence in the predictions made in this report must be considered low given the paucity of data on many of the variables inherent in the impact description. Furthermore there is considerable paucity of information of the distributional biology of many of the marine mammal species in the region.

6 IMPACT ASSESSMENT - SIGNIFICANCE OF IMPACT

The significance of the impact on marine mammal populations would be assumed to be minimal as the sphere of influence of approximately 20 km will be small compared to the population distribution ranges of resident species and the migration range of the migratory species.

Although outside of the direct noise influence of the present mining operations, the localised distribution patterns of southern right-whale dolphins (offshore of the mining area) should be taken into consideration if mining were to be expanded to deeper waters. This species is generally found further south than the population off southern Namibia (Findlay 1989MS), and the lack of records between the Namibian distribution and the southern distribution suggest that the Namibian population is isolated and limited to this region of the cold Benguela current system.

7 MANAGEMENT ACTIONS REQUIRED

7.1 Mitigation / Enhancement Objectives

The relatively small area under the sphere of noise influence of mining operations suggests that little mitigation of mining operations is required. Coley (1994) suggested that the sphere of influence of mining operations was no larger than the noise influence of a medium sized merchant vessel, although based on literature reviews the mining noise appears higher than merchant vessel noise particularly in the frequencies where seal and odontocete cetacean hearing is maximum.

7.2 Mitigating Actions

It is recommended that sound levels of the sonardyne transponder are increased slowly to full levels if use is being resumed after a period of no operation. This would "clear" the zone of injury prior to operating at potential injury levels. Given the rapid mobility of odontocete species, this could be carried out over a one to two hour period. The Acoustic Thermography of Ocean Climate (ATOC) project allows sounds to build up gradually to the 195 dB re 1 μPa -m to allow any marine mammal to vacate the zone of influence before full power is assumed (ARPA 1995).

7.3 Performance Monitoring

Continual monitoring of the abundance of marine mammal species within the sphere of influence of the mining should be carried out. However two aspects would need to be considered in monitoring of marine mammal species.

1. No pre-mining monitoring of marine mammal species was carried out, so that there are no baseline data by which to compare new or future data.

2. The costs of such monitoring (aerial or shipboard) would be high and would probably have to be carried out on a seasonal basis to provide adequate information (little or no data exist on the seasonal distribution of many of the "resident" cetacean species in the area).

An initial cost effective method of determining avoidance of vessels by marine mammals is to keep records of species sighted from vessels involved in mining operations. Although strictly not quantitative in approach such data could provide some information on avoidance behaviour of marine mammals when mining vessels are operational.

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APPENDIX I.

ESTIMATION OF THE RADII OF AUDIBILITY OF DE BEERS MARINE MINING OPERATIONS TO MARINE MAMMAL SPECIES.

1 INTRODUCTION

As stated in the main body of the report, measurements of the source density spectrum levels of De Beers mining operations from the *Grand Banks* and *Louis G Murray* were undertaken by Coley (1994, 1995). Spectrum levels are measured as the mean square pressure per unit frequency or $\mu Pa^2/Hz$.

Although simple in concept, there are numerous factors which complicate the source-path-receiver model, particularly the path and receiver components of the model.

2 METHODS

On the basis of measured critical ratios for marine mammals and the fact that mammals generally can detect sound signals whose received level equal the background level in the 1/3 octave band, the source density spectra measured by Coley (1994, 1995) were integrated over 1/3 octave bandwidths (where the bandwidth equals 23% of the centre frequency). These 1/3 octave levels were then attenuated over various ranges using a model of spherical spreading -

$$L_r = L_s - 20 \log R - aR - 60$$

where L_r is the received level at range R (km) in dB re 1 μPa
L_s is the source level in the same dB units at 1 m
a is the molecular absorption co-efficient (from table)
and the constant of 60 is a conversion factor related to the change in range units from 1 m to 1 km.

It must be noted that a number of assumption are made in this simple model. Firstly, Richardson *et al* (1995) note that masking bandwidths may be less than 1/3 octave wide and therefore that the radii of audibility calculated by integration over 1/3 octave bandwidths may be overestimated. Furthermore the assumption of a simple spherical spreading model for shallow water transmission is tenuous, particularly at low frequencies.

Ambient noise levels at 1/3 octave levels for comparison to the above measured and calculated levels have been extracted from the literature. The prevalence of sea states in the region could provide some information of the temporal scale of the effects of mining noise.

General audiograms for pinniped and odontocete cetacean species have been extracted from the literature and applied to the source levels in the 1/3 octave bands as integrated from measurements of Coley (1994,1995). It should be noted however that the maximum sensitivity of the groups occurs near the upper end of the frequency measurements undertaken. The one baleen whale partial audiogram and other information has been extracted from the literature to define a probable audiogram for baleen whales.

3 RESULTS

One - third octave sound levels for centre frequencies of 10 Hz to 25 kHz at 1m, 100m, 500m, 1 km, 5 km, 10 km and 20 km for the *Grand Banks* and drill and *Louis G Murray* and crawler are presented in **Figures A-1 and A-2** respectively. Ambient noise levels for 1/3 octave bands are presented in **Figure A-3** (After Knudsen *et al.* 1948, in Richardson *et al.* 1995), while generalised audiograms for odontocete and pinniped groups and a partial response audiogram for a mysticete (gray whale) are presented in **Figure A-4** along with the expected optimum hearing sensitivity based on other baleen whale data. The genrealised audiograms for the odontocete cetacean and seal groups are overlayed in **Figures A-1 and A-2**.

Coley (1995) suggests that the range (above ambient) of the high frequency Sonardyne Transponder source (192 dB re 1μPa at 1 m at 36 kHz) would be approximately 8 km from the source in a sea state 3. Krige (*in litt*) notes that when operated in the low frequency range (approximately 10 KHz) the Sonardyne transponder has a greater than ambient noise level at 49 km.

4 DISCUSSION

Louis G Murray and crawler

Results show that the *Louis G Murray* and crawler noise has the potential to be heard by odontocete cetaceans at up to 10 km from the source in lowest sea state conditions. Pinniped threshold levels suggest a radius of audibility of between 10 and 20 km in a narrow frequency band (around 3 kHz) in calm sea conditions. As sea state increases this limit would decrease (to about 1-5 km in sea state 6). The higher ambient levels at lower frequencies where baleen whale hearing is probably most acute suggest that under calm conditions (sea state 0) baleen whale limit of audibility would be approximately one kilometre from the source.

Grand Banks and drill

Odontocete cetaceans would have the ability to hear the *Grand Banks* and drill combination at over 10 km from the source under sea state 0 conditions, although this limit would drop to between 5 and 10 km under sea state 6 conditions. Pinnipeds would detect the *Grand Banks* / drill combination (in the 3 - 10 kHz frequency range) at over 20 km under calm conditions, but as with odontocete cetaceans this would be limited to between 5 and 10 km under sea state 6 conditions. The limit of audibility of the *Grand Banks* and drill for baleen whales would range between approximately 10 km under sea state 0 conditions to 500 m under sea state 6 conditions.

Transponder

The frequency range of the Sonardyne transponder (8 to 65 kHz) coincides with optimal hearing abilities of both odontocete cetacean and seal species and the high levels of noise produced are within the ranges of discomfort experienced by human divers underwater. Optimal levels in the 25 to 50 kHz range are around 40 dB re 1 μPa at 1 m for odontocete cetaceans and 60 dB re 1 μPa at 1 m in the 10 to 25 kHz range for seals. With transmission loss based on a spherical spreading model these would correspond to audibility limits of between 5 and 10 km from the source for both groups. Although Watkins (1986) states that baleen whales react to sounds at frequencies of up to 28 kHz, it is assumed here that the transponder frequencies are outside of baleen whale hearing abilities.

5 CONCLUSION

Given the uncertainty of a number of components in the SPR model (including ambient noise levels, transmission loss and lack of information on hearing thresholds) the zones of audibility have been calculated from worst case scenario assumptions in the model. These correspond to lowest sea states. Limits of audibility of crawler operations have been estimated at 10 km, 20 km and 1 km for odontocete cetaceans, pinnipeds and baleen whales respectively. Limits of audibility of drill operations have been estimated at 10 km, 20 km and 10 km for odontocete cetaceans, pinnipeds and baleen whales respectively. Limits of audibility of transponder operations have been estimated at between 5 and 10 km for odontocete cetaceans and pinnipeds respectively.

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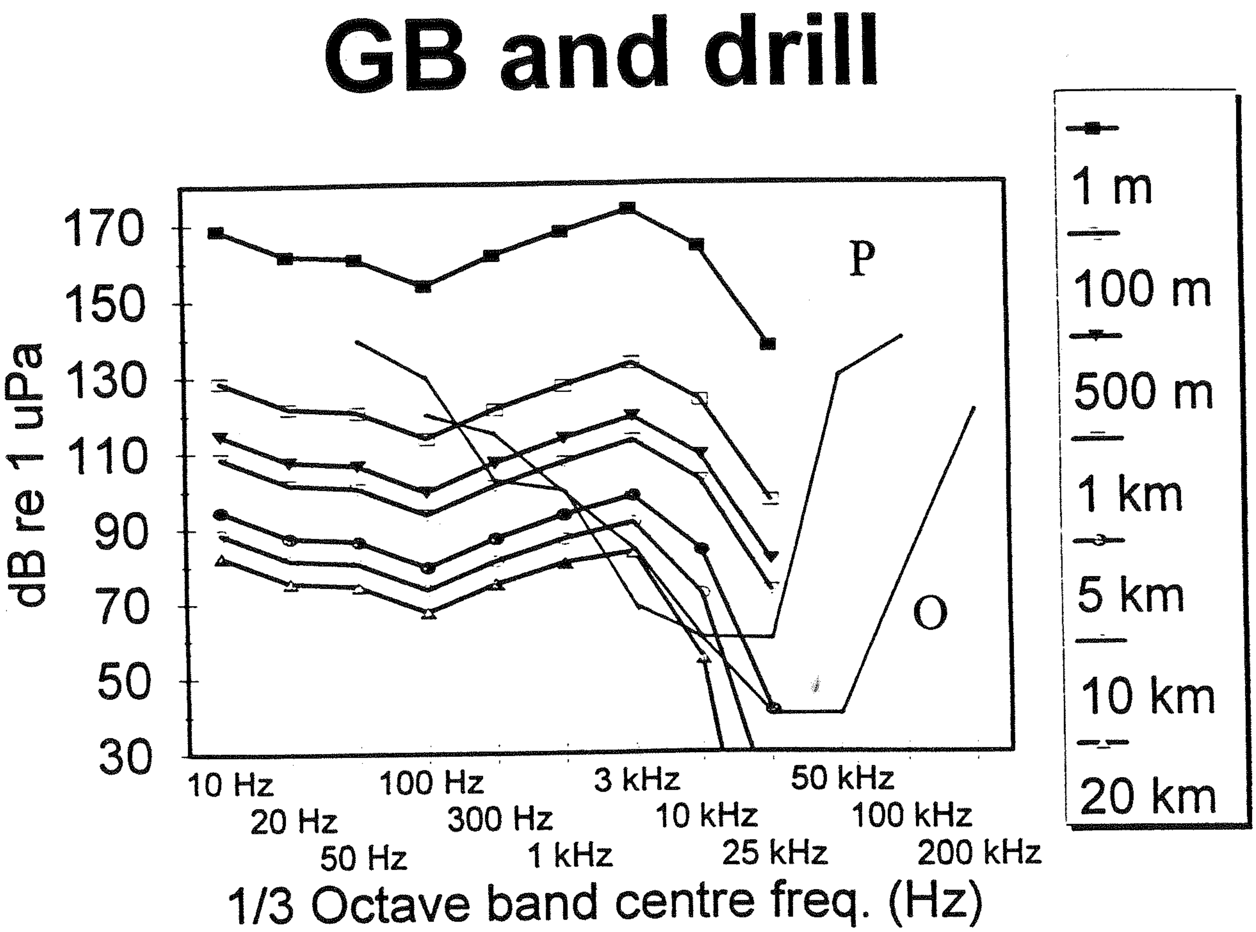

Figure A-1. Mining noise levels (in 1/3 octave bands) and attenuation with distance of noise levels of mining operations carried out with the *Grand Banks* and drill combination. Also shown are generalised audiograms for odontocete cetacean (O) and seal (P) groups (from Figure A-4).

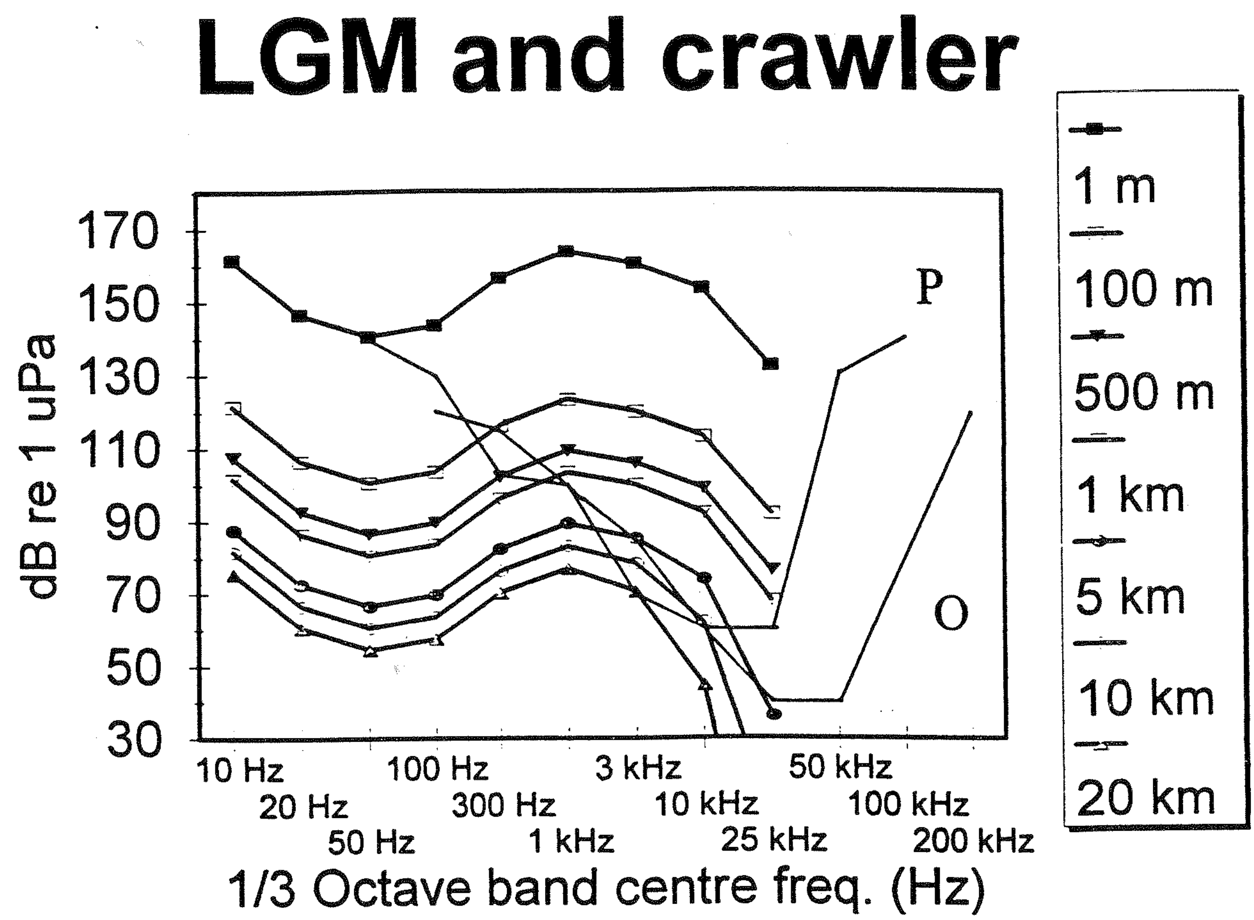

Figure A-2. Mining noise levels (in 1/3 octave bands) and attenuation with distance of noise levels of mining operations carried out with the Louis G Murray and crawler combination. Also shown are generalised audiograms for odontocete cetacean (O) and seal (P) groups (from Figure A-4).

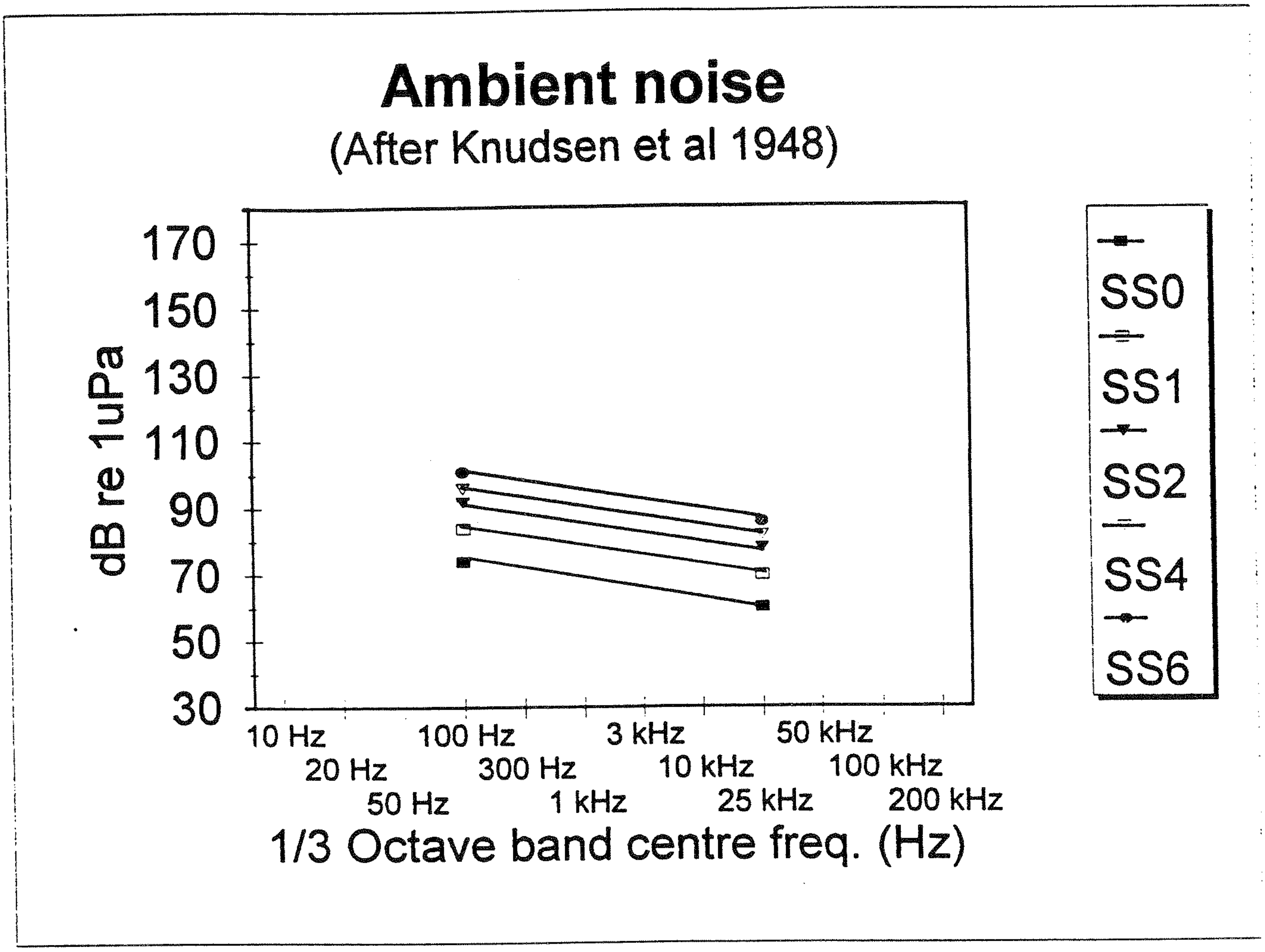

Figure A-3. Ambient noise levels (in 1/3 octave bands) for different seas states (After Knudsen *et al* 1984, in Richardson *et al* 1995).

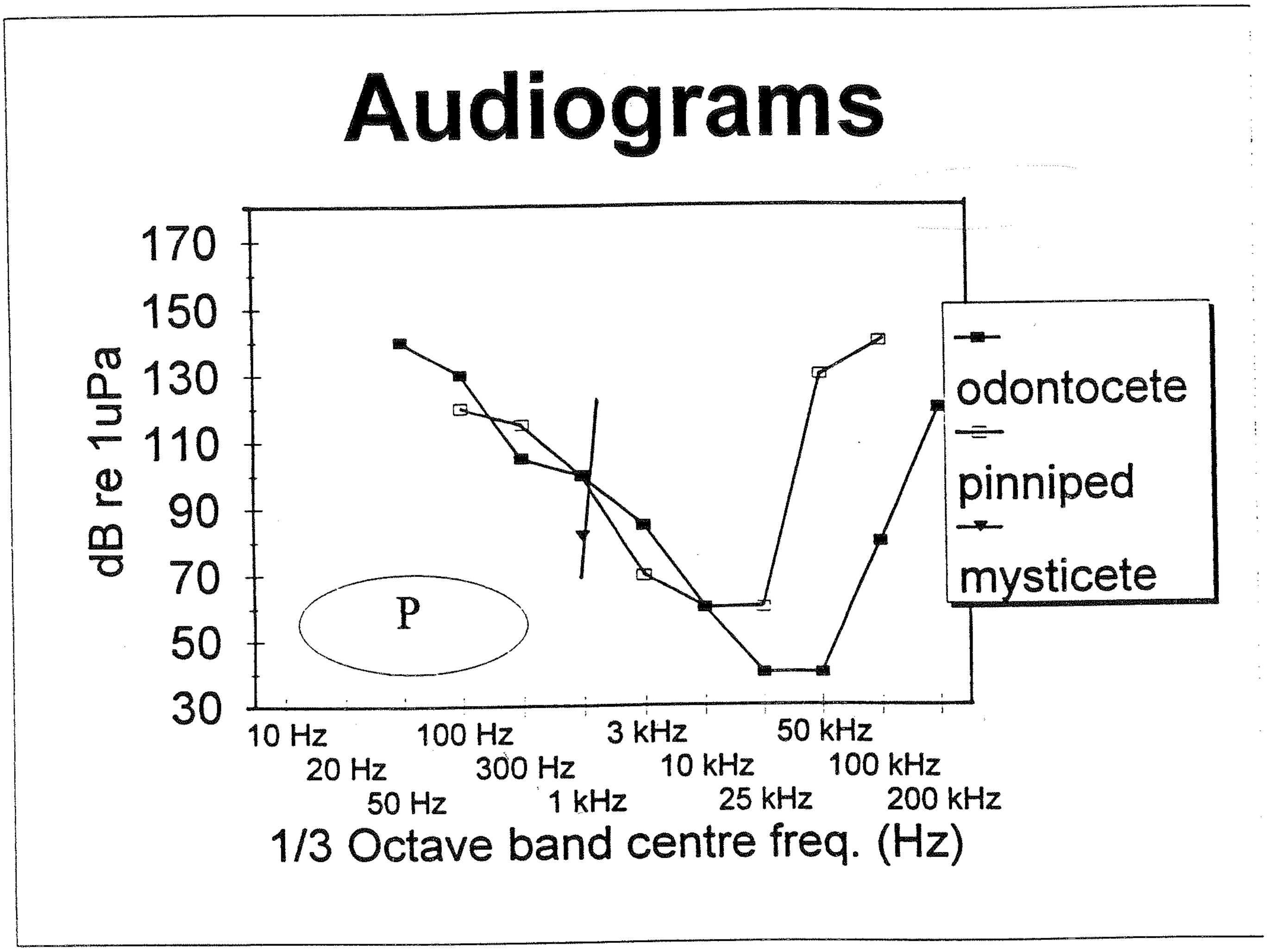

Figure A-4. Generalised audiograms for odontocete cetaceans, otariid seals and a partial audiogram for a mysticete species. (From Richardson *et al.* (1995) and Dahlheim and Ljungblad (1990)). P represents the probable zone of maximum sensitivity for mysticete species.

APPENDIX II.

BRIEF REVIEW OF VOCALISATION FREQUENCIES OF BALEEN WHALES.

Vocalisations produced by *bowhead whales* are tonal frequency-modulated sounds at 50-400 Hz. Although the majority of these sounds have little energy above 400 Hz, some extend to 1200 Hz. Source levels for simple moans have been measured at 128 - 178 dB re 1 μPa and source levels as high as 185-189 dB re 1 μPa at 1 m have been measured.

Southern right whales produce "up" and "down" sounds to maintain physical and acoustic contact. An up sound consist of a simple tonal FM up-sweep at 50 - 200 Hz (lasting less than 1.5 seconds) while a "down" sound consists of a low frequency tonal FM down-sweep of 100-200 Hz and of a similar duration. Source levels for right whales have been estimated at 172 -187 dB re μPa at 1m. Clark (1982, 1983) reports a range of other sounds produced by southern right whales including tones, high frequency FM sweeps, complex amplitude-modulated pulsatile sounds, mixtures of amplitude and frequency modulation all of which have their major energy in the 50 Hz to 1 kHz range.

Gray whales make knock and pulse sounds with frequencies of between 100 Hz and 2 kHz (most energy at 327 - 825 Hz). Cummings *et al.* (1968) reports the source level for knocks at ~ 142 dB re 1 μPa at 1 m.

Humpback whales produce three types of sounds, namely

a) complex stereotyped songs associated with reproduction (see Helweg *et al.* 1992). Components of these songs range from less than 20 Hz to over 4 kHz.Estimated source levels range from 144 - 174 dB re 1 μPa at 1 m. Individual songs last up to 30 minutes and bouts of singing are of unknown duration. Such singing is probably a reproductive display by males (Tyack and Whitehead 1983).
b) Social communication sounds on the winter breeding grounds (often produced by males competing for females) have frequency ranges of between 50 Hz and over 10 kHz with the major portion of the energy at less than 3 kHz. Although the source levels of such noises are unknown Tyack and Whitehead (1983) note that they can elicit a response from other humpbacks at 9 km away.
c) Sounds made by humpbacks on the feeding grounds in Alaska have been measured in the 20 Hz to 2 kHz frequency range at estimated source levels of 175-192 dB re 1 μPa at 1 m.

Blue whales produce long low frequency moans. Cummings and Thompson (1971) recorded moans of up to 36 seconds at 12.5 to 200 Hz off Chile. Source levels of these sounds were at up to 188 dB re 1 μPa at 1 m, while Edds (1982) recorded narrow-band moans of 16 seconds between 18 and 20 Hz. Richardson *et al.* (1995) notes that military hydrophone systems (SOSUS) are providing information on long distance low frequency calls of blue whales and notes that some calls have been detected at over 1000 km. *Fin whales* commonly produce 20 Hz sounds of 1 second duration. Watkins (1981) notes that such a sound would sweep downwards from ~ 23 Hz to 18 Hz over 1 second. Most have source levels of ~ 160-186 dB re 1 μPa at 1 m, although extremes of over 140 dB re 1 μPa at 1 m being recorded. Although such whale calls have been detected at over 185 km, Payne and Webb (1971) suggest that fin whales should be detected at much greater ranges. Fin whales also produce higher frequency sounds of up to 150 Hz at 155-165 dB re 1 μPa at 1 m. *Sei whales* have been recorded as producing phrase sounds of less than 1 second duration in the 1.5 to 3.5 kHz range. *Bryde's whales* recorded in the Gulf of California produced short moans of between 70 and 245 Hz (mean 124 Hz) with estimated source levels of ~ 152 to 174 dB re 1 μPa at 1 m.

The calls of some baleen whales species include components as low as 50 Hz and blue and fin whales can have dominant call components as low as 20 Hz. Richardson *et al.* (1995) speculates that if hearing sensitivity is good at 50 Hz then strong infrasounds at 5 Hz may be detected. Upper limits of the frequency range of up to 8 kHz has been recorded in humpback whales.

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APPENDIX III.

RESPONSE OF FISH TO UNDERWATER NOISE.

Fish may be affected by noise in two manners, through resonance of the swimbladder or through actual hearing (McCauley 1994).

Hearing

Fish hearing results from the vibrations of otoliths against sensory epithelia which encapsulates the otoliths. Reviews of hearing in fish have been provided by Popper and Fay (1973), Hawkins (1973), Travolga *et al.* (1981), Atema *et al.* (1988), Fay (1988) and Popper and Fay (1993). Fish are highly variable in their sensitivity to sound, although generally most fish can hear within the frequency range of 100 Hz to 1 kHz. Minimum thresholds vary considerably with maximum sensitivity ranging between 50 and 110 dB re 1 μPa, with peak sensitivities at 500 to 1000 Hz. Certain species have good sensitivity at very low frequencies of 1 to 10 Hz.

The wide differences in hearing capability and anatomy will result in a range of both behavioural responses and susceptibility to injury from noise levels.

Swimbladder resonance

Many fish species have a swimbladder, which comprises a thin membraneous sac ventral to the spine and within the body cavity. The function of the swimbladder may be either for buoyancy and or assisting with hearing. As a result of acoustic impedance swimbladders act as pressure receivers, vibrating in phase with sound waves.

Certain species (including the Clupeiformes) have coupling between swimbladders and the ears, which transmit sound energy from the swimbladders to the ears. Such species may have extended high frequency hearing up to 3 kHz.

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