Marine Noise

In-water noise will unavoidably be generated during the development of the proposed port expansion, and as a consequence of ongoing operations at both the new and existing facilities. Noise sources include pile driving, dredging activities and general vessel traffic.

Construction and associated activities will result in a temporary increase in noise levels and a change in the characteristics of ambient background noise. Operation of the expanded EAW will also have an associated marine noise impact, as maritime traffic will increase. These alterations could potentially affect transitory and resident marine fauna within the vicinity of these activities.

At this time the actual noise levels likely to be generated from this project, the exact frequency and duration of noise generating activities, and the time of year these activities are likely to occur, are unknown. Therefore, representative data from analogous harbour development projects have been drawn from the available literature.

A detailed review of underwater sound propagation, natural and anthropogenic sources of marine noise, and the potential vulnerabilities of marine fauna of interest is presented in **Appendix K**. This chapter presents a synopsis of the salient issues detailed in that Appendix.

13.1 Important Marine Fauna with Regard to Noise Generation

13.1.1 Cetaceans

The most commonly recorded cetacean species in Darwin Harbour are three coastal dolphins—the Australian snubfin (*Orcaella heinsohni*), the Indo-Pacific humpback (*Sousa chinensis*) and the Indo-Pacific bottlenose (*Tursiops aduncus*) (Palmer, 2008).

Other cetaceans that have been recorded in Darwin Harbour include the sperm whale (*Physeter macrocephalus*), the pygmy sperm whale (*Kogia simus*) and the humpback whale (*Megaptera novaeangliae*). However, recordings of these species are rare and represent vagrant individual sightings. Occasional pods of false killer whales (*Pseudorca crassidens*) are known to visit the harbour but little research has been conducted into their utilisation of the area (Whiting, 2003). The blue whale (*Balaenoptera musculus*) is not known to inhabit Darwin Harbour.

The peak audio-sensitivity of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) is between 10 kHz and 100 kHz. This is indicative of the other dolphin species which frequent Darwin Harbour, and collectively these species are considered by Southall et al. (2007) to be ‘mid-frequency cetaceans.

Baleen whales exhibit peak hearing acuity at frequencies lower than that for dolphins, and are referred to by Southall et al. (2007) as ‘low-frequency cetaceans. Humpback whales, for example, are predicted to exhibit maximum sensitivity in the range of 2-6 kHz.

13.1.2 Sirenians

Dugongs (*Dugong dugon*) are known to occur in Darwin Harbour in low numbers. Dugongs have been recorded in higher densities at Gunn Point and the Vernon Islands, approximately 30-50 km north-east of the mouth of the harbour. They have also been observed foraging on the rocky reef flats between Channel Island and the western end of Middle Arm Peninsula.

Little information is available on the auditory systems of sirenians, particularly dugongs. Initial research results into the auditory physiology and hearing sensitivity have highlighted some significant anatomical differences between dugongs and other marine mammals (URS, 2003). Their auditory range appears to be most sensitive in the middle frequencies (1-18 kHz) (URS, 2004). Dugong vocalisations are composed of barks at 0.5-2.2 kHz and higher frequency clicks and chirps at 3-18 kHz, and their sensitive range of audibility is between 1-18 kHz (Anderson & Barclay, 1995).

There are many anecdotal reports of dugongs avoiding areas with high boat traffic, though very little research has been undertaken to investigate the sensitivity of dugongs to noise. There are also anecdotal observations which suggest that dugongs may temporarily move from an area following explosive blasting.

13.1.3 Turtles

Six species of marine turtles are known to occur in the waters of northern Western Australian and the NT—the green turtle (*Chelonia mydas*), flatback turtle (*Natator depressus*), hawksbill turtle (*Eretmochelys imbricate*), loggerhead turtle (*Caretta caretta*), leatherback turtle (*Dermochelys coriacea*) and the olive Ridley turtle (*Lepidochelys olivacea*). Of these, the green, hawksbill and flatback turtles use Darwin Harbour regularly, and the olive Ridley and loggerhead turtles are suspected to be infrequent users. The leatherback turtle is considered to be an oceanic species and is unlikely to occur in Darwin Harbour (Whiting, 2001).

Very few studies have been conducted on the impact of sound on turtles and their subsequent behavioural response. Marine turtles do not have an external hearing organ, however, and it is thought that turtle auditory perception occurs through a combination of bone and water conduction.

Sea turtles have been recorded as demonstrating a startle response to sudden noises (Lenhardt et al., 1983; McCauley et al., 2000b). Studies have shown that the hearing range for marine turtles is approximately 100-700 Hz (McCauley, 1994), and maximum sensitivity between 300 and 500 Hz for green turtles (Ridgeway et al., 1969). Minimal information, however, is available regarding any reliable threshold level for the onset of behavioural effects.

A study found that a caged green and loggerhead turtle increased their swimming activity noticeably in response to a 166 dB (re 1 µPa) noise, and above 175 dB (re 1 µPa) their behaviour became erratic. In the case of pulsed low frequency sound effects on turtle nesting behaviour, nest numbers monitored on beaches near the Port of Hay Point (Queensland) before, during and after a pile-driving program lasting several months in 1996-97 were compared. Results showed no significant trend in nest numbers, indicating that the female turtles had not been particularly sensitive to this pulsed source (Dames & Moore 2000), but nest numbers were too few to provide a conclusive result.

13.1.4 Saltwater Crocodiles

The saltwater crocodile (*Crocodylus porosus*) occurs in Darwin Harbour, although its abundance is controlled by a trapping and removal program for public safety. Because only limited nesting sites for the saltwater crocodile are available inside Darwin Harbour, the area is not considered critical habitat for crocodile survival in the NT (Whiting, 2003).

The estuarine crocodile's ears are located immediately behind the eyes. The eardrum is protected by an elongated flap of skin. Hearing sensitivity can be altered by opening a slit in front of the flap, or lifting the flap upward. When submerged, the ears normally close, as hearing becomes secondary to the ability to feel vibrations through the water. Detectable frequencies range from below 10 Hz to over 10 kHz and sound pressure levels below 60 dB can be detected within certain bandwidths (Richardson, Webb & Manolis 2002).

13.1.5 Fish

Darwin Harbour waters support a high abundance of both resident benthic and transient pelagic fish species. A survey within the harbour undertaken by Larson and Williams (1997), documented a total of 415 species including 31 new records for the NT. Fish are known to inhabit a considerable range of habitats within the harbour catchment.

Barramundi is a particularly important commercial and recreational species in the NT. Spawning occurs at river mouths between the months of September and March and eggs and larval fish are carried by tides into supralittoral swamps at the interface of salt and freshwater, at or near the upper high tide level. Griffin (2000) indicated that the Darwin Harbour barramundi stock probably spawns in the vicinity of Lee Point and Shoal Bay as there is very little suitable nursery habitat within Darwin Harbour.

The variation among fishes in respect to sensitivity to sound is immense, and is in part due to the diversity of anatomical structures involved in detection (Popper & Fay 1999). Audiograms of fish species classified as 'hearing specialists' show high sensitivity to sound levels as low as 60 dB (re 1 µPa) across a broad frequency range (Blaxter 1980; Nedwell et al. 2004a).

Syngnathid species are 'hearing generalists' meaning that they do not have any auditory specialisations that confer sensitive hearing abilities. For the Syngnathidae the important metric when determining the susceptibility to physical injury, is its body mass. It is therefore the hatchlings that will be the most susceptible to physical injury from a pressure wave.

The capacity for hearing in syngnathid is not well understood. The frequency of noise making suggests that hearing sensitivity is greatest in the higher frequency ranges and, by extension that the least sensitivity is in the lower frequency range. Therefore is considered that any syngnathids exposed to noise below 180 dB (re 1 µPa) are unlikely to be significantly affected. In addition to being 'hearing specialists' and 'hearing generalist', it is now known that fish can also detect particle displacement (Fay 1988, Smith 2010).

There have been very few studies of the effects of anthropogenic sounds on the behaviour of fishes. Data are lacking not only on the immediate behavioural effects on fishes close to a source, but also effects on fishes further from the source.

13.1.6 Invertebrates

There is some evidence that increased background noise (for up to three months) may affect some invertebrate species. Legardère (1982) demonstrated that sand shrimp (*Crangon crangon*) exposed in a sound proof room to noise that was about 30 dB above ambient for three months demonstrated decreases in both growth rate and reproductive rate. In addition, Legardère and Régnault (1980) showed changes in the physiology of the same species with increased noise, and that these changes continued for up to a month following the termination of the signal.

13.2 Components of Anthropogenic Noise

13.2.1 Overview

The main anthropogenic sources of noise associated with Darwin Harbour and the EAW development include trading, working and recreational vessels, dredging activities and pile-driving programmes. This section reviews what is known about these noise sources. A broad overview of representative sources of anthropogenic noise is presented in Table 13-1.

Table 13-1 Typical Frequency Ranges of Anthropogenic Noise Sources (from data in NRC 2003)

Frequency Band	Principal Contributors
<10 Hz	Ship propeller blade and shaft rates, seismic survey sources, explosives, aircraft sonic booms.
10-100 Hz	Distant ships, explosives, seismic survey sources, construction and industrial activities.
100-1,000 Hz	All sources of the 10-100 Hz band plus nearby ships' cavitation, launches, small aircraft and seismic air-gun arrays, low frequency active sonar.
1,000-10,000 Hz	Shipping sources (close range), plus outboard powered boats, military tactical sonars, seafloor profilers and depth sounders.
10,000-100,000 Hz	Mine-hunting sonar, fish finders and some hydrographic survey systems.
>100,000 Hz	Mine-hunting sonar, fish-finders, high-resolution seafloor mapping devices (side-scan sonar), some depth sounders, some oceanographic and research sonar for small-scale oceanic features and some hydrographic survey systems (e.g. ADCP).

13.2.2 Vessels

Surface shipping remains the most widespread source of low frequency (<1000 Hz) anthropogenic noise (Popper et al. 1998). Ships generate substantial broadband noise from their propellers, motors, auxiliary machinery, gear boxes and shafts, plus their hull wake and turbulence. Diesel motors produce more noise than steam or gas turbines, but most long distance (low frequency) noise is generated by the 'hissing' cavitation of spinning propellers.

The Port of Darwin contains well established trading and recreational facilities that receive a wide variety of vessels, from small pleasure boats to commercial tankers, and traffic within the port has been increasing over time. Sound source levels of various vessel types are listed in Table 13-2.

Table 13-2 Comparison of Sound Source Levels from a Range of Anthropogenic Sound Sources

Source	Peak frequency or band	Peak source level/s (re 1 µPa 1 m)
Large tankers and bulk carrier blade and shaft rates*	10-30 Hz	180-186 dB
Container ship blade and shaft rates **	7-33 Hz	181 dB
Large tanker and bulk carrier cavitation	1000–4000 Hz	Not sure
64 m rig supply tender*	*(broadband)*	*177 dB*
Tug towing barge cavitation noise*	1000-5000 Hz	145-171 dB
20 m fishing vessel*	*(broadband)*	*168 dB*
25 m SWATH ferry with 2 x inboard diesels	315 Hz	166 dB
13 m catamaran with 2 x inboard diesels*	315/1600 Hz	159/160 dB
Bertram cabin cruiser with 2 inboard diesels*	400 Hz	156 dB
8 m rigid-hulled inflatable boat with 2 x 250 hp outboards blade and shaft rates*	50-300 Hz	177-180 dB
8 m rigid-hulled inflatable boat with 2 x outboards cavitation noise	1000 – 10 000 Hz	
4.5 m inflatable with 1 x 25 hp outboard*	2000-20 000 Hz	157-159 dB
Cutter-suction dredge (working)	100 Hz tonal	180 dB
Clamshell dredge (working)	250 Hz pulses	150-162 dB
Pile driving operations	Low tonal pulses	170-180 dB
Seismic survey	0-1000 Hz	200-232 dB
Drilling	10-4000 Hz	154-170 dB
Supply vessel	1-500 Hz	182 dB

* recorded at 10-11 knots; ** recorded at approximately 15 knots.

Source: Richardson et al., 1995; Dames & Moore, 1996; Au and Green ,2000; McCauley et al., 2002; University of Rhode Island, undated; URS, 2008.

13.2.3 Dredges

Typical dredge noise levels are summarised in Table 13-3. Received sound levels from some large trailer suction hopper dredges operating in rocky areas have been recorded in excess of 150 dB (re 1 µPa) at 1 km, while large CSDs can emit strong tones from the water pumps that are audible to 20-30 km ranges (Richardson et al., 1995; Dames & Moore, 1996).

Operating dredges will emit sound at their maximum source levels, which are in the 180 to 190 dB (re 1µPa) range (Richardson et al. 1995, Simmonds, Dolman & Weilgart 2004). Underwater noise levels from the self-propelled hopper barges engaged in transferring dredge spoil can be higher than the noises from the dredge itself, particularly during the loading and dumping operation of rocky material.

Reported source levels for general marine dredging operations range from 160-180 dB (re 1 µPa at 1 m) for 1/3 octave bands, with peak intensities between 50 and 500 Hz (Greene & Moore, 1995).

Table 13-3 Typical Sound Levels Produced by Dredges

Dredge Type	Frequency Range (Hz)	Distance from source (m)	Sound Level (rms) (dB re 1 µPa)	Notes
Cutter Suction	Broadband	1	180	
	Broadband	1	177	
	20-1000	190	133	
	20-1000	200	140	
Hopper	Broadband	1	188	
	20-1000	930	142	
	20-1000	930	177	
	20-1000	430	138	Loading
	20-1000	1500	131	Dumping
	10-2000	2000	127	
	10-2000	5000	120	
	10-2000	9000	110	

Source: Richardson et al. 1995; Simmonds, Dolman & Weilgart, 2004

13.2.4 Pile Driving

Underwater sound pressures from pile driving depend primarily on the size of the piles and the hammer. Other factors, however, can cause large variations in measured sound pressures at a particular project site or between sites. These factors primarily include water depth, tidal conditions or currents, and geotechnical conditions that determine how difficult it is to drive the pile and the contribution of ground borne sound.

McCauley et al. (2002) found that a pile driving event comprised one or two intense impulses associated with the weight being driven down, followed by 2-6 lower level bounces of the weight. Power spectra showed peaks mostly between 100 Hz and 1 kHz. Individual signals typically fell by 20-30 dB between the initial drops and last bounces. Signal duration averaged 47 ± 0.5 milliseconds (range 10-200 ms).

13.3 Categories of Sound Impacts

Reviews such as Richardson et al. (1995), Gisiner (1998), McCauley and Cato (2003) and URS (2003) note how sound waves from nearby, discernible sound sources affect marine mammals differently to those from distant, undiscernible ships and other low frequency sources which add to background ambient noise.

Development of harbour facilities serviced by heavy vessel traffic will also elevate local background levels, and may cause some species to avoid former nearby breeding or feeding areas owing to the amount of vessel movement disturbances as well as the noise. While some marine mammals appear more capable of habituating to such activities than others (such as dolphins in urbanised estuaries), their calving or pupping areas may be restricted to less disturbed locations.

Different types of noise can be broadly categorised as follows:

- Continuous or near-continuous sources that may prevent marine mammals or turtles from hearing social communications or other acoustic cues (= temporary masking effects).

- Noise that induces behavioural changes and responses in marine mammals and turtles.
- Noise that induces behavioural responses by the prey of toothed whales (fish, cephalopods).
- Very intense noise that may cause temporary or possibly permanent loss of hearing sensitivity to marine mammals via damage to the auditory hair cells (or other tissue trauma via possible excitatory and organ resonance mechanisms).

To assess the potential scale and likelihood of these effects, 'safety ranges' or zones of influence have been developed for predicting, measuring and managing noise-generating activities, in the same way that zones of lethality[2] have been used for assessing the spatial extent of possible marine animal injuries from the non-acoustic blast impulses of underwater explosions.

13.3.1 Zones of Influence

Depending on the type of source, the species of interest, its known or assumed habits and acoustic behaviours, one or several of the following zones can help determine an appropriate safety range. For a given source, these zones can be roughly ordered from likely largest to smallest as follows:

- Zone of audibility.
- Zone that induces behavioural avoidance or other undue stress.
- Zone that masks distant (low frequency) or nearby (high frequency) communication calls, echolocation pulses and possible navigation cues.
- Zone eliciting discomfort, flight and possible temporary hearing shift.
- Zone of pain, possible permanent hearing shift or other tissue injury.

An example of the zones of influence is shown in Figure 13-1. Further detail on each of these zones also follows.

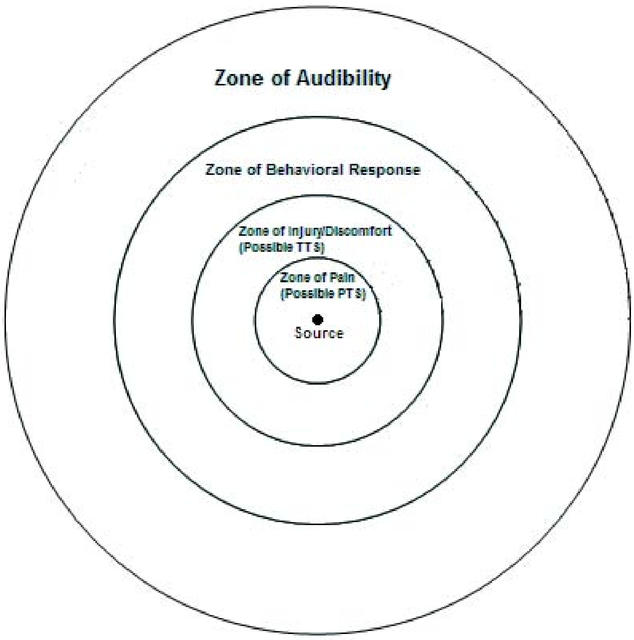

Figure 13-1 Zones of Influence

[2] The maximum amplitudes of acoustic waves that do not contain sufficient energy to kill, maim or stun marine mammals or turtles outright (e.g. Lewis 1996, Richardson et al. 1995, URS 2003).

Behavioural reactions to sound vary with the species and individuals of interest, including their state of attention and activity, maturity, experience and parental duty, all of which will alter with season, location, and time of day. Reactions involving relatively small avoidance responses by individuals are not biologically significant, whereas those produced in scenarios involving a near permanent sound source which may displace animals from key feeding or breeding grounds over monthly or seasonal time scales would impact growth, stress levels, breeding success, survivorship and population recovery rates.

For any given location and propagation conditions, the range at which the received sound of a source invokes a behavioural response will depend on the auditory sensitivity of the species of interest, while the biological significance of this response will vary according to the type of activity being undertaken. Not all behaviour responses increase risk of harm to individuals, breeding success or population recovery rates. Some responses may be momentary inconsequential reactions such as the turn of a head, or have limited duration and lie within the bounds of natural behaviour variations.

13.3.2 Exposure Criteria for Injury

Exposure criteria proposed by Southall et al. (2007) relate to injury to certain marine mammal groups and are based on received sound levels that meet the definition of Permanent Threshold Shift (PTS) onset. However, due to the lack of data in regard to PTS, criteria have been derived from measured or assumed Temporary Threshold Shift (TTS) onset thresholds and growth rate estimates for each marine mammal group.

The injury criteria for individual marine mammals exposed to ‘discrete’ noise events as proposed by Southall et al. (2007) are presented in Table 13-4.

Table 13-4 Proposed injury criteria for individual marine mammals exposed to 'discrete' noise events, either single or multiple exposures within a 24 h period (Southall et al. 2007)

Marine Mammal Group	Single pulses	Multiple pulses	Nonpulses
Low-frequency cetaceans			
Sound pressure level	230 dB re: 1 μPa (peak) (flat)	230 dB re: 1 μPa (peak) (flat)	230 dB re: 1 μPa (peak) (flat)
Sound exposure level	198 dB re: 1 μPa^2-s (M_{lf})	198 dB re: 1 μPa^2-s (M_{lf})	215 dB re: 1 μPa^2-s (M_{lf})
Mid-frequency cetaceans			
Sound pressure level	230 dB re: 1 μPa (peak) (flat)	230 dB re: 1 μPa (peak) (flat)	230 dB re: 1 μPa (peak) (flat)
Sound exposure level	198 dB re: 1 μPa^2-s (M_{mf})	198 dB re: 1 μPa^2-s (M_{mf})	215 dB re: 1 μPa^2-s (M_{mf})
High-frequency cetaceans			
Sound pressure level	230 dB re: 1 μPa (peak) (flat)	230 dB re: 1 μPa (peak) (flat)	230 dB re: 1 μPa (peak) (flat)
Sound exposure level	198 dB re: 1 μPa^2-s (M_{hf})	198 dB re: 1 μPa^2-s (M_{hf})	215 dB re: 1 μPa^2-s (M_{hf})

Source: Southall *et al*, 2007

13.3.3 Exposure Criteria for Behaviour

Not all behavioural responses to noise will have a significant impact on a population or even an individual. For example, it is unlikely that a startle response to a brief, transient event will persist long enough to create any response which could be deemed significant.

In addition, even strong behavioural responses to single pulses would be expected to dissipate sufficiently rapidly to have limited long term effect on individuals, let alone populations. Predicted linkages between adverse effects upon individuals and how these may translate to the population level have been presented conceptually by Tougaard et al. (2010), as depicted in Figure 13-2.

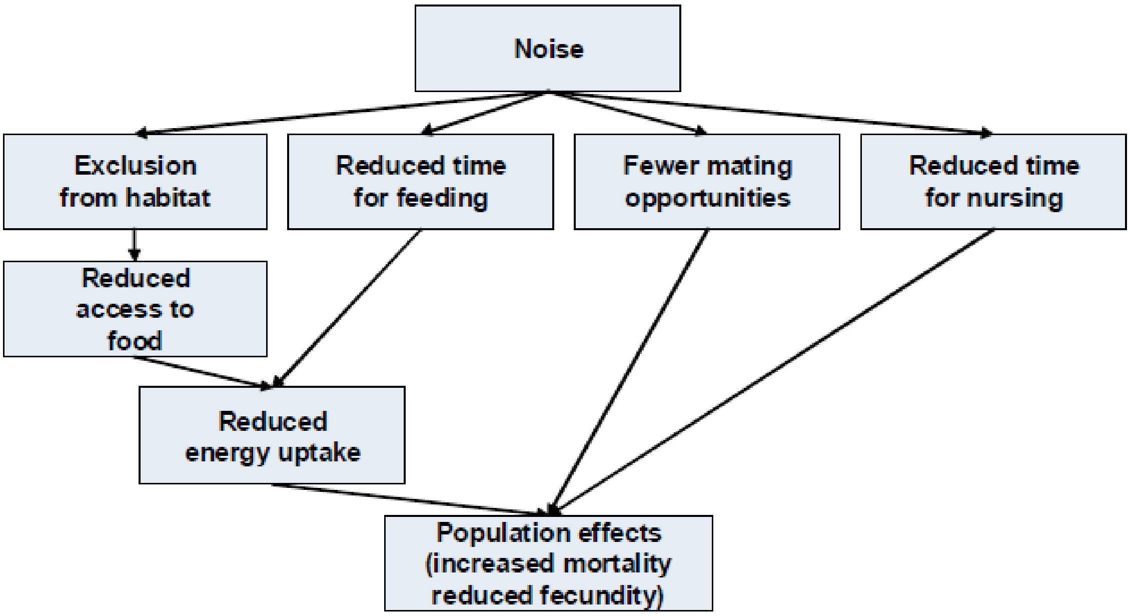

Figure 13-2 Conceptual Model Illustrating How Behavioural Reactions to Noise can have Effects on Population Parameters Directly and Indirectly

Source: Tougaard et al., 2010

Activity at the time of exposure, habituation and sensitisation to the sound, similarities between anthropogenic sound and biologically relevant natural sounds, age, sex, reproductive status, time of year and behavioural state, all affect variability in behavioural response to sounds. In general, however, short term startle-type responses are unlikely to be significant unless sustained over an extended period of time, as they are otherwise unlikely to affect vital rates (e.g. survival, maturation reproduction) or result in population effects (Southall et al., 2007).

13.4 Potential Effects of EAW Noise on Marine Fauna

It is difficult to predict which species will be most vulnerable to anthropogenic noise because of the wide range of individual and population sensitivities, as well as differences in wariness or motivation or degree of habituation. It may therefore only be possible to make generalisations about the vulnerability of species groups based on behavioural observations of responses to anthropogenic sounds, habits, and what is known about a species auditory sensitivity or vocal range.

When evaluating likely impacts, consideration should also be given to differences in local conditions that may affect sound propagation (e.g. depth, bottom type, size and type of source). The sources of noise examined include dredging, pile driving, and shipping noise.

13.5 Dredging

Some auditory masking may occur from dredging noise in Darwin Harbour. However, masking will only occur in the low frequencies (below approximately 5 kHz, with most noise below 1 kHz). Dredging noise is unlikely to occur at frequencies used by toothed cetaceans in echolocation.

The peak audio-sensitivity of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) is from 10 kHz to 100 kHz (Johnson 1967), compared 160-180 dB at 100 Hz propagated from a dredging barge. Much of the sound generated by dredging is thus below the audible range of Indo-Pacific bottlenose dolphins and those audible sounds would be at low intensity compared to their threshold of hearing (130 dB at 100 Hz).

Therefore, it is unlikely that significant disturbances to spotted bottlenose dolphins would be caused by underwater noise from dredging activities. It is also noted that recent large scale dredging in Port Phillip Bay, Victoria, was completed with no unacceptable adverse impacts to this species reported during environmental monitoring and audits (Port of Melbourne, 2010).

As the majority of dredge-derived noise is below 500 Hz (typically 100-200 Hz), it is likely that dugongs will not detect most dredging noise. It is therefore unlikely that dredging operations will mask dugong vocalisations. Sirenians have strong habitat and site association due to the limiting range of their main food source (seagrasses), however, and have shown a strong preference for sites with low ambient noise. It is therefore possible that dugongs may show short-term displacement from the close vicinity of the dredging area, but dugongs potentially have little ability to the majority of dredging noise.

Information from a number of conservative studies indicates that acute damage to fish caused by sound does not occur at received levels below about 160 dB (re 1 µPa), and only at such relatively low levels in rare circumstances. Noise levels as high as, or higher than, 160 dB (re 1 µPa) would only be generated within no more than a few metres or tens of metres of a CSD. This indicates that any potential for acute damage to fish would only be likely to occur in very close proximity to the cutter head.

Dredging noise varies through time and periodically dredging ceases whilst the dredger spuds in or undertakes maintenance and repair. This creates periods of calm and quiet, during which fish can move through the area undisturbed.

13.6 Pile Driving

The intense pulses of pile driving have been observed to injure swim bladders and kill fishes at close range to the pile in limited circumstances, and they have the potential to elicit a startle response from cetaceans.

Thresholds above which physical injury to marine mammals could occur are unlikely to be exceeded, other than in the immediate vicinity of pile-driving activities. Noise levels are likely to remain above thresholds for behavioural and acoustic disturbance for extended distances from the activity source (David, 2006).

13 Marine Noise

Noise levels from percussive piling have their highest energy at lower frequencies from about 20 Hz to 1 kHz, and whilst smaller cetaceans (approximately 3 to 4 m in length) are not known to be highly sensitive to sounds below 1 kHz, they can hear in some of this range (dolphin peak hearing range reported to be 8 to 90 kHz).

The reactions from cetaceans and dugongs could range from brief interruption of normal activities to short- or long-term displacement from noisy areas, and some acoustic masking of vocalisations in the lower frequencies could occur (David, 2006).

An assessment of the effect of impact pile driving noise on bottlenose dolphins was made by Bailey et al. (2010), on two wind turbines installed off north-east Scotland. The turbines were in deep (>40 m) water, potentially affecting a protected population of bottlenose dolphins. Pile driving noise was measured at a distance of 100 m (maximum broadband peak to peak sound level 205 dB [re 1 µPa]) to 80 km (no longer distinguishable above background noise). These sound levels were related to noise exposure criteria for marine mammals to assess possible effects. For bottlenose dolphins, it was discerned that auditory injury would only have occurred within 100 m of the pile driving (Bailey et al. 2010).

From their review of the available literature, Popper et al. (2006) propose interim criteria for injury to fish exposed to pile driving activities. Popper et al. (2006) suggest dual criteria, and propose that the onset of direct physical injury to fish exposed to pile driving would be at a sound exposure level of 187 dB (re 1 µPa^2.sec) and a peak sound pressure level of 208 dB (re 1 µPa).

These criteria are in line with the findings of Caltrans (2004) (cited in Popper et al. 2006), which showed no damage to steelhead trout (*Oncorhynchus mykiss*) and shiner surfperch[3] (*Cymatogaster aggregata*) when exposed to sound levels of between 158-182 dB (re 1 µPa^2.sec) at distances of 23 m to 316 m, and peak levels within the same range.

More recently *The Agreement in Principle for Interim Criteria for Injury to Fish from Pile Driving Activities*, utilising information in Carlson, Hastings, and Popper (2007), similarly identified sound pressure levels of 206 dB (re 1 µPa [peak]) and 187 dB (re 1 µPa^2.sec) cumulative sound exposure level (SEL) for all listed fish, except those that are less than 2 grams in weight. In that case the criterion for the cumulative SEL is 183 dB (re 1 µPa^2.sec). The criteria for non-auditory tissue damage were based on several studies where fish were exposed to relatively high amplitude blasts (peak pressures of approximately 20 psi or 223 dB [re 1µPa]) (Rodkin, Pommerenck and Reyff, 2010).

Several recent studies that exposed caged fish to pile driving sounds were summarized by Reyff (2010). When compared to control groups of fish, physical injuries or adverse behavioural responses from exposed fish were not observed in any of the experiments.

During a study at the Port of Seattle (Fishermen's Terminal Study 2006-07), juvenile Coho salmon exposed to maximum peak sound pressure levels of up to 208 dB (re 1 µPa [peak]), an average single strike SEL of 175 dB (re 1 µPa^2.sec), and a cumulative SEL of 207 dB (re 1 µPa^2.sec) in one workday resulting from 1,627 pile strikes. The juveniles survived for the 10-day holding period, revealed no external or internal injuries related to pile driving sound exposure, and readily consumed hatchery food during the first and subsequent feeding trials. Subtle behavioural changes of fish were noted in response to pile strikes. Thus these results and recent studies of fish in cages exposed to pile driving showed no physical trauma for fish exposed to levels significantly above a cumulative SEL of 187 dB.

[3] Note both these fish are teleost species, as are barramundi, and would be expected to exhibit similar hearing acuity.

13.7 Shipping Noise

It is not possible to predict the potential effects from changes or increases in vessel traffic noise upon dolphins, particularly in operating harbours where vessel noises are an established artefact of the ambient ‘soundscape’. Anecdotal illumination can, however, be drawn from similar scenarios in other harbours. For example, in Hong Kong, the routes of two major shipping fairways, namely Urmston Road and the South Lantau Freeway, pass through areas that are heavily used by Indo-Pacific humpback dolphins as indicated by ongoing long-term dolphin monitoring across all of Hong Kong’s western waters. A high level of anthropogenic background noise is reported around the key habitat areas for humpback dolphins, which is comparable to the sound level of a storm at sea and therefore increased disturbance from any additional construction vessels was expected to be minimal (Wursig & Greene, 2002).

A considerable body of fisheries literature exists on the behavioural response of fish to the noise of approaching vessels (Olsen, 1990). These studies have shown that fish avoid approaching vessels when the radiated noise levels exceed their threshold of hearing by 30 dB or more, usually by swimming down or horizontally away from the vessel path. Environmental and physiological factors play a part in determining the noise levels that will trigger an avoidance reaction in fish. For many vessels fish avoidance reaction distances are 100-200 m but for the noisiest 400 m is more likely. The degree of observed effect weakens with depth, with fish below about 200 m depth being only mildly affected and the effect is only temporary with normally schooling patterns resuming shortly after the noise source has passed. Surface and mid water dwelling fish may theoretically be adversely affected by noise generated during vessel movement, however the clear and abundant presence of fish that accumulate adjacent to operating industrial infrastructure (oil / gas production platforms, wharves, shiploaders, etc.) indicates that they are able to habituate to some noise with no apparent detriment.

13.8 Mitigation Measures

It is difficult to predict which species may be most vulnerable to anthropogenic noise because of the wide range of individual and population sensitivities as well as differences in wariness, motivation or degree of habituation. Currently, it is only be possible to make generalisations about the vulnerability of species groups based on behavioural observations of responses to man-made sounds, habits and what is known about a species auditory sensitivity or vocal range.

Some auditory masking may occur from dredging noise in Darwin Harbour. However, masking will only occur in the low frequencies (below approximately 5 kHz, with most noise below 1 kHz) and will be generally confined to a zone in close proximity to the dredging. Dredging noise is not likely to occur at the higher frequencies used by toothed cetaceans in echolocation.

The intense pulses of pile driving have been observed to injure swim bladders and sometimes kill fishes in limited circumstances, and they have the potential to elicit a startle response from cetaceans, particularly if the hammering operation is commenced without any form of soft-start procedure. Thresholds above which physical injury to marine mammals could occur are unlikely to be exceeded, other than in the immediate vicinity of pile-driving activities.

As shipping and vessel noise is a continuous noise source of relatively low intensity, thresholds above which injury to marine mammal hearing could occur will not be exceeded. Any impacts from vessel noise will be limited to behavioural disturbance and/or masking of other biologically important sounds.

A number of measures have been proposed to avoid, reduce or mitigate any potential impacts as a result of noise-intensive marine activities conducted by DLP within Darwin Harbour. The outcomes of recent modelling compared to established noise exposure criteria have been used to establish proposed safety for marine mammals and turtles during piling, dredging and other noise intensive activities. For sources of generally low acoustic disturbance (e.g. dredging, trenching) a safety range of 500 m is considered adequate for marine mammals and turtles to avoid the onset of physical injury. For sources of potentially elevated acoustic disturbance (e.g. pile driving) a safety range of 1000 m is proposed for marine mammals and turtles to avoid the onset of physical injury. Additional start-up procedures, observers and training will assist in mitigating any potential impacts as a result of noise-intensive marine activities.

13.9 Operational Management Procedures

Operational management procedures are provided for activities categorised into two disturbance levels. Sources of generally *low* acoustic disturbance include dredging, rock and sand/sludge dumping and general vessel traffic. A source of potentially *elevated* acoustic disturbance includes pile driving.

13.9.1 Marine Fauna Exclusion Zones

Sources of Generally Low Acoustic Disturbance (e.g. Dredging, Trenching)

The predictions derived from acoustic propagation modelling of dredging undertaken in the general vicinity of East Arm were evaluated in comparison with the exposure criteria referred to in Section 0, in order to predict safe ranges for marine mammals, turtles and fish. This modelling demonstrated that a safety range of 500 m from the source, for marine mammals and turtles, would be more than adequate to avoid the onset of injury (predicated as the threshold for the onset of PTS).

- It is proposed that prior to the commencement of any noise-intensive activity, a marine fauna exclusion zone extending 500 m in all seaward directions from the noise source should be established (see indicative examples provided in Figure 13-3)

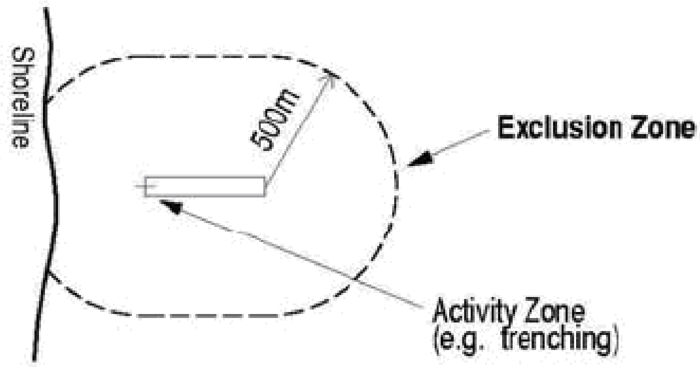

Figure 13-3 Example of Indicative Marine Fauna Safety Zone

- From one hour prior to the commencement of any noise-intensive activity, vessel and/or land-based observers should monitor the exclusion zone to check for the presence of any important marine fauna species (e.g. dolphins and dugongs).

- Activities may commence if no important marine fauna have been sighted within the exclusion zone 30 mins prior to the commencement of the activity.
- If any such species are observed within the exclusion zone, noise-intensive activities should not commence until the animal is observed to leave the exclusion zone, or until 30 mins of observations have passed since the last sighting and no more important marine fauna have been sighted.
- To enhance the effectiveness of surveillance, activities should preferably be commenced in appropriate sea conditions (e.g. sea state 3 or below) so that observers have a reasonable probability of sighting important marine fauna (see Section 13.9.4).
- Where practicable, suitably experienced personnel should continuously maintain an adequate look-out for the presence of important marine fauna within the exclusion zone during noise-intensive activities.

Sources of Potentially Elevated Acoustic Disturbance (e.g. Pile Driving)

The predictions derived from acoustic propagation modelling of pile driving undertaken in the general vicinity of East Arm were evaluated in comparison with the exposure criteria referred to in Section 0, in order to predict safe ranges for marine mammals, turtles and fish. The modelling indicated that a safety range of 50 m for marine mammals and turtles should avoid the onset of injury (PTS) from pile driving, and that an exclusion area of 500 m should be sufficient to avoid significant, adverse behavioural reactions. No injuries to 0.1 kg fish are predicted at distances of around 50–100 m from the pile (i.e. noise source), or for fish of 1 kg mass or greater at distances in excess of 50 m.

- Prior to the commencement of any noise-intensive activity, a marine fauna exclusion zone extending 500 m in all directions from the noise source should be established (see indicative example provided in Figure 13-3).
- From one hour prior to the commencement of any noise-intensive activity, vessel based observers (or land-based observers if appropriate) should monitor the exclusion zone to check for the presence of any important marine fauna species. Activities may only commence if no important marine fauna have been sighted within the exclusion zone 30 mins prior to the commencement of the activity.
- If any such species are observed within the zone, noise-intensive activities should not commence until the animal is observed to leave the exclusion zone, or until 30 mins of observations have passed since the last sighting and no more important marine fauna have been sighted.
- Activities should only be conducted in daylight conditions and preferably with appropriate sea conditions (e.g. sea state 3 or below) so that observers have a reasonable probability of sighting any marine fauna incursion into the exclusion zone.
- Suitably experienced personnel should continuously maintain an adequate look-out for the presence of important marine fauna during noise-intensive activities.

13.9.2 Initial Start-Up Procedures

These standard operational procedures (SOPs) apply to pile driving only.

Soft Start Procedure

- If no important marine fauna have been sighted within the applicable activity specific exclusion zone, the soft start procedure (also known as ramp-up) may commence, as outlined below:

  - If practicable, soft start procedures for pile driving should be used each time pile driving is commenced for the day, gradually increasing power over a 30 minute period.
- During daylight hours, visual observations should be maintained continuously during soft starts to identify any marine fauna within the precaution zones.

Start-up Delay Procedure

- If important marine fauna are sighted within the applicable activity specific exclusion zone during the soft start procedure, pile driving should be shut down.
- Soft start procedures should only resume after the animal has been observed to move outside the exclusion zone, or when 30 minutes have lapsed since the last sighting.

13.9.3 Stop Work Trigger

- If important marine fauna are sighted within the exclusion zone at any time noise activities should cease.
- Noise-intensive activities should only resume after the animal has been observed to move outside the exclusion zone, or when 30 minutes have lapsed since the last sighting.

13.9.4 Elevated Sea Conditions

- It is acceptable to commence or continue activities in elevated sea conditions (sea state 3 or above), in accordance with the SOPs:
  - provided that there have not been three or more instigated shut-down situations during the preceding 24 hour period, or
  - if operations were not previously underway during the preceding 24 hours, providing no marine fauna of interest have been sighted within the exclusion zone.

Note: In respect of potential impact to marine fauna, there are advantages to conducting activities during elevated sea conditions (e.g. times of rough sea and increased wind [sea state 3 or above]). The reason for this is that elevated sea states limit acoustic propagation ranges (especially in shallow coastal waters) and the increased background noise masks other noises, thus effectively reducing noise levels perceived by marine fauna. Noting this, such conditions should actually be exploited as a means of mitigating potential impacts.

13.9.5 Night Time and Low Visibility Activities

Sources of Generally Low Acoustic Disturbance

- At night-time or at other times of low-visibility (when observations cannot extend to the extent of the exclusion zone e.g. during fog or periods of high winds), the activity may commence in accordance with the SOPs:
  - provided that there have not been three or more instigated shut-down situations during the preceding 24 hour period; or
  - if operations were not previously underway during the preceding 24 hours, providing no marine fauna of interest have been sighted within the exclusion zone.

- During low visibility, where conditions allow, continuous observations within the marine fauna exclusion zone to spot important marine fauna should be maintained. If marine fauna are detected, then the stop work procedures should be implemented.

Sources of Potentially Elevated Acoustic Disturbance

- Activities should not take place outside of daylight hours.
- If low visibility conditions occur during daylight hours (when observations cannot extend to the extent of the exclusion zone e.g. during fog or periods of high winds) then the stop work procedures should be implemented.

13.9.6 Additional Operating Procedures (AOPs)

For acoustic sources operating in areas where it has been determined that the likelihood of encountering marine fauna is moderate to high, or where higher than predicated numbers of marine fauna have been encountered during operations, the application of additional measures may assist in reducing potential impacts and allowing for a greater level of management confidence.

The following measures are recommended, however, application of all these measures may not be necessary, applicable or possible for all operations, and should be assessed for applicability on an activity specific basis.

Observers

As the likelihood of encountering marine fauna increases, project managers should consider using additional observers. This will allow for greater confidence in identifying any important marine fauna within designated exclusion zones.

Night Time / Poor Visibility

Limit initiation of soft start procedures to conditions that allow adequate visual inspection of the exclusion zone.

Undertake last suitable light searches, via vessel, of the area to determine if marine fauna are present.

13.10 Conclusion

It may be concluded that noise intensive activities at EAW are generally unlikely to trigger any long-term, persistent, deleterious impact upon marine fauna. This conclusion is founded upon several key points, namely:

- The relatively low levels of noise expected to be generated and their attenuated propagation
- The temporary nature of the predicted acoustic disturbance
- The absence of any identified critical or important habitat in the subject project area for significant marine fauna.

It is possible that construction activities, particularly pile driving, will elicit some short-term behavioural changes in some fauna. These are likely to be confined to startle responses, and possibly also changes to feeding patterns and temporary avoidance of the project area. None of these are considered likely to result in long-term harm to either individuals or populations of any of the marine fauna considered.

13.11 Commitments

- *Prior to the commencement of any marine noise-intensive activity, a marine fauna exclusion zone extending 500 m in all seaward directions from the noise source would be established.*
- *Standard Operating Procedures (SOPs) would be implemented within the marine fauna exclusion zone to protect any important marine fauna species from the impacts of marine noise.*

References

Anderson, P. K. & Barclay, R. M. R., 1995, *Acoustic signals of solitary dugongs: physical characteristics and behavioural correlates*, Journal of Mammalogy 76:1226-1237.

Au, W. W. L. & Green, M., 2000, *Acoustic interaction of humpback whales and whale-watching boats*, Marine Environmental Research 49: 469-481.

Bailey, H., Senior, B., Simmons, D., Rusin, J., Picken, G., and Thompson, P., 2010, *Assessing underwater noise levels during pile-driving at an offshore wind farm and its potential effects on marine mammals*, Marine Pollution Bulletin 60: 888-897.

Blaxter, J. H. S., 1980, The swimbladder and hearing, in '*Hearing and Sound Communication in Fishes'* pp. 61–71 in, (eds W. N. Tavolga, A. N. Popper, and R. R. Fay), Springer-Verlag, New York.

Carlson, T.J., Hastings, M.C., and Popper, A.N., 2007, *Update on recommendation for revised interim sound exposure criteria for fish during pile driving activities, California*. Accessed 30 March 2011 at (http://www.caltrans.ca.gov/hq/env/bio/fisheries_bioacoustics.htm)

Dames & Moore, 1996, *Port of Hay Point Draft Impact Assessment Study for Dalrymple Bay Coal Terminal Stage 3 Expansion and Hay Point Coal Terminal Upgrade*, report prepared for Ports Corporation of Queensland.

Dames & Moore, 2000, *Dalrymple Bay Coal Terminal Expansion Stages 6 & 7- Draft Environmental Impact Statement. November 2000*, Ports Corporation of Queensland, Brisbane.

David, J. A., 2006, *Likely sensitivity of bottlenose dolphins to pile driving noise*, Water and Environment Journal 20: 48-54.

Fay, R. R., 1988, *Hearing in Vertebrates, A Psychophysics Databook*, Hill-Fay Assoc., Winnetka.

Gisiner, R. C., 1998, *Proceedings – Workshop on the Effects of Anthropogenic Noise in the Marine Environment*, accessed 19 March 2011 at (www.onr.navy.mil)

Greene, C. R. J. & Moore, S. E., 1995, *Man-made noise*. In: '*Marine Mammals and Noise*', (eds W. J. Richardson, C. R. J. Greene, C. I. Malme & Thomson DH.), Pp 101-158, Academic Press, San Diego.

Griffin, R. K., 2000, Background paper on possible interactions of prawn farms and barramundi habitat in the Shoal Bay area, in: *Draft Public Environmental Report: Howard River (East) Aquaculture Project*, Appendix L.

Johnson, C. S., 1967, Sound detection thresholds in marine mammals, in '*Marine Bioacoustics II*' (Ed W. N. Tavolga), Pp 247–60, Pergamon, Oxford.

Larson, H. K. & Williams, RS 1997, Darwin Harbour fishes: a survey and annotated checklist, in: *Proceedings of the Sixth International Marine Biological Workshop: The marine flora and fauna of Darwin Harbour, Northern Territory, Australia'* (Hanley et al. eds), Pp 339- 380, Museum and Art Gallery of the NT and the Australian Marine Sciences Association, Darwin.

Legardère, J-P., 1982, *Effects of noise on growth and reproduction of Crangon crangon in rearing tanks*, Marine Biology 71: 177-185.

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Lenhardt, M. L., Bellmund, S., Byles, S., Harkins, S. W. & Musick, J. A., 1983, *Marine turtle reception of bone conducted sound*, Journal of Auditory Research 23L:119–25

McCauley, R.D., 1994, The environmental implications of offshore oil and gas development in Australia – seismic surveys. In '*Environmental Implications of Offshore Oil and Gas Development in Australia – The Findings of an Independent Scientific Review Swan*', (eds. J. M. Neff & P. C. Young), Pp 19–122, Australian Petroleum Exploration Association, Sydney.

McCauley, R. D., Maggi, A., Perry, M. & Siwabessy, J., 2002, *Analysis of Underwater Noise Produced by Pile Driving, Twofold Bay, NSW – Phase 11, Signal Measures*, prepared for Baulderstone Hornibrook Pty Ltd.

McCauley, R. D. & Cato, D., 2003, Acoustics and marine mammals: Introduction, importance, threats and potential as a research tool. In: '*Marine Mammals – Fisheries, Tourism and Management Issues*'. (eds N. Gales, M. H. Kirkwood R. Kirkwood), Pp. 344-365, CSIRO Publishing, Victoria.

McCauley, R. D., Fewtrell, J., Duncan, A., Jenner, C., Jenner, M-N., Penrose, J. D., Prince, R. I. T., Adhitya, A., Murdoch, J. & McCabe, K., 2000a, *Marine seismic surveys: a study of environmental implications*, APPEA Journal 692-706.

Nedwell, J. R., Edwards, B., Turnpenny, A. W. H. & Gordon, J., 2004a, *Fish and Marine Mammal Audiograms: A summary of available information*, report prepared for Joint Industry Group.

Olsen, K. 1990, *Fish Behaviour and acoustic sampling. Marine Seismic Surveys - A Study of Environmental Implications*, APPEA Journal 2000: 692–707.

Palmer, C., 2008, *Coastal dolphin research in the Northern Territory*, Marine Biodiversity Group, Department of Natural Resources, Environment, the Arts and Sport, presentation made at the Coast to Coast Conference 2008, Darwin.

Popper, AN & Fay, RR 1999, *The auditory periphery in fishes*. Pp. 43–100. In: *Comparative Hearing: Fish and Amphibians*. Fay, R.R. and Popper, A.N. (eds). Springer-Verlag, New York

Popper, A. N., Ketten, D., Dooling, R., Price, J. R., Brill, R., Erbe, C., Schusterman, R. & Ridgway, S., 1998, Effects of anthropogenic sounds on the hearing of marine animals, in: '*Proceedings of the Workshop on the Effects of Anthropogenic Noise in the Marine Environment*', (ed R. C. Gisiner.), Pp 19-57, Office of Naval Research, Virginia.

Popper, A. N., Carlson, T. J., Hawkins, A. D., Southall, B. L., and Gentry, R. L., 2006, *Interim criteria for injury of fish exposed to pile driving operations: a white paper*, accessed 30 March 2011 at (http://www.wsdot.wa.gov/)

Port of Melbourne, 2010, *PoMC Quarterly and Annual Reports*, accessed 19 March 2011 at (http://www.portofmelbourne.com/channeldeep/environment/reports/qrtly/index.asp)

Reyff, J.A., 2010, Underwater sounds from unattenuated and attenuated marine pile driving, In '*Proceedings of the Second International Conference on the Effects of Noise on Aquatic Life*'.

Richardson, W. J., Greene, C.R., Malme, C.I. & Thomson, D.H., 1995, *Marine Mammals and Noise*, Academic Press, San Diego.

Richardson, K. G., Webb, J. W., & Manolis, S. C., 2002, *Crocodiles: Inside Out. A Guide to the Functional Morphology of Crocodilians*, Surrey Beatty and Sons, Sydney.

Ridgeway, S. H., Wever, G. E., McCormick, J. G., Palin, J., & Anderson, J. H., 1969, *Hearing in the Giant Sea Turtle, Cheldonia Mydas*, Auditory Research Laboratories, Princeton University, and Marine Bioscience Facility, Naval Undersea Research and Development Center.

Rodkin, R., Pommerenck, K., and Reyff, J., 2010, Interim criteria for injury to fish from pile driving activities – recent experiences. In '*Proceedings of the Second International Conference on the Effects of Noise on Aquatic Life*'.

Simmonds, M. P., Dolman, S. & Weilgart, L., 2004, *Oceans of Noise*, accessed 19 March 2011 at (http://www.wdcs.org/publications.php)

Smith, M. E., 2010, Predicting Hearing Loss in Fishes. In: '*Proceedings of the Second International Conference on the Effects of Noise on Aquatic Life*', Cork, Ireland.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene Jr, C.R., Kastak, D., Ketten, D.R., Miller, J.H., Nachtingall, P.E., Richardson, W.J., Thomas, J.A. & Tyack, P.L., 2007, *Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations*, Aquatic Mammals 33: 411-509.

Tougaard, J., Kyhn, L. A., Amundin, A., Wennerberg, D. & Bordin, C., 2010, Behavioral reactions of harbor porpoise to pile driving noise, in: *Proceedings of the Second International Conference on the Effects of Noise on Aquatic Life*.

University of Rhode Island, undated. *Discovery of Sound in the Sea*. accessed 19 March 2011 at (http://dosits.org)

URS Australia Pty Ltd, 2003, *Draft Environmental Management Plan for Australian Maritime Exercise Areas (Appendix P: Sensitivity of Marine Biota to Anthropogenic Noise)*, unpublished confidential draft report prepared for Australian Defence Force & Directorate of Environmental Stewardship

URS Australia Pty Ltd, 2004, *Review of DEH Guidelines on the Application of the EPBC Act to Interactions between Offshore Seismic Operations and Larger Cetaceans*, confidential report prepared for the Department of the Environment and Heritage.

URS, 2008, *Review of Literature on Sound in the Ocean and Effects of Noise and Blast on Marine Fauna*, prepared for the Water Corporation of Western Australia.

Whiting, S.D., 2001, *Preliminary observations of dugongs and sea turtles around Channel Island, Darwin Harbour*, Unpublished report prepared for the Power and Water Authority.

Whiting, S. D., 2003, *Marine mammals and marine reptiles of Darwin Harbour*, proceedings of the Darwin Harbour Public Presentations, Darwin Harbour Plan of Management.

Würsig, B., and Greene, C. R., 2002, *Underwater sounds near a fuel receiving facility in western Hong Kong: relevance to dolphins*, Marine Environmental Research 54:129-145