APPENDIX D

NOISE IMPACTS ON MARINE MAMMALS

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D-1.0 NOISE IMPACTS ON MARINE MAMMALS

D-1.1 Introduction

Noise is widely acknowledged to be an environmental pollutant for humans and many other terrestrial species, and has recently come to be recognized as a pollutant for marine animals as well. Noise levels in the sea began to increase steadily with the onset of industrialization in the mid-nineteenth century and the transition from wind-driven to mechanized shipping became the first major step in the anthropogenic sound increase within the oceans. Human-generated sound in the sea comes from a variety of sources, including commercial ship traffic, oil exploration and production, construction, acoustic research, and sonar use. Underwater sounds are also generated by natural occurrences such as wind-generated waves, earthquakes, rainfall, and marine animals. Marine mammals produce and hear a broad range of sounds to navigate and communicate because the oceans are much more transparent to sound than to light. As humans introduce more sound into the oceans, the conflict with marine mammal auditory systems becomes inevitable (NRC 1994, 2000, 2003 and 2005).

D-1.2 Marine Mammal Sound Production

It is well known that marine mammals emit vocalizations over a broad range of frequencies for communication and navigation. A list of marine mammal species expect to occur in the vicinity of the Bienville Offshore Energy Terminal (BOET) have been compiled and evaluated in respect to the frequencies that they use as part of daily communication and navigation. Table D-1 lists these species and their associated frequencies.

D-1.3 Interim Frequency Weighting in Marine Mammals

Although hearing ranges need to be determined for each of the species of marine mammals, the Noise Exposure Criteria Group (NECG) has proposed interim values for frequency-weighting in five groups of marine mammals: low-, mid-, and high-frequency cetaceans; pinnipeds in air; and pinnipeds in water (NECG 2005, unpublished) (Table D-2).

Table D-1. Sound Frequencies and Levels Used by Marine Mammals That May Occur in the Bienville Offshore Energy Terminal Vicinity

Common Name	Scientific Name	Sound Type	Frequencies and Levels Used by Marine Mammals		
			Total Frequency (Hz)	Dominant Frequency (Hz)	Source Level (dB)
Sperm whale	*Physeter macrocephalus*	Clicks	100 – 30,000 [a]	2,000 – 16,000 [a]	160 – 180 [e]
Sei whale	*Balaenoptera borealis*	FM sweeps	1,500 – 3,500 [b, e]		
Blue whale	*Balaenoptera musculus*	Moans	12 – 400 [e]	12 – 25 [e]	188 [e]
		Clicks	6,000 – 8,000 [e]	6,000 – 8,000 [e]	130 – 159 [e]
Fin whale	*Balaenoptera physalus*	Moans	14 – 750 [a, e]	20 – 40 [a, e]	160 – 190 [e]
		Clicks	16,000 – 28,000 [e]		
Bryde's whale	*Balaenoptera edeni*	Moans	70 – 950 [e]	45 – 900 [b, e]	152 – 174 [e]
Northern right whale	*Eubalaena glacialis*	Pulsive	30 – 2,200 [a, e]	50 – 500 [a, e]	172 – 187 [e]
Humpback whale	*Megaptera novaeangliae*	Song	30 – 8,000 [a, e]	100 – 4,000 [a, e]	144 – 186 [e]
		Moan	20 – 1,800 [e]	35 – 360 [e]	175 [e]
		Click	2,000 – 8,200 [e]		
Atlantic spotted dolphin	*Stenella frontalis*	Whistles		6,866 – 12,698 [d]	
Bottlenose dolphin	*Tursiops truncatus*	Whistles	800 – 24,000 [a,e]	3,500 – 14,500 [a,e]	125 – 173 [e]
		Clicks	1,000 – 150,000 [a,e]	30,000 – 130,000 [a,e]	218 – 228 [e]
Pantropical spotted dolphin	*Stenella attenuata*	Whistles	3,100 – 21, 400 [e]	6,700 – 17,800 [e]	
Risso's dolphin	*Grampus griseus*	Whistles		7,000 – 15,000 [b,c]	
		Clicks		65,000 [e]	
Spinner dolphin	*Stenella longirostris*	Whistles	1,000 – 22,500 [e]	6,800 – 16,900 [e]	109 – 125 [e]
Striped dolphin	*Stenella coeruleoalba*	Whistles	6,000 – 24,000 [e]	7,824 – 11,635 [d]	

[a] NRC 2000.
[b] Frankel 2002.
[c] Taken from general statement in (b) that most dolphin whistles center around 7 to 15 kHz.
[d] CFA 2004a.
[e] CFA 2004b.

Table D-2. Interim Frequency Weighting in Cetaceans Proposed by the Noise Exposure Criteria Group

Functional Hearing Group	Estimated Auditory Bandwidth	Genera Represented
Low-frequency cetaceans	7 Hz to 22 kHz	*Balaena, Caperea, Eschrichtius, Megaptera, Balaenoptera* (13 species/sub-species)
Mid-frequency cetaceans	150 Hz to 160 kHz	*Steno, Sousa, Sotalia, Tursiops, Stenella, Delphinus, Lagenodelphis, Lagenorhynchus, Lissodelphis, Grampus, Peponocephala, Feresa, Pseudorca, Orcinus, Globicephala, Orcacella, Physeter, Kogia, Delphinapterus, Monodon, Ziphius, Berardius, Tasmacetus, Hyperoodon, Mesoplodon* (56 species/sub-species)
High-frequency cetaceans	200 Hz to 180 kHz	*Phocoena, Neophocaena, Phocoenoides, Platanista, Inia, Lipotes, Pontoporia, Cephalorhynchus* (18 species/sub-species)
Pinnipeds in water	75 Hz to 75 kHz	*Arctocephalus, Callorhinus, Zalophus, Eumetopias, Neophoca, Phocarctos, Otaria, Erignathus, Phoca, Pusa, Halichoerus, Histriophoca, Pagophilus, Cystophora, Monachus, Mirounga, Leptonychotes, Ommatophoca, Lobodon, Hydrurga, and Odobenus* (41 species/sub-species)
Pinnipeds in air	75 Hz to 30 kHz	Same genera as pinnipeds in water (41 species/sub-species)

Note: The frequency cutoffs can be obtained from anatomical studies. The estimated auditory bandwidths are conservative estimates of the upper and lower boundaries for the most sensitive members of each group.

Source: Adapted from NECG 2005, unpublished.

D-1.4 Marine Mammal Responses to Anthropogenic Sound Sources

The problem in determining the biological significance of marine mammal responses is that the response is often not recognized when it is observed. Marine mammals are so hard to observe that serious problems may never be known without studies that are targeted to understand their normal behavior and physiology in the wild. The little that is known about behavioral responses of marine mammals to anthropogenic noise highlights the importance of understanding the demographic status of the animal(s) receiving the sound; the characteristics, location, and movement of the sound source; and the location of the animal(s). The history of the individual animal is also important, since prior exposure to the sound could have resulted in habituation or sensitization (NRC 2005).

Current knowledge of the lives of marine mammals is so limited that it is difficult to determine whether the small part of a behavioral reaction that can usually be observed is biologically significant. "The last few decades have seen a rapid increase in studies of the responses of marine mammals to noise and there is growing evidence that some sounds play a role in lethal strandings of deep-diving beaked whales, but there is not one case in which data can be integrated into models to demonstrate that noise is causing adverse affects on a marine mammal population" (NRC 2005). For most noise effects, the primary source of uncertainty stems from the difficulty in determining the effects of behavioral or physiological changes in an individual animal's ability to survive, grow, and reproduce. Available research detailing the responses of species that have the potential to occur in the vicinity of BOET are detailed in the sections below.

Sounds that occur within the auditory bandwidth of a species have the ability to "mask" other sounds occuring in the environment. Masking occurs when the noise created decreases the ability of an individual to hear other sounds. Masking becomes a problem when it covers biologically significant sounds, such as the call of a calf or conspecific (individual belonging to the same species), or the sound of a predator or hazard (NOAA 2003).

The MMPA prohibits the "take" of marine mammals, which is defined as the harassment, hunting, or capturing of marine mammals, or the attempt thereof. "Harassment" is further defined as any act of pursuit, annoyance, or torment. Currently, Level A harassment (potentially injurious to a marine mammal or marine mammal stock in the wild) for a marine mammal is defined as 180 dB rms re 1 µPa. Level B harassment (potentially disturbing a marine mammal or marine mammal stock in the wild by causing disruption to behavioral patterns) is 160 dB rms re 1 µPa for an impulse sound and 120 dB rms re 1 µPa for a continuous sound. (NOAA 2005, GPO 2005.)

D-1.4.1 Bottlenose Dolphin (*Tursiops truncatus*)

D-1.4.1.1 Temporary Threshold Shift

Temporary Threshold Shift (TTS) is a brief, transitory increase in an individual animal's hearing threshold in response to exposure to sound. During TTS experiments, Schlundt et al. (2000) noted disturbance reactions of captive bottlenose dolphins. The behavioral reactions involved avoidance of the sound source, refusal of participation in the test, aggressive threats, or attacks on the equipment. Finneran and Schlundt (2004) showed that the probability of those reactions increased with increasing received level from 160 to 200 dB rms re 1 µPa at 1m except for low-frequency (400-Hz) stimuli near the low-frequency boundary of auditory sensitivity. The reactions suggest that the signals were perceived as annoyingly loud.

The scientists at the Hawaii Institute of Marine Biology used continuous random noise with a bandwidth slightly greater than 1 octave as the fatiguing stimulus (using both behavioral and electrophysiological techniques) to measure TTS in the bottlenose dolphin. The fatiguing stimulus had a broadband received level of 179 dB rms re 1 µPa, which was about 99 dB above the animal's pure-tone threshold of 80 dB at the test-tone frequency of 7.5 kHz (Nachtigall et al. 2003). Exposure to 50 minutes of the fatiguing stimulus resulted in a TTS of 2-18 dB. Recovery from the TTS occurred within 20 minutes after the cessation of the fatiguing stimulus. More recent studies (Nachtigall et al., 2004) that used an auditory brainstem response (ABR) showed a TTS of 5-8 dB in response to 30 minutes of a 160-dB rms re 1 µPa fatiguing stimulus. Although the intensity of the fatiguing stimulus fell rapidly above 11 kHz, the greatest TTS was shown at 16 kHz.

Researchers at the Space and Naval Warfare Systems Center (SPAWAR) of the US Navy in San Diego used impulse sounds from a seismic watergun as the fatiguing stimulus and a behavioral technique to measure TTS (Finneran et al. 2002). The fatiguing stimulus had a variable duration of about 1 millisecond (ms), peak pressure of 160 kPa, a sound pressure of 226 dB peak-to-peak (p-p) re 1 µPa at 1m, and an energy flux density of 186 dB re 1 $\mu Pa^2 s$. No TTS could be demonstrated at 0.4, 4 or 30 kHz in spite of raising the fatiguing stimulus to its maximum intensity of 228 dB (Finneran et al. 2002).

Ridgway et al. (1997) exposed bottlenose dolphins exposed to 1-sec tones. Schlundt et al. (2000) expanded on this study to measure masked underwater hearing thresholds in five bottlenose dolphins before and immediately after exposure to intense 1-sec tones at 0.4, 3, 10, 20, and 75 kHz. TTSs of 6 dB or larger were observed after exposure to between 192 and 201 dB re 1 µPa. The exceptions occurred at 75 kHz, where one dolphin exhibited TTS after exposure at 182 dB re 1 µPa and the other dolphin did not show any shift after exposure to maximum levels of 193 dB re 1 µPa, and at 0.4 kHz, where no subjects exhibited shifts upon exposure to levels up to 193 dB re 1 µPa. At the conclusion of the study, all thresholds had returned to baseline values. There was no evidence of Permanent Threshold Shift (PTS).

Au et al. (1999) exposed captive bottlenose dolphins to 30 to 50 minutes of octave-band continuous noise in the 5 to 10 kHz band. Hearing was not affected when the noise level was 171 dB re 1 µPa (energy flux density of 205 dB re 1 μPa^2-s). Moderately strong TTS of 12 to 18 dB was obtained when the noise level was 179 dB re 1 µPa (energy flux density 213 dB re 1 μPa^2-s).

D-1.4.1.2 Response to Explosives

Jefferson and Curry (1994) reviewed studies of the effects of “Seal bombs”, with a source level of about 190 dB re 1 µPa, on marine mammals and found that they were largely ineffective. The use of these explosives was unsuccessful in keeping bottlenose dolphins off Africa and dolphins in the Mediterranean Sea away from fishing gear (Jefferson and Curry 1994). However, other studies reported that when “Seal bombs” were used to influence the movements of the dolphins around purse-seine nets set during tuna fishing operations in the eastern Pacific Ocean the dolphins would slow down and become confused and then form a protective school. (Cassano et al. 1990; Myrick et al. 1990 a, b; Glass 1989).

Finneran et al. (2000) exposed trained captive bottlenose dolphins to single simulated sounds of distant explosions. Broadband received sound levels were 170 to 221 dB re 1 µPa (p-p; 155 to 206 dB rms). Maximum spectral density was about 102 to 142 dB re 1 μPa^2/Hz at a 6.1 Hz bandwidth. Pulse durations were 5.4 to 13 ms. Behavioral alterations began at 196 to 209 dB (p-p; 181 to 194 dB rms; 120 to 127 dB re 1 μPa^2/Hz. The sound levels required to induce disturbance appear to have been similar to those found by Ridgway et al. (1997) and Schlundt et al. (2000). Behavioral alterations were departures from trained behaviors to the stimuli and included swimming around the enclosure rather than traveling directly between stations, vocalizing, refusing to return to a station, and remaining on a station.

Finneran et al. (2000) exposed two bottlenose dolphins to broadband sounds resembling that of distant underwater explosions. The intensity and duration of the pulses were not sufficient to cause TTS. A bottlenose dolphin showed a TTS of 5.6 dB when exposed to energy of 177 dB re 1 μPa^2-s. The waveform produced by the piezoelectric transducers lacked energy in the lower part of the spectrum, which contains most of the energy generated by explosives.

D-1.4.1.3 Resonance Effects

Marine mammals have many airspaces and gas-filled tissues, including lungs and air filled sinuses, that could theoretically be driven into resonance by impinging acoustic energy. Finneran (2003) used a backscatter technique to measure the resonance of the lungs of a bottlenose dolphin. He obtained a resonance frequency of 36 Hz for the bottlenose dolphin. However, the resonance was highly dampened and far less intense than predicted. The lungs experience a symmetric expansion and contraction. Finneran (2003) concluded that the tissue and other mass surrounding the lungs dampen the susceptibility of the lungs and probably other structures to resonate intensely.

D-1.4.1.4 General Behavioral/Physiological Changes to Noise

Würsig (personal observation cited in Richardson et al., 1995) summarized the responses of several species of dolphins to boats as “resting dolphins tend to avoid boats, foraging dolphins ignore them, and socializing dolphins may approach.”

Preliminary results from exposure of a bottlenose dolphin to a seismic watergun with peak pressure of 226 dB re 1 μPa showed no changes in catecholamines, neuroendocrine hormones, serum chemistries, lymphoid cell subsets, or immune function (Romano et al. 2001).

Oceanic dolphins typically vocalize more at night than during the day (Gordon 1987, Goold 2000).

D-1.4.2 Humpback Whale (*Megaptera novaeangliae*)

D-1.4.2.1 Response to Low Frequency Noise

Fristrup et al. (2003) analyzed 378 songs recorded before, during, and after playback in a playback experiment involving Surveillance Towed Array Sensor System-Low Frequency Active (SURTASS-LFA) sonar sounds and singing humpback whales. They found that the songs of the humpback whales were longer when the playback was louder.

Miller et al. (2000) followed 16 singers during 18 of the same playbacks in Fristrup et al. (2003). During 18 playbacks, nine of the whales stopped singing. Of the nine, four stopped when they joined with another whale (a normal baseline behavior), so, there were five cessations of song potentially in response to the sonar. The received levels measured next to the whales were 120-150 dB rms re 1 µPa, and there was no relationship between received level and the probability of cessation of singing. For six whales in which at least one complete song was recorded during the playback, the songs were an average of 29% longer.

Humpback whales moved away from low-frequency (3-kHz range) sonar pulses and sweeps but did not change their calling (Maybaum 1993)

D-1.4.2.2 General Behavior

Singing male humpbacks were found to vocalize more at night than during the day (Au et al., 2000).

Humpback whales, tended to cease vocalizations when near boats (Watkins, 1986).

Humpback whales are more likely to respond at lower received levels to a stimulus with a sudden onset than to one that is continuously present (Malme et al., 1985). These startle responses are one reason many seismic surveys are required to gradually increase the signal. With a gradual increase in signal, fewer animals will experience the startle reaction and individuals can vacate the area as the sound increases. There is no evidence, however, that this action reduces the disturbance associated with these activities.

Watkins (1986) summarized 25 years of observations of whale responses near Cape Cod to whale-watching boats and other vessels. Humpbacks changed dramatically from mixed responses that were often negative to often strongly positive reactions, which suggests acclimatization to the noise source.

D-1.4.2.3 Seismic Noise

Migrating or lingering humpback whales off Western Australia (McCauley et al. 1998, 2000) all showed clear avoidance reactions to seismic sounds at received levels of about 160 to 170 dB rms re 1 µPa and, in some cases, somewhat lower levels. Humpback whales showed avoidance at a mean received sound level of 140 dB rms re 1µPa.

D-1.4.3 Sperm Whale (*Physeter macrocephalus*)

D-1.4.3.1 Sonar

Sperm whales typically show a reduction or cessation of vocalization in response to short sequences of pulses from acoustic pingers (Watkins and Schevill 1975)

Sperm whales continued calling then encountered continuous pulsing from echo sounders (Watkins, 1977) and when exposed to received sound levels of 180 dB rms re 1 μPa from the discharge of a detonator (Madsen and Møhl, 2000);

Sperm whales in the Caribbean became silent in the presence of military sonar signals (3-8-kHz range; Watkins et al. 1985).

D-1.4.3.2 General Behavior

Immature sperm whales may have medium- and high-frequency hearing abilities similar to other smaller odontocete species tested to date. Whether this is true for adult sperm whales is unknown, and their absolute hearing thresholds are also unknown. Sperm whales often react (by becoming silent) when exposed to pulsed sounds at frequencies ranging from a few kHz up to at least 24 kHz (Richardson et al. 1995).

D-1.4.3.3 Seismic Noise

Sperm whales reacted to seismic sounds at a distance of about 20 km where received sound levels were 146 dB re 1 µPa (p-p) or 124 dB re 1 μPa^2 (Madsen et al. 2002).

D-1.4.4 Fin Whale (*Balaenoptera physalus*)

A fin whale continued to call with no change in rate, level, or frequency components as a container ship went from idle to full power within a kilometer of the whale (Edds 1988).

Watkins (1986) summarized 25 years of observations of whale responses near Cape Cod to whale-watching boats and other vessels. Fin whales changed from mostly negative to uninterested reactions.

D-1.5 Airburst Characterization

During operation of BOET, the intake of water for regasification may cause small organisms and debris to become impinged on the intake screens. Material that is not removed by the sweeping flow will be removed from the screen by a burst of air, or airburst, that will force all remaining material from the screen. Preliminary information on the characterization of the sound created by the airburst was determined by testing a similar airburst system. Those characteristics are shown in Table D-3. Although the airburst of the proposed system is expected to be louder (a higher decibel sound), the frequency of the sound and the rate of attenuation are expected to be the same. At startup of operations, each of the 16 screens (8 screens per HiLoad) will be cleaned once per day by use of the airburst. One screen will be cleaned at a time, followed by a 20-minute interval before the next screen is cleaned. Each burst will last approximately 10 seconds, with the highest intensity sound occurring for approximately 2 seconds. After an initial start-up period, differential pressure sensors on the screens will determine the frequency of airbursts needed. Based on the hydrodynamic design of the screens and their position within the water column, plugging is not expected to occur frequently. Therefore, the frequency of the necessary airbursts is expected to be less than once per day.

Table D-3. Sound Characterization of the Airburst System

Test Number	Distance from Source (ft)	Sound Duration (sec)	Estimated Maximum Intensity (dB re 1 µPa)	dB Change	Sound Intensity (Hz)
Source	0	---	108.77	---	---
1	35	10.10	108.50	0.0076/ft	10.60
2	100	6.30	108.01	0.0075/ft	7.00
3	400	1.65	105.34	0.0089/ft	15.00
4	500	2.00	104.69	0.0065/ft	18.00
5	1,000	---	100.88	3.81/500 ft	---
6	1,500	---	97.07	3.81/500 ft	---
7	2,000	---	93.26	3.81/500 ft	---
8	3,000	---	85.64	3.81/500 ft	---
9	4,000	---	78.02	3.81/500 ft	---
10	5,000	---	70.40	3.81/500 ft	---
11	10,000	---	51.35	3.81/500 ft	---

Note: The value of the source was estimated; the values of tests 1–4 were measured during the study; the values of tests 5–11 were calculated values per regression.

--- = Information not calculated.

Source: Cook Legacy 2005.

D-1.6 Conclusions

It is difficult to determine the biologically significant effects from most anthropogenic noise sources because of the difficulty in determining if the effects of behavioral or physiological changes alter an individual animal's ability to survive, grow, and reproduce. However, based on the studies presented some determinations of can be made about what levels and frequency of sound result in adverse reactions in marine mammals (Table D-4). The airburst system utilized at BOET is not expected to adversely affect marine mammals in the vicinity because of the low frequency, the level of sound below harassment levels, and the expected low frequency of use after start-up of operations.

Table D-4. Lower Limits of Anthropogenic Noise That Result in Adverse Behavioral or Physiological Effects in Specific Marine Mammals

Common Name	Scientific Name	Sonar		Seismic		Explosives	
		Frequency	Decibel	Frequency	Decibel	Frequency	Decibel
Bottle-nosed dolphin	*Tursiops truncatus*	16,000 Hz [j]	160 dB rms re 1 μPa [a, j]	400 - 30,000 Hz [d]	No effect [c,d]	----	181 dB rms re 1 μPa [b]
Humpback whale	*Megaptera novaeangliae*	3,000 Hz [e]	120 dB rms re 1 μPa [f]	----	140 dB rms re 1 μPa [g]	----	----
Sperm whale	*Physeter macrocephalus*	3,000 Hz [h]	----	----	146 dB re 1 μPa p-p [i]	----	----

μPa = Micropascals.
dB = Decibel(s)
Hz = Hertz.
p-p = Peak-to-peak.
rms = Root mean square.

[a] Finneran and Schundt 2004.
[b] Finneran et al. 2000.
[c] Romano et al. 2001.
[d] Finneran et al. 2002.
[e] Maybaum 1993.
[f] Miller et al. 2000.
[g] McCauley et al. 1998, 2000.
[h] Watkins et al. 1985.
[i] Madsen et al. 2002.
[j] Nachtigall et al. 2004.

TTS experiments in bottlenose dolphins have shown adverse responses and resulted in TTS over a range of frequencies (400 Hz to 75,000 Hz) when the sound reached levels as low as 160 dB rms re 1 μPa at 1m. Bottlenose dolphins exhibited adverse responses to explosives at source levels of 181 dB rms re 1 μPa. Resonance from low frequency sound does not appear to cause adverse effects due to resonance in Bottlenose dolphins but information is not available for high frequencies.

Humpback whales tend to either stop or prolong singing when exposed to low frequency sonar at 120 dB rms re 1 μPa and have been shown to move away from the source. Humpbacks tend to avoid contact with boats but some studies show that may be come acclimated to noise sources over long periods of time. They have also been shown to avoid seismic noises when the sounds approach 140 dB rms re 1 μPa.

Sperm whales cease singing when exposed to sonar with frequencies in the low kHz to approximately 24 kHz. They also react to seismic sounds at distances of up to 20 km and sound levels as low as 146 dB re 1 μPa.

There are few studies available on the fin whale but they appear to have no response to sonar or boat activities. No information is available on there response to seismic or explosive sounds.

Based on the information available, local species of marine mammals could have adverse responses to anthropogenic sounds at over a wide range of frequencies when the level reaches or exceeds 140 dB rms re 1 μPa.

D-1.7 References

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