ASSESSMENT OF THE EFFECTS OF UNDERWATER NOISE FROM THE PROPOSED NEPTUNE LNG PROJECT

By

LGL LIMITED
environmental research associates

and

JASCO Research Ltd

For

Ecology and Environment, Inc
Rosslyn Center
1700 North Moore Street
Arlington, VA 22209

LGL Report No. TA4200-3

12 October 2005

ASSESSMENT OF THE EFFECTS OF UNDERWATER NOISE FROM THE PROPOSED NEPTUNE LNG PROJECT

By

LGL Limited
environmental research associates
P.O. Box 280, 22 Fisher St.
King City, ON L7B 1A6

and

JASCO Research Limited
2001 – 1969 Upper Water Street
Halifax, NS B3J 3R7

For

Ecology and Environment, Inc
Rosslyn Center
1700 North Moore Street
Arlington, VA 22209

LGL Report No. TA4200-3

12 October 2005

The proposed Neptune LNG project will deliver LNG to offshore deepwater ports for re-gasification and shipment to shore by pipeline. Details of the project are discussed in the main application. The relevant aspects are discussed later in the present report. The proposed project activities during construction and operation will introduce noise into the water column, which may affect marine animals. The potential for those effects to occur and their significance are addressed in this assessment. The potential for ship-collisions with marine mammals was not part of the scope of the present assessment and is discussed elsewhere in the application matereials.

Three groups of marine animals are considered: marine mammals (whales and seals), sea turtles, and marine fish and invertebrates. The assessment consists of four parts. **(1)** The first part of the assessment determines the species and numbers in each group that are present in the area likely to be influenced by the project. This is followed by **(2)** a review of the known effects of the types of noise emanating from the Neptune project based on information from other studies. Part **(3)** is an acoustic analysis of the source levels of the various project noises followed by modeling of the propagation of the noises out from the source. Finally, **(4)** the propagation results are combined with the animal density data to determine the numbers of animals that might be exposed to the noise. This is followed by an assessment of potential effects based on the known responses of these animals as determined in other studies.

PART (1): NUMBERS AND SPECIES OF ANIMALS PRESENT

By

Susan Dufault*
John Christian**

*LGL Limited
14 Langley Avenue
Dartmouth, NS B2W 2Y6

**LGL Limited
Box 13248, Station A
388 Kenmount Rd.
St. John's, NL A1B 4A5

5 October 2005

TABLE OF CONTENTS

Marine Mammals

Species

This section describes the general distributions, densities, and conservation status of marine mammals likely to be seen in the Neptune project area. All marine mammals are protected in U.S. waters under the Marine Mammal Protection Act (MMPA) of 1972, which prohibits the take of all marine mammals within U.S. waters and by U.S. citizens on the high seas (NMFSa). In addition, species considered to be endangered or threatened with extinction throughout all or a significant portion of their range are afforded additional protection under the Endangered Species Act (ESA) of 1973 (NMFSb). The ESA also provides for the conservation of the ecosystems on which these species depend.

Fifteen species of cetaceans, including dolphins, small and large toothed whales, and baleen whales occur regularly in the Massachusetts Bay area. These are listed in Table 1. Some of these species are listed under the ESA as ***Endangered***. These are the North Atlantic right whale, humpback whale, blue whale, fin whale, and sei whale. In addition, the North Atlantic coastal stock of bottlenose dolphins is listed under the MMPA as ***Depleted***. Because of its ***Endangered*** listing under the ESA, the sperm whale (*Physeter macrocephalus*) is also included in Table 1, although it is rarely seen in Massachusetts Bay. The sperm whale is generally a deep water animal, and its distribution off the northeastern U.S. is concentrated around the 1,000-m (3,280-ft) depth contour, with sightings extending offshore beyond the 2,000-m (6,560-ft) depth contour. Sperm whales also can be seen in shallow water south of Cape Cod from May to November (CETAP 1982).

In addition to the 16 cetacean species outlined in Table 1, ten other cetacean species have been recorded for Massachusetts as rare vagrants or from strandings (Cardoza et al. 1999). These include six species of beaked whale—the northern bottlenose whale (*Hyperoodon ampullatus*), Cuvier's beaked whale (*Ziphius cavirostris*), Sowerby's beaked whale (*Mesoplodon bidens*), Blainville's beaked whale (*M. densirostris*), Gervais' beaked whale (*M. europaeus*), and True's beaked whale (*M. mirus*)—all of which are pelagic animals and recorded mostly as strandings; the beluga whale (*Delphinapterus leucas*), a northern species with rare vagrants reported as far south as Long Island (Katona et al. 1993); the pantropical spotted dolphin (*Stenella attenuata*) and false killer whale (*Pseudorca crassidens*), which are primarily tropical species with rare sightings in Massachusetts waters (Cardoza et al. 1999); and the pygmy sperm whale (*Kogia breviceps*), which is generally an offshore species that occasionally wanders inshore. These vagrant species are not discussed further.

Four species of pinniped occur in the Massachusetts Bay area (Table 1). None of these species is listed under the ESA. Harbor seals (*Phoca vitulina*) and gray seals (*Halichoerus grypus*) can be found year-round in northeastern U.S. waters, while harp seals (*Pagophilus groenlandica*) and hooded seals (*Cystophora cristata*) are seasonal visitors from much further north, seen mostly in the winter and early spring. Prior to 1990, harp and hooded seals were only very occasionally sighted in the Gulf of Maine, but recent sightings suggest increasing numbers of these species now visit these waters (Harris et al. 2001, 2002). Juveniles of a third Arctic seal species, the ringed seal (*Pusa hispida*), are seen on occasion as far south as Cape Cod in the winter, but this species is considered to be quite rare in these waters (Provincetown Center for Coastal Studies 2005) and is not discussed further.

TABLE 1. The habitat, occurrence, and conservation status of marine mammals found regularly in the Massachusetts Bay area.

Species	**Habitat**	**Occurrence in area**	**ESA Designation[1]**
Mysticetes			
North Atlantic right whale (*Eubalaena glacialis*)	Coastal and shelf waters	Common	Endangered
Humpback whale (*Megaptera novaeangliae*)	Mainly nearshore waters and banks	Common	Endangered
Blue whale (*Balaenoptera musculus*)	Coastal and pelagic	Uncommon	Endangered
Fin whale (*Balaenoptera physalus*)	Continental slope, pelagic	Common	Endangered
Sei whale (*Balaenoptera borealis*)	Primarily offshore, pelagic	Uncommon	Endangered
Minke whale (*Balaenoptera acutorostrata*)	Continental shelf, coastal	Common	N.L.
Odontocetes			
Sperm whale (*Physeter macrocephalus*)	Usually pelagic and deep seas	Rare	Endangered
Killer whale (*Orcinus orca*)	Widely distributed	Uncommon	N.L.
Long-finned pilot whale (*Globicephala melas*)*	Mostly pelagic	Common	N.L.
Bottlenose dolphin (*Tursiops truncatus*)	Coastal and oceanic	Uncommon	[Depleted[[2]
Atlantic white-sided dolphin (*Lagenorhynchus acutus*)	Continental shelf and slope	Common	N.L.
White-beaked dolphin (*Lagenorhynchus albirostris*)	Continental shelf	Uncommon	N.L.
Risso's dolphin (*Grampus griseus*)	Deep water	Uncommon	N.L.
Short-beaked common dolphin (*Delphinus delphis*)	Continental shelf and pelagic	Uncommon	N.L.
Striped dolphin (*Stenella coeruleoalba*)	Continental slope and pelagic	Uncommon	N.L.
Harbor porpoise (*Phocoena phocoena*)	Continental shelf	Common	N.L.

Table 1 (concluded).

Pinnipeds			
Harbor seal (*Phoca vitulina*)	Coastal	Year-round resident	N.L.
Gray seal (*Halichoerus grypus*)	Coastal	Year-round resident	N.L.
Harp seal (*Pagophilus groenlandica*)	Ice	Seasonal resident, January–March	N.L.
Hooded seal (*Cystophora cristata*)	Ice	Seasonal resident, January–March	N.L.

*The short-finned pilot whale (*G. macrorhynchus*), which is difficult to distinguish from the long-finned species at sea, has also been reported from Massachusetts (Cardoza et al. 1999); however, this species is predominantly a tropical species, with the northernmost limit of its range in the North Atlantic at Cape Hatteras (Leatherwood and Reeves 1983), and is very unlikely to be seen in the Massachusetts Bay area.

[1] Listed by the U.S. National Marine Fisheries Service (NMFS) Office of Protected Resources (http://www.nmfs.noaa.gov/prot_res/) under the Endangered Species Act of 1973 as follows: Endangered = the species has been determined to be in imminent danger of extinction throughout all or a significant portion of its range.

[2] North Atlantic coastal bottlenose dolphin stock is listed under the MMPA as Depleted.

Abbreviation: N.L., not listed.

Densities

The most comprehensive surveys for cetaceans within the Massachusetts Bay area were conducted in 1978–1982 as part of the Cetacean and Turtle Assessment Program (CETAP). The CETAP surveys encompassed waters overlying the U.S. Outer Continental Shelf from Cape Hatteras, North Carolina, to Nova Scotia, Canada. The CETAP investigators calculated seasonal density estimates for different portions of this region for several cetacean species that were sighted sufficiently often during those surveys. Those estimates for the entire Gulf of Maine are presented in Table 2. The Gulf of Maine area that was used to calculate these density estimates in the CETAP study is outlined in red in Figure 1.

Much more recently, the U.S. Navy (2005) conducted a Marine Resource Assessment (MRA) for northeastern U.S. waters. In that assessment, they used data from NMFS shipboard and aerial line-transect surveys (1991–2003) and from other rigorously collected line-transect surveys found in the North Atlantic Right Whale Consortium database to calculate seasonal sightings per unit effort (SPUE) values for marine mammals in northeastern U.S. waters. SPUE values are presented as the number of animals seen per 1,000 km (540 nm) of survey effort. Seasons were defined as winter, January–March; spring, April–June; summer, July–September; and fall, October–December. Their calculated SPUE values, which are uncorrected for sightability, are presented for the entire area in Table 3. A single SPUE value was calculated for each species and for each season for the entire 478,072-km^2 (139,205 nm^2) area, with a southern limit of 38°N and

TABLE 2. Seasonal densities of cetaceans in the Gulf of Maine from the 1978–1982 CETAP surveys.

Species	**Average density (individuals per 1,000 km^2)[1]**			
	Spring	**Summer**	**Fall**	**Winter**
Mysticetes				
North Atlantic right whale	2.78	2.61	0.00	0.00
Humpback whale	7.70	4.75	0.843	0.00
Fin whale	38.7	23.1	9.89	0.00
Sei whale	0.386	0.00	0.00	0.00
Minke whale	0.835	1.57	1.35	0.00
Odontocetes				
Sperm whale	0.00	0.00	0.00	0.00
Cuvier's beaked whale	0.00	0.00	0.00	0.00
Mesoplodont beaked whale	0.00	0.00	0.00	0.00
Pilot whale	8.05	0.00	4.50	0.00
Bottlenose dolphin	0.00	0.00	0.00	0.00
Atlantic white-sided dolphin	333[1]	188	296	39.4
Risso's dolphin	0.00	0.00	0.00	0.00
Short-beaked common dolphin	0.00	0.00	0.00	8.20
Spotted dolphin	0.00	0.00	0.00	0.00
Striped dolphin	0.00	0.00	0.00	0.00
Harbor porpoise	23.3	31.1	1.03	1.20

[1] Density estimates were corrected for interspecific differences in sightability. This correction included an estimate of the probability that an animal that is on the trackline is at the surface when the survey platform passes *and* is sighted by the observers. Density estimates were presented by CETAP (1982) in units of individuals per km^2. Those estimates were converted to units of individuals per 1,000 km^2 to facilitate comparison with other density estimates (see below). One thousand square kilometers is approximately equal to 291.2 square nautical miles.

Seasons were defined as follows: spring, 20 March to 20 June; summer, 21 June to 21 September; fall, 22 September to 20 December; and winter, 21 December to 19 March.

Species not appearing in the table were sighted too rarely during the CETAP surveys to estimate densities.

Source: CETAP (1982).

an eastern limit of 65°W. The seaward extent of this area is outlined in green in Figure 1. Thus, the SPUE values provided in the U.S. Navy (2005) report cover a wide range of latitudes, water depths, and distances from land, and these overall estimates do not necessarily reflect the specific marine mammal densities that are likely to be found in the Massachusetts Bay area.

In addition to the calculated SPUE values presented in Table 3, The U.S. Navy (2005) also used geospatial and statistical interpolation to predict SPUE values at unsampled locations and provide a model of marine mammal occurrence for the entire MRA area, as defined above. In that model, the entire area was divided into a grid of 10-minute longitude × 10-minute latitude cells. An SPUE value for each species was calculated for each cell that had at least 5 km of rigorous survey effort.

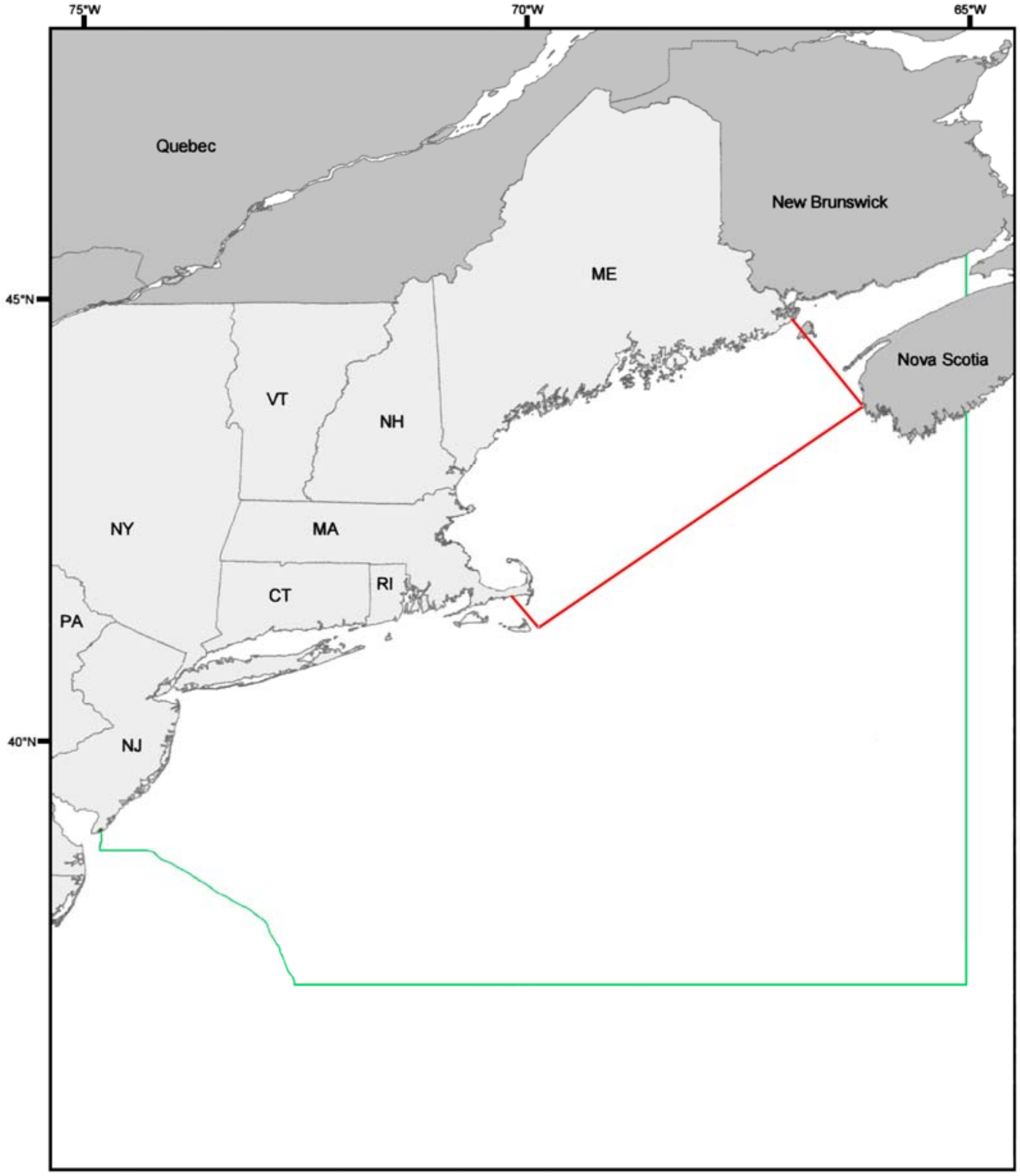

FIGURE 1. Map of the northeastern United States showing the seaward extent of the Cetacean and Turtle Assessment Program (CETAP) Gulf of Maine survey area (outlined in red) and the much larger U.S. Navy Marine Resource Assessment area (outlined in green).

For those cells with less than 5 km of survey effort, an SPUE value was estimated through statistical interpolation based on the SPUE values of surrounding cells. Thus, predicted values for the occurrence of each marine mammal species within each 10-minute × 10-minute cell were derived for the entire area. The predicted SPUE values were then separated into quartiles based on the range of SPUE values predicted for each species for all 10-minute × 10-minute cells for all seasons combined. Quartile 1 included the highest 25% of the SPUE range and Quartile 4 including the lowest 25% of the SPUE range. For example, for the North Atlantic right whale, the lowest predicted SPUE value for all 10-minute × 10-minute cells for all seasons was 0.01 animals per 1,000 km and the highest predicted SPUE value was 84.56 animals per 1,000 km. So Quartile 1 includes the top 25% of the 0.01–84.56 range, that is, 63.41–84.56. Thus, the entire area was mapped into four density levels for each species, representing the highest

TABLE 3. Seasonal SPUE values for marine mammals in the northeastern United States.

Species	**Mean (Minimum–Maximum) SPUE in animals per 1,000 km**			
	Winter	**Spring**	**Summer**	**Fall**
Mysticetes				
North Atlantic right whale	0.48 (0–62.92)	2.29 (0–179.52)	2.32 (0–445.15)	1.44 (0–441.35)
Humpback whale	0.41 (0–56.16)	2.74 (0–235.32)	3.10 (0–169.45)	1.96 (0–234.29)
Fin whale	2.14 (0–618.17)	4.85 (0–883.04)	4.73 (0–371.25)	3.79 (0–241.20)
Sei whale	0.15 (0–161.80)	2.71 (0–546.02)	0.71 (0–198.37)	0.07 (0–26.61)
Minke whale	0.07 (0–18.03)	1.59 (0–118.31)	1.46 (0–158.41)	0.58 (0–64.89)
Odontocetes				
Sperm whale	1.43 (0–290.31)	3.08 (0–641.76)	8.77 (0–2,758.26)	0.86 (0–237.83)
All beaked whales	0.07 (0–61.57)	0.31 (0–104.94)	2.43 (0–376.45)	0.08 (0–57.06)
Pilot whales	10.54 (0–3,281.32)	46.34 (0–5,430.41)	29.49 (0–4,037.82)	45.46 (0–7,108.86)
Bottlenose dolphin	35.86 (0–7,679.18)	34.74 (0–3,551.87)	42.14 (0–4,208.84)	50.07 (0–15,736.08)
Atlantic white-sided dolphin	5.42 (0–1,123.21)	62.09 (0–5,260.14)	57.37 (0–11,338.47)	43.95 (0–14,280.75)
White-beaked dolphin	0.10 (0–118.55)	0.15 (0–84.76)	0.01 (0–12.62)	0.00 (0–0)
Risso's dolphin	11.20 (0–5,389.51)	20.60 (0–7,245.12)	34.07 (0–5,752.05)	28.34 (0–12,826.16)
Common dolphins	92.32 (0–20,904.50)	117.49 (0–21,732.03)	49.70 (0–19,451.52)	89.97 (0–19,904.67)
Spotted dolphin	0.00 (0–0)	2.68 (0–995.54)	17.67 (0–11,376.45)	2.49 (0–1,913.54)
Striped dolphin	9.59 (0–4,449.61)	14.64 (0–6,788.01)	71.40 (0–17,682.06)	N.A.
Harbor porpoise	27.60 (0–2,508.61)	5.65 (0–330.80)	27.60 (0–2,508.61)	7.01 (0–1,555.64)
Pinnipeds				
Harbor seal	2.48 (0–930.80)	3.01 (0–2,463.90)	5.56 (0–1,874.38)	0.96 (0–504.24)
Gray seal	0.00 (0–0.13)	0.16 (0–169.77)	0.18 (0–209.69)	0.18 (0–229.67)

Table 3 (concluded).

Sightings per unit effort (SPUE) values were calculated using data from NMFS shipboard and aerial line-transect surveys (1991–2003) and from other rigorously collected line-transect surveys found in the North Atlantic Right Whale Consortium database for U.S. waters from Delaware to Nova Scotia, Canada. No corrections for missed animals were applied.

One thousand kilometers is approximately equal to 540 nautical miles.

Abbreviation: N.A., not available.

Source: U.S. Navy (2005).

25% (Quartile 1), the second highest 25% (Quartile 2), the second lowest 25% (Quartile 3), and the lowest 25% (Quartile 4) of all densities observed in all seasons combined. Table 4 provides the Quartile output values of the predicted SPUEs for the different marine mammal species or species groups commonly found in northeastern U.S. waters. Table 5 provides the quartile level of marine mammal density predicted by the U.S. Navy's (2005) model for the Neptune area and for the greater Massachusetts Bay area by season for each species or species group. An SPUE of zero indicates that there was survey effort in the area but no sightings occurred.

It should be noted that the sightings per unit effort data are not corrected for animals that are below the surface during the survey or animals that are at the surface but not seen. Also, the probability of seeing a particular marine mammal at the surface is a function of the species involved. Some species are easier to see than others. Therefore, care should be taken when using the SPUE data and when comparing the numerical findings for the various species.

Individual Species Accounts

Mysticetes

North Atlantic right whale (*Eubalaena glacialis*)

Right whales are generally found in waters with surface temperatures ranging from 8°C-15°C in areas that are 100-200 m deep (Winn et al. 1986). In the lower Bay of Fundy, they are generally distributed in an area where the bottom topography is relatively flat and the water column is stratified (Woodley and Gaskin 1996). In the Great South Channel, the average right whale dive depth was found to be only 7.3 m and few dives were deeper than 30 m (Winn et al. 1994). The primary prey item of the North Atlantic right whale is the copepod *Calanus finmarchicus*, and shifts in the distribution and abundance of this species can dramatically affect right whale distribution (Kenney 2001).

Right whales are known to aggregate in five seasonal habitat areas along the east coast of North America (IWC 2001a). Two of these areas are off the northeastern United States near the Neptune project area—Cape Cod Bay and Massachusetts Bay, and the Great South Channel. Right whales arrive in Cape Cod Bay in low numbers in January, their abundance peaks in March–May, and usually diminishes in June. They can be seen in the Great South Channel from April to July, with a peak abundance in May and June (IWC 2001a). Although there has been a great deal of effort put into identifying their distribution, on average, only about 25% of the known right whale population can be accounted for in any month except August and September (IWC 2001a).

TABLE 4. Quartile ranges[1] of the predicted SPUE values (in number of animals per 1,000 km) estimated by the U.S. Navy's (2005) geospatial analysis model.[2]

Species		**Quartile 4**	**Quartile 3**	**Quartile 2**	**Quartile 1**
Mysticetes					
North Atlantic right whale	0.01	21.14	42.27	63.41	84.56
Humpback whale	0.01	13.85	27.71	41.56	55.43
Fin whale	0.00	16.45	32.89	49.34	65.79
Sei whale	0.00	17.27	34.54	51.80	69.07
Minke whale	0.00	4.66	9.33	13.99	18.65
Odontocetes					
Sperm whale	0.01	49.26	98.52	147.77	197.04
All beaked whales	0.02	12.07	24.14	36.21	48.30
Pilot whales	0.01	271.42	542.85	814.27	1,085.70
Bottlenose dolphin	0.03	278.81	557.63	836.44	1,115.28
Atlantic white-sided dolphin	0.00	265.21	530.42	795.42	1,060.85
White-beaked dolphin	0.00	3.17	6.34	9.51	12.68
Risso's dolphin	0.00	503.63	1,007.25	1,510.88	2,014.50
Common dolphins	0.00	464.07	928.15	1,392.22	1,856.30
Spotted dolphin	0.45	143.57	287.15	430.72	574.75
Striped dolphin	0.02	376.97	753.93	1,130.90	1,507.89
Harbor porpoise	0.00	162.36	324.73	487.09	649.46
Pinnipeds					
Harbor seal	0.01	65.84	131.68	197.53	263.37
Gray seal	0.00	4.22	8.45	12.67	16.90

[1] The lower limit of each Quartile range is located in the left column and the upper limit of each Quartile range is located in the right column beneath each Quartile column heading. Thus, the upper limit of Quartile 4 takes the same value as the lower limit of Quartile 3. For example, for the North Atlantic right whale, Quartile 4 ranges from 0.01 to 21.14, Quartile 3 ranges from 21.14 to 42.27, Quartile 2 ranges from 42.27 to 63.41, and Quartile 1 ranges from 63.41 to 84.56.

[2] Uncorrected sightings per unit effort (SPUE) values were calculated for U.S. waters from Delaware to Nova Scotia, Canada (see Figure 1), for each 10-minute latitude × 10-minute longitude cell within the area using measured SPUE values and geospatial and statistical analyses to predict SPUE values for unsampled locations. Predicted seasonal SPUE values were pooled and divided into quartiles such that Quartile 4 represents the range of the lowest 25% of the predicted SPUE values, while Quartile 1 represents the range of the highest 25% of the predicted SPUE values. One thousand kilometers is approximately equal to 540 nautical miles.

Source: U.S. Navy (2005).

TABLE 5. SPUE quartile level for the Neptune area (and for the greater Massachusetts Bay area) by season for each species or species group as predicted by the U.S. Navy's geospatial model.

Species	**Predicted SPUE Quartile Level for Neptune Project Area (and Greater Massachusetts Bay Area)**			
	Winter	**Spring**	**Summer**	**Fall**
Mysticetes				
North Atlantic right whale	4 (4)	4 (4)	4 (4)	0 (4)
Humpback whale	4 (4)	4 (3)	3 (4)	3 (2,3,4)
Fin whale	4 (4)	4 (3,4)	4 (3,4)	4 (4)
Sei whale	0 (0)	0 (4)	0 (4)	4 (4)
Minke whale	4 (0,4)	4 (3,4)	4 (3,4)	4 (4)
Odontocetes				
Sperm whale	0 (0)	0 (0)	0 (0)	0 (0)
All beaked whales	0 (0)	0 (0)	0 (0)	0 (0)
Pilot whales	4 (0,4)	4 (4)	4 (0,4)	4 (4)
Bottlenose dolphin	0 (0,4)	0 (0,4)	0 (0,4)	4 (0,4)
Atlantic white-sided dolphin	4 (4)	4 (4)	4 (4)	4 (4)
White-beaked dolphin	0 (0)	0 (0,4)	0 (0)	0 (0)
Risso's dolphin	0 (0)	0 (0,4)	0 (0,4)	4 (0,4)
Common dolphins	0 (0)	0 (0,4)	0 (0,4)	4 (0,4)
Spotted dolphin	0 (0)	0 (0)	0 (0)	0 (0)
Striped dolphin	0 (0)	0 (0)	0 (0)	N.A.
Harbor porpoise	4 (4)	4 (4)	4 (4)	4 (4)
Pinnipeds				
Harbor seal	4 (4)	0 (0,4)	0 (0)	0 (0,4)
Gray seal	0 (0,4)	0 (0,4)	0 (0)	0 (0)

Source: U.S. Navy (2005).

Cape Cod Bay and Massachusetts Bay (as far north as 42°12' N and as far west as 70°30'W) and the Great South Channel (east of Cape Cod) are considered ***critical habitats*** for the North Atlantic right whale (NMFS 2005). Figure 2 shows the boundaries of these areas. The Neptune project area lies within the boundary of the Northeast Mandatory Ship Reporting zone that encompasses these two areas. The Mandatory Ship Reporting system was instituted to increase mariners' awareness of the severity of the problem of ship strikes of right whales and to seek their help in minimizing the threat. All commercial ships of 300 gross tons or greater must report to a shore-based station upon entering this zone and provide their name, call sign, course, speed, location, destination, and route (NMFSc). This system is in force year-round. NMFS is also considering rerouting vessels or restricting vessel speeds in designated areas or in dynamic management areas (which would be defined dynamically in real time based on right whale sightings) in the implementation of its Right Whale Ship Strike Reduction Strategy (EPA 2005).

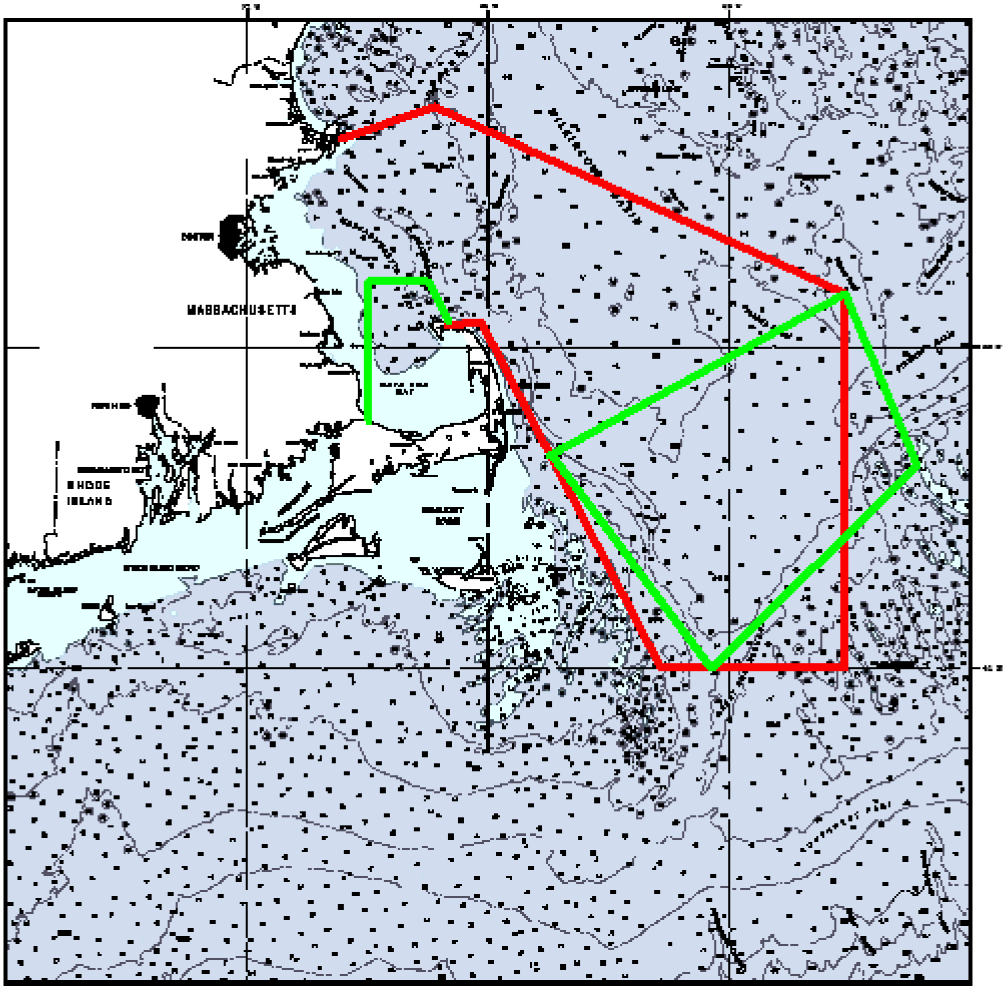

FIGURE 2. Map of Massachusetts waters showing the seaward boundary of the right whale Mandatory Ship Reporting system area (red outline) and the boundaries of the Cape Cod Bay and Great South Channel right whale critical habitats (green outlines). The Cape Cod Bay critical habitat is bounded to the south and east by the Cape Cod shoreline.

The western North Atlantic population of right whales is estimated to be on the order of about 300 individuals (IWC 2001b; Kraus et al. 2001) and appears to be declining (Caswell et al. 1999). Based on the Department of the Navy's (2005) geospatial model, right whale density near the Neptune area was estimated to be in the range of 0.01–21.14 animals per 1,000 linear km (540 nm) of survey during the winter, spring, and summer, while they found no right whales during systematic cetacean surveys in the area during the fall (Tables 4 and 5). In the greater Massachusetts Bay area, right whale density was estimated to be in the range of 0.01–21.14 animals per 1,000 km (540 nm) during all seasons.

Humpback whale (*Megaptera novaeangliae*)

The humpback whale is considered to be mainly a coastal species, although it often traverses deep pelagic areas while migrating. Its migrations between high-latitude summering grounds and low-latitude wintering grounds are reasonably well known (Winn and Reichley 1985). The Gulf of Maine–Scotian Shelf is one of five areas in the North Atlantic where humpback whales aggregate in the summer to feed (Katona and Beard 1990). Their distribution within the northeastern U.S. summer feeding area is highly dependent on the distribution of primary prey species, such as sand lance and herring, and can vary dramatically (Weinrich et al. 1997).

Waring et al. (2004) provide a best available estimate of 11,570 (CV = 0.069) for the western North Atlantic stock of humpback whales and a best available estimate of 902 (CV = 0.41) for the Gulf of Maine population of humpback whales. Based on the U.S. Department of the Navy's (2005) geospatial model, humpback whale density near the Neptune area was estimated to be in the range of 0.01–13.85 animals per 1,000 km (540 nm) of linear survey during the winter and spring and 13.85–27.71 animals per 1,000 km during the summer and fall (Tables 4 and 5). In the greater Massachusetts Bay area, humpback whale density was estimated to be in the range of 0.01–13.85 animals per 1,000 km during the winter and summer, from 13.85–27.71 animals per 1,000 km during the spring, and from 0.01–41.56 animals per 1,000 km during the fall.

Blue whale (*Balaenoptera musculus*)

The blue whale is widely distributed throughout the world's oceans and occurs in coastal, shelf, and oceanic waters. It is believed that blue whales undergo north–south seasonal migrations between summering and wintering areas, but some likely stay at low latitudes year round (Perry et al. 1999). Migratory routes occur in the open ocean and are not well known. Known summer feeding areas are at high latitudes, while the locations of wintering areas are somewhat speculative (Perry et al. 1999). In the western North Atlantic, blue whales occur in the Gulf of St. Lawrence and east of Nova Scotia in the spring, summer, and fall; in the Davis Strait in summer; and off southern Newfoundland in winter (summarized by Waring et al. 2002).

All populations of blue whales have been exploited commercially, and many have been severely depleted as a result. The North Atlantic population has been estimated to be 1,400 (NMFS 1998), while that of the western North Atlantic is probably on the order of a few hundred individuals (COSEWIC 2002). Waring et al. (2002) provide a minimum population estimate for the western North Atlantic of 308 individuals. The western North Atlantic population of blue whales was severely depleted by whaling, and sightings of this species almost anywhere within its range are uncommon.

Fin whale (*Balaenoptera physalus*)

Fin whales occur in coastal and shelf waters, as well as in oceanic waters. Most fin whales are seasonal migrants from high-latitude feeding areas in the summer to low-latitude breeding and calving areas in the winter. Migrations occur in the open ocean, and the locations of these migrations as well as the locations of winter breeding and calving areas are uncertain (Perry et al.

1999). Fin whales occur in the waters from Cape Hatteras to Nova Scotia where they are the dominant species of baleen whale in these waters (Perry et al. 1999). Hain et al. (1992) found the most important habitat for fin whales on the northeastern U.S. continental shelf to extend from the Great South Channel along the 50-m isobath past Cape Cod and over Stellwagen Bank, then northeast past Cape Ann and over Jeffreys Ledge. Fin whales are most abundant in this region in spring and summer; winter abundance is about 75% less, but they still occur in the area during that season (Hain et al. 1992).

Waring et al. (2004) provide a best available estimate of 2,814 (CV = 0.21) for the western North Atlantic stock of fin whales. This estimate was corrected for school size bias and g(0). Hain et al. (1992) estimated the total abundance of fin whales in northeastern U.S. waters to be 5,000 in the spring and summer and 1,500 in the fall and winter. Based on the U.S. Navy's (2005) geospatial model, fin whale density near the Neptune area was estimated to be in the range of 0.00–16.45 animals per 1,000 km (540 nm) during all seasons (Tables 4 and 5). In the greater Massachusetts Bay area, fin whale density was estimated to be in the range of 0.00–16.45 animals per 1,000 km during the fall and winter and from 0.00–32.89 animals per 1,000 km during the spring and summer.

Sei whale (*Balaenoptera borealis*)

The sei whales is mainly a pelagic species found in deep waters associated with the continental shelf edge (Perry et al. 1999). Sei whales undergo seasonal migrations from high-latitude summer feeding areas to low-latitude winter breeding areas; the locations of these wintering areas are unknown (Perry et al. 1999). Sei whales are most abundant in northeastern U.S. waters in spring, occurring primarily near George's Bank, and move north to the southern Scotian Shelf in June and July. The southern Gulf of Maine is rarely used by sei whales; however, in years of greater copepod abundance, they can be found further inshore on Stellwagen Bank and in Cape Cod Bay in the summer (Payne et al. 1990; Schilling et al. 1992).

There are currently no good estimates available of the size of the western North Atlantic stock of sei whales (Waring et al. 2004). Based on the U.S. Navy's (2005) geospatial model, sei whale density near the Neptune area is estimated to be in the range of 0–17.27 animals per 1,000 km (540 nm) during the fall, while there were no sei whale sightings during systematic cetacean surveys in the area during the winter, spring, and summer (Tables 4 and 5). In the greater Massachusetts Bay area, sei whale density was estimated to be in the range of 0.00–17.27 animals per 1,000 km during the spring, summer, and fall, with no sei whale sightings during systematic cetacean surveys in the greater Massachusetts Bay area during winter.

Minke whale (*Balaenoptera acutorostrata*)

Minke whales occur in all oceans of the world. They are believed to undergo seasonal migrations from high-latitude feeding grounds in the summer to low-latitude breeding grounds in the winter. While their summer distributions are rather well described, their winter breeding areas are poorly known. It seems that some minke whales remain at high latitudes throughout the year (Reeves and Brown 1994), while others disperse widely (Folkow and Blix 1991). Although they can be seen offshore, they are found most often in coastal and inshore regions

(Jefferson et al. 1993). Minke whales are believed to prefer shallow waters, and are generally sighted in waters <200 m deep (Hooker et al. 1999, Hamazaki 2002). Minke whales can be seen in northeastern U.S. waters in all months of the year except January and February, and are widespread and fairly abundant from late March until October (Murphy 1995; Waring et al. 2004).

Minke whale populations are generally considered to be much healthier than those of the other baleen whales. Waring et al. (2004) provide a best available estimate of 4,018 (CV = 0.16) for the Canadian east coast stock of minke whales, which inhabits Davis Strait to the Gulf of Mexico. Based on the U.S. Navy's (2005) geospatial model, minke whale density near the Neptune area is estimated to be in the range of 0.00–4.66 animals per 1,000 linear km (540 nm) during all seasons (Tables 4 and 5). In the greater Massachusetts Bay area, minke whale density is estimated to be in the range of 0–4.66 animals per 1,000 km during the fall and winter and from 0–9.33 animals per 1,000 km during the spring and summer.

Odontocetes

Sperm whale (*Physeter macrocephalus*)

Sperm whales are generally distributed over large areas that have high secondary productivity and steep underwater topography (Jaquet and Whitehead 1996). Their distribution and relative abundance can vary in response to prey availability (Jaquet and Gendron 2002). The sperm whale is generally thought to be a deep water species; sperm whales routinely dive to depths of hundreds of meters and may occasionally dive as deep as 3000 m (Rice 1989). Sperm whale distribution in northeastern U.S. waters is concentrated around the 1,000-m (3,280-ft) depth contour, although they can be seen in shallow water south of Cape Cod from May to November (CETAP 1982).

There currently are no valid estimates for the size of any sperm whale population (Whitehead 2002), but they are likely to be rare in the Massachusetts Bay area. The U.S. Navy (2005) MRA found no sperm whale sightings in any season during systematic cetacean surveys in the Neptune area or in the greater Massachusetts Bay area.

Killer whale (*Orcinus orca*)

Killer whales have been observed in all oceans of the world (Ford 2002). Although they prefer cold waters, they have been reported from tropical waters as well (Heyning and Dahlheim 1988). High densities of this species occur at high latitudes, especially in areas where prey is abundant. The greatest abundance of killer whales is found within 800 km (432 nm) of major continents (Mitchell 1975), although they also have been reported in offshore waters (Heyning and Dahlheim 1988). Killer whales were seen only 12 times during the 1978–1982 CETAP surveys and were found in both shallow and deep waters from Cape Ann to Cape Hatteras (CETAP 1982). No abundance estimates are available for the western North Atlantic stock of killer whales (Waring et al. 2004). There also are no density estimates for killer whales in the Gulf of Maine.

Long-finned pilot whale (*Globicephala melas*)

Pilot whales are widely distributed throughout the world's oceans. They are abundant throughout the North Atlantic Ocean to as far north as 70°N (Bernard and Reilly 1999). In northeastern U.S. waters, pilot whale distribution is broadly centered about the 1,000-m (3,280-ft) depth contour and extends both inshore and offshore (CETAP 1982). Pilot whales were commonly sighted inshore of the 100-m (328-ft) depth contour in the Gulf of Maine during CETAP surveys. While their distribution appears constant throughout the year for most of the northeastern U.S. waters, on-shelf sightings in the Gulf of Maine are almost completely absent during the winter (CETAP 1982).

Waring et al. (2002) provide a best available estimate of 14,524 (CV = 0.30) for the western North Atlantic stock of pilot whales. Both long-finned and short-finned pilot whales are included in this estimate. Based on the U.S. Department of the Navy's (2005) geospatial model, pilot whale density near the Neptune area is estimated to be in the range of 0.01–271.42 animals per 1,000 linear km (540 nm) of survey during all seasons (Tables 4 and 5). In the greater Massachusetts Bay area, pilot whale density is estimated to be in the range of 0.01–271.42 animals per 1,000 km during the spring and fall and from 0–271.42 animals per 1,000 km during the summer and winter.

Bottlenose dolphin (*Tursiops truncatus*)

Bottlenose dolphins are distributed worldwide in tropical and temperate oceans (Wells and Scott 1999). There are two distinct bottlenose dolphin types: a shallow water type, mainly found in coastal waters, and a deep water type, mainly found in oceanic waters (Duffield et al. 1983; Hoelzel et al. 1998; Walker et al. 1999). In higher latitudes, the distribution of coastal bottlenose dolphins appears to be seasonal, with a more northerly range in the summer (Shane et al. 1986; Wells and Scott 1999). In northeastern U.S. waters, bottlenose dolphins can be seen throughout the year (Kenney 1990). They are most abundant from May through October, with a peak in August, and least abundant during the winter. Bottlenose dolphins are rarely sighted in inshore waters north of Cape Hatteras in the winter (Kenney 1990).

Kenney (1990) provides a population estimate of 10,000–13,000 bottlenose dolphins for the northeastern United States. Based on the U.S. Navy's (2005) geospatial model, bottlenose dolphin density near the Neptune area is estimated to be in the range of 0.03–278.8 animals per 1,000 km (540 nm) during the fall, while they found no bottlenose dolphin sightings during systematic cetacean surveys in the area during the winter, spring, and summer (Tables 4 and 5). In the greater Massachusetts Bay area, bottlenose dolphin density is estimated to be in the range of 0–278.8 animals per 1,000 km (540 nm) during all seasons.

Atlantic white-sided dolphin (*Lagenorhynchus acutus*)

Atlantic white-sided dolphins occur in temperate and sub-Arctic portions of the North Atlantic, where they are quite abundant (Reeves et al. 1999a). This species is distributed primarily shoreward of the 100-m depth contour (CETAP 1982). In northeastern U.S. waters, Atlantic white-sided dolphin distribution is centered on and around George's Bank and the Great South Channel throughout the year, but particularly during November to June (Northridge et al. 1997). During this time, there are few sightings in the Gulf of Maine; however, during the summer and early fall, Atlantic white-sided dolphins are recorded widely throughout the Gulf of Maine (Northridge et al. 1997).

The total population of Atlantic white-sided dolphins in the North Atlantic may be as high as a few hundred thousand (Reeves et al 1999a). Waring et al. (2004) provide a best available estimate of 51,640 (CV = 0.38) for the Gulf of Maine stock of Atlantic white-sided dolphins. Based on the U.S. Navy's (2005) geospatial model, Atlantic white-sided dolphin density near the Neptune area is estimated to be in the range of 0.00–265.21 animals per 1,000 km (540 nm) during all seasons (Tables 4 and 5). In the greater Massachusetts Bay area, Atlantic white-sided dolphin density is also estimated to be in the range of 0.00–265.21 animals per 1,000 km during all seasons.

White-beaked dolphin (*Lagenorhynchus albirostris*)

White-beaked dolphins are found in cold temperate and sub-Arctic waters in the North Atlantic (Reeves et al. 1999b). They are less abundant in the western North Atlantic than in the eastern portion of their range, with the greatest abundances occurring in this region off Labrador and southwest Greenland (Kinze 2002). White-beaked dolphins are rarely sighted in northeastern U.S. waters (Northridge et al. 1997). Most sightings during the 1978–1982 CETAP surveys occurred in Massachusetts Bay near Cape Cod and Cape Ann, and most sightings of this species occurred during the spring (CETAP 1982).

There are no good current estimates available for the western North Atlantic stock of white-beaked dolphins (Waring et al. 2004). Based on the U.S. Navy's (2005) geospatial model, white-beaked dolphin density near the Neptune area is estimated to be zero in all seasons (Tables 4 and 5), because they found no sightings of this species in this area during systematic cetacean surveys. In the greater Massachusetts Bay area, white-beaked dolphin density is estimated to be zero in every season except spring, in which the density was estimated to be in the range of 0.00–3.17 animals per 1,000 km (540 nm).

Risso's dolphin (*Grampus griseus*)

The Risso’s dolphin is primarily a tropical and mid-temperate species distributed worldwide. It occurs between 60ºN and 60ºS where surface water temperatures are greater than around 10ºC (Kruse et al. 1999). In northeastern U.S. waters, Risso's dolphin distribution is concentrated along the shelf edge during spring, summer, and fall; in winter, they are further south along the shelf edge in the Mid-Atlantic Bight (CETAP 1982). This species can be seen shoreward of the 100-m depth contour in spring, summer, and fall (CETAP 1982).

Waring et al. (2002) provide a best available estimate of 29,110 (CV = 0.29) for the western North Atlantic stock of Risso's dolphins. Based on the U.S. Navy's (2005) geospatial model, Risso's dolphin density near the Neptune area was estimated to be in the range of 0.00–503.63 animals per 1,000 km (540 nm) during the fall; there were no sightings of this species during systematic cetacean surveys during the winter, spring, and summer (Tables 4 and 5). In the greater Massachusetts Bay area, Risso's dolphin density was estimated to be in the range of

0–503.63 animals per 1,000 km during spring, summer, and fall, with no sightings of this species during systematic cetacean surveys during the winter.

Short-beaked common dolphin (*Delphinus delphis*)

Common dolphins are widely distributed in tropical and temperate oceans around the world. The northernmost limit of their range is typically about 50°N in the Atlantic (Evans 1994). In the northwest Atlantic, they have been sighted in August as far north as 47°N off Newfoundland (Gaskin 1992). Common dolphin distribution has been shown to be associated with steep underwater topography (Evans 1994). In northeastern U.S. waters, common dolphins occur along the shelf edge throughout the year (CETAP 1982). Their distribution is centered along the 100-m to 200-m depth contours.

Waring et al. (2002) provide a best available estimate of 30,768 (CV = 0.32) for the western North Atlantic stock of common dolphins. Based on the U.S. Navy's (2005) geospatial model, common dolphin density near the Neptune area is estimated to be in the range of 0.00–464.07 animals per 1,000 km (540 nm) during the fall, while there were no sightings of this species during systematic cetacean surveys during the winter, spring, and summer (Tables 4 and 5). In the greater Massachusetts Bay area, common dolphin density was estimated to be in the range of 0–464.07 animals per 1,000 km during spring, summer, and fall, with no sightings of this species during systematic cetacean surveys during the winter.

Striped dolphin (*Stenella coeruleoalba*)

Striped dolphins have a cosmopolitan distribution in tropical to warm temperate waters (Perrin et al. 1994). Their preferred habitat seems to be deep water (Davis et al. 1998) along the edge and seaward of the continental shelf, particularly in areas influenced by warm currents (Waring et al. 2002). The northern limit of their distribution in the North Atlantic seems to be a function of the meandering of the Gulf Stream, and most sightings have been south of 43°N (Archer 2002). In northeastern U.S. waters, striped dolphins are distributed along the shelf edge from Cape Hatteras to the southern edge of Georges Bank and offshore over the continental slope and rise in the Mid-Atlantic Bight area (CETAP 1982). Sightings are generally concentrated about the 1,000-m (3,280-ft) depth contour.

Waring et al. (2000) provide a best available estimate of 61,546 (CV = 0.40) for the western North Atlantic stock of striped dolphins. The U.S. Navy (2005) MRA showed no striped dolphin sightings in any season among the systematic cetacean survey results in the Neptune area or in the greater Massachusetts Bay area.

Harbor porpoise (*Phocoena phocoena*)

The harbor porpoise is found in shelf waters throughout the northern hemisphere, usually in waters colder than 17°C (Read 1999). In northeastern U.S. waters, harbor porpoises are distributed primarily north of 40°N. They are common shoreward of the 100-m depth contour (CETAP 1982). Harbor porpoises are most common in the spring and summer but can be found around Cape Cod and throughout the Gulf of Maine in the fall and winter as well.

Waring et al. (2004) provide a best available estimate of 89,700 (CV = 0.22) for the Gulf of Maine/Bay of Fundy stock of harbor porpoises. Based on the U.S. Navy's (2005) geospatial model, harbor porpoise density near the Neptune area is estimated to be in the range of 0.00–162.36 animals per 1,000 km (540 nm) during all seasons (Tables 4 and 5). In the greater Massachusetts Bay area, harbor porpoise density is also estimated to be in the range of 0.00–162.36 animals per 1,000 km during all seasons.

Pinnipeds

Harbor seal (*Phoca vitulina*)

Harbor seals have one of the largest distributions of any pinniped. They can be found in most coastal waters of the North Atlantic and North Pacific to as far north as about 80°N off Spitzbergen (Bigg 1981). Harbor seals occur year-round along the coast of Maine and from late September to May south of Maine to Long Island Sound (Baraff and Loughlin 2000). Waring et al. (2004) provide a best available estimate of 99,340 (CV = 0.097) for the western North Atlantic stock of harbor seals.

Based on the U.S. Navy's (2005) geospatial model, harbor seal density near the Neptune area was estimated to be in the range of 0.01–65.84 animals per 1,000 km (540 nm) during the winter; there were no sightings of this species among the systematic survey results for the area during spring, summer, and fall (Tables 4 and 5). In the greater Massachusetts Bay area, harbor seal density was estimated to be in the range of 0–65.84 animals per 1,000 km during the fall, winter, and spring, with no sightings of this species during systematic surveys in this area during the summer.

Gray seal (*Halichoerus grypus*)

Gray seals are distributed in coastal areas of the North Atlantic, off eastern Canada, Iceland, the United Kingdom, and Norway during the breeding season from September to December (Bonner 1981). Outside the breeding season, they range farther. Large-scale movements up to 2,100 km (1,133 nm) have been demonstrated (NAMMCO 1997). The largest breeding colony in the North Atlantic is on Sable Island, east of Nova Scotia, with about 85,000 individuals (Hall 2002). Gray seals were considered to be extinct in U.S. waters before 1958, but their numbers have increased since the passage of legislation to protect them, by the state of Massachusetts in 1965 and by the MMPA in 1972 (Baraff and Loughlin 2000). Monitoring of this species around Nantucket Sound in the 1960s and 1970s found counts of fewer than 17 grey seals; this increased to 61 in 1984 and to 2,010 in 1994 (Baraff and Loughlin 2000).

The U.S. Navy (2005) found no gray seal sightings in any season during systematic surveys in the Neptune area (Tables 4 and 5). In the greater Massachusetts Bay area, gray seal density was estimated to be in the range of 0–4.22 animals per 1,000 km (540 nm) during the winter and spring, with no sightings of this species during systematic surveys during the summer and fall.

Harp seal (*Pagophilus groenlandica*)

Harp seals range throughout the North Atlantic and Arctic Oceans from the Gulf of St. Lawrence to Russia (Lavigne 2002). They are one of the most abundant pinniped species, with an estimated population size in 2000 of 5.2 million (95% C.I. = 4.0-6.4 million) in the northwest

Atlantic (Healey and Stenson 2000). This population size appears to have been stable since 1996. The northwest Atlantic harp seal population summers in the Canadian Arctic and Greenland, migrating south to the Gulf of St. Lawrence and off southern Labrador and northern Newfoundland where pups are born on the sea ice in late February or March (DFO 2000). Females nurse their pups for about 12 days, then mate and disperse. Prior to 1990, harp seals were only very occasionally sighted in the Gulf of Maine, but recent sightings suggest an increasing number of this species now visits these waters (Harris et al. 2002). They are present in the winter, from January–March.

Hooded seal (*Cystophora cristata*)

The traditional range of the hooded seal encompasses a large portion of the North Atlantic from as far south as Nova Scotia to as far north as north of Svalbard in the Barents Sea (Kovacs 2002). However, it is not uncommon for hooded seals, particularly young animals, to be found outside their normal range. Hooded seals congregate to breed in spring in the Gulf of St. Lawrence, north of Newfoundland, in the Davis Strait, and east of Greenland (Kovacs 2002). After breeding, they move to moulting areas on the southeast and northeast coasts of Greenland. Hooded seals disperse widely in the summer and fall (Kovacs 2002). There are no good estimates of the hooded seal population size because this species is difficult to survey, but the total population probably numbers on the order of half a million (Kovacs 2002). Prior to 1990, hooded seals were only very occasionally sighted in the Gulf of Maine, but recent sightings suggest an increasing number of this species now visits these waters (Harris et al. 2001). They are present in the winter, from January–March.

Sea Turtles

Species

Five species of sea turtle could potentially occur in the Massachusetts Bay area (Table 6). Three of the species outlined in Table 6 are listed under the U.S. Endangered Species Act (ESA) of 1973 as ***Endangered***. The remaining two are considered ***Threatened***. The two species of turtle most likely to be seen in the Neptune area are the leatherback and the loggerhead turtles. Sightings are likely to occur only in the summer. Juvenile or subadult Kemp's ridley turtles stray as far north as Stellwagen Bank, but the northern limit of their usual distribution is presumed to be the waters south of Cape Cod (Ward 1995). Although hawksbill and green turtles have been reported for Massachusetts waters (Ward 1995), they are rarely seen this far north.

Densities

The most comprehensive surveys for sea turtles within the Massachusetts Bay area were conducted in 1978–1982 as part of the Cetacean and Turtle Assessment Program (CETAP 1982). The CETAP surveys encompassed waters overlying the U.S. Outer Continental Shelf from Cape Hatteras, North Carolina to Nova Scotia, Canada. The CETAP investigators calculated seasonal density estimates for different portions of this region for the two turtle species that were sighted sufficiently often during those surveys. Those estimates for the entire Gulf of Maine are presented in Table 7.

TABLE 6. The occurrence and conservation status of sea turtles found in the Massachusetts Bay area.

Species	Occurrence in area	U.S. ESA Designation[1]
Leatherback turtle (*Dermochelys coriacea*)	Common	Endangered
Loggerhead turtle (*Caretta caretta*)	Uncommon	Threatened
Kemp's ridley turtle (*Lepidochelys kempii*)	Uncommon	Endangered
Hawksbill turtle (*Eretmochelys imbricata*)	Rare	Endangered
Green turtle (*Chelonia mydas*)	Rare	Endangered[2]

[1] Listed by the U.S. National Marine Fisheries Service (NMFS) Office of Protected Resources (http://www.nmfs.noaa.gov/prot_res/) under the Endangered Species Act of 1973 as follows: Endangered = the species has been determined to be in imminent danger of extinction throughout all or a significant portion of its range; Threatened = the species is likely to become an endangered species within the foreseeable future.

[2] The green turtle is considered Endangered under the U.S. ESA in its breeding colony populations in Florida and on the Pacific coast of Mexico. It is considered Threatened elsewhere in its range. To be conservative, it is assumed that the rare individual that might occur in the Massachusetts Bay area is from an Endangered population.

TABLE 7. Seasonal densities of turtles in the entire Gulf of Maine from the 1978–1982 CETAP surveys.

Species	Density in area (per 1,000 km^2)[1]			
	Spring	Summer	Fall	Winter
Leatherback turtle	0.00	0.807	1.15	0.00
Loggerhead turtle	0.00	0.175	0.00	0.00

[1] Density estimates were corrected for interspecific differences in sightability, that is, f(0), which includes an estimate of the probability that an animal that is on the trackline is at the surface and is sighted, that is, g(0). Density estimates were presented by CETAP (1982) as individuals per km^2 and have been converted here to individuals per 1,000 km^2 to facilitate comparison with other density estimates (see below). One thousand square kilometers is approximately equal to 291.2 square nautical miles.

Seasons were defined as follows: spring, 20 March to 20 June; summer, 21 June to 21 September; fall, 22 September to 20 December; and winter, 21 December to 19 March.

Species not appearing in the table were sighted too rarely during the CETAP surveys to estimate densities.

Much more recently, the U.S. Navy (2005) used data from NMFS shipboard and aerial line-transect surveys to calculate seasonal sightings per unit effort (SPUE) values for sea turtles in northeastern U.S. waters from Delaware to Nova Scotia, Canada. Seasons were defined as: winter, January–March; spring, April–June; summer, July–September; and fall, October–December. Their calculated SPUE values, which are uncorrected for sightability, for the entire area are presented in Table 8. A single SPUE value was calculated for each species and for each season for the entire 478,072-km^2 (139,205 nm^2) area, with a southern limit of 38°N and an

TABLE 8. Seasonal SPUE values for sea turtles in the northeastern United States.

Species	**Mean SPUE (animals per 1,000 km)**			
	Winter	**Spring**	**Summer**	**Fall**
Leatherback turtle	0.01	0.16	1.05	0.15
Loggerhead turtle	1.29	10.37	7.87	3.45
Kemp's ridley turtle	0.30	0.00	0.82	0.00

Sightings per unit effort (SPUE) values were calculated using data from NMFS shipboard and aerial line-transect surveys (1991–2003) and from other rigorously collected line-transect surveys found in the North Atlantic Right Whale Consortium database for U.S. waters from Delaware to Nova Scotia, Canada. One thousand kilometers is approximately equal to 540 nautical miles.

Source: U.S. Navy (2005).

eastern limit of 65°W. Thus, this area represents a wide range of latitudes and water depths, and these overall estimates do not necessarily reflect densities of turtles that may be found in the Massachusetts Bay area. In particular, all sightings of the Kemp's ridley turtle used to calculate these estimates occurred south of Cape Cod.

In addition to the measured SPUE values presented in Table 8, the U.S. Navy (2005) also used geospatial and statistical interpolation to predict SPUE values at unsampled locations and provide a model of sea turtle occurrence for their entire study area, as defined above. They mapped the occurrence of sea turtles within this area by dividing the predicted SPUE values into quartiles based on the range of SPUE values predicted for each species for all seasons combined, with Quartile 1 including the highest 25% of the SPUE range and Quartile 4 including the lowest 25% of the SPUE range. Table 9 provides the Quartile output values of the predicted SPUEs for the three different sea turtle species commonly found in northeastern U.S. waters.

The U.S. Navy (2005) found no sea turtle sightings in the Neptune project area or in the greater Massachusetts Bay area during systematic sightings surveys in the fall, winter, or spring. In the summer, there were no leatherback sea turtle sightings in the Neptune project area, but they calculated the density of leatherback sea turtles to be in the range of 0.00–3.46 per 1,000 km (540 nm) at other locations within the greater Massachusetts Bay area. The density of loggerhead sea turtles in both the Neptune project area and in the greater Massachusetts Bay area during the summer was estimated to be in the range of 0.00–47.27 per 1,000 km (540 nm). No Kemp's ridley sea turtles were found during systematic sightings surveys in the Neptune project area or in the greater Massachusetts Bay area.

Marine Invertebrates and Fish

Marine invertebrate and fish species that occur in the vicinity of the proposed Neptune DWP are numerous and considerably diverse in terms of life history and acoustic sensitivity. The Neptune DWP Project Application document (E & E 2005) and the U.S. Navy Marine Resources Assessment for NE Operating Areas (U.S. Navy 2005) provide substantial

TABLE 9. Quartile ranges of the predicted SPUE values (in number of animals per 1,000 km) estimated by the U.S. Navy's (2005) geospatial analysis model.[1]

Species		Quartile 4	Quartile 3	Quartile 2	Quartile 1
Leatherback sea turtle	0.00	3.46	6.92	10.38	13.84
Loggerhead sea turtle	0.00	47.27	94.54	141.81	189.08
Kemp's ridley sea turtle	0.00	8.98	17.97	26.95	35.93

[1] Sightings per unit effort (SPUE) values were calculated for U.S. waters from Delaware to Nova Scotia, Canada (see Figure 1), for each 10-minute latitude × 10-minute longitude cell within the area using measured SPUE values and geospatial and statistical analyses to predict SPUE values for unsampled locations. Predicted seasonal SPUE values were pooled and divided into quartiles such that Quartile 4 represents the range of the lowest 25% of the predicted SPUE values, while Quartile 1 represents the range of the highest 25% of the predicted SPUE values. One thousand kilometers is approximately equal to 540 nautical miles.

Source: U.S. Navy (2005).

information on life stage occurrence, seasonality, life history and habitat preference for many marine invertebrates and fish in the area. Certain important commercial species have been selected for consideration in the later analyses of the potential impacts of exposure to the sound produced during construction and operation of the DWP.

The commercially important marine invertebrates (crustaceans and molluscs) that will be considered in this section include the following:

1) Atlantic sea scallop (*Placopecten magellanicus*),
2) American lobster (*Homarus americanus*),
3) Various clam species (e.g., ocean quahog),
4) Various crab species (e.g., deepsea red, Jonah), and
5) Long-finned squid (*Loligo pealei*).

The commercially important marine fish that will be considered in this section include the following:

1) American plaice (*Hippoglossoides platessoides*),
2) Atlantic cod (*Gadus morhua*),
3) Atlantic herring (*Clupea harengus harengus),*
4) Atlantic mackerel (*Scomber scombrus*),
5) Bluefin tuna (*Thunnus thynnus*),
6) Bluefish (*Pomatomus saltatrix*),
7) Haddock (*Melanogrammus aeglefinus*),
8) Hake (*Urophycis* spp.),
9) Pollock (*Pollachius virens*),
10) Silver hake (*Merluccius bilinearis*),
11) Winter flounder (*Pleuronectes americanus*),
12) Witch flounder (*Glyptocephalus cynoglossus*), and
13) Yellowtail flounder (*Limanda ferruginea*).

In addition, eight fish species listed as 'species of concern' (**SC**) under the Endangered Species Act (ESA) might also occur in the vicinity of the DWP. They include the following:

1) Barndoor skate (*Raja laevis*) (**SC**) (1999),
2) Thorny skate (*Amblyraja radiata*) (**SC**) (2004),
3) White marlin (*Tetrapturus albidus*) (**SC**) (2002),
4) Rainbow smelt (*Osmerus mordax*) (**SC**) (2004),
5) Cusk (*Brosme brosme*) (**SC**) (2004),
6) Atlantic wolffish (*Anarhichas lupus*) (**SC**), (2004),
7) Atlantic halibut (*Hippoglossus hippoglossus*) (**SC**), (2004), and
8) Warsaw grouper (*Epinephelus nigritus*) (**SC**), (2004).

The dates in parentheses refer to year of listing under the ESA.

Three listed or species of concern fishes occur along and within the Massachusetts coastal region. They include the federally and state-listed endangered shortnose sturgeon (Acipenser brevirostrum), the state endangered Atlantic sturgeon (Acipenser oxyrinchus), and the Gulf of Maine Distinct Population Segment of Atlantic salmon (Salmo salar). Since none of these species are expected to occur in offshore waters associated with the project, subsequent discussion of impacts to these species is not considered.

Information on each of the aforementioned 29 species/species groups pertaining to seasonality, life stage occurrence, and absence/presence of a swim bladder is presented in Table 10. These data will be referred to in the discussion on the potential effects of anthropogenic sound on marine invertebrates and fish.

As summarized by Navy Marine Resources Assessment for NE Operating Areas (U.S. Navy 2005), there has been substantial historical commercial fishing effort in the vicinity of the proposed *Neptune* DWP using trawl, gillnet and pot/trap. Target species identified for these fisheries include the following:

- Monkfish (a.k.a. goosefish) (*Lophius americanus*)
- Skate
- Spiny dogfish (*Squalus acanthias*)
- Atlantic sea scallop
- Clams
- American lobster
- Northern shrimp (*Pandalus borealis*)
- Atlantic mackerel
- Squid
- Bluefish
- Deep-sea red crab
- Black sea bass (*Centropristis striata*)

Table 10. Seasonality, life stage occurrence, and absence/presence of swim bladder for selected invertebrate and fish species that occur in the project area within the 120 m depth contour.

SPECIES	**Seasonality**	**Life Stage Occurrence**[1]	**Swim Bladder**[2]
Atlantic sea scallop	Year-round	**ELJA**	n/a
American lobster	Year-round	ELJA	n/a
Clams	Year-round	ELJA	n/a
Crabs	Year-round	ELJA	n/a
Longfin squid	Warm month migrant	ELJA	n/a
American plaice	**Cold Month Migrant**	ELJA	Larvae (P); Adult (A)[3]
Atlantic cod	Year-round	ELJA	P
Atlantic herring	Year-round	ELJA	P
Atlantic mackerel	Warm month migrant	ELJA	A
Bluefin tuna	Warm month migrant	A	P
Bluefish	Warm month migrant	JA	P
Haddock	Year-round	ELJA	P
Hake (*Urophycis* spp.)	Warm month migrant	ELJA	P
Pollock	Cold month migrant	ELJA	P
Silver hake	Warm month migrant	ELJA	P
Winter flounder	Year-round	ELJA	Larvae (P); Adult (A)[3]
Witch flounder	Year-round	ELJA	Larvae (P); Adult (A)[3]
Yellowtail flounder	Year-round	ELJA	Larvae (P); Adult (A)[3]

Table 10 (concluded).

Shortnose sturgeon	Year-round	JA	P
Atlantic salmon	Spring and fall	JA	P
Atlantic sturgeon	Year-round	JA	P
Barndoor skate	Year-round	JA	A
Thorny skate	Year-round	JA	A
White marlin	Warm month migrant	A	P
Rainbow smelt	Year-round	JA	P
Cusk	Year-round	ELJA	P
Atlantic wolffish	Year-round	ELJA	A
Atlantic halibut	Warm month migrant	ELJA	Larvae (P); Adult (A)[3]
Warsaw grouper	Year-round	ELJA	P
Monkfish	Year-round	ELJA	A
Spiny dogfish	Year-round	ELJA	A
Northern shrimp	Year-round	ELJA	n/a
Black sea bass	Summer/early fall	A	P
Striped bass	Summer/early fall	A	P

Sources: E&E (2005);U.S. Navy (2005)

[1] E denotes eggs; L denotes larvae; J denotes juvenile; A denotes adult

[2] P denotes presence of swim bladder; A denotes absence of swim bladder

[3] Adult flatfish have such reduced swim bladders that they are functionally absent

The Department of the Navy MRA (2005) also identified recreational fishing hotspots in the general area being considered. The two most extensive areas occur northwest of Race Point (southern Massachusetts Bay) and northeast of Cape Ann (northern Massachusetts Bay/southern Gulf of Maine). The primary recreational fishery target species include bluefish, Atlantic mackeral and cod in federal waters, and striped bass (*Morone saxatilis*) in state waters.

Information on seasonality, life stage occurrence, and absence/presence of a swim bladder for monkfish, spiny dogfish, northern shrimp, black sea bass and striped bass is also presented in Table 10.

PART (2): KNOWN EFFECTS of UNDERWATER NOISE from PROJECT ACTIVITIES

By

Susan Dufault*
John Christian**

*LGL Limited
14 Langley Avenue
Dartmouth, NS B2W 2Y6

**LGL Limited
Box 13248, Station A
388 Kenmount Rd.
St. John's, NL A1B 4A5

5 October 2005

TABLE OF CONTENTS

Marine Mammals

Marine mammals rely heavily on the use of underwater sounds to communicate and gain information about their environment. The reactions of marine mammals to noise can be variable and depend on the species involved, time of year, and the activity of the animal at the time of exposure to noise. Because underwater noise sometimes propagates for long distances, the radius of audibility can be large for a strong noise. However, marine mammals usually do not respond overtly to audible, but weak, man-made sounds (Richardson et al. 1995). Thus, the zone of "responsiveness" is usually much smaller than the zone of audibility. Potential effects of noise on marine mammals include masking, disturbance (behavioral), hearing impairment (temporary threshold shift [TTS] and permanent threshold shift [PTS]), and non-auditory physiological effects.

Masking

Masking is the obscuring of sounds of interest by other sounds, often at similar frequencies. Marine mammals are highly dependent on sound, and their ability to recognize sound signals amid noise is important in communication, predator and prey detection, and, in the case of toothed whales, echolocation.

Even in the absence of man-made sounds, the sea is usually noisy. Background ambient noise often interferes with or masks the ability of an animal to detect a sound signal even when that signal is above its absolute hearing threshold. Natural ambient noise includes contributions from wind, waves, precipitation, other animals, and (at frequencies above 30 kHz) thermal noise resulting from molecular agitation (see Chapter 5 of Richardson et al. 1995). Background noise can also include sounds from distant human activities such as shipping and oil exploration and production. Masking of natural sounds can result when human activities produce high levels of background noise. Conversely, if the background level of underwater noise is high (e.g., on a day with strong wind and high waves), an anthropogenic noise source will not be detectable as far away as would be possible under quieter conditions, and will itself be masked. Ambient noise is highly variable on continental shelves (e.g., Thompson 1965; Myrberg 1978; Chapman et al. 1998; Desharnais et al. 1999). This inevitably results in a high degree of variability in the range at which marine mammals can detect anthropogenic sounds.

Although masking is a natural phenomenon to which marine mammals must be adapted, introduction of strong sounds into the sea at frequencies important to marine mammals will inevitably increase the severity and the frequency of occurrence of masking. For example, if a baleen whale is exposed to continuous low-frequency noise from an industrial source, this will reduce the size of the area around that whale within which it will be able to hear the calls of another whale. In general, little is known about the importance to marine mammals of detecting sounds from conspecifics, predators, prey, or other natural sources. In the absence of much information about the importance of detecting these natural sounds, it is not possible to predict the impacts if mammals are unable to hear these sounds as often, or from as far away, because of masking by industrial noise (Richardson et al. 1995). In general, masking effects are expected to be less severe when sounds are transient than when they are continuous.

Although some degree of masking is inevitable when high levels of man-made broadband sounds are introduced into the sea, marine mammals have evolved systems and behavior that function to reduce the impacts of masking. Structured signals such as the echolocation click sequences of small toothed whales may be readily detected even in the presence of strong background noise because their frequency content and temporal features usually differ strongly from those of the background noise (Au and Moore 1988; 1990). It is primarily the components of background noise that are similar in frequency to the sound signal in question that determine the degree of masking of that signal. Low-frequency industrial noise, such as shipping, has little or no masking effect on high-frequency echolocation sounds. Redundancy and context can also facilitate detection of weak signals. These phenomena may help marine mammals detect weak sounds in the presence of natural or man-made noise.

Most masking studies in marine mammals present the test signal and the masking noise from the same direction. The sound localization abilities of marine mammals suggest that, if signal and noise come from different directions masking would not be as severe as the usual types of masking studies might suggest (Richardson et al. 1995). The dominant background noise may be highly directional if it comes from a particular anthropogenic source such as a ship or industrial site. Directional hearing may significantly reduce the masking effects of these noises by improving the effective signal-to-noise ratio. In the cases of high-frequency hearing by the bottlenose dolphin (*Tursiops truncatus*), beluga whale (*Delphinapterus leucas*), and killer whale (*Orcinus orca*), empirical evidence confirms that masking depends strongly on the relative directions of arrival of sound signals and the masking noise (Penner et al. 1986; Dubrovskiy 1990; Bain et al. 1993; Bain and Dahlheim 1994).

Toothed whales, and probably other marine mammals as well, have additional capabilities besides directional hearing that can facilitate detection of sounds in the presence of background noise. There is evidence that some toothed whales can shift the dominant frequencies of their echolocation signals from a frequency range with much ambient noise toward frequencies with less noise (Au et al. 1974, 1985; Moore and Pawloski 1990; Thomas and Turl 1990; Romanenko and Kitain 1992; Lesage et al. 1999). A few marine mammal species are known to increase the source levels of their calls in the presence of elevated sound levels (Dahlheim 1987; Au 1993; Lesage et al. 1999; Terhune 1999).

These data demonstrating adaptations for reduced masking pertain mainly to the very high-frequency echolocation signals of toothed whales. There is less information about the existence of corresponding mechanisms at moderate or low frequencies, or in other types of marine mammals. For example, Zaitseva et al. (1980) found that, for the bottlenose dolphin, the angular separation between a sound source and a masking noise source had little effect on the degree of masking when the sound frequency was 18 kHz, in contrast to the pronounced effect at higher frequencies. Directional hearing has been demonstrated at frequencies as low as 0.5-2 kHz in several marine mammals, including killer whales (see Section 8.4 in Richardson et al. 1995). This ability may be useful in reducing masking at these frequencies.

In summary, high levels of noise generated by anthropogenic activities may act to mask the detection of weaker biologically important sounds by some marine mammals. This masking may be more prominent for lower frequencies. For higher frequencies, such as used in echolocation by toothed whales, several mechanisms are available that may allow them to reduce the effects of such masking.

Disturbance

Disturbance can induce a variety of effects, such as subtle changes in behavior, more conspicuous dramatic changes in activities, and displacement. Disturbance is one of the main concerns of the potential impacts of man-made noise on marine mammals. For many species and situations, there is no detailed information about reactions to noise. Behavioral reactions of marine mammals to sound are difficult to predict because they are dependent on numerous factors including species, state of maturity, experience, current activity, reproductive state, time of day, and weather state. If a marine mammal does react to an underwater sound by changing its behavior or moving a small distance, the impacts of that change may not be important to the individual, the stock, or the species as a whole. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on the animals could be important.

Based on the literature reviewed in Richardson et al. (1995), it is apparent that most small and medium-sized toothed whales exposed to prolonged or repeated underwater sounds are unlikely to be displaced unless the overall received level is at least 140 dB re 1 μPa. The limited available data indicate that the sperm whale (*Physeter macrocephalus*) is sometimes, though not always, more responsive than other toothed whales. Baleen whales probably have better hearing sensitivities at lower sound frequencies, and in several studies have been shown to react at received sound levels of approximately 120 dB re 1 μPa.

Toothed whales appear to exhibit a greater variety of reactions to man-made underwater noise than do baleen whales. Toothed whale reactions can vary from approaching vessels (e.g., to bow ride) to strong avoidance, while baleen whale reactions range from neutral (little or no change in behavior) to strong avoidance. In general, pinnipeds seem more tolerant of, or at least habituate more quickly to, potentially disturbing underwater noise than do whales.

Hearing Impairment

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds. The minimum sound level necessary to cause permanent hearing impairment is higher, by a variable and generally unknown amount, than the level that induces barely detectable temporary hearing loss or temporary threshold shift (TTS). The level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds exceeding 180 and 190 dB re 1 μPa (rms), respectively (NMFS 2000).

Temporary Threshold Shift

TTS is the mildest form of hearing impairment. It is the process whereby exposure to a strong sound results in a non-permanent elevation in hearing threshold making it more difficult to hear sounds (Kryter 1985). TTS can last from minutes or hours to days. The magnitude of the TTS depends on the level and duration of the noise exposure, among other considerations (Richardson et al. 1995). For sound exposures at or somewhat above the TTS level, hearing sensitivity recovers rapidly after exposure to the noise ends. TTS commonly occurs in mammals, including humans.

Only a few data on sound levels and durations necessary to elicit mild TTSs have been obtained for marine mammals, and all of these data are quite recent. TTS studies in humans and terrestrial mammals provide information helpful in understanding general principles of TTS, but it is unclear to what extent these data can be extrapolated to marine mammals.

Permanent Threshold Shift

There are no data on noise levels that might induce permanent hearing impairment in marine mammals. In theory, physical damage to a marine mammal's hearing apparatus could occur immediately if it is exposed to sound impulses that have very high peak pressures, especially if they have very short rise times. Also, very prolonged exposure to a noise strong enough to elicit a TTS, or shorter-term exposure to noise levels well above the TTS level, could cause hearing injury. Such damage can result in a permanent decrease in functional sensitivity of the hearing system at some or all frequencies. Richardson et al. (1995) hypothesized that permanent hearing impairment caused by prolonged exposure to continuous man-made noise is not likely to occur in marine mammals for sounds with source levels up to ~200 dB re 1 µPa-m.

Single or occasional occurrences of mild TTS do not cause permanent auditory damage in humans or other terrestrial mammals, and presumably do not do so in marine mammals. Sound impulse duration, peak amplitude, and rise time are the main factors thought to determine the onset and extent of PTS. Based on existing data, Ketten (1995) noted that the criteria for differentiating the sound pressure levels that result in a PTS (or TTS) are location and species specific. PTS effects may also be influenced strongly by the health of the receiver's ear.

For sound exposures at or somewhat above the TTS level, hearing sensitivity recovers rapidly after exposure to the noise ends. At least in terrestrial mammals, the received sound level from a single noise exposure must be far above the TTS level for there to be any risk of PTS (Kryter 1985, 1994; Richardson et al. 1995). Relationships between TTS and PTS levels have not been studied in marine mammals but are assumed to be similar to those in humans and other terrestrial mammals.

Non-Auditory Physiological Effects

Non-auditory physiological effects may also occur in marine mammals exposed to very strong underwater sound. Possible types of non-auditory physiological effects or injuries that, in theory, might occur, include stress, neurological effects, bubble formation, resonance effects, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strongly pulsed sounds, particularly at higher frequencies. None of the activities associated with the Neptune project will generate sounds loud enough to cause physiological effects.

Marine Mammal Hearing

Direct hearing measurements are available for only a few marine mammal species because of the difficulty of obtaining such measurements from free-living animals. The results of hearing studies in marine mammals that could occur in the Neptune project area are presented below when available. It is generally thought that an animal's hearing range is likely to be related to the range of sounds that it produces. Evidence in support of this in marine mammals comes from the fact that the peak spectral frequencies of echolocation signals recorded in odontocetes are near the best frequencies of hearing for individuals of the same species for which behavioral audiograms have been recorded (Ketten 2000). The characteristics of the vocalizations of those species of marine mammal that could occur in the Neptune project area and for which no direct hearing measurements are available are presented below.

Mysticetes

There are no hearing measurements available for any baleen whale species. However, baleen whales are considered to be low-frequency specialists, in general, with peak spectra of their vocalizations ranging from 12 Hz to 3 kHz (Ketten 2000). Most project sounds are also primarily at low frequencies. Sounds produced by baleen whales include low-frequency moans with fundamental frequencies <200 Hz, simple impulsive calls with peak frequencies <1 kHz, broadband amplitude- and frequency-modulated pulsed calls, and complex songs with varied phrasing and frequency spectra (Ketten 2000). Infrasonic signals, with frequencies between 10 Hz and 20 Hz are well documented in the blue whale and the fin whale (Ketten 2000). Table 1 presents the characteristics of the different types of sounds produced by the species of baleen whale that could occur in the Neptune project area.

Odontocetes

Odontocetes are considered to be high-frequency specialists, with peak spectra of their vocalizations ranging between 10 and 200 kHz (Ketten 2000). Most noise from the Neptune project will be at low frequencies, well below the best hearing frequencies of the toothed whales. Hearing measurements have been made in several species of odontocete, including the killer whale, Risso's dolphin, and harbor porpoise. Two species of odontocete—the bottlenose dolphin and the beluga whale—are rather well studied because of the availability of well-trained, captive individuals.

Sperm Whale

One attempt has been made to measure sperm whale hearing directly. Ridgway and Carder (2001) measured the auditory brain stem response (ABR) produced by sounds with peak frequencies of 2.5, 5, 10, 20, 40, and 60 kHz in an approximately two-week old stranded male sperm whale. That individual had its greatest hearing sensitivity at frequencies between 5

TABLE 1. Characteristics of sounds produced by baleen whales that could occur in the Neptune project area.

Species	**Type of sound**	**Frequency range (Hz)**	**Dominant frequencies (Hz)**	**Source level (dB re 1 µPa at 1 m)**
North Atlantic right whale	LF unmodulated	100–200	120	–
(*Eubalaena glacialis*)*	LF upsweep	100–200	120	–
	MF modulated	200–800	500	–
	MF unmodulated	200–800	500	–
	Gunshot	broadband	–	–
Humpback whale	FM and PM	25–1,900	25–1,900	–
(*Megaptera novaeangliae*)	grunt	25–89	25–80	176
	Pulse	30–8,000	120–4,000	144–174
	Song			
Blue whale	FM moan	12.5–200	16–25	188
(*Balaenoptera musculus*)	Song	16–60	16-60	–
Fin whale	FM moan	14–118	20	160–186
(*Balaenoptera physalus*)	Tone	34–150	34–150	–
	Song	17–25	17–25	186
Sei whale	FM sweep	1,500–3,500	1,500–3,500	–
(*Balaenoptera borealis*)				
Minke whale	FM tone	60–130	60–130	165
(*Balaenoptera acutorostrata*)	Thump	100–200	100–200	–
	Grunt	60–140	60–140	151–175
	Ratchet	850	850	–

Source: Information as extracted from the primary literature and summarized by Au (2000). *Data on North Atlantic right whale sounds are from Laurinolli et al. (2003).

Abbreviations: FM, frequency-modulated; LF, low frequency; MF, mid-frequency; PM, pulse-modulated.

kHz and 20 kHz based on that method. The animal's hearing sensitivity at 40 kHz was greater than its sensitivity at 2.5 kHz. However, caution must be used when considering these results, because ABR measurements have a lack of frequency specificity and are not comparable with measurements made using behavioral techniques (Au 2000). In addition, these measurements were made on a restrained animal in a small bath, complicating the acoustic propagation conditions. Furthermore, the measurements were made on a neonate sperm whale and, hence, it is not clear how the hearing sensitivity they recorded may compare with those of adult animals.

Madsen et al. (2002a) proposed that sperm whales likely have a best hearing range that is lower in frequency than the hearing ranges of most other odontocetes, but not as low as those of the baleen whales. Measurements of hearing abilities in killer whales (the largest odontocete for which detailed audiograms have been produced) suggest that those animals have a maximum hearing sensitivity at a frequency (15 or 20 kHz) that is lower than that of many other odontocetes (Hall and Johnson 1972; Kastelein et al. 2003; Szymanski et al. 1999; Thomas et al. 1988; Tremel et al. 1998).

The main types of vocalizations produced by sperm whales are clicks. Whitehead (2003) provided a summary of the types of clicks produced by sperm whales, which can be categorized as: usual clicks (used for searching echolocation; apparent source level: 230 dB re 1 µPa rms; peak frequency: 15 kHz), creaks (used for homing echolocation; apparent source level: 205 dB re 1 µPa rms; peak frequency: 15 kHz), codas (used in social communication; apparent source level: 180 dB re 1 µPa rms; peak frequency: 5 kHz), and slow clicks (used for communication in males; apparent source level: 190 dB re 1 µPa rms; peak frequency: 500 Hz). The term 'apparent source level' comes from the fact that sperm whale clicks are highly directional, and the same click recorded from different directions can have source level differences up to 35 dB (Møhl et al. 2000).

Pygmy Sperm Whale

Ridgway and Carder (2001) measured ABRs in a rehabilitated female pygmy sperm whale and found that individual to have its greatest hearing sensitivity at frequencies between 90 kHz and 150 kHz based on that method. As mentioned previously, Au (2000) cautioned on the use of ABR measurement as a means to assess hearing because it is not directly comparable with hearing measurements made via behavioral techniques, which are usually measured in terms of the root-mean-square (rms) acoustic pressure at the subject's threshold using a long stimulus with a well-established frequency. The ABR is an onset response triggered by the beginning of a brief acoustic signal that is relatively broadband and, therefore, the nervous system may not be responding to the peak frequency but to other frequencies within the signal, and hence, there is a lack of frequency specificity in this measurement.

Beaked Whales

Caldwell and Caldwell (1971) recorded the sounds made by a stranded juvenile male Blainville's beaked whale (*Mesoplodon densirostris*). They reported that the animal made chirps and whistle sounds as well as pulsed sounds. Its vocalizations, recorded in air, had fundamental frequencies ranging from >1 kHz to almost 6 kHz.

Lynn and Reiss (1992) recorded the vocalizations made by two stranded young (possibly neonate) male Hubbs' beaked whales (*Mesoplodon carlhubbsi*). They recorded two different types of pulse sequences from those animals. One type consisted of predominantly low-frequency pulses, with the majority of their energy between 300 Hz and 2 kHz, although they also had some high-frequency components that extended beyond the 40-kHz limit of the recording system. The second type of pulse sequence they recorded was more broadband, consisting of pulses with energy from 300 Hz to >40 kHz. The investigators also recorded whistles from those animals that ranged in frequency from 2.6–10.7 kHz. Marten (2000) also analyzed the vocalizations of the same two Hubbs' beaked whales and found their high-frequency click trains to have peak frequencies ranging from 5–10 kHz up to 78 kHz, which was the upper limit of the recording system. The low-frequency clicks of these animals had peak frequencies centered at 1.77 kHz.

Baird's beaked whales (*Berardius bairdii*) were noted to make frequency-modulated whistles with fundamental frequencies from 4–8 kHz and clicks, irregular pulse series, and click bursts (Dawson et al. 1998). Clicks had their largest spectral peak between 22 kHz and 25 kHz and second largest peak between 35 kHz and 45 kHz. A few clicks had one of their four largest spectral peaks above 80 kHz. Most pulses in irregular pulse series had a strong spectral peak at around 23 kHz with a second peak at about 42 kHz and a few had one of their largest spectral peaks at >80 kHz. Almost all click bursts had dominant frequencies between 23 kHz and 24.6 kHz; one had a dominant frequency of 45.1 kHz.

Northern bottlenose whales off Nova Scotia, Canada, made whistles, with frequencies ranging from 3 to 16 kHz; chirp-like calls, starting at about 4 kHz and upsweeping to 13 kHz; and clicks, with frequencies as low as <500 Hz to > 26 kHz (Winn et al. 1970). This species also was found to make deep-water clicks, with frequencies consistently within the 21–25 kHz range, and surface clicks, with more variable frequencies in the range of 4–21 kHz (Hooker and Whitehead 2002).

Frantzis et al. (2002) recorded the clicks made by Cuvier's beaked whales (*Ziphius cavirostris* L) off Greece within the audible frequency range as they did not have equipment to measure ultrasonic sounds. They found the energy of the clicks they recorded to be concentrated into a narrow peak between 13 kHz and 17 kHz.

Killer Whale

Hall and Johnson (1972) first studied the hearing sensitivity of killer whales. They measured the hearing thresholds of a subadult male at frequencies between 500 Hz and 31 kHz. That animal had its greatest hearing sensitivity (30 dB re 1 µPa) at a frequency of 15 kHz and did not respond to signals with frequencies higher than 31 kHz. It appears likely that the killer whale studied by Hall and Johnson (1972) is not representative of the species and likely had hearing deficiencies at higher frequencies (Nachtigall et al. 2000). More recently, Szymanski et al. (1999) measured the hearing sensitivity of two adult female killer whales using both behavioral (go/no-go response paradigm) and electrophysiological (ABR) methods. Those animals were most sensitive (36 dB re 1 µPa) to a frequency of 20 kHz using the behavioral method. Both whales responded to 100-kHz tones, while one responded to a 120-kHz tone. The ABR method produced an audiogram that was similar in shape to the one produced by the behavioral methods, but overall, it was 12 dB (range: 5–41 dB) less sensitive than the behavioral methods.

False Killer Whale

The hearing sensitivity of a captive false killer whale in Hawaii was measured by Thomas et al. (1988). That animal had its greatest hearing sensitivity at frequencies ranging from 16–64 kHz. Below 8 kHz, its sensitivity dropped off at 38 dB per octave, and above 64 kHz, its sensitivity dropped off at 150 dB per octave. The animal's hearing thresholds followed a typical mammalian u-shaped curve. The authors of that study noted large (>10 dB) deviations in hearing thresholds on some days that were attributed to illness or social stress.

Au et al. (1997) measured low-frequency hearing sensitivity for a false killer whale. The hearing thresholds for that animal were 140.7 ± 1.2 dB for a 75-Hz pure tone signal and 139.0 ± 1.1 dB for the acoustic thermometry of ocean climate (ATOC) signal (75 Hz, 195 dB re 1 μPa source level).

Long-Finned Pilot Whale

Hearing has not been measured directly in pilot whales. The vocalizations of these animals consist of whistles in the frequency range of 1–8 kHz and clicks in the frequency range of 1–18 kHz (summarized by Richardson et al. 1995). Long-finned pilot whales apparently ceased vocalizing during the Heard Island Feasibility Test transmissions of loud (maximum source level: 220 dB re 1 μPa at 1 m), low-frequency (peak frequency: 57 Hz; maximum bandwidth: 30 Hz) sound, suggesting that these animals were sensitive to this low-frequency sound, at least at this high level (Bowles et al. 1994).

Beluga Whale

The hearing ability of the beluga whale is rather well known due to our ability to study well-trained captive animals. Because it is perhaps the best understood species, it is discussed in some detail here even though it is not a regular visitor to the Neptune project area.

The low-frequency hearing abilities of three captive beluga whales were measured by Awbrey et al. (1988). Hearing sensitivities for those animals were measured at 125, 250, and 500 Hz and at 1, 2, 4, and 8 kHz. The hearing sensitivities of the three animals were similar, although the young male was slightly more sensitive to low frequencies than the adults. His hearing thresholds were 118 dB re 1 μPa at 125 Hz (compared with 122 and 124 dB for the two adults), 114 dB re 1 μPa at 250 Hz (versus 126 and 122 for the two adults), and 106 dB re 1 μPa at 500 Hz (versus 109 and 108 for the two adults). The mean hearing thresholds for the three belugas at the higher frequencies were 101, 101, 77, and 65 dB re 1 μPa at 1, 2, 4, and 8 kHz, respectively.

The hearing sensitivity of a female beluga whale was measured by Johnson et al. (1989) at frequencies from 40 Hz to 4 kHz in the presence of masking white noise. Her hearing thresholds ranged from 140 ± 3 dB re 1 μPa at 40 Hz to 81 ± 3 dB re 1 μPa at 4 kHz. Critical ratios (a measure of the energy of the signal at threshold relative to energy in the white noise) were calculated in this study, and they indicate that the beluga whale's masked hearing was about 3 dB more sensitive than that of the bottlenose dolphin, which was not significant at higher frequencies.

The hearing capabilities of beluga whales were also measured by Klishin et al. (2000) in a single adult male using electrophysiological methods. They measured rhythmic responses to amplitude-modulated tones, known as the envelope following response (EFR). Measurement of the EFR provides results that are more comparable with those from behavioral studies than results provided by ABR measurements (Au 2000) and can be specified by rms pressure (Klishin et al. 2000), commonly used in behavioral studies. Hearing thresholds were measured at frequencies from 8–128 kHz. The animal was found to have its maximum hearing sensitivity (54.6 dB) at a frequency of 54 kHz. Its best hearing range was from 32–108 kHz.

Ridgway et al. (2001) measured the hearing sensitivity of two beluga whales (one male and one female) at depths of 5, 100, 200, and 300 m (~16.4, ~328, ~656, ~985 feet, respectively) in the open ocean in deep waters 2–4 km (1.1–2.2 nm) offshore of San Clemente, CA. The whales were trained to respond by whistling when presented with tones of 500-ms duration and frequencies of 0.5–100 kHz. While the whales used lower-amplitude, higher-frequency whistle responses to the sound stimuli at depth, their hearing abilities were not affected by depth. In fact, most of the lowest thresholds recorded were when the whales were at depths of 100, 200, or 300 m, compared with the 5-m near-surface depth. Hearing thresholds recorded at depth did not differ significantly from those at the near-surface.

Bottlenose Dolphin

The bottlenose dolphin was the first species of odontocete for which an audiogram was produced. Johnson (1967) measured the hearing sensitivity of a single 8- or 9-year old male bottlenose dolphin to frequencies ranging from 75 Hz to 150 kHz. That animal's greatest hearing sensitivity (45 dB re 1 µPa) was at about 50 kHz. Its hearing threshold at 75 Hz was 137 dB re 1 µPa and its hearing threshold at 150 kHz was 135 dB re 1 µPa, which was thought to be its effective upper frequency limit of hearing.

Au et al. (2002) measured the hearing sensitivity of a single 18-year-old female bottlenose dolphin using behavioral techniques and produced an audiogram remarkably similar to that of Johnson (1967). They also measured its hearing sensitivity to 2-second broadband signals with peak frequencies around 100 kHz, designed to simulate echoes from bottlenose dolphin echolocation signals. The measured hearing thresholds for these broadband signals were 33.9 ± 3.1 dB re 1 μPa^2 for a unimodal stimulus and 32.3 ± 2.8 dB re 1 μPa^2 for a bimodal stimulus, which were lower than those found using pure tone signals.

Turl (1993) measured the low-frequency hearing sensitivity of a bottlenose dolphin in the frequency range of 50–300 Hz. That dolphin's hearing thresholds at 300 and 200 Hz were similar to those reported by others, with signal detection at sound pressure levels approximately 10–15 dB above the ambient noise level. However, for frequencies from 50–150 Hz, after a few trials, the dolphin's sensitivity suddenly improved and she was able to detect signals near the ambient noise level. Turl suggested that the dolphin was detecting particle velocity or some combination of pressure and velocity rather than the acoustic stimulus itself at lower frequencies.

An eastern Pacific bottlenose dolphin (*Tursiops* spp.) captured near Baja California, Mexico, was found to have maximum hearing sensitivities at 25 kHz (47 dB) and 50 kHz (46 dB) (Ljungblad et al. 1982). That dolphin responded reliably to signals in the range of 2–135 kHz but did not respond to 136- to 160-kHz signals at sound pressure levels up to 120 dB re 1 μPa.

Ridgway and Carder (1997) presented evidence of individual variation in the hearing sensitivities of eight (four male and four female) bottlenose dolphins. Three of the male dolphins (aged 23, 26, and 34 years) had lost sensitivity to 70-, 80-, 100-, and 120-kHz tones, and one female dolphin was insensitive to 100- and 120-Hz tones. They also reported on one 9-year-old female bottlenose dolphin who did not respond to any sound when measured behaviorally and electrophysiologically. She also was unable to vocalize. Brill et al. (2001) reported age-related hearing loss in a 33-year-old male bottlenose dolphin. That dolphin had lost sensitivity to frequencies >55 kHz and his right ear was 16–33 dB less sensitive than his left ear in the 10–40-kHz range.

Dolphins *Lagenorhynchus* spp.

Hearing has not been measured in Atlantic white-sided dolphins or white-beaked dolphins. However, Tremel et al. (1998) measured hearing sensitivity in a female Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) at frequencies from 100 Hz to 140 kHz. That dolphin was most sensitive (<90 dB re 1 μPa) to frequencies from 2–128 kHz and did not respond to a 75-Hz signal at 146 dB re 1 μPa or to a 150 kHz signal at 127 dB re 1 μPa.

Risso's Dolphin

Au et al. (1997) measured the low-frequency hearing sensitivity of a Risso's dolphin. The hearing thresholds for that animal were 142.2 ± 1.7 dB for a 75-Hz pure tone signal and 140.8 ± 1.1 dB for the ATOC signal (75 Hz, 195 dB re 1 μPa source level).

Common Dolphin

Hearing has not been measured directly in common dolphins. The vocalizations of these animals consist of whistles with dominant frequencies of 2–18 kHz, chirps with dominant frequencies of 8–14 kHz, and barks with dominant frequencies of <500 Hz to 3 kHz (summarized by Richardson et al. 1995). One study showed that common dolphins avoided the immediate vicinity (1–2 km, 0.54–1.1 nm) of operating seismic airguns (peak source level of ~205 dB re 1μPa at 200 Hz), suggesting some sensitivity to this low-frequency sound, at least at this high level (Goold 1996).

Striped Dolphin

The hearing ability of a female striped dolphin that stranded off the Netherlands was assessed by Kastelein et al. (2003) using behavioral techniques. The animal had been rehabilitated and kept in captivity for three years prior to the experiments. Her hearing sensitivity was measured at frequencies between 0.5 and 160 kHz. The low-frequency 500-Hz cutoff was a constraint of the sound production system. The animal had hearing capabilities at all frequencies tested, with a maximum sensitivity (42 dB re 1 µPa) at 64 kHz and a typical u-shaped audiogram. The range of her most sensitive hearing was 29–123 kHz.

Harbor Porpoise

The hearing capability of the harbor porpoise was first measured by Andersen (1970) using a captive 3.5-year-old female. That animal was found to have its most sensitive hearing in the frequency range of 4–40 kHz. Its hearing sensitivity diminished by about 15 dB per octave below 4 kHz and from 40–140 kHz, resulting in a typical mammalian u-shaped hearing curve. More recently, Kastelein et al. (2002) investigated the hearing capabilities of a two-year old stranded male harbor porpoise using behavioral techniques. They also produced a u-shaped audiogram for the animal that showed hearing capabilities from 0.25–180 kHz. The porpoise's range of best hearing in that study was 16–140 kHz, with a lower sensitivity at around 64 kHz. The maximum hearing sensitivity of that animal was between 100 and 140 kHz (~33 dB re 1 µPa), with hearing sensitivity falling off dramatically above 140 kHz. This is similar to the frequency range of harbor porpoise echolocation clicks, which were reported by Au et al. (1999) to have peak frequencies of 125–130 kHz and by Tielmann et al. (2002) to have peak frequencies of 125–136 kHz with a mean peak frequency of 131 kHz.

Pinnipeds

Hearing has been directly measured in several pinniped species. Pinnipeds generally have lower best frequencies, lower high-frequency cutoffs, and poorer sensitivity at the best frequency than do odontocetes (Richardson et al. 1995). At low frequencies, pinnipeds have better hearing sensitivity than do odontocetes (Kastak and Schusterman 1998). The four species of pinniped that could be encountered in the Neptune project area all belong to the subfamily Phocinidae. The information available on the underwater hearing ability of phocinid seals suggests that these animals have audiograms that are essentially flat from 1 kHz to 30–50 kHz, with thresholds of 60–85 dB re 1 µPa, and that underwater hearing sensitivity above 60 kHz is generally poor (Richardson et al. 1995). Hearing sensitivity to 100-Hz pure tones was measured in one harbor seal to be 96 dB re 1 µPa (Kastak and Schusterman 1995). Phocinids are, for the most part, more sensitive to sounds in water than in air (Richardson et al. 1995). The high-frequency cutoff of in-air hearing sensitivity is ~20 kHz, and in-air hearing sensitivity is poor below 2 kHz. However, data suggest that harbor seals hear equally well in air and under water (Kastak and Schusterman 1998).

Sea Turtle Hearing

The hearing capabilities of sea turtles are poorly known. Direct hearing measurements have been made in only a few species. These experiments indicate that sea turtles generally hear best at low frequencies and that the upper frequency limit of their hearing is likely about 1 kHz. Sea turtle underwater hearing is believed to be about 10 dB less sensitive than their in-air hearing (Lenhardt 1995).

An early experiment measured cochlear potential in three Pacific green turtles (*Chelonia mydas agassizii*) and suggested a best hearing sensitivity in air for those animals in the range of

300–500 Hz and an effective hearing range of 60–1,000 Hz (Ridgway et al. 1969). Lenhardt et al. (1996) used a behavioral "acoustic startle response" to measure the underwater hearing sensitivity of a juvenile Kemp's ridley (*Lepidochelys kempii*) and a juvenile loggerhead (*Caretta caretta*) turtle to a 430-Hz tone. Their results suggest that those species have a hearing sensitivity at that frequency that is similar to those of the green turtles studied by Ridgway et al. (1969). Lenhardt (1995) was also able to induce startle responses in loggerhead turtles to low-frequency (20–80 Hz) sounds projected into their tank. He suggested that sea turtles have a range of best hearing from 100–800 Hz, an upper limit of about 2,000 Hz, and serviceable hearing abilities below 80 Hz.

More recently, the hearing abilities of loggerhead sea turtles were measured using auditory evoked potentials in 35 juvenile animals caught in tributaries of Chesapeake Bay (Bartol et al. 1999). Those experiments suggest that the effective hearing range of the loggerhead sea turtle is 250–750 Hz and that its most sensitive hearing is at 250 Hz.

TYPES OF NOISE ASSOCIATED WITH THE NEPTUNE PROJECT

Underwater sounds produced during the construction and operation of the Neptune LNG deepwater port can be classified into three broad categories. Sounds of short duration that are produced intermittently or at regular intervals, such as sounds from pile driving, are classified as "pulsed." Sounds produced for extended periods, such as sounds from generators, are classified as "continuous." Sounds from moving sources, such as ships, can be continuous, but for an animal at a given location, these sounds are "transient" (i.e., increasing in level as the ship approaches and then diminishing as it moves away). Studies indicate that marine animals respond somewhat differently to the three categories of noise. In general, baleen whales tend to react to lower received levels of continuous sound than of pulsed sound. Masking effects are expected to be less severe when sounds are pulsed or transient than when they are continuous. Because little information is available on the effects on marine mammals of the specific noise sources likely to be produced at the Neptune site, marine mammal reactions to the three broad categories of noise produced by other industrial activities are reviewed below.

Continuous Sounds

Drilling Operations

There will be no drilling activity associated with the Neptune LNG project. However, because there are no studies available on the reactions of marine mammals to sounds produced at an LNG facility, examples of marine mammals reactions to drilling sounds are presented here as an example of how these animals react to the continuous sounds from a stationary offshore industrial facility.

Baleen Whales

Baleen whales sometimes show behavioral changes in response to received broadband drillship noises of 120 dB or greater. On their summer range in the Beaufort Sea, bowhead whales (*Balaena mysticetus*, a species closely related to the right whale) reacted to drillship noises within 4–8 km (2.2–4.3 nm) of a drillship at received levels 20 dB above ambient, or about 118 dB (Richardson et al. 1990). Reactions were stronger at the onset of the sound (Richardson et al. 1995). Migrating bowhead whales avoided an area with a radius of 10–20 km (5.4–10.8 nm) around drillships and their associated support vessels, corresponding to a received noise level around 115 dB (Greene 1987; Koski and Johnson 1987; Hall et al. 1994; Davies 1997; Schick and Urban 2000). For gray whales (*Eschrichtius robustus*) off California, the predicted reaction zone around a semi-submersible drill rig was less than 1 km (0.54 nm), at received levels of ~120 dB (Malme et al. 1983, 1984). Humpback whales (*Megaptera novaeangliae*) showed no obvious avoidance response to broadband drillship noises at a received level of 116 dB (Malme et al. 1985).

Toothed Whales

Dolphins and other toothed whales may show considerable tolerance of floating and bottom-founded drillrigs and their support vessels. Kapel (1979) reported many pilot whales (*Globicephala melas*) within visual range of drillships and their support vessels off West Greenland. Beluga whales (*Delphinapterus leucas*) have been observed swimming within 100-150 m of an artificial island while drilling was underway (Fraker and Fraker 1979; 1981), and within 1,600 m of the drillship *Explorer I* while the vessel was drilling (Fraker and Fraker 1981). Some belugas in Bristol Bay and the Beaufort Sea, Alaska, when exposed to playbacks of drilling sounds, altered course to swim around the source, increased swimming speed, or reversed direction of travel (Stewart et al. 1982; Richardson et al. 1995). Reactions of beluga whales to semi-submersible drillship noise were less pronounced than were reactions to motorboats with outboard engines. Captive belugas exposed to playbacks of recorded semi-submersible noise seemed quite tolerant of that sound (Thomas et al. 1990).

Pinnipeds

Responses of pinnipeds to drilling noise have not been well studied. Richardson et al. (1995) summarized the few available studies, which showed ringed seals (*Pusa hispida*) and bearded seals (*Erignathus barbatus*) in the Arctic to be rather tolerant of drilling noise. Seals were often seen near active drillships and approached, to within 50 m, a sound projector broadcasting low-frequency drilling sound.

Other Continuous Sounds

Toothed Whales

Harbor porpoises (*Phocoena phocoena*) off Vancouver Island, British Columbia, were found to be sensitive to the simulated sound of a 2-MW offshore wind turbine (Koschinski et al. 2003). The porpoises remained significantly further away from the sound source when it was active, and this effect was seen out to a distance of 60 m. The device used in that study produced sounds in the frequency range of 30–800 Hz, with peak source levels of 128 dB re 1 µPa at 1 m at the 80 and 160 Hz frequencies.

TTSs were measured in a single captive bottlenose dolphin (*Tursiops truncatus*) after exposure to a continuous tone with maximum sound pressure levels at frequencies ranging from

4–11 kHz that was gradually increased in intensity to 179 dB re 1 μPa and in duration to 55 minutes (Nachtigall et al. 2003). No threshold shifts were measured at sound pressure levels of 165 or 171 dB re 1 μPa. However, at 179 dB re 1 μPa, TTSs >10 dB were measured during different trials with exposures ranging from 47-54 minutes. Hearing sensitivity was apparently recovered within 45 minutes after noise exposure.

Pinnipeds

Reactions of harbor seals (*Phoca vitulina*) to the simulated noise of a 2-MW windpower generator were measured by Koschinski et al. (2003). Harbor seals surfaced significantly further away from the sound source when it was active and did not approach the sound source as closely. The device used in that study produced sounds in the frequency range of 30–800 Hz, with peak source levels of 128 dB re 1 μPa at 1 m at the 80 and 160 Hz frequencies.

Kastak et al. (1999) reported that they could induce mild TTSs in California sea lions (*Zalophus californianus*), harbor seals, and northern elephant seals (*Mirounga angustirostris*) by exposing them to underwater octave-band noise at frequencies in the 100-2000 Hz range for 20-22 minutes. Mild TTSs became evident when the received levels were 60-75 dB above the respective hearing thresholds, that is, at received levels of about 135-150 dB. Three of the five animals tested showed shifts of approximately 4.6-4.9 dB, and all recovered to baseline hearing sensitivity within 24 hours of exposure. Schusterman et al. (2000) showed that TTS by these seals occurred at somewhat lower received levels when the animals were exposed to the sound for 40 minutes than for 20-22 minutes, confirming that there is a duration effect in pinnipeds. There are some indications that, for corresponding durations of sound, pinnipeds may incur a TTS at a somewhat lower received level than do small odontocetes (Kastak et al. 1999; cf. Au 2000).

Transient Sounds

Vessels

Broadband source levels (at 1 m) for most small ships where marine mammal reactions have been measured are in the 170-180 dB re 1 μPa range, excluding infrasonic components (Richardson et al. 1995). Broadband underwater sounds from the offshore supply ship *Robert Lemeur* in the Beaufort Sea were 130 dB at a distance of 0.56 km (0.3 nm) (Greene 1987), and were 11 dB higher when bow thrusters were operating than when they were not (Greene 1985, 1987). The *Robert Lemeur* had nozzles around the thruster propellers. Broadband noise levels from ships lacking nozzles or cowlings around the propellers can be about 10 dB higher than those from ships with the nozzles (Greene 1987).

Baleen Whales

Reactions of baleen whales to boat noises include changes in swimming direction and speed, blow rate, and the frequency and kinds of vocalizations (Richardson et al. 1995). Baleen whales, especially minke whales (*Balaenoptera acutorostrata*), occasionally approach stationary or slow-moving boats, but more commonly avoid boats. Avoidance is strongest when boats approach directly or when vessel noise changes abruptly (Watkins 1986; Beach and Weinrich

1989). Humpback whales responded to boats at distances of at least 0.5 to 1 km (0.3–0.54 nm), and avoidance and other reactions have been noted in several areas at distances of several kilometers (Jurasz and Jurasz 1979; Dean et al. 1985; Bauer 1986; Bauer and Herman 1986). During some activities and at some locations, humpbacks exhibit little or no reaction to boats (Watkins 1986). Some baleen whales seem to show habituation to frequent boat traffic. Over 25 years of observations in Cape Cod waters, minke whales' reactions to boats changed from frequent positive interactions to a general lack of interest, while humpback whales reactions changed from being often negative to being often positive and finback whales (*B. physalus*) reactions changed from being mostly negative to being mostly uninterested (Watkins 1986).

Right whales (*Eubalaena glacialis*) also show variable responses to boats. There may be an initial orientation away from a boat, followed by a lack of observable reaction (Atkins and Swartz 1989). A slowly moving boat can approach a right whale, but an abrupt change in course or engine speed will elicit a reaction (Goodyear 1989; Mayo and Marx 1990; Gaskin 1991). When approached by a boat, right whale mothers will interpose themselves between the vessel and calf and will maintain a low profile (Richardson et al. 1995). In a long-term study of baleen whale reactions to boats, while other baleen whale species appeared to habituate to boat presence over the 25-year period (see above), right whales continued to show either uninterested or negative reactions to boats with no change over time (Watkins 1986). In a recent study, using a multi-sensor acoustic recording tag and controlled sound exposure experiments, right whales were found to show no response to playbacks of the sound of an approaching 120-m container ship or to actual vessels (Nowacek et al. 2004). The closely related bowhead whale typically begins avoiding diesel-powered boats at distances of ~4 km (2.2 nm); the whale often first attempts to "outrun" the vessel, but may turn to swim perpendicular to the boat’s track when it approaches within a few hundred meters (Richardson et al. 1985a,b; Koski and Johnson 1987). Bowheads may be displaced by a few kilometers when fleeing, although some return to the area within a day.

Toothed Whales

Some species of small toothed cetaceans avoid boats when they are approached to within 0.5 to 1.5 km (0.3–0.8 nm), with occasional reports of avoidance at greater distances (Richardson et al. 1995). Some toothed whale species appear to be more responsive than others. Beaked whales and beluga whales seem especially responsive to boats.

Dolphins may tolerate boats of all sizes, often approaching and riding the bow and stern waves (Shane et al. 1986). At other times, dolphin species that are known to be attracted to boats will avoid them. Such avoidance is often linked to previous boat-based harassment of the animals (Richardson et al. 1995). Coastal bottlenose dolphins that are the object of whale-watching activities have been observed to swim erratically (Acevedo 1991), remain submerged for longer periods of time (Janik and Thompson 1996; Nowacek et al. 2001), display less cohesiveness among group members (Cope et al. 1999), whistle more frequently (Scarpaci et al. 2000), and rest less often (Constantine et al. 2004) when boats were nearby. Pantropical spotted dolphins (*Stenella attenuata*) and spinner dolphins (*S. longirostris*) in the eastern Tropical Pacific, where they have been targeted by the tuna fishing industry because of their association with these fish, show avoidance of survey vessels up to six nautical miles away (Au and Perryman 1982; Hewitt 1985), whereas spinner dolphins in the Gulf of Mexico were observed bowriding the survey vessel in all 14 sightings of this species during one survey (Würsig et al. 1998).

Harbor porpoises tend to avoid boats. In the Bay of Fundy, Polacheck and Thorpe (1990) found harbor porpoises to be more likely to be swimming away from the transect line of their survey vessel than swimming toward it and more likely to be heading away from the vessel when they were within 400 m of it. Similarly, off the west coast of North America, Barlow (1988) observed harbor porpoises avoiding a survey vessel by moving rapidly out of its path within 1 km (0.54 nm) of that vessel.

Beluga whales are generally quite responsive to vessels. Belugas in Lancaster Sound in the Canadian Arctic showed dramatic reactions in response to icebreaking ships, with received levels of sound ranging from 101 dB to 136 dB re 1 µPa in the 20–1,000-Hz band at a depth of 20 m (Finley et al. 1990). Responses included emitting distinctive pulsive calls that were suggestive of excitement or alarm and rapid movement in what seemed to be a flight response. Reactions occurred out to 80 km (43.2 nm) from the ship. Although belugas in the St. Lawrence River occasionally show positive reactions to ecotourism boats by approaching and investigating those boats, one study found the belugas to surface less frequently, swim faster, and group together in the presence of boats (Blane and Jaakson 1994). Another study found belugas to use higher-frequency calls, a greater redundancy in their calls (more calls emitted in a series), and a lower calling rate in the presence of vessels (Lesage et al. 1999). The level of response of belugas to vessels is partly a function of habituation. The distant fleeing responses in the High Arctic do not occur in the Beaufort Sea and the Gulf of St. Lawrence where ship traffic is much more frequent and regular.

Most beaked whales tend to avoid approaching vessels (e.g., Würsig et al. 1998). They may also dive for an extended period when approached by a vessel (e.g., Kasuya 1986). Northern bottlenose whales (*Hyperoodon ampullatus*), on the other hand, are sometimes quite tolerant of slow-moving vessels (Reeves et al. 1993; Hooker et al. 2001).

Sperm whales generally show no overt reactions to vessels unless they are approached to within several hundred meters (Watkins and Schevill 1975; Würsig et al. 1998; Magalhães et al. 2002). Observed reactions include spending more (Richter et al. 2003) or less (Watkins and Schevill 1975) time at the surface, increasing swimming speed or changing heading (Papastavrou et al. 1989; Richter et al. 2003), and diving abruptly (Würsig et al. 1998).

Pinnipeds

Ship and boat noise do not seem to have strong effects on seals in the water, but the data are limited. When in the water, seals appear to be much less apprehensive of approaching vessels. Some will approach a vessel out of apparent curiosity, including noisy vessels such as those operating seismic airgun arrays (Moulton and Lawson 2000). Gray seals have been known to approach and follow fishing vessels in an effort to steal catch or the bait from traps. In contrast, seals hauled out on land often are quite responsive to nearby vessels. Terhune (1985) reported that northwest Atlantic harbor seals (*Phoca vitulina concolor*) were extremely vigilant when hauled out, and were wary of approaching (but less so passing) boats. Suryan and Harvey (1999) reported that Pacific harbor seals (*P. vitulina richardii*) commonly left the shore when powerboat operators approached to observe the seals. Those seals detected a powerboat at a mean distance of 264 m, and seals left the haul-out site when boats approached to within 144 m.

Pulsed Sounds

The noise generated by the Neptune project will mostly be continuous sources. However, there may be pile-driving used to set the anchors for the two unloading buoys. Pile-driving produces pulsive noise and therefore, a discussion of the known effects of pulsive noise is included here. Most research has been on the effects of the airgun pulses used of offshore oil and gas exploration.

Masking Effects

Masking effects of pulsed noise on marine mammal calls and other natural sounds are believed to be negligible given the discontinuous nature of these sounds. Some whales are known to continue calling in the presence of seismic pulses—their calls can be heard between the pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene and McLennan 2000). Although there was one report that sperm whales ceased calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), more recent studies have reported that sperm whales continued calling in the presence of seismic pulses (Madsen et al. 2002; Jochens and Biggs 2003).

Disturbance Effects

Observed behavioral reactions of baleen whales to pulsed sounds vary depending on the sound source level, type of whale exposed to the sounds, and the whales' activity when the sounds were heard. Most baleen whales exhibit some displacement from strong pulsed sounds. In most cases, the displacement is temporary and/or of limited extent. Experimental results (e.g., Würsig et al. 2000; Akamatsu et al. 1993) show that responses to impulsive noise sources are also highly variable among toothed whales. Under some circumstances, some species will avoid such noises when received levels exceed 180 dB. The variability is presumably related to the fact that the observations and experiments on toothed whales involved a variety of species in a variety of situations, and involved sources that emitted sounds at widely varying source levels and at differing frequencies, pulse lengths, and inter-pulse intervals.

Data on short-term reactions (or lack of reactions) of cetaceans to impulsive noises do not necessarily provide information about long-term effects. It is not known whether impulsive noises affect reproductive rate or distribution and habitat use in subsequent days or years. Gray whales continue to migrate annually along the west coast of North America despite intermittent seismic exploration (and much ship traffic and an existing developed oil field) in that area for decades (Malme et al. 1984). Bowhead whales continue to travel to the eastern Beaufort Sea each summer despite previous long-term seismic exploration in their summer and autumn range. Bowheads are often seen in summering areas where seismic exploration occurred in preceding summers (Richardson et al. 1987). They also have been observed over periods of days or weeks in areas repeatedly ensonified by seismic pulses. However, it is not known whether the same individual bowheads were involved in these repeated observations (within and between years) in strongly ensonified areas. It is also not known whether whales that tolerate exposure to seismic pulses are stressed.

Data on the reactions of seals to pulsed sounds are limited, but the few reports available (e.g., Richardson et al. 1995; Yurk and Trites 2000) suggest that they would exhibit either no, or short-term, behavioral responses. Some seals exhibited some displacement from strong pulsed sounds and others showed high tolerance for strong underwater sound pulses. Seals' reactions to pulsed sounds vary depending on the sound source level, type of seal exposed to the sounds, and activity at the time of exposure. In most cases, displacement was temporary and/or of limited extent, with some species showing high tolerance for strong underwater sound pulses. Pinnipeds in both water and air sometimes tolerate strong noise pulses from non-explosive and explosive scaring devices, especially if attracted to the area for feeding or reproduction (Mate and Harvey 1987; Reeves et al. 1996).

Hearing Impairment

There are no data on the levels or properties of sound that are required to induce a TTS in any baleen whale, because it is not possible to study hearing directly in such a large, free-living marine animal. TTSs for pinnipeds exposed to brief pulses (either single or multiple) have not been measured.

Temporary hearing loss in toothed whales exposed to pulsed sounds has been reported. Ridgway et al. (1997) and Schlundt et al. (2000) exposed bottlenose dolphins and beluga whales to single 1-s pulses of underwater sound. TTSs generally became evident at received levels of 192-201 dB re 1 µPa rms at 3, 10, 20, and 75 kHz. At 75 kHz, one dolphin exhibited a TTS at 182 dB, and at 0.4 kHz, no dolphin or beluga exhibited a TTS after exposure to levels up to 193 dB (Schlundt et al. 2000). There was no evidence of permanent hearing loss, as all hearing thresholds returned to baseline values at the end of the study.

Finneran et al. (2002) exposed a beluga whale and a bottlenose dolphin to single pulses using an 80-in^3 water gun. Masked TTS (MTTS), defined as a TTS that occurred with considerable background noise, was observed in a beluga after exposure to a single impulse with a peak-to-peak pressure of 226 dB re 1 µPa, peak pressure of 160 kPa, and total energy flux of 186 dB re 1 µPa2·s. Thresholds returned to within 2 dB of the pre-exposure value approximately four minutes after exposure. No MTTS was observed in a bottlenose dolphin exposed to one pulse with a peak-to-peak pressure of 228 dB re 1 µPa, equivalent to a peak pressure of 207 kPa and total energy flux of 188 dB re 1 µPa2·s (Finneran et al. 2000, 2002). In that study, TTS was defined as occurring when the post-exposure threshold was ≥6 dB higher than the pre-exposure threshold. Pulse duration at the highest exposure levels, where MTTS became evident in the beluga, was typically 10-13 ms.

There are no published data on TTS in marine mammals exposed to repeated transient sounds.

Non-Auditory Physiological Effects

Very little is known about the potential for impulsive sounds to cause non-auditory physiological effects in marine mammals. Available data suggest that such effects, if they occur at all, would be limited to short distances from the very loud noise sources. However, the available data do not allow for meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in these ways. Marine mammals that show behavioral avoidance of pulsed sounds, including most baleen whales, some odontocetes, and some pinnipeds, are unlikely to incur auditory impairment or other physical effects.

Romano et al. (2004) exposed a beluga whale and a bottlenose dolphin to single underwater impulsive sounds (up to 200 kPa) from a seismic water gun and measured nervous system and immune system indicators before and after these exposures. In the beluga whale, levels of norepinephrine, epinephrine, and dopamine increased significantly with increasing sound levels and were significantly greater after sound exposures >100 kPa than after sound exposures <100 kPa and after control exposures. In the bottlenose dolphin, there was a significant increase in aldosterone level and a significant decrease in monocyte count after exposure to impulsive sounds. How short-term stress responses might affect the long-term health of cetaceans is unknown.

Seismic Surveys

Baleen Whales

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales have often been reported as showing no overt reactions to airgun pulses at distances beyond a few kilometers. However, recent studies of humpback and bowhead whales indicate that reactions, including avoidance, sometimes occur at greater distances from the seismic source than previously documented. Avoidance distances often exceed the distances at which boat-based observers can see whales.

Studies of humpback whales have determined that received levels of pulses in the 160-170 dB re 1 μPa rms range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. On the other hand, some baleen whales show considerable tolerance of seismic pulses. However, when the pulses are strong enough, avoidance or other behavioral changes become evident. Because the responses become less obvious with diminishing received sound level, it has been difficult to determine the maximum distance (or minimum received sound level) at which marine mammal reactions to seismic pulses occur.

Migrating humpback, gray, and bowhead whales have reacted to seismic survey pulses by deviating from their normal migration route and/or interrupting their feeding and moving away (e.g., Malme et al. 1984, 1985, 1988; Richardson et al. 1986, 1995; Ljungblad et al. 1988; Richardson and Malme 1993; McCauley et al. 1998, 2000; Miller et al. 1999). Finback and blue whales (*Balaenoptera musculus*) have also displayed some behavioral reactions to airgun noise

(McDonald et al. 1995; Stone 1997, 1998, 2000). Prior to the late 1990s, it was thought that migrating bowhead whales, gray whales, and humpback whales all begin to show strong avoidance reactions to seismic pulses at received levels of about 160 to 170 dB re 1 µPa rms. Subtle behavioral changes sometimes became evident at somewhat lower received levels. Recent studies have shown that some species of baleen whale may show strong avoidance at received levels somewhat lower than 160-170 dB re 1 µPa rms. The observed avoidance reactions included movement away from feeding locations or statistically significant deviations in the whales' direction of swimming and/or migration corridor as they approached or passed the sound sources. In the case of the migrating whales, the observed changes in behavior appeared to be of little biological consequence to the animals. They simply avoided the sound source by slightly displacing their migration route yet remained within the natural boundaries of the migration corridors.

Malme (1993) summarized the received levels of seismic (airgun) sounds at which an estimated 50% of bowhead and gray whales avoided the source. He then examined the received levels in relation to effective pulse pressure and in relation to response thresholds of the same two species to continuous sound. With pulsed (airgun) sounds, the sound pressure necessary to elicit avoidance in 50% of the whales was about 50 dB higher than that for continuous sounds.

McCauley et al. (1998, 2000) studied the responses of humpback whales off western Australia to a full-scale seismic survey with a 16-gun 2678-in^3 array, and to a single 20-in^3 airgun with a source level of 227 dB re 1 µPa-m (peak-peak). They found that the overall distribution of migrating humpbacks through their study area was not affected by the full-scale seismic program. McCauley et al. (1998) did, however, document localized avoidance of the array and of the single gun. Avoidance reactions began at 5 to 8 km (2.7–4.3 nm) from the array, and those reactions kept most pods about 3 to 4 km (1.6–2.2 nm) from the operating seismic boat. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km (7.6 nm). Avoidance distances with respect to the single airgun were smaller but consistent with the results from the full array in terms of the received sound levels. The mean avoidance distance from the airgun corresponded to a received sound level of 140 dB re 1 µPa rms; this was the level at which humpbacks started to show avoidance reactions to an approaching airgun. The startle response occurred at a mean received level of 122 dB rms. The standoff range, that is, the closest point of approach of the airgun to the whales, corresponded to a received level of 143 dB rms. The initial avoidance response generally occurred at distances of 5 to 8 km (2.7–4.3 nm) from the airgun array and 2 km (1.1 nm) from the single gun. However, some individual humpback whales, especially males, approached within distances of 100 to 400 m, where the maximum received level was 179 dB re 1 µPa rms.

Humpback whales summering in southeast Alaska did not exhibit persistent avoidance when exposed to seismic pulses (Malme et al. 1985). Some humpbacks seemed "startled" at received levels of 150-169 dB re 1 µPa. Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 re 1 µPa effective pulse pressure level.

Toothed Whales

Little systematic information is available on the reactions of toothed whales to seismic pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above have been reported for toothed whales, and none similar in size and scope to the studies of bowhead and gray whales mentioned above. Toothed whales reactions to seismic surveying are variable and not well characterized. Dolphins and porpoises are often seen by observers on active seismic vessels, occasionally at close distances (e.g., bow riding). However, some studies, especially near the UK, showed localized (~1 km, 0.54 nm) avoidance. Recent studies show little evidence of reactions by sperm whales to airgun pulses, contrary to earlier indications. There are no specific data on responses of beaked whales to seismic surveys. There is increasing evidence that some beaked whales may strand after exposure to strong noise from mid-frequency sonars. Whether they ever do so in response to low frequency seismic survey noise is unknown.

Dolphins

Seismic operators sometimes see species of toothed whales near operating airgun arrays (e.g., Duncan 1985; Arnold 1996; Stone 2003). When a 3,959-in^3, 18-gun array was firing off California, toothed whales behaved in a manner similar to that observed when the airguns were silent (Arnold 1996). Most, but not all, dolphins often seemed to be attracted to the seismic vessel and floats, and some rode the bow wave of the seismic vessel, seemingly unperturbed by firing guns. However, in Puget Sound, Dall's porpoises observed when a 6,000-in^3, 12-16 gun array was firing, tended to be heading away from the boat (Calambokidis and Osmek 1998). White-beaked (*Lagenorhynchus albirostris*) and white-sided dolphins (*L. acutus*) in the U.K. showed fewer positive interactions (approaching, bow riding, swimming alongside) with a seismic vessel while its airgun array was operating. These species, along with killer whales, harbor porpoises, and bottlenose dolphins all were seen further away from the seismic vessel when its airguns were firing than when they were not (Stone 2003).

Goold (1996a,b,c) studied the effects of 2D seismic surveys in the Irish Sea on common dolphins (*Delphinus delphis*). Passive acoustic surveys were conducted from the "guard ship" that towed a hydrophone 180 m aft. The results indicated that there was a local displacement of dolphins around the seismic operation. However, observations indicated that the animals were tolerant of the sounds at distances outside a 1-km (0.54-nm) radius from the guns (Goold 1996a). Initial reports of larger-scale displacement were later shown to represent a normal autumn migration of dolphins through the area, and were not attributable to seismic surveys (Goold 1996a,b,c).

Beaked Whales

There are no data on the behavioral reactions of beaked whales to seismic surveys. Much attention has been given to a recent (September 2002) stranding of Cuvier's beaked whales in the Gulf of California (Mexico) while a seismic survey was under way in the general area (Malakoff 2002). The evidence linking the Gulf of California strandings to the seismic surveys is inconclusive, and to this date is not based on any physical evidence. However, it may be noteworthy that the ship implicated in the stranding was operating its multi-beam bathymetric sonar, which emits high-frequency noise thought to be in the best hearing range of toothed whales like the Cuvier's beaked whale.

Sperm Whales

There are some limited observations suggesting that sperm whales in the Southern Ocean ceased calling during some (but not all) times when exposed to weak noise pulses from extremely distant (>300 km, 162 nm) seismic exploration (Bowles et al. 1994). This "quieting" was suspected to represent a disturbance effect. Sperm whales exposed to pulsed man-made sounds at higher frequencies often cease calling (Watkins and Schevill 1975; Watkins et al. 1985).

On the other hand, recent (and more extensive) data from vessel-based monitoring programs in UK waters suggest that sperm whales in that area show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (Stone 2003). These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may underestimate reactions by some of the more responsive species or individuals, which may be beyond visual range. A recent study off northern Norway indicated that sperm whales continued to call when exposed to pulses from a distant seismic vessel, with received levels of up to 146 dB re 1 µPa peak-peak, and remained in the area throughout the survey (Madsen et al., 2002). Similarly, sperm whales in the Gulf of Mexico did not alter their calling behavior in the presence of seismic pulses, and there was no indication that they moved away from the sound source at received levels of up to 148 dB (Jochens and Biggs 2003). A study conducted off Nova Scotia detected no difference in the acoustic abundance of male sperm whales between years without any seismic survey activity and years with an active seismic program, with received levels of 130 to 150 dB re 1 µPa (McCall Howard 1999). In addition, in the Gulf of Mexico, Davis et al. (2000) found no differences in sighting frequencies of sperm whales among areas with and without seismic surveys, with received levels of up to >12 dB above ambient noise levels.

Pinnipeds

Few studies on the reactions of pinnipeds to noise from open-water seismic exploration have been published (for review, see Richardson et al. 1995). However, pinnipeds have been observed during a number of seismic monitoring studies in recent years. Monitoring studies in the Beaufort Sea during 1996-2001 provide a substantial amount of information on avoidance responses (or lack thereof) and associated behavior. Pinnipeds exposed to seismic noise have also been observed during recent seismic surveys along the U.S. west coast.

During seismic exploration off Nova Scotia, gray seals (*Halichoerus grypus*) exposed to noise from airguns and linear explosive charges reportedly did not react strongly (J. Parsons in G.D. Greene et al. 1985). An airgun caused an initial startle reaction among South African fur seals but was ineffective in scaring them away from fishing gear (Anonymous 1975). Thus, pinnipeds are expected to be rather tolerant of, or habituate to, repeated underwater sounds from distant seismic sources, at least when the animals are strongly attracted to the area.

In the UK, a radio-telemetry study has demonstrated short-term changes in the behavior of harbor seals (*Phoca vitulina*) and gray seals exposed to airgun pulses (Thompson et al. 1998). In that study, harbor seals were exposed to seismic pulses from a 90-in^3 array (3 × 30-in^3 airguns), and behavioral responses differed among individuals. One harbor seal avoided the array at distances up to 2.5 km (1.3 nm) from the source and only resumed foraging dives after the seismic survey stopped. Another harbor seal exposed to the same small airgun array showed no detectable behavioral response, even when the array was within 500 m (1640 ft). All gray seals exposed to a single 10-in^3 airgun showed an avoidance reaction. Seals moved away from the source, increased swimming speed and/or dive duration, and switched from foraging dives to predominantly transit dives. These effects appeared to be short-term as all gray seals either remained in, or returned at least once to, the foraging area where they had been exposed to seismic pulses. These results suggest that there are interspecific as well as inter-individual differences in seal responses to seismic sounds.

Monitoring work in the Alaskan Beaufort Sea during 1996-2001 provided considerable information regarding the behavior of seals exposed to seismic pulses (Harris et al. 2001; Moulton and Lawson 2002). These seismic projects usually involved arrays of 6 to 16 airguns with total volumes 560 to 1,500 in^3. The combined results suggest that some seals avoided the immediate area around seismic vessels. In most survey years, ringed seal sightings tended to be farther away from the seismic vessel when the airguns were operating than when they were not (Moulton and Lawson 2002). However, these movements were relatively small and were on the order of 100 m to (at most) a few hundreds of meters, and many seals remained within 100-200 m of the trackline as the operating airgun array passed.

The operation of the airgun array had minor and variable effects on the behavior of seals visible at the surface within a few hundred meters of the array. The behavioral data indicate that some seals were more likely to swim away from the source vessel during periods of airgun operations and more likely to swim toward or parallel to the vessel during non-seismic periods. No consistent relationship was observed between exposure to airgun noise and the proportions of seals engaged in other recognizable behaviors, e.g., "looked" and "dove." Such a relationship might have occurred if seals seek to reduce exposure to strong seismic pulses, given the reduced airgun noise levels close to the surface where "looking" occurs (Moulton and Lawson 2002).

In summary, visual monitoring from seismic vessels has shown only slight (if any) avoidance of the strong pulsed sounds from the airguns by pinnipeds, and only slight (if any) changes in behavior. These studies show that pinnipeds frequently do not avoid the area within a few hundred meters of an operating airgun array. However, initial telemetry work suggests that avoidance and other behavioral reactions may be stronger for some individuals than evident to date from visual studies.

Marine Invertebrates and Acoustics

In the following sections, all cited sound pressure levels (SPLs) are described in terms of the type of measure (e.g., zero-peak, peak-peak, RMS) when the information is available. In cases where ‘measure type’ information is not provided, the SPL values are followed by the qualifier “UMT”. UMT denotes ‘unidentified measure type’. It is important to note that most of the sound that would be produced by the *Neptune* DWP construction activities is continuous in nature.

This section discusses the use of sound (i.e., production and detection) by marine invertebrates and the potential impacts of anthropogenic sound on them. The invertebrates discussed in the following sections well represent the most commercially valuable invertebrate species/species groups (i.e., bivalves, decapod crustaceans, squid) that occur in the vicinity of the proposed DWP.

Sound Production

Many invertebrates are capable of sound production (e.g., barnacles, amphipods, shrimp, crabs, lobsters) (Budelman 1992 *in* Schmitz 2002; Au and Banks 1998; Tolstoganova 2002; Fish 1966 *in* Schmitz 2002). Mechanisms of sound production by invertebrates typically involve the scraping or rubbing of various body parts, although there are also other means of sound production. Behaviors most often associated with invertebrate acoustic communication include territorial behavior, mating, courtship and aggression.

Snapping shrimp (*Synalpheus parneomeris*) are among the major sources of biological sound in temperate and tropical shallow water areas (Au and Banks 1998). By rapidly closing one of its frontal chela (claws), a snapping shrimp generates a loud click and directs a forward jet of water. Both the sound and the jet of water function as weaponry in the territorial behavior. Measured source peak-to-peak SPLs ranged from 183 to 189 dB re: 1 µPa at 1 m, and extended over a frequency range of 2 to 200 kHz.

While feeding, king crab (*Paralithodes camtschaticus*) produce pulsed sounds with a frequency spectrum of 0.1 to 18 kHz (Tolstoganova 2002). These feeding sounds produced by conspecifics seemed to stimulate increased movement by those crabs receiving the sounds. Some king crabs were observed approaching the animals producing the sounds. King crabs also appeared to produce ‘discomfort’ sounds when environmental conditions were manipulated. These discomfort sounds differ from the feeding sounds in terms of frequency range and pulse duration.

Pye and Watson III (2004) reported that both male and female American lobster produce a buzzing vibration when grasped. They discovered that larger lobsters vibrated more consistently than did smaller lobsters, perhaps an indication that sound production is a component of the mating behavior of these animals.

Sound Detection

There has been considerable debate about the hearing capabilities of aquatic invertebrates. In contrast to fish and aquatic mammals, no structures have been discovered in aquatic invertebrates (except aquatic insects) that are stimulated by the pressure component of sound. However, vibrations (i.e., mechanical disturbances of the water) characterize sound waves as well. Therefore, rather than being pressure-sensitive, invertebrates appear to be most sensitive to particle displacement (Breithaupt 2002).

Typical decapod crustaceans have an extensive array of hair-like receptors both within and upon the body surface that could potentially respond to water- or substrate-borne displacements. They are also equipped with an abundance of proprioceptive organs (chordotonal organs associated with joints of antennae, legs and other appendages, and internal statocyst receptor systems) that could serve secondarily to perceive vibrations (Hawkins and Myrberg 1983).

The decapod sensory hairs are associated with sensory cells that can be stimulated by acceleration, velocity and hydrodynamic flow (Vedel and Clarac 1976; Wiese 1976). Hair fans described for a macruran decapod are sensitive to both water flow and vibrational stimuli, and are functionally analogous to the teleost lateral line (Breithaupt and Tautz 1990). Hairs may be tuned to different frequencies by virtue of their lengths (Tautz 1979 *in* Breithaupt and Tautz 1990). The chordotonal organs associated with antennae and appendage joints are capable of responding to low frequency waterborne vibrations (Budelmann 1992).

Statocysts are equilibrium organs that contain mechanosensory sensilla responsive to changes in the spatial orientation of the animal. They are located in the basal segments of each antennule in crabs (Cate and Roye 1997). Statocysts consist of a fluid-filled chamber that contains a mass known as a statolith. A statolith consists of sand grains embedded in a gelatinous matrix that lies in contact with some of the sensory hairs that line part of the chamber walls (Cohen and Dijkgraaf 1961).

Statocysts occur in a variety of invertebrates. They range from external organs such as the pendulum in some hydromedusae (Horridge 1971 *in* Hawkins and Myrberg Jr. 1983) to completely enclosed capsules with several patches of sensory hairs orientated in different directions, as described above for decapod crustaceans. Being mass-loaded, statocysts could potentially detect particle motion in much the same way as otolith-loaded inner ear hair cells of some vertebrates (Popper and Faye 1999). Cohen and Dijkgraaf (1961) stated that the statocyst is only responsive to angular rotations and strong vibrations propagated directly through a solid medium, and is not responsive to sounds propagated in either air or water. However, a recent study by Lovell *et al.* (2005) which investigated the mechanism of sound reception and the hearing abilities of the prawn, *Palaemon serratus*, showed that the physiological response to sound was initiated by the statocyst. Complete ablation of the electrophysiological response was achieved by removel of the prawn statocyst. It was the first time that the auditory brainstem response (ABR) recording technique was used on invertebrate animals. Lovell *et al.* (2005) showed that the statocyst of the prawn was sensitive to the motion of water particles displaced by low-frequency sounds ranging from 100 Hz to 3 kHz, with a hearing acuity similar to that of a hearing generalist fish (minimum threshold of approximately 105 dB re 1 μPa $_{\mathrm{RMS}}$ at 100 Hz, and 130 dB re 1 μPa $_{\mathrm{RMS}}$ at 3 kHz). The novel aspect of this work is that the sound source was positioned out of water, more than 1 m from the air/water interface. Therefore, the moving part of the transducer did not contact the water and generate near-field displacements. This study suggests greater sensitivity of marine invertebrates to low-frequency sound-induced particle motion than previously thought.

There is more known about the acoustic detection capabilities of decapod crustaceans (e.g., lobster, crab, shrimp) than any other marine invertebrate group. Decapod crustaceans have been used most extensively in studies on sound detection in aquatic invertebrates. Physiological and behavioural study findings indicate that these crustaceans respond primarily to hydrodynamic stimulation. As indicated above, response to sound stimuli by aquatic invertebrates appears to be in reaction to particle displacement rather than pressure (Tautz and Sandeman 1980; Goodall *et al.* 1990). Crustaceans seem to be most sensitive to sounds at low frequencies (i.e., <1 kHz) (Budelmann 1992; Popper *et al.* 2001). As a result of their investigation of the sensitivity of North Sea shrimp (*Crangon crangon*) to movement and vibration of water, Heinisch and Wiese (1987) concluded that this decapod's sensitivity was maximal at 170 Hz and that its particle displacement response threshold amplitude was 0.7 µm. This displacement threshold was very similar to the 0.888 µm threshold found for Norway lobster (Goodall *et al.* 1990). It has been demonstrated that both male and female immature American lobsters detect sounds in the frequency range 20 Hz to 1 kHz, while mature lobsters exhibited two peaks of acoustic sensitivity at frequency ranges 20 to 300 Hz, and 1 to 5 kHz (Pye and Watson III 2004). The latter frequency range within which a peak of acoustic sensitivity was observed by Pye and Watson III (2004) suggests that some marine invertebrates are sensitive to higher frequency sounds than previously thought. This was also reflected in the previous section on sound production by the higher frequency sounds being produced by various marine invertebrates.

Potential Impacts of Continuous Sound on Invertebrates

There has been an increasing awareness that anthropogenic underwater sound impacts marine organisms to varying degrees. Types of man-made sounds associated with marine activities include repeated pulses (e.g., seismic, pile driving), single pulses (e.g., explosions), and continuous sounds, both fixed location (e.g. oil rig noise) and transient (e.g., vessel noise). Most of these anthropogenic sounds are low frequency (i.e., <1,000 Hz). The most obvious exception to this is ultrasound produced by some sonar systems. The low frequencies of most of these types of sound correspond with those frequencies at which invertebrates appear to have the lowest acoustic detection thresholds.

Research on the impact of sound on non-mammalian marine species has been somewhat limited. The sources of anthropogenic sound that are of most concern and are most commonly used in studies of the effects of sound on invertebrates are seismic airguns and underwater explosions. The existing body of information relating to the impacts of sound on marine invertebrate species can be divided into three effect categories: (1) pathological, (2) physiological, and (3) behavioral. Pathological effects include lethal and sub-lethal physical damage to invertebrates; physiological effects include primary and secondary stress responses in invertebrates; and behavioral effects include changes in exhibited behaviors of invertebrates. Behavioral changes might be a direct reaction to a detected sound or a result of anthropogenic sound masking natural sounds that invertebrates make use of in their normal behavior. For example, Jeffs *et al.* (2003) provided some experimental evidence supporting the hypothesis that underwater sound may play a role in the orientation and settlement of pelagic crustacea. The authors investigated whether larval and post-larval stages of coastal crabs were attracted to coastal reef sounds. Their results indicated that pelagic stages of crab responded to underwater sounds and that they may use these sounds to help orient toward the coast. Pathological, physiological and behavioral effects are often interrelated in complex ways. For example, some physiological and behavioral effects could potentially lead to the ultimate pathological effect of mortality. Further information on each of these types of potential effects is presented in the following sections.

Since the sounds likely to be generated by construction and operation activities associated with the proposed *Neptune* LNG DWP Project are predominantly continuous in nature, the emphasis in the following sections will be on studies that used continuous sound sources. Unfortunately, there is a paucity of relevant continuous sound effects data for invertebrates.

Pathological/Physiological Effects

Lagardère (1982) investigated differences in growth and reproduction between brown shrimp (*Crangon crangon*) reared in aquaria under different sound level conditions over a three-month period. Above 20 Hz, the shrimp reared in the "noise" tanks were exposed to continuous SPLs 15 to 60 dB (UMT) higher than those in the "quiet" tanks. The greatest differences in sound pressure occurred between frequencies 40 and 63 Hz. The author concluded that there was a significant reduction in growth and reproduction rates in the shrimp exposed to the noisier conditions. Lagardère (1982) also claimed that the noisier conditions appeared to increase the mortality rate of the shrimp in the "noise" tank. However, it is unclear how these results, which were obtained within the reflective walls of a tank can be related to field conditions.

Behavioral Effects

Martec Limited (2004) recently investigated the potential effects of operational compressed natural gas pipelines/gathering lines on the behavior of American lobsters. Operational pipelines are known to emit continuous sound. Acoustic surveys showed sound peaks at frequencies ranging from 34 to 100 Hz, well within the sound detection frequency range of crustaceans. Pipeline sounds were detected on either side of the pipeline at a maximum distance of 200 m. The maximum measured SPLs were approximately 10 dB above the ambient sound level. Using a 'catch and release' program, the study did not detect any behavioral impacts on the lobsters.

Summary of Known Effects of Continuous Sound

Little information is available regarding the effects of exposure to continuous sound on marine invertebrates. Although there were indications that longterm exposure to continuous sound might influence such things as growth rate in shrimp, it should be noted that the animals used in the study were captive in a tank. It is likely that free-swimming invertebrates would exhibit avoidance behaviour in response to SPLs that were substantially higher than ambient levels. Transmission pipeline sounds did not appear to overtly impact the movements and behavior of lobsters.

FISH AND ACOUSTICS

The group of important fish (i.e., those listed in Table 1) that occur in the vicinity of the proposed Neptune DWP is comprised of species showing considerable diversity in hearing sensitivity, anatomical features related to sound detection (e.g., swim bladder, connections between swim bladder and ear), habitat preference, and life history. The discussion of continuous sound effects on fish in the following sections will pinpoint relevancies to the identified important fish species in the area of concern.

Sound Production

Many of the studies of non-human acoustic production have focused on animal groups such as insects, birds and mammals. Fishes also produce sounds that are associated with behaviors that include territoriality, mate search, courtship and aggression. It has also been speculated that sound production may provide the means for long distance communication and communication under poor underwater visibility conditions (Zelick *et al.* 1999) although the fact that fish communicate at low frequency sound levels where the masking effects of ambient noise are naturally highest suggests that very long distance communication would rarely be possible.

Fishes have evolved a diversity of sound-generating organs and acoustic signals of various temporal and spectral contents. Ladich (2000) measured the hearing sensitivities of closely related species that use different channels (acoustic vs. non-acoustic) for communication. Major differences in auditory sensitivity were indicated but they did not show any apparent correspondence to the ability to produce sounds. Fish sounds vary in structure, depending on the mechanism used to produce them (Schneider 1967 *in* Hawkins 1993). Generally, fish sounds are predominantly composed of low frequencies (<3 kHz). Most of the sounds are probably produced in a social context that involves interaction among individuals (i.e., communication). One of the most common contexts of sound production by fish is during reproductive behavior (Hawkins 1993). Recent research in Canada investigated the reproductive function of sound production by Atlantic cod (Rowe and Hutchings 2004). In support of other studies on cod sound production (e.g., Finstad and Nordeide 2004), Rowe and Hutchings (2004) concluded that sound production by cod could potentially be important to spawning behavior by acting as a sexually selected indicator of male size, condition and fertilization potential. Researchers from Auburn University and state biologists from Alabama have recently discovered that pallid and shovelnose sturgeon produce sounds as part of their reproductive behavior in freshwater (www.ag.auburn.edu/faa/ichthyology/sound.html).

Sounds produced by fish are quite complex. Wysocki and Ladich (2003) concluded that aspects of sound such as temporal patterns, amplitude fluctuations and frequency content can be represented in the fish auditory system and help conspecifics to extract specific information for acoustic communication.

Sound Detection

Since objects in the water scatter sound, fish are able to detect these objects through monitoring the ambient noise. Therefore, fish are probably able to detect prey, predators, conspecifics, and physical features by listening to the environmental sounds (Hawkins 1981).

Lagardère *et al.* (1994) concluded from their experiment with sole (*Solea solea*) that this species perceives and reacts to horizontal variability in ambient noise levels. Their results indicated positive relationships between wind speed and (1) amplitude of ambient noise measured above the bottom, (2) amount of small-scale (two to three meters) sound variability, (3) reduction of swimming trajectory size, and (4) increase in swimming speed. The authors suggested that wind-generated acoustic gradients are suitable as environmental cues for positioning, and that fish use them for this purpose. Such behavior may be a factor in influencing movements of fish populations at sea during poor weather conditions.

Studies have also been done on the abilities of larval fish to detect sound and respond to it in order to achieve successful settlement (Tolimieri *et al.* 2004; Leis *et al.* 2003; Leis *et al.* 2002)

There are two sensory systems that enable fish to monitor the vibration-based information of their surroundings. The two sensory systems, the inner ear and the lateral line, constitute the acoustico-lateralis system.

The Inner Ear

Both vestibular and auditory functions in fishes are mediated by the inner ear, which consists of several mechanosensory end organs that are located in interconnected fluid-filled chambers (Platt and Popper 1981). Among fishes, at least two major pathways for sound transmittance between source and ear have been identified. The first and most primitive is the conduction of sound directly from the water to tissue and bone. Otoliths, bones of the inner ear of fish, are denser than the rest of the fish and the surrounding water. When sound waves pass through a fish, the denser otolith moves differently than the remainder of the fish, stimulating cilia on the sensory hair cells in the inner ear. This motion is interpreted as sound. The shape and size of otoliths vary among species, resulting in interspecific differences in interpretation of and sensitivity to sound stimuli (Popper and Fay 1999). The otoliths are responsible for the acute sensitivity of some fish to sounds of frequencies less than 20 Hz (infrasound) (Sand and Karlsen 2000). At the other end of the sound spectrum, Popper (2000) indicated that the mechanism for ultrasound detection in some fishes (Mann *et al.* 2001; Mann *et al.* 1998) remains obscure, though it is hypothesized that the highly derived utricle of the inner ear of certain species (e.g., clupeiforms) is involved. One possible explanation for clupeid sensitivity to ultrasound is that it is an adaptation to predation from echolocating cetaceans (Wilson and Dill 2002).

The second sound pathway to the ear is indirect and often involves a swim bladder. Not all fish species have swim bladders. Seventeen of the 28 fish species in Table 1 have swim bladders throughout their life history. The swim bladder and any other gas bubble near the ear expands and contracts in volume in response to sound pressure fluctuations; this motion is transmitted to the otoliths (Blaxter 1981). In some fish (e.g., clupeids), the swim bladder is either very close to the inner ear or it is physically connected to the inner ear by a system of bones called Weberian ossicles (modified anterior vertebrae). Other connections between the swim bladder and the inner ear include elongated gas ducts or extensions of the swim bladder (e.g., Atlantic cod). Regardless of the connection mechanism, the energy of the pressure waves that compress the gas inside the swim bladder is transduced to particle displacement that is then interpreted by the inner ear as sound. Only some species of fish appear to be sound pressure sensitive via this indirect pathway to the ears and they are called “hearing specialists”. The sound pressure sensitivity of hearing specialists is typically higher and their upper frequency range of detection extended compared to those species that hear only by the previously described direct pathway. The species having only the direct pathway (i.e., without swim bladders, with reduced swim bladders, or with swim bladders that are not “connected” to the inner ear) tend to have relatively low auditory sensitivity and narrow auditory frequency range. These species are known as "hearing generalists" (Popper and Fay 1999). Atlantic herring is the only fish in Table 1 that can be considered a hearing specialist. Typically, most fish detect sounds of frequencies up to two kHz but others, such as herring, can detect much higher frequencies. The examples of acoustic sensitivity frequency ranges presented in Table 2 are for those species most relevant to the area around the proposed DWP. The methods used to determine the audiograms include ABR, behavioral response, cardiac response, and conditioned response.

Numerous studies have been conducted on the inner ear (e.g., Platt *et al.* 2004; Ramcharitar *et al.* 2001, 2004; Saidel *et al.* 1995) and peripheral auditory structures of fishes (Akamatsu *et al.* 2003; Higgs *et al.* 2003; Finneran and Hastings 2000; Yan and Curtsinger 2000; Yan 1998; Lewis and Rogers 1996). These studies reflect the considerable variability in mechanisms of hearing in fishes.

The Lateral Line

Most bony fishes and elasmobranchs (e.g., sharks, skates) possess lateral lines that detect water particle motion. The essential stimulus for the lateral line consists of differential water movement between the body surface and the surrounding water and this stimulus is detected by organs known as "neuromasts" that are located on the skin or just under the skin in fluid-filled canals (Denton and Gray 1988). As is the case with the inner ear, neuromasts have sensory hair cells that move in response to the particle displacement. Generally, fish use the neuromasts to detect low frequency acoustic signals (160 to 200 Hz) over a distance of one to two body lengths. The lateral line is typically used in concert with other sensory information, including hearing (Sand 1981; Coombs and Montgomery 1999).

Variability of Fish Hearing Sensitivities

Although the hearing sensitivities of very few fish species have been studied to date, it is becoming obvious that the intra- and inter-specific variability is considerable (Coombs 1981). Nedwell *et al.* (2004) recently compiled and published available fish audiogram information. A non-invasive electrophysiological recording method known as 'auditory brainstem response' (ABR) is now commonly used in the production of fish audiograms (Yan 2004).

Generally, most fish have their best hearing (lowest auditory thresholds) in the low frequency range (i.e., <1 kHz). Even though some fish are able to detect sounds in the ultrasonic frequency range, the thresholds at these higher frequencies tend to be considerably higher than those at the lower end of the auditory frequency range. This generalization applies to the fish species occurring in the proposed DWP area.

With respect to elasmobranch sound detection, most of the limited work done to date has involved sharks. Measurements have shown that sharks are sensitive to the displacement or kinetic component of sound. Since sharks lack any known pressure-to-displacement transducers, such as the swimbladder, they must presumably rely on the displacement sensitivity of their mechano-receptive cells. It has also been shown that sharks are sensitive to low frequencies (i.e., <300 Hz). The upper range of behavioral sensitivity in some sharks has been

Table 2. Measured auditory sensitivities of fish that are most relevant to the proposed *Neptune* LNG DWP.

Species	**Auditory Threshold Range (db re 1 μPa)**	**Minimum Auditory Threshold Frequency**	**Auditory Frequency Range Tested (Hz)**	**Reference**
Atlantic cod	63-139	20 Hz	10-600	Offut (1974)[1]
Atlantic cod	75-110	160 Hz	30-450	Hawkins and Myrberg. (1983)[1]
Atlantic cod	95-118	17 Hz	17-400	Fay (1988)[1]
Atlantic cod	80-150	200 Hz	?-38,000	Astrup and Møhl (1998)
Haddock	80-105	100-300 Hz	25-450	Fay (1988)[1]
Atlantic herring	75-136	100 Hz	30-4,000 Hz	Enger (1967)[1]
Pollock	81-108	60 Hz	40-470 Hz	Fay (1988)[1]
Pollock	92-115	200-300 Hz	140-500 Hz	Chapman and Hawkins (1969)[1]
Atlantic salmon	95-132	160 Hz	32-380 Hz	Fay (1988)[1]
Skate	123-141	200 Hz	100-800 Hz	Casper *et al.* (2003)[1]
Yellowtail tuna	89-128	500 Hz	50-1,100 Hz	Fay (1988)[1]
American shad	118-170	400 Hx	200-200,000 Hz	Mann *et al.* (1997)[1]
European plaice	4 x 10^{-5}m s^{-2} rms	0.1 and 30 Hz	0.1-30 Hz	Karlsen (1992)[2]
European plaice	4 x 10^{-5}m s^{-2} rms	30 Hz	30-200 Hz	Chapman and Sand (1974)[3]
Little skate	123-140	200 Hz	100-800 Hz	Casper *et al.* (2003)[4]
Little skate	123-152	200 Hz	200-800 Hz	Casper *et al.* (2003)[5]

[1] Cited in Nedwell *et al.* (2004)

[2] auditory threshold measured in terms of particle acceleration (vibration)

[3] Cited in Karlsen (1992)

[4] Using ABR method

[5] Using behavioral conditioning

measured at around 600 to 800 Hz (Corwin 1981). Kelly and Nelson (1975) investigated the hearing thresholds of horn sharks using both conditioning and heart-rate techniques. The sharks responded within the frequency range 20 to 160 Hz, with the lowest pressure threshold at 40 Hz (~ 142 dB re 1 µPa) and the lowest particle motion threshold at 80 Hz.

Myrberg, Jr. (2001) provided a comprehensive review of the acoustical biology of elasmobranchs. Using two different methods, ABR and behavioral conditioning, Casper *et al.* (2003) determined the hearing sensitivity of the little skate (*Raja erinacea*) (Table 2). Their findings were in agreement with Corwin's hypothesis that hearing sensitivity is correlated with feeding behavior. That is, bottom dwelling elasmobranchs (e.g., little skate) appear to have less sensitive hearing than free-swimming raptorial elasmobranchs like lemon sharks and bull sharks (Kritzler and Wood 1961). Elasmobranchs identified in Table 1 include barndoor skate, thorny skate and spiny dogfish.

Frequency tuning and directional responses of single auditory nerve fibers in the lake sturgeon (*Acipenser fulvescens*) have recently been studied (www.life.umd.edu/biology/popperlab/research/primitive.htm). Acoustic particle motion was simulated as a source stimulus emitting frequencies ranging from 50 to 1,000 Hz. The best responses were observed at frequencies between 100 and 200 Hz. The data from this test indicated that the auditory nerve fibers in sturgeon are frequency-tuned and directionally tuned, just as is found in most modern day bony fishes. Shortnose sturgeon and Atlantic sturgeon have been identified as species that occur around the DWP area.

Sisneros and Bass (2003) studied the seasonal variability in fish auditory sensitivity. Their work suggested that the hearing sensitivity of female midshipman fish (*Porichthys notatus*) varied between seasons in order to optimize the detection of male-produced sounds during reproductive season.

Potential Impacts of Continuous Sound on Fish

As with the marine invertebrates, literature relating to the impacts of sound on marine fish species can be conveniently divided into the following categories: (1) pathological effects, (2) physiological effects, and (3) behavioral effects. Pathological effects include lethal and sub-lethal physical damage to fish; physiological effects include primary and secondary stress responses; and behavioral effects include changes in exhibited behaviors of fish. Behavioral changes might be a direct reaction to a detected sound or as a result of the anthropogenic sound masking natural sounds that the fish normally detect and to which they respond. The three types of effects are often interrelated in complex ways. For example, some physiological and behavioral effects could potentially lead to the ultimate pathological effect of mortality. Hastings and Popper (2005) recently reviewed what is known about the effects of sound on fishes and identified studies needed to address areas of uncertainty relative to measurement of sound and the responses of fishes. Popper *et al.* (2003/2004) also recently published a paper that reviews the effects of anthropogenic sound on the behavior and physiology of fishes.

The following discussions of the three primary types of potential effects on fish of exposure to sound will consider continuous sound sources since such sounds will be generated by construction and operation activities associated with the proposed Neptune Project. Note that most research reported in the literature has focused on the effects of seismic airguns which produce pulsed sounds (see section on pile driving for consideration of such pulsed sounds).

Pathological Effects

There remains considerable question about which aspects of an underwater sound are responsible for potentially impacting marine fish. In addition to peak pressure and pressure pulse rise and decay time, other aspects of underwater acoustics that need to be considered include energy densities over the frequency range of received sound, continuous versus pulsed sounds, temporal width of the pulse, and duty cycle of the exposure period.

The potential pathological effects on fish from exposure to sound energy can also be grouped by degree of severity: (1) acute sub-lethal effects, (2) chronic sub-lethal effects, and (3) acute and chronic mortality. Logically, acute and chronic sub-lethal effects have potential to indirectly lead to chronic mortality.

Temporary Threshold Shift (TTS)

As is the case with marine mammals, it appears that loud sounds can temporarily affect the auditory sensitivity of fish by causing an upward shift in auditory threshold. This effect is known as temporary threshold shift (TTS). This temporary effect on fish hearing has been studied under laboratory conditions using controlled continuous sound sources and the auditory brainstem response (ABR) technique (Ramcharitar and Popper 2004; Smith et al. 2004; Scholik and Yan 2002; Wysocki and Ladich 2005). The sound is generally delivered via underwater speakers in these studies.

Smith *et al.* (2004) examined the effects of short- (ten minutes to one day) and long-term (1 to 21 days) exposure to increased ambient sound on the hearing of goldfish (*Carassius auratus*) using continuous white noise with a bandwidth ranging from 100 Hz to 10 kHz and a loud source level of 160 to 170 dB re 1 µPa (UMT). The source level was constant across all frequencies. Using the ABR technique, auditory thresholds were measured before and after exposure to determine any changes in auditory sensitivity. The goldfish had a baseline bandwidth of auditory sensitivity that ranged from 100 Hz to 4 kHz, and baseline auditory thresholds ranging from 60 to 120 dB re 1 µPa. Temporary threshold shift was apparent after only ten minutes of exposure to the white noise, and was as high as 28 dB after 24 hours of exposure. This difference in auditory sensitivity did not increase after longer exposure times. It took some fish as long as 14 days to return to pre-exposure auditory sensitivities.

Amoser and Ladich (2003) studied the effects of intense white noise on the hearing abilities of two otophysine fish species (i.e., fish with Weberian ossicles connecting the swim bladder to the inner ear). Nonvocal goldfish (*Carassius auratus*) and the vocalizing catfish (*Pimelodus pictus*) were exposed to continuous sound with an approximate received SPL of 158 dB re 1 µPa (UMT). The SPL was constant across all frequencies. Fish were exposed to the noise for either 12 or 24 hours. Using the ABR technique, hearing sensitivities were determined prior to exposure, immediately following exposure, and at 3, 7 and 14 days after exposure. Both species showed a significant loss in hearing sensitivity, as much as 26 dB in the goldfish and 32 dB in the catfish. The greatest loss in hearing sensitivity occurred at the most sensitive frequencies for both species. The period of exposure did not seem to influence the degree of hearing sensitivity loss. The goldfish hearing sensitivity returned to normal after three days of recovery but the catfish required a 14 days recovery time to regain pre-exposure sensitivity.

Fathead minnows (*Pimephales promelas*) were exposed to continuous recorded sound from a small boat's outboard motor for two hours (Scholick and Yan 2002). The received SPL was 142 dB re 1 µPa (UMT) with most of the energy at 1.3 kHz. The fathead minnow's most sensitive hearing range had been previously determined as 0.8 to 2 kHz (Scholick and Yan 2001). Using the ABR technique immediately after exposure, Scholick and Yan (2002) demonstrated that the boat engine noise significantly elevated the fathead minnow auditory threshold at frequencies 1, 1.5, and 2 kHz. The auditory threshold elevations ranged from 7.8 to 13.5 dB. Elevations in auditory threshold were not observed at frequencies below one kHz and above two kHz. The time required for the auditory thresholds to return to pre-exposure levels was not indicated.

Visible Ear Damage

In order to study the effects on the ear sensory epithelium and the lateral line, Hastings *et al.* (1996) exposed oscar fish (*Astronotus ocellatus*) to synthesized sounds with characteristics similar to those of commonly encountered man-made sources. The sounds used in the exposures varied in frequency (60 or 300 Hz), intensity (100, 140, or 180 dB re 1 µPa; UMT) and duty cycle (20% or continuous). Fish tissue was examined at one and four days after exposure. The only damage observed was in fish exposed for one hour to 300 Hz continuous tones at 180 dB re 1 µPa at 1 m (UMT), and sacrificed four days post-exposure.

Enger (1981) provided the earliest evidence of the potential of loud sounds to pathologically affect fish hearing. He demonstrated that the sensory cells of the ears of Atlantic cod (*Gadus morhua*) were damaged after one to five hours of exposure to continuous synthesized sounds with a source SPL of 180 dB re 1 µPa at 1 m (UMT). The frequencies tested included 50, 100 200, and various frequencies between 300 and 400 Hz. The cod were exposed at less than one meter from the sound source.

Physiological Effects

The biochemical stress responses of marine fish to underwater sound have received limited study. The study of the various biochemical parameters influenced by acoustic stress could potentially provide some indication of the extent of the stress and any subsequent longer-term detrimental effect. Stressors could potentially affect animal populations by reducing reproductive capacity and adult abundance.

Smith *et al*. (2004) examined the effects of short- (ten minutes to one day) and long-term (1 to 21 days) exposure to increased ambient sound on the stress of goldfish (*Carassius auratus*) by exposing them to continuous white noise with a bandwidth ranging from 0.1 to 10 kHz and a source SPL of 160 to 170 dB re 1 µPa at 1 m (UMT). The SPL was constant across all frequencies. The authors assessed noise-induced alterations in physiological stress by measuring plasma cortisol and glucose levels. Cortisol levels had significantly increased ten minutes after exposure in the short-term exposure experiments but returned to normal after 60 minutes. Noise exposure did not significantly affect cortisol or glucose concentrations in the long-term noise experiment.

The heart rates of fish embryos within eggs were monitored as they were exposed to continuous pure tones in the range of 100 to 1,200 Hz at levels of 80 to 150 dB re 1 µPa at 1 m (UMT) (Simpson *et al.* 2005). Changes in heart rate were detected in embryos as early as 3 days after fertilization. The frequency range of sound to which there was a heart rate response widened as the embryos grew older.

Behavioral Effects

Because of an assumed low probability of serious pathological and physiological effects of underwater noise on marine fish, most concern about this issue now focuse on the possible effects on fish behavior, namely those behaviors associated with reproduction, migration, and distribution.

A small number of studies investigating the possible effects of noise, primarily seismic sound, on fish behavior have been conducted over the years. Studies looking at change in distribution are often conducted at larger spatial and temporal scales than are typical for studies that examine specific behaviors, such as startle response, alarm response and avoidance response. The studies that examine those specific defined responses often involve caged fish rather than free-ranging fish (Hirst and Rodhouse 2000).

Masking of natural/ambient sounds (e.g., communication, detection of predators and prey, gleaning of information about the surrounding environment) also has the potential to affect fish behavior.

Captive Fish Studies

Schwarz and Greer (1984) defined three responses of fish in reaction to underwater noise: (1) startle, (2) avoidance, and (3) alarm. A startle response is defined as a single powerful flexion of the body followed by a five to ten second period of faster swimming. Fish that exhibit a startle response do not change swimming direction. An avoidance response is defined as a mildly negative behavior. Schooling fish will often tighten up into a compact school and then slowly move away from the sound source. An alarm response contains elements of an avoidance response but these occur at greater speed and intensity. The group of fish quickly packs, polarizes and flees away and downward from the sound source. The school might dive to the bottom and lie motionless, or dive to midwater and then repeatedly and quickly change direction, or dive to midwater and break up into a number of smaller schools, each of which flees in a different direction and changes direction repeatedly.

Akamatsu *et al.* (1996) observed the reactions of captive Japanese anchovy (*Engraulis japonicus*) to continuous pure tones of frequencies 100, 200, 300, 500 and 700 Hz. Startle responses were observed over a received SPL range of 146.8 dB re 1 µPa at 300 Hz to 154.5 dB re 1 µPa at 100 Hz (UMT). There was no observable response to a received SPL of 158 dB re 1 µPa at 700 Hz. The Japanese anchovy exhibited its minimum behavioral threshold at frequency 300 Hz.

The reactions of penned herring and cod to playback of original, frequency filtered and time-smoothed vessel sounds were studied by Engås *et al.* (1995). Avoidance reactions by both herring and cod were observed during exposure to the original, 60 to 300 Hz and 300-Hz to 3-kHz spectra but less so at 20 to 60 Hz. The duration of response by cod was greater with exposure to the original sound compared to time-smoothed sound. The authors concluded that the main determinant for triggering avoidance reactions by cod and herring is vessel sound level within the most sensitive frequency ranges, although other sound characteristics such as temporal structure also seemed to be important. The maximum amplitudes measured in the 20 to 60 Hz, 60 to 300 Hz, and 300-Hz to 3-kHz bands were approximately 112 dB, 125 dB and 140 dB (UMT), respectively.

Schwarz and Greer (1984) described the behavioral responses of net-penned Pacific herring (*Clupea harengus pallasi*) to a variety of tape-recorded sounds. Sounds recorded in the field included those of moving and idling herring fishing vessels, sonar, echo sounder and deck gear. Natural sounds included rain on the water surface, gull cries, killer whale vocalizations, sea lion barks, and sounds made by herring. Sounds of more uniform structure were created by synthesizer and played back to determine the relative effectiveness of various combinations of amplitude, frequency and temporal pattern. Herring did not respond to any of the natural sounds nor to the sonar or echo sounder. The echo sounder produced regular broadband clicks within the 50-Hz to 2-kHz frequency range. Alarm responses, and less so startle responses, were elicited by those electronic sounds with very short rise times. Avoidance responses were elicited by sounds of large vessels approaching at constant speed, by smaller vessels on accelerated approach, and by some of the electronic sounds. Larger vessels tended to make sounds with more energy in the lower frequencies and higher amplitude SPLs than smaller vessels. The authors concluded that the magnitude, direction and rate of change of amplitude were among the most important factors affecting the duration and intensity of herring response. Irregular pulses were more effective in eliciting response than either regular pulses or continuous tones. The authors concluded that temporal pattern of sound rather than frequency spectrum of sound has the greatest impact on fish behavior.

Herring produced some interesting sounds other than those associated with feeding and hydrodynamics. Herring “chirps” consist of one or several bursts of pulses in the 1.8- to 3.2-kHz range, and they tended to occur in bouts. Herring “whistles” are narrow band continuous sounds in the 1.6- to 2-kHz range. Captive herring did not appear to respond to these chirps and whistles (Schwarz and Greer 1984).

Blaxter *et al.* (1981) investigated the startle responses of captive herring to various well-defined sound stimuli. Three kinds of stimuli were used: (1) a single complete cycle, (2) a burst of about 10 complete cycles, and (3) a ramp-up of complete cycles of increasing amplitude. They found that a sound consisting of only one cycle of a sine wave was as effective in eliciting a fish response as a sound of the same amplitude lasting many cycles. The herring response threshold appeared to be raised during the ramp-up experiment. Amplitude pressures of single-cycle stimuli that elicited responses (10.5 to 17.5 Pa, equivalent to 140 to 145 dB re 1 µPa [UMT]) were essentially independent of the duration of the stimuli (2 to 40 milliseconds). The frequency range of the stimulus sounds was between 80 and 92 Hz. Most responses began with a startle response away from the sound source. The authors contend that the directionality component of the responses is somewhat dependent on detection of particle displacement while the initiation of response is triggered by pressure alone. Therefore, the authors concluded that the herring can determine the amplitude of a sound and the direction from which it came.

Popper *et al.* (2004) published a review paper on the responses of clupeid fish to ultrasound. They discuss the physiological, developmental and anatomical evidence suggesting that one end organ of the inner ear, the utricle, is likely the detector of ultrasound in most clupeid fish.

Amoser *et al.* (2004) studied the effects of sounds produced during a powerboat race on freshwater fish communities. Considering that the powerboats generated sound levels of about 180 dB re 1 µPa at 1 m (UMT) over a frequency range similar to the hearing sensitivity ranges of the whitefish, salmonids, perches and cyprinids used in the study, the authors concluded that most of the fish species would be disturbed within 200 to 400 m of the powerboats.

Free-ranging Fish Studies

The power of modern marine research vessels using diesel engines means significant levels of sound may be radiated underwater (Mitson and Knudsen 2003). Much of the necessary machinery to drive and operate a ship produces vibration within the frequency range of 10 Hz to 1.5 kHz, radiating pressure waves out from the hull.

Avoidance behavior in cod in response to a bottom-trawling vessel using a split beam echo sounder system on a free-floating buoy was examined by Handegard *et al.* (2003). Their study indicated significant horizontal and vertical displacements of cod during and after propeller passage. The horizontal distributional change seemed to occur slightly later than the diving reaction.

Fernandes *et al.* (2000) investigated fish avoidance in reaction to the presence of survey vessels. To study the potential bias caused by vessel noise in survey data, the authors deployed an AUV (Autonomous Underwater Vehicle) that was located between 200 and 800 m ahead of the vessel during a herring survey in the North Sea. The AUV was equipped with the same type of scientific echosounder as the survey vessel and therefore gathered equivalent acoustic data prior to the research vessel. There was not any significant difference in the amount of fish detected by the research vessel and that detected by the AUV. It is important to point out that the research vessel (*Scotian*) involved in this work is relatively quiet and built to minimize sound emission.

Misund *et al.* (1996) examined the reactions of herring schools to the sound field of a survey vessel. The survey vessel generated the highest sound intensities between 125 and 500 Hz, the highest source level equaling 146 dB re 1 µPa at 1 m (UMT) at 250 Hz. The lowest sound intensities were immediately off the bow of the vessel and the highest sound intensities were off either side of the vessel (butterfly effect). Of the 110 herring schools recorded during this work, only 21 appeared to react to the vessel. Sixteen of the 21 moved towards the path of the approaching vessel, seemingly influenced by the rising sound intensity to the side of the vessel path and consequently being herded ahead of the vessel. The herded schools first reacted to the approaching vessel at a distance of 25 to 1,000 meters ahead and within a sector of about 20º on each side of the vessel. Seventeen other schools detected within the same distance and sector limits did not appear to react to the vessel.

Misund (1993) examined the avoidance behavior of herring and mackerel in purse seine capture situations using true motion sonar. Operating purse seiners typically generate loud low-frequency sound with peak energy around 100 Hz (Olsen 1971 *in* Misund 1993) which falls within the hearing range of teleost fish. The specific vessel sound sources are propeller cavitation and engines that together generate a continuous sound spectrum. Schools of both herring and mackerel typically exhibited horizontal avoidance in response to the purse seiners.

Daytime vertical movements of Spanish sardines (*Sardinella aurita*) in response to an approaching marine vessel were described by Gerlotto and Fréon (1992). All five of the observed schools dove before passage of the vessel, shifting, on average, about five meters deeper. The school that was initially closest to the surface dove deepest. The schools also showed compression in response to the approaching vessel. Overall, the diving reaction of this sardine species appears limited compared to herring. The diving reaction was only perceptible in the upper 20 m of the school.

Wahlberg and Westerberg (2005) recently presented a review of the current knowledge regarding fish detection of, and reaction to, sound produced by offshore windmill farms. They concluded that a more careful analysis of the effects of windmill sound on fish is only possible with better data on the nature of the acoustic field around the windmills. This idea should be applied to any sound source to which behavioral effects are derived through modeling.

Summary of Potential Impacts of Continuous Sound on Fish

Potential effects of exposure to continuous sound on marine fish include temporary threshold shift, physical damage to the ear region, physiological stress responses, and behavioral responses such as startle response, alarm response, avoidance, and perhaps lack of response due to masking of acoustic cues. Most of these effects appear to be either temporary or intermittent, and therefore probably do not significantly impact the fish at a population level. The studies which resulted in physical damage to the fish ears used noise exposure levels and durations that were far more extreme than would be encountered under conditions similar to those expected at the Neptune project.

PART (3): NOISE SOURCES OF THE NEPTUNE PROJECT AND PROPAGATION MODELING OF UNDERWATER NOISE

By

Marjo H. Laurinolli
Cristina D. S. Tollefsen
Scott A. Carr
Stephen P. Turner

JASCO Research Ltd.
Suite 2001 – 1969 Upper Water Street, Halifax, NS B3J 3R7
(902) 491-4489; scott@jasco.com

for

LGL Limited
environmental research associates
22 Fisher St., P.O. Box 280
King City, ON L7B 1A6
905-833-1244
radavis@lgl.com

11 October 2005

Table of Contents

List of Tables

List of Figures

INTRODUCTION

The proposed Neptune Liquefied Natural Gas (LNG) Deepwater Port (DWP) is located in federal waters approximately 35 km northeast of Boston in the vicinity of several marine sanctuaries and critical whale habitats. Mitigation of underwater noise effects on marine animals during pipeline and terminal construction and future operations of the terminal are important in this area. Acoustic modeling was performed, to predict received levels of underwater noise resulting from the planned construction, operation and eventual decommissioning of the Neptune LNG Deepwater Port.

The JASCO acoustic modelling approach computes frequency and range-dependent sound transmission specific to the location, depth, and season of interest. Results are provided for construction and operational scenarios in the form of 10 dB contour plots of received sound levels and tables of average range and area coverage of each contour interval.

OCEANOGRAPHIC AND GEOACOUSTIC ENVIRONMENT

Ocean environment data for the area must be compiled before the underwater acoustic propagation modelling can proceed. Necessary parameters include: bathymetry, seasonal sound velocity profiles, and geoacoustic profiles of the seabed over the region to be considered.

Bathymetry

Bathymetry data were retrieved from the National Geophysical Data Center (NGDC) Coastal Relief Model (NOAA Satellite and Information Service 2005). The data sources include the US National Ocean Service, the US Geological Survey, Monterey Bay Aquarium Research Institute, Us Army Corps of Engineers, and other academic institutions. The gridded dataset was downloaded with 3-arc-second (~90 m) resolution and converted to Universal Transverse Mercator (UTM) projection. The data were further interpolated to have 50-m resolution in both directions for the model input.

Seasonal Sound Speed Profiles

Quality controlled depth related temperature and salinity (CTD) data were obtained from the Marine Environmental Data Service (MEDS) at the Department of Fisheries and Oceans Canada (DFO) in Ottawa, Canada. The dataset covers the area 41° to 43° N and 71° to 69° W for the years 1999-2004. A total of 1376 stations of CTD data were averaged for the four seasons (winter = Jan-Mar; spring = Apr-Jun; summer = Jul-Sep; fall = Oct-Dec). The sound speed profiles (Figure 1) were calculated using Mackenzie (1981). For the acoustic impacts, sound speeds were taken from the profiles at 1, 50, 100, 150, 200 and 250 m (Table 1).

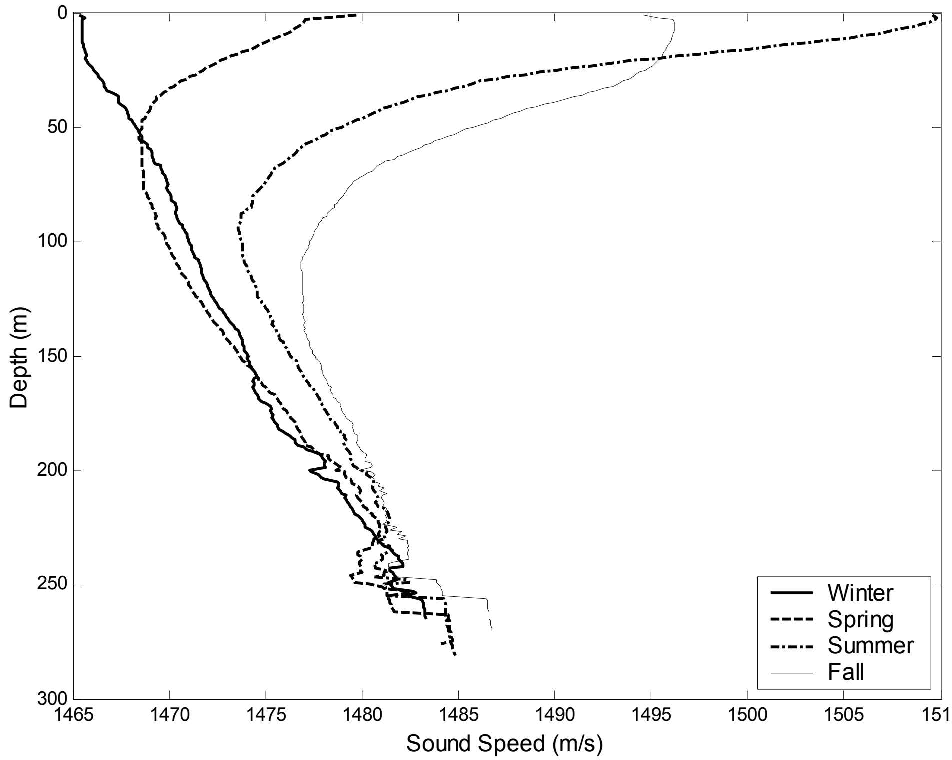

Figure 1: Average seasonal sound speed profiles from 1999-2004 for the Gulf of Maine.

Table 1: Sound speeds (m/s) used as model input parameters.

Season	Depth					
	1m	50m	100m	150m	200m	250m
winter	1465.3	1468.3	1471.0	1474.1	1477.3	1481.5
spring	1479.7	1468.6	1469.9	1473.7	1478.7	1480.4
summer	1509.6	1479.0	1473.8	1476.3	1479.9	1481.2
fall	1494.6	1485.8	1477.3	1477.6	1479.9	1484.0

Ambient Noise

Stellwagen Bank National Marine Sanctuary (SBNMS)

Only recently has a program been in place to systematically monitor ambient noise levels in the Stellwagen Bank National Marine Sanctuary (SBNMS) (NOAA, 2005). Accordingly, a long-term picture of ambient noise levels in the area does not exist. Since 1996, an annual monitoring program conducted by National Undersea Research Center personnel in conjunction with the North Atlantic and Great Lakes Aquanaut Program during the summer months has provided some measurements of ambient noise levels. However, only a sample of preliminary noise level data are provided in a NOAA report (NOAA, 2005), and some statistical results are provided on the Aquanauts website (Aquanauts, 2004). During the monitoring program, measurements are taken four times daily at six sites within the SBNMS. The NOAA report contains noise level data at three frequencies (50 Hz, 100 Hz, and 500 Hz) for four individual measurement days during consecutive years. The preliminary data provided imply that ambient noise levels within the SBNMS range from 50 to 100 dB *re* 1 μPa Hz^{-1}.

Statistical analysis provided by the Aquanaut program suggests that the noise levels vary from year to year as well as from site to site. At one site the average noise levels for a season range from 120 to 140 dB *re* 1 μPa Hz^{-1}, for frequencies from 100 Hz to 10 kHz (Aquanauts, 2004). From the limited data available, it may be concluded that the ambient noise in the SBNMS is quite variable and can range from 50 to 140 dB Hz^{-1}, depending on location, time of the measurement, and frequency.

Cape Cod Bay

Acoustic monitoring performed by C. W. Clark in Cape Cod Bay, a critical habitat for the highly endangered northern right whale, revealed persistently elevated levels of low-frequency vessel noise from January through May, a period of relatively low fishing and recreational boating activity. Average spectrum noise levels in the 50-200 Hz frequency band were above 110 dB re 1μPa^2/Hz.

Seabed Geoacoustic Profile

When modelling sound transmission through the ocean, it is important to take into consideration sound travel through the bottom sediment. The types and thicknesses of bottom materials determine the geoacoustic properties of sound transmission. For lower frequency sounds and shallow water (<200 m) it is ideal to know the composition of the entire sediment column and the underlying rocks (Hamilton 1980).

The geology of Massachusetts Bay has been formed through glaciation and marine reworking (Intec Engineering 2005a). The metamorphic bedrock has been covered by a thin and discontinuous layer of reworked sand and gravelly clay overtop of consolidated glacial deposits. The surficial sediment varies from areas with coarse sand, gravel, and rock to areas with sand or mud.

Sediment types in Massachusetts and Cape Cod Bays are extremely patchy in composition and distribution (Knebel and Circe 1995). This is due to variations in bottom-current strength caused by irregular topography and differences in fine-grained sediment input. There are differences between estuarine, inner shelf and basinal parts of the area. The estuary consists of deposited fine-grained sediments. The inner shelf of depths 30-50m has been eroded and receives little input of fine sediments and is thus mainly composed of glacial drift, gravel, medium to coarse sands, and boulders or exposed bedrock (Knebel and Circe 1995; USGS 1997). Boston Harbor, Stellwagen Basin and Cape Cod Bay are long-term sinks for fine sediments (USGS 1997). The Stellwagen Basin is a depositional area with fine-grained muddy sands to muds. Areas with sediment reworking consist of patches of sandy gravels to muds from a combination of erosion and deposition from variable bottom currents (Knebel and Circe 1995). The top of Stellwagen Bank is predominantly clay with patches of gravelly sand and scattered cobbles and many boulders (Intec Engineering 2005a).

The four sediment types described for the Gulf of Maine by NOAA (2000) are gravel, sand, silt-sand, and silt-clay. Stellwagen Bank is covered predominantly by sands but with gravels and gravelly-sands to the east. The National Marine Sanctuary (NMS) has sand with patches of gravel on the east side. Next to Stellwagen Bank, there are sand-silt and silt-clay sediments. Jeffrey's Ledge north of Stellwagen Bank has mainly gravels or gravelly-sand and sand in the southeast. Between Stellwagen Bank and Jeffrey's Ledge there is mainly sand with some gravel. East of Stellwagen Bank is more depositional with larger amounts of silt within the sand.

The base case deepwater port (DWP) manifold and trunkline gas transmission line routing goes from east to west through: sand-clay/silt, sand/silt/clay, clay-silt/sand, sand, and shallow/outcropping bedrock (Intec Engineering 2005a). Geoacoustic properties (Table 2) of the bottom sediments were taken or calculated from Hamilton (1980) for the continental terrace environment. Since the majority of the sediments in the study area seem to be in the range of sands to muds (silt and clay), the density (ρ) and compressional sound velocity (c_p) for sand-silt-clay was chosen. The shear wave velocity (c_s) was calculated as:

$$c_s = 1.137c_p - 1.485$$

The compressional attenuation ($\alpha_{p)}$ was determined from the regression curves in for sand-silt-clay with porosity of 66.3%. The shear attenuation was calculated from $\alpha_s = \kappa_s c_s$ where κ_s = 17.3 dB/m/kHz from Warrick (1974) as reported in Hamilton (1980).

Table 2: Base values of geoacoustic properties for sand-silt-clay sediment at the seafloor on the continental shelf.

Parameter	Base Value
ρ	1.596 g/cm^3
c_p	1579 m/s
c_s	310 m/s
α_π	0.17 dB/λ
α_σ	5.4 dB/λ

Sediment cores in the Stellwagen Basin identified the deepest solid reflector to be at 33 m below the seafloor (Tucholke and Hollister 1973). One core was almost equal amounts of silt and clay with only small amounts of sand. A second core had a higher percentage of sand. The sediments were poorly sorted and identified as till or glaciomarine drift. The bedrock in the Gulf of Maine consists of Cambro-Ordivician aged metamorphosed sedimentary rocks with a compressional wave velocity of about 3500 m/s and a density of 2.4 g/cm^3 (Osler 1994).

MODEL DESCRIPTION

Introduction

The acoustic modelling approach used by JASCO Research is based on the company's unique underwater sound modelling software MONM (Marine Operations Noise Model) that incorporates a state-of-the-art range-dependent split-step parabolic equation acoustic model with shear wave computation capability. The algorithm has been benchmarked against test data sets provided in the open scientific literature and is compliant with recognized underwater acoustic modelling standards. This model has been used in past contracted work for precise estimation of noise produced by sub-sea construction noise, marine facilities operation and seismic exploration in locations that include the Gully oceanic region off Nova Scotia, the Beaufort Sea, Queen Charlotte Basin in British Columbia and Sakhalin Island in Eastern Russia.

The core algorithm in MONM computes frequency-dependent sound transmission loss parameters along fans of radial tracks originating from each point in a specified set of source positions. Transmission loss indicates the degree to which sound levels decrease with range from the source locations. The modelling is performed in individual 1/3-octave spectral bands covering frequencies from 10Hz to a few kHz, which encompasses the overlap between the auditory frequency range of marine mammals and the spectral region in which sound propagates significantly beyond the immediate vicinity of the source. The MONM software makes use of geo-referenced databases to automatically retrieve the bathymetry and acoustic environment parameters along each propagation traverse, and incorporates a proprietary tessellation algorithm that increases the angular density of modelling segments at greater ranges from a source to provide more computationally efficient coverage of the area of interest. The grid of transmission loss values produced by the model for each source location are used to attenuate the spectral acoustic output levels of the corresponding noise source to generate absolute received sound levels at each grid point; these are then summed across frequencies to provide broadband received levels. A further step of Cartesian re-sampling and summing of the received noise levels from all the sources in a modelling scenario yields the aggregate noise level for the entire operation on a regular grid from which contours can be drawn on a GIS map. The model can either generate contours at evenly spaced levels or draw boundaries representing biologically significant threshold levels.

The MONM has been extensively validated against field measurements in the course of complex undersea construction operations. The illustration below provides an example of the accuracy of the model in predicting the aggregate noise levels over an area from four vessels performing a dredging and pipe-laying operation. The spectral source levels of the individual vessels, which had been measured independently and in different locations, were used as input to the MONM along with locally measured water column and bottom acoustic parameters. The actual received levels from a line of sonobuoys are in agreement with the model results to within about 2 dB.

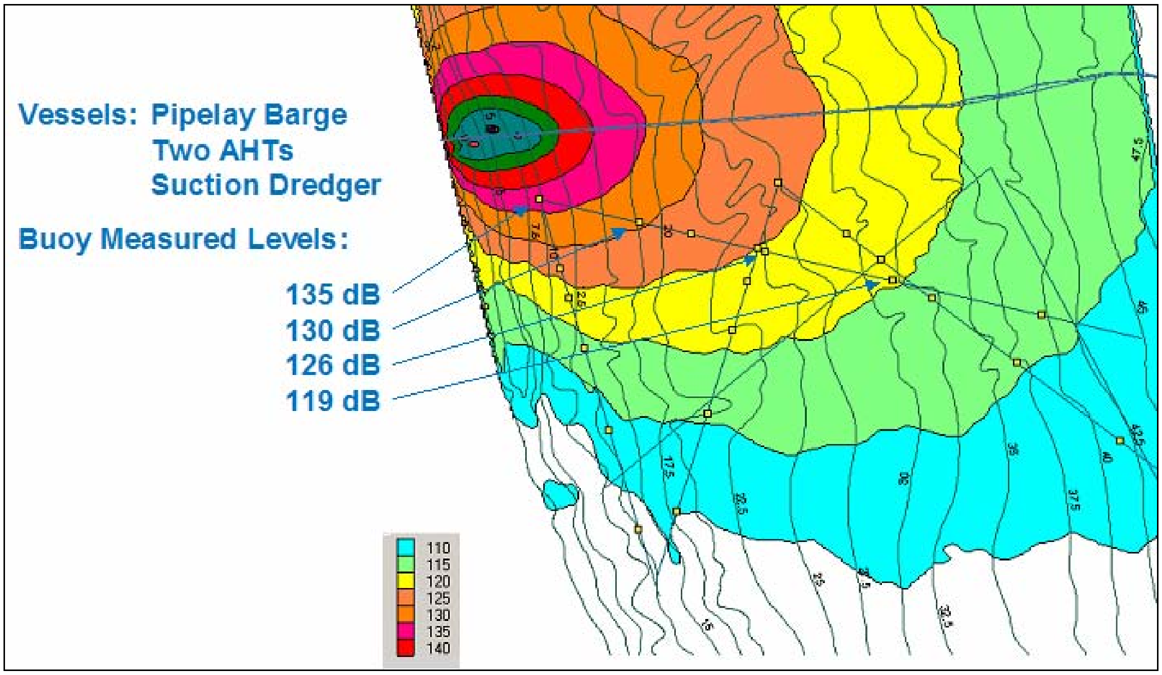

Figure 2: Illustration of model accuracy

Modelling Approach

Source Level Compilation

The team has identified relevant noise sources and made use of our extensive reference library of source levels, both measured by our company and available in the public literature, to produce acceptable analogues that will be used in the underwater sound propagation modelling. Source levels in 1/3-octave bands are the key input to the noise propagation model in order to forecast received sound levels at surrounding locations.

As a recent example of our work, in summer and fall 2004, JASCO carried out what is probably the most comprehensive single source level monitoring programme to date. JASCO performed this work for a Shell subsidiary (SEIC). The program quantified 1/3-octave levels from vessels, offshore platforms, dredging and pipelaying equipment and tugs of several sizes. Some of the 1/3-octave source levels are reported on the SEIC website:

http://www.sakhalinenergy.com/documents/doc_33_cea_tbl4-7.pdf

The figure below shows one of the 1/3-octave source level measurements from this report. Source levels for more than 20 vessels performing multiple operations were monitored during the programme. These source levels are used with our Marine Operations Noise Model to predict sound levels at a given location and to subsequently assess possible impacts on marine mammals or fish.

Gerardus Mercator: Trailer Hopper Suction Dredger

Trailer Hopper Suction Dredger (hopper size: 18,000m^3) using suction to excavate large volumes of soil to excavate the seabed. Spoil is stored on the side of the trench and is returned once pipeline has been installed. Vessel uses thrusters to maintain station.

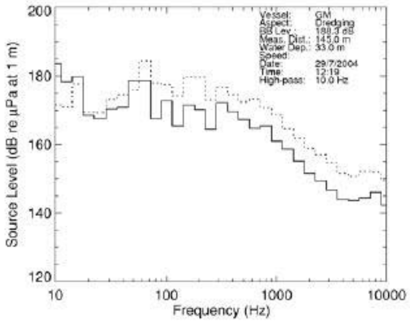

Figure: 1/3-octave source levels abeam of *Gerardus Mercator* while dredging.
BROADBAND LEVEL (dB re 1 µPa) = 188.3

Sources of Underwater Noise

The following sources of underwater noise have been identified as potentially important:

Construction Activities

- Construction vessel traffic
- Pipelaying
- Anchor installation using either Driven Piles or Suction Piles

Operational Activities

- LNG carrier transits
- Support vessel transits
- Mooring – maneuvering on thrusters during approach to the mooring buoy
- Operation of processing equipment (regasification)

Decommissioning Activities

- Removal of DWP anchors and mooring lines

Model Setup

Ocean environment data for the area was compiled before the underwater acoustic propagation modelling proceeded. Necessary parameters included: bathymetry, seasonal sound velocity profiles, and geoacoustic profiles of the seabed over the region to be considered, as described above in section 0.

Scenario Modelling

All underwater acoustic modelling was performed using JASCO's Marine Operations Noise Model (MONM) to compute the spatial underwater sound field in the vicinity of specific operations at the proposed Neptune DWP site(s). To carry out the modelling, control files were set up which corresponded to each of the scenarios being studied. After running the software for each scenario, and as the results are generated, routine validation and quality assurance checks were performed to ensure that no anomalies may have arisen either from incorrect specification of any parameters or from problems in the underlying geographic and geoacoustic datasets.

VESSEL INFORMATION

LNG Carrier

The LNG carriers that service the Neptune deepwater port are designed to store, transport, and vaporize LNG, and subsequently deliver pipeline-quality natural gas to shore.

The LNG carriers are designed to allow the operational flexibility for entering port and conducting a conventional LNG offload at a shore-side port terminal, such as the Boston/Everett LNG Terminal.

Each LNG carrier that services the deepwater port combines storage and transportation capabilities of a conventional LNG carrier with dedicated onboard LNG vaporization equipment. The vessels have conventional marine propulsion systems for transit between overseas LNG loading ports. Each LNG carrier is equipped with two bow thrusters and a stern thruster for maneuvering and positioning at the deepwater port at speeds of 5 knots or less.

Typically, each LNG carrier has the following characteristics:

- Dead weight tonnage (DWT) of approximately 76,500 tons;
- LNG storage capacity of approximately 140,000 m^3;
- Hull dimensions:
    - Length overall (LOA) 280 meters (918 feet)
    - Length between perpendiculars (LBP) 270 meters (886 feet)
    - Breadth molded 43 meters (141 feet)
    - Maximum Design Draft 11.3 meters (37 feet)
    - Normal Operating Draft 10.7 meters (35 feet)
    - Maximum height above waterline 41.1 meters (135 feet)
- Maximum design speed on even keel is 19.5 knots.

The LNG carriers can achieve a speed up to 19.5 knots on even keel at design draft in calm weather with 21% sea margin, and the machinery operating at 90%.

Main propeller

- Diameter: 8.6 m
- No. of blades: 5
- Power/RPM at service speed of 19.5 knots: 35,550 SHP x 86.9 rpm

Side thrusters

Aft

- 2 x 1250 kW
- Diameter: 2.20 m
- No. of blades: 4
- Power/RPM at 100% power: 1250 kW / 1160 rpm

Forward

- 2 x 2200 kW
- Diameter: 2.85 m
- No. of blades: 4
- Power/RPM at 100% power: 2000 kW / 880 rpm

Support Vessel Operations

The facility will have a dedicated support vessel, which will be operated from an existing dock facility in either Boston or Gloucester, Massachusetts. The support vessel will be in the vicinity of the unloading buoys during the LNG carrier arrival, mooring, unmooring, and departure phases.

The support vessel will be a multi-purpose offshore tug with the following characteristics:

- LOA 125 to 145 feet
- Beam approximately 40 feet
- Design Draft 18 to 22 feet
- Gross Tons Under 300
- DWT approximately 700
- Horsepower 4,900 to 7,010 HP
- Bollard Pull (Ahead) 65 tons
- Bollard Pull (Astern) 58 tons
- Maximum Speed 13 knots
- Crew 5 to 8

Support Vessel Functions

The dedicated support vessel performs the following missions:

- Transportation of pilots, USCG inspectors and boarding teams, classification society surveyors, owner's representatives, shipping agents, LNG carrier relief crews, and technicians as necessary;
- Logistics--delivery of consumables, groceries, supplies, spare parts, mail;
- Security Surveillance of areas around the LNG carriers and unloading buoys;
- Provide Class I fire fighting capability;
- Emergency evacuation of personnel injured or endangered by conditions at the port facility;
- Safety Zone traffic control and monitoring; and
- Capable of rescue towing of the LNG carrier at a speed of 3 knots in seas up to Beaufort 5 conditions.

Construction vessels

The construction vessels proposed to be used are as follows:

Vessel	Power (hp)	Auxiliary Equipment	Comments
Pipelay/Derrick barge	4000	Tensioners	Based on Horizon Lonestar
Anchor handling	6140	Winches, tuggers	Based on Seacor Force
Anchor handling	6140	Winches, tuggers	Based on Seacor Energy
DSV	1700	Compressors	Based on Cal Diver V
DSV	1800	Compressors	Based on Cal Diver II
Supply	4000	Bow thruster	Based on HOS Crossfire
Survey	1200	Sonar, survey equip	Based on Fugro Universal Surveyor
Crew boat	6300	Bow thruster	Based on HOS Hotshot

CONSTRUCTION SCENARIOS

Anchor Installation

The preferred method for installing the anchoring system is based on the use of suction piles. Each unloading buoy will have eight suction piles that are 72 inches (6 feet) in diameter. The final size and length of the piles would be determined after data from deep soil borings are obtained and evaluated. On-site construction activities in Massachusetts Bay will be initiated in mid-May 2009 and complete in late September 2009 assuming no delays.

If the base case suction pile fails to penetrate to depth, it may be possible to pump it back out and start over again. As a contingency, a prefabricated driven pile would be deployed. If this pile could not be driven to full penetration due to unusually hard local sediments conditions, it may be possible to accept a shorter penetration, drill the core to allow further driving, or drive an insert pile. Alternatives include high-holding power marine anchors, which work in almost all sediment conditions (different anchor types for different sediment conditions).

Suction Pile Anchoring System

Suction anchors are a commonly used alternative to the driven-pile embedment anchor. Suction anchors use a long pipe that is open at the bottom end and closed off at the top. The closed end is outfitted with pump fittings so that when the pipe is dropped vertically to the seabed, water can be evacuated and the pipe sucked into the bottom soil. The anchor line is attached to a pad eye near the midpoint of the pipe allowing tension to be applied to the pipe in the transverse direction. This approach places the tension line well down into the soil allowing a large wedge of soil to support the line load. Advantages of the suction piles include less penetration required than conventional driven piles plus ease of recovery, location accuracy, minimal disruption to the site and lees underwater radiated noise.

Suction piles work on principle of differential pressures between surface and water depth of the pile. A suction caisson is used as the anchor. The caisson is cylindrical in shape with the bottom end open. Embedment of the anchor is accomplished by using an ROV and submerged suction pump spread to pump water out of the top of the caisson until it is fully penetrated into the seabed. The process is simply reversed to recover the anchor. Once the suction anchor is pumped out of the seabed, it is recovered over the stern of the anchor-handling vessel.

Suction Pile Scenario Parameters

Source location:	Lat: 42° 29.00’ N	Long: 70° 36.84’ W
Source depth:	80 m	
Receiver depth:	Surface (1 m) , 50m, Bottom	
Time of year:	Summer	

Suction Pile Scenario Modelling Approach

The primary source of noise related to the installation of the suction piles will result from the use of a submerged suction pump spread. No measured data is available to characterize the noise produced by a suction pump spread. For the purpose of modeling underwater noise source level have been estimated based on a typical pump of similar size to the one proposed. Table 3 Noise will also result from the operation of support vessels and barges required during the operation. The installation of suction piles was modeled for an anchor for the northern buoy at position "N-2" at bearing 77.36°, with an 1100 m cable to the northern buoy (Figure 3 to Figure 5). This location is the closest buoy anchor to the SBNMS.

Table 3: 30 HP Water Pump - 1/3 Octave Band Source Levels

Centre Frequency	Source Level
(Hz)	(dB re 1 μPa-1m)
12.5	111.0
16	111.0
20	111.0
25	111.0
31.5	111.0
40	112.1
50	113.3
63	115.0
80	115.8
100	116.8
125	118.0
160	119.1
200	120.4
250	122.0
315	123.0
400	124.4
500	126.0
630	126.5
800	127.2
1000	128.0
1250	128.5
1600	129.2
2000	130.0
Broadband	138.0

Suction Pile Scenario Modelling Results

The model results are presented in 10 dB contour intervals surrounding the sound sources (Figure 3 to Figure 5). The area coverage within each contour interval and the average range to each 10 dB level are provided in Table 4 to Table 6. The average range was only calculated in a sector out towards the sea to avoid interference by the coastline.

Table 4: Area coverage and average range of suction piling sound levels received at the surface (1m) at anchor location N-2 in the summer.

Contour level (dB)	Area inside (km^2)	Average range (km)
50	411	10.9
60	98	5.5
70	13	2.1
80	1	0.7
90	0	0.1

Table 5: Area coverage and average range of suction piling sound levels received at 50 m depth at anchor location N-2 in the summer.

Contour level (dB)	Area inside (km^2)	Average range (km)
50	530	12.4
60	129	6.3
70	17	2.4
80	2	0.7
90	0	0.3

Table 6: Area coverage and average range of suction piling sound levels received at the ocean bottom at anchor location N-2 in the summer.

Contour level (dB)	Area inside (km^2)	Average range (km)
50	501	11.9
60	133	6.4
70	21	2.6
80	2	0.8
90	0	0.2

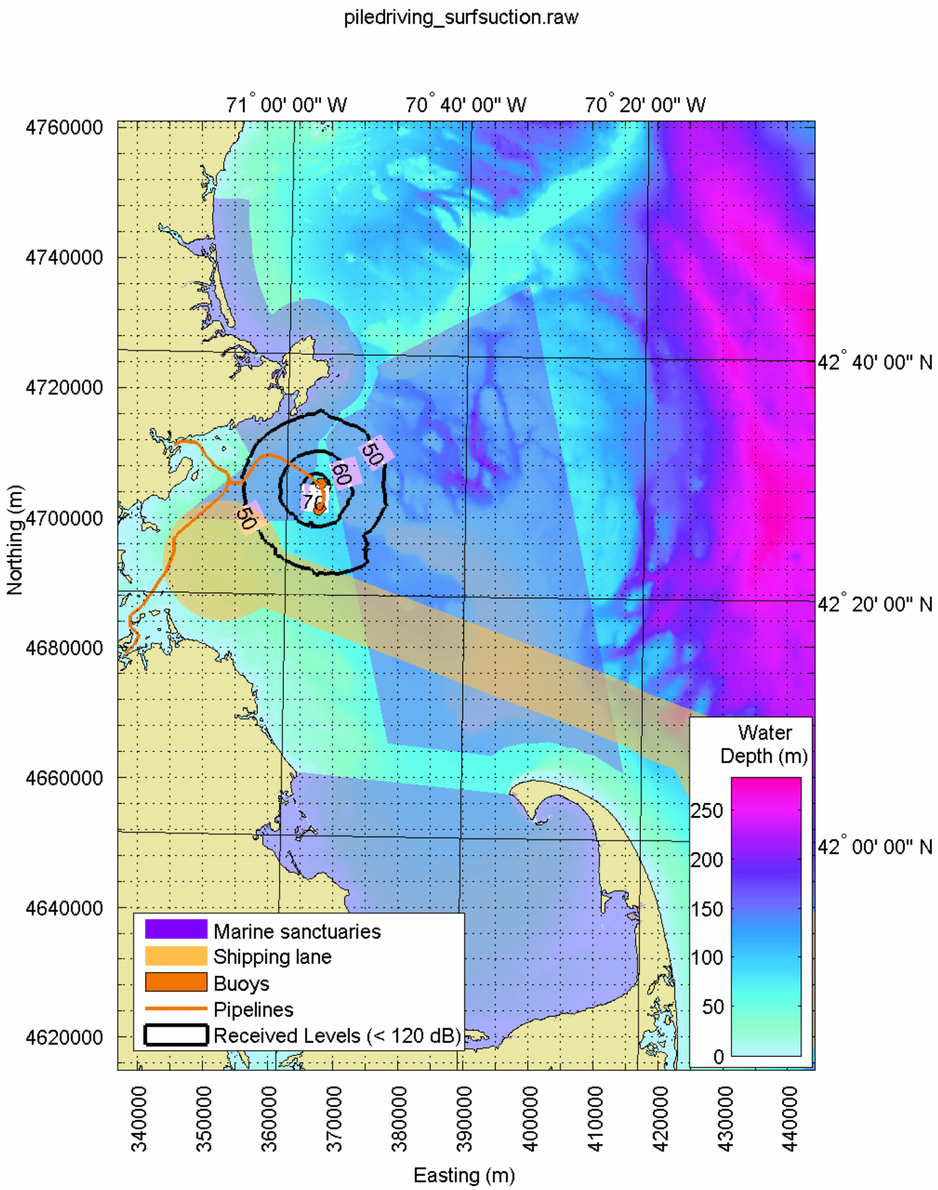

Figure 3: Suction pile installation sound levels received at the surface (1m) at anchor location N-2 east-northeast of the northern buoy in the summer season. Source was modeled at 80 m depth.

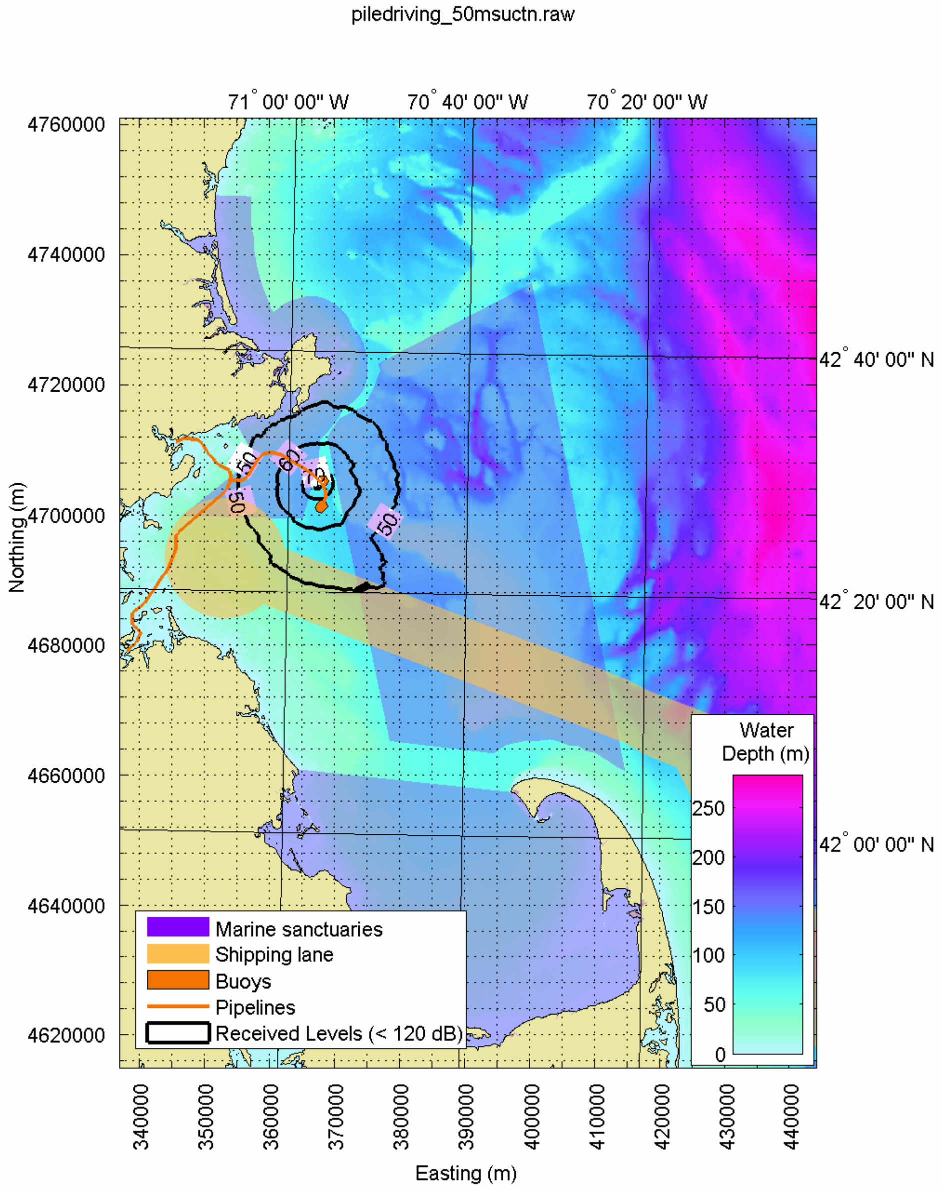

Figure 4: Suction pile installation sound levels received at 50-m water depth at anchor location N-2 east-northeast of the northern buoy in the summer season.

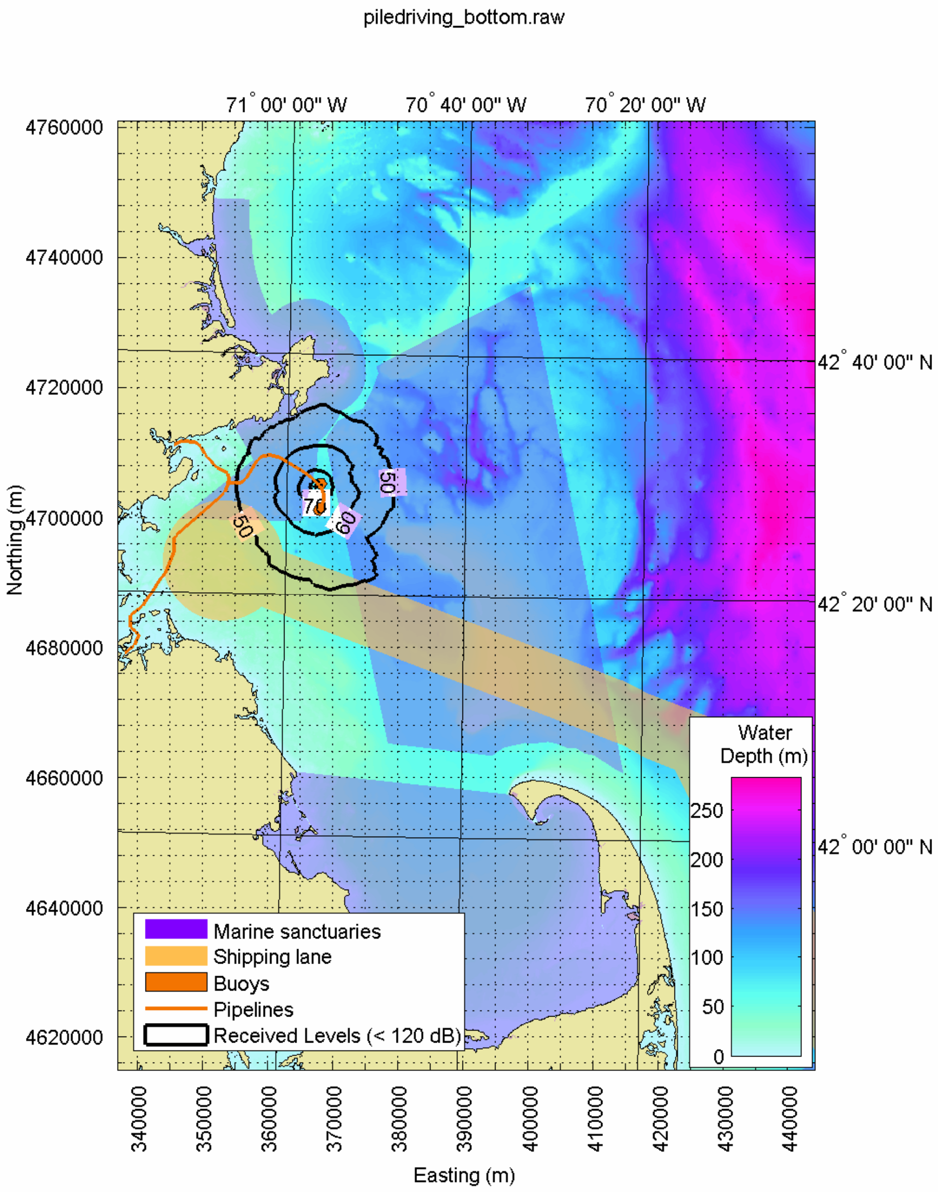

Figure 5: Suction pile installation sound levels received at the bottom at anchor location N-2 east-northeast of the northern buoy in the summer season.

Driven-pile Anchoring System

Although suction pilings are the proposed anchoring method for the unloading buoys, driven piles are one alternative anchoring system. If driven piles would be used, eight steel anchor piles, each 72" diameter and 15 to 20 m long, will be installed by hydraulic hammering at approximately 1,200 m radius from each unloading buoy. Each pile weighs 35 to 50 tonnes. The piles would be completely underwater. Sufficient information was not available on suction piling, thus it was not modeled.

Piledriving Scenario Parameters

Source location:	Lat: 42° 29.00' N	Long: 70° 36.84' W
Source depth:	80 m	
Receiver depth:	Surface, 50m, Bottom	
Time of year:	Summer	

Piledriving Modelling Approach

Piledriving was modeled for an anchor for the northern buoy at position "N-2" at bearing 77.36°, with an 1100 m cable to the northern buoy (Figure 6 to Figure 8). This location is the closest buoy anchor to the SBNMS. The source used for the model was taken from Greene and Davis (1999) for measurements made from piledriving at the Venture platform for the Sable Offshore Energy Project on the Scotian Shelf. The steel piles for this platform were likely similar to those used at the North Triumph platform that were 72" in diameter. The Menck MHU 3000 type hydraulic hammer used normally operates at a blow rate of 32 BPM (Menck GmbH 2005). The broadband source energy level was calculated by Malme et al. (1998) to be 205.9 dB re 1 $\mu Pa^2 s$. The corresponding 1/3 octave band energy levels are shown in Table 7. Source levels in dB re 1 μPa@1m were estimated assuming a pulse length of 100ms, using the following formula:

$$SPL_{rms}\ (\text{dB re } 1\ \mu Pa@1m) = SEL\ (\text{dB re } 1\ \mu Pa^2 s) - 10 \text{ Log } T \quad \text{where } T = 100\text{ms}$$

The source level was modeled at the bottom (80 m). The piledriving for installation of the 16 buoys' anchors is scheduled to take 15 days in the summer during August and September (Suez LNG NA LLC 2005a), therefore only the summer season was modeled.

Table 7: 1/3-octave band source levels for piledriving

Centre Frequency *(Hz)*	*Source Spectra* *(dB re 1 μPa^{2}s)*	*Source Level* *(dB re 1 μPa@1m)*
12.5	192.0	202.0
16	182.0	192.0
20	177.0	187.0
25	174.0	184.0
31.5	176.0	186.0
40	178.0	188.0
50	174.0	184.0
63	178.0	188.0
80	188.0	198.0
100	190.0	200.0
125	194.0	204.0
160	198.0	208.0
200	199.5	209.5
250	199.0	209.0
315	194.0	204.0
400	194.5	204.5
500	195.0	205.0
630	188.0	198.0
800	185.0	195.0
1000	184.0	194.0
1250	185.0	195.0
1600	184.0	194.0
2000	182.0	192.0
Broadband	205.9	216.0

Piledriving Modelling Results

The model results are presented in 10 dB contour intervals surrounding the sound sources (Figure 6 to Figure 8). The area coverage within each contour interval and the average range to each 10 dB level are provided in Table 8 to Table 10. The average range was calculated in a sector originating at the mean source location and bounded by Cape Ann to the north, and Cape Cod to the south, to avoid interference by the coastline.

The received sound levels from piledriving were louder at the 50-m depth than at the surface or ocean bottom. At this depth, the area coverage of the 120 dB contour interval was 2276 km^2 and the average range was 29.9 km.

Table 8: Area coverage and average range of piledriving sound levels received at the surface (1m) at anchor location N-2 in the summer.

Contour level (dB)	Area inside (km^2)	Average range (km)
90	7591	67.7
100	5354	51.7
110	3352	37.8
120	1843	26.3
130	756	15.5
140	224	8.4
150	28	3.0
160	2	0.8
170	0	0.2

Table 9: Area coverage and average range of piledriving sound levels received at 50 m depth at anchor location N-2 in the summer.

Contour level (dB)	Area inside (km^2)	Average range (km)
90	9117	67.1
100	6318	63.0
110	4110	44.1
120	2276	29.9
130	1012	17.5
140	319	9.6
150	52	4.1
160	5	1.3
170	1	0.5

Table 10: Area coverage and average range of piledriving sound levels received at the ocean bottom at anchor location N-2 in the summer.

Contour level (dB)	Area inside (km^2)	Average range (km)
90	8276	69.2
100	5948	56.6
110	3806	41.6
120	2164	28.5
130	917	16.8
140	307	9.5
150	59	4.4
160	6	1.4
170	0	0.0

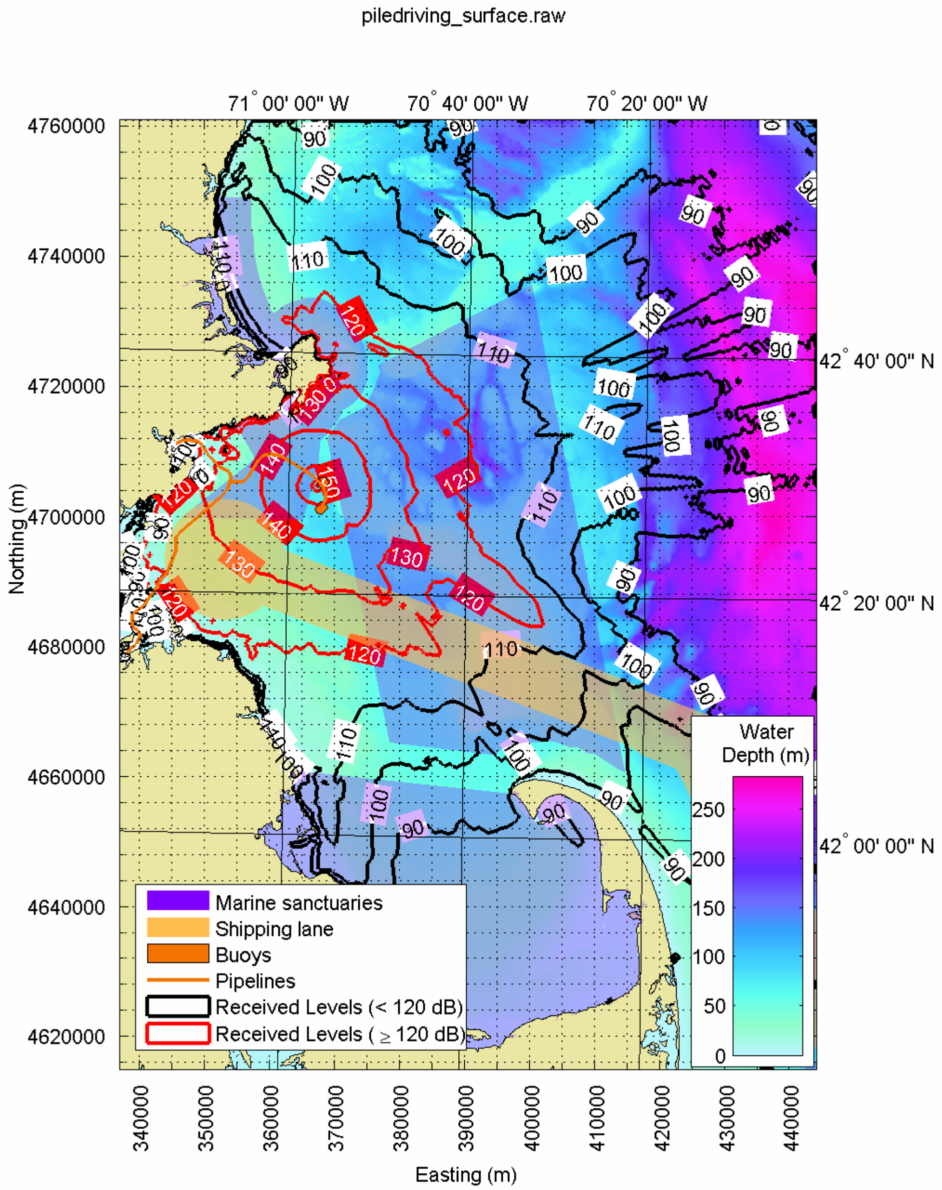

Figure 6: Piledriving sound levels received at the surface (1m) at anchor location N-2 east-northeast of the northern buoy in the summer season. Source was modeled at 80 m depth.

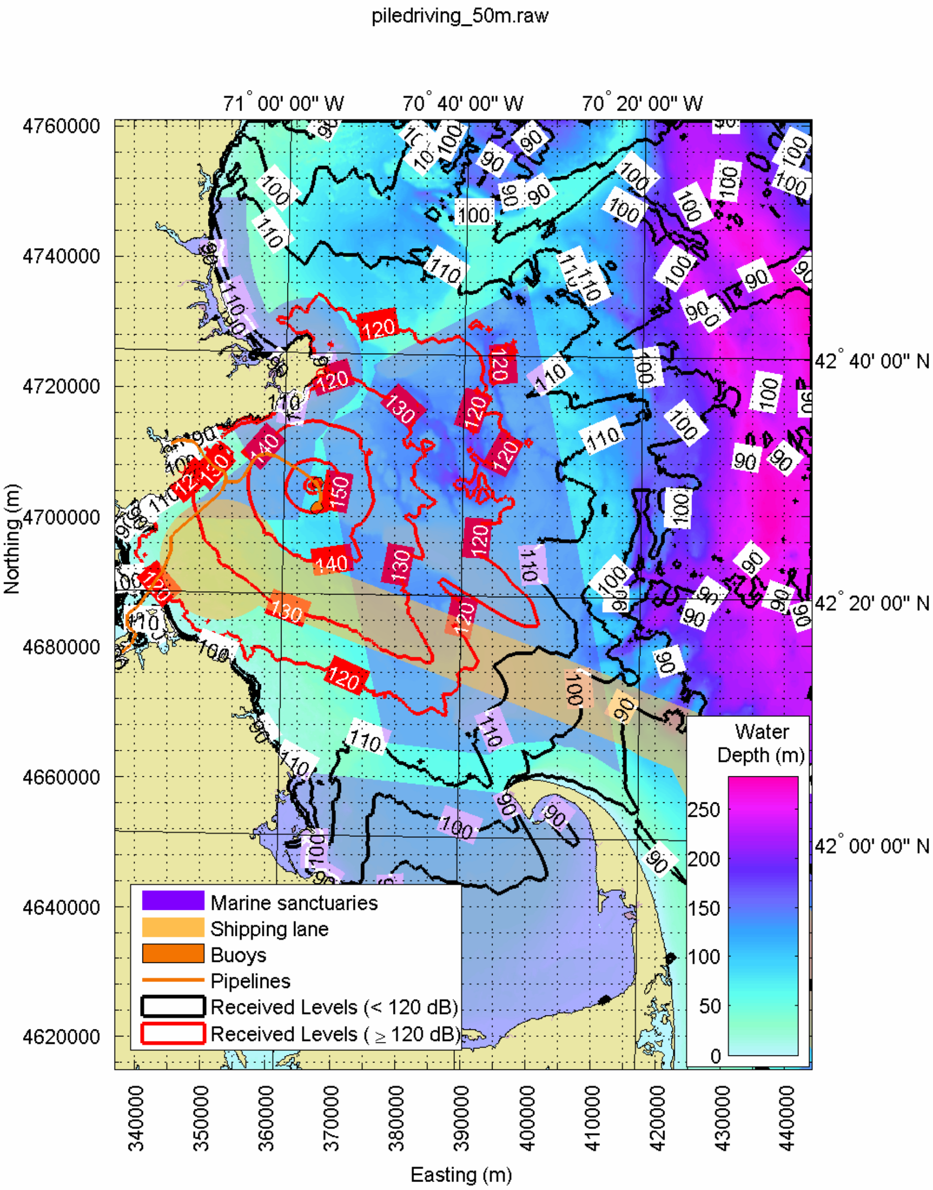

Figure 7: Piledriving sound levels received at 50-m water depth at anchor location N-2 east-northeast of the northern buoy in the summer season.

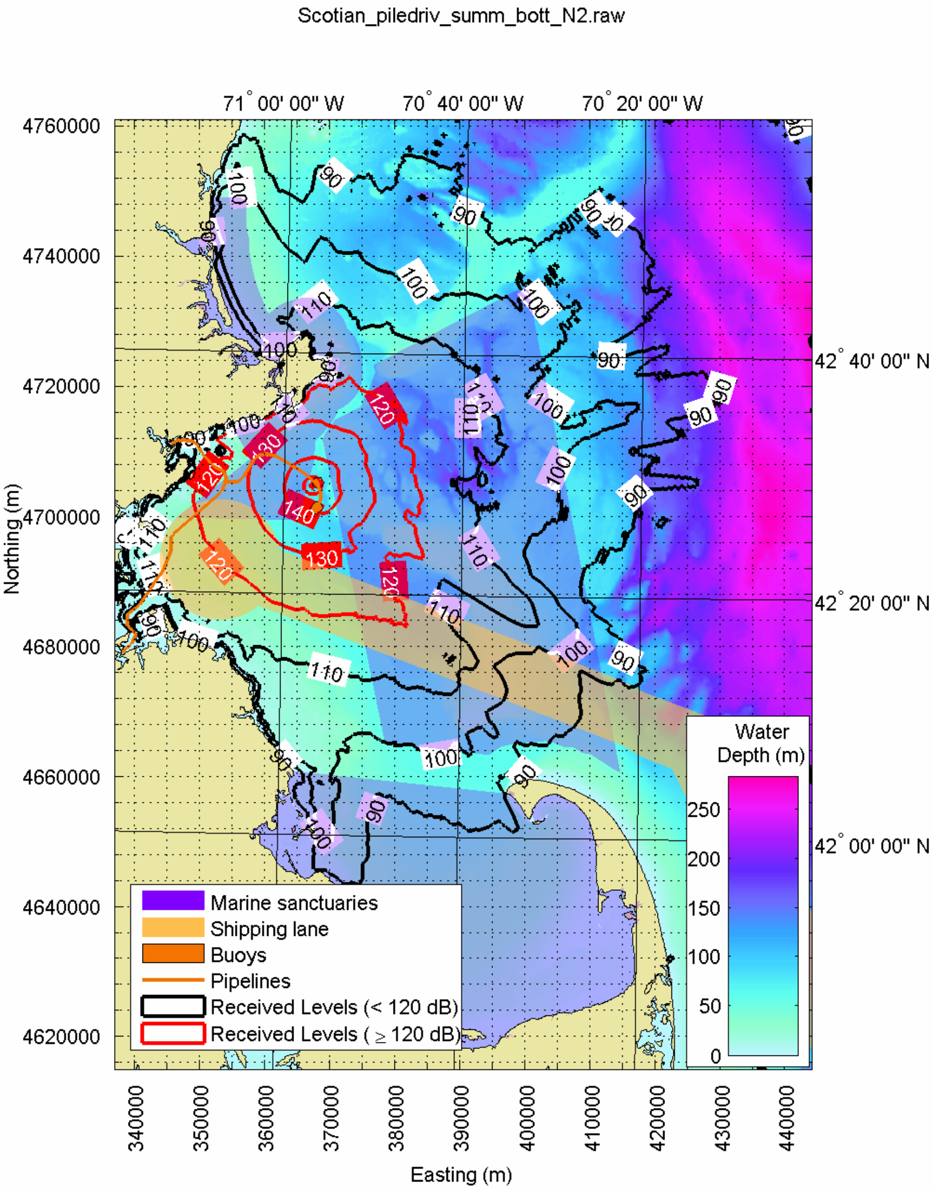

Figure 8: Piledriving sound levels received at the bottom at anchor location N-2 east-northeast of the northern buoy in the summer season.

Pipeline Construction

These scenarios considered a typical pipeline construction operation, with the goal of predicting the underwater noise field from a group of vessels commonly used to construct a pipeline. A typical scenario includes a dredger or pipelaying barge, two anchor handling tugs, and a survey vessel. More than one location was modeled to reflect differing propagation conditions.

Typical pipeline construction operations were modeled using measured noise levels from six vessels that best represent those that may be used in the Neptune LNG deep water port construction (Table 11). Combinations of these vessels in different locations and seasons were modeled to predict the underwater noise field received at three different depths: at the surface, at 50 m, and at the bottom. The pipelaying along the 4.02 km flowline between the two buoys is scheduled to take 6 days, the trenching 5 days, and the backfilling another 5 days during June and July 2009 (Suez LNG NA LLC 2005a). The construction of the 17.45 km northern route pipeline is scheduled to take 22 days to lay pipe, 10 days to trench, and 10 days to backfill (Suez LNG NA LLC 2005a).

Table 11: Vessels used for modelling of noise levels and their respective engine powers and broadband source levels (dB re 1 μPa at 1m).

Vessel	Type	Length *(m)*	Total engine Power *(hp)*	Broadband Source Level *(dB re 1 μPa-1m)*
Gerardus Mercator	TSHD	152.5	29,000	185.7 *dredging*
Semac 1	Pipelay Barge	148.5	not available	179.2 *pipelaying*
Castoro II	Pipelay Barge	130.0	3,350	168.1 *anchor operations*
Setouchi Surveyor	Survey Vessel	64.6	2,600 + 2,000 (thruster)	186.0 *using thrusters*
Britoil 51	AHTS	45.0	6,600 + 500 (thruster)	199.7 *anchor pulling*
Katun	AHTS	67.6	12,240	181.8 *anchor pulling*

Pipe Burial Scenario – Pipeline Construction Scenario 1

The pipeline construction plans call for the use of a towed trenching plow for burial of the pipe. Models were run for sound levels from a trailer suction hopper dredger (TSHD) since sound levels were not available for a plow at that time. Plowing operations are expected to produce underwater noise levels around 185 re 1 µPa at 1m (Aspen Environmental Group, 2005). These levels are consisted with those used for the TSHD (185.7 dB re 1 µPa at 1m). This scenario is referred to as Pipeline Construction Scenario 1.

Pipeline Construction Scenario 1 Parameters

Source location:

Northern buoy	Lat: 42° 29.14’ N	Long: 70° 36.30’ W
On northern route pipeline	Lat: 42° 31.37’ N	Long: 70° 40.92’ W
Source depth:	8 m	
Receiver depth:	Surface	
Time of year:	Summer	

Pipeline Construction Scenario 1 Modelling Approach

The trenching scenario used data from the trailer suction hopper dredger (TSHD) *Gerardus Mercator* (GM) from Jan de Nul of Holland. As discussed above the broadband level is assumed to be representative of a plowing operation.

The GM is 152.5 m long, 29,000 hp dredger with a18,000 m^3 hopper capacity that uses suction to remove the sediment and deposit it next to the trench. Thrusters are used to maintain its position so tugs are not needed. It is normally used to dredge at about 55 m water depth but can extend to 112 m. The broadband source level of the GM while dredging is 188.3 dB re 1 µPa at 1m and the corresponding 1/3-octave band levels are shown in Table 12 and Figure 9. The dredger was modeled at the location of the north buoy (Figure 10) and midway along the northern pipeline route (Figure 11).

Table 12: Vessel source levels (dB re 1 µPa at 1 m) in 1/3-octave frequency bands.

Centre Frequency (Hz)	Gerardus Mercator	Semac 1	Castoro II	Setouchi Surveyor	Britoil 51	Katun
16	179.8	157.8	162.7	184.5	193.1	169.9
20	168.5	158.1	158.3	176.7	191.1	167.4
25	167.6	161.5	151.8	172.1	196.7	167.6
31.5	170.3	163.2	149.1	170.8	188.8	161.1
40	170.9	166.0	146.6	168.3	177.3	159.0
50	178.6	165.8	147.9	169.7	176.4	159.4
63	178.6	164.6	153.3	169.0	179.2	169.0
80	167.6	166.3	153.2	159.0	178.8	171.5
100	172.7	163.4	156.4	155.9	178.1	172.6
125	165.4	163.0	162.2	162.5	176.7	175.8
160	171.6	163.4	155.6	154.8	175.9	170.5
200	170.2	163.6	151.4	154.7	173.5	166.8
250	164.4	176.9	151.7	167.7	178.8	168.0
315	172.2	162.2	143.6	161.7	172.8	165.5
400	169.7	160.8	145.2	159.7	165.4	162.5
500	167.3	161.3	145.8	166.9	170.7	171.3
630	164.6	160.5	145.5	160.4	168.8	164.2
800	165.4	159.5	150.5	157.6	165.1	160.5
1000	161.0	155.8	150.8	158.1	164.2	159.2
1250	158.7	150.5	142.7	152.9	167.3	161.4
1600	155.1	147.8	138.6	159.1	165.9	162.5
2000	151.7	145.6	143.2	155.2	166.5	159.2
Broadband	185.7	179.2	168.1	186.0	199.7	181.8

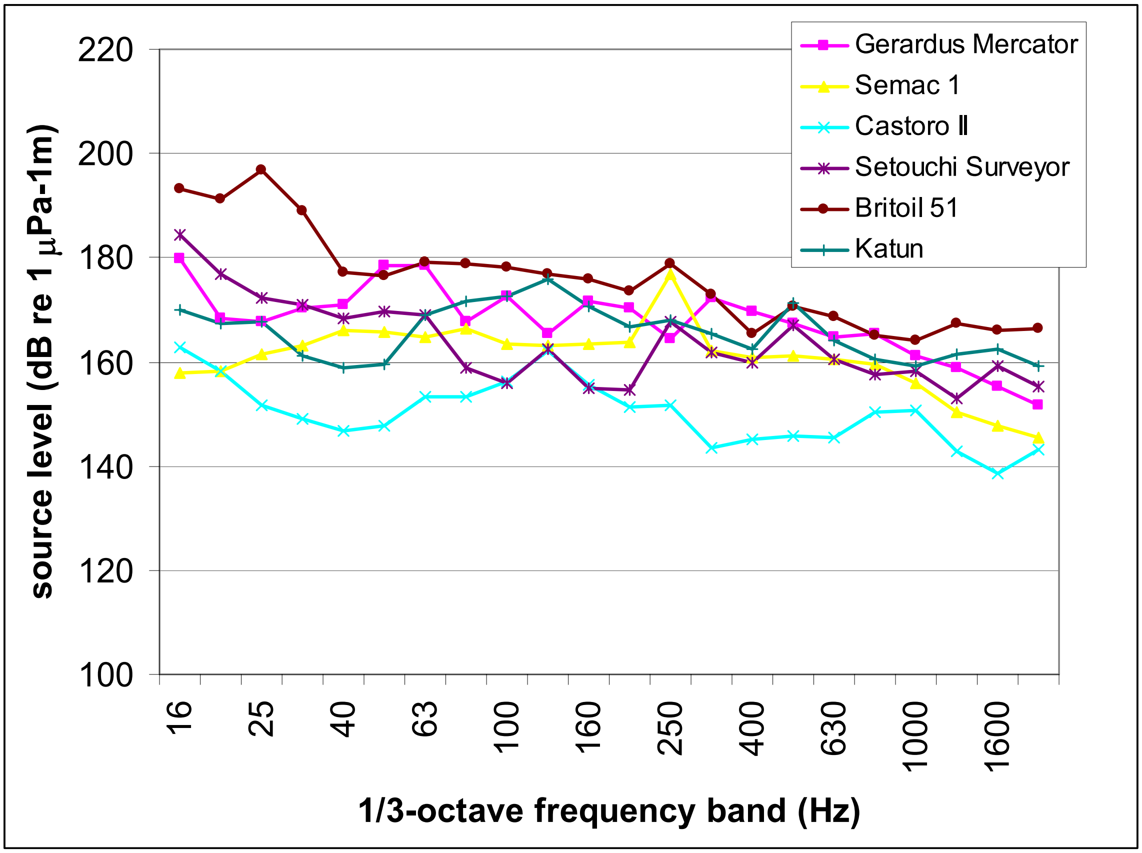

Figure 9: Vessel source levels (dB re 1 μPa at 1 m) in 1/3-octave frequency bands

Pipeline Construction Scenario 1 Modelling Results

The model results are presented in 10 dB contour intervals surrounding the sound sources (Figure 10 and Figure 11). The area coverage within each contour interval and the average range to each 10 dB level are provided in Table 13 and Table 14. The average range was calculated in a sector originating at the mean source location and bounded by Cape Ann to the north, and Cape Cod to the south, to avoid interference by the coastline.

If the Gerardus Mercator TSHD were dredging at the location of the northern buoy, the 120 dB received levels at the surface would extend to 3.9 km from the source and cover an area of 52 km^2. At a location approximately midway along the northern pipeline route, the 120 dB sound levels would reach 4.2 km and cover an area of 49 km^2.

Table 13: Area coverage and average range of surface received contours for Pipeline Construction Scenario 1 (trenching by Gerardus Mercator at the northern buoy location in summer)

Contour level (dB)	Area inside (km^2)	Average range (km)
90	1409	23.9
100	640	13.9
110	213	7.6
120	52	3.9
130	8	1.7
140	1	0.5
150	0	0.0

Table 14: Area coverage and average range of surface received contours for Pipeline Construction Scenario 1 (trenching by Gerardus Mercator along the pipeline in summer).

Contour level (dB)	Area inside (km^2)	Average range (km)
90	1198	23.6
100	518	15.0
110	195	8.8
120	49	4.2
130	8	1.7
140	1	0.6
150	0	0.0

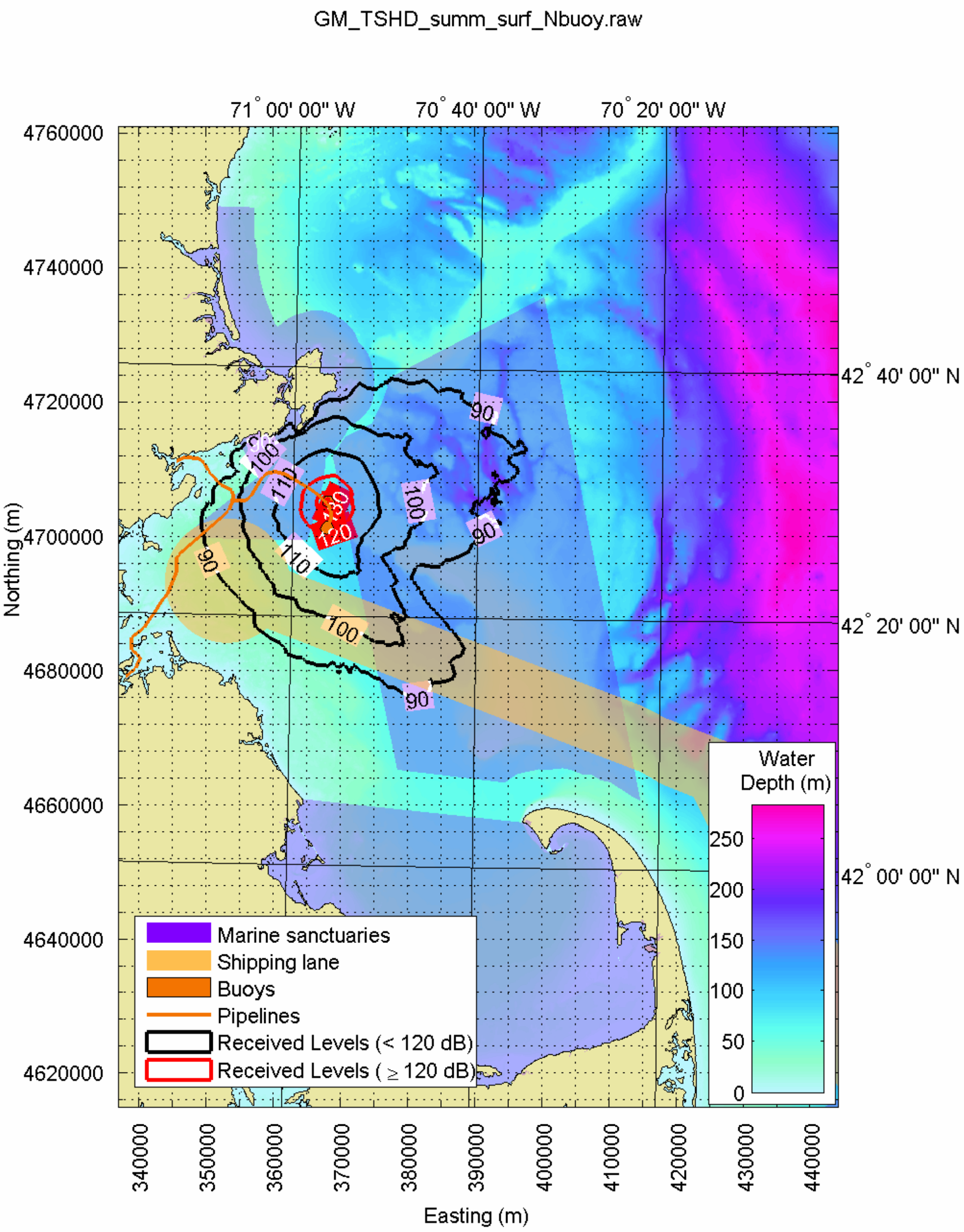

Figure 10: Pipeline Construction Scenario 1 - Surface received levels of trenching by Gerardus Mercator at the northern buoy location in summer.

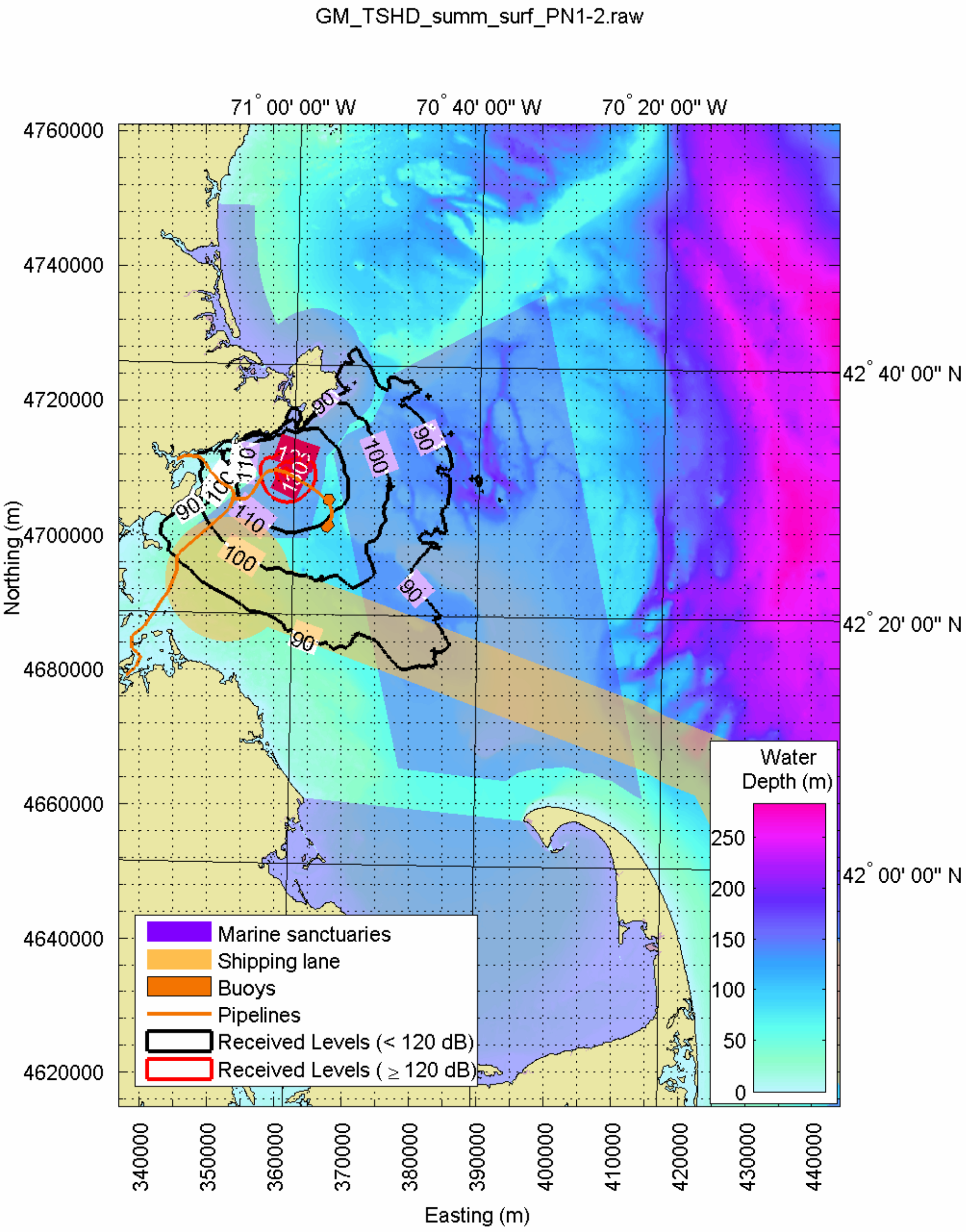

Figure 11: Pipeline Construction Scenario 1 - Surface received levels of trenching by Gerardus Mercator along the pipeline in summer.

Pipelaying Scenarios

These scenarios assume that the pipelaying and plowing/backfilling occur consecutively rather than at the same time as indicated in the “Neptune Contingency Plan Schedule” dated 22 August 2005 (Suez LNG NA LLC 2005a). The pipelay barge modeled first is called Semac 1 from Saipem S.p.A. of Italy. Semac 1 is a large semi-submersible 148.5 m long (hp unknown) deep water pipelay barge held on station with a 12-point anchor mooring spread. The broadband source level for this vessel during anchor operations is 179.3 dB re 1 μPa. Pipelaying also requires dedicated support from one or two anchor handling/towing/supply tugs (AHTS) and supply vessels. The spread is also usually supported by a survey vessel. Pipelaying in water up to 130 m can also be modeled with the quieter (166.6 dB re 1 μPa at 1m) 135 m long, 3350 bhp Castoro II barge also of Saipem.

The survey vessel modeled in this case is the *Setouchi Surveyor* and the two AHTS tugs are *Britoil 51* and *Katun*. Supply vessels were not included. The *Setouchi Surveyor* is 64.6 m long with 2600 hp main engines and 2000 hp side thrusters. The broadband source level of *Setouchi* in transit is 190.8 dB re 1 μPa at 1m. The *Britoil 51* is 45 m long with 6600 hp engines and a 500 hp thruster. The broadband source level of Britoil is 199.7 dB re 1 μPa at 1m during anchor pull operations and 202.7 dB re 1 μPa at 1m during full speed transit. The broadband source level of the 67.6 m long *Katun* is 184.4 dB re 1 μPa at 1m during anchor pull operations and 190.3 dB re 1 μPa at 1m during transit.

Three pipelaying scenarios were modeled:

- Pipeline Construction Scenario 2: *Semac* barge, 2 tugs, 1 survey (*Semac 1* spread) along flowline between N and S buoys.
- Pipeline Construction Scenario 3: *Castoro II* barge, 2 tugs, 1 survey (*Castoro II* spread) along flowline between N and S buoys.
- Pipeline Construction Scenario 4: *Castoro II* barge, 2 tugs, 1 survey (*Castoro II* spread) along northern route pipeline

The model results are presented in 10 dB contour intervals surrounding the sound sources. The area coverage within each contour interval and the average range to each 10 dB level are provided in Tables 11-21. The average range was calculated in a sector originating at the mean source location and bounded by Cape Ann to the north, and Cape Cod to the south, to avoid interference by the coastline.

The surface received results for pipelaying by *Semac 1* (Table 13 to Table 15) and *Castoro II* (Table 16) in the summer are very similar. The 120 dB contour interval does extend further east on average for the *Castoro* than the *Semac*, possibly due to differing frequency content.

Along the flowline between the buoys, the 120 dB received levels from the Castoro spread reach a similar range (10.6-10.8 km) at all three water depths in the summer. The area coverage of the 120 dB contour interval is 127 to 144 km^2. In the spring, sound travels about 200 m farther than in the summer and the levels are similar at the surface and mid-depth. The area of the 120 dB contour is 151 to 163 km^2.

The pipelaying spread modeled on the northern route pipeline shows 120 dB sound levels reaching 6.5 to 7.6 km on average. The 50 m depth in the spring experienced the least transmission loss at this location.

Pipeline Construction Scenario 2

Pipeline Construction Scenario 2 Parameters

Source location:			***Source Depth:***
Semac 1	Lat: 42° 29.14' N	Long: 70° 36.30' W	5.3 m
Setouchi Surveyor	Lat: 42° 28.63' N	Long: 70° 35.90' W	4.8 m
Katun	Lat: 42° 28.87' N	Long: 70° 36.66' W	4.0 m
Britoil 51	Lat: 42° 29.41' N	Long: 70° 36.31' W	3.0 m
Receiver depth:	Surface		
Time of year:	Summer		

Pipeline Construction Scenario 2 Modelling Approach

The lay barge *Semac 1* was modeled at the northern buoy location (Figure 12). The survey vessel is 1 km away along the flowline between the two buoys. The tugs are 500 to 700 m from the lay barge. The area coverage and average ranges to the contour lines are in Table 15.

Pipeline Construction Scenario 2 Modelling Results

Table 15: Area coverage and average range of contours for Pipeline Construction Scenario 2 (Surface received sound levels of pipelaying by *Semac 1* spread along flowline between N and S buoys in summer)

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2032	31.8
100	1120	21.9
110	468	13.0
120	128	7.1
130	24	3.7
140	3	2.4
150	0	0.0

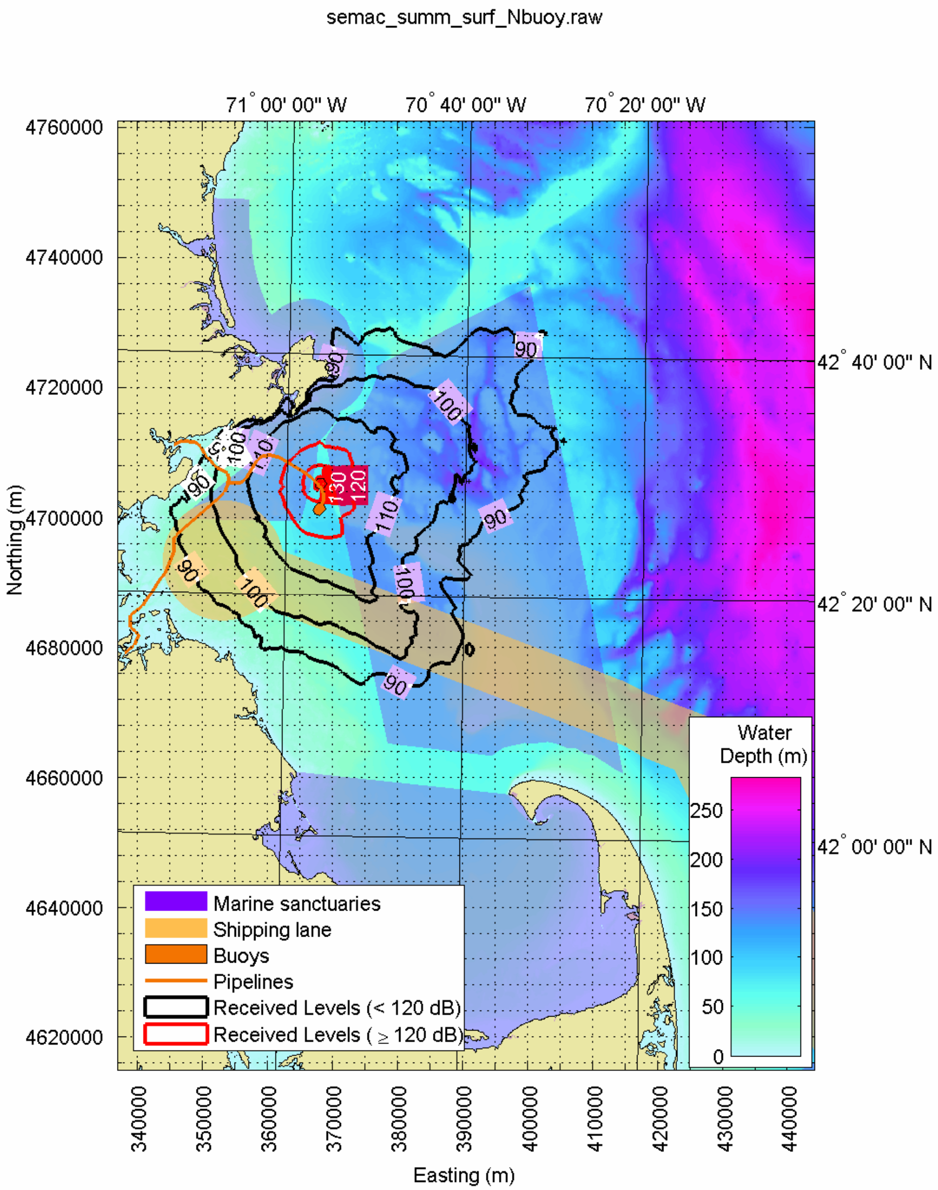

Figure 12: Pipeline Construction Scenario 2 - Surface received sound levels of pipelaying by *Semac 1* spread along flowline between N and S buoys in summer.

Pipeline Construction Scenario 3

Pipeline Construction Scenario 3 Parameters

Source location:	Lat:	Long:	***Source Depth:***
Castoro II	42° 28.63’ N	70° 35.98’ W	2.2 m
Setouchi Surveyor	42° 29.15’ N	70° 36.23’ W	4.8 m
Katun	42° 28.62’ N	70° 36.34’ W	4.0 m
Britoil 51	42° 28.90’ N	70° 35.62’ W	3.0 m
Receiver depth:	Surface, 50m, Bottom		
Time of year:	Summer and Spring		

Pipeline Construction Scenario 3 Modelling Approach

The lay barge *Castoro II* was chosen for this example because it may better represent the *Horizon Lonestar* pipelay barge. The *Castoro II* requires the support of only one AHTS but may have a second one. The spread was modeled on the flowline between the two buoys for water surface (Figure 13), 50-m depth (Figure 14), and ocean bottom (Figure 15) received sound levels in the summer season and at the surface (Figure 16) and at 50m depth (Figure 17) in spring.

Pipeline Construction Scenario 3 Modelling Results

Table 16: Area coverage and average range of contours for Pipeline Construction Scenario 3 (Surface received sound levels of pipelaying by *Castoro II* spread along flowline. between N and S buoys in summer)

Contour level (dB)	Area inside (km^2)	Average range (km)
90	1998	34.4
100	1095	25.7
110	452	17.0
120	127	10.8
130	22	9.3
140	3	9.1
150	0	0.0

Table 17: Area coverage and average range of contours for Pipeline Construction Scenario 3 (received sound levels at 50 m depth of pipelaying by *Castoro II* spread along flowline between N and S buoys in summer)

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2225	36.4
100	1194	26.6
110	496	17.0
120	134	10.6
130	21	9.4
140	3	9.1
150	0	0.0

Table 18: Area coverage and average range of contours for Pipeline Construction Scenario 3 (received sound levels at bottom depth of pipelaying by *Castoro II* spread along flowline between N and S buoys in summer.)

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2103	35.5
100	1145	26.1
110	486	17.1
120	144	10.8
130	26	9.3
140	4	9.1
150	0	0.0

Table 19: Area coverage and average range of contours for Pipeline Construction Scenario 3 (surface received sound levels of pipelaying by *Castoro II* spread along flowline between N and S buoys in spring.)

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2426	39.5
100	1268	27.6
110	540	17.8
120	151	11.0
130	25	9.3
140	3	9.1
150	0	0.0

Table 20: Area coverage and average range of contours for Pipeline Construction Scenario 3 (received sound levels at 50 m depth of pipelaying by *Castoro II* spread along flowline between N and S buoys in spring.)

Contour level (dB)	Area inside (km^2)	Average range (km)
90	3690	54.0
100	1578	30.7
110	620	18.6
120	163	10.9
130	24	9.4
140	4	9.1
150	1	9.0
160	0	0.0

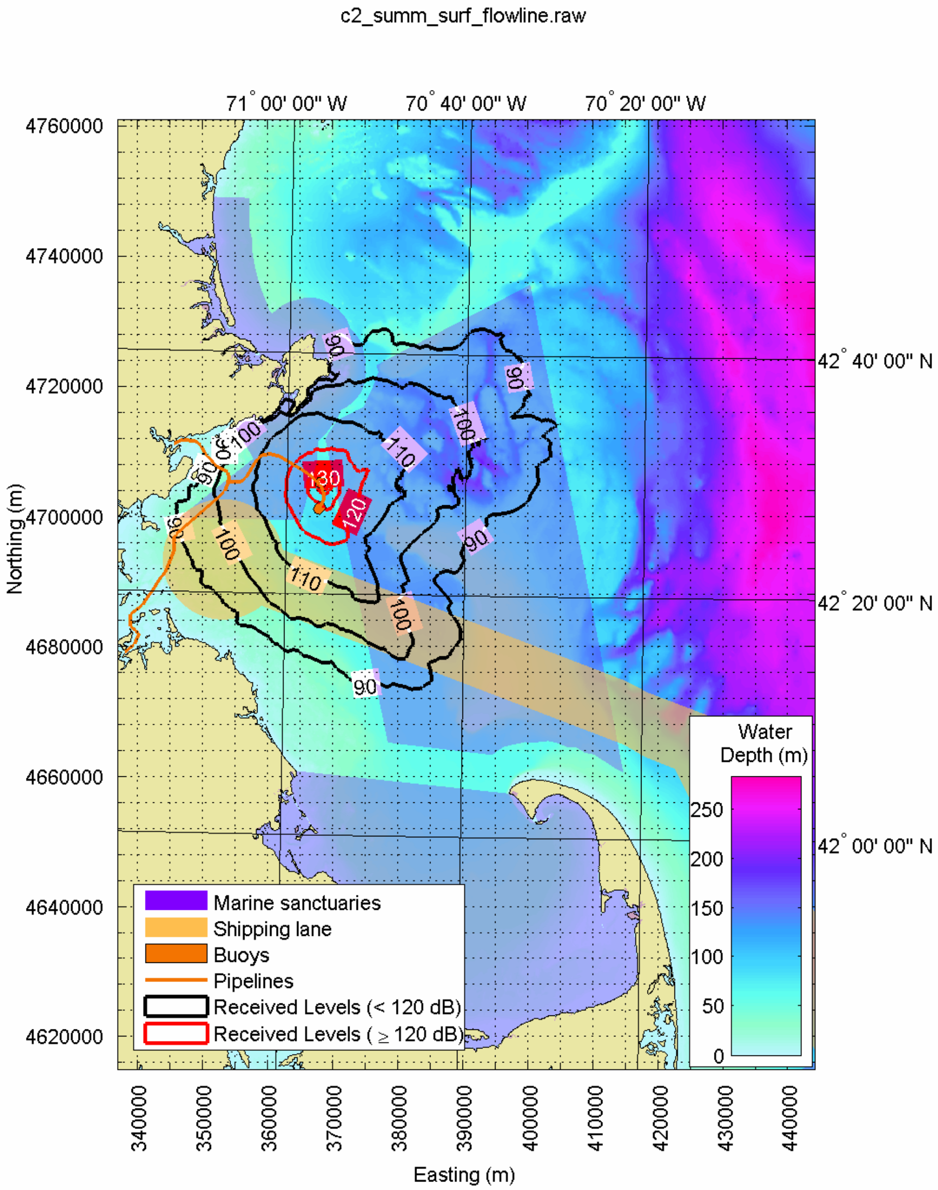

Figure 13: Pipeline Construction Scenario 3 - Surface received sound levels of pipelaying by *Castoro II* spread along flowline between N and S buoys in summer.

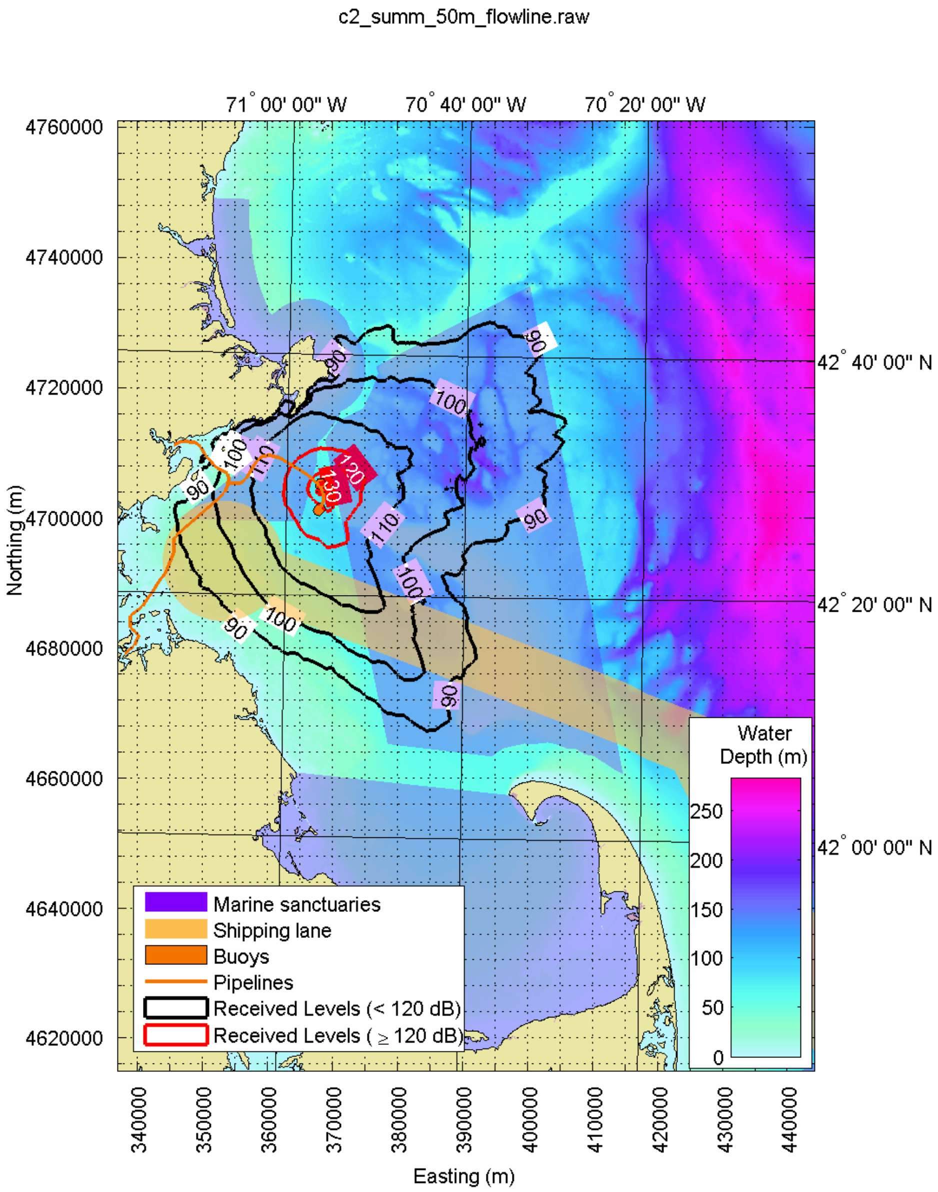

Figure 14: Pipeline Construction Scenario 3 - Received sound levels at 50 m depth of pipelaying by Castoro II spread along flowline between N and S buoys in summer.

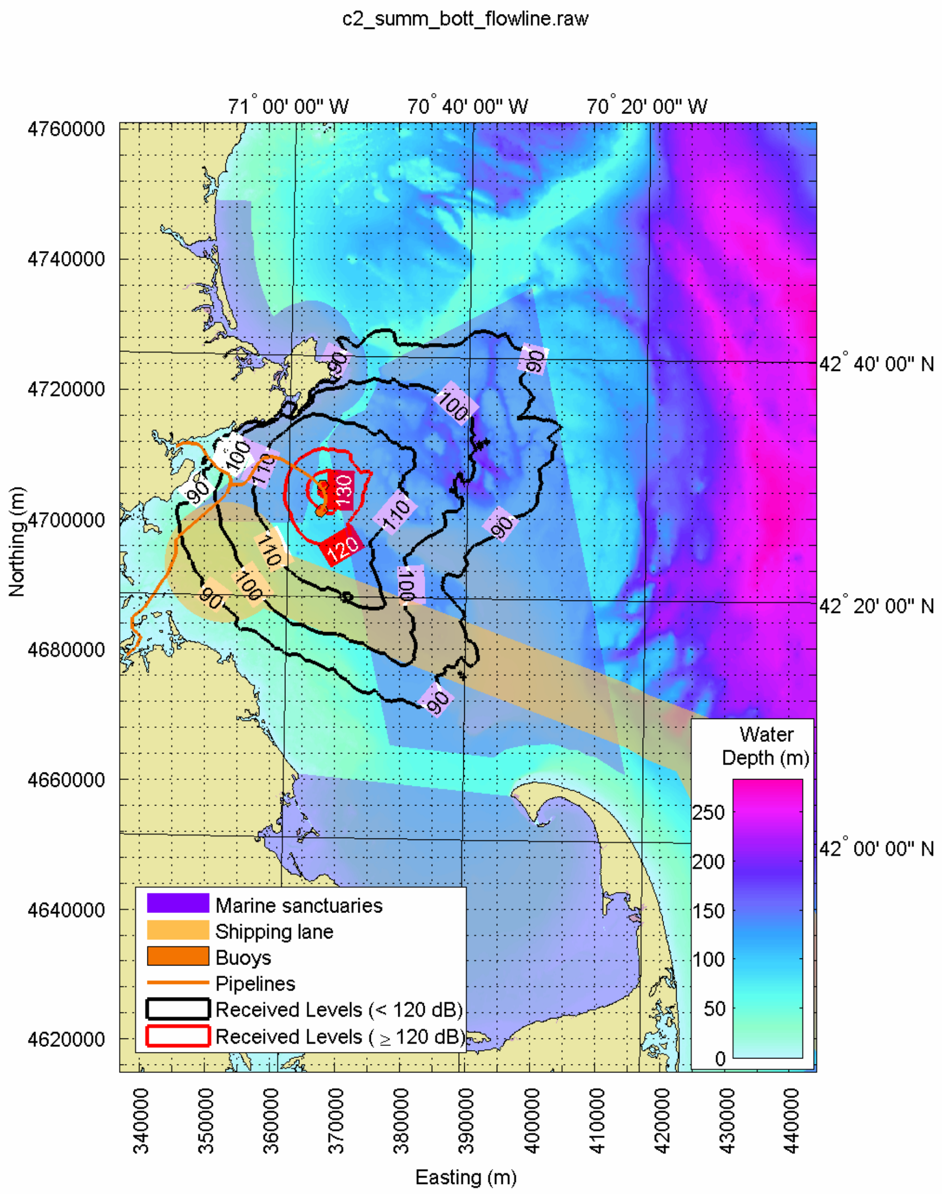

Figure 15: Pipeline Construction Scenario 3 - Received sound levels at bottom depth of pipelaying by *Castoro II* spread along flowline between N and S buoys in summer.

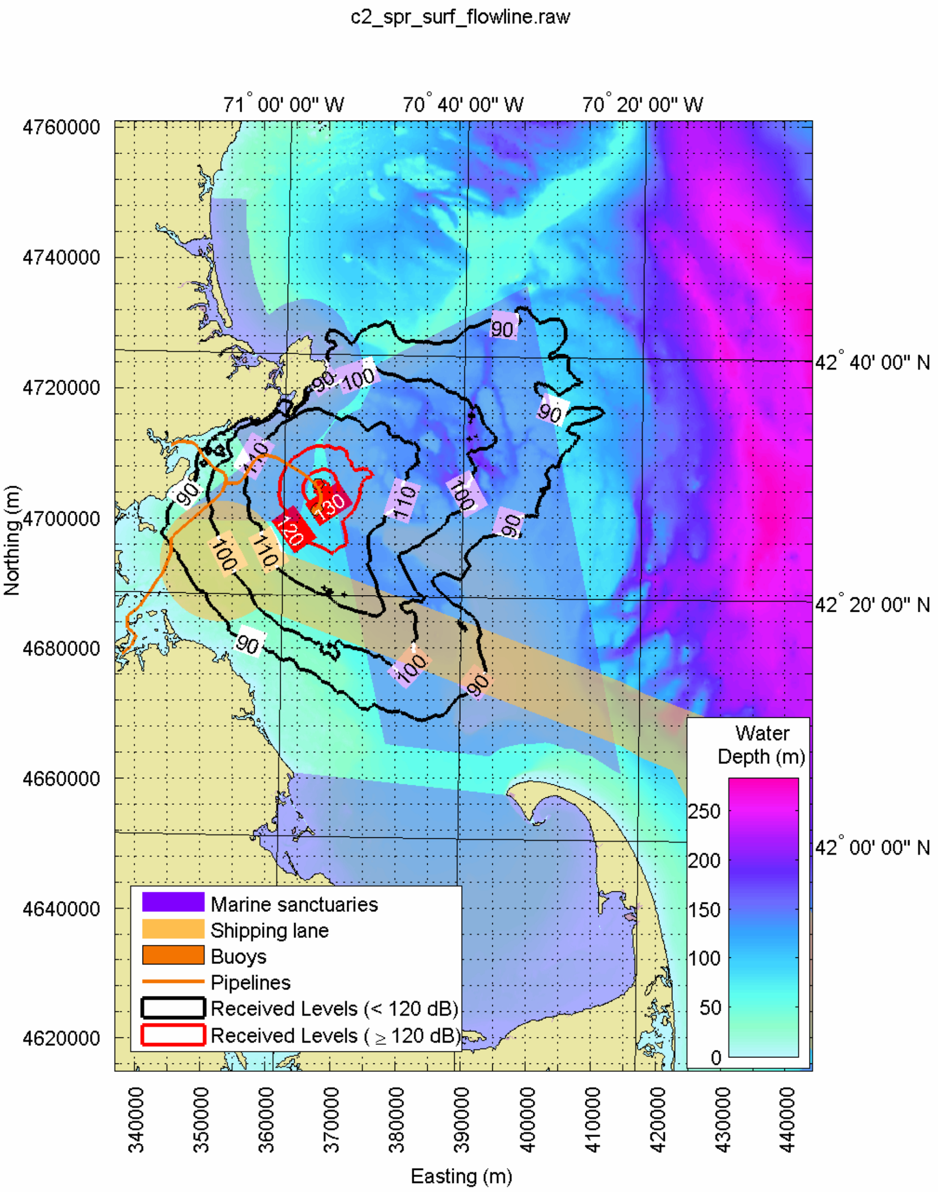

Figure 16: Pipeline Construction Scenario 3 - Surface received sound levels of pipelaying by *Castoro II* spread along flowline between N and S buoys in spring.

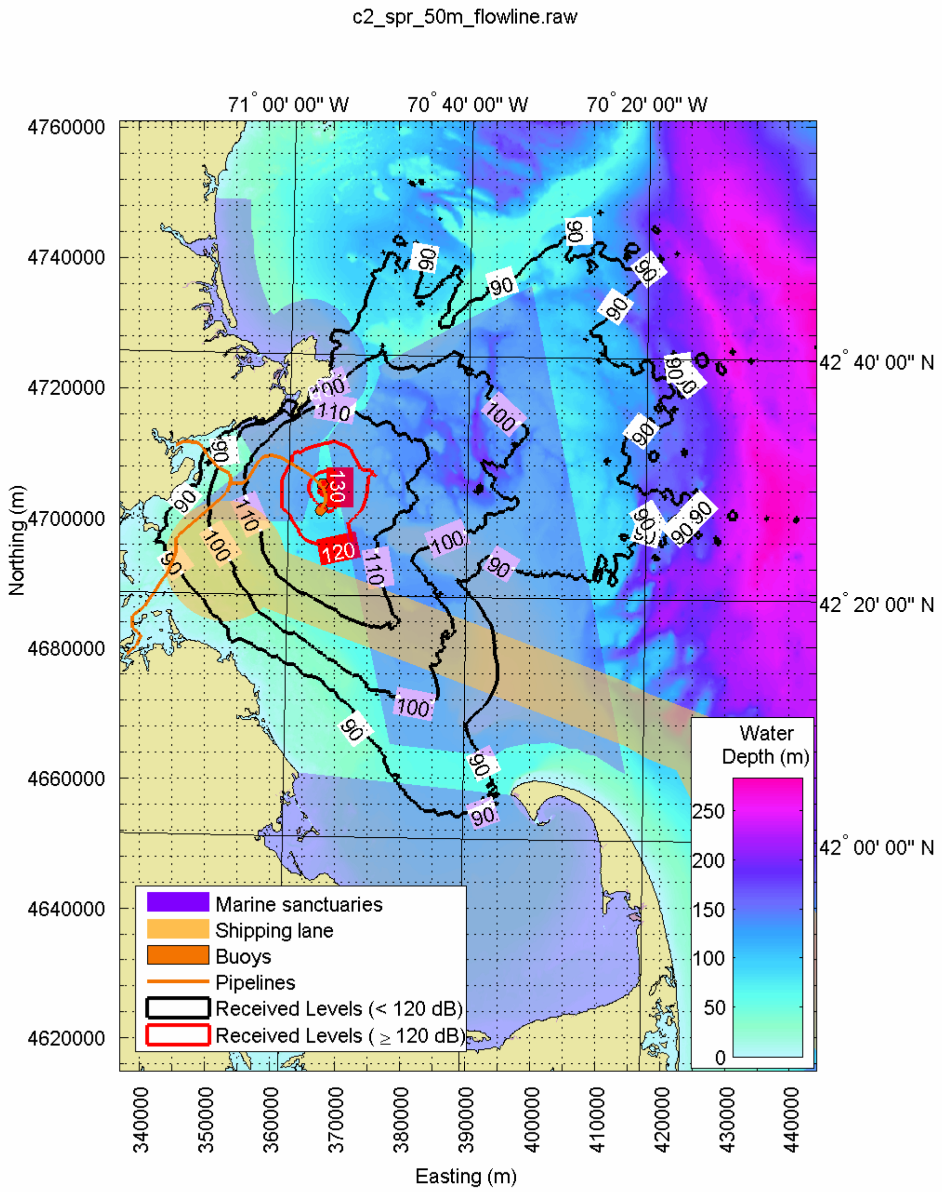

Figure 17: Pipeline Construction Scenario 3 - Received sound levels at 50 m depth of pipelaying by *Castoro II* spread along flowline between N and S buoys in spring.

Pipeline Construction Scenario 4

Pipeline Construction Scenario 4 Parameters

Source location:	Lat:	Long:	***Source Depth***
Castoro II	42° 31.37' N	70° 40.92' W	2.2 m
Setouchi Surveyor	42° 31.51' N	70° 41.77' W	4.8 m
Katun	42° 31.09' N	70° 41.27' W	4.0 m
Britoil 51	42° 31.63' N	70° 41.29' W	3.0 m
Receiver depth:	Surface, 50m, Bottom		
Time of year:	Summer and Spring		

Pipeline Construction Scenario 4 Modelling Approach

The *Castoro II* pipelay spread was also modeled along the northern route pipeline for received levels at the surface (Figure 18), at 50 m (Figure 19), and at the ocean bottom (Figure 20) in the summer and at the surface (Figure 21) and at 50m depth (Figure 22) in spring.

Pipeline Construction Scenario 4 Modelling Results

Table 21: Area coverage and average range of contours for Pipeline Construction Scenario 4 (surface received sound levels of pipelaying by *Castoro II* spread along the northern route pipeline in summer.)

Contour level (dB)	Area inside (km^2)	Average range (km)
90	1626	29.4
100	815	18.7
110	353	12.3
120	120	6.5
130	27	2.8
140	4	1.0
150	1	0.5
160	0	0.0

Table 22: Area coverage and average range of contours for Pipeline Construction Scenario 4 (received sound levels at 50 m depth of pipelaying by *Castoro II* spread along the northern route pipeline in summer.)

Contour level (dB)	Area inside (km^2)	Average range (km)
90	1969	33.0
100	983	21.6
110	401	13.3
120	132	6.9
130	29	2.9
140	4	1.1
150	1	0.5
160	0	0.0

Table 23: Area coverage and average range of contours for Pipeline Construction Scenario 4 (received sound levels at bottom depth of pipelaying by *Castoro II* spread along the northern route pipeline in summer.)

Contour level (dB)	Area inside (km^2)	Average range (km)
90	1849	32.1
100	912	20.3
110	392	13.1
120	134	7.0
130	30	3.0
140	4	1.1
150	1	0.5
160	0	0.0

Table 24: Area coverage and average range of contours for Pipeline Construction Scenario 4 (Surface received sound levels of pipelaying by *Castoro II* spread along the northern route pipeline in spring.)

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2166	33.9
100	944	20.9
110	386	12.9
120	129	6.8
130	28	3.0
140	4	1.1
150	1	0.5
160	0	0.0

Table 25: Area coverage and average range of contours for Pipeline Construction Scenario 4 (received sound levels at 50 m depth of pipelaying by *Castoro II* spread along the northern route pipeline in spring)

Contour level (dB)	Area inside (km^2)	Average range (km)
90	4698	62.2
100	1632	30.6
110	511	15.7
120	152	7.6
130	32	3.2
140	5	1.1
150	1	0.5
160	0	0.0

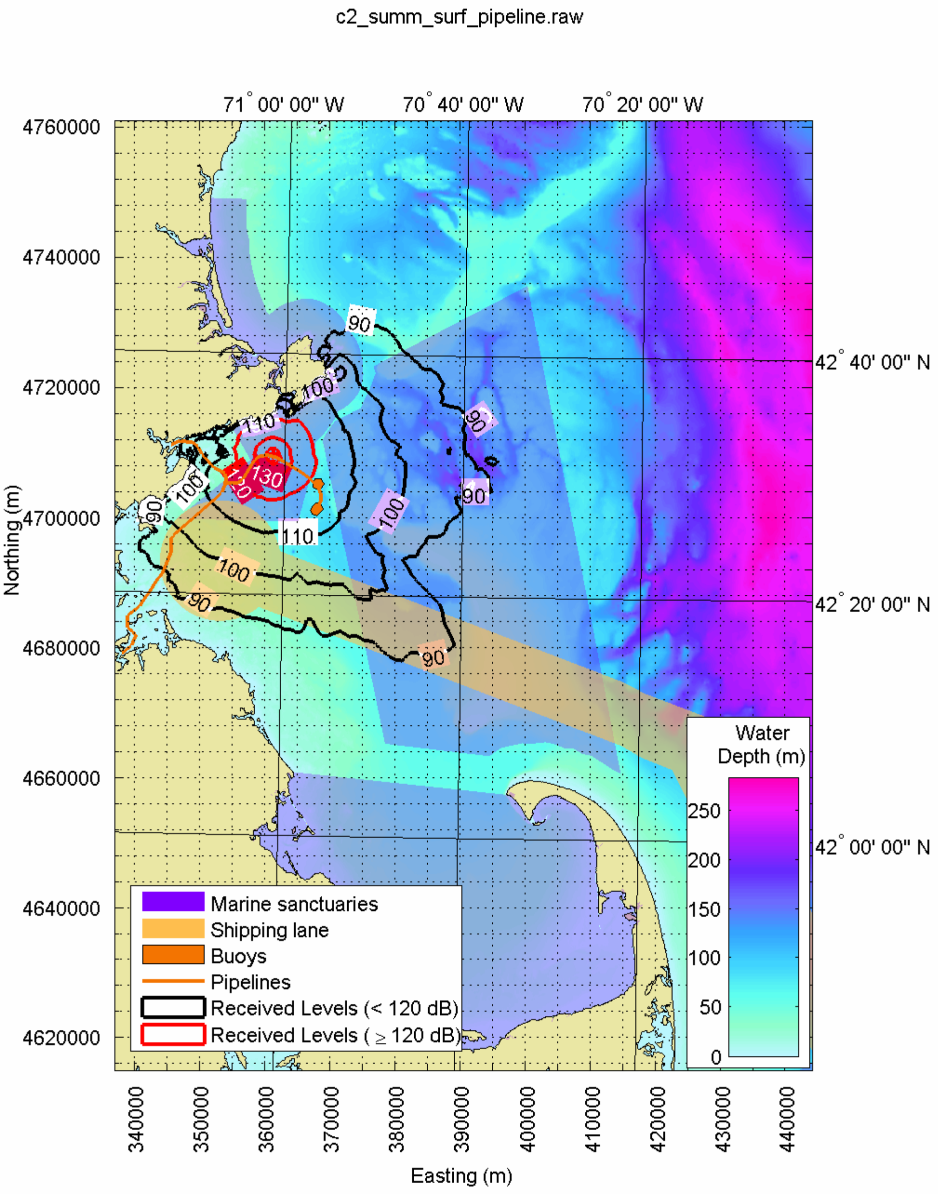

Figure 18: Pipeline Construction Scenario 4 - Surface received sound levels of pipelaying by *Castoro II* spread along the northern route pipeline in summer.

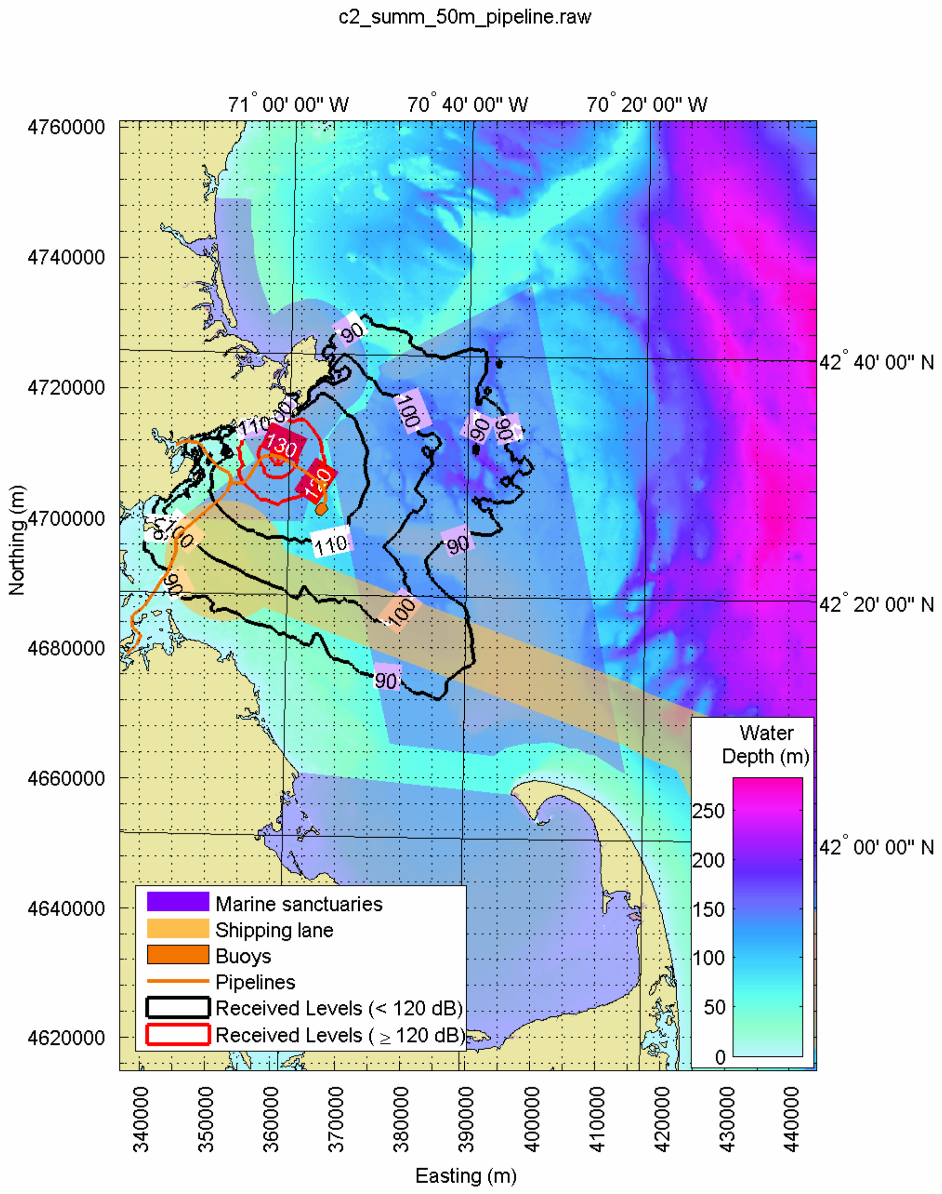

Figure 19: Pipeline Construction Scenario 4 - Received sound levels at 50 m depth of pipelaying by *Castoro II* spread along the northern route pipeline in summer.

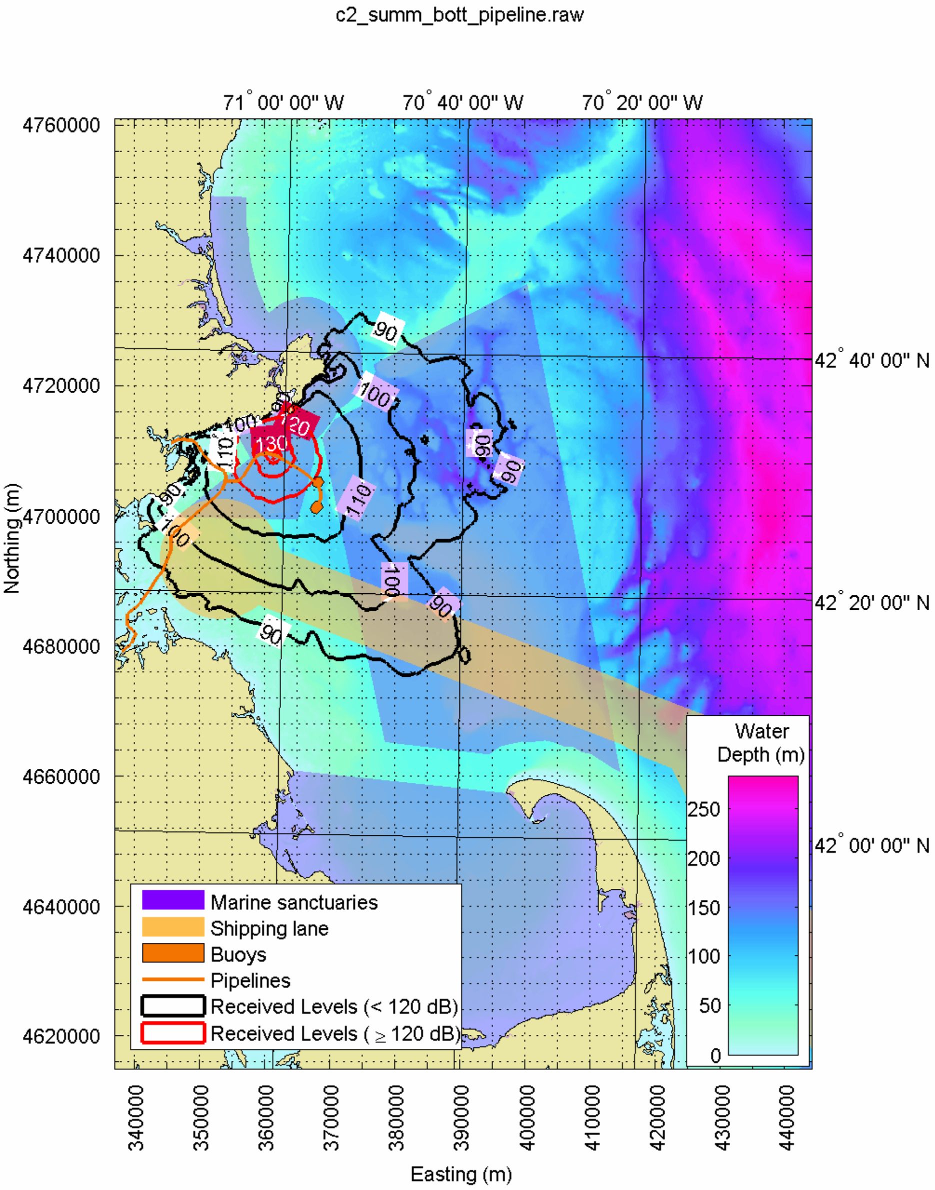

Figure 20: Pipeline Construction Scenario 4 - Received sound levels at bottom depth of pipelaying by *Castoro II* spread along the northern route pipeline in summer.

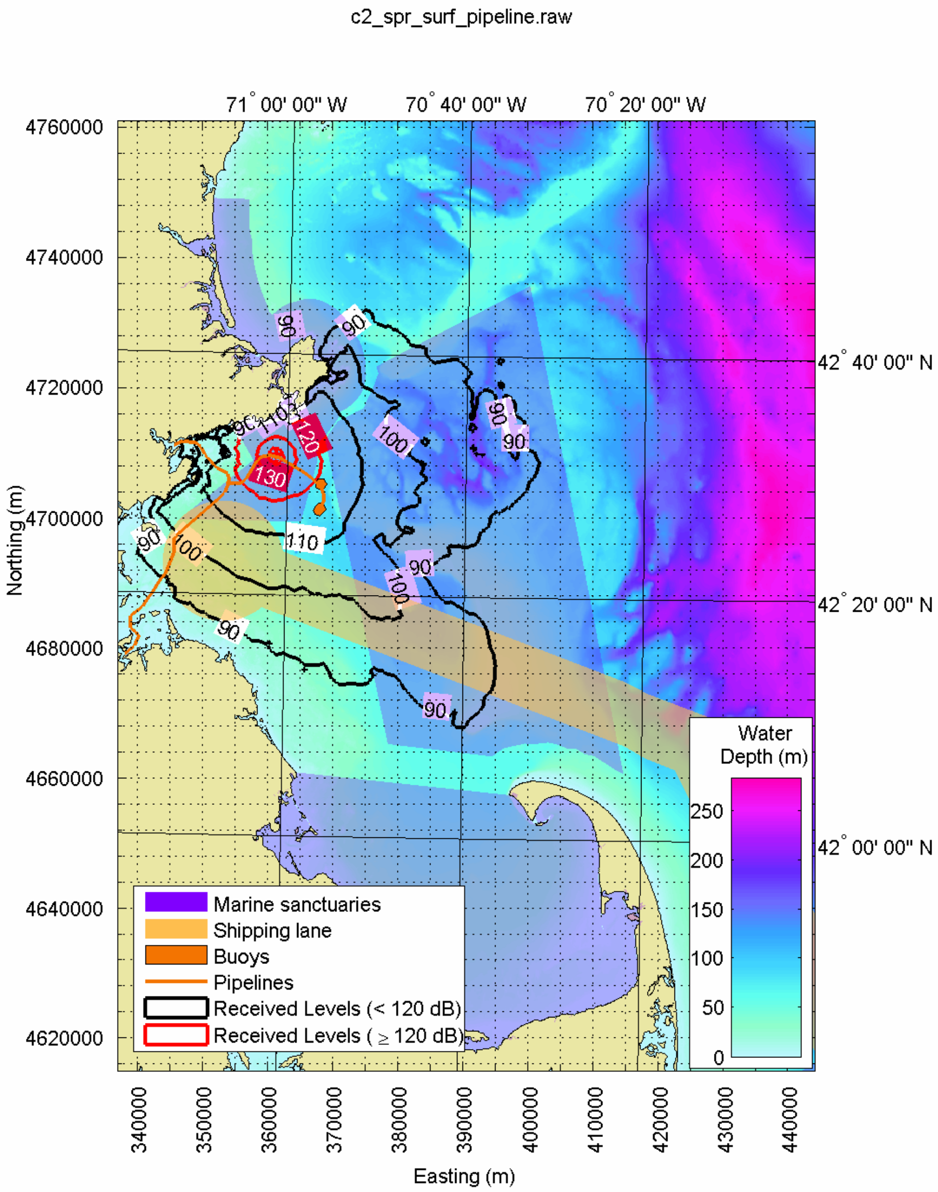

Figure 21: Pipeline Construction Scenario 4 - Surface received sound levels of pipelaying by *Castoro II* spread along the northern route pipeline in spring.

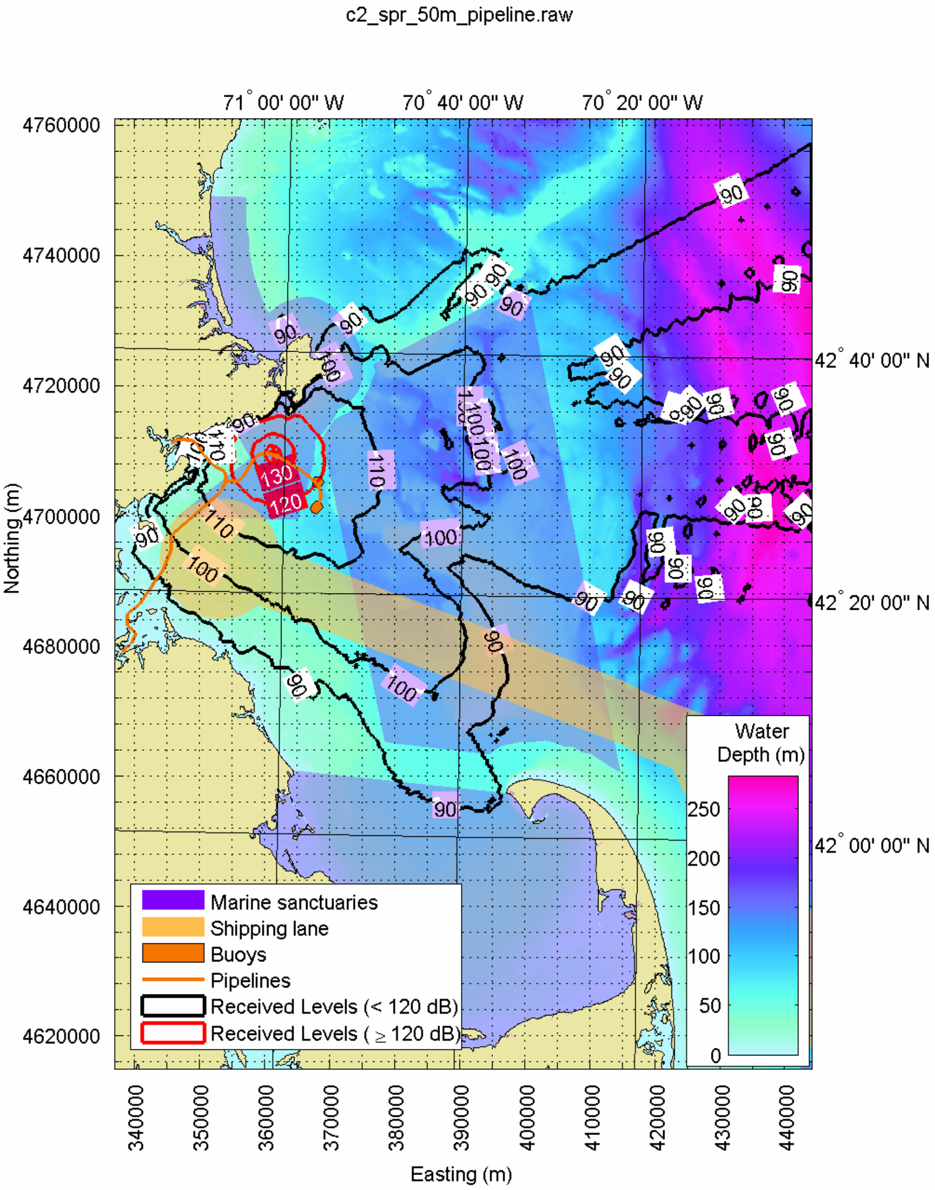

Figure 22: Pipeline Construction Scenario 4- Received sound levels at 50 m depth of pipelaying by *Castoro II* spread along the northern route pipeline in spring.

Decommissioning Scenario (not modeled)

At the end of the economic life of the deepwater port, the subsea valves would be closed, the risers and control umbilicals would be disconnected from the riser manifolds, and the mooring lines would be disconnected from the unloading buoys and from the anchor points. The major components would be removed from the deepwater port site. Removal of the piles would be accomplished by using an ROV to pump water into the top of the caisson until it is fully withdrawn from the seabed.

The pipelines will be decommissioned in place and will include the following actions:

- Closing hot tap valves and plugging the end;
- Pigging and flushing the pipelines;
- Filling the pipelines with seawater;
- Removing the manifolds and tie-in spools;
- Cutting and plugging each end of the pipelines; and
- Burying each end of the pipelines at least 3 feet below the seafloor or cover each end with protective concrete mats.

Noise associated with decommissioning is expected to result primarily from the operation of the vessels required to perform the activities discussed above. Removal of the suction piles is the reverse of the installation procedure and is expected to produce similar noise levels as those discussed in section 0.

OPERATIONAL SCENARIOS

The operational modelling scenarios were run along the northern pipeline route as described in documents dated 23 August 2005 by Suez LNG NA LLC titled “Northern Pipeline Route” and “Terminal Location and Layout Design Changes”. Received levels were modeled at the surface (1 m depth), at 50 m depth, and at the bottom.

LNG Carrier Transit

This scenario modeled noise produced by an LNG vessel during a typical transit to the DWP. The main source of noise was that produced by the main propulsion system and propeller of the LNG carrier. The LNG carrier was located at the midpoint between its transit shipping lane and the buoys. The dedicated support vessel was modeled near the LNG carrier.

LNG Carrier Transit Scenario 1

In this scenario, the model assumed The LNG carrier is expected to transit to the deepwater port (DWP) buoys from the shipping lane just west of the Stellwagen Bank National Marine Sanctuary (SBNMS) along with a supply vessel. Sound levels from the LNG carrier in transit were modeled midway between the shipping lane and south buoy west of SBNMS at 42° 25’ 10.15” N, 70° 36’ 15.93” W. The supply vessel was positioned 300 m west of the LNG carrier.

LNG Carrier Transit Scenario 1 Parameters

Source locations:			***Source depths:***
Overseas Harriette:	Lat: 42° 25’ 10.15” N	Long: 70° 36’ 15.93” W	8 m
Neftegaz 22:	Lat: 42° 25’ 09.97” N	Long: 70° 36’ 29.05” W	3.4 m
Receiver depths:	Surface, 50m, Bottom		
Time of year:	Spring, Summer, Fall, Winter		

LNG Carrier Transit Scenario 1 Modelling Approach

Measurements of underwater noise generated by LNG carriers are not available. However some work has been done to characterize underwater noise from large tankers. Source levels used in the modeling are based either on data from a review of literature or calculated based on empirical formulas.

Large commercial vessels and supertankers have poweful engines and large, slow-turning propellers. These vessels produce high sound levels, mainly at low frequencies. At these frequencies the noise is dominated by propeller cavitation noise combined with dominant tones arising from the propeller blade rate. An empirical expression for the source spectrum level (1 Hz bandwidth) in the frequency range between 100 Hz and 10 kHz is

$$SL = 163 + 10 \text{ Log } BD^4N^3f^{-2} \text{ dB re } 1\ \mu\text{Pa}$$

where B = number of blades, D = propeller diameter in m, N = propeller revolutions/s, and f = frequency in Hz. For ducted propellers, the constant is some 7 dB larger. Table 26 ncludes predicted source levels for a vessel at half speed (45 rpm) using this formula.

Measured source levels from the M/V Overseas Harriette (Arveson and Vendittis 2000) were used as an estimate of the source levels of a large carrier such as the one expected to be used for the Neptune DWP. The Overseas Harriette is a large bulk cargo ship 173 m long powered by a direct-drive low-speed diesel engine and a single 4 blade propeller 4.9 m in diameter. It has a power output of 11,200 hp and a maximum speed of 15.6 knots.

The specifications provided for the LNG carrier are that it is a single propeller 280-m long vessel powered by a geared steam turbine engine with 35,000 hp and a maximum speed of 19.5 knots. The LNG carrier has a 5 blade propeller, 8.6 m in diameter. The Overseas Harriette is therefore less powerful and possibly less loud but the sound level spectrum should be of similar shape with much louder noise at low frequency. The vessel modeled has a peak sound level at 50 Hz. The Overseas Harriette was modeled at its maximum speed to demonstrate a possible worst case scenario. At this transit speed, the carrier would spend about 1.5 hours in the shipping lane through the SBNMS and 0.5 hours traveling from the lane to the buoys. The corresponding 1/3 octave band levels are shown in Table 26.

The support vessel used in the model was the Neftegaz 22 which is a supply tug 81 m long with 7200 hp and a maximum speed of 15 knots. The support vessel expected to be used is about 40 m long with up to 7000 hp and a maximum speed of 13 knots. The broadband source level of Neftegaz 22 operating at full speed is 186.1 dB re 1 µPa at 1m and the 1/3 octave band source levels are also shown in Table 26. The source depth of the support vessel was modeled at 3.4 m.

All four seasons were modeled at the surface and at 50 m depth, since the port is expected to operate year-round. The bottom received levels could not be modeled due to time constraints. The sound levels for both pile driving and pipelaying were louder at 50 m depth than at the surface or bottom in spring, summer and fall. The winter sound speed profile is upward refracting, therefore the received sound levels at the surface are expected to be higher than at the bottom or at 50 m.

Table 26: Modeled 1/3-octave band source levels representing LNG carrier in transit and a support vessel at full speed.

Centre Frequency	*Source Levels* **(dB re 1 μPa-1m)**			
(Hz)	Overseas Harriette (at 16.5 knots)	Modeled carrier (half speed)	Support Vessel (full speed, 15 knots)	Support Vessel (cruising speed)
10	174.1	163.6	183.1	178.7
12.5	174.2	163.6	177.9	176.1
16	175.3	163.6	167.5	170.5
20	177.9	163.6	166.8	175.2
25	179.7	163.6	170.6	165.5
31.5	181.8	163.6	166.1	166.8
40	183.6	163.6	171.9	170.0
50	184.3	163.6	175.7	162.5
63	183.6	163.6	173.1	161.8
80	182.0	163.6	165.9	159.3
100	180.2	163.6	165.7	163.4
125	178.9	161.7	163.4	163.1
160	176.8	159.5	162.0	162.1
200	174.3	157.6	163.1	164.5
250	171.2	155.7	165.0	166.5
315	168.9	153.7	164.4	173.3
400	168.1	151.6	164.0	167.4
500	167.5	149.6	161.4	160.7
630	166.9	147.6	166.1	163.7
800	166.2	145.6	165.9	158.0
1000	165.8	143.6	159.8	160.8
1250	165.1	141.7	160.5	159.9
1600	164.2	139.5	167.2	162.8
2000	163.3	137.6	163.3	162.0
Broadband	192.0	174.7	186.1	183.6

LNG Carrier Transit Scenario 1 Modelling results

The model results are presented in 10 dB contour intervals surrounding the sound sources (Figure 23 to Figure 34). Table 27 to Table 33 provide the area coverage within each contour interval and the average range to each 10 dB level. These tables, along with g. Figure 23 to Figure 29, present the worst case results at full speed 16 knots transit.

Table 27: Area coverage and average range of 16 knots carrier transit scenario 1 sound levels received at the surface (1 m depth) during the spring

Contour level (dB)	Area inside (km^2)	Average range (km)
90	3132	34.7
100	1609	23.7
110	612	14.6
120	205	8.7
130	44	4.1
140	5	1.5
150	1	0.6
160	0	0.0

Table 28: Area coverage and average range of 16 knots carrier transit scenario 1 sound levels received at 50 m depth during the spring

Contour level (dB)	Area inside (km^2)	Average range (km)
90	4289	53.8
100	2010	28.0
110	798	18.5
120	227	9.0
130	42	4.0
140	4	1.4
150	1	0.6
160	0	0.0

Table 29: Area coverage and average range of 16 knots carrier transit scenario 1 sound levels received at the surface (1 m depth) during the summer

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2470	28.8
100	1159	21.5
110	466	12.8
120	164	7.7
130	38	3.9
140	5	1.4
150	1	0.6
160	0	0.0

Table 30: Area coverage and average range of 16 knots carrier transit scenario 1 sound levels received at 50 m depth during the summer

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2636	30.8
100	1269	22.3
110	516	13.6
120	162	7.5
130	35	3.7
140	4	1.3
150	0	0.0

Table 31: Area coverage and average range of 16 knots carrier transit scenario 1 sound levels received at the surface (1 m depth) during the fall

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2920	32.7
100	1409	23.2
110	553	13.9
120	183	8.1
130	41	4.0
140	5	1.5
150	1	0.6
160	0	0.0

Table 32: Area coverage and average range of 16 knots carrier transit scenario 1 sound levels received at 50 m depth during the fall

Contour level (dB)	Area inside (km^2)	Average range (km)
90	3400	37.5
100	1672	25.6
110	698	16.4
120	199	8.3
130	39	3.8
140	4	1.4
150	1	0.6
160	0	0.0

Table 33: Area coverage and average range of 16 knots speed carrier transit scenario 1 sound levels received at the surface (1 m depth) during the winter

Contour level (dB)	Area inside (km^2)	Average range (km)
90	7196	62.7
100	2485	28.0
110	780	17.2
120	230	9.3
130	47	4.3
140	5	1.5
150	1	0.6
160	0	0.0

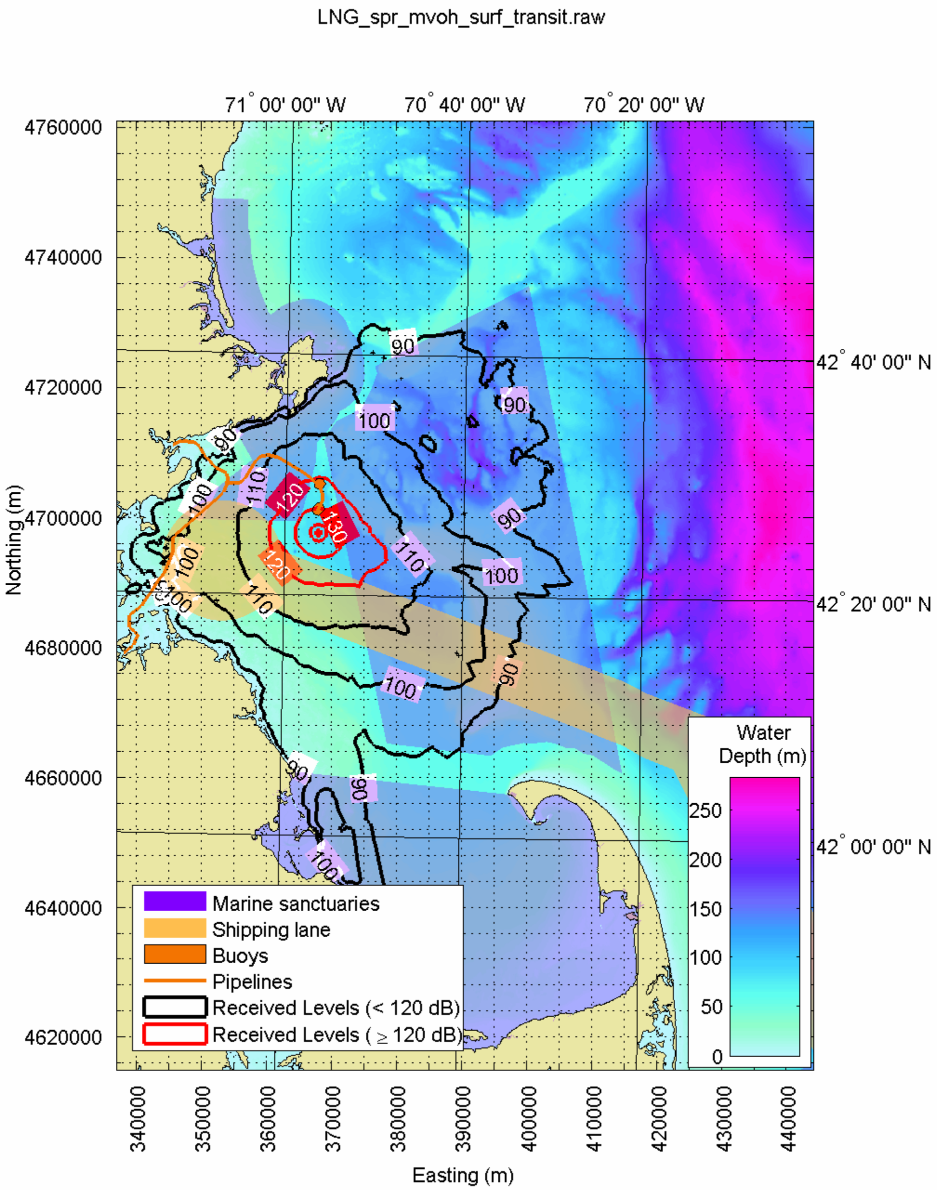

Figure 23: Carrier transit scenario 1 at 16 knots sound levels received at the surface (1m) in the spring for LNG carrier and supply ship located between the shipping lane and south buoy

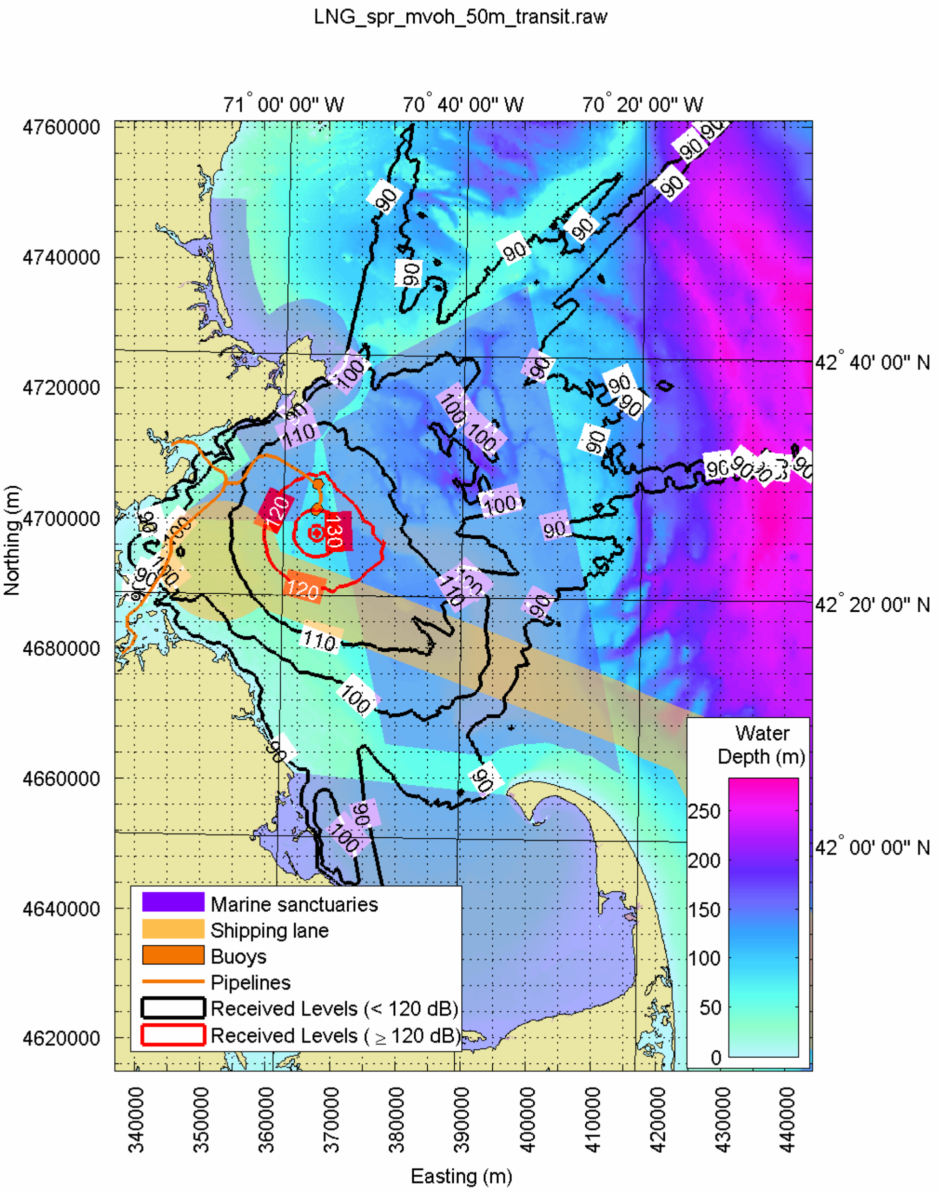

Figure 24: Carrier transit scenario 1 at 16 knots sound levels received at 50 m depth in the spring for LNG carrier and supply ship located between the shipping lane and south buoy

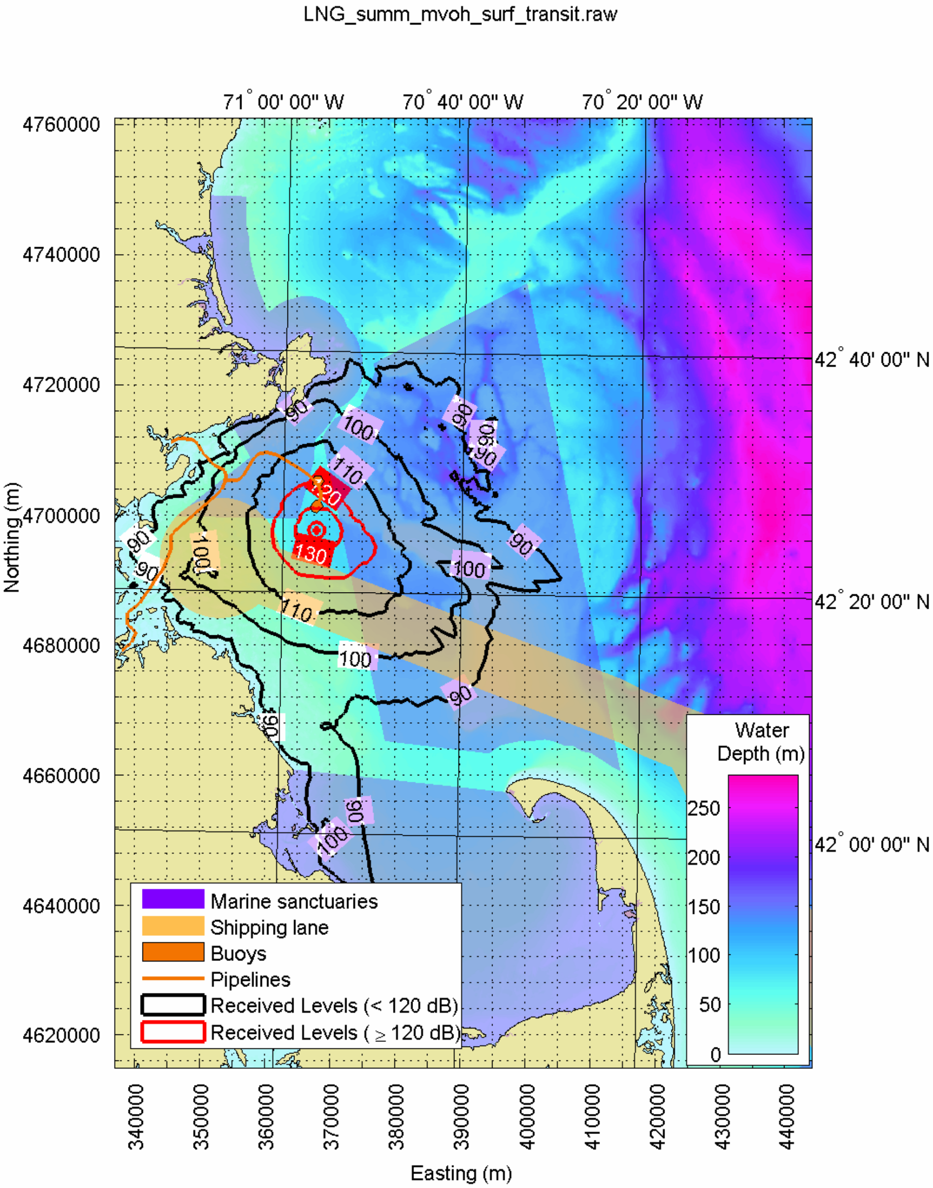

Figure 25: Carrier transit scenario 1 at 16 knots sound levels received at the surface (1 m depth) the summer for LNG carrier and supply ship located between the shipping lane and south buoy

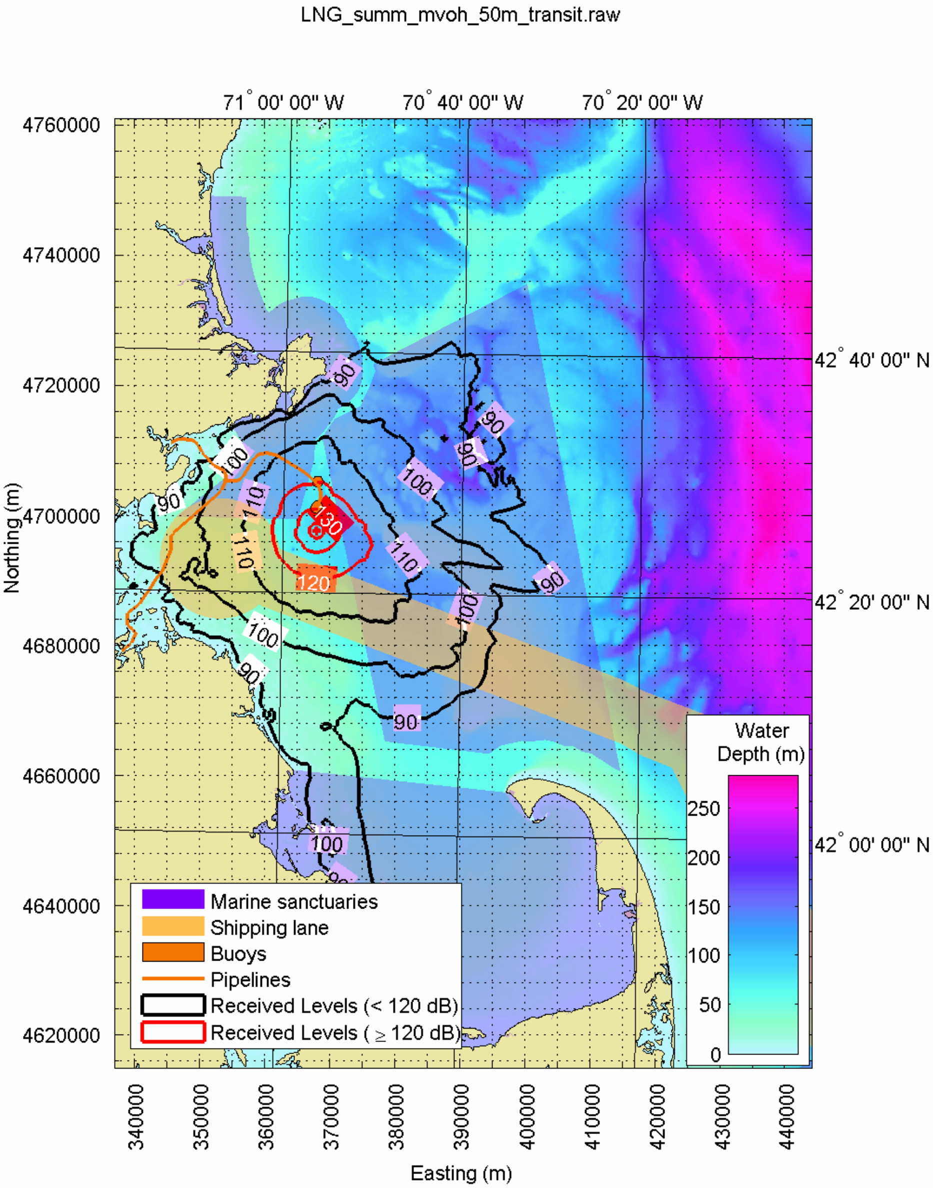

Figure 26: Carrier transit scenario 1 at 16 knots sound levels received at 50 m depth in the summer for LNG carrier and supply ship located between the shipping lane and south buoy

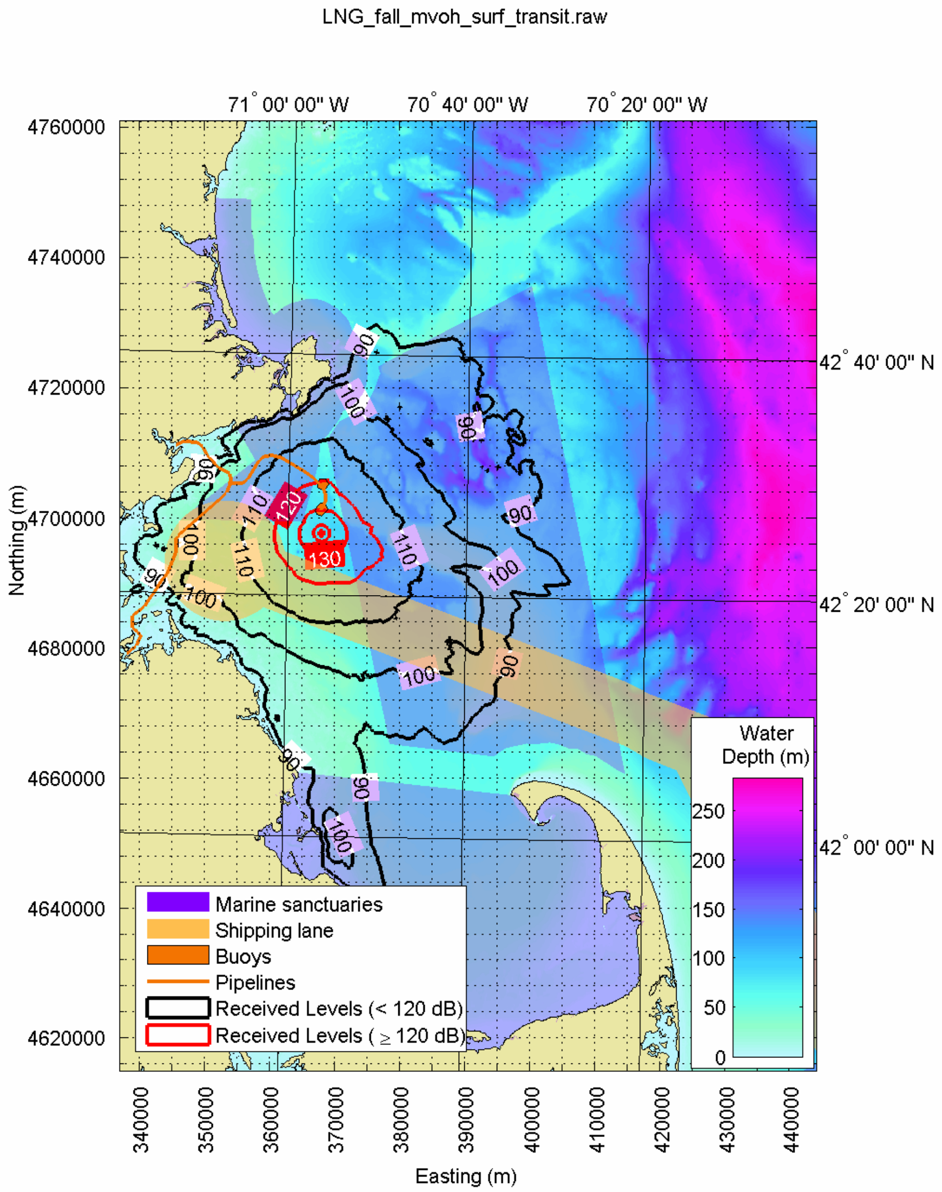

Figure 27: Carrier transit scenario 1 at 16 knots sound levels received at the surface (1m) in the fall for LNG carrier and supply ship located between the shipping lane and south buoy

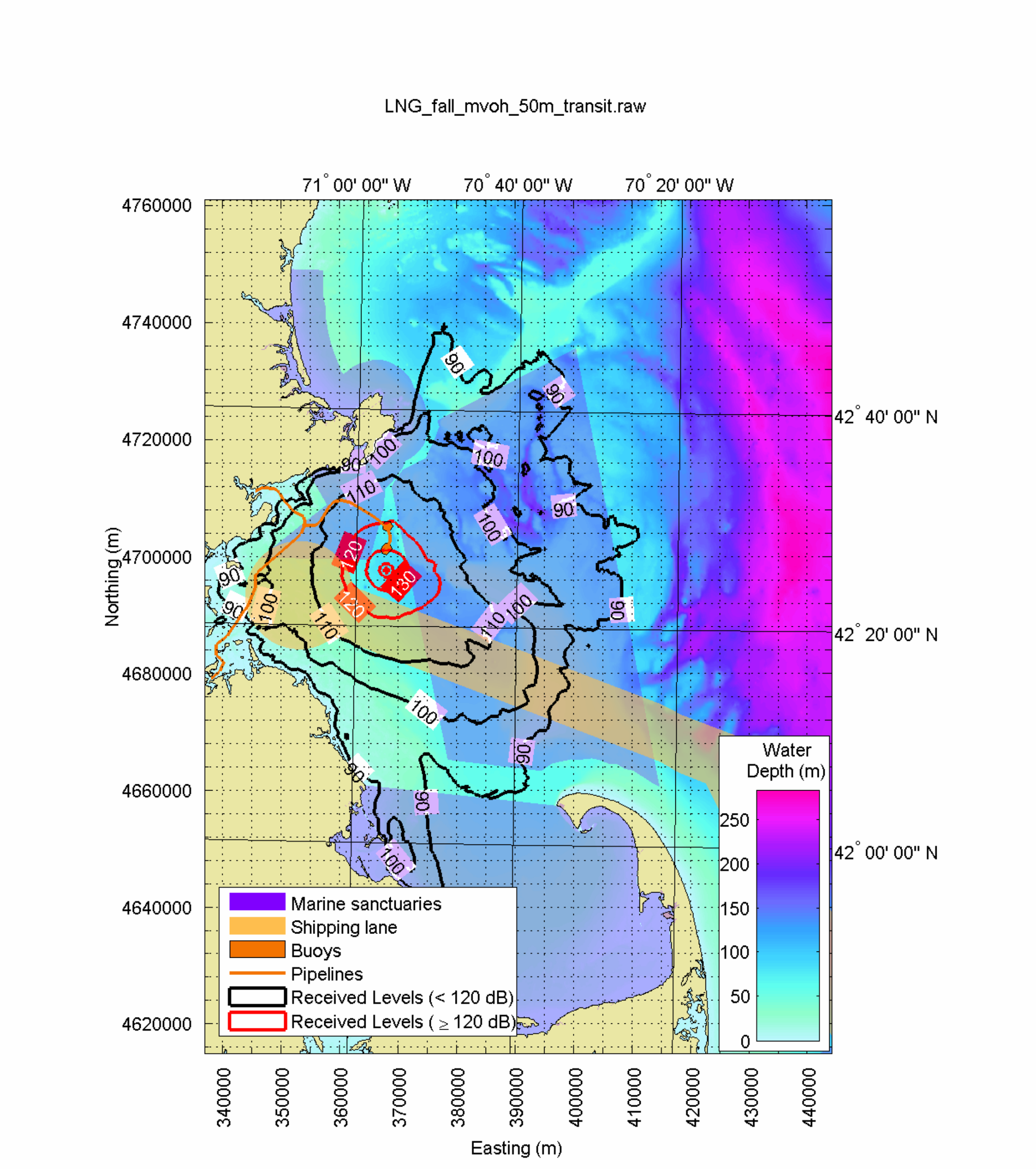

Figure 28: Carrier transit scenario 1 at 16 knots sound levels received at 50 m depth in the fall for LNG carrier and supply ship located between the shipping lane and south buoy

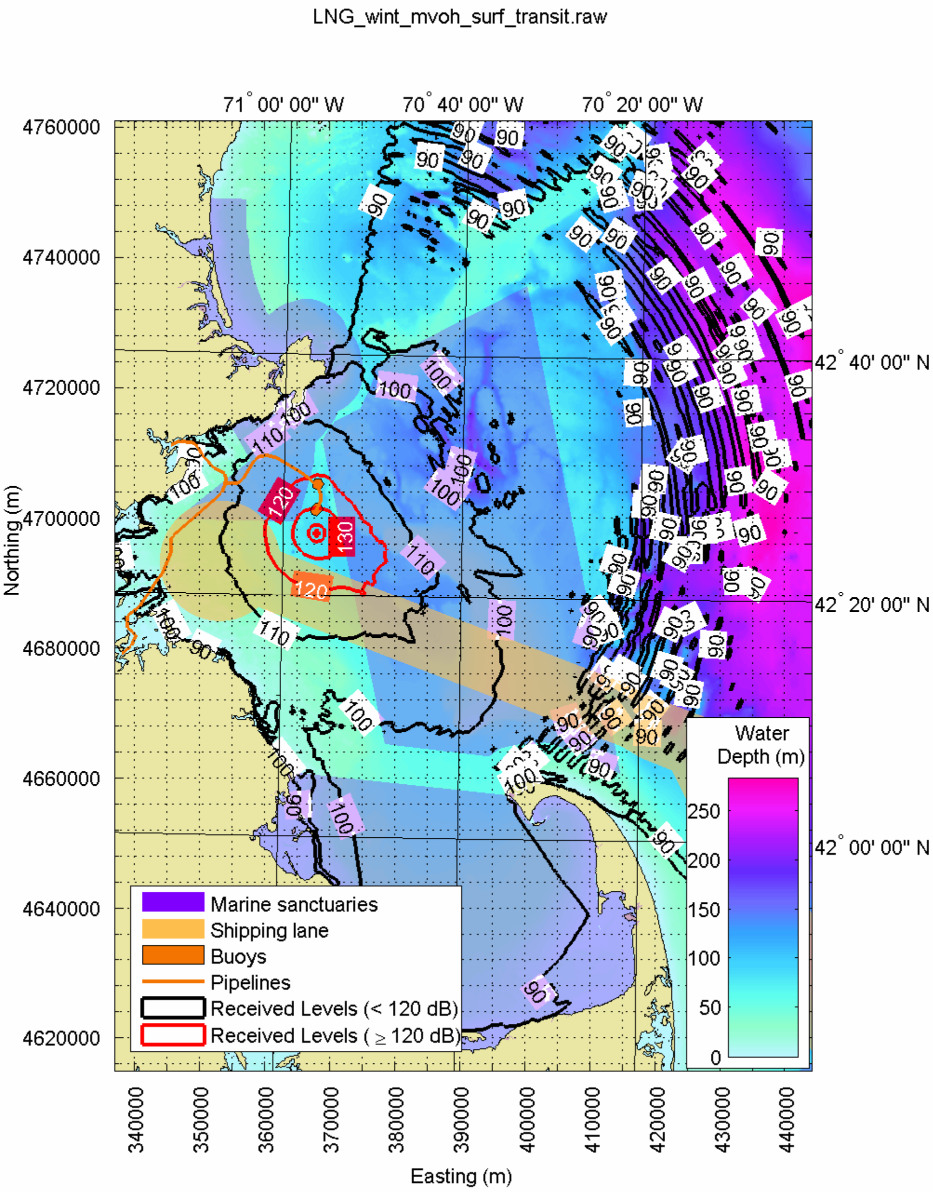

Figure 29: Carrier transit scenario 1 at 16 knots sound levels received at the surface (1m) in the winter for LNG carrier and supply ship located between the shipping lane and south buoy

LNG Carrier Transit Scenario 2

A second scenario of LNG carrier transit was modeled using source levels calculated based on the LNG carrier propeller specifications and running at half speed, expected to be around 8-10 knots.

LNG Carrier Transit Scenario 2 Parameters

Source locations:			***Source depths:***
Modeled LNG carrier	Lat: 42° 25' 10.15" N	Long: 70° 36' 15.93" W	8 m
Neftegaz 22	Lat: 42° 25' 09.97" N	Long: 70° 36' 29.05" W	3.4 m

Receiver depths: Surface, 50m, Bottom
Time of year: Spring, Summer, Winter Fall

LNG Carrier Transit Scenario 2 Modelling Approach

The slower speed assumed in the scenario may be more representative of the speed of the carrier through and near the marine sanctuaries. The support vessel *Neftegaz 22* was also modeled at cruising speed. At this transit speed, the carrier would spend about 3 hours in the shipping lane through the SBNMS and 1 hour traveling from the lane to the buoys. The 1/3-octave band levels are shown above in Table 26. Only the water depth expected to have the loudest received levels was modeled in each season.

The slower speed transit results at half speed (45 rpm, 8-10 knots) are presented in Figure 30 to Figure 33 and Table 34 to Table 37. The average range was calculated in a sector originating at the mean source location and bounded by Cape Ann to the north, and Cape Cod to the south, to avoid interference by the coastline.

LNG Carrier Transit Scenario 2 Modelling results

For the full speed carrier and support vessel scenario, the 120 dB sound levels traveled the farthest in the spring and winter models. Sound levels in the summer were lower than in the other seasons. The 120 dB contour extended to an average distance of 9.0 km in spring, to 7.7 km in summer, to 8.3 km in the fall, and 9.3 km in the winter. The maximum area coverage of the 120 dB sound level for each season ranged from 164 to 230 km^2.

At the slower transit speed, the 120 dB contours range significantly shorter distances than at high speed. The average range of the 120 dB contour was 2.4 to 2.8 km in any season at the depths modeled. The area coverage was 18 to 25 km^2.

Table 34: Area coverage and average range of half speed (45 rpm, 8-10 knots) speed carrier transit scenario 2 sound levels received at 50 m depth during the spring

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2171	27.1
100	788	18.7
110	193	7.9
120	25	2.8
130	2	0.6
140	0	0.0

Table 35: Area coverage and average range of half speed (45 rpm, 8-10 knots) speed carrier transit scenario 2 sound levels received at 50 m depth during the summer

Contour level (dB)	Area inside (km^2)	Average range (km)
90	1493	23.0
100	523	15.8
110	130	6.5
120	19	2.4
130	1	0.6
140	0	0.0

Table 36: Area coverage and average range of half speed (45 rpm, 8-10 knots) speed carrier transit scenario 2 sound levels received at 50 m depth during the fall

Contour level (dB)	Area inside (km^2)	Average range (km)
90	1910	25.9
100	710	17.8
110	173	7.5
120	23	2.6
130	2	0.6
140	0	0.0

Table 37: Area coverage and average range of half speed (45 rpm, 8-10 knots) speed carrier transit scenario 2 sound levels received at the surface during the winter

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2883	28.9
100	789	16.6
110	145	6.9
120	18	2.4
130	1	0.6
140	0	0.0

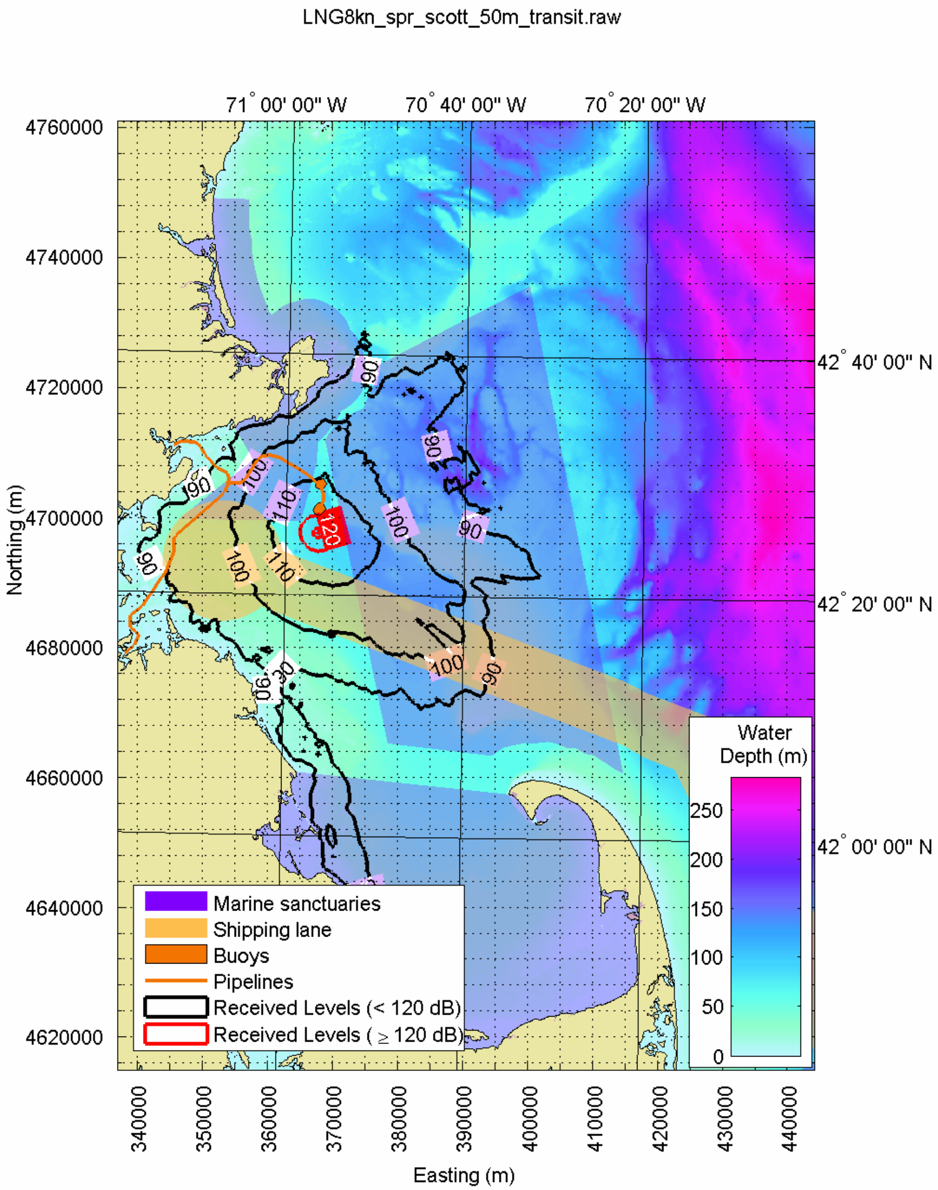

Figure 30: Carrier transit scenario 2 at half speed (45 rpm, 8-10 knots) sound levels received at 50 m depth in the spring for LNG carrier and supply ship located between the shipping lane and south buoy

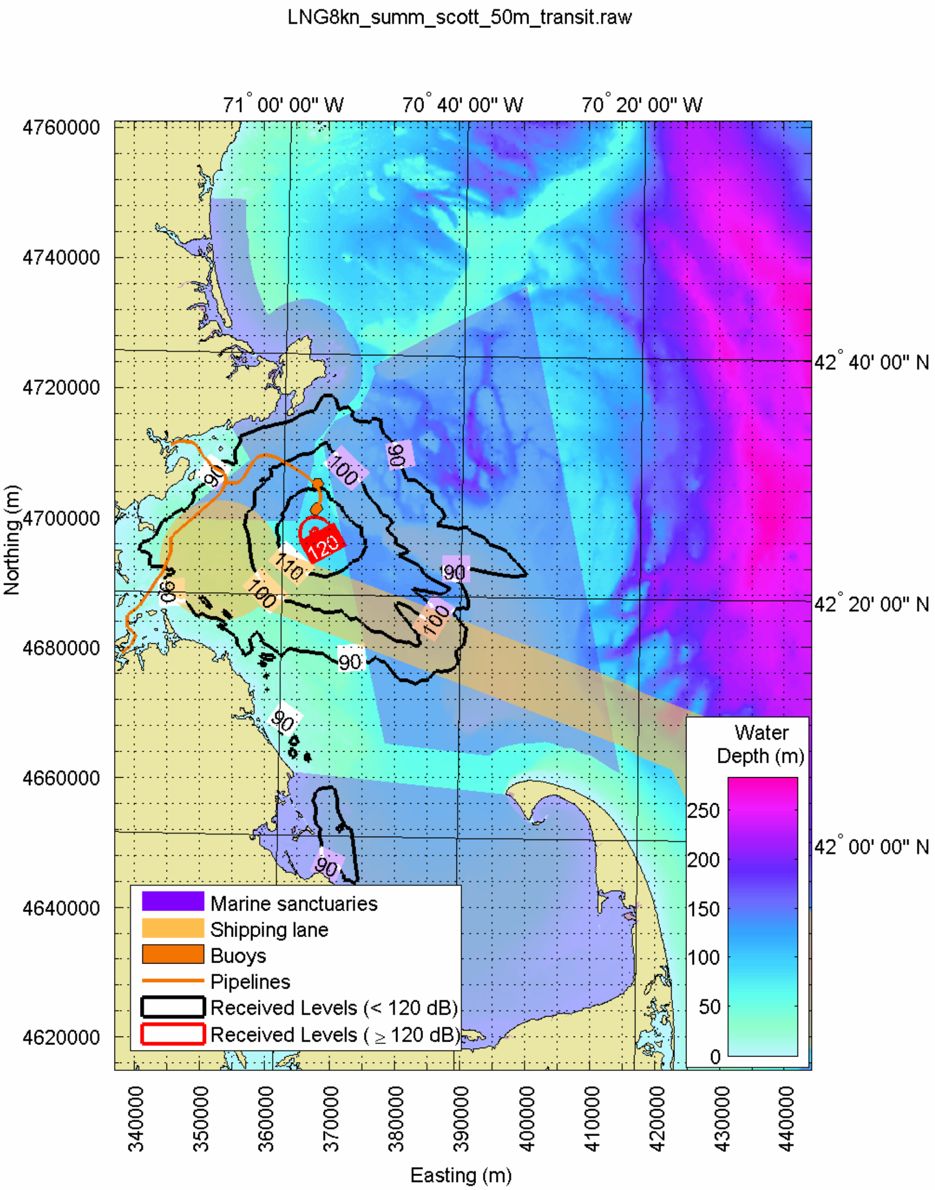

Figure 31: Carrier transit scenario 2 at half speed (45 rpm, 8-10 knots) sound levels received at 50 m depth in the summer for LNG carrier and supply ship located between the shipping lane and south buoy

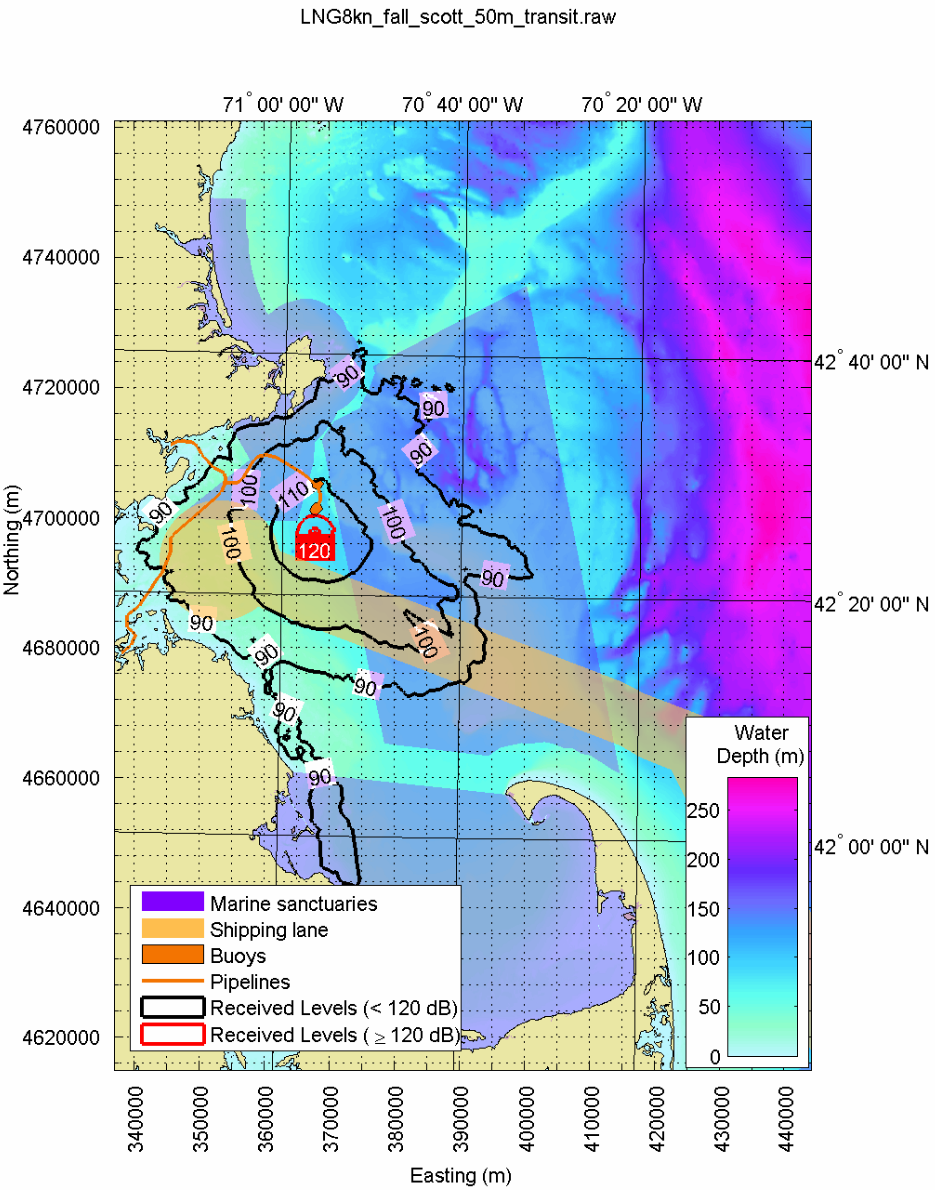

Figure 32: Carrier transit scenario 2 at half speed (45 rpm, 8-10 knots) sound levels received at 50 m depth in the fall for LNG carrier and supply ship located between the shipping lane and south buoy

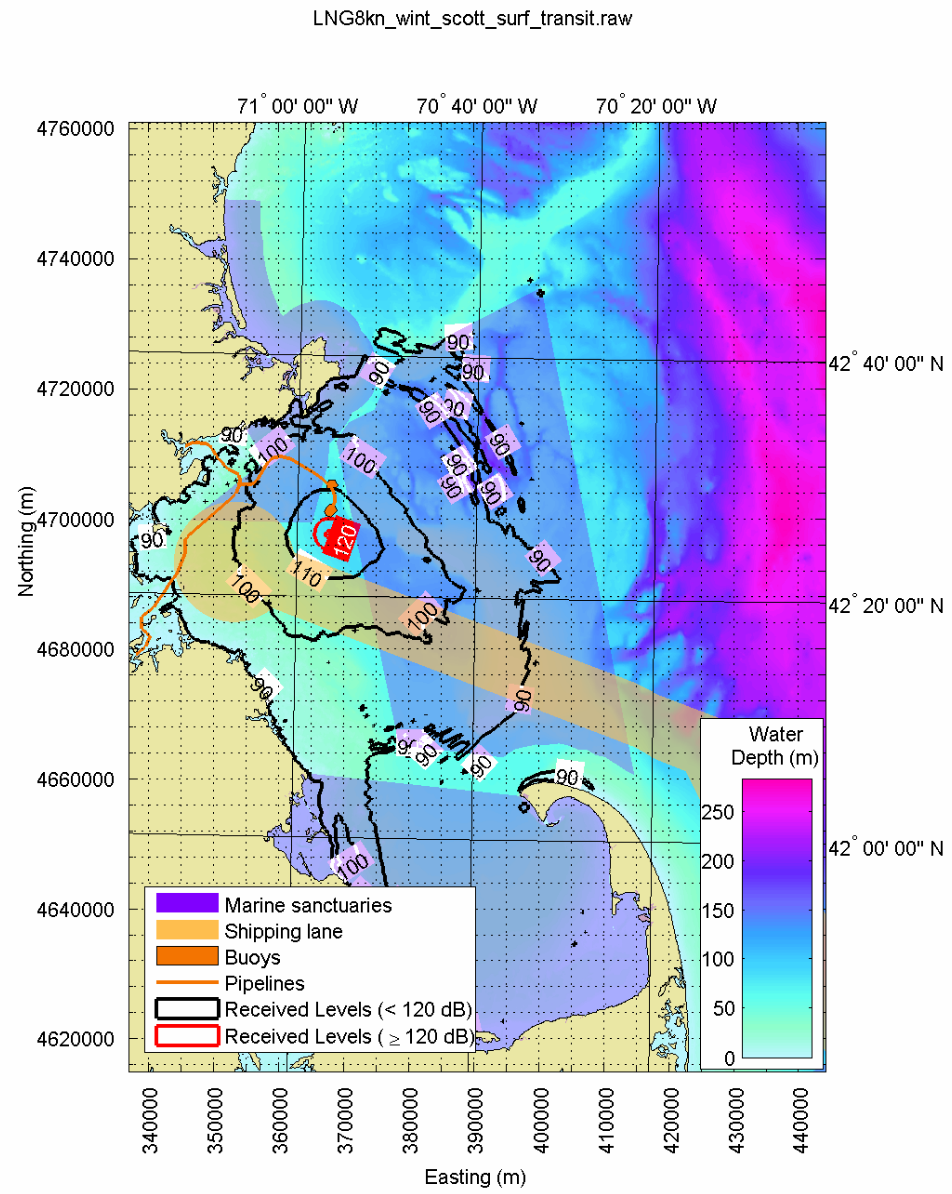

Figure 33: Carrier transit scenario 2 at half speed (45 rpm, 8-10 knots) sound levels received at the surface in the winter for LNG carrier and supply ship located between the shipping lane and south buoy

LNG Carrier Approach and Mooring (Dynamic Positioning)

Dynamically positioned LNG carriers were modeled at both the south and north buoys, and consisted of two bow thrusters and one stern thruster operating simultaneously. Thruster source levels were based on calculations from propeller specifications. The bow thrusters are 2200 kW each with maximum 880 rpm. The stern thruster is 1250 kW with maximum 1160 rpm. The source depth was modeled at 8 m. The broadband source level of the bow thrusters modeled was 201.1 dB re 1 µPa at 1m and the stern thruster was 197.2 dB re 1 µPa at 1m. Each LNG carrier is expected to be moored at the buoy for 4 to 8 days (E&E 2004) and it was estimated that the thrusters would be operating for about 10 to 30 minutes to position the vessel at the buoy. The thrusters should not be needed to leave the buoy. The corresponding 1/3 octave band levels are shown in Table 38 for both bow and stern thrusters.

The port is expected to operate year-round. The spring and summer scenarios were modeled at all three depths. The fall scenario was modeled at 50-m depth and bottom depth. The winter scenario was modeled at the surface and bottom. The two missing scenarios, fall at the surface and winter at 50 m, could not be completed within the project deadline.

Table 38: Modeled 1/3-octave band source levels representing LNG carrier dynamic positioning at the deepwater port.

Centre Frequency	*Source Level(dB re 1 µPa@1m)*	
(Hz)	*Two Bow Thrusters*	*Stern Thruster*
31.5	192.2	188.3
40	192.2	188.3
50	192.2	188.3
63	192.2	188.3
80	192.2	188.3
100	192.2	188.3
125	190.3	186.4
160	188.1	184.2
200	186.2	182.3
250	184.2	180.3
315	182.2	178.3
400	180.2	176.3
500	178.2	174.3
630	176.2	172.3
800	174.1	170.2
1000	172.2	168.3
1250	170.3	166.4
1600	168.1	164.2
2000	166.2	162.3
Broadband	201.1	197.2

Dynamic Positioning Scenario 1: South Buoy

Dynamic Positioning Parameters Scenario 1: South Buoy

Source location:	Lat: 42° 27' 05.93" N
	Long: 70° 36' 22.52" W
Source depth:	8 m
Receiver depths:	Surface, 50m, Bottom
Time of year	Spring, Summer, Winter, Fall

Dynamic Positioning Modelling Results Scenario 1: South Buoy

The model results are presented in 10 dB contour intervals surrounding the sound sources (Figure 34 to Figure 43). The area coverage within each contour interval and the average range to each 10 dB level are provided in Table 49 to Table 60. The average range was calculated in a sector originating at the mean source location and bounded by Cape Ann to the north, and Cape Cod to the south, to avoid interference by the coastline.

In the spring, the modeled 120 dB sound levels reach the farthest at 50 m depth (19.7 km) and covers the largest area (942 km^2). The 120 dB sound level in the summer reaches a similar distance of about 15 km at the 50 m depth and bottom. The received sound levels are lower in the summer than in the spring. In the fall, the 120 dB contour reaches 17.8 km at 50 m depth and 16.2 km at the bottom. In the winter, the 120 dB sound levels extend to an average of 16.9 km at the surface and 22.2 km at the bottom.

Table 39: Area coverage and average range of dynamic positioning sound levels received at the surface (1 m depth) during the spring at the south buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	4235	52.3
100	2627	36.7
110	1500	25.6
120	640	15.2
130	210	9.1
140	47	4.7
150	6	3.7
160	1	3.6

Table 40: Area coverage and average range of dynamic positioning sound levels received at 50 m depth during the spring at the south buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	8444	63.8
100	5106	60.5
110	2214	34.6
120	942	19.7
130	274	10.4
140	49	4.9
150	5	3.7
160	1	3.6

Table 41: Area coverage and average range of dynamic positioning sound levels received at bottom depth during the spring at the south buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	3128	47.3
100	2895	38.2
110	1840	26.9
120	814	16.3
130	280	9.8
140	62	4.9
150	7	2.3
160	1	2.0

Table 42: Area coverage and average range of dynamic positioning sound levels received at the surface (1 m depth) during the summer at the south buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2918	41.8
100	1940	30.0
110	1069	20.9
120	486	13.7
130	169	8.3
140	40	4.5
150	5	3.7
160	1	3.6

Table 43: Area coverage and average range of dynamic positioning sound levels received at 50 m depth during the summer at the south buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	3692	49.9
100	2325	35.3
110	1356	25.2
120	583	14.9
130	180	8.7
140	40	4.5
150	5	3.7
160	1	3.6

Table 44: Area coverage and average range of dynamic positioning sound levels received at bottom depth during the summer at the south buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2878	40.0
100	2109	30.7
110	1260	23.7
120	592	14.5
130	215	8.6
140	51	4.5
150	7	2.3
160	1	2.0

Table 45: Area coverage and average range of dynamic positioning sound levels received at 50 m depth during the fall at the south buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	5427	59.8
100	3391	44.9
110	1866	29.6
120	827	10.017.8
130	245	10.0
140	45	4.7
150	5	3.7
160	1	3.6

Table 46: Area coverage and average range of dynamic positioning sound levels received at bottom depth during the fall at the south buoy at the south buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	3115	47.4
100	2649	35.6
110	1728	26.3
120	765	16.2
130	253	9.2
140	56	4.7
150	7	2.3
160	1	2.0

Table 47: Area coverage and average range of dynamic positioning sound levels received at the surface (1 m depth) during the winter at the south buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	10331	72.7
100	5028	51.8
110	2081	28.7
120	810	26.9
130	237	9.0
140	49	4.7
150	6	3.6
160	1	3.6

Table 48: Area coverage and average range of dynamic positioning sound levels received at bottom depth during the winter at the south buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	1098	53.5
100	678	46.6
110	2154	30.4
120	1117	22.2
130	317	10.7
140	66	5.0
150	8	2.3
160	1	2.0

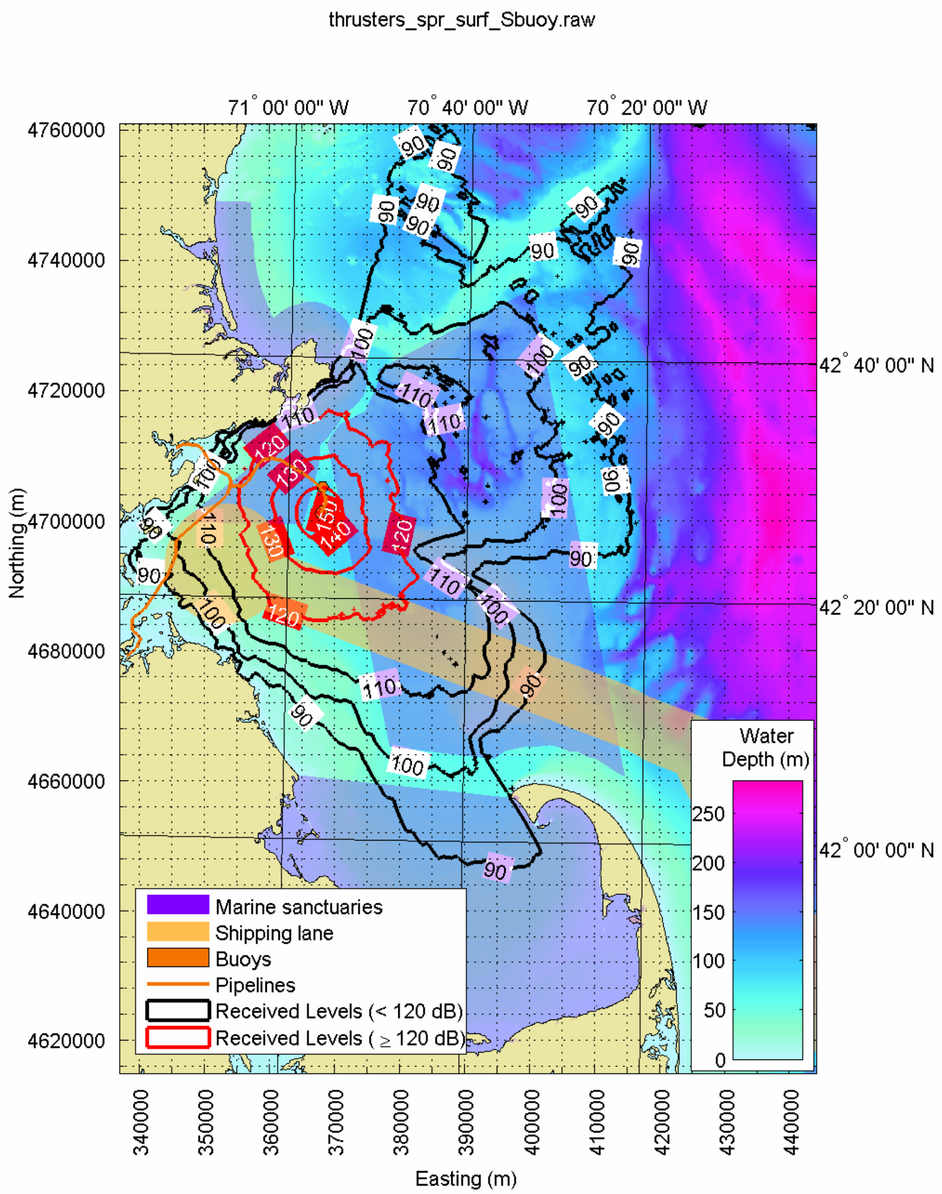

Figure 34: Dynamic positioning sound levels received at the surface (1 m depth) in the spring for LNG carrier at the south buoy.

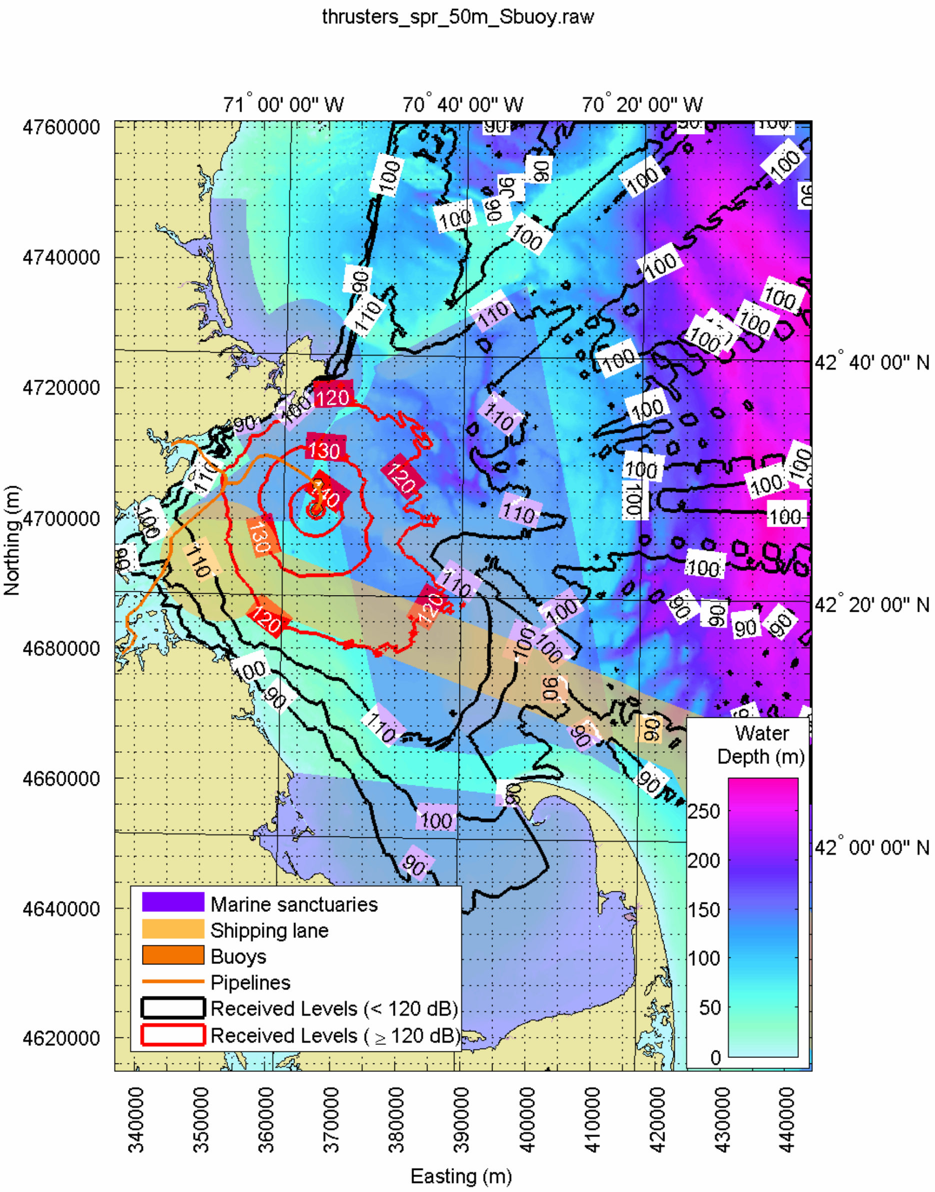

Figure 35: Dynamic positioning sound levels received at 50 m depth in the spring for LNG carrier at the south buoy.

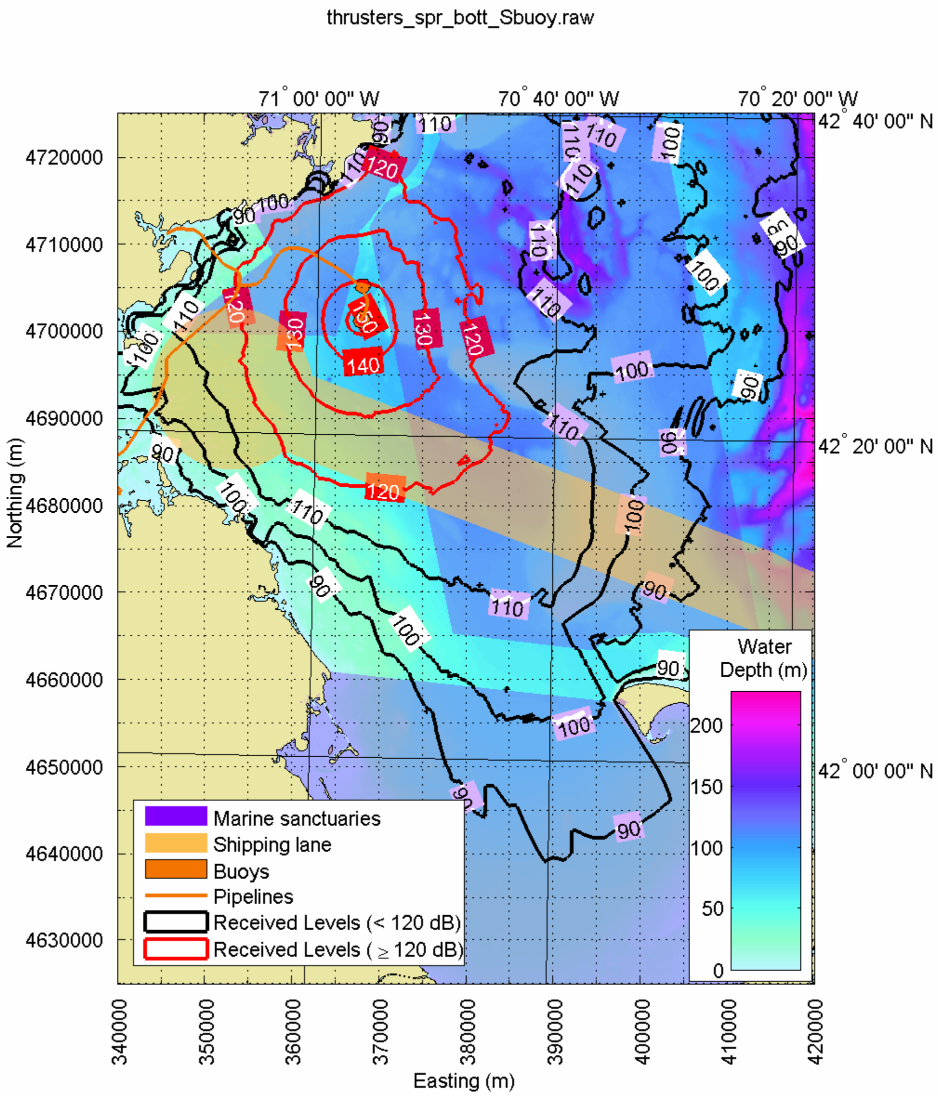

Figure 36. Dynamic positioning sound levels received at bottom depth in the spring for LNG carrier at the south buoy.

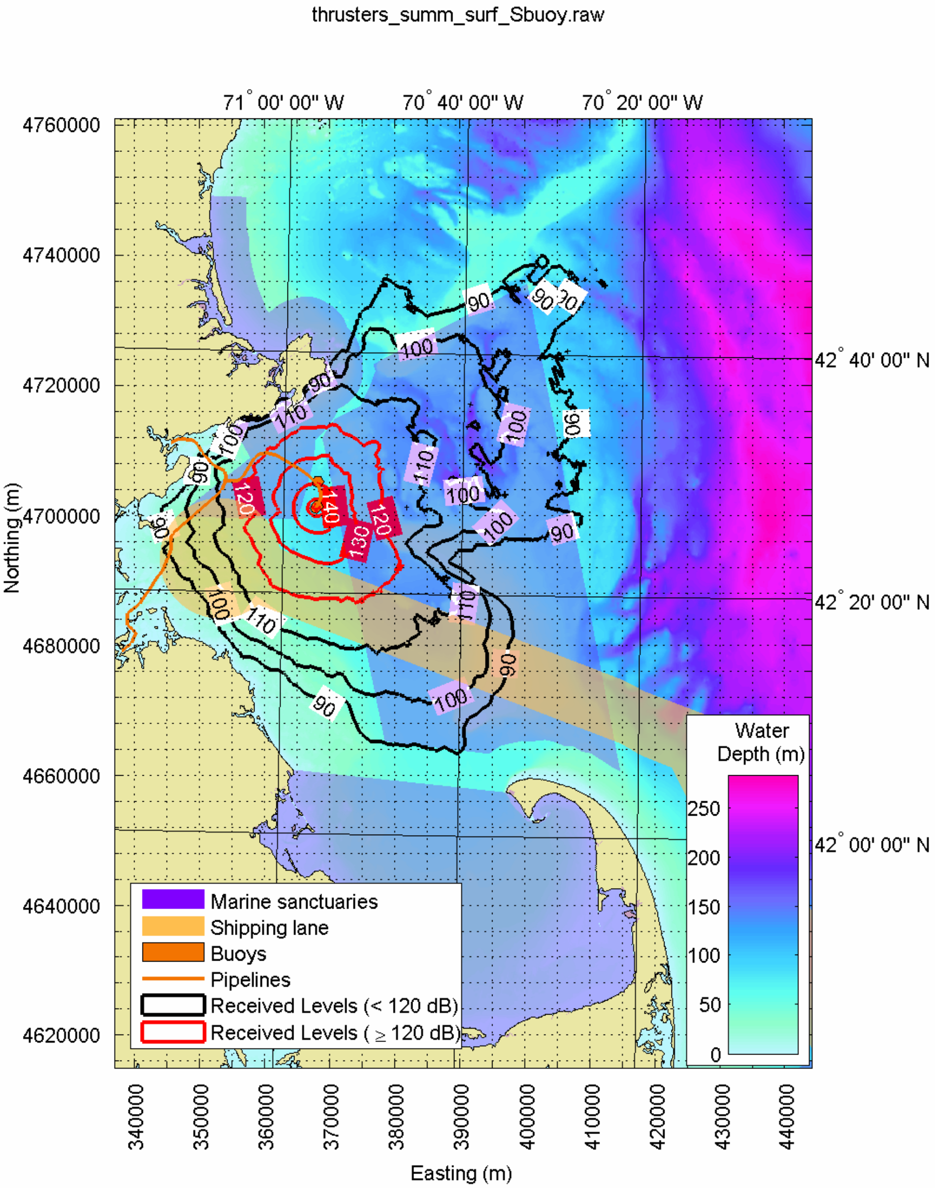

Figure 37: Dynamic positioning sound levels received at the surface (1 m depth) in the summer for LNG carrier at the south buoy.

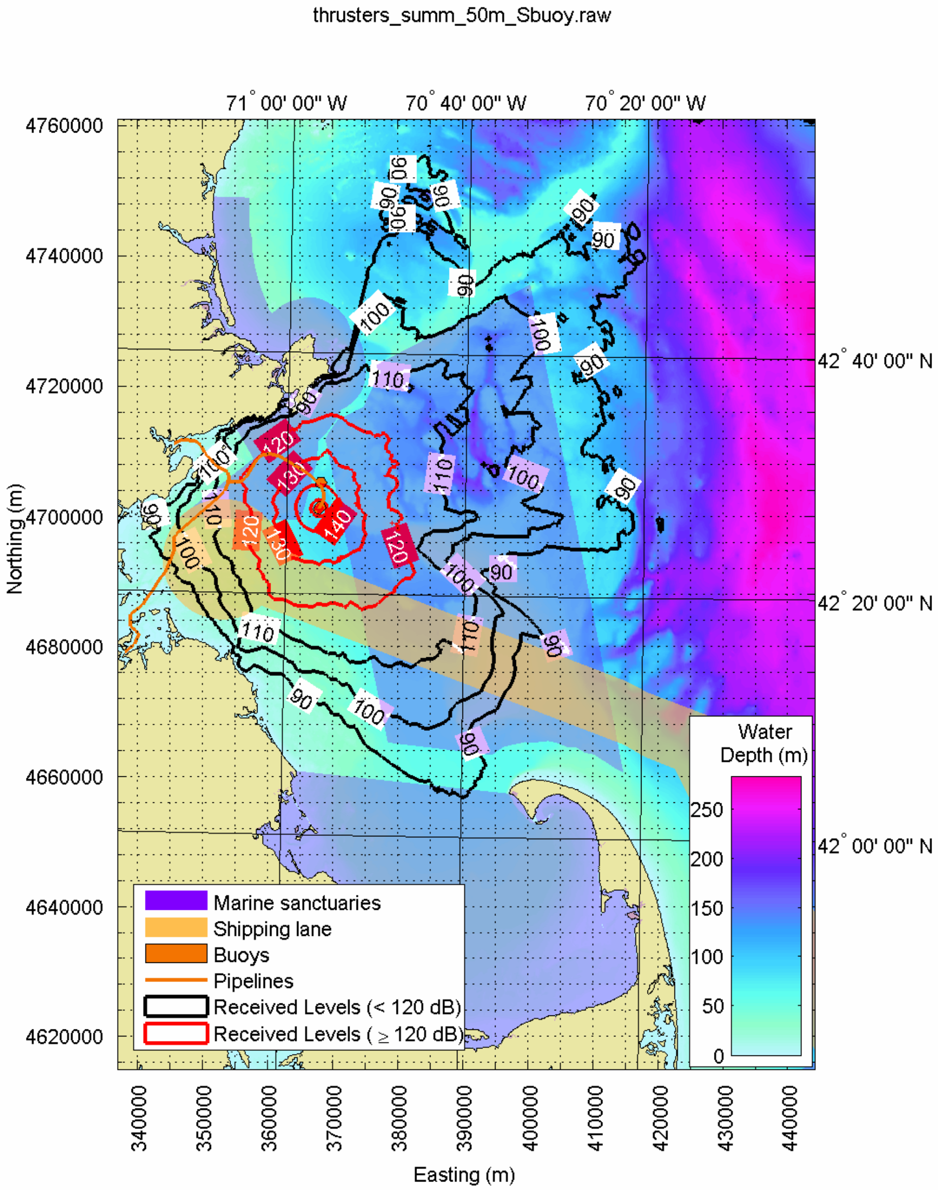

Figure 38: Dynamic positioning sound levels received at 50 m depth in the summer for LNG carrier at the south buoy.

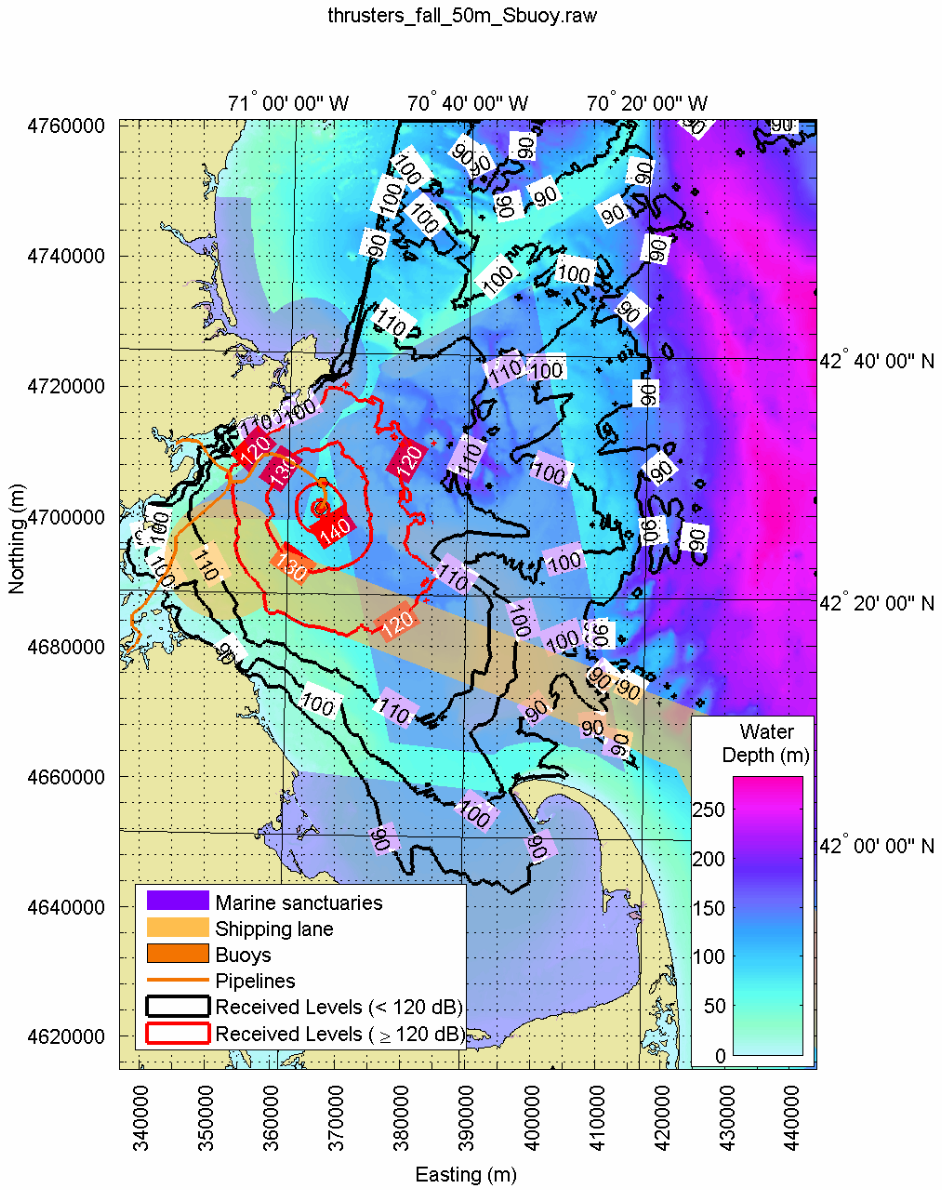

Figure 39: Dynamic positioning sound levels received at 50 m depth in the fall for LNG carrier at the south buoy.

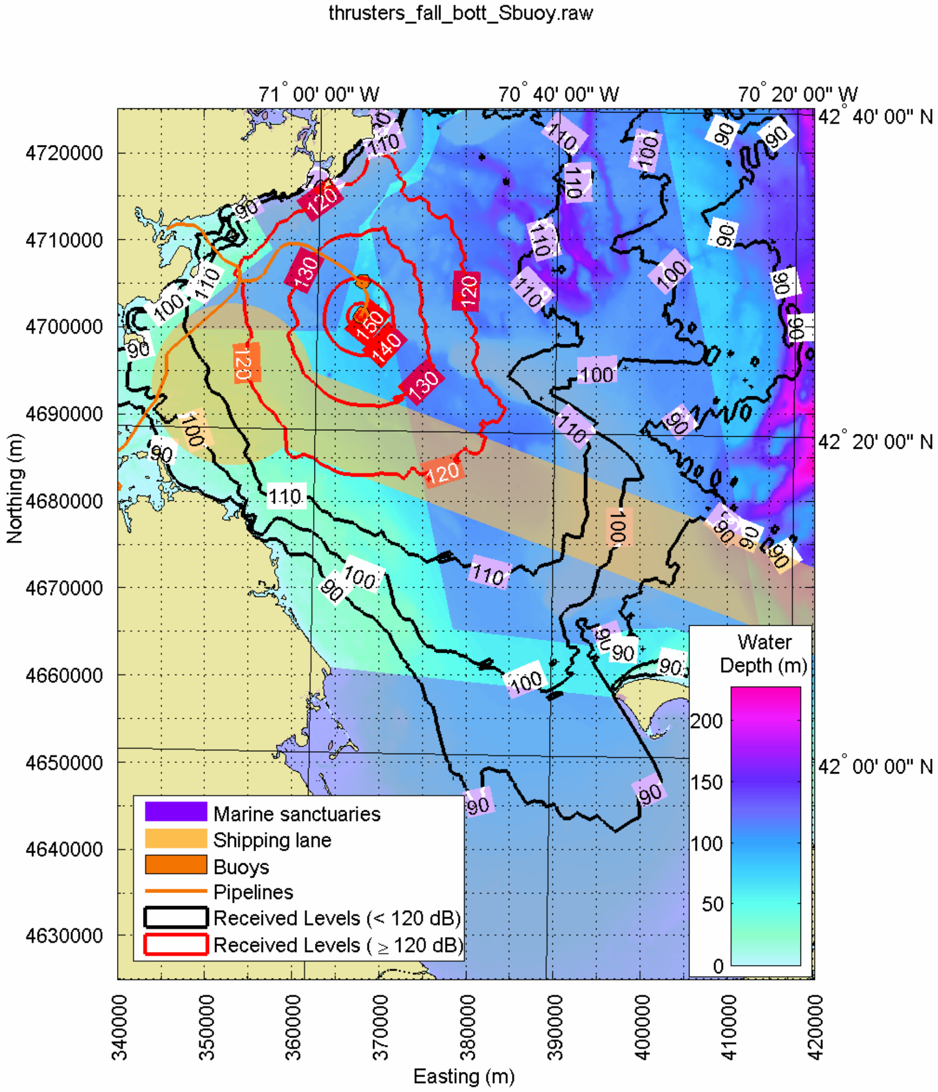

Figure 40. Dynamic positioning sound levels received at bottom depth in the fall for LNG carrier at the south buoy.

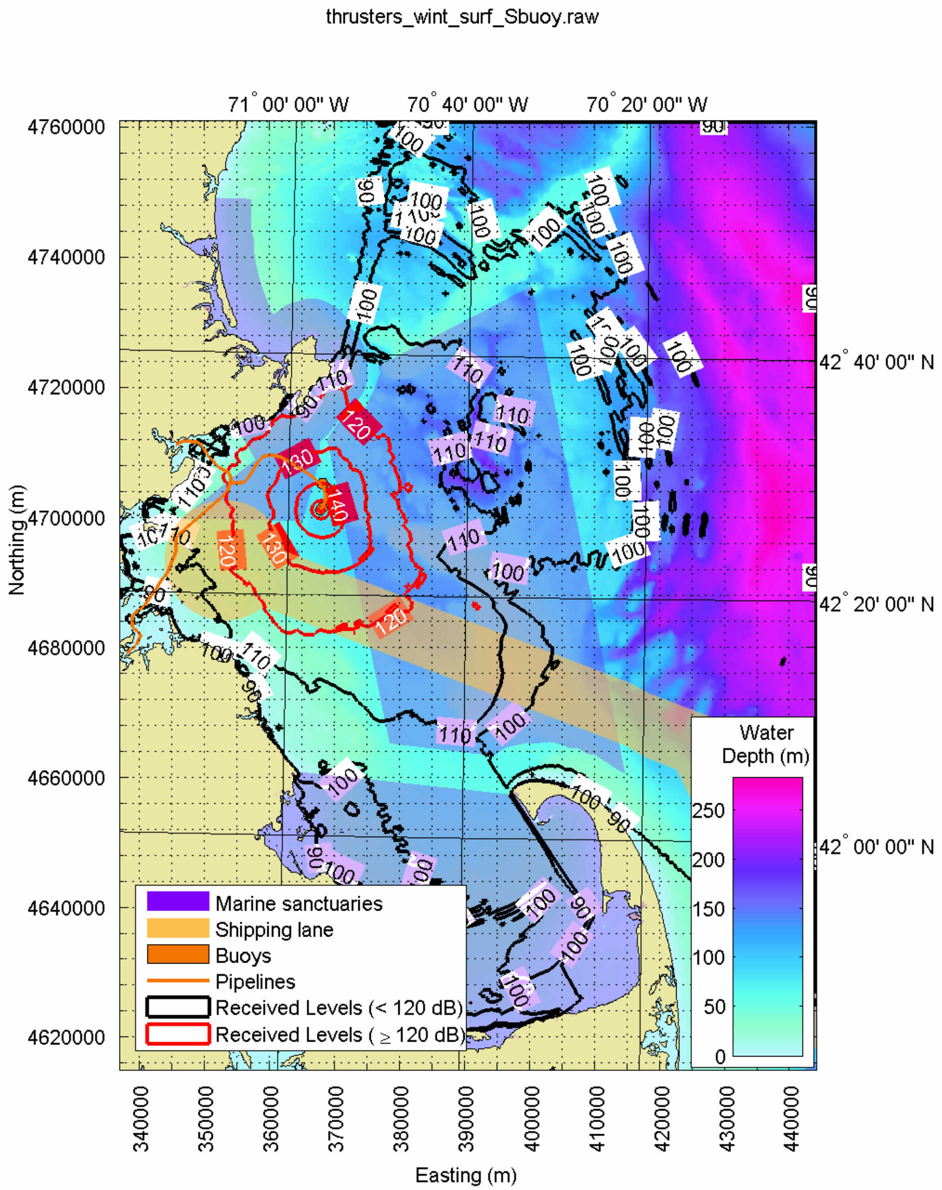

Figure 41: Dynamic positioning sound levels received at the surface (1 m depth) in the winter for LNG carrier at the south buoy.

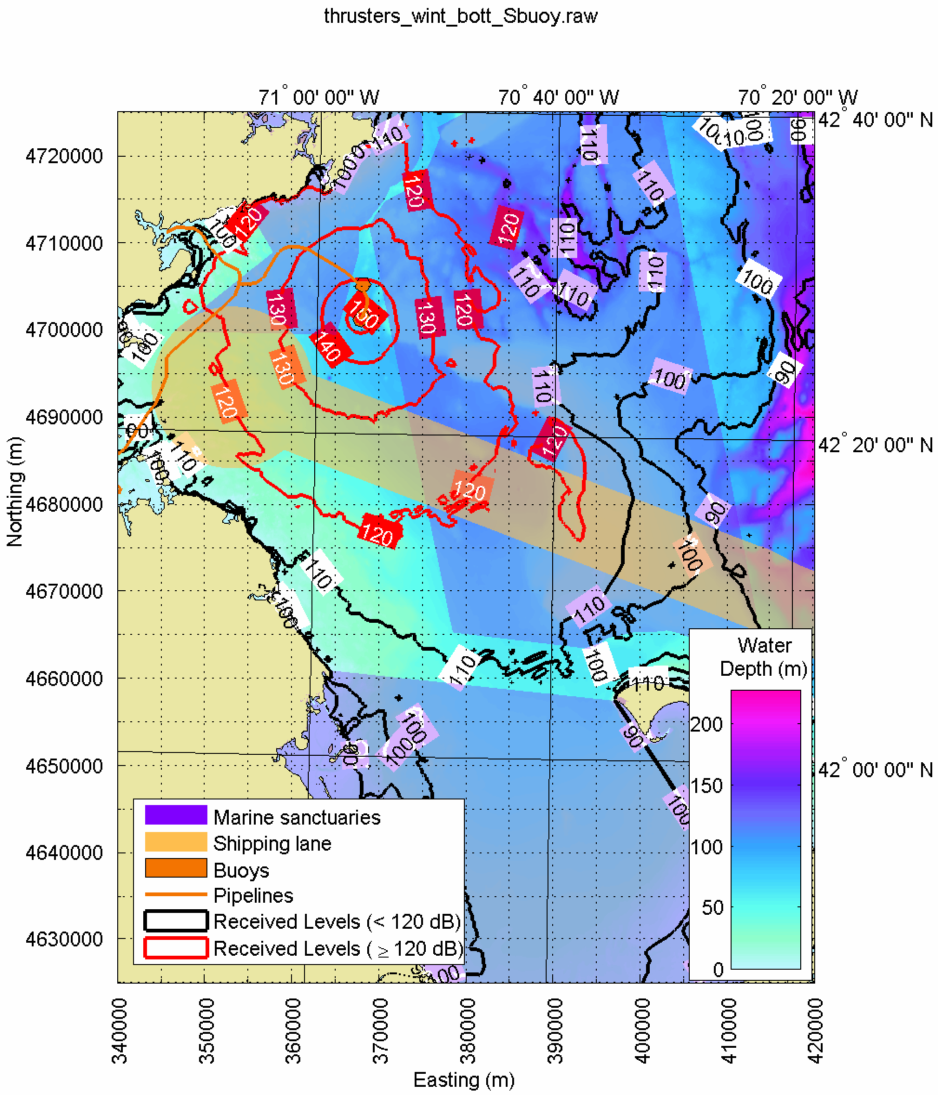

Figure 42. Dynamic positioning sound levels received at bottom depth in the winter for LNG carrier at the south buoy.

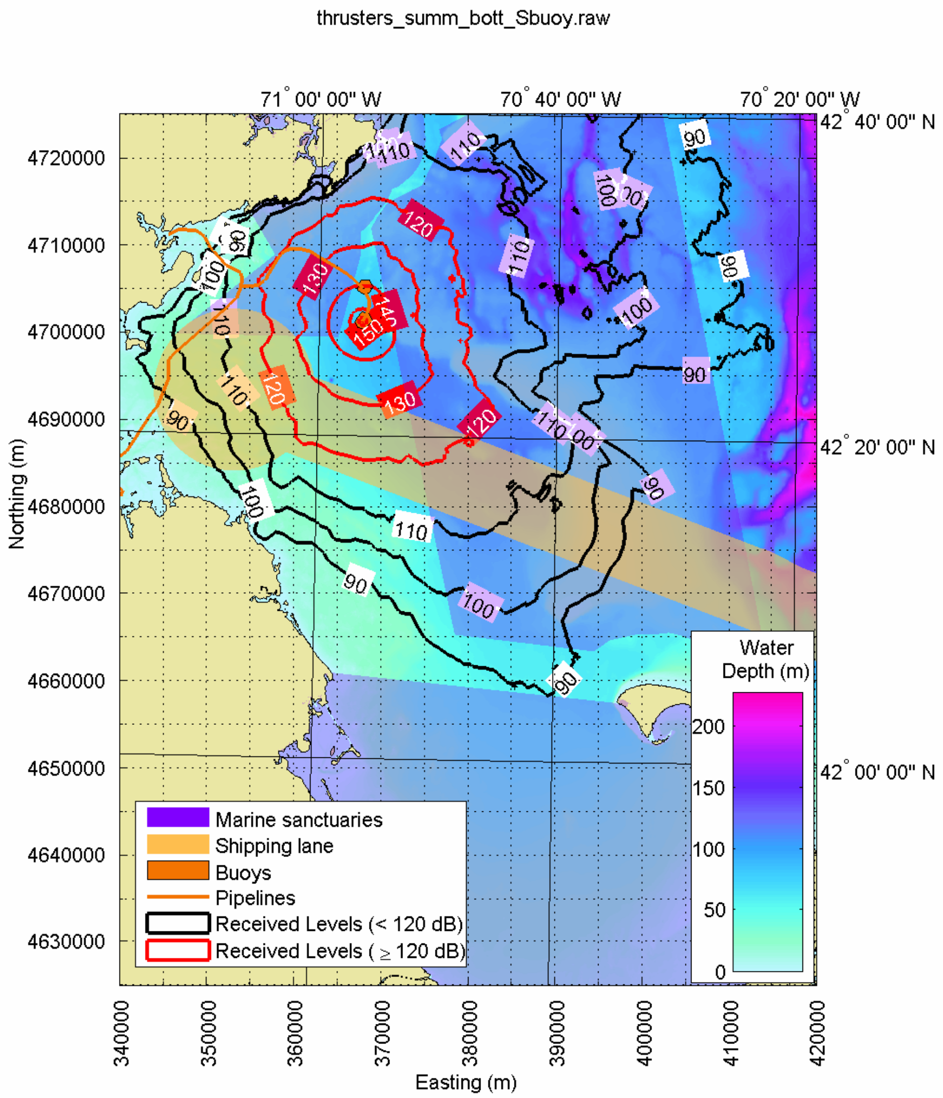

Figure 43. Dynamic positioning sound levels received at bottom depth in the summer for LNG carrier at the south buoy.

Dynamic Positioning Scenario 2: North Buoy

Dynamically positioned LNG carriers were also modeled at the north buoy. All four seasons were modeled at the water surface, at 50 m depth, and at the bottom depth.

Dynamic Positioning Parameters Scenario 2: North Buoy

Source location:	Lat: 42° 29' 05.85" N Long: 70° 36' 20.82" W
Source Depth:	8 m
Receiver depths:	Surface, 50m, Bottom
Time of year:	Spring, Summer, Fall, Winter

Dynamic Positioning Modelling Approach Scenario 2: North Buoy

The model results are presented in 10 dB contour intervals surrounding the sound sources, and the area coverage within each contour interval and the average range to each 10 dB level were calculated. The average range was calculated in a sector originating at the mean source location and bounded by Cape Ann to the north, and Cape Cod to the south, to avoid interference by the coastline.

Dynamic Positioning Modelling Results Scenario 2: North Buoy

The model results are presented in 10 dB contour intervals surrounding the sound sources (Figure 44 to Figure 55). The area coverage within each contour interval and the average range to each 10 dB level are provided in Table 49 to Table 60 The average range was calculated in a sector originating at the mean source location and bounded by Cape Ann to the north, and Cape Cod to the south, to avoid interference by the coastline.

In the spring, the modeled 120 dB sound levels reach the farthest at 50 m depth (21.0 km) and covers the largest area (920 km^2). The 120 dB sound level in the summer reaches a similar distance of about 14 km at the 50 m depth and bottom. The received sound levels are lower in the summer than in the spring. In the fall, the 120 dB contour reaches the farthest, 18.4 km, at the 50 m depth. In the winter, the 120 dB sound levels extend the farthest, to 29.1 km, at 50 m depth. Seasonally, thruster sound travels the farthest in the winter.

Table 49: Area coverage and average range of dynamic positioning sound levels received at the surface (1 m depth) during the spring at the north buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2239	45.0
100	2519	36.7
110	1456	25.8
120	567	14.2
130	184	8.9
140	44	5.1
150	6	2.9
160	1	2.6

Table 50: Area coverage and average range of dynamic positioning sound levels received at 50 m depth during the spring at the north buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	1260	52.3
100	2684	42.8
110	2217	34.4
120	920	21.0
130	242	9.9
140	48	5.3
150	5	2.9
160	1	2.7

Table 51: Area coverage and average range of dynamic positioning sound levels received at bottom depth during the spring at the north buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2642	49.1
100	3000	39.9
110	1955	29.8
120	755	16.4
130	243	9.9
140	59	5.7
150	7	3.0
160	1	2.6

Table 52: Area coverage and average range of dynamic positioning sound levels received at the surface (1 m depth) during the summer at the north buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2665	38.8
100	1917	30.7
110	975	20.2
120	427	12.7
130	147	8.1
140	38	4.9
150	5	2.9
160	1	2.6

Table 53: Area coverage and average range of dynamic positioning sound levels received at 50 m depth during the summer at the north buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2867	44.7
100	2204	33.5
110	1285	24.1
120	518	14.0
130	159	8.4
140	37	4.8
150	5	2.9
160	1	2.6

Table 54: Area coverage and average range of dynamic positioning sound levels received at bottom depth during the summer at the north buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2926	41.7
100	2117	32.4
110	1162	22.8
120	517	13.8
130	184	8.8
140	48	5.3
150	7	3.0
160	1	2.6

Table 55: Area coverage and average range of dynamic positioning sound levels received at the surface during the fall at the north buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	2590	45.8
100	2333	34.1
110	1326	23.9
120	524	13.8
130	167	8.5
140	41	5.0
150	5	2.9
160	1	2.6

Table 56: Area coverage and average range of dynamic positioning sound levels received at 50 m depth during the fall at the north buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	1872	49.8
100	3075	41.1
110	1896	29.1
120	801	18.4
130	218	9.4
140	44	5.1
150	5	2.9
160	1	2.7

Table 57: Area coverage and average range of dynamic positioning sound levels received at bottom depth during the fall at the north buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	1915	49.8
100	2787	38.8
110	1753	27.6
120	699	15.8
130	222	9.5
140	54	5.5
150	7	3.0
160	1	2.6

Table 58: Area coverage and average range of dynamic positioning sound levels received at the surface (1 m depth) during the winter at the north buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	667	60.9
100	3271	47.0
110	2231	30.4
120	732	15.8
130	209	9.4
140	48	5.3
150	6	2.9
160	1	2.6

Table 59: Area coverage and average range of dynamic positioning sound levels received at 50 m depth during the winter at the north buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	668	60.3
100	864	51.8
110	1151	38.8
120	1699	29.1
130	347	12.0
140	60	5.8
150	6	2.9
160	1	2.7

Table 60: Area coverage and average range of dynamic positioning sound levels received at bottom depth during the winter at the north buoy

Contour level (dB)	Area inside (km^2)	Average range (km)
90	999	53.2
100	655	48.6
110	2203	32.6
120	1047	19.1
130	283	10.5
140	63	5.9
150	8	3.0
160	1	2.6

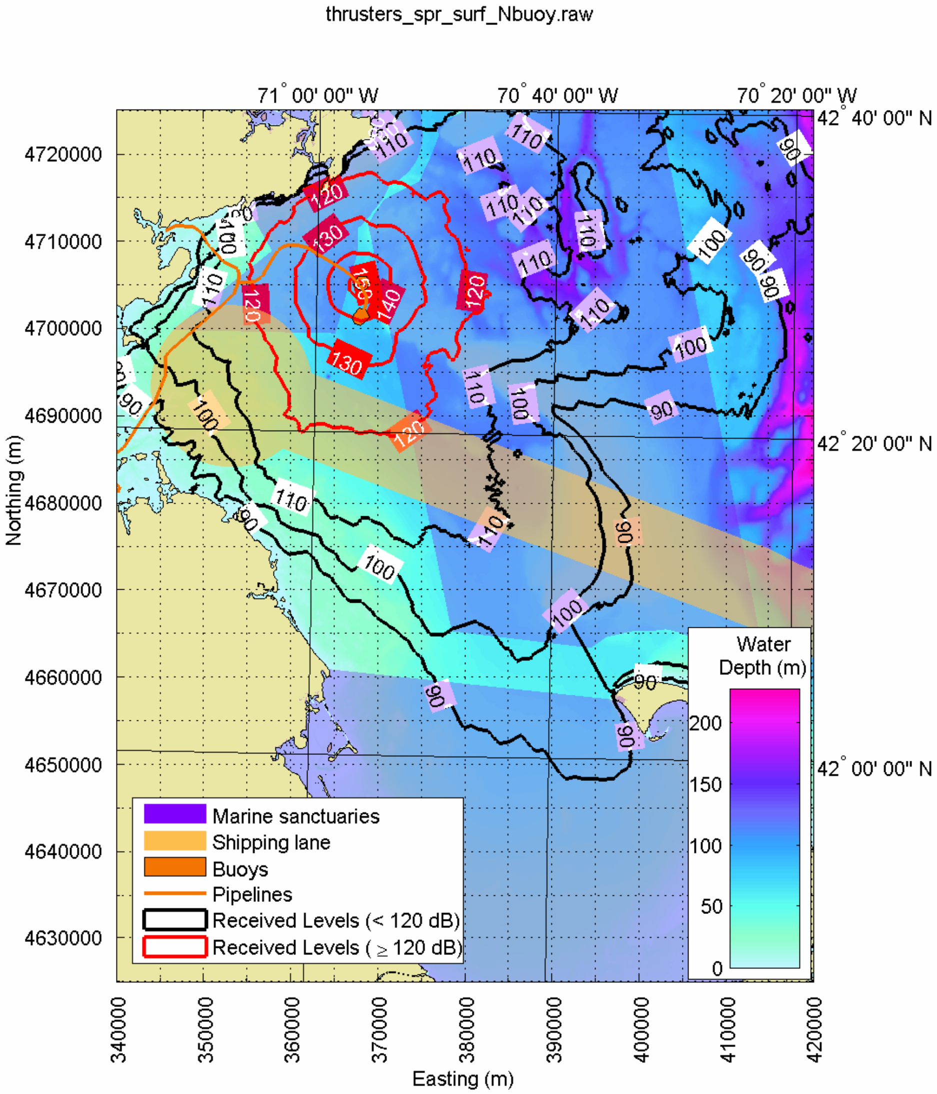

Figure 44. Dynamic positioning sound levels received at surface depth in the spring for LNG carrier at the north buoy.

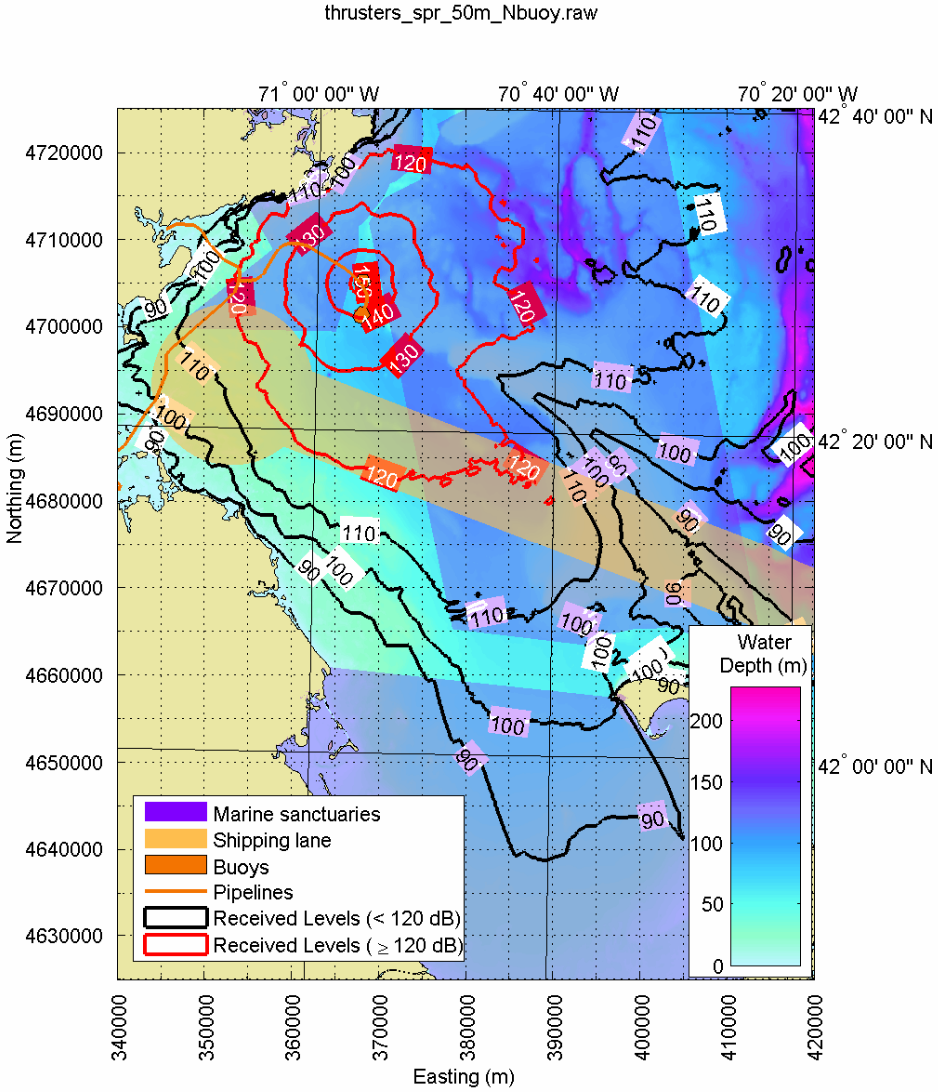

Figure 45. Dynamic positioning sound levels received at 50 m depth in the spring for LNG carrier at the north buoy.

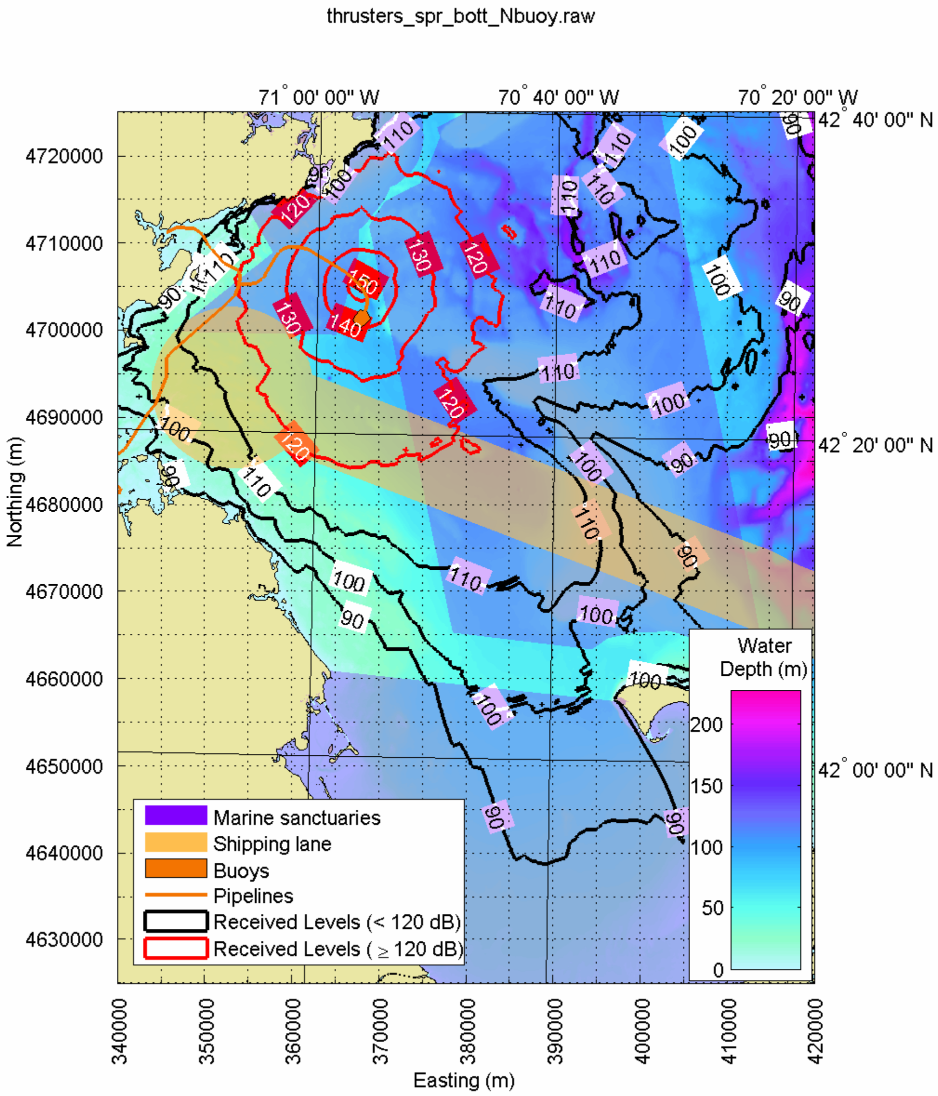

Figure 46. Dynamic positioning sound levels received at bottom depth in the spring for LNG carrier at the north buoy.

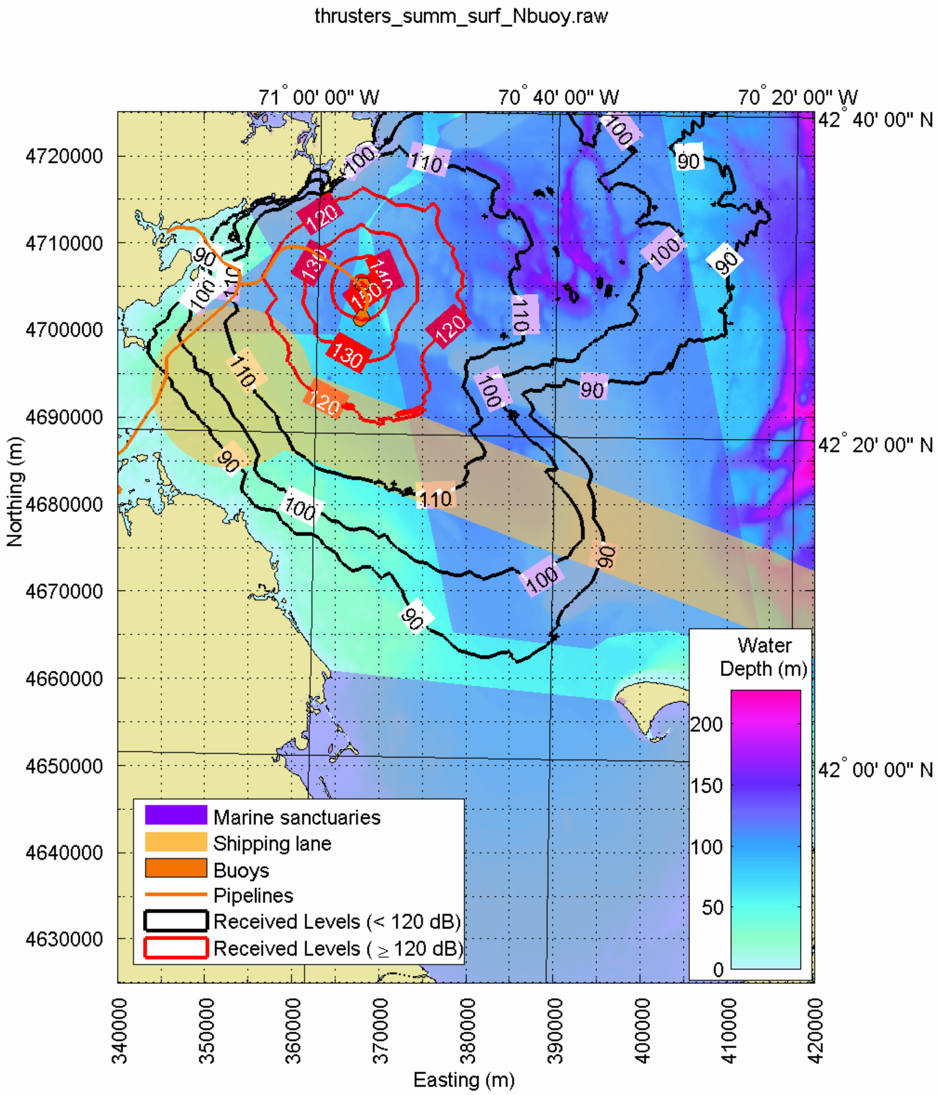

Figure 47. Dynamic positioning sound levels received at surface depth in the summer for LNG carrier at the north buoy.

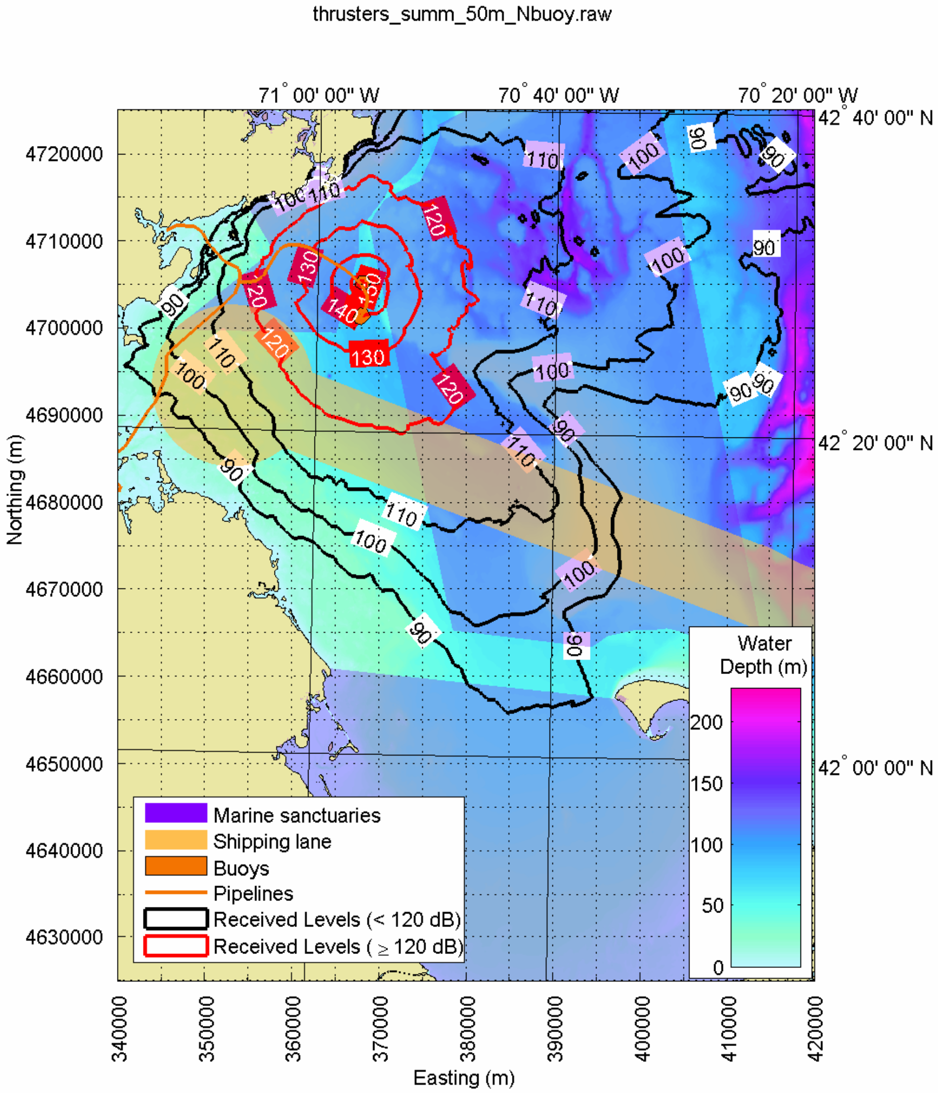

Figure 48. Dynamic positioning sound levels received at 50 m depth in the summer for LNG carrier at the north buoy.

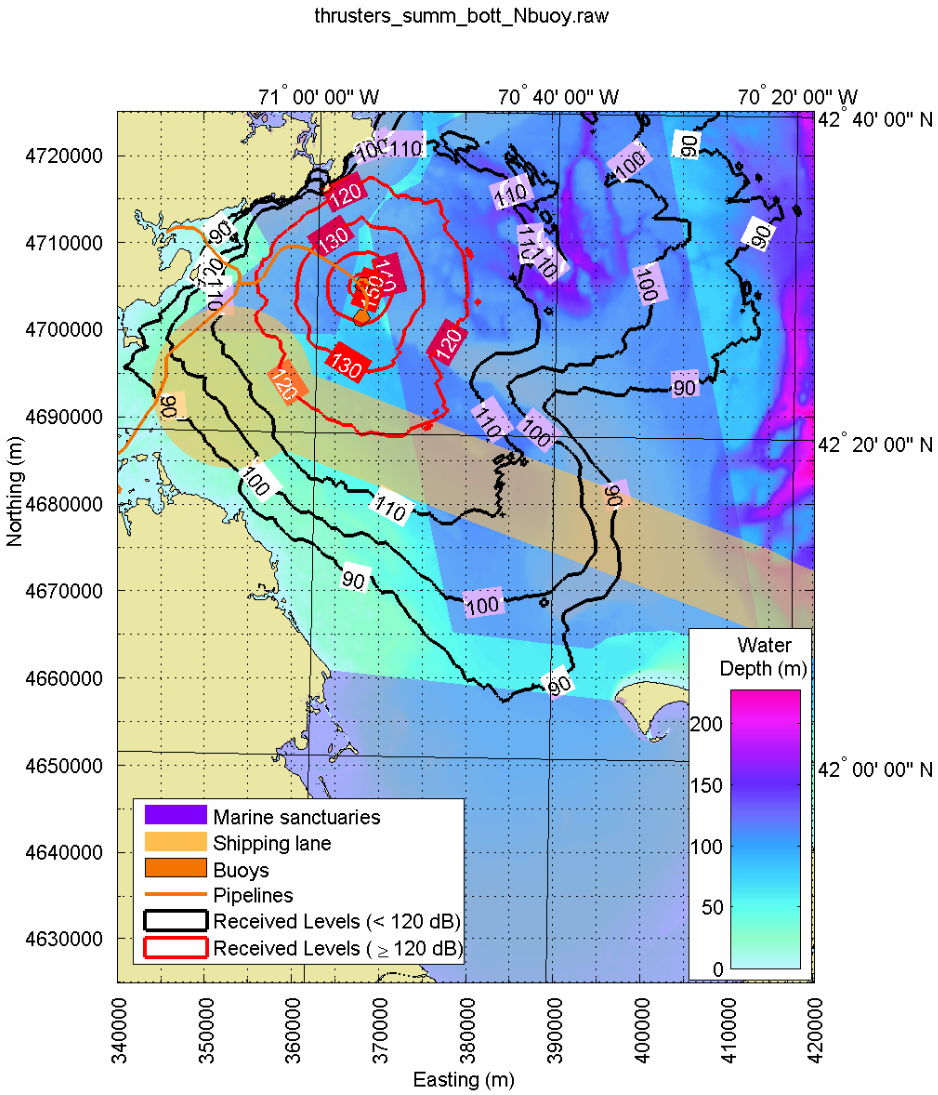

Figure 49. Dynamic positioning sound levels received at bottom depth in the summer for LNG carrier at the north buoy.

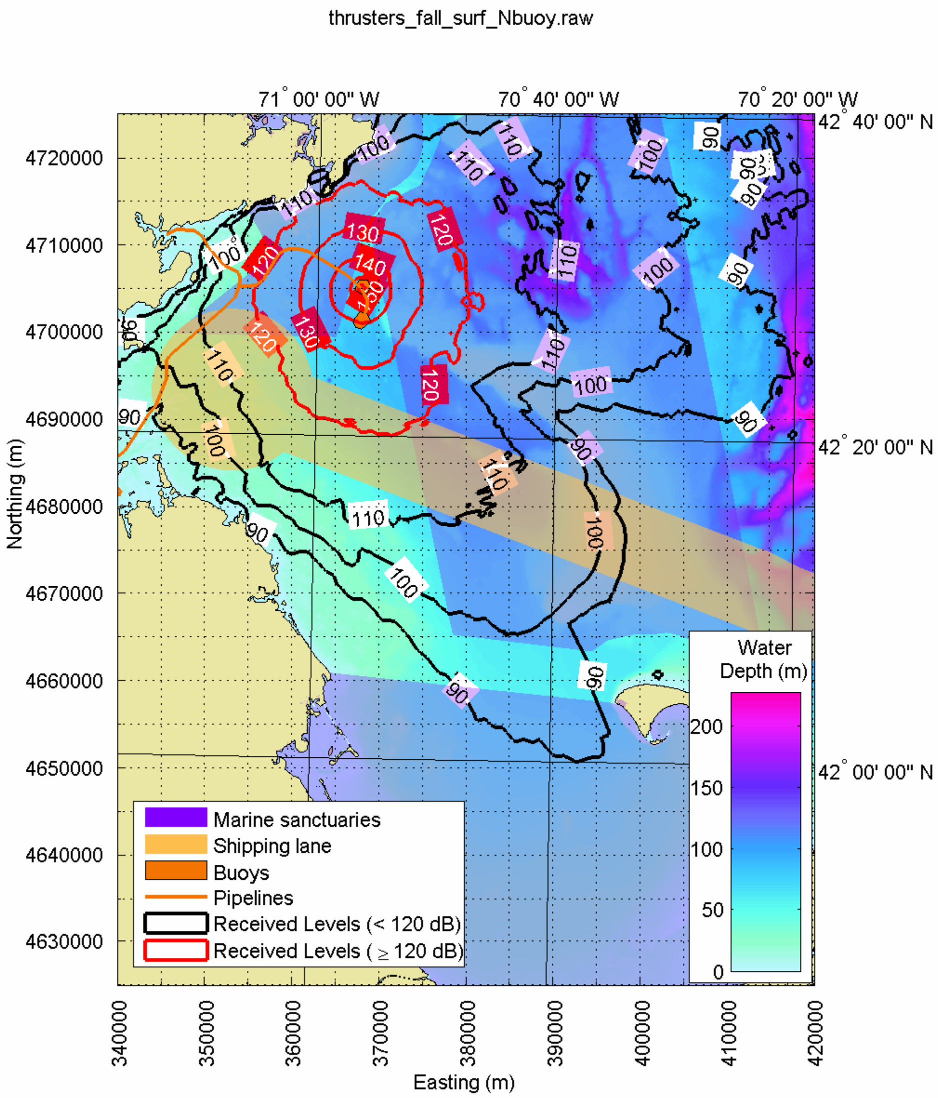

Figure 50. Dynamic positioning sound levels received at surface depth in the fall for LNG carrier at the north buoy.

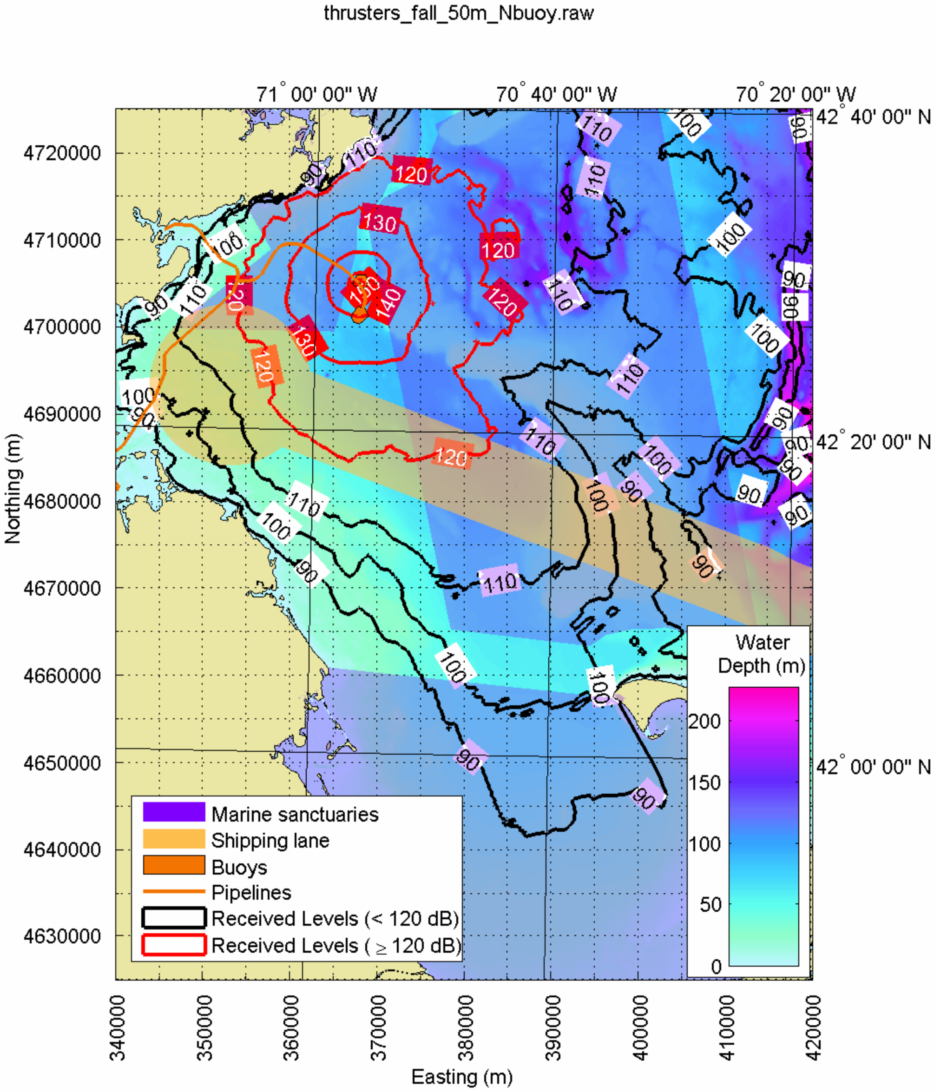

Figure 51. Dynamic positioning sound levels received at 50 m depth in the fall for LNG carrier at the north buoy.

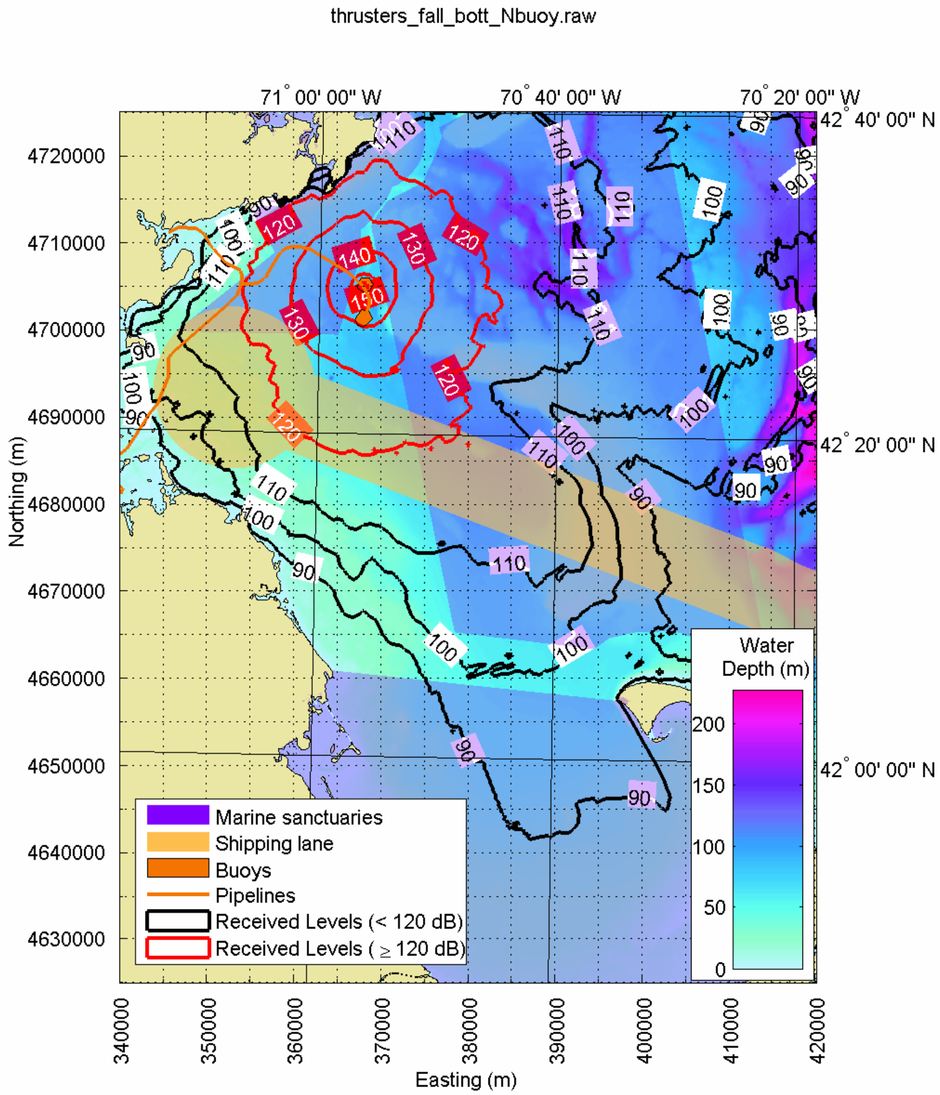

Figure 52. Dynamic positioning sound levels received at bottom depth in the fall for LNG carrier at the north buoy.

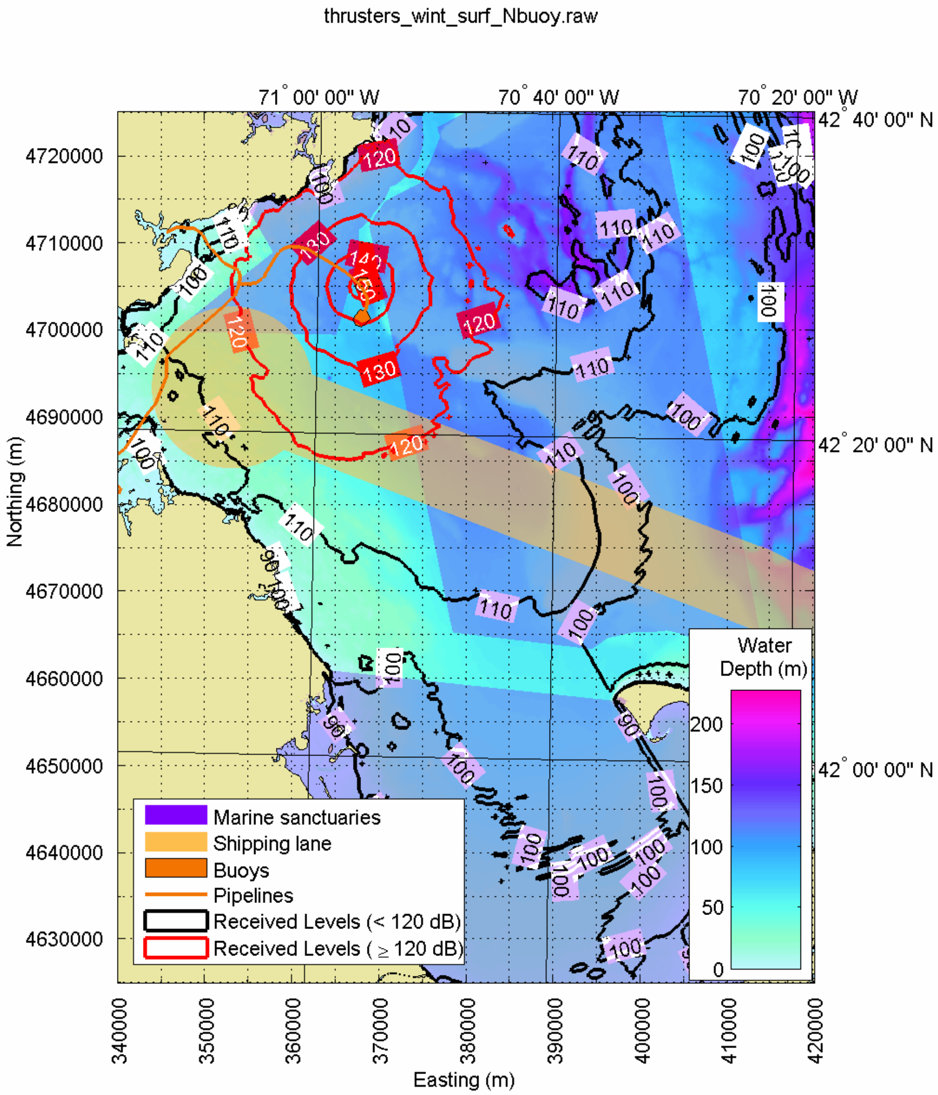

Figure 53. Dynamic positioning sound levels received at surface depth in the winter for LNG carrier at the north buoy.

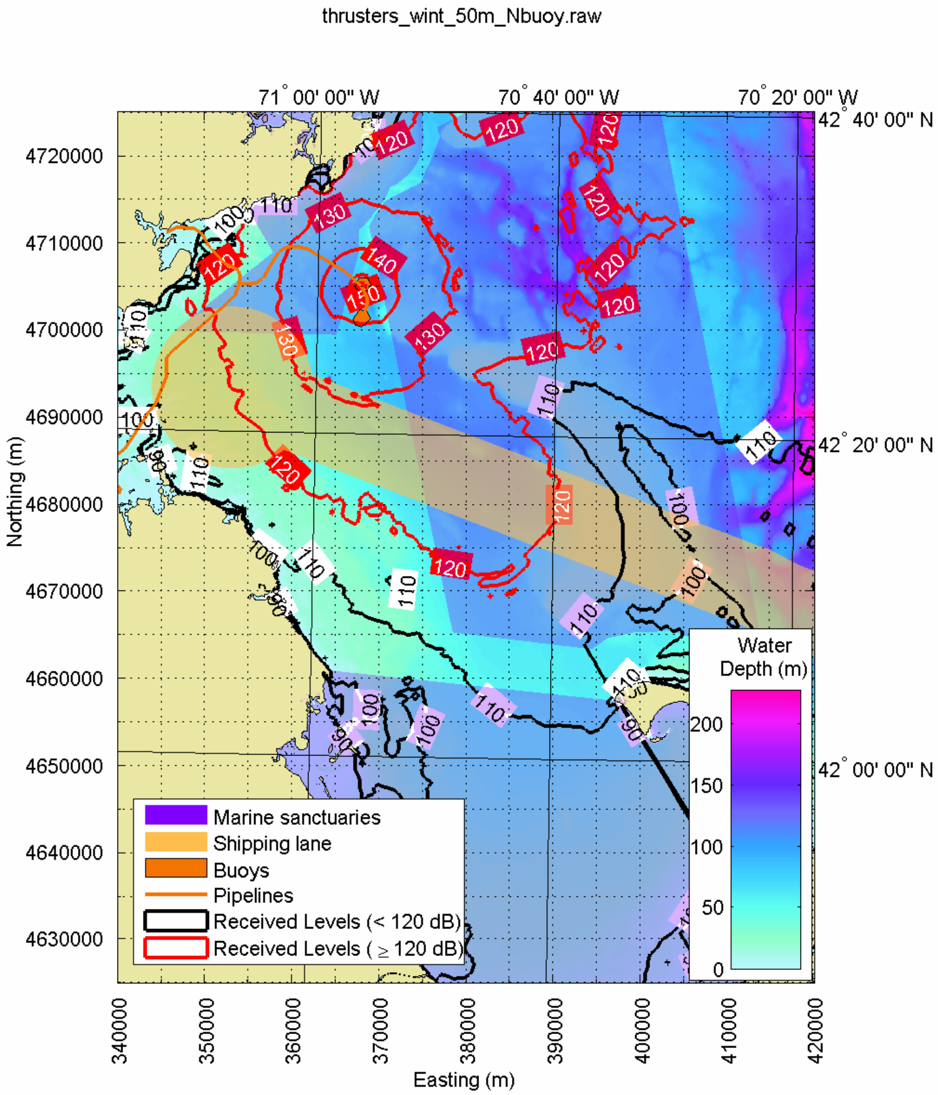

Figure 54. Dynamic positioning sound levels received at 50 m depth in the winter for LNG carrier at the north buoy.

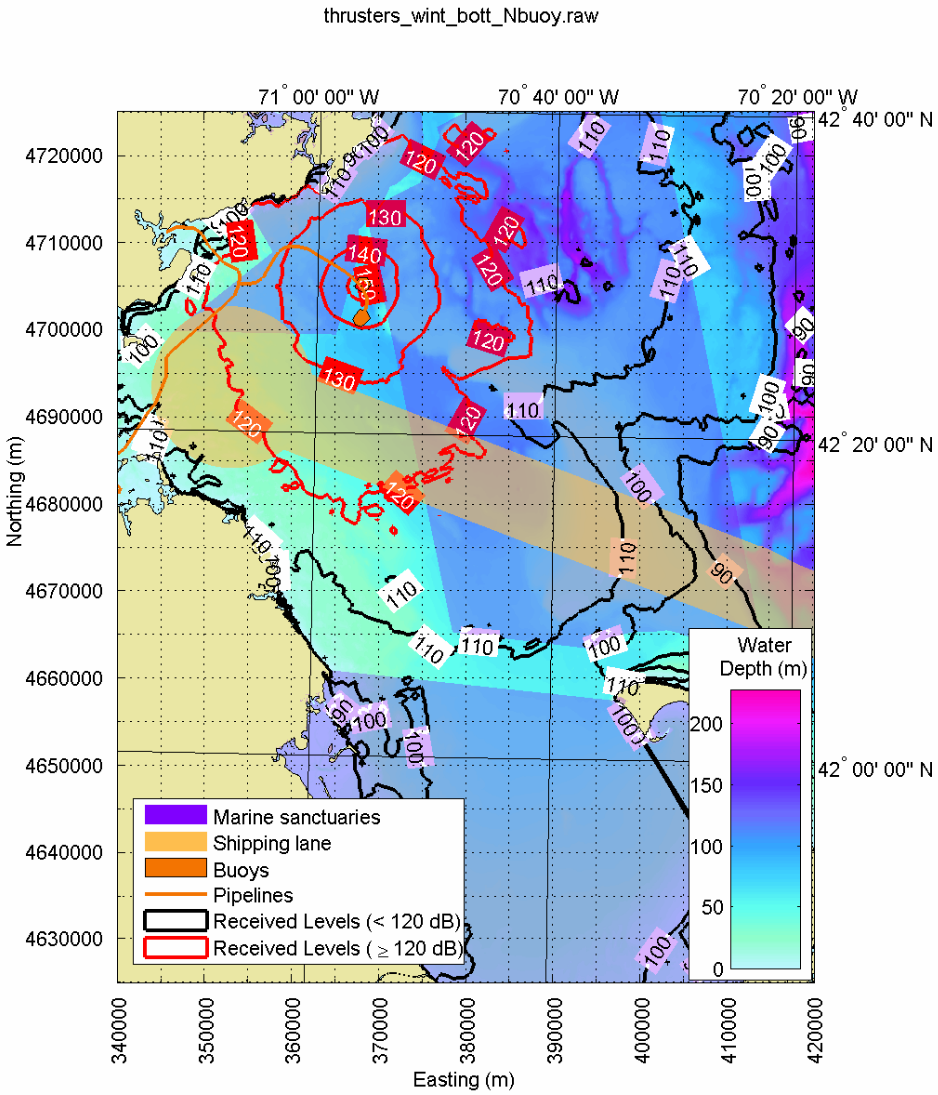

Figure 55. Dynamic positioning sound levels received at bottom depth in the winter for LNG carrier at the north buoy.

LNG Carrier Regasification Operation

This scenario modeled noise produced by two LNG carriers attached to the mooring buoys during regasification operations. The purpose is to characterize the underwater noise field produced by shipboard equipment required for regasifying the LNG and feeding the gas into the riser/pipeline. The scenario addressed average sound levels with 2 ships operating regasification and pumping equipment simultaneously. Two LNG carriers were modeled to capture the worst-case scenario when they are conducting regasification operations at the same time.

LNG Carrier Regasification Scenario

LNG Carrier Regasification Scenario Parameters

Source location:		
North buoy	Lat: 42° 29’ 05.96” N	Long: 70° 36’ 20.82” W
South buoy	Lat: 42° 27’ 05.93” N	Long: 70° 36’ 22.52” W
Source depth:	5.5 m	
Receiver depths:	Surface, 50m	
Time of year:	Spring, Summer, Fall, Winter	

LNG Carrier Regasification Scenario Modelling Approach

For a short period of time as one LNG carrier is finishing downloading its LNG, a second carrier will be on the other buoy performing regasification. Each LNG carrier is equipped with three vaporization units of Hamworthy Gas System type with the capacity to vaporize 210 metric tons per hour. Normally two units operate at one time with a combined send-out of about 420 tons per hour. If all three units are operating, the maximum send-out capacity is about 630 metric tons per hour. The deepwater port will operate 24 hours a day, 365 days per year to provide a continuous supply of natural gas (Intec Engineering 2005c).

The liquid natural gas and seawater are pumped into the units by a cargo pump and seawater pump. There may also be a send-out pump. Presumably a turbine generator runs all the pumps. Each of the three units on the carrier consists of:

- One or two high-pressure cryogenic LNG pumps (2800 hp each)
- One water glycol circulation pump (80 hp)
- Four heat exchangers (unknown power or noise output)

This model run included two LNG carriers, one at each buoy. Each carrier consisted of one LNG pump, one glycol circulation pump, one seawater pump, one cargo pump, and a turbine generator. The broadband source level of this configuration is 164.6 dB re 1 μPa. An estimate of one-octave band source levels in water are given in Table 61.

Table 61: Estimate of 1-octave band levels for regasification on one LNG carrier.

Centre frequency *(Hz)*	Source Level *(dB re 1 μPa-1m)*
31.5	131.8
63	135.5
125	139.2
250	143.0
500	146.5
1000	148.9
2000	151.2
Broadband	164.6

LNG Carrier Regasification Scenario Modelling Results

The model results are presented in 10 dB contour intervals surrounding the sound sources, and the area coverage within each contour interval and the average range to each 10 dB level were calculated. Results for the 50-m depth in spring are in Table 62 and Figure 56; results for received levels at 50 m depth in summer are in Table 63 and Figure 57; results for received levels at 50 m depth in the fall are in Table 64 and Figure 58; and results for received levels at the surface in winter are in Table 65 and Figure 59. The average range was calculated in a sector originating at the mean source location and bounded by Cape Ann to the north, and Cape Cod to the south, to avoid interference by the coastline.

The received sound levels for regasification modeled here did not exceed 110 dB to any significant distance. The source level modeled may also be higher than one would expect at 1 m in the water because these measurements were taken in air and do not take into consideration sound dampening by the hull of the vessel.

Table 62: Area coverage and average range of carrier regasification sound levels received at 50 m depth during the spring

Contour level (dB)	Area inside (km^2)	Average range (km)
90	221	9.7
100	18	5.5
110	0	0.0
120	0	0.0
130	0	0.0
140	0	0.0

Table 63: Area coverage and average range of carrier regasification sound levels received at 50 m depth during the summer

Contour level (dB)	Area inside (km^2)	Average range (km)
90	125	7.8
100	11	5.3
110	0	0.0
120	0	0.0
130	0	0.0
140	0	0.0

Table 64: Area coverage and average range of carrier regasification sound levels received at 50 m depth during the fall

Contour level (dB)	Area inside (km^2)	Average range (km)
90	214	9.6
100	17	5.4
110	0	0.0
120	0	0.0

Table 65: Area coverage and average range of carrier regasification sound levels received at the surface during the winter

Contour level (dB)	Area inside (km^2)	Average range (km)
90	221	9.1
100	22	5.7
110	1	3.5
120	0	0.0
130	0	0.0

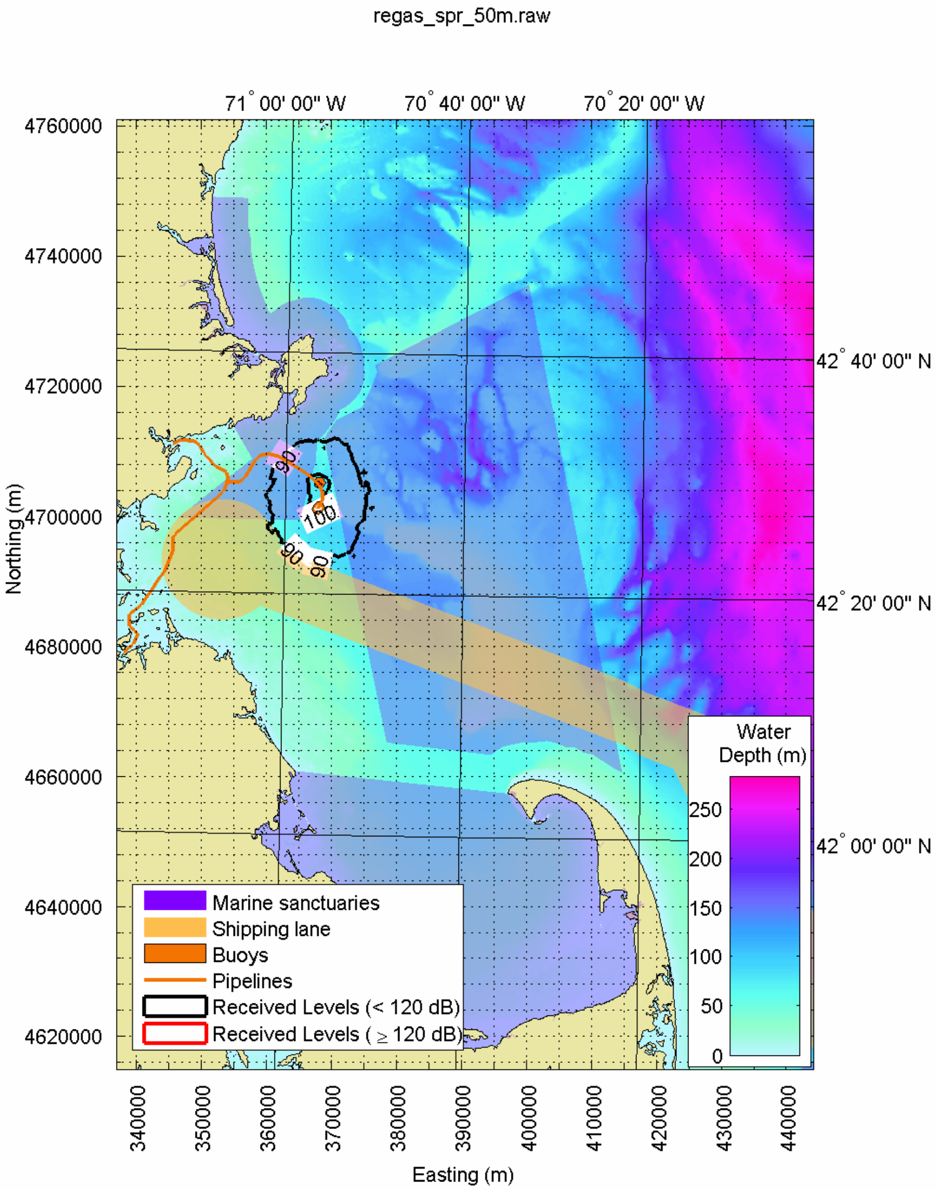

Figure 56: Carrier regasification sound levels received at 50 m depth in the spring for twoLNG carriers, one at each buoy.

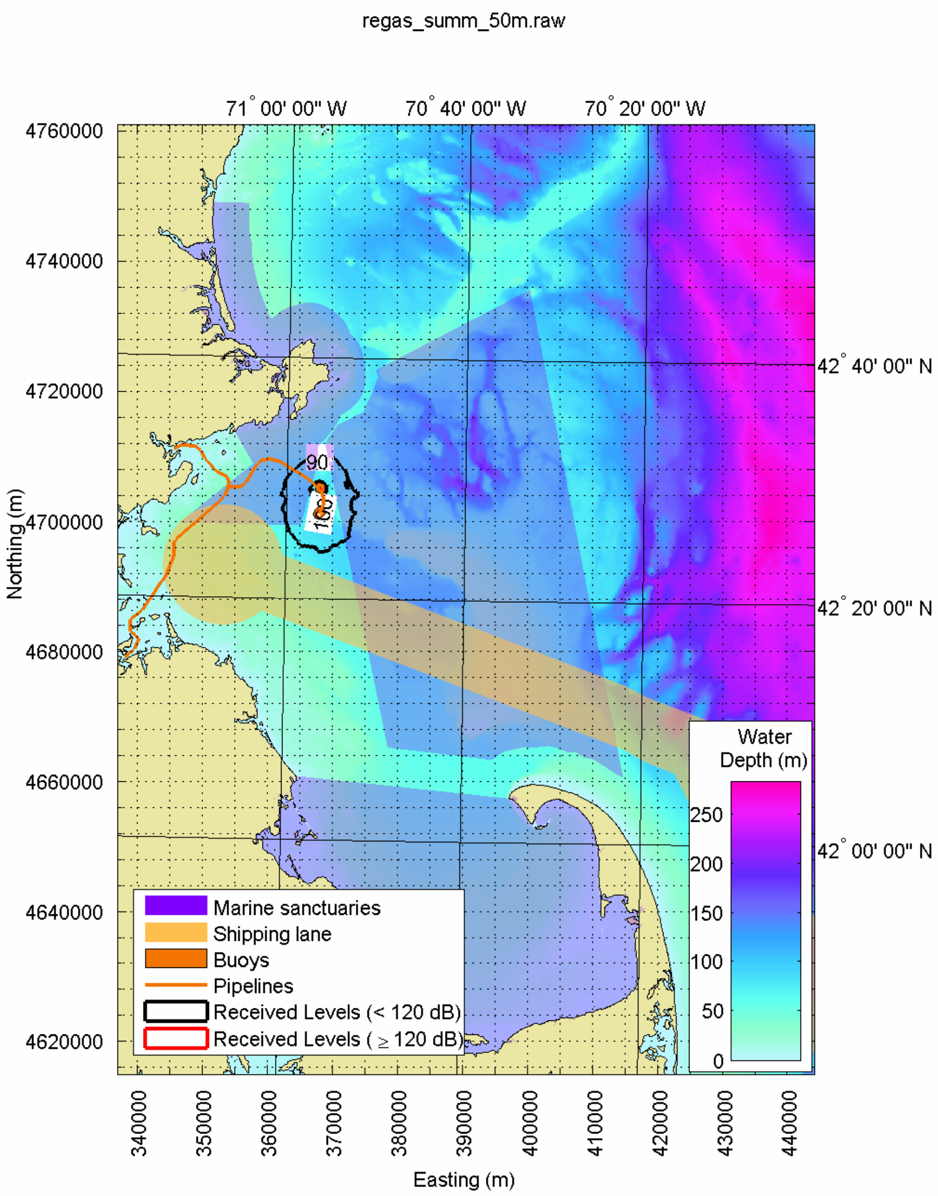

Figure 57: Carrier regasification sound levels received at 50 m depth in the summer for two LNG carriers, one at each buoy.

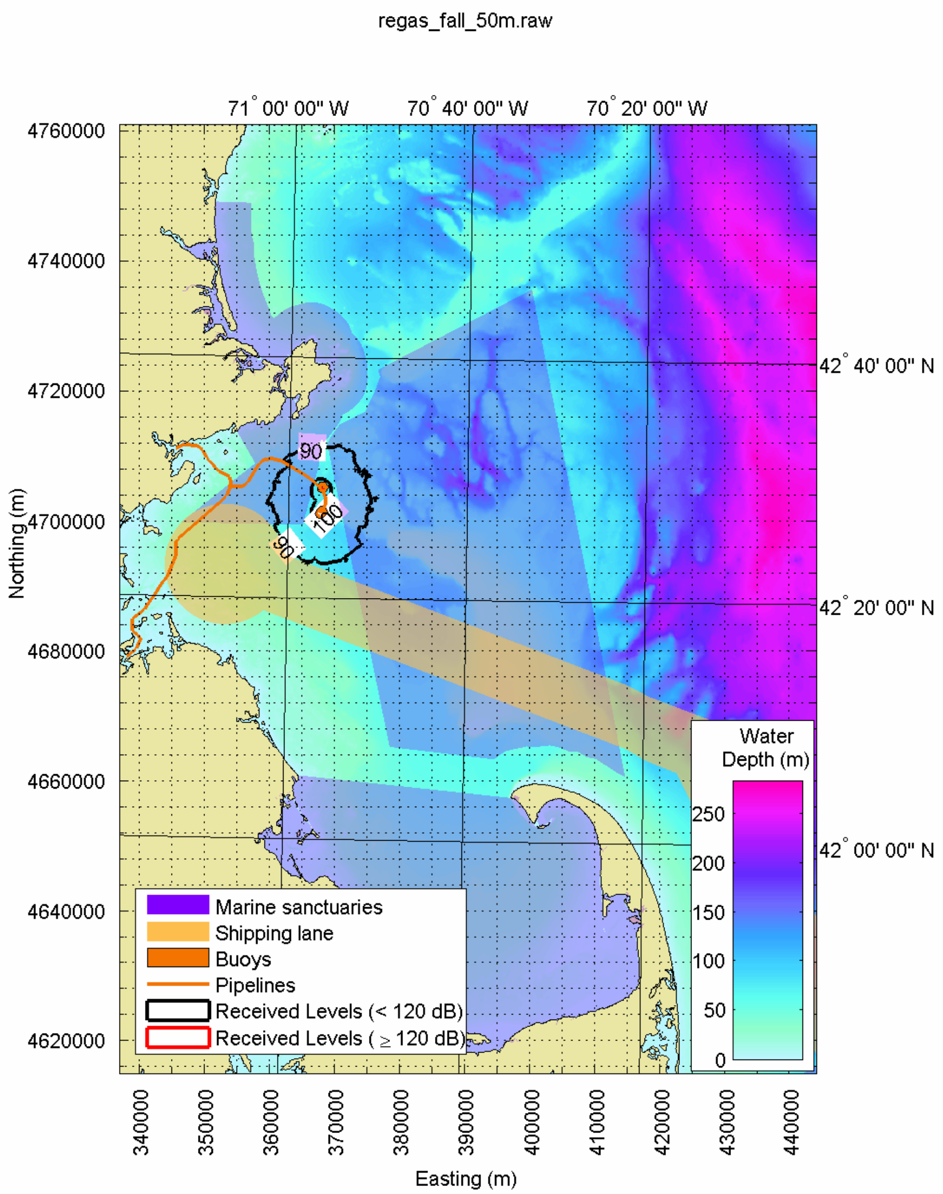

Figure 58: Carrier regasification sound levels received at 50 m depth in the fall for two LNG carriers, one at each buoy.

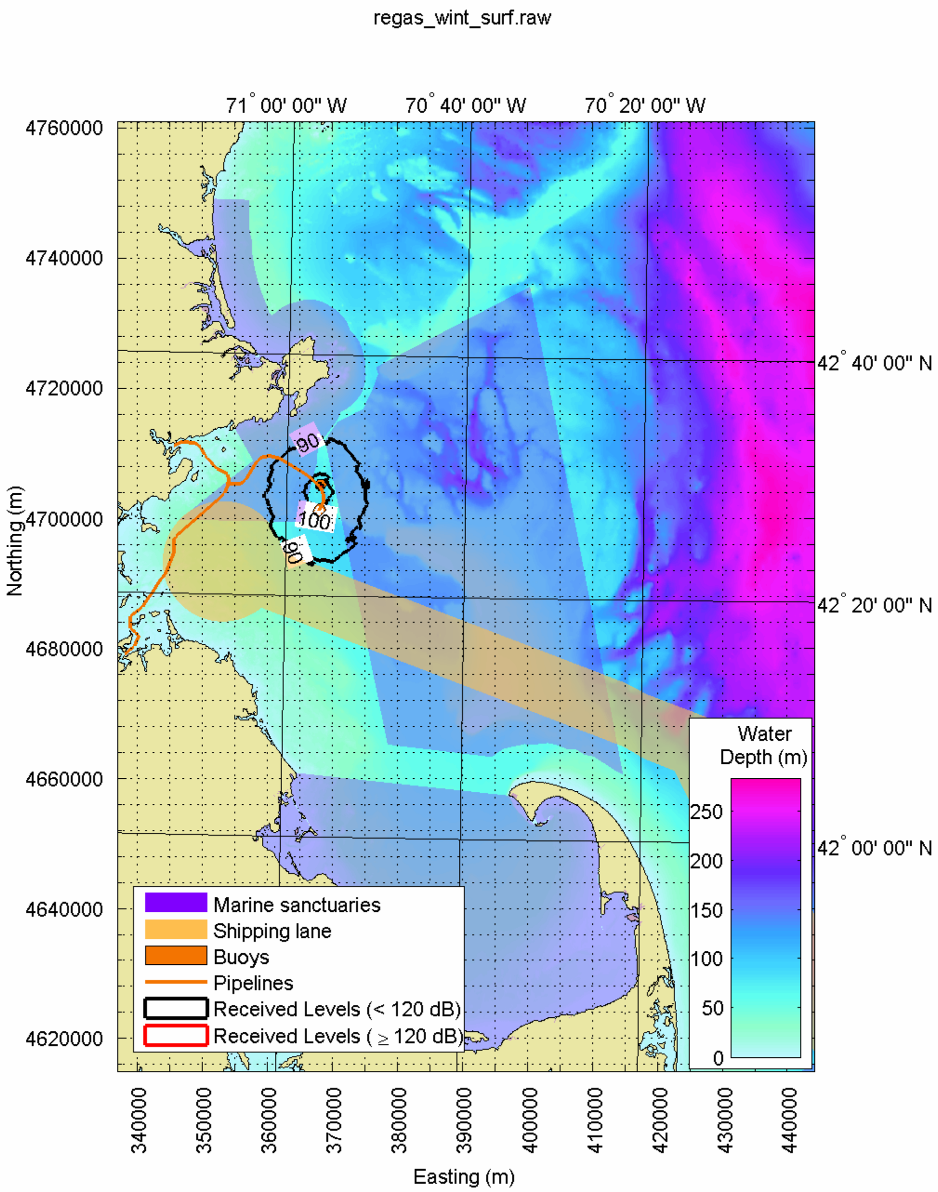

Figure 59: Carrier regasification sound levels received at the surface (1 m depth) in the winter for two LNG carriers, one at each buoy.

PART (4): PREDICTED EFFECTS OF UNDERWATER NOISE FROM THE NEPTUNE PROJECT ON MARINE MAMMALS, SEA TURTLES, MARINE INVERTEBRATES AND FISH

By

Rolph A. Davis[1]
John Christian[2]
Susan Dufault[3]

[1]LGL Limited
22 Fisher St., P.O. Box 280
King City, ON L7B 1A6

[2]LGL Limited
Box 13248, Station A
388 Kenmount Rd.
St. John's, NL A1B 4A5

[3]LGL Limited
14 Langley Avenue
Dartmouth, NS B2W 2Y6

5 October 2005

TABLE OF CONTENTS

In this section of the report, we integrate the information from the previous three sections to predict the biological effects of the underwater noise associated with the proposed Neptune Project. Data on the species and numbers of marine animals in the project area are summarized in Section 1. Information on the known effects of the types of noise associated with the Neptune Project is summarized in Section 2 based on the results of other studies. The source levels and modeled propagation characteristics of underwater noise from the Neptune Project are presented in Section 3. Here, in Section 4, we determine the number of animals that might be affected by the proposed project based on the modeled sound fields from the project activities.

Characteristics of Project Noise

There are several types of underwater noise associated with the Neptune Project. These range from a short period of pile driving to continuous noise associated with the project throughout its lifetime. Each type of noise will be discussed for each group of marine animals that were determined to be of interest. The types of noise are summarized below. [These types should be categorized by "Construction", "Operation", and "Decommissioning".]

Construction

The main underwater noise associated with construction of the project will be associated with pile-driving, if it is used to set the anchors for the unloading buoys and with the pipeline installation.

Pile driving

Each of the two unloading buoys will be fixed in place by eight anchors fixed to the bottom by piles. The preferred method is to use a suction pile anchoring system that does not involve the use of pile-driving in the usual sense. An alternate construction option is to use pile driving to fix the anchors to the bottom. Either type of installation would be a one-time operation that would last for about 15 days to do both unloading buoys. Pile drivers produce pulses of noise and can operate at up to 30 blows per minute whereas the main noise from installation of suction piles would be from pumps used sink the piles and from associated vessel traffic. The suction piles do not involve pulsive noise.

Pipeline Installation

Pipeline construction operations were described in Section 3 of this report. The operation would involve up to 6 vessels operating in different combinations. The pipe laying along the 4-km flowline between the two buoys is scheduled to take 6 days (in July 2009), the trenching 5 days (within July to August 2009), and the backfilling another 5 days (within August to September 2009) (Suez LNG NA LLC 2005a). The construction of the 17.45-km northern route pipeline is scheduled to take 22 days to lay pipe (within June to July 2009), 10 days to trench (in August 2009), and 10 days (in September 2009) to backfill (Suez LNG NA LLC 2005a).

Although sounds created by construction equipment and vessels during pipeline construction would be continuous during the daytime for the period of pipeline construction, the construction actitivities would progress slowly along the pipeline route as the pipeline is laid, then later plowed into the bottom, and a third time when the plow backfills the pipeline trench. Thus, any one area would be subject to the maximum sound levels for only a day or two each time, as the construction activities pass that area.

Project Operation

LNG Carriers in Transit

The effects of underwater noise from the LNG carriers are analyzed from the time that the vessels leave the main shipping lanes and head north to the unloading buoys. The vessels would travel at half power (8-10 knots) when they leave the shipping lanes. The carriers would be accompanied by a smaller supply/guard vessel traveling at the same reduced speed. The arrival and departure of the carriers would produce a transient continuous sound that would steadily increase on approach and then decline as the vessel passes marine animals. A carrier would arrive at the DWP every 4 to 8 days; it would stay at the DWP for 4 to 8 days; and then return to the shipping lanes.

It should be noted that we only address the potential effects of underwater noise from the LNG carriers after they leave the regulated shipping lanes. The presence of the LNG carriers in the shipping lanes would add only incrementally to the ship noise in the lanes. Consideration of the carrier noise in the shipping lanes would necessitate an analysis of all of the ship noise emanating from the shipping lanes, a task beyond the scope of the present assessment.

LNG Carriers Maneuvering at DWP

As the carrier approaches the DWP location, it would use its thrusters to position itself so that the unloading buoy can be retrieved and secured to the vessel. It is estimated that the thrusters would be used for 10-30 minutes during each arrival by an LNG carrier. The noise from the thrusters would be continuous during the short period that they are used.

Re-Gasification

Once secured to the unloading buoy, the LNG carrier would begin the re-gasification process using internal processes. The ship would be on location for an average of 4 to 8 days to re-gasify its full load of LNG. Underwater noise associated with the re-gasification and maintenance of shipboard facilities, such as power generation, would be continuous from a fixed location.

Gas Pipeline

The operation of the approximately 21.5 km of pipeline associated with the Neptune Project is expected to emit very little noise. A recent study by Martec Limited (2004) found that noise from a compressed natural gas pipeline was detectable only out to about 200 m (~660 ft).

Decommissioning

The decommissioning of the project is planned to to include the removal of the mooring buoys and their anchoring system. The pipeline would be left in place, cleaned and flooded with seawater. Thus, decommissioning would involve some ship traffic and associated noise and perhaps some brief noise associated with cutting the pipeline and removal of the piles anchoring the mooring buoys.

Potentially Affected Marine Animals

The principal groups of marine animals addressed in this assessment are baleen whales, toothed whales, seals, sea turtles, fish, and marine invertebrates. Each group is discussed separately below.

A problem with conducting a quantitative assessment of the effects of the Neptune project is the lack of true density estimates for any of the animals of concern. The linear data in the Navy MRA (2005) provide an index of abundance based on all of the usable available data. To convert the linear data into densities, we assume here that the effective survey width is a 0.5 km (500 m) strip on each side of the survey vehicle. Thus, each linear km of survey will encompass an area of 1 km². This, of course, is a gross oversimplification of reality. For most whale species, individuals are sighted well beyond the assumed distance of 0.5 km on each side of the trackline. Thus, the adopted approach will over-estimate the actual numbers of animals per km² because the linear estimates actually include animals beyond the 0.5 km strip width. On the other hand, all surveys fail to detect a portion of the animals that are actually present on the surface or underwater. Therefore, the approach adopted here accounts for an unkown fraction of the missed animals. Because these biases cannot be quantified, it is important to treat the following numerical assessments as approximations.

Mysticetes or Baleen Whales

Six species of baleen whale (North Atlantic right, humpback, blue, fin, sei, and minke) regularly occur in the Massachusetts Bay area. Of the six species, only the minke is not listed as endangered. Because of their depleted status, blue whale sightings are rare throughout their range and are insufficient to calculate density indices , and hence are not discussed further.

Pulsive Sounds

Based on research summarized in Section 2, NMFS (1995, 2000) has developed criteria for allowable levels of noise to which baleen whales can be exposed without potentially affecting them. For pulsive sounds, NMFS requires that individual whales not be exposed to received levels of over 180 dB re 1 µPa (rms) and pinnipeds to levels over 190 dB to protect the animals from damaging noise levels. Received levels of over 160 dB may cause disturbance or "Level B" harassment. Level B harassment is defined by the Marine Mammal Protection Act as "*… disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering.*"

The only pulsive sounds from the Neptune Project would occur if pile driving is used to fix the eight anchors of each of the two unloading buoys. Based on the acoustic modeling in Section 3, it is predicted that the 180 dB contour would occur only out to a few tens of meters from the source of the pile-driving noise. Because of the general vessel activity that would occur in conjunction with the pile driving, it is safe to conclude that no baleen whales would approach close enough to be exposed to 180 dB levels. The 160-dB received level contour at a depth of 50 m (164 ft) is expected to extend no more than ~1.4 km (~0.75 nm) from the source, which might expose some baleen whales to disturbing levels. The maximum area ensonified by levels over 160 dB would be about 6 km². At the water surface and near the bottom, the received levels would be slightly lower. During the approximately two-weeks of pile-driving a very small number of baleen whales might briefly be exposed to potentially disturbing noise levels above 160 dB.

Transient Continuous Sounds

Two types of transient sounds will occur: the slow-moving pipeline installation operation and faster regular passages by the LNG carriers as they arrive at and leave the unloading buoys. The pipeline installation operation would occur only during a seven-week period during June and July 2009. The passages by the LNG carriers would occur every 4-8 days during the life of the project.

The responses of marine animals to continuous underwater sounds are poorly known and highly variable within and among species depending upon many circumstances. Based on a small number of experimental studies of baleen whales (see Chapter 2), it is indicated that baleen whales may exhibit overt disturbed behavior when exposed to continuous received noise levels of about 120 dB re 1µPa. Based on this research, NMFS has used a criterion of 120 dB as the level above which whales may be disturbed by continuous underwater noise. This criterion has been adopted in the present analysis.

Pipeline Installation Operations—During the pipeline installation operations along the flowline between the unloading buoys, the 120 dB re 1 µPa noise contour would extend from 7.1 to 11 km (3.8 to 5.9 nm) and encompass areas from 127 to 163 km² (37 to 47 nm ^{2}). Construction of the flowline would take 16 days within July to September 2009. Constuction of the Northern Pipeline Route would take 42 days during the June to September period. Received levels of 120 dB would extend out from 6.5 to 7.6 km (3.5 to 4.1 nm) and encompass areas ranging from 120 to 152 km² (35 to 44 nm^2). Noise over 120 dB associated with pipeline installation would extend to 3.9 to 4.2 km (2.1 to 2.3 nm) from the source and encompass areas of 49 to 52 km² (14 to 15 nm^2) (See Section 3 for details).

Based on the Department of the Navy's (2005) geospatial analysis model, the average density-indices of baleen whales in the Neptune area during summer are predicted to be as listed here (see Tables 4 and 5 in Section 1).

North Atlantic right whale	0.01-21.14 per 1000 km	
Humpback whale	13.85-27.71	"
Fin whale	0.00-16.45	"
Sei whale	0.00-17.27	"
Minke whale	0.00-4.66	"

Assuming that the adopted method of converting linear density-indices into areal density estimates is reasonable and assuming that the highest numbers of whales in the density-index ranges are present and that the largest area (163 km², 47 nm^2) is subject to 120 dB, then about 4 right whales, 4-5 humpback whales, 3 fin whales, 3 sei whales, and 1 minke whale would be subjected to potentially disturbing levels of noise during parts of a three-month period during the summer of 2009. There will undoubtedly be some turnover of individuals during the three-month period; thus, more individuals would be affected but for shorter periods assuming that the average density remains the same. There are no available quantitative data on turnover rates. Given the small numbers of baleen whales involved and the slowly moving nature of the pipeline installation operation, it is not likely that there would be any important effects on baleen whale populations or on individual whales.

LNG Carrier Transits—The LNG carriers would travel at half power (~8-10 kn) when they leave the shipping lanes and sail to the DWP. Power, and underwater noise, would be reduced as the carriers approach the DWP but, to be conservative in the assessment, we have used the modeled acoustic results for the half power case. Depending upon the season and the receiver depth, the distance that the 120-dB received level contour would extend from the carrier ranges from 2.4 to 2.8 km (1.3 to 1.5 nm) and the area encompassed ranges from 18 to 25 km² (5.2 to 7.3 nm^2). An animal close to the path of the ship would be exposed to levels above 120 dB for 20-25 minutes, whereas most other animals that are exposed would be exposed for much less time. Also, one carrier would arrive at one unloading buoy and another carrier would depart from the other unloading buoy every 4-8 days. Thus, the amount of time that any individual baleen whale would be likely to be exposed to disturbing noise is very small and probably inconsequential, particularly since most marine mammals habituate to regularly occurring, non-threatening ship passages.

Fixed-Location Continuous Sounds

Three types of underwater noise would occur at the fixed locations of the two unloading buoys. The first is the the sounds associated with the establishment of the suction piles during the construction phase. The other two type of noise at the unloading buoys are the sounds from the three thrusters on each carrier that would be used to position the carrier over the unloading buoy and the noises that would emanate from the carrier while it is fixed to the unloading buoy. The latter noises would be associated with the re-gasification process and with maintaining ship functions while moored with the main engines turned off.

Suction Piles at Unloading Buoys—Establishment of the suction piles piles at the unloading buoys will produce only low levels of underwater noise with no levels above the 120 dB criterion for continuous noise. There wil be no effects on baleen whales.

LNG Carrier Maneuvering at DWP—When a carrier arrives at the DWP, it would use its thrusters for 10-30 minutes to position the ship to connect to the mooring and unloading buoy. This would occur at alternate unloading buoys every 4-8 days because only one unloading buoy is occupied at a time, with a small overlap at changeover. If it is assumed that the thrusters would be used every 6 days (mid-point of 4-8 days) on average and that the average period of use would be 20 minutes per session (mid-point of 10-30 minutes), then the total period of use of the thrusters over a full year would be only about 20 hours.

Operation of the thrusters would create higher noise levels than the other continuous project noise sources. The modeled scenario for the South Buoy with all three thrusters operating predicted that there would be an area ensonified by noise levels of over 120 dB ranging from 486 to 942 km^2 (142 to 274 nm^2) and extending out to 13.7 to 19.7 km (7.4 to 10.6 nm) from the source. Higher levels (up to 22.2 km and 1117 km^2) are expected to occur in winter when fewer whales are present (see Section 3). The corresponding numbers for the North Buoy are 12.7 to 21.0 km (29.1 km in winter) and 427 to 920 km^2 (1699 km^2 in winter). Based on the U.S. Navy's (2005) geospatial analysis model, the average density-indices of baleen whales in the Neptune area during the whole year are predicted to be as listed here (see Tables 4 and 5 in Section 1).

North Atlantic right whale	0.01-21.14 per 1000 km	
Humpback whale	13.85-27.71	“
Fin whale	0.00-16.45	“
Sei whale	0.00-17.27	“
Minke whale	0.00-4.66	“

Assuming that the highest numbers of whales in the ranges are present all year and that the largest area (942 km^2, 274 nm^2) is subject to 120 dB, then about 20 right whales, 26 humpback whales, 15 fin whales, 15 sei whales, and 4 minke whales would be subjected to potentially disturbing levels of noise during each exposure over the course of the year. The higher received noise levels in winter would occur when numbers of whales in Massachusetts Bay are reduced; thus, no adjustment in the numbers animals affected is made for the winter data. Again, there are no data on turnover rates, making it impossible to determine the number of different whales that might be exposed to the noise. Given the relatively small numbers of baleen whales involved, the small amount of exposure (20 hours per year) and the fixed locations of the noises sources, it is not likely that there would be any important effects on baleen whale populations or on individual whales from the use of thrusters to maneuver the carrier at the unloading buoys.

Re-Gasification—This section discusses noise that would emanate from the carrier while it was fixed to the unloading buoy. These noises would be associated with the regasification process and with maintaining ship functions while moored with the main engines turned off. Except during exceptionally severe weather conditions, there would always be a carrier at one of the unloading buoys during the life of the project.

The noise levels of the regasification process are quite low and barely reach 110 dB in the water near the vessel. There would be no situations in which the noise level would exceed 120 dB even a few meters from the vessel. Therefore, there would be no effects on baleen whales.

Gas Pipeline-The natural gas pipeline is expected to generate noise levels that are only detectable out to about 200 m distance. The levels would be well below the 120 dB required to disturb whales.

Odontocetes or Toothed Whales

There are about 11 species or species-groups of odontocetes that occur in the Neptune area. Some of these, such as the sperm whale and the beaked whales, are deepwater species that would be very rare in the Neptune area.

Pulsive Sounds

The safety criteria used for baleen whales are also applied to toothed whales by NMFS. The only pulsive sounds from the Neptune Project would occur if pile driving was used to fix the eight anchors of each of the two unloading buoys. Based on the acoustic modeling in Section 3, it is predicted that the 180-dB contour would occur at a few tens of meters from the source of the pile-driving noise. Because of the general vessel activity that would occur in conjunction with the pile driving, it is safe to conclude that no toothed whales would approach close enough to be exposed to 180-dB levels during the 15-day period when pile driving would be conducted. The 160-dB received level contour used to minimize disturbance is expected to extend no more than ~1.4 km (~0.75 nm), at a depth of 50 m (164 ft), from the source, which would reduce exposure by toothed whales to disturbing noise levels. It is possible that a few curious odontocetes or pods of odontocetes could approach within 1.4 km of the pile driving operation where they might be disturbed.

Transient Continuous Sounds

Pipeline Installation Operations—The pipeline installation operations are summarized in the discussion of baleen whales. The density-indices for the most common odontocetes expected to be in the Neptune area are listed below based on Table 4 and 5 in Section 1.

Long-finned pilot whale	0.01-271.42 per 1000 km	
Atlantic white-sided dolphin	0.00-265.21	“
Harbor Porpoise	0.00-162.36	“

In addition, bottlenose dolphins, Risso’s dolphins, and common dolphins occur in Massachusetts Bay and may come inshore to the Neptune area on occasion. Dolphin distribution is generally patchy with a few large pods being present rather than an even distribution.

The same assumptions used for baleen whales are employed here; i.e., largest area affected by 120 dB noise (163 km², 47 nm^2) and the upper end of the density range. With these assumptions, the following numbers of odontocetes could be exposed to disturbing noise levels over the three-month summer period in 2009: 44 pilot whales, 43 white-sided dolphins, and 26 harbor porpoises. Pods of odontocetes are often fast moving and do not stay in the small areas discussed here for very long. Therefore, different pods may be exposed to the noise during the three-month construction period, but each pod is likely to be exposed for only a short period. There are no data on turnover rates, but the overall number of whale-days of exposure might be well represented by the numbers calculated here.

LNG Carrier Transits—As noted for baleen whales, the distance that the 120-dB received level contour would extend from the carrier ranges from 2.4 to 2.8 km (1.3 to 1.5 nm) and the area encompassed ranges from 18 to 25 km^2 (5.2 to 7.3 nm^2). An animal close to the path of the ship would be exposed to levels above 120 dB for 20-25 minutes, whereas most other animals that are exposed would be exposed for much less time. Also, one carrier would arrive at one unloading buoy and another carrier would depart from the other unloading buoy every 4-8 days. Thus, the amount of time that any individual toothed whale would be likely to be exposed to disturbing noise is very small and probably inconsequential. This is particularly so for dolphins, which often approach moving ships quite closely.

Fixed Location Continuous Sounds

Suction Piles at Unloading Buoys—Establishment of the suction piles piles at the unloading buoys will produce only low levels of underwater noise with no levels above the 120 dB criterion for continuous noise. There wil be no effects on toothed whales.

LNG Carrier Maneuvering at DWP—In the discussion of baleen whales, it was assumed that the thrusters would be used every 6 days (mid-point of 4-8 days) on average and that the average period of use would be 20 minutes per session (mid-point of 10-30 minutes), yielding a total period of use of the thrusters over a full year of about 20 hours. The modeled acoustic scenario for the South Buoy with all three thrusters operating predicted that there would be an area ensonified by noise levels of over 120 dB ranging from 486 to 942 km^2 (142 to 274 nm^2) and extending out to 13.7 to 19.7 km (7.4 to 10.6 nm) from the source. Higher levels (up to 22.2 km and 1117 km^2) are expected to occur in winter when fewer whales are present (see Section 3). The corresponding numbers for the North Buoy are 12.7 to 21.0 km (29.1 km in winter) and 427 to 920 km^2 (1699 km^2 in winter). Based on the Department of the Navy's (2005) geospatial analysis model, the average densities of toothed whales in the Neptune area during the year are predicted to be as listed here (see Tables 4 and 5 in Section 1).

Long-finned pilot whale	0.01-271.42	per 1000 km
Bottlenose dolphin (fall only)	0.03-278.81	"
Atlantic white-sided dolphin	0.00-265.21	"
Risso's Dolphin (fall only)	0.00-503.06	"
Common Dolphin (fall only)	0.00-464.07	"
Harbor Porpoise	0.00-162.36	"

Again, it should be remembered that dolphin distribution is generally patchy with a few large pods being present rather than an even distribution.

Assuming that the highest numbers of odontocetes in the range are present and that the largest area (942 km^2, 274 nm^2) is subject to 120 dB, then about 255 pilot whales, 249 white-sided dolphins, and 153 harbor porpoises would be subjected to potentially disturbing levels of noise during each exposure over the course of a year. During the fall period, an additional 262 bottlenose dolphins, 473 Risso's dolphins, and 436 common dolphins might be exposed during this three-month period. The higher received noise levels in winter would occur when numbers of whales in Massachusetts Bay are reduced; thus, no adjustment in the numbers animals affected is made for the winter data. Again, there are no data on turnover rates, making it impossible to determine the number of different odontocetes that might be exposed to the noise. Given the patchy distribution of odontocetes involved, the small amount of exposure (20 hours per year), and the fixed locations of the noises sources, it is not likely that there would be any important effects on odontocete populations or on individual animals caused by the proposed use of thrusters to maneuver the carrier at the unloading buoys.

Re-Gasification—As noted for baleen whales, the noise levels of the re-gasification process are quite low and barely reach 110 dB in the water near the vessel. There would be no situations in which the noise level would exceed 120 dB even a few meters from the vessel. Therefore, there would be no effects on toothed whales.

Gas Pipeline-The natural gas pipeline is expected to generate noise levels that are only detectable out to about 200 m distance. The levels would be well below the 120 dB required to disturb toothed whales.

Pinnipeds or Seals

Only two species of seal, the harbor seal and gray seal, regularly occur in the Massachusetts Bay area. The harbor seal is much more common in the Neptune area but it is absent from that area during the summer.

Pulsive Sounds

The NMFS (1995, 2000) criterion to protect pinnipeds from damaging pulsive noise levels is that individual seals should not be exposed to received levels of over 190 dB re 1 µPa (rms). Received levels of over 160 dB may cause disturbance or “Level B” harassment.

The only pulsive sounds from the Neptune Project would occur if pile driving was used to fix the eight anchors of each of the two unloading buoys. Based on the acoustic modeling in Section 3, it is predicted that the 190-dB contour would not occur at any distance from the source of the pile-driving noise. Thus, there would be no damage to seals from the noise associated with pile driving. The 160-dB received level contour is expected to extend no more than ~1.4 km from the source, which again would likely preclude exposure of many seals to disturbing levels. This is particularly true in this case because seals are essentially absent from the Neptune area during summer when the pile driving would occur.

Transient Continuous Sounds

Pipeline Installation Operations—These operations are summarized in the discussion of baleen whales. Because the pipeline installation operations would occur during the summer when seals are essentially absent from the Neptune area, there would be no effects on seals.

LNG Carrier Transits—As noted for baleen whales, the distance that the 120-dB received level contour would extend from the carrier ranges from 2.4 to 2.8 km (1.3 to 1.5 nm) and the area encompassed ranges from 18 to 25 km² (5.2 to 7.3 nm^2). An animal close to the path of the ship would be exposed to levels above 120 dB for 20-25 minutes, whereas most other animals that are exposed would be exposed for much less time. Also, one carrier would arrive at one unloading buoy and another carrier would depart from the other unloading buoy every 4-8 days. Thus, the amount of time that any individual seal would be likely to be exposed to disturbing noise is very small and probably inconsequential. This is particularly so for harbor seals, which are well habituated to the presence of humans, fishing boats, and ships in Massachusetts Bay and in many other coastal areas of North America.

Fixed Location Continuous Sounds

Suction Piles at Unloading Buoys—Establishment of the suction piles piles at the unloading buoys will produce only low levels of underwater noise with no levels above the 120 dB criterion for continuous noise. There wil be no effects on pinnipeds.

LNG Carrier Maneuvering at DWP—In the discussion of whales, it was calculated that the thrusters would be used for only about 20 hours per year. Noise emanating from the maneuvering operation would ensonify an area with noise levels of over 120 dB ranging from 524 to 1,699 km² (153 to 495 nm^2) and extending out to 13.8 to 29.1 km (7.5 to 15.7 nm) from the source (see Section 3). According to the Department of the Navy's (2005) geospatial analysis model, the only seal that regularly occurs in the Neptune area is the harbor seal in winter (see Tables 4 and 5 in Section 1). Using the assumptions developed for whales, it can be calculated that about 112 harbor seals would be exposed to noise levels above 120 dB during winter. Given the infrequency of the use of the thrusters and the observed ability of harbor seals to habituate to human activities including noise, it is unlikely that that there would be any deleterious effects on the harbor seal population or on individual seals from the maneuvering operations of the LNG carriers.

Re-Gasification—As noted for baleen whales, the noise levels of the re-gasification process are quite low and barely reach 110 dB in the water near the vessel. There would be no situations in which the noise level would exceed 120 dB even a few meters from the vessel. Therefore, there would be no effects on seals when the carriers are moored and undertaking the re-gasification process.

Gas Pipeline-The natural gas pipeline is expected to generate noise levels that are only detectable out to about 200 m distance. The levels would be well below the 120 dB required to disturb seals.

Sea Turtles

Two species of sea turtle occur in the Neptune area and Massachusetts Bay in summer (see Section 1). The leatherback turtle was not recorded on systematic surveys in the Neptune area but was found with density-indices of 0-3.46 per 1000 km in the Massachusetts Bay area. The loggerhead turtle was recorded at densities of 0.00-47.27 per 1000 km in the Neptune area (U.S. Navy 2005).

The effects of underwater noise on sea turtles are not well studied. There are no safety criteria for sea turtles similar to those used by NMFS for marine mammals.

Pulsive Sounds

There is very little information available on the responses of sea turtles to pulsed sounds. The available information comes from experiments using seismic airguns. Avoidance out to 30 m (98 ft) was demonstrated in loggerhead turtles in a 10-m (33-m) deep canal exposed to seismic airgun sounds (O'Hara and Wilcox 1990). The airguns used in that study produced a sound with its strongest components at a frequency of 25 Hz, with some frequencies up to 1 kHz. Although those authors did not report received sound pressure levels, McCauley et al. (2000), using a similar sound source, estimated that the received sound pressure levels in the O'Hara and Wilcox (1990) study would have been on the order of 175–176 dB re 1 μPa rms.

McCauley et al. (2000) observed the responses of a caged green turtle and a loggerhead turtle to the approach and retreat of an operating seismic airgun. Those animals noticeably increased their swimming activity above a source level of approximately 166 dB re 1 μPa rms. Above 175 dB re 1 μPa rms their behavior became more erratic, possibly indicating an agitated state. The turtles spent increasingly more time swimming as the airgun level increased. The point at which the turtles showed the more erratic behavior likely indicates the point at which avoidance would occur for unrestrained turtles. To be conservative, it is assumed here that 170 dB represents the threshold at which pulsive sounds elicit a disturbance response in sea turtles. Received noise levels of 170 dB would occur only a few meters from the pile-driving operation and are not expected to have any deleterious effects on the few sea turtles that might be present in the area.

Continuous Sounds

The only information available on sea turtle reactions to continuous sound sources comes from one study of captive loggerhead turtles. In that study, resting turtles reacted to low-frequency (20–80 Hz) continuous tones projected into their tank by swimming to the surface and remaining there (Lenhardt 1995). These "startle responses" were elicited using sound vibrations in the tank. There are no data on the disturbance responses of free-swimming, wild sea turtles. Sea turtles are low-frequency hearing specialists similar to baleen whales, which have disturbance criteria for pulsive sounds of 160 dB and continuous sounds of 120 dB, or a difference of 40 dB. Based on very limited data, it appears that pulsive sounds of 175 dB are necessary to disturb sea turtles. A 40-dB difference in pulsive to continuous response ratio for sea turtles would establish a received level for continuous sounds of about 135 dB to elicit disturbance responses by sea turtles. A disturbance response threshold of 130 dB is used in the following analyses.

Pipeline Installation Operations—During the pipeline installation operations along the flowline between the unloading buoys, the 130 dB re 1 μPa noise contour would extend from 3.7 to 9.4 km (2.0 to 5.1 nm) and encompass areas from 21 to 26 km² (6.1 to 7.6 nm^2). Construction of the flowline would take 16 days within July to September 2009. Constuction of the Northern Pipeline Route would take 42 days during the June to September period. Received levels of 130 dB would extend out from 2.8 to 3.2 km (1.5 to 1.7 nm) and would encompass areas ranging from 27 to 32 km² (7.9 to 9.3 nm^2). Noise over 130 dB associated with dredging for pipeline installation would extend out to 1.7 km (0.9 nm) from the source and encompass an area of 8 km² (2.3 nm^2) (See Section 3 for details).

As noted earlier, the high end of the density estimate for loggerhead turtles in the Neptune area during summer was 47.27 per 1,000 km. Assuming a maximum area (32 km², 9.3 nm^2) ensonified by received levels above 130 dB and assuming that the maximum density of turtles is present and evenly distributed, then about 2 loggerhead turtles would be present in the area ensonified by potentially disturbing noise levels. Leatherback turtles were present in Massachusetts Bay but not in the Neptune area (U.S. Navy 2005) during summer. It is concluded, based on the small area ensonified, the small number of turtles that might be disturbed, and the single summer of activities, that the effects of noise from the pipeline installation operations would be negligible on turtle populations and on individual turtles.

LNG Carrier Transits—The LNG carriers would travel at half power (~8-10 kn) when they left the shipping lanes and sailed to the DWP. For all seasons and receiver depths, the distance that the 130-dB received level contour would extend from the carrier ranges to about 600 m (~2,000 ft) and the area encompassed ranges from 1 to 2 km² (0.3 to 0.6 nm^2). One carrier would arrive at one unloading buoy and another carrier would depart from the other unloading buoy every 4-8 days. Thus, the amount of time that any individual sea turtle would be likely to be exposed to disturbing noise is exceedingly small and undoubtedly inconsequential.

Suction Piles at Unloading Buoys—Establishment of the suction piles piles at the unloading buoys will produce only low levels of underwater noise with no levels above the 120 dB criterion for continuous noise. There wil be no effects on sea turtles.

LNG Carrier Maneuvering at DWP—When a carrier arrived at the DWP, it would use its thrusters for 10-30 minutes to position the ship. This would occur at alternate unloading buoys every 4-8 days because only one unloading buoy is occupied at a time, with a small overlap at changeover. If it is assumed that the thrusters would be used every 6 days (mid-point of 4-8 days) on average and that the average period of use would be 20 minutes per session (mid-point of 10-30 minutes), then the total period of use of the thrusters over the three-month summer would be only about 5 hours.

Operation of the thrusters would create higher noise levels than the other continuous project noise sources. The modeled scenario with all three thrusters operating predicted that there would be an area in summer ensonified by noise levels of over 130 dB ranging from 187 to 215 km² (55 to 63 nm^2) and extending out to 8.1 to 8.8 km (4.4 to 4.8 nm) from the source (see Section 3). As noted earlier, the high end of the density-index range for loggerhead turtles in the Neptune area during summer was 47.27 per 1000 km. Assuming a maximum area (215 km²) ensonified by received levels above 130 dB and assuming that the maximum density of turtles is present and evenly distributed, then about 10 loggerhead turtles would be present in the area ensonified by potentially disturbing noise levels. Leatherback turtles were present in Massachusetts Bay but not in the Neptune area (U.S. Navy 2005) during summer. It is concluded, based on the relatively small area ensonified, the small number of turtles that might be disturbed, and the infrequency (10-30 minutes every 4-8 days) of the noises, that the effects of the noise from the maneuvering operations of the LNG carriers would be negligible on turtle populations and on individual turtles.

Re-Gasification—This section discusses noise associated with the re-gasification process and with maintaining ship functions while moored with the main engines turned off. Except during exceptionally severe weather conditions, there would always be a carrier at one of the unloading buoys during the life of the project.

The noise levels of the re-gasification process are quite low and barely reach 110 dB in the water near the vessel. There would be no situations in which the noise level would exceed 120 dB, much less 130 dB, even a few meters from the vessel. Therefore, there would be no effects on sea turtles.

Gas Pipeline-The low noise from the pipeline would have no effect on sea turtles.

It should be emphasized that there are no data on the disturbing effects of continuous underwater noise on free-swimming sea turtles. The criterion used in the above analyses is reasonable but arbitrary.

Marine Fish

The main species of fish in the Neptune area are discussed in Section 1 and the known effects of underwater noise on fish are reviewed in Section 2. The noise levels that are necessary to cause temporary hearing loss and damage to hearing are higher and last longer than noise produced during the Neptune Project. The situation for disturbance responses is less clear. Fish do react to underwater noise from vessels and move out of the way, move to deeper depths, or change their schooling behavior. The received levels at which fish react are not known and apparently are somewhat variable depending upon circumstances and species of fish.

In order to assess the possible effects of underwater project noise, it is best to examine project noise in relation to continuous noises routinely produced by other projects and activities such as shipping, fishing, etc. and pulsive noises produced by seismic exploration.

Pulsive Sounds

The pulsive sounds produced during pile driving for the Neptune project are much less intense than the pulses from the air guns used in offshore seismic surveys by the oil and gas industry. Such surveys routinely have source levels of 250 dB re 1 µPa at 1 m. The corresponding source level for the Neptune pile driving would be several orders of magnitude less at 206 dB. The available information suggests that seismic exploration has minimal effects on fish and fisheries, although there are some conflicting data. It is highly unlikely that the low levels of pulsed noise from the Neptune pile driving for a period of 15 days would have any effect on fish populations in the area.

Continuous Noise

The two long-term sources of continuous noise associated with the project are the ship transits between the Boston shipping lanes and the unloading buoys and the re-gasification process at the carriers when moored to the unloading buoys. As discussed in Section 3 and earlier in this section, the noise levels associated with these two activities are relatively low and unlikely to have any effect on biological resources of the area.

Two other activities produce short periods of continuous noise. These are the pipeline installation activities and the carrier maneuvering bouts at the DWP. These are louder activities, although still less than the noise levels associated with large ships at cruising speed. The pipeline installation operations would occur only during a three-month period in one summer. The carrier maneuvering using the ship's thrusters would produce short periods of louder noise for 10-30 minutes every 4-8 days. On average, these thruster noises would be heard about 20 hours per year. Even in the unlikely event that these two activities caused disturbance to marine fish, the short periods of time involved serve to minimize the effects.

Marine Invertebrates

As reviewed under Marine Fish, the Neptune Project is generally a low noise project. Also, marine invertebrates do not hear noise in the same way that vertebrates do, rather they detect pressure changes, usually at fairly close range. This combination makes it unlikely that noise from the Neptune Project would have any effect on populations of marine invertebrates. A special case is discussed below.

Potential Effects of the Gas Transmission Pipeline on American Lobsters

A special situation of concern is the potential for the natural gas pipeline to affect lobster populations and harvests. There are three aspects of the proposed gas transmission pipeline that could potentially have some effect on lobsters. They are: (1) the physical barrier to lobster movement, (2) the emission of continuous sound, and (3) the generation of an electromagnetic field.

A recent study conducted off Nova Scotia, Canada, investigated the potential effects of operational compressed natural gas pipelines/gathering lines on the behavior of American lobsters (Martec Limited 2004). It is known that operational pipelines emit sound, generate electromagnetic fields, and may act as physical barriers to mobile epibenthos. Acoustic measurements conducted during the investigation indicated sound pressure level peaks at frequencies ranging from 34 to 100 Hz, well within the sound detection frequency range of crustaceans such as lobster. Pipeline sounds were detected on both sides of the pipeline out to a distance of 200 m. The maximum measured SPLs were approximately 10 dB above the ambient sound pressure level.

It is unlikely that noise from the proposed gas transmission pipeline would negatively impact the movements and behaviors of American lobsters occurring in the area.

Assessment of Overall Effects of Underwater Noise

The previous sections have analyzed the likely effects of underwater noise from each of the project components. Of more interest, however, is an assessment of the probable combined effects of all of the project elements. The three phases of the project, Construction, Operation, and Decommissioning will occur consecutively with no overlap in activities. None of the project activities are likely to generate underwater noise that would affect marine fish and invertebrates. Possible effects on other species are discussed below.

During construction, the project activities would occur over a three-month period with noise from pipeline construction causing some possible disturbance to small numbers of baleen whales (<20), odontocete whales (~100), and (~2) loggerhead turtles. Pinnipeds are unlikely to be present during summer and would not be affected. The installation of the suction piles would produce only low levels of noise during the construction period and would not increase the numbers of animals affected. If it is necessary to use conventional impact pile-driving, then potentially disturbing levels of pulsive noise would extend out for 1-2 km, which is well within the potential zone of disturbance of the pipeline installation activities. Thus, pile-driving will not likely increase the numbers animals affected by the construction activities.

During the operational life of the project, marine animals would be exposed to noise from the carriers in transit at half speed, the sounds of thrusters positioning the carriers at the unloading buoys, and the sounds associated with the regasification process. The latter two activities would occur at each of the two fixed location unloading buoys. The noise from the regasification process is low and does not reach the 120 dB re 1µPa (rms) disturbance criterion for continuous noise. Thus, the brief bursts (10-30 minutes) of noise associated with use of thrusters to position the ships are the only noises that would disturb marine animals at the unloading buoys. The thruster noise could affect a maximum of about 80 baleen whales, 1170 toothed whales, ~110 harbor seals (winter), and ~10 loggerhead turtles. It is concluded that because of the short duration of each episode and their infrequent occurrence (every 4-8 days), that there would little long-term effect on the individual animals and no effects on populations. The LNG carriers traveling at half speed between the shipping lanes and unloading buoys generate only low amounts of noise that would produce disturbing levels only out to ~2.8 km. Thus, small numbers of animals might be disturbed for a short period (<30 min) by each passage an LNG carrier. However, given the ability of most marine mammals to habituate to non-threatening passages by commercial vessels, it is not likely that there will be any serious effects on the individuals that are potentially disturbed.

The decommissioning phase would not generate significant levels of underwater noise and no effects on marine animals are expected.

Requirements under MMPA and ESA

Many marine projects in U.S. waters or involving U.S. citizens in international waters require "incidental take" authorizations under the Marine Mammal Protection Act (MMPA). These authorizations have not usually been required for shipping operations but there are unique elements of the Neptune Project that go beyond a purely shipping project. The following discussion addresses the need for MMPA authorizations during Construction, Operation, and Decommissioning phases of the project.

Construction

The main project activities during Construction relate to the installation of the pipeline during a three-month period in 2009. In addition, the anchors will be fixed to the bottom using suction piles. It is possible that use of suction piles will not be feasible necessitating the use of conventional impact pile-driving. The piles will be set over a two-week period within the period of pipeline installation.

It will likely be necessary to apply for an Incidental Harassment Authorization (IHA) under the MMPA because there will be situations where underwater noise levels will be elevated above the selected criteria of 120 dB re 1µPa (rms) for continuous noise sources. If impact pile-driving becomes necessary, then the areas near the piles will be ensonified above 160 dB re 1 µPa (rms), the relevant criterion for impulsive sounds, and an IHA will be required. If it is decided to petition for issuance of 5-year regulations to authorize "takes" of marine mammals during Operation (see below), then the "takes" during Construction could also be authorized under those Regulations, and a separate IHA for the Construction phase might not be required.

Operation

The shipping noise associated with the project is not substantial once the vessels leave the commercial shipping lanes. Also, noise levels will be low when the LNG carriers are attached to the unloading buoys and the re-gasification process is underway. If these were the only two activities associated with operations, then authorizations under the MMPA would probably not be necessary. However, the use of the ship's thrusters to position the vessels at the unloading buoys will generate brief periods of increased continuous noise that will exceed 120 dB re 1 µPa (rms) out to a radius of a few km around the buoys. Although these brief bursts of noise would total no more than about 24 hours in any one year, it will likely be necessary to petition for five-year regulations under the MMPA. With five-year regulations in place, then a Letter of Authorization (LOA) could be issued by NMFS each year.

The authorizations discussed above apply to marine mammals and are required under the MMPA and the associated implementing regulations at 50 C.F.R. 216.100-108. In practice, applications for these authorizations (or the EIS or EA that is normally required in support of the MMPA application) must address sea turtles. Sea turtles, like several of the relevant species of marine mammals, are listed under the Endangered Species Act, and that triggers the requirement for a Section 7 consultation under the Endangered Species Act (ESA). No specific take regulations have been issued under the ESA.

It should be pointed out that in applications for IHAs and LoAs, it is necessary to propose monitoring and mitigation measures, and there is a requirement to implement these, and to report on them.

Decommissioning

There is no requirement for an authorization under the MMPA for the decommissioning of the Neptune Project because the associated noise levels are not expected to disturb marine mammals or sea turtles.

Bibliography/References

Acevedo, A. 1991. Interactions between boats and bottlenose dolphins, *Tursiops truncatus*, in the entrance to Ensenada De La Paz, Mexico. Aquat. Mamm. 17(3):120-124.

Akamatsu, T., Y. Hatakeyama and N. Takatsu. 1993. Effects of pulsed sounds on escape behavior of false killer whales. Nippon Suisan Gakkaishi 59: 1297-1303.

Akamatsu, T., Y. Matsushita, Y. Hatakeyama, and Y. Inoue. 1996. Startle response level of Japanese anchovy *Engraulis japonicus* to underwater pure tone signals. Fish. Sci. 62(4):648-649.

Akamatsu, T., K. Nakamura, H. Nitto and M. Watabe. 1996. Effects of underwater sounds on escape behavior of steller sea lions. Fish. Sci. 62(4):503-510.

Akamatsu, T., A. Nanami, and H.Y. Yan. 2003. Spotlined sardine *Sardinops melanostictus* listens to 1-kHz sound by using its gas bladder. Fish. Sci. 69: 348-354.

Alerstam, T. 2003. The lobster navigators. Nature 421(2): 27-28.

Amoser, S. and F. Ladich. 2003. Diversity in noise-induced temporary hearing loss in otophysine fishes. J. Acoust. Soc. Am. 113(4): 2170-2179.

Amoser, S., L.E. Wysocki, and F. Ladich. 2004. Noise emission during the first powerboat race in an alpine lake and potential impact on fish communities. J. Acoust. Soc. Am. 116(6): 3789-3797.

Andersen, S. 1970. Auditory sensitivity of the harbour porpoise *Phocoena phocoena*. pp. 255-259. In: Pilleri, G., ed. Investigations on Cetacea. Volume II. Berne-Bümpliz, Berne, Switzerland.

Anonymous. 1948. Effects of underwater explosions on oysters, crabs and fish. Preliminary report. Chesapeake Biological Laboratory, Publication No. 70.

Anonymous. 1962. Tests to investigate effects of seismic explosions on flatfish and crabs. Fish Commission, State of Oregon.

Anonymous. 1975. Phantom killer whales. S. Afr. Ship. News Fish. Ind. Rev. 30: 50-53.

Aplin, J.A. 1947. The effects of explosives on marine life. California Department of Fish and Game 33(1): 23-30.

Aquanaut. 2004. Bioacoustics Background, Procedures, and Charts, available on the Aquanaut Program website, http://ap.nurc.uconn.edu/Acoustics/AP%202004%20Acoustics/acoustics%20index.htm

Archer, F.I., 2nd. 2002. Striped dolphin *Stenella coeruleoalba*. p. 1201-1203 *In:* W.F. Perrin, B. Würsig and J.G.M. Thewissen (eds.), Encyclopedia of Marine Mammals. Academic Press, San Diego, CA. 1414 p.

Arnold, B.W. 1996. Visual monitoring of marine mammal activity during the Exxon 3-D seismic survey/Santa Ynez Unit, offshore California/9 November to 12 December 1995.

Rep. from Impact Sciences Inc., San Diego, CA, for Exxon Co. U.S.A., Thousand Oaks, CA. 25 p.

Arveson, P.T. and D.J. Vendittis. 2000. Radiated noise characteristics of a modern cargo ship. Journal of the Acoustical Society of America 107(1):118-129.

Aspen Environmental Group. Monterey Accelerated Research System Cabled Observatory EIR/EIS, March 2005. Chapter 4. p4.8-6.

Astrup, J. and B. Møhl. 1998. Discrimination between high and low repetition rates of ultrasonic pulses by the cod. J. Fish Biol. 52: 205-208.

Atkins, N. and S.L. Swartz. 1989. Proceedings of the workshop to review and evaluate whale watching programs and management needs/November 14-16, 1988, Monterey, California. Center for Marine Conservation, Washington, DC. 53 p.

Au, W.W.L. 1993. The Sonar of Dolphins. Springer-Verlag, New York, NY. 277 p.

Au, W.W.L. 2000. Hearing in whales and dolphins: an overview. p. 1-42. In: W.W.L. Au, A.N. Popper, and R.R. Fay (eds.), Hearing by Whales and Dolphins. Springer Handbook of Auditory Research Volume 12. Springer-Verlag, New York.

Au, W.W.L. and K. Banks 1998. The acoustics of snapping shrimp *Synalpheus parneomeris* in Kaneohe Bay. J. Acoust. Soc. Am. 103: 41-47.

Au, W.W.L. and P.W.B. Moore. 1988. Detection of complex echoes in noise by an echolocating dolphin. J. Acoust. Soc. Am. 83: 662-668.

Au, W.W.L., and P.W.B. Moore. 1990. Critical ratio and critical bandwidth for the Atlantic bottlenose dolphin. J. Acoust. Soc. Am. 88: 1635-1638.

Au, D. and W. Perryman. 1982. Movement and speed of dolphin schools responding to an approaching ship. Fish. Bull 80(2):371-379.

Au, W.W.L., D.A. Carder, R.H. Penner and B.L. Scronce. 1985 . Demonstration of adaptation in beluga whale echolocation signals. J. Acoust. Soc. Am. 77: 726-730.

Au, W.W.L., Lemonds, D.W., Vlachos, S., P.E. Nachtigall and H.L. Roitblat. 2002. Atlantic bottlenose dolphin (*Tursiops truncatus*) hearing threshold for brief broadband signals. J. Compar. Psychol. 116(2):151-157.

Au, W.W.L., P.E. Nachtigall and J.L. Pawloski. 1997. Acoustic effects of the ATOC signal (75 Hz, 195 dB) on dolphins and whales. J. Acoust. Soc. Am. 101(5):2973-2977.

Au, W.W.L., P.E. Nachtigall and J.L. Pawloski. 1999 Temporary threshold shift in hearing induced by an octave band of continuous noise in the bottlenose dolphin. J. Acoust. Soc. Am. 106: 2251.

Au, W.W.L., R.A. Kastelein, T. Rippe and N.M. Schooneman. 1999. Transmission beam pattern and echolocation signals of harbor porpoise (*Phocoena phocoena*). J. Acoust. Soc. Am. 106(6):3699-3705.

Au, W.W.L., R.W. Floyd, R.H. Penner and A.E. Murchison. 1974. Measurement of echolocation signals of the Atlantic bottlenose dolphin, *Tursiops truncatus* Montagu, in open waters. J. Acoust. Soc. Am. 56: 1280-1290.

Awbrey, F.T., J.A. Thomas and R.A. Kastelein. 1988. Low-frequency underwater hearing sensitivity in belugas, *Delphinapterus leucas*. J. Acoust. Soc. Am. 84(6):2273-2275.

Bain, D.E. and M.E. Dahlheim. 1994. Effects of masking noise on detection thresholds of killer whales. p. 243-256. In: T.R. Loughlin (ed.), Marine Mammals and the Exxon Valdez. Academic Press, San Diego, CA. 395 p.

Bain, D.E., B. Kriete and M.E. Dahlheim. 1993. Hearing abilities of killer whales (*Orcinus orca*). J. Acoust. Soc. Am. 94: 1829.

Baraff, L.S. and T.R. Loughlin. 2000. Trends and potential interactions between pinnipeds and fisheries of New England and the U.S. west coast. **Mar. Fish. Rev.** 62(4):1-39

Barlow, J. 1988. Harbor porpoise, *Phocoena phocoena*, abundance estimation for California, Oregon, and Washington. I: Ship surveys. Fish. Bull. 86(3):417-432.

Bartol, S.M., J.A. Musick and M.L. Lenhardt. 1999. Auditory evoked potentials of the loggerhead sea turtle (*Caretta caretta*). Copeia 1999(3):836-840.

Bauer, G.B. 1986. The behavior of humpback whales in Hawaii and modifications of behavior induced by human interventions. Ph.D. Thesis, University of Hawaii. 314 p.

Bauer, G.B. and L.M. Herman. 1986. Effects of vessel traffic on the behavior of humpback whales in Hawaii. Rep. from Kewalo Basin Mar. Mamm. Lab., Honolulu, HI, for U.S. Nat. Mar. Fish. Serv., Honolulu, HI. 151 p.

Beach, D.W. and M.T. Weinrich. 1989. Watching the whales: is an educational adventure for humans turning out to be another threat for endangered species? Oceanus 32: 84-88.

Bel'kovich, V.M. 1960. Some biological observations on the white whale from the aircraft. Zool. Zh. 39(9): 1414-1422 (Transl. NOO-T-403. U.S. Naval Oceanogr. Office, Washington, DC. 14 p. NTIS AD-693583).

Bernard, H.J. and S.B. Reilly. 999. Pilot whales *Globicephala* Lesson, 1828. p. 245-279 *In:* S.H. Ridgway and R. Harrison (eds.), Handbook of Marine Mammals. Vol. 6. The Second Book of Dolphins and the Porpoises. Academic Press, San Diego, CA.

Bigg, M. 1981. *Phoca vitulina* Linnaeus, 1758 and *Phoca largha* Pallas, 1811. p. 1-27 *In:* S.H. Ridgway and R.J. Harrison (eds.), Handbook of Marine Mammals. Vol. 2. Seals. Academic Press, San Diego, CA.

Blane, J.M. and R. Jaakson. 1994. The impact of ecotourism boats on the St. Lawrence beluga whales. Environ. Conserv. 21(3):267-269.

Blaxter, J.H.S. 1981. The swimbladder and hearing. p. 61-69 *In:* W.N. Tavolga, A.N. Popper, and R.R. Fay (eds.) Hearing and Sound Communication in Fishes. Springer-Verlag New York Inc.

Blaxter, J.H.S., J.A.B. Gray and E.J. Denton. 1981. Sound and startle responses in herring shoals. J. mar. biol. Ass. UK 61:851-869.

Boles, L.C. and K.J. Lohmann. 2003. True navigation and magnetic maps in spiny lobsters. Nature 421(2): 60-63.

Bonner, W.N. 1981. Grey seal *Halichoerus grypus* Fabricius, 1791. p. 111-144 *In:* S.H. Ridgway and R.J. Harrison (eds.), Handbook of Marine Mammals. Vol. 2. Seals. Academic Press, San Diego, CA.

Booman, C., J. Dalen, H. Leivestad, A. Levsen, T. van der Meeren and K. Toklum. 1996. Effecter av luftkanonskyting på egg, larver og yngel. Fisken Og Havet 1996(3):1-83 (Norwegian with English summary).

Bowles, A. and B.S. Stewart. 1980. Disturbances to the pinnipeds and birds of San Miguel Island, 1979-1980. p. 99-137. In: J.R. Jehl, Jr., and C.F. Cooper (eds.), Potential effects of space shuttle sonic booms on the biota and geology of the California Channel Islands: Research reports. Tech. Rep. 80-1. Rep. from Cent. Mar. Stud., San Diego State Univ., and Hubbs/Sea World Res. Inst., San Diego, CA, for U.S. Air Force, Space Div. 246 p.

Bowles, A.E., M. Smultea, B. Würsig, D.P. DeMaster and D. Palka. 1994. Relative abundance and behavior of marine mammals exposed to transmissions for the Heard Island feasibility test. J. Acoust. Soc. Am. 96: 2469-2484.

Bowles, A.E., M. Smultea, B. Würsig, D.P. DeMaster and D. Palka. 1994. Relative abundance and behavior of marine mammals exposed to transmissions from the Heard Island Feasibility Test. J. Acoust. Soc. Am. 96(4):2469-2484.

Breithaupt, T. 2002. Sound perception in aquatic crustaceans. In: (ed.) K. Wiese. The Crustacean Nervous System, Springer-Verlag, Berlin-Heidelberg, Germany. Pp. 548-558.

Breithaupt, T. and J. Tautz. 1990. The sensitivity of crayfish mechanoreceptors to hydrodynamic and acoustic stimuli. p. 114-120 *In:* K. Wiese, W.D. Krenz, J. Tautz, H. Reichert, and B. Mulloney, (eds). Frontiers in Crustacean Neurobiology. Birkhäuser, Basel.

Brill, R.L., P.W.B. Moore and L.A. Dankiewicz. 2001. Assessment of dolphin (*Tursiops truncatus*) auditory sensitivity and hearing loss using jawphones. J. Acoust. Soc. Am. 109(4):1717-1722.

Budelmann, B.U. 1992. Hearing in crustacea. p. 131-139 *In:* D.B. Webster, R.R. Fay, and A.N. Popper (eds.). The Evolutionary Biology of Hearing.

Calambokidis, J. and S.D. Osmek. 1998. Marine mammal research and mitigation in conjunction with air gun operation for the USGS 'SHIPS' seismic surveys in 1998. Draft Rep. from Cascadia Research, Olympia, WA, for U.S. Geol. Surv., Nat. Mar. Fish. Serv., and Minerals Management Service Var. pag.

Caldwell, D.K. and M.C. Caldwell. 1971. Sounds produced by two rare cetaceans stranded in Florida. Cetology 4:1-6.

Cardoza, J.E., G.S. Jones and T.W. French. 1999. MassWildlife's State Mammal List. Available at: http://www.mass.gov/dfwele/dfw/dfwmam.htm.

Casper, B.M., P.S. Lobel, and H.Y. Yan. 2003. The hearing sensitivity of the little skate, *Raja erinacea*: A comparison of two methods.

Caswell, H., M. Fujiwara and S. Brault. 1999. Declining survival probability threatens the North Atlantic right whale. **Proc. Natl. Acad. Sci. USA** 96:3308-3313.

Cate, H.S. and D.B. Roye. 1997. Ultrastructure and physiology of the outer row statoliths sensilla of the blue crab *Callinectes sapidus*. J. Crust. Biol. 17(3): 398-411.

CETAP (Cetacean and Turtle Assessment Program). 1982. A Characterization of Marine Mammals and Turtles in the Mid- and North Atlantic Areas of the U.S. Outer Continental Shelf. Final Report of the Cetacean and Turtle Assessment Program, University of Rhode Island Graduate School of Oceanography, Kingston, Rhode Island. 570 pp.

Chadwick, M. 2004. Proceedings of the peer review on potential impacts of seismic energy on snow crab. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2004/045.

Chapman, C.J. and A.D. Hawkins. 1969. The importance of sound in fish behaviour in relation to capture by trawls. FAO Fisheries Report 62(3): 717-729.

Chapman, D.M.F., F. Desharnais and G. Heard. 1998. Scotian Shelf acoustic study. Rep. by the Defence Research Establishment Atlantic, Dartmouth, NS, for LGL Limited, environmental research associates, King City, ON., Dartmouth, NS. 15 p + App.

Christian, J.R., Mathieu, A., Thomson, D.H., White, D. and Buchanan, R.A. 2004a. Effect of seismic energy on snow crab (*Chionoecetes opilio*). Report by LGL Limited for Environmental Studies Research Fund (ESRF), Calgary, AB.

Christian, J.R., A. Mathieu, and R.A. Buchanan. 2004b. Chronic effects of seismic energy on snow crab (*Chionoecetes opilio*). Report by LGL Limited for Environmental Studies Research Fund (ESRF), Calgary, AB.

Clarke, R. 1956. Marking whales from a helicopter. Norsk Hvalfangst-Tid. 45(6): 311-318.

Cohen, M.J. and S. Dijkgraaf. 1961. Mechanoreception. p. 65-108 *In:* T. Waterman (ed.) The Physiology of Crustacea, Volume 2. Academic Press, New York.

Constantine, R., D.H. Brunton and T. Dennis. 2004. Dolphin-watching tour boats change bottlenose dolphin (*Tursiops truncatus*) behaviour. Biol. Cons. 117:299-307.

Coombs, S and J.C. Montgomery. 1999. The enigmatic lateral line system. p. 319-362 *In:* R.R. Fay and A.N. Popper (eds.) Comparative Hearing: Fish and Amphibians. Springer-Verlag New York Inc.

Coombs, S. 1981. Interspecific differences in hearing capabilities for select teleost species. p. 173-178 *In:* W.N. Tavolga, A.N. Popper, and R.R. Fay (eds.) Hearing and Sound Communication in Fishes. Springer-Verlag New York Inc.

Cope, M., D. St. Aubin and J. Thomas. 1999. The effect of boat activity on the behavior of bottlenose dolphins (*Tursiops truncatus*) in the nearshore waters of Hilton Head, South Carolina. Presented at the 13th Biennial Conference on the Biology of Marine Mammals, November 28-December 3, 1999, Wailea, Hawaii. p. 37-38.

Corwin, J.T. 1981. Audition in elasmobranchs. p. 81-102 *In:* W.N. Tavolga, A.N. Popper, and R.R. Fay (eds.) Hearing and Sound Communication in Fishes. Springer-Verlag New York Inc.

COSEWIC. 2002. COSEWIC Assessment and Update Status Report on the Blue Whale *Balaenoptera musculus:* Atlantic Population Pacific Population in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. 32 pp.

CSA (Continental Shelf Associates, Inc). 2003. Explosive Platform Removal Information Synthesis Report. Draft report. OCS Study MMS 2003-xxx. Prepared by Continental Shelf Associates, Inc. for the US Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA.

Dahlheim, M.E. 1987. Bio-acoustics of the gray whale (*Eschrichtius robustus*). Ph.D. Thesis, Univ. of BC, Vancouver, BC. 315 p.

Dalen, J. and G.M. Knutsen. 1987. Scaring effects in fish and harmful effects on eggs, larvae and fry by offshore seismic explorations. Symposium on Underwater Acoustics, Halifax, 1986.

Davies, J.R. 1997. The impact of an offshore drilling platform on the fall migration path of bowhead whales: a GIS-based assessment. M.S. Thesis, Western Washington Univ., Bellingham, WA. 52 p.

Davis, R.A., D.H. Thomson and C.I. Malme. 1998. Environmental assessment of seismic exploration on the Scotian Shelf. Report by LGL Limited, King City, ON and Charles I. Malme, Eng. and Sci. Services, Hingham. MA for Mobil Oil Canada Properties Ltd., Shell Canada Ltd., Imperial Oil Ltd. and the Canada-Nova Scotia Offshore Petroleum Board, Halifax, NS. 180 p. + App.

Davis, R.W., G.S. Fargion, N. May, T.D. Leming, M. Baumgartner, W.E. Evans, L.J. Hansen and K. Mullin. 1998. Physical habitat of cetaceans along the continental slope in the north-central and western Gulf of Mexico. **Mar. Mamm. Sci.** 14(3):490-507.

Davis, R.W., W.E. Evans and B. Würsig, eds. 2000. Cetaceans, sea turtles and seabirds in the northern Gulf of Mexico: distribution, abundance and habitat associations. Volume II: Technical Report. Prepared by Texas A&M University at Galveston and the National Marine Fisheries Service. U.S. Department of the Interior, Geological Survey, Biological Resources Division, USGS/BRD/CR-1999-0006 and Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2000-003. 346 pp. Available at: http://www.mms.gov/itd/pub/2000/2000-003/pdf.

Dawson, S., J. Barlow and D. Ljungblad. 1998. Sounds recorded from Baird's beaked whale, *Berardius bairdii*. Mar. Mamm. Sci. 14(2):335-344.

Dean, F.C., C.M. Jurasz, V.P. Palmer, C.H. Curby and D.L. Thomas. 1985. Analysis of humpback whale (*Megaptera novaeangliae*) blow interval data/ Glacier Bay, Alaska, 1976-1979. (Vol. 1) plus diagrams (Vol. 2). Rep. by Univ. Alaska, Fairbanks, AK, for U.S. Nat. Park Serv., Anchorage, AK. 224 p.

Denton, E.J. and J.A.B. Gray. 1988. Mechanical factors in the excitation of the lateral lines of fishes. p. 613-617 *In:* J. Atema, R.R. Fay, A.N. Popper, and W.N. Tavolga (eds.) Sensory Biology of Aquatic Animals. Springer-Verlag New York Inc.

Department of the Navy. 2005. Marine Resource Assessment for the Northeast Operating Areas: Atlantic City, Narragansett Bay, and Boston. Naval Facilities Engineering Command, Atlantic; Norfolk, Virginia, Contract Number N62470-02-D-9997, Task Order Number 0018. Prepared by Geo-Marine, Inc., Newport News, Virginia. 556 pp.

Desharnais, F., G.J. Heard, M.G. Hazen and I.A. Fraser. 1999. The underwater acoustic noise field on Sable Bank. Can. Acoust. 27: 30-31.

DFO. 2000. Northwest Atlantic harp seals. Canadian Department of Fisheries and Oceans Science Stock Status Report E1-01(2000).

DFO (Department of Fisheries and Oceans). 2004a. Potential impacts of seismic energy on snow crab. DFO Can. Sci. Advis. Sec. Habitat Status Report 2004/003.

DFO (Department of Fisheries and Oceans). 2004b. Review of scientific information on impacts of seismic sound on fish, invertebrates, marine turtles and marine mammals. DFO Can. Sci. Advis. Sec. Habitat Status Report 2004/002.

Dubrovskiy, N.A. 1990. On the two auditory subsystems in dolphins. p. 233-254. In: J.A. Thomas, and R.A. Kastelein (eds.), Sensory Abilities of Cetaceans/Laboratory and Field Evidence. Plenum Press, New York. 710 p.

Duffield, D.A., S.H. Ridgway and L.H. Cornell. 1983. Hematology distinguishes coastal and offshore forms of dolphins (*Tursiop*s). **Can. J. Zool.** 61(4):930-933.

Duncan, P.M. 1985. Seismic sources in a marine environment. p. 56-88. In: Proc. Workshop on Effects of Explosives Use in the Marine Environment, Jan. 1985, Halifax, N.S. Tech. Rep. 5. Can. Oil & Gas Lands Admin. Envir. Prot. Br., Ottawa, ON. 398 p.

Ecology and Environment, Inc. (E&E). 2004. Neptune deepwater port application: Description of the deepwater port, 21 December 2004. 9 pp.

E & E (Ecology and Environment, Inc). 2005. Deppwater Port License Application *Neptune* Project, Massachusetts Bay. Volume II – Environmental Evaluation (Public). Report for Neptune LNG LLC, Boston, MA.

Engås, A., O.A. Misund, A.V. Soldal, B. Horvei, and A. Solstad. 1995. Reactions of penned herring and cod to playback of original, frequency-filtered and time-smoothed vessel sound. Fish. Res. 22: 243-254.

Engås, A., S. Lokkeborg, A.V. Soldal and E. Ona. 1993. Comparative trials for cod and haddock using commercial trawl and longline at two different stock levels. J. Northw. Atl. Fish. Sci. 19:83-90

Engås, A, S. Løkkeborg, E. Ona and A.V. Soldal. 1996. Effects of seismic shooting on local abundance and catch rates of cod (*G. morhua*) and haddock (*M. aeglefinus*). Can. J. Fish. Aquat. Sci. 53(10):2238-2249.

Enger, P.S. 1981. Frequency discrimination in teleosts - central or peripheral. p. 243-255 *In:* W.N. Tavolga and A.N. Popper (eds.), Hearing and sound communication in fishes. Springer-Verlag, New York.

EPA (Environmental Protection Agency). 2005. Endangered Fish and Wildlife; National Environmental Policy Act; Right Whale Ship Strike Reduction Strategy Notice of Intent to Prepare an Environmental Impact Statement and Conduct Public Scoping. June 22, 2005. Federal Register 70(119):36121-36124. Available at: http://www.epa.gov/fedrgstr/EPA-IMPACT/2005/June/Day-22/i12352.htm.

Evans, W.E. 1994. Common dolphin, white-bellied porpoise *Delphinus delphis* Linnaeus, 1758. p. 191-224 *In:* S.H. Ridgway and R. Harrison (eds.), Handbook of Marine Mammals. Vol. 5. The First Book of Dolphins. Academic Press, San Diego, CA. 416 p.

Falk, M.R. and M.J. Lawrence. 1973. Seismic exploration: its nature and effects on fish. Tech. Rep. Ser. No. Vol. CEN/T-73-9. Resource Management Branch, Fisheries Operations Directorate, Central Region, Winnipeg.

Fernandes, P.G., A.S. Brierly, E.J. Simmonds, N.W. Millard, S.D. McPhail, F. Armstrong, P. Stevenson, and M. Squires. 2000. Fish do not avoid survey vessels. Nature 404: 35-36.

Finley, K.J., G.W. Miller, R.A. Davis and C.R. Greene. 1990. Reactions of belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*, to ice-breaking ships in the Canadian high Arctic. Can. Bull. Fish. Aquat. Sci. 224:97-117.

Finneran, J.J. and M.C. Hastings. 2000. A mathematical analysis of the peripheral auditory system mechanics in the goldfish (*Carassius auratus*). J. Acoust. Soc. Am. 108(3), Part 1: 1308-1321.

Finneran, J.J., C.E. Schlundt, D.A. Carder, J.A. Clark, J.A. Young, J.B. Gaspin and S.H. Ridgway. 2000. Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and a beluga whale (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. J. Acoust. Soc. Am. 108: 417-431.

Finneran, J.J., C.E. Schulundt, R. Dear, D.A. Carder and S.H. Ridgway. 2002. Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. J. Acoust. Soc. Amer. 111: 2929-2940.

Finstad, J.L. and J.T. Nordeide. 2004. Acoustic repertoire of spawning cod, *Gadus morhua*. Environ. Biol. Fish. 70: 427-433.

Fish, J.F. and J.S. Vania. 1971. Killer whale, Orcinus orca, sounds repel white whales, *Delphinapterus leucas*. Fishery Bulletin 69: 531-535.

Folkow, L.P. and A.S. Blix. 1991. Norwegian whale sighting and acoustic surveys in the Atlantic Ocean during the winter of 1989/90. **Rep. Int. Whal. Commn** 41:531-538.

Ford, J.K.B. 2002. Killer whale. p. 669-675 *In:* W.F. Perrin, B. Würsig and J.G.M. Thewissen (eds.), Encyclopedia of Marine Mammals. Academic Press, San Diego, CA.

Fraker, M.A. and P.N. Fraker. 1979. The 1979 whale monitoring program/Mackenzie Estuary. Rep. by LGL Ltd. for Esso Resources Canada Ltd., Edmonton, AB. 51 p.

Fraker, P.N. and M.A. Fraker. 1981. The 1980 whale monitoring program, Mackenzie Estuary. Rep. by LGL Ltd. for Esso Resources Canada Ltd., Calgary, AB. 98 p.

Frantzis, A. 1998. Does acoustic testing strand whales? Nature 392:29.

Frantzis, A., J.C. Goold, E.K. Skarsoulis, M.I Taroudakis and V. Kandia. 2002. Clicks from Cuvier's beaked whales, *Ziphius cavirostris* (L). J. Acoust. Soc. Am. 112(1):34-37.

Frost, K.J., L.F. Lowry and R.R. Nelson. 1984. Belukha whale studies in Bristol Bay, Alaska. p. 187-200 In: B.R. Melteff and D.H. Rosenberg, Proceedings of the workshop on biological interactions among marine mammals and commercial fisheries in the southeastern Bering Sea, October 18-21, 1983, Anchorage, Alaska, USA. Alaska Sea Grant Report 84-1.

Gaskin, D.E. 1991. An update on the status of the right whale, *Eubalaena glacialis*, in Canada. Can. Field-Nat. 105: 198-205.

Gaskin, D.E. 1992. Status of the common dolphin, *Delphinus delphis*, in Canada. **Can. Field-Natur.** 106(1):55-63.

Gausland, I. 2003. Seismic surveys impact on fish and fisheries. Report for Norwegian Oil Industry Association (OLF).

Geo-Marine, Inc. 2005. Marine resources assessment for the Northeast Operating Areas: Atlantic City, Narragansett Bay, and Boston. Report for Department of the Navy, U.S. Fleet Forces Command, Norfolk VA.

Gerlotto, F. and P. Fréon. 1992. Some elements on vertical avoidance of fish schools to a vessel during acoustic surveys. Fish. Res. 14: 251-259.

Goertner, J.F. 1981. Fish-kill ranges for oil well severance explosions. Report for Naval Surface Weapons Center, Virginia, USA.

Goodall, C., C. Chapman, and D. Neil. 1990. The acoustic response threshold of the Norway lobster, *Nephrops norvegicus* (L.) in a free sound field. p. 106-113 *In:* K. Wiese, W.D. Krenz, J. Tautz, H. Reichert, and B. Mulloney, (eds). Frontiers in Crustacean Neurobiology. Birkhäuser, Basel.

Goodyear, J. 1989. Feeding ecology, night behavior, and vessel collision risk of Bay of Fundy right whales. p. 24. In: Abstracts, 8th Biennial Conference on the Biology of Marine Mammals, Pacific Grove, CA.

Goold, J.C. 1996. Acoustic assessment of populations of common dolphin *Delphinus delphis* in conjunction with seismic surveying. J. Mar. Biol. Ass. U.K. 76:811-820.

Goold, J.C. 1996a. Acoustic assessment of common dolphins off the west Wales coast, in conjunction with 16th round seismic surveying. Rep. to Chevron UK Ltd, Repsol Exploration (UK) Ltd and Aran Energy Exploration Ltd from School of Ocean Sciences, University of Wales, Bangor, Wales. 22 p.

Goold, J.C. 1996b. Acoustic assessment of populations of common dolphin *Delphinus delphis* in conjunction with seismic surveying. J. Mar. Biol. Assoc. U.K. 76: 811-820.

Goold, J.C. 1996c. Acoustic cetacean monitoring off the west Wales coast. Rep. to Chevron UK Limited, Repsol Exploration (UK) Ltd and Aran Energy Exploration Ltd from School of Ocean Sciences, University of Wales, Bangor, Wales. 20 Gowanloch, J.N. and J.E. McDougall. 1944. Louisiana experiments pave ways for expanded oil research. Louisiana Conservationist 3: 3-6.

Gowanloch, J.N. and J.E. McDougall. 1945. Effects from the detonation of explosives on certain marine life. Oil 4: 13-16.

Greene Jr., C.R. 1985. Characteristics of waterborne industrial noise, 1980-84. p. 197-253. In: W.J. Richardson (ed.), Behavior, disturbance responses and distribution of bowhead whales *Balaena mysticetus* in the eastern Beaufort Sea, 1980-84. OCS Study MMS 85-0034. Rep. from LGL Ecol. Res. Assoc. Inc., Bryan, TX, for U.S. Minerals Management Service, Reston, VA. 306 p. NTIS PB87-124376.

Greene Jr., C.R. 1987. Characteristics of oil industry dredge and drilling sounds in the Beaufort Sea. J. Acoust. Soc. Am. 82: 1315-1324.

Greene, C.R., Jr. and M.W. McLennan. 2000. Sound levels from a 1210 in^3 airgun array. p. 3-1-3-9. In: W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 2000: 90-day report. Rep. TA2424-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 121 p.

Greene Jr., C.R. and R.A. Davis. 1999. Piledriving and vessel sound measurements during installation of a gas production platform near Sable Island, Nova Scotia, during March and April, 1998. Rep 205-2 by Greeneridge Sciences Inc., Santa Barbara, CA and LGL Ltd, King City, ON. Sable Offshore Energy Project, Halifax, NS. 15p.

Greene, G.D., F.R. Engelhardt and R.J. Paterson (eds.). 1985. Proceedings of the workshop on effects of explosives use in the marine environment. Canadian Oil and Gas Lands Administration and Environmental Protection Branch Ottawa, Ontario. 398 p.

Guerra, A., A.F. González, and F. Rocha. 2004. A review of the records of giant squid in the north-eastern Atlantic and severe injuries in *Architeuthis dux* stranded after acoustic explorations. ICES CM 2004/CC:29.

Hain, J.H.W, M.J. Ratnaswamy, R.D. Kenney and H.E. Winn. 1992. The fin whale, *Balaenoptera physalus*, in waters of the northeastern United States Continental Shelf. **Rep. Int. Whal. Commn** 42:653-669.

Hall, A. 2002. Gray seal *Halichoerus grypus*. p. 522-524 *In:* W.F. Perrin, B. Würsig and J.G.M. Thewissen (eds.), Encyclopedia of Marine Mammals. Academic Press, San Diego, CA.

Hall, J.D. and C.S. Johnson. 1972. Auditory thresholds of a killer whale *Orcinus orca* Linnaeus. J. Acoust. Soc. Am. 51:515-517.

Hall, J.D., M.L. Gallagher, K.D. Brewer, P.R. Regos and P.E. Isert. 1994. ARCO Alaska, Inc. 1993 Kuvlum exploration area site-specific monitoring program/Final report. Rep. from Coastal & Offshore Pacific Corp., Walnut Creek, CA, for ARCO Alaska Inc. [Anchorage, AK]. 219 p. + Data Appendix Vol. 1, 2.

Hamazaki, T. 2002. Spatiotemporal prediction models of cetacean habitats in the mid-western North Atlantic ocean (from Cape Hatteras, North Carolina, U.S.A. to Nova Scotia, Canada). **Mar. Mamm. Sci.** 18(4):920-939.

Hamilton, E.L. 1980. Geoacoustic modeling of the sea floor. Journal of the Acoustical Society of America 68(5):1313-1340.

Handegard, N.O., K. Michalsen, and D. Tjøstheim. 2003. Avoidance behaviour in cod (*Gadus morhua*) to a bottom-trawling vessel. Aquatic Living Resources 16: 265-270.

Harris, D.E., B. Lelli and G. Jakush. 2002. Harp seal records from the southern Gulf of Maine: 1997 – 2001. **Northeast. Naturalist** 9(2):331-340.

Harris, D.E., B. Lelli, G. Jakush and G. Early. 2001. Hooded seal (*Cystophora cristata*) records from the southern Gulf of Maine. **Northeast. Naturalist** 9(4):427-434.

Harris, R.E., G.W. Miller and W.J. Richardson. 2001. Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea. Mar. Mamm. Sci. 17(4):795-812.

Hassel, A., T. Knutsen, J. Dalen, K. Skaar, S. Løkkeborg, O.A. Misund, Ø. Østensen, M. Fonn, and E.K. Haugland. 2004. Influence of seismic shooting on the lesser sandeel (*Ammodytes marinus*). ICES J. Mar. Sci. 61: 1165-1173.

Hassel, A., T. Knutsen, J. Dalen, S. Løkkeborg, K. Skaar, Ø. Østensen, E.K. Haugland, M. Fonn, Å. Høines, and O.A. Misund. 2003. Reaction of sandeel to seismic shooting: A field experiment and fishery statistics study. Institute of Marine Research, Bergen, Norway.

Hastings, M.C. and A.N. Popper. 2005. Effects of sound on fish. Report for Prime Contractor Jones and Stokes, Sacramento CA. California Department of Transportation Contract No. 43A0139, Task Order 1. 82 p.

Hastings, M.C., A.N. Popper, J.J. Finneran and P.J. Lanford. 1996. Effect of low frequency underwater sound on hair cells of the inner ear and lateral line of the teleost fish *Astronotus ocellatus*. J. Acoust. Soc. Am., 99:1759-1766.

Hawkins, A.D. 1981. The hearing abilities of fish. p. 109-133 *In:* W.N. Tavolga, A.N. Popper, and R.R. Fay (eds.) Hearing and Sound Communication in Fishes. Springer-Verlag New York Inc.

Hawkins, A.D. 1993. Underwater sound and fish behaviour. p. 129-169 *In:* T.J. Pitcher (ed.) Behaviour of Teleost Fishes. Chapman & Hall, London.

Hawkins, A.D. and A.A. Myrberg, Jr. 1983. Hearing and sound communication under water. p. 347-405 *In:* B. Lewis (ed.) Bioacoustics, a Comparative Approach. Academic Press, Sydney.

Healey, B.P. and G.B. Stenson. 2000. Estimating pup production and population size of the northwest Atlantic harp seal (*Phoca groenlandica*). NAFO Sci. Res. Doc. 00/55.

Heinisch, P. and K. Wiese. 1987. Sensitivity to movement and vibration of water in the North Sea shrimp Crangon crangon L. J. Crust. Biol. 7(3): 401-413.

Hewitt, R.P. 1985. Reaction of dolphins to a survey vessel: effects on census data. Fish. Bull. 83(2):187-193.

Heyning, J.E. and M.E. Dahlheim. 1988. *Orcinus orca.* **Mamm. Spec.** 304:1-9.

Higgs, D.M., A.K. Rollo, M.J. Souza, and A.N. Popper. 2003. Development of form and function in peripheral auditory structures of the zebrafish (*Danio rerio*). J. Acoust. Soc. Am. 113(2): 1145-1154.

Hirst, A.G. and P.G. Rodhouse. 2000. Impacts of geophysical seismic surveying on fishing success. Reviews in Fish Biology and Fisheries 10: 113-118.

Hoelzel, A.R., C.W. Potter and P.B. Best. 1998. Genetic differentiation between parapatric 'nearshore' and 'offshore' populations of the bottlenose dolphin. **Proc. R. Soc Lond. B** 265:1177-1183.

Holliday, D.V., R.E. Pieper, M.E. Clarke and C.F. Greenlaw 1987. The effects of airgun energy releases on the eggs, larvae, and adults of the northern anchovy (*Engraulis mordax*). API Publication 4453. Report by Tracor Applied Sciences for American Petroleum Institute, Washington, DC. 115 p.

Hooker, S.K. and H. Whitehead. 2002. Click characteristics of northern bottlenose whales (*Hyperoodon ampullatus*). Mar. Mamm. Sci. 19(1):69-80.

Hooker, S.K., H. Whitehead, and S. Gowans. 1999. Marine protected area design and the spatial and temporal distribution of cetaceans in a submarine canyon. **Conserv. Biol.** 13(3):592-602.

Hooker, S.K., R.W. Baird, S. Al-Omari, S. Gowans and H. Whitehead. 2001. Behavioural reactions of northern bottlenose whales (*Hyperoodon ampullatus*) to biopsy darting and tag attachment procedures. Fish. Bull. 99: 303-308.

IMG-Golder Corp. 2002. Behavioural and physical response of riverine fish to airguns. Report prepared for WesternGeco, Calgary, Alberta.

Intec Engineering. 2005a. Neptune project desktop geophysics survey. Prepared for Neptune LNG LLC. Document No. 11185601-0501-TRP-001. Revision 3, 4 February 2005. 32 p.

Intec Engineering. 2005b. Neptune Deepwater Port Northern Route Layout. Document No. 11185601-301-GIS013. 1 p.

Intec Engineering. 2005c. Neptune project deepwater port operation philosophy. Document No. 11185601-0201-TNT-001. 12 p.

IWC (International Whaling Commission). 2001a. Report of the workshop on the comprehensive assessment of North Atlantic right whales. **J. Cetacean Res. Manage. Spec. Iss.** 2:1-60.

IWC (International Whaling Commission). 2001b. Report of the workshop on status and trends of western North Atlantic right whales. **J. Cetacean Res. Manage. Spec. Iss.** 2:61-88.

IWC (International Whaling Commission). 2005. Whale Population Estimates. International Whaling Commission, Cambridge, U.K. Available at http://www.iwcoffice.org/conservation/estimate.htm.

Janik, V.M. and P.M. Thompson. 1996. Changes in surfacing patterns of bottlenose dolphins in response to boat traffic. Mar. Mamm. Sci. 12(4):597-602.

Jaquet, N. and D. Gendron. 2002. Distribution and relative abundance of sperm whales in relation to key environmental features, squid landings and the distribution of other cetacean species in the Gulf of California, Mexico. **Mar. Biol.** 141:591-601.

Jaquet, N. and H. Whitehead. 1996. Scale-dependent correlation of sperm whale distribution with environmental features and productivity in the South Pacific. **Mar. Ecol. Prog. Ser.** 135(1-3):1-9.

Jefferson, T. A. and B.E. Curry. 1994. Review and evaluation of potential acoustic methods of reducing or eliminating marine mammal-fishery interactions. Rep. from Mar. Mamm. Res. Prog., Texas A & M Univ., College Station, TX, for U.S. Mar. Mamm. Comm., Washington, DC. 59 p. NTIS PB95-100384.

Jefferson, T.A., S. Leatherwood, and M.A. Webber. 1993. Marine Mammals of the World. FAO Species Identification Guide. United Nations Environment Programme, Food and Agriculture Organization of the United Nations, Rome, Italy. vii + 320 pp.

Jeffs, A., N. Tolimieri, and J.C. Montgomery. 2003. Crabs on cue for the coast: the use of underwater sound for orientation by pelagic crab stages. Mar. Freshw. Res. 54: 841-845.

Jepson, P.D., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P Herráez, A.M. Pocknell, F. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham and A. Fernández. 2003. Gas-bubble lesions in stranded cetaceans: was sonar responsible for a spate of whale deaths after an Atlantic military exercise? Nature 425:575-576.

Jochens, A.E. and D.C. Biggs, editors. 2003. Sperm whale seismic study in the Gulf of Mexico. Annual report: Year 1. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2003-069. 139 pp. Available at: http://www.gomr.mms.gov/homepg/regulate/environ/studies/2003/2003-069.pdf.

Johnson, B.W. 1977. The effects of human disturbance on a population of harbor seals. Environ. Assess. Alaskan Cont. Shelf, Annu. Rep. Princ. Invest., NOAA, Boulder, CO, 1977(1): 422-432. 708 p. NTIS PB-280934/1.

Johnson, C.S. 1967. Sound detection thresholds in marine mammals. In: Tavolga, W.N., ed. Marine Bioacoustics. Pergamon, New York. p. 247-260.

Johnson, C.S., M.W. McManus and D. Skaar. 1989. Masked tonal hearing thresholds in the beluga whale. J. Acoust. Soc. Am. 85(6):2651-2654.

Jurasz, C.M. and V.P. Jurasz. 1979. Feeding modes of the humpback whale, *Megaptera novaeangliae*, in southeast Alaska. Sci. Rep. Whales Res. Inst. Tokyo 31: 69-83.

Kapel, F.O. 1979. Exploitation of large whales in West Greenland in the twentieth century. Rep. Int. Whal. Comm. 29: 197-214.

Karlsen, H.E. 1992. Infrasound sensitivity in the plaice (*Pleuronectes platessa*). J. Exp. Biol. 171: 173-187.

Kastak, D. and R.J. Schusterman. 1995. Aerial and underwater hearing thresholds for 100 Hz pure tones in two pinniped species. p. 71-79 *In*: Kastelein, R.A., J.A. Thomas and P.E. Nachtigall, editors. Sensory Systems of Aquatic Mammals. De Spil Publishers, Woerden, The Netherlands.

Kastak, D. and R.J. Schusterman. 1998. Low-frequency amphibious hearing in pinnipeds: methods, measurements, noise, and ecology. J. Acoust. Soc. Am. 103(4):2216-2228.

Kastak, D., R.J. Schusterman, B.L. Southall and C.J. Reichmuth. 1999. Underwater temporary threshold shift induced by octave-band noise in three species of pinniped. J. Acoust. Soc. Am. 106: 1142-1148.

Kastelein, R.A., M. Hagedoorn, W.W.L. Au and D. de Haan. 2003. Audiogram of a striped dolphin (*Stenella coeruleoalba*). J. Acoust. Soc. Am. 113(2):1130-1137.

Kastelein, R.A., P. Bunskoek, M. Hagedoorn, W.W.L. Au and D. de Haan. 2002. Audiogram of a harbor porpoise (*Phocoena phocoena*) measured with narrow-band frequency-modulated signals. J. Acoust. Soc. Am. 112(1):334-344.

Kasuya, T. 1986. Distribution and behavior of Baird's beaked whales off the Pacific coast of Japan. The Scientific Reports of the Whales Research Institute 37: 61-83.

Katona, S.K. and J.A. Beard. 1990. Population size, migrations and feeding aggregations of the humpback whale (*Megaptera novaeangliae*) in the western North Atlantic ocean. **Rep. Int. Whal. Commn Spec. Iss.** 12:295-305.

Katona, S.K., Rough, V. and Richardson, D.T. 1993. A Field Guide to Whales, Porpoises, and Seals from Cape Cod to Newfoundland, 4th ed. Washington, DC: Smithsonian Institution Press. 316 p.

Keevin, T.M. and G.L. Hempen. 1997. The environmental effects of underwater explosions with methods to mitigate impacts. Report for the U.S. Army Corps of Engineers, St. Louis, Missouri.

Kelly, J.C. and D.R. Nelson. 1975. Hearing thresholds of the horn shark, *Heterodontus francisci*. J. Acoust. Soc. Amer. 58(4): 905-909.

Kemp, R.J. 1956. Do seismographic explosions affect marine life? Texas Game and Fish 14:11-13.

Kenney, R.D. 1990. Bottlenose dolphins off the northeastern United States. p. 369-386 *In:* S. Leatherwood and R.R. Reeves, (eds.), The Bottlenose Dolphin. Academic Press, Inc., San Diego, CA.

Kenney, R.D. 2001. Anomalous 1992 spring and summer right whale (*Eubalaena glacialis*) distributions in the Gulf of Maine. **J. Cetacean Res. Manage. Spec. Iss.** 2:209-223.

Ketten, D.R. 1995. Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. p. 391-406. In: J.A. Kastelein, P.E. Thomas, and P.E. Nachtigall (eds.), Sensory Systems of Aquatic Mammals. De Spil, Woerden.

Ketten, D.R. 2000. Cetacean ears. pp. 43-108 In: Au, W.W.L., A.N. Popper and R.R. Fay, editors. Hearing by Whales and Dolphins. Springer-Verlag New York Inc., New York.

Kingsley, M.C.S., H.J. Cleator and M.A. Ramsay. 1994. Summer distribution and movements of narwhals (*Monodon monoceros*) in Eclipse Sound and adjacent waters, north Baffin Island, N.W.T. Meddelelser om Grønland, Bioscience 39: 163-174.

Kinze, C.C. 2002. White-beaked dolphin *Lagenorhynchus albirostris*. p. 1332-1334 *In:* W.F. Perrin, B. Würsig and J.G.M. Thewissen (eds.), Encyclopedia of Marine Mammals. Academic Press, San Diego, CA.

Kleinenberg, S.E., A.V. Yablokov, B.M. Bel'kovich and M.N. Tarasevich. 1964. Beluga (*Delphinapterus leucas*) investigation of the species. Transl. from Russian by Israel Program Sci. Transl., Jerusalem, 1969. 376 p.

Klima, E.F., G.R. Gitschlag and M.L. Renaud. 1988. Impacts of the explosive removal of offshore petroleum platforms on sea turtles and dolphins. Mar. Fish. Rev. 50: 33-42.

Klishin, V.O., V.V. Popov and A.Y. Supin. 2000. Hearing capabilities of a beluga whale, *Delphinapterus leucas*. Aquat. Mamm. 26(3):212-228.

Knebel, H. J. and R.C. Circe. 1995. Seafloor environments within the Boston Harbor-

Massachusetts Bay sedimentary system: A regional synthesis. J. Coastal Res. 11(1):230-251.

Koschinski, S., B.M. Culik, O. Damsgaard Henriksen, N. Tregenza, G. Ellis, C. Jansen and G. Kathe. 2003. Behavioural reactions of free-ranging porpoises and seals to the noise of a simulated 2 MW windpower generator. Mar. Ecol. Prog. Ser. 265:263-273.

Koshleva, V. 1992. The impacts of airguns used in marine seismic explorations on organisms living in the Barents Sea. Fisheries and Offshore Petroleum Exploitation 2nd International Conference, Bergen, Norway, 6-8 April 1992.

Koski, W.R. and S.R. Johnson. 1987. Behavioral studies and aerial photogrammetry. Rep. by LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Shell Western E & P Inc., Anchorage, AK. 371 p.

Kostyuchenko, L.P. 1973. Effects of elastic waves generated in marine seismic prospecting on fish eggs in the Black Sea. Hydrobiol. J. 9:45-48.

Kovacs, K.M. 2002. Hooded seal *Cystophora cristata*. p. 580-582 *In:* W.F. Perrin, B. Würsig and J.G.M. Thewissen (eds.), Encyclopedia of Marine Mammals. Academic Press, San Diego, CA.

Kraus, S.D., P.K. Hamilton, R.D. Kenney, A.R. Knowlton and C.K. Slay. 2001. Reproductive parameters of the North Atlantic right whale. **J. Cetacean Res. Manage. Spec. Iss.** 2:231-236.

Kritzler, H. and L. Wood. 1961. Provisional audiogram for the shark, *Carcharhinus leucas*. Science, New Series 133(3463): 1480-1482.

Kruse, S., D.K. Caldwell and M.C. Caldwell. 1999. Risso's dolphin *Grampus griseus* (G. Cuvier, 1812). p. 183-212 *In:* S.H. Ridgway and R. Harrison (eds.), Handbook of Marine Mammals. Vol. 6. The Second Book of Dolphins and the Porpoises. Academic Press, San Diego, CA. 486 p.

Kryter, K.D. 1985. The Effects of Noise on Man. Academic Press, Inc., Orlando, FL. 688 p.

Kryter, K.D. 1994. The Handbook of Hearing and the Effects of Noise. Academic Press, Inc., Orlando, FL. 673 p.

La Bella, G., S. Cannata, C. Froglia, A. Modica, S. Ratti, and G. Rivas. 1996. First assessment of effects of air-gun seismic shooting on marine resources in the Central Adriatic Sea. Society of Petroleum Engineers. International Conference on Health, Safety and Environment, New Orleans, Louisiana, 9-12 June. p. 227-238.

Ladich, F. 2000. Acoustic communication and the evolution of hearing in fishes. Phil. Trans. R. Soc. Lond. B 355: 1285-1288.

Lagardère, J.-P. 1982. Effects of noise on growth and reproduction of *Crangon crangon* in rearing tanks. Marine Biology 71(2): 177-185.

Lagardère, J.P., M.L. Bégout J.Y. Lafaye and J.P. Villotte. 1994. Influence of wind-produced noise on orientation in the sole (*Solea solea*). Can. J. Fish. Aquat. Sci. 51: 1258-1264.

Laurinolli, M.H., A.E. Hay, F. Desharnais and C.T. Taggart. 2003. Localization of North Atlantic right whale sounds in the Bay of Fundy using a sonobuoy array. Mar. Mamm. Sci. 19(4):708-723.

Lavigne, D.M. 2002. Harp seal *Pagophilus groenlandicus*. p. 560-562 *In:* W.F. Perrin, B. Würsig and J.G.M. Thewissen (eds.), Encyclopedia of Marine Mammals. Academic Press, San Diego, CA.

Leatherwood, S. and R.R. Reeves. 1983. The Sierra Club Handbook of Whales and Dolphins. Sierra Club, San Francisco, CA. 302 p.

Leatherwood, S., F.T. Awbrey and J.A. Thomas. 1982. Minke whale response to a transiting survey vessel. Rep. Int. Whal. Comm. 32: 795-802.

Leis, J.M., B.M. Carson-Ewart, A.C. Hay, and D.H. Cato. 2003. Coral-reef sounds enable nocturnal navigation by some reef-fish larvae in some places and at some times. J. Fish Biol. 63: 724-737.

Leis, J.M., B.M. Carson-Ewart, and D.H. Cato. 2002. Sound detection *in situ* by the larvae of a coral-reef damselfish (*Pomacentridae*). Mar. Ecol. Prog. Ser. 232: 259-268.

Lenhardt, M.L. 1995. Seismic and very low frequency sound induced behaviors in captive loggerhead marine turtles (*Caretta caretta*). p. 238-240 *In*: Bjorndal, K.A., A.B. Bolten, D.A. Johnson and P.J. Eliazar (compilers). Proceedings of the Fourteenth Annual Symposium on Sea Turtle Biology and Conservation. NOAA Tech. Memo. NMFSC-SEFSC-351.

Lenhardt, M., S. Moein and J. Musick. 1996. A method for determining hearing thresholds in marine turtles. p. 160-161 *In*: Keinath, J.A., D.E. Barnard, J.A. Musick and B.A. Bell (compilers). 1996. Proceedings of the Fifteenth Annual Workshop on Sea Turtle Biology and Conservation. NOAA Tech. Memo. NMFS-SEFSC-387.

Lesage, V., C. Barrette, M.C.S. Kingsley and B. Sjare. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River Estuary, Canada. Mar. Mamm. Sci. 15: 65-84.

Lewis, T.N. and P.H. Rogers. 1996. The vibrational response of single-chambered fish swimbladders to low-frequency sound. ICES J. Mar. Sci. 53: 285-287.

Linton, T., A. Landry Jr., J.E. Buckner Jr. and R. Berry. 1985. Effects upon selected marine organisms of explosives used for sound production in geophysical exploration. The Texas Journal of Science 27(4): 341-353.

Ljungblad, D.K., B. Würsig, S.L. Swartz and J.M. Keene. 1988. Observations on the behavioral responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. Arctic 41: 183-194.

Ljungblad, D.K., P.D. Scoggins and W.G. Gilmartin. 1982. Auditory thresholds of a captive Eastern Pacific bottle-nosed dolphin, Tursiops spp. J. Acoust. Soc. Am. 72(6):1726-1729.

Løkkeborg, S. 1991. Effects of geophysical survey on catching success in longline fishing. ICES CM B:40. 9 p.

Løkkeborg, S. and A.V. Soldal. 1993. The influence of seismic explorations on cod (*Gadus morhua*) behaviour and catch rates. ICES Mar. Sci. Symp. 196:62-67.

Lovell, J.M., M.M. Findley, R.M. Moate, and H.Y. Yan. 2005. The hearing abilities of the prawn *Palaemon serratus*. Comp. Biochem. Physiol. Part A 140: 89-100.

Lynn, S.K. and D.L. Reiss. 1992. Pulse sequence and whistle production by two captive beaked whales, *Mesoplodon* species. Mar. Mamm. Sci. 8(3):299-305.

Mackenzie, K. 1981. Nine-term equation for the sound speed in the ocean. Journal of the Acoustical Society of America 70(3): 807-812.

Madsen, P.T., B. Mohl, B.K. Nielsen and M. Wahlberg. 2002. Male sperm whale behavior during exposures to distant seismic survey pulses. Aquat. Mamm. 28(3):231-240.

Madsen, P.T., B. Møhl, B.K. Nielsen and M. Wahlberg. 2002a. Male sperm whale behaviour during exposures to distant seismic survey pulses. Aquat. Mamm. 28(3):231-240.

Madsen, P.T., M. Wahlberg and B. Møhl. 2002b. Male sperm whale (*Physeter macrocephalus*) acoustics in a high-latitude habitat: implications for echolocation and communication. Behav. Ecol. Sociobiol. 53:31-41.

Madsen, P.T., R. Payne, N.U. Kristiansen, M. Wahlberg, I. Kerr and B. Møhl. 2002c. Sperm whale sound production studied with ultrasound time/depth-recording tags. J. Exp. Biol. 205:1899-1906.

Magalhães, S., R. Prieto, M.A. Silva, J. Gonçalves, M. Afonso-Dian and R.S. Santos. 2002. Short-term reactions of sperm whales (*Physeter macrocephalus*) to whale-watching vessels in the Azores. Aquat. Mamm. 28(3):267-274.

Malakoff, D. 2002. Suit ties whale deaths to research cruise. Science 298(5594): 722-723.

Malme, C.I. 1993. Prediction of potential disturbance of baleen whales by low-frequency acoustic transients. J. Acoust. Soc. Am. 94: 1850.

Malme, C.I., B. Würsig, J.E. Bird and P. Tyack. 1988. Observations of feeding gray whale responses to controlled industrial noise exposure. p. 55-73. In: W.M. Sackinger, M.O. Jeffries, J.L. Imm, and S.D. Treacy (eds.), Port and ocean engineering under arctic conditions. Geophysical Inst., Univ. Alaska, Fairbanks, AK.

Malme, C.I., C.R. Greene, and R. A. Davis. 1998. Comparison of radiated noise from pile driving operations with predictions using the RAM model. LGL Rep. TA2224-2. Rep. by LGL Ltd., environmental research associates, King City, ON, Engineering and Scientific Services, Hingham, MA, and Greeneridge Sciences Inc., Santa Barbara, CA for Sable Offshore Energy Project, Halifax, NS. 10 p.

Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack and J.E. Bird. 1983. Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior. BBN Rep. 5366. Bolt, Beranek and Newman Rep. for Minerals Management Service, U.S. Dept. of the Interior, Washington, DC. Var. pag.

Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack and J.E. Bird. 1984. Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior. Phase II: January 1984 migration. BBN Rep. 5586. Bolt, Beranek and Newman Rep. for Minerals Management Service, U.S. Dept. of the Interior, Washington, DC. Var. pag.

Malme, C.I., P.R. Miles, P. Tyack, C.W. Clark and J.E. Bird. 1985. Investigation of the potential effects of underwater noise from petroleum industry activities on feeding humpback whale behavior. BBN Rep. 5851; OCS Study MMS 85-0019. Rep. from BBN Labs Inc., Cambridge, MA, for U.S. Minerals Management Service, Anchorage, AK. Var. pag.

Mann, D.A., D.M. Higgs, W.N. Tavolga, M.J. Souza, and A.N. Popper. 2001. Ultrasound detection by clupeiform fishes. J. Acoust. Soc. Am. 109(6): 3048-3054.

Mann, D.A., Z. Lu, M.C. Hastings, and A.N. Popper. 1998. Detection of ultrasonic tones and simulated dolphin echolocation clicks by a teleost fish, the American shad (*Alosa sapidissima*). J. Acoust. Soc. Am. 104(1): 562-568.

Martec Limited. 2004. Effects of pipelines/gathering lines on snow crab and lobster. Martec Technical Report #TR-04-53 for Environmental Studies Research Funds (ESRF), Calgary, Alberta.

Marten, K. 2000. Ultrasonic analysis of pygmy sperm whale (*Kogia breviceps*) and Hubbs' beaked whale (*Mesoplodon carlhubbsi*) clicks. Aquat. Mamm. 26(1):45-48.

Mate, B.R. and J.T. Harvey. 1987. Acoustical deterrents in marine mammal conflicts with fisheries. ORESU-W-86-001. Oregon State Univ., Sea Grant Coll. Progr., Corvallis, OR. 116 p.

Matishov, G.G. 1992. The reaction of bottom-fish larvae to airgun pulses in the context of the vulnerable Barents Sea ecosystem. Fisheries and Offshore Petroleum Exploitation 2nd International Conference, Bergen, Norway, 6-8 April 1992.

Maybaum, H.L. 1993. Responses of humpback whales to sonar sounds. J. Acoust. Soc. Am. 94: 1848-1849.

Mayo, C.A. and M.K. Marx. 1990. Surface foraging behaviour of the North Atlantic right whale, Eubalaena glacialis, and associated zooplankton characteristics. Can. J. Zool. 68: 2214-2220.

McCall Howard, M.P. 1999. Sperm whales Physeter macrocephalus in the Gully, Nova Scotia: Population, distribution, and response to seismic surveying. B.Sc. (Honours) Thesis. Dalhousie University, Halifax, Nova Scotia.

McCauley, R.D, J. Fewtrell, A.J. Duncan, C. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine seismic surveys: Analysis and propagation of air-gun signals; and effects of air-gun exposure on humpback whales, sea turtles, fishes and squid. Prepared for Australian Petroleum Production and Exploration Association (APPEA), Centre for Marine Science and Technology, Curtin University, Perth, Australia, 198 p.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch and K.A. McCabe. 2000. Marine seismic surveys—A study of environmental implications. APPEA J. 40: 692-708.

McCauley, R.D., J. Fewtrell, and A.N. Popper. 2003. High intensity anthropogenic sound damages fish ears. J. Acoust. Soc. Am., 113, 1: 638-642.

McCauley, R.D., M.-N. Jenner, C. Jenner, K.A. McCabe and J. Murdoch. 1998. The response of humpback whales (*Megaptera novaeangliae*) to offshore seismic survey noise: preliminary results of observations about a working seismic vessel and experimental exposures. APPEA (Australian Petroleum Producers and Explorers Association) Journal 1998: 692-707.

McDonald, M.A., J.A. Hildebrand and S.C. Webb. 1995. Blue and fin whales observed on a seafloor array in the Northeast Pacific. J. Acoust. Soc. Am. 98: 712-721.

Menck GmbH. 2005. MHU facts and figures. Kaltenkirchen, Germany. http://www.menck.com/fileadmin/user_upload/MHU_facts_figures.pdf

Miller, G.W., R.E. Elliott, W.R. Koski, V.D. Moulton and W.J. Richardson. 1999. Whales [1998]. p. 5-1 to 5-109. In: W.J. Richardson (ed., 1999), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. xx + 390 p.

Miller, P.J.O., N. Biassoni, A. Samuels and P. Tyack. 2000. Whale songs lengthen in response to sonar: male humpbacks modify their sexual displays when exposed to man-made noise. Nature 405:903.

Misund, O.A. 1993. Avoidance behaviour of herring (*Clupea harengus*) and mackerel (*Scomber scombrus*) in purse seine capture situations. Fish. Res. 16: 179-194.

Misund, O.A., J.T. Øvredal and M.T. Hafsteinson. 1996. Reactions of herring schools to the sound field of a survey vessel. Aquat. Living Resour. 9:5-11.

Mitchell, E.D. 1975. Report on the meeting on small cetaceans, Montreal, April 1-11, 1974. **J. Fish. Res. Bd. Can.** 32:914-91.

Mitson, R.B. and H.P. Knudsen. 2003. Causes and effects of underwater noise on fish abundance estimation. Aquat. Living Resour. 16: 255-263.

Møhl, B., M. Wahlberg and P.T. Madsen. 2000. Sperm whale clicks: directionality and source level revisited. J. Acoust. Soc. Am. 107(1):638-648.

Moore, P.W.B. and D.A. Pawloski. 1990. Investigations on the control of echolocation pulses in the dolphin (*Tursiops truncatus*). p. 305-316. In: J.A. Thomas, and R.A. Kastelein (eds.), Sensory Abilities of Cetaceans/Laboratory and Field Evidence. Plenum Press, New York. 710 p.

Moulton, V.D. and J.W. Lawson. 2002. Seals, 2001. p. 3-1 to 3-48. In: W.J. Richardson (ed.), Marine mammal and acoustical monitoring of WesternGeco's open-water seismic program in the Alaskan Beaufort Sea, 2001. Rep. from LGL Ltd. and Greeneridge Sciences Inc., Santa Barbara, CA, for WesternGeco, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. LGL Rep. TA2564-4.

Mullin, K.D., W. Hoggard, C.L. Roden, R.R. Lohoefener, C.M. Rogers and B. Taggart. 1991. Cetaceans on the upper continental slope in the north-central Gulf of Mexico. OCS Study/MMS 91-0027. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, LA. 108 p.

Murphy, M. 1995. Occurrence and group characteristics of minke whales, *Balaenoptera acutorostrata*, in Massachusetts Bay and Cape Cod Bay. **Fish. Bull. U.S.** 93(3):577-585.

Myrberg , A.A, Jr. 1978. Ocean noise and the behavior of marine animals: relationships and implications. p. 169-208. In: J.L. Fletcher, and R.G. Busnel (eds.), Effects of noise on wildlife. Academic Press, New York.

Myrberg, Jr., A.A. 2001. The acoustical biology of elasmobranchs. Environ. Biol. Fish. 60: 31-45.

Nachtigall, P.E., D.W. Lemonds and H.L. Roitblat. 2000. Psychoacoustic studies of dolphin and whale hearing. pp. 330-363 In: Au, W.W.L., A.N. Popper and R.R. Fay, editors. Hearing by Whales and Dolphins. Springer-Verlag New York Inc., New York.

Nachtigall, P.E., J.L. Pawloski and W.W.L. Au. 2003. Temporary threshold shifts and recovery following noise exposure in the Atlantic bottlenosed dolphin (*Tursiops truncatus*). J. Acoust. Soc. Am. 113(6):3425-3429.

NAMMCO. 1997. Report of the Scientific Committee. p. 96-178 *In*: NAMMCO annual Report 1996. North Atlantic Marine Mammal Commission, Tromsø, Norway.

Nedwell, J.R., B. Edwards, A.W.H. Turnpenny, and J. Gordon. 2004. Fish and marine mammal audiograms: A summary of available information. Subacoustech Ltd. Report No. 534R0214 for Chevron Texaco Ltd., TotalFinaElf Exploration UK PLC, DSTL, Department of Trade and Industry, and Shell U.K. Exploration and Production Ltd.

NMFS (National Marine Fisheries Service). 1998. Recovery plan for the blue *whale (Balaenoptera musculus*). Prepared by R.R. Reeves, P.J. Clapham, R.L. Brownell, Jr. and G.K. Silber for the National Marine Fisheries Service, Silver Spring, MD. 42 p.

NMFS (National Marine Fisheries Service). 2005. Recovery Plan for the North Atlantic Right Whale (*Eubalaena glacialis*). National Marine Fisheries Service, Silver Spring, MD. Available at: http://www.nmfs.noaa.gov/pr/PR3/recovery.html.

NMFS (U.S. Natl. Mar. Fish. Serv.). 1987. Endangered fish and wildlife; approaching humpback whales in Hawaiian waters. Fed. Regist. 52(225, 23 Nov.): 44912-44915 [50 CFR Part 222].

NMFS. 2000. Taking and importing marine mammals; Taking marine mammals incidental to Naval activities/Proposed rule. Fed. Regist. 65(239 12 December): 77546-77553.

NMFSa (National Marine Fisheries Service). n.d. Marine Mammal Protection Act (MMPA) of 1972. NOAA Fisheries Office of Protected Resources, Silver Spring, MD. Available at http://www.nmfs.noaa.gov/pr/laws/mmpa.htm.

NMFSb (National Marine Fisheries Service). n.d. Endangered Species Act (ESA) of 1973. NOAA Fisheries Office of Protected Resources, Silver Spring, MD. Available at: http://www.nmfs.noaa.gov/pr/laws/esa.htm.

NMFSc (National Marine Fisheries Service). n. d. The Mandatory Ship Reporting System Fact Sheet. Available at: http://www.nmfs.noaa.gov/pr/PR2/Conservation_and_Recovery_Program/msr/FactsMSR.html.

NOAA. 2000. Stellwagen Bank NMS Submarine Cable EA.

NOAA. 2005. Noise Levels and Sources in the Stellwagen Bank National Marine Sanctuary and the St. Lawrence River Estuary, U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Marine Sanctuaries Conservation Series MSD-05-1

NOAA Fisheries. 2004. Preliminary report: multidisciplinary investigation of harbor porpoises (*Phocoena phocoena*) stranded in Washington State from 2 May – 2 June 2003 coinciding with the mid-range sonar exercises of the *USS Shoup*. Available at: www.nwr.noaa.gov/mmammals/cetaceans/reportonly.pdf

NOAA Satellite and Information Service. 2005. NGDC Coastal Relief Model. National Geographic Data Center, http://www.ngdc.noaa.gov/mgg/coastal/

Norris, K.S. and B. Møhl. 1983. Can odontocetes debilitate prey with sound? American Naturalist 122: 85-104.

Northridge, S., M. Tasker, A. Webb, K. Camphuysen, and M. Leopold. 1997. White-beaked *Lagenorhynchus albirostris* and Atlantic white-sided dolphin *L. acutus* distributions in northwest European and US North Atlantic waters. **Rep. Int. Whal. Commn** 47:797-805.

Nowacek, D.P., M.P. Johnson and P.L. Tyack. 2004. North Atlantic right whales (*Eubalaena glacialis*) ignore ships but respond to alerting stimuli. Proc. R. Soc. Lond. B 271:227-231.

Nowacek, S.M., R.S. Wells and A.R. Solow. 2001. Short-term effects of boat traffic on bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. Mar. Mamm. Sci. 17(4):673-688.

O'Hara, J. and J.R. Wilcox. 1990. Avoidance responses of loggerhead turtles, *Caretta caretta*, to low frequency sound. Copeia 1990(2):563-567.

Osborn, L.S. 1985. Population dynamics, behavior, and the effect of disturbance on haulout patterns of the harbor seal *Phoca vitulina richardsi*/Elkhorn Slough, Monterey Bay, California. B.A. Thesis, Dep. Environ. Stud. & Dep. Biol., Univ. Calif., Santa Cruz. 75 p.

Papastavrou, V., S.C. Smith and H. Whitehead. 1989. Diving behaviour of the sperm whale, *Physeter macrocephalus*, off the Galapagos Islands. Can. J. Zool. 67:839-846.

Patenaude, N.J., W.J. Richardson, M.A. Smultea, W.J. Richardson, W.R. Koski, G.W. Miller, B. Würsig and C.R. Greene, Jr. 2002. Aircraft sound and disturbance to bowhead and beluga whales during spring migration in the Alaskan Beaufort Sea. Mar. Mamm. Sci. 18(2):309-335.

Payne, J.F. 2004. Potential effect of seismic surveys on fish eggs, larvae and zooplankton. Can. Sci. Advis. Sec. Res. Doc. 2004/125.

Payne, P.M., D.N. Wiley, S.B. Young, S. Pittman, P.J. Clapham and J.W. Jossi. 1990. Recent fluctuations in the abundance of baleen whales in the southern Gulf of Maine in relation to changes in selected prey. **Fish Bull. U.S.** 88(4):687-696.

Payne, R., O. Brazier, E.M. Dorsey, J.S. Perkins, V.J. Rowntree and A. Titus. 1983. External features in southern right whales (*Eubalaena australis*) and their use in identifying individuals. p. 371-445. In: R. Payne (ed.), Communication and Behavior of Whales. AAAS Sel. Symp. 76. Westview Press, Boulder, CO. 643 p.

Pearson, W., Skalski, J., Sulkin, S. and C. Malme. 1994. Effects of seismic energy releases on the survival and development of zoeal larvae of Dungeness crab (*Cancer magister*). Mar. Environ. Res., 38: 93-113.

Pearson, W.H., J.R. Skalski and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on behaviour of captive rockfish (*Sebastes* spp). Can. J. Fish. Aquat. Sci. 49(7):1343-1356.

Penner, R.H., C.W. Turl and W.W. Au. 1986. Target detection by the beluga using a surface-reflected path. J. Acoust. Soc. Am. 80: 1842-1843.

Perrin, W.F., C.E. Wilson and F.I. Archer II. 1994. Striped dolphin *Stenella coeruleoalba* (Meyen, 1833). p. 129-159 *In:* S. H. Ridgway and R. J. Harrison (eds.), Handbook of Marine Mammals. Vol. 5. The First Book of Dolphins. Academic Press, San Diego, CA.

Perry, S.L., D.P. DeMaster and G.K. Silber. 1999. The great whales: history and status of six species listed as endangered under the U.S. Endangered Species Act of 1973. **Mar. Fish. Rev.** 61(1):7-23.

Pickett, G.D., D.R. Eaton, R.M.H. Seaby, and G.P. Arnold. 1994. Results of bass tagging in Poole Bay during 1992. Ministry of Agriculture, Fisheries and Food Directorate of Fisheries Research, Laboratory Leaflet Number 74, Southampton.

Platt, C. and A.N. Popper. 1981. Fine structure and function of the ear. p. 3-36 *In:* W.N. Tavolga, A.N. Popper, and R.R. Fay (eds.) Hearing and Sound Communication in Fishes. Springer-Verlag New York Inc.

Platt, C., J.M. Jørgensen, and A.N. Popper. 2004. The inner ear of the lungfish *Protopterus*. J. Comp. Neurol. 471: 277-288.

Polacheck, T. and L. Thorpe. 1990. The swimming direction of harbor porpoise in relationship to a survey vessel. Rep. Int. Whal. Commn 40:463-470.

Popper, A.N. 2000. Hair cell heterogeneity and ultrasonic hearing: recent advances in understanding fish hearing. Phil. Trans. R. Soc. Lond. B 355: 1277-1280.

Popper, A.N. 2003. Effects of anthropogenic sounds on fishes. Fisheries 28(10): 24-31.

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

Popper, A.N., D.T.T. Plachta, D.A. Mann, and D. Higgs. 2004. Response of clupeid fish to ultrasound: a review. ICES J. Mar. Sci. 61: 1057-1061.

Popper, A.N., J. Fewtrell, M.E. Smith, and R.D. McCauley. 2003/2004. Anthropogenic sound: Effects on the behaviour and physiology of fishes. Marine Technology Society Journal 37(4): 35-40.

Popper, A.N., M. Salmon, and K.W. Horch. 2001. Acoustic detection and communication by decapod crustaceans. J. Comp. Physiol. A 187: 83-89.

Popper, A.N., M.E. Smith, P.A. Cott, B.W. Hanna, A.O. MacGillivary, M.E. Austin, and D.A. Mann. 2005. Effects of exposure to seismic airgun use on hearing of three fish species. J. Acoust. Soc. Am. 117(6): 3958-3971.

Provincetown Center for Coastal Studies. 2005. Seal Identification. Available at: http://www.coastalstudies.org/what-we-do/stellwagen-bank/seal-identification.htm.

Pye, H.J. and W.H. Watson III. 2004. Sound detection and production in the American lobster, *Homarus americanus*: Sensitivity range and behavioural implications. J. Acoust. Soc. Am. 115(2), Part 2: 2486.

Ramcharitar, J. and A.N. Popper. 2004. Masked auditory thresholds in sciaenid fishes: A comparative study. J. Acoust. Soc. Am. 116(3): 1687-1691.

Ramcharitar, J., D.M. Higgs, and A.N. Popper. 2001. Sciaenid inner ears: A study in diversity. Brain Behav. Evol. 58: 152-162.

Ramcharitar, J.U., X. Deng, D. Ketten, and A.N. Popper. 2004. Form and function in the unique inner ear of a teleost: The silver perch (*Bairdiella chrysoura*). J. Comp. Neurol. 475: 531-539.

Read, A.J. 1999. Harbour porpoise *Phocoena phocoena* (Linnaeus, 1758). p. 323-355 *In:* S. H. Ridgway and R. J. Harrison (eds.), Handbook of Marine Mammals. Vol. 6. The Second Book of Dolphins and the porpoises. Academic Press, San Diego, CA. 486 p.

Reeves, R.R. and M.W. Brown. 1994. Marine mammals and the Canadian Patrol Frigate shock trials: a literature review and recommendations for mitigating the impacts. Final report, August 1994. Prepared for National Defence Headquarters, Ottawa, Ontario by East Coast Ecosystems Research Organization. 105 pp.

Reeves, R.R., C. Smeenk, C.C. Kinze, R.L. Brownell, Jr. and J. Lien. 1999a. Atlantic white-sided dolphin *Lagenorhynchus acutus* Gray, 1828. p. 31-56 *In:* S. H. Ridgway and R. J. Harrison (eds.), Handbook of Marine Mammals. Vol. 6. The Second Book of Dolphins and the porpoises. Academic Press, San Diego, CA.

Reeves, R.R., C. Smeenk, C.C. Kinze, R.L. Brownell, Jr. and J. Lien. 1999b. White-beaked dolphin *Lagenorhynchus albirostris* Gray, 1846. p. 1-30 *In:* S. H. Ridgway and R. J. Harrison (eds.), Handbook of Marine Mammals. Vol. 6. The Second Book of Dolphins and the porpoises. Academic Press, San Diego, CA.

Reeves, R.R., E. Mitchell and H. Whitehead. 1993. Status of the Northern Bottlenose Whale, *Hyperoodon ampullatus*. Can. Field-Naturalist 107: 491-509.

Reeves, R.R., R.J. Hofman, G.K. Silber and D. Wilkinson. 1996. Acoustic deterrence of harmful marine mammal-fishery interactions: proceedings of a workshop held in Seattle, Washington, 20-22 March 1996. NOAA Tech. Memo NMFS-OPR-10. U.S. Dep. Commerce, Nat. Mar. Fish. Serv. 70 p.

Rendell, L.E. and J.C.D. Gordon. 1999. Vocal response of long-finned pilot whales (*Globicephala melas*) to military sonar in the Ligurian Sea. Mar. Mamm. Sci. 15(1):198-204.

Rice, D.W. 1989. Sperm whale *Physeter macrocephalus* Linnaeus, 1758. p. 177-233 *In:* S.H. Ridgway and R. Harrison (eds.), Handbook of Marine Mammals. Vol. 4. River Dolphins and the Larger Toothed Whales. Academic Press, San Diego, CA.

Richardson, W.J. and C.I. Malme. 1993. Man-made noise and behavioral responses. p. 631-700 In: J.J. Burns, J.J. Montague and C.J. Cowles (eds.), The bowhead whale. Spec. Publ. 2, Society for Marine Mammalogy, Lawrence, Kansas. 787 p.

Richardson, W.J., B.W. Würsig and C.R. Greene Jr. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. J. Acoust. Soc. Am. 79: 1117-1128.

Richardson, W.J., B.W. Würsig and C.R. Greene Jr. 1990. Reactions of bowhead whales, *Balaena mysticetus*, to drilling and dredging noise in the Canadian Beaufort Sea. Mar. Environ. Res. 29: 135-160.

Richardson, W.J., D.H. Thomson, C.R. Green Jr. and C.I. Malme. 1995. Marine mammals and noise. Academic Press, Inc., San Diego, CA. 576 p.

Richardson, W.J., M.A. Fraker, B. Würsig and R.S. Wells. 1985a. Behaviour of bowhead whales *Balaena mysticetus* summering in the Beaufort Sea: reactions to industrial activities. Biol. Conserv. 32: 195-230.

Richardson, W.J., R.A. Davis, C.R. Evans, D.K. Ljungblad and P. Norton. 1987. Summer distribution of bowhead whales, *Balaena mysticetus*, relative to oil industry activities in the Canadian Beaufort Sea, 1980-84. Arctic 40: 93-104.

Richardson, W.J., R.S. Wells and B. Würsig. 1985b. Disturbance responses of bowheads, 1980-84. p. 89-196. In: W.J. Richardson (ed.), Behavior, disturbance responses and distribution of bowhead whales *Balaena mysticetus* in the eastern Beaufort Sea, 1980-84. OCS Study MMS 85-0034. Rep. from LGL Ecol. Res. Assoc. Inc., Bryan, TX, for U.S. Minerals Management Service, Reston, VA. 306 p. NTIS PB87-124376.

Richter, C.F., S.M. Dawson and E. Slooten. 2003. Sperm whale watching off Kaikoura, New Zealand: effects of current activities on surfacing and vocalisation patterns. Science for Conservation 219. Department of Conservation, Wellington. 78 p. Available at http://www.doc.govt.nz/Publications/004~Science-and-Research/Science-for-Conservation/PDF/SFC219.pdf

Ridgway, S.H. and D.A. Carder. 1997. Hearing deficits measured in some *Tursiops truncatus*, and discovery of a deaf/mute dolphin. J. Acoust. Soc. Am. 101(1):590-594.

Ridgway, S.H. and D.A. Carder. 2001. Assessing hearing and sound production in cetaceans not available for behavioral audiograms: Experience with sperm, pygmy sperm, and gray whales. Aquat. Mamm. 27(3):267-276.

Ridgway, S.H., D.A. Carder, R.R. Smith, T. Kamolnick, C.E. Schlundt and W.R. Elseberry. 1997. Behavioral responses and temporary shift in masked hearing threshold of bottlenose dolphins, *Tursiops truncatus*, to 1-second tones of 141 to 201 dB re 1 μPa. Tech. Rep. 1751, Revision 1. Tech. Rep. to Naval Command, Control and Ocean Surveillance Center (NCCOSC), RDT&E DIV D3503, San Diego, CA. 27 p.

Ridgway, S.H., D.A. Carder, T. Kamolnick, R.R. Smith, C.E. Schlundt and W.R. Elsberry. 2001. Hearing and whistling in the deep sea: Depth influences whistle spectra but does not attenuate hearing by white whales (*Delphinapterus leucas*) (Odontoceti, Cetacea). J. Exp Biol. 204:3829-3841.

Ridgway, S.H., E.G. Wever, J.G. McCormick, J. Palin and J.H. Anderson. 1969. Hearing in the giant sea turtle, *Chelonia mydas*. Proc. Natl. Acad. Sci. 64:884-890.

Rogers, T.L. and S.M. Brown. 1999. Acoustic observations of Arnoux's beaked whale (*Berardius arnuxii*) off Kemp Land, Antarctica. Mar. Mamm. Sci. 15(1):192-198.

Romanenko, E.V. and V.Ya. Kitain. 1992. The functioning of the echolocation system of *Tursiops truncatus* during noise masking. p. 415-419. In: J.A. Thomas, R.A. Kastelein and A.Ya. Supin (eds.), Marine Mammal Sensory Systems. Plenum, New York. 773 p.

Romano, T.A., M.J. Keogh, C. Kelly, P. Feng, L. Berk, C.E. Schlundt, D.A. Carder and J.J. Finneran. 2004. Anthropogenic sound and marine mammal health: measures of the nervous and immune systems before and after intense sound exposure. Can. J. Fish. Aquat. Sci. 61:1124-1134.

Ross, C.W., G.V. Hurley, and J. Parsons. 1985. The environmental impact of linear explosives on fish in nearshore waters near Sable Island, Nova Scotia. p. 152-193 *In:* G.D. Greene, F.R. Engelhardt, and R.J. Paterson (eds.) Proceedings of the Workshop on Effects of Explosives Use in the Marine Environment, January 29 to 31, 1985, Halifax. Canada Oil and gas lands Administration, Environmental Protection Branch, Technical Report No. 5.

Rowe, S. and J.A. Hutchings. 2004. The function of sound production by Atlantic cod as inferred from patterns of variation in drumming muscle mass. Can. J. Zool. 82: 1391-1398.

Saetre, R. and E. Ona. 1996. Seismiske undersøkelser og skader på fiskeegg og -larver en vurdering av mulige effekter pa bestandsniv0. [Seismic investigations and damages on fish eggs and larvae; an evaluation of possible effects on stock level] Fisken og Havet 1996:1-17, 1-8. (in Norwegian, with an English summary - full translation not published).

Saidel, W.M., P.J. Lanford, H.Y. Yan, and A.N. Popper. 1995. Hair cell heterogeneity in the goldfish saccule. Brain Behav. Evol. 46: 362-370.

Sand, O. 1981. The lateral line and sound reception. p. 459-478 *In:* W.N. Tavolga, A.N. Popper, and R.R. Fay (eds.) Hearing and Sound Communication in Fishes. Springer-Verlag New York Inc.

Sand, O. and H.E. Karlsen. 2000. Detection of infrasound and linear acceleration in fishes. Phil. Trans. R. Soc. Lond. B 355: 1295-1298.

Santulli, A., C. Messina, L. Ceffa, A. Curatolo, G. Rivas, G. Fabi and V. Damelio. 1999. Biochemical responses of European sea bass (*Dicentrachus labrax*) to the stress induced by offshore experimental seismic prospecting. Mar. Poll. Bull. 38:1105-1114.

Scarpaci, C., S.W. Bigger, P.J. Corkeron and D. Nugegoda. 2000. Bottlenose dolphins (*Tursiops truncatus*) increase whistling in the presence of 'swim-with-dolphin' tour operations. J. Cetacean Res. Manage. 2(3):183-185.

Schick, R.S. and D.L. Urban. 2000. Spatial components of bowhead whale (*Balaena mysticetus*) distribution in the Alaskan Beaufort Sea. Can. J. Fish. Aquat. Sci. 57(11): 2193-2200.

Schilling, M.R., I. Seipt, M.T. Weinrich, S.E. Frohock, A.E. Kuhlberg and P.J. Clapham. 1992. Behavior of individually-identified sei whales *Balaenoptera borealis* during an episodic influx into the southern Gulf of Maine in 1986. **Fish. Bull. U.S.** 90(4):749-755.

Schlundt, C.E., J.J. Finneran, D.A. Carder and S.H. Ridgway. 2000. Temporary shift in masked hearing thresholds of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. J. Acoust. Soc. Am. 107: 3496-3508.

Schmitz, B. 2002. Sound production in crustacea with special reference to the Alpheidae. In: (ed.) K. Wiese. The Crustacean Nervous System. Springer-Verlag, Berlin-Heidelberg, Germany. Pp. 536-547.

Scholik, A.R. and H.Y Yan. 2002. Effects of boat engine noise on the auditory sensitivity of the fathead minnow, *Pimephales promelas*. Environ. Biol. Fish. 63: 203-209.

Scholik, A.R. and H.Y. Yan. 2001. Effects of underwater noise on auditory sensitivity of a cyprinid fish. Hear. Res. 152: 17-24.

Schrope, M. 2002. Whale deaths caused by US Navy's sonar. Nature 415: 106.

Schusterman, R., D. Kastak, B. Southall and C. Kastak. 2000. Underwater temporary threshold shifts in pinnipeds: tradeoffs between noise intensity and duration. J. Acoust. Soc. Am. 108: 2515-2516.

Schwarz, A.L. and G.L. Greer. 1984. Responses of Pacific herring, *Clupea harengus pallasi,* to some underwater sounds. Can. J. Fish. Aquat. Sci. 41:1183-1192.

Shane, S.H., R.S. Wells and B. Wursig. 1986. Ecology, behavior and social organization of the bottlenose dolphin: a review. **Mar. Mamm. Sci.** 2(1):34-63.

Shin, H.-O., D.-J. Lee, and H.-I. Shin. 2003. Behaviour of Israeli carp *Cyprinus carpio* traced by long baseline telemetry techniques during dynamite explosion work. Fish. Sci. 69: 27-36.

Sieling, F.W. 1951. Experiments on the effects of seismographic exploration on oysters in the Barataria Bay region, 1949-1950. Texas A. & M. Research Foundation, Project 9.

Sieling, F.W. 1952. Experiments on the effects of seismographic exploration on oysters.

Simpson, S.D., H.Y.Yan, M.L. Wittenrich, and M.G. Meekan. 2005. Response of embryonic coral reef fishes (Pomacentridae: *Amphiprion* spp.) to noise. Mar. Ecol. Prog. Ser. 287: 201-208.

Sisneros, J.A. and A.H. Bass. 2003. Seasonal plasticity of peripheral auditory frequency sensitivity. J. Neurosc. 23(3): 1049-1058.

Skalski, J.R., W.H. Pearson and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (*Sebastes* spp.). Can. J. Fish. Aquat. Sci. 49(7):1357-1365.

Slotte, A., K. Hansen, J. Dalen, and E. Ona. 2004. Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian coast. Fish. Res. 67: 143-150.

Smith, M.E., A.S. Kane, and A.N. Popper. 2004. Noise-induced stress response and hearing loss in goldfish (*Carassius auratus*). J. Exper. Biol. 207: 427-435.

Smultea, M.A., J.R. Mobley, Jr., and D. Fertl. 2001. Sperm whale (*Physeter macrocephalus*) reactions to small fixed-wing aircraft. Abstract presented at the Fourteenth Biennial Conference on the Biology of Marine Mammals, November 28-December 3, 2001, Vancouver, Canada. p. 200.

Steffe, A. and J. Murphy. 1992. Offshore prawn catches in the Newcastle region, May to November 1991. Fisheries Research Institute, NSW, Cronulla, NSW.

Stewart, B.S., W.E. Evans and F.T. Awbrey. 1982. Effects of man-made waterborne noise on behavior of belukha whales (*Delphinapterus leucas*) in Bristol Bay, Alaska. HSWRI Tech. Rep. 82-145. Rep. from Hubbs/Sea World Res. Inst., San Diego, CA, for Nat. Oceanic & Atmosph. Admin., Juneau, AK. 29 p.

Stone, C.J. 1997. Cetacean observations during seismic surveys in 1996. JNCC Report 228. Joint Nature Conservancy, Aberdeen, Scotland. 41 p. + App.

Stone, C.J. 1998. Cetacean observations during seismic surveys in 1997. JNCC Report 278. Joint Nature Conservancy, Aberdeen, Scotland. 55 p. + App.

Stone, C.J. 2000. Cetacean observations during seismic surveys in 1998. JNCC Report 301. Joint Nature Conservancy, Aberdeen, Scotland. 62 p. + App.

Stone, C.J. 2003. The effects of seismic activity on marine mammals in UK waters, 1998-2000. JNCC Report No. 323, Joint Nature Conservation Committee, Peterborough, UK. 43 pp. + appendices.

Suez LNG NA LLC. 2005a. Neptune Contingency Plan Schedule. Document 11185602-600-GND-011-B. 1 p.

Suez LNG NA LLC. 2005b. Terminal Location and Layout Design Changes. Document 11185602-600-GND-003-0. 4 p.

Suez LNG NA LLC. 2005c. Northern Pipeline Route. Document 11185602-600-GND-004-0. 4 p.

Suryan, R.M., and J.T. Harvey. 1999. Variability in reactions of Pacific harbor seals, *Phoca vitulina richardsi*, to disturbance. Fish. Bull. 97: 332-339.

Sverdrup, A., E. Kjellsby, P.G. Krüger, R. Fløysand, F.R. Knudsen, P.S. Enger, G. Serck-Hanssen, and K.B. Helle. 1994. Effects of experimental seismic shock on vasoactivity of arteries, integrity of the vascular endothelium and on primary stress hormones of the Atlantic salmon. J. Fish Biol. 45: 973-995.

Szymanski, M.D., D.E. Bain, K. Kiehl, S. Pennington, S. Wong and K.R. Henry. Killer whale (*Orcinus orca*) hearing: auditory brainstem response and behavioral audiograms. J. Acoust. Soc. Am. 106(2):1134-1141.

Tautz, J. and D.C. Sandeman. 1980. The detection of water borne vibration by sensory hairs on the chelae of the crayfish. J. Exp. Biol. 88: 351-356.

Terhune, J.M. 1985. Scanning behavior of harbor seals on haul-out sites. J. Mammal. 66: 392-395.

Terhune, J.M. 1999. Pitch separation as a possible jamming-avoidance mechanism in underwater calls of bearded seals (*Erignathus barbatus*). Can. J. Zool. 77: 1025-1034.

Thomas, J., N. Chun, W. Au and K. Pugh. 1988. Underwater audiogram of a false killer whale (*Pseudorca crassidens*). J. Acoust. Soc. Am. 84(3):936-940.

Thomas, J.A. and C.W. Turl. 1990. Echolocation characteristics and range detection threshold of a false killer whale (*Pseudorca crassidens*). p. 321-334. In: J.A. Thomas and R.A. Kastelein (eds.), Sensory abilities of cetaceans/Laboratory and field evidence. Plenum, New York. 710 p.

Thomas, J.A., R.A. Kastelein and F.T. Awbrey. 1990. Behavior and blood catecholamines of captive belugas during playbacks of noise from an oil drilling platform. Zoo Biol. 9(5):393-402.

Thompson, P.M., M. Sjöberg, E.B. Bryant, P. Lovell and A. Bjørge. 1998. Behavioural and physiological responses of harbour (*Phoca vitulina*) and grey (*Halichoerus grypus*) seals to seismic surveys. p. 134. In: The World Marine Mammal Science Conference Proceedings, Monaco.

Thompson, P.O. 1965. Marine biological sound west of San Clemente Island. NEL Res. Rep. 1290. U.S. Navy Electronics Laboratory, San Diego, CA. 42 p.

Thomsen, B. 2002. An experiment on how seismic shooting affects caged fish. Faroese Fisheries Laboratory, University of Aberdeen, Scotland.

Tielmann, J., L.A. Miller, T. Kirketerp, R.A. Kastelein, P.T. Madsen, B.K. Nielsen and W.W.L. Au. 2002. Characteristics of echolocation signals used by a harbour porpoise (*Phocoena phocoena*) in a target detection experiment. Aquat. Mamm. 28(3):275-284.

Tinney Jr., R.T. 1988. Review of information bearing upon the conservation and protection of humpback whales in Hawaii. Rep. for U.S. Mar. Mamm. Comm., Washington, DC. 56 p. NTIS PB88-195359.

Todd, S., P. Stevick, J. Lien, F. Marques and D. Ketten. 1996. Behavioural effects of exposure to underwater explosions in humpback whales (*Megaptera novaeangliae*). Can. J. Zool. 74:1661-1672.

Tolimieri, N., O. Haine, A. Jeffs, R. McCauley, and J. Montgomery. 2004. Directional orientation of pomacentrid larvae to ambient reef sound. Coral Reefs 23: 184-191.

Tolstoganova, L.K. 2002. Acoustical behaviour in king crab (*Paralithodes camtschaticus*). In: (eds.) A.J. Paul, E.G. Dawe, R. Elner, G.S. Jamieson, G.H. Kruse, R.S. Otto, B. Sainte-Marie, T.C. Shirley, and D. Woodby. Crabs in Cold Water Regions: Biology, Management, and Economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks. Pp. 247-254.

Traxler, S.L., B.R. Murphy, and T.L. Linton. 1993. Subsediment seismic explosions do not injure caged fishes in a freshwater reservoir. J. Freshw. Ecol. 8(1): 73-75.

Tremel, D.P., J.A. Thomas, K.T. Ramirez, G.S. Dye, W.A. Bachman, A.N. Orban and K.K. Grimm. 1998. Underwater hearing sensitivity of a Pacific white-sided dolphin, *Lagenorhynchus obliquidens*. Aquat. Mamm. 24(2):63-69.

Turl, C.W. 1993. Low-frequency sound detection by a bottlenose dolphin. J. Acoust. Soc. Am. 94(5):3006-3008.

Turnpenny, A.W.H. and J.R. Nedwell. 1994. The effects on marine fish, diving mammals and birds of underwater sound generated by seismic surveys. Consultancy report by Fawley Aquatic Research Laboratories Ltd. For UK Offshore Operators Association (UKOOA).

U.S. Department of Commerce and U.S. Navy. 2001. Joint interim report: Bahamas marine mammal stranding event of 15-16 March 2000. Available at: http://www.nmfs.noaa.gov/prot_res/overview/Interim_Bahamas_Report.pdf.

U.S. Department of the Navy. 2005. Marine Resource Assessment for the Northeast Operating Areas: Atlantic City, Narragansett Bay, and Boston. Naval Facilities Engineering Command, Atlantic; Norfolk, Virginia, Contract Number N62470-02-D-9997, Task Order Number 0018. Prepared by Geo-Marine, Inc., Newport News, Virginia. 556 pp.

Vedel, J.P. and F. Clarac. 1976. Hydrodynamic sensitivity by cuticular organs in the rock lobster Palinurus vulgaris. Mar. Behav. Physiol. 3: 235-251.

Wahlberg, M. and H. Westerberg. 2005. Hearing in fish and their reactions to sounds from offshore wind farms. Mar. Ecol. Prog. Ser. 288: 295-309.

Walker, J.L., C.W. Potter and S.A. Macko. 1999. The diets of modern and historic bottlenose dolphin populations reflected through stable isotopes. **Mar. Mamm. Sci.** 15(2):335-350.

Ward, N. 1995. Stellwagen Bank: A Guide to the Whales, Sea Birds, and Marine Life of the Stellwagen Bank National Marine Sanctuary. Center for Coastal Studies, Provincetown, Massachusetts. 232 p.

Wardle, C.S., T.J. Carter, G.G. Urquhart, A.D.F. Johnstone, A.M. Ziolkowski, G. Hampson and D. Mackie. 2001. Effects of seismic air guns on marine fish. Cont. Shelf Res. 21(8-10): 1005-1027.

Waring, G.T., J.M. Quintal and C.P. Fairfield (eds.). 2002. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments - 2002. NOAA Tech. Memo. NMFS-NE-169. 318 p.

Waring, G.T., J.M. Quintal and S.L. Swartz (eds.). 2000. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments - 2000. NOAA Tech. Memo. NMFS-NE-162. 309 p.

Waring, G.T., R.M. Pace, J.M. Quintal, C.P. Fairfield and K. Maze-Foley, eds. 2004. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments -- 2003. U.S. Department of Commerce, NOAA Technical Memorandum NOAA-TM-NMFS-NE-182.

Watkins, W.A. 1986. Whale reactions to human activities in Cape Cod waters. Mar. Mamm. Sci. 2: 251-262.

Watkins, W.A. and K.E. Moore. 1983. Three right whales (*Eubalaena glacialis*) alternating at the surface. J. Mammal. 64: 506-508.

Watkins, W.A. and W.E. Schevill. 1975. Sperm whales (*Physeter catodon*) react to pingers. Deep-Sea Res. 22: 123-129.

Watkins, W.A., K.E. Moore and P. Tyack. 1985. Sperm whale acoustic behaviors in the southeast Caribbean. Cetology 49: 1-15.

Watkins, W.A., M.A. Daher, K.M. Fristrup, T.J. Howald and G.N. Di Sciara. 1993. Sperm whales tagged with transponders and tracked underwater by sonar. Mar. Mamm. Sci. 9(1):55-67.

Webb, C.L.F. and N.J. Kempf. 1998. The impact of shallow-water seismic in sensitive areas. Society of Petroleum Engineers Technical Paper. SPE 46722.

Weinrich, M., M. Martin, R. Griffiths, J. Bove and M. Schilling. 1997. A shift in distribution of humpback whales, *Megaptera novaeangliae*, in response to prey in the southern Gulf of Maine. **Fish. Bull. U.S.** 95(4):826-836.

Wells, R.S. and M.D. Scott. 1999. Bottlenose dolphin *Tursiops truncatus* (Montagu, 1821). p. 137-182 *In:* S. H. Ridgway and R. J. Harrison (eds.), Handbook of Marine Mammals. Vol. 6. The Second Book of Dolphins and the porpoises. Academic Press, San Diego, CA. 486 p.

Whitehead, H. 2002. Sperm whale *Physeter macrocephalus*. p. 898-903 *In:* W.F. Perrin, B. Würsig and J.G.M. Thewissen (eds.), Encyclopedia of Marine Mammals. Academic Press, San Diego, CA.

Whitehead, H. 2003. Sperm Whales: Social Evolution in the Ocean. University of Chicago Press, Chicago, IL. 431 pp.

Wiese, K. 1976. Mechanoreceptors for near field water displacements in crayfish. J. Neurophysiol. 39: 816-833.

Wilson, B. and L.M. Dill. 2002. Pacific herring respond to simulated odontocete echolocation sounds. Can. J. Fish. Aquat. Sci. 59: 542-553.

Winn, H.E. and N.E. Reichley. 1985. Humpback whale *Megaptera novaeangliae* (Borowski, 1781). p. 241-273 *In:* S.H. Ridgway and R. Harrison (eds.), Handbook of Marine Mammals. Vol. 3. The Sirenians and Baleen Whales. Academic Press, London, U.K.

Winn, H.E., C.A. Price and P.W. Sorensen. 1986. The distributional biology of the right whale (*Eubalaena glacialis*) in the western North Atlantic. **Rep. Int. Whal. Commn Spec. Iss.** 10:129-138.

Winn, H.E., J.D. Goodyear, R.D. Kenney and R.O. Petricig. 1994. Dive patterns of tagged right whales in the Great South Channel. **Cont. Shelf Res.** 15(4/5):593-611.

Winn, H.E., P.J. Perkins and L. Winn. 1970. Sounds and behavior of the northern bottle-nosed whale. pp. 53-59 *In*: Proceedings of the Seventh Annual Conference on Biological Sonar and Diving Mammals, Stanford Research Institute, Menlo Park, CA.

Woodley, T.H. and D.E. Gaskin. 1996. Environmental characteristics of North Atlantic right and fin whale habitat in the lower Bay of Fundy, Canada. **Can. J. Zool.** 74:75-84.

Würsig, B., C.R. Greene Jr. and T.A. Jefferson. 2000. Development of an air bubble curtain to reduce underwater noise of percussive piling. Mar. Environ. Res. 48: 1-15.

Würsig, B., S.K. Lynn, T.A. Jefferson and K.D. Mullin. 1998. Behaviour of cetaceans in the northern Gulf of Mexico relative to survey ships and aircraft. Aquat. Mamm. 24: 41-50.

Wysocki, L.E. and F. Ladich. 2005. Effects of noise exposure on click detection and the temporal resolution ability of the goldfish auditory system. Hear. Res. 201: 27-36.

Wysocki, L.E.and F. Ladich. 2003. The representation of conspecific sounds in the auditory brainstem of teleost fishes. J. Exp. Biol. 206: 2229-2240.

Yan, H.Y. 1998. Auditory role of the suprabranchial chamber in gourami fish. J. Comp. Physiol. A 183: 325-333.

Yan, H.Y. 2004. The role of gas-holding structures in fish hearing: An acoustically evoled potentials approach. *In*: (eds.) G. Von der Emede and J. Mogdans. Senses of Fishes. Narosa Publishing House. Pp. 189-209.

Yan, H.Y. and W.S. Curtsinger. 2000. The otic gasbladder as an ancillary auditory structure in a mormyrid fish. J. Comp. Physiol. A 186: 595-602.

Yurk, H. and A.W. Trites. 2000. Experimental attempts to reduce predation by harbor seals on outmigrating juvenile salmonids. Trans. Amer. Fish. Soc. 129: 1360-1366.

Zaitseva, K.A., V.P. Morozov and A.I. Akopian. 1980. Comparative characteristics of spatial hearing in the dolphin *Tursiops truncatus* and man. Neurosci. Behav. Physiol. 10: 180-182 (Transl. from Zh. Evol. Biokhim. Fiziol. 14(1): 80-83, 1978).

Zelick, R., D.A. Mann, and A.N. Popper. 1999. Acoustic communication in fishes and frogs. p. 363-411 *In:* R.R. Fay and A.N. Popper (eds.). Comparative Hearing: Fish and Amphibians. Springer-Verlag, New York.

<u>Websites</u>

www.ag.auburn.edu/faa/ichthyology/sound.html (Accessed August 2005)

www.life.umd.edu/biology/popperlab/research/primitive.html (Accessed August 2005)