ENVIRONMENTAL ASSESSMENT REPORT NO. 2 FOR THE ACOBAR ACOUSTIC TOMOGRAPHY EXPERIMENT IN FRAM STRAIT

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EXECUTIVE SUMMARY

The Nansen Environmental and Remote Sensing Center (NERSC) conducted a full-scale acoustic tomography experiment (ACOBAR[1] Experiment) in Fram Strait from 2010 to 2012, approximately 83 kilometers (km) (45 nautical miles [nmi]) from the west coast of Svalbard, Norway and 313 km (169 nmi) from the east coast of Greenland. The ACOBAR Experiment built upon the initial underwater acoustic tomography system installed in Fram Strait during 2008 by the DAMOCLES[2] Integrated Project. The goal of the ACOBAR Experiment was the continued development and installation of an ocean acoustic tomography system in Fram Strait to provide data needed to monitor the changing Arctic heat flux and circulation as well as to understand the effects of climate variability on water mass transport and sea ice exchange through the Strait.

The experiment area within Fram Strait was triangular-shaped, covered roughly 26,000 km^2 (7,580 nmi^2), and was located wholly outside any territorial seas. Water depths in the experiment area ranged from about 1,400 meters (m) to over 5,000 m. Two vessels were used for deployment and recovery of experiment equipment: the research vessel (RV) *Håkon Mosby*, a 47-m vessel owned and managed by the Norwegian Institute of Marine Research (IMR), and the KV *Svalbard*, a 104-m Norwegian Coast Guard icebreaker and offshore patrol vessel (OPV).

The following two types of underwater acoustic signals were transmitted during the ACOBAR Experiment and are analyzed in this Environmental Assessment Report (EAR):

- Acoustic tomography signals: frequency band 205 to 305 Hz, source level 184 dB re 1 µPa @ 1 m, signal type 100 Hz frequency modulated (FM) sweep over 60 sec, signal interval 3 hr every day or every other day, at a depth of approximately 400 to 560 m.
- RAFOS signals: frequency band 260 to 261 Hz, source level 188 dB re 1 µPa @ 1 m, signal type 1.5 Hz FM sweep over 80 sec, signal interval 6 hr, at a depth of approximately 400 to 560 m.

A post-experiment acoustic and environmental analysis has been conducted on the ACOBAR Experiment activities and sound transmissions to confirm the predicted potential for impacts on the marine environment that was documented in the first EAR. Based on the actual implementation of the experimental equipment and scientific analysis of the acoustic sources, the experiment did not impact the environment of Fram Strait. The low source level of the acoustic sources, combined with their placement in relationship to Marine Protected Areas (MPAs) and the long intervals between transmissions, precluded the experiment activities from affecting any resources of an MPA. Based on the potential for impacts, it is highly unlikely that the experiment activities affected any marine species listed as endangered or threatened under the U.S. Endangered Species Act nor any marine species that are listed as threatened (vulnerable, endangered, or critically endangered) by the International Union for Conservation of Nature (IUCN). Additionally, is very unlikely that any behavioral takes of marine mammals (under the U.S. Marine Mammal Protection Act) occurred as a result of this experiment. In conclusion, the scientific analysis of the ACOBAR experimental activities indicated that no ethical issues resulted, as the experiment had no potential for causing grave danger to marine mammals potentially occurring in the Fram Strait area.

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[1] ACOBAR = Acoustic Technology for Observing the Interior of the Arctic Ocean
[2] DAMOCLES = Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies

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LIST OF ACRONYMS AND ABBREVIATIONS

~	approximately
°	degrees
<	less than
>	greater than
≤	less than or equal to
/	per
%	per cent
µPa	micro-Pascal
ACOBAR	Acoustic Technology for Observing the Interior of the Arctic Ocean
ADCP	acoustic Doppler current profiler
AWI	Alfred Wegener Institute (of Polar and Marine Research), Bremerhaven, Germany
C	Celsius (Centigrade)
CEQ	Council for Environmental Quality
CW	continuous wave
COTS	commercial-off-the-shelf
CTD	conductivity-temperature-depth
DAMOCLES	Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies
dB	decibel(s)
dB re 1 µPa @1 m	decibels relative to one micro-Pascal measured at one meter from center of source
dB re 1 µPa rms	decibels relative to one micro-Pascal root-mean-squared
dB re 1 μPa^2-sec	sound exposure level (SEL), which refers to the squared pressure over a duration of the sound, referenced to the standard underwater sound reference level (1 µPa) expressed in dB, and are assumed to be standardized at the units presented in the left column.
DI	Directivity Index
DKK	Greenland Danish Krone
EEZ	economic exclusion zone
EGC	East Greenland Current
ESA	Endangered Species Act (U.S.)
ESL	energy source level
EU	European Union
FAO	Food and Agricultural Organization (U.N.)
FM	frequency modulation
GPS	global positioning system
Hz	Hertz
ICES	International Council for Exploration of the Sea (Copenhagen, Denmark)
IMR	Institute of Marine Research (Bergen, Norway)
IUCN	International Union for Conservation of Nature (Geneva, Switzerland)
IWC	International Whaling Commission (HQ-Impington, UK)
kHz	kiloHertz
km	kilometer(s)
km^2	square kilometers
kt	knot(s)

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

KV	Norwegian Coast Guard vessel
m	meter(s)
MF	mid-frequency
MMPA	Marine Mammal Protection Act (U.S.)
MPA	Marine Protected Area (IUCN)
m/s	meters per second
NAMMCO	North Atlantic Marine Mammal Commission (HQ-Tromso, Norway)
NERSC	Nansen Environmental and Remote Sensing Center (Bergen, Norway)
NMFCA	Norwegian Ministry of Fisheries and Coastal Affairs
NOK	Norwegian Kroner
OPV	Offshore Patrol Vessel
PTS	permanent threshold shift
RAFOS	SOFAR spelled backward (SOund Frequency And Ranging)
RL	received level
RV	research vessel
sec	second(s)
SEL	sound exposure level
SL	source level
STAR	Simple Tomographic Acoustic Receiver
Sv	Sverdrup; unit of measure for ocean volume transport where 1 Sv = 10^6 m^3/sec
TL	transmission loss
TTS	temporary threshold shift
WRC	Webb Research Corporation
WSC	West Spitsbergen Current
ZOI	zone of influence

1   INTRODUCTION

The Nansen Environmental and Remote Sensing Center (NERSC) (Bergen, Norway) conducted a full-scale acoustic tomography experiment in Fram Strait from 2010 to 2012. Fram Strait lies between Greenland and Svalbard, Norway and represents an important exchange pathway for water masses, sea ice, and heat flux between the Arctic Basin and the Atlantic Ocean. The Fram Strait experiment is part of the ACOBAR (ACoustic technology for OBserving the interior of the ARctic Ocean) Program. The ACOBAR Program builds upon the underwater acoustic tomography system deployed in Fram Strait during 2008 by the DAMOCLES (Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies) Integrated Project. ACOBAR projects are Norwegian managed and use Norwegian ships.

Since the Fram Strait experiment, hereafter referred to as the ACOBAR Experiment, is funded by FP7 of the European Union (EU), the EU requires that an environmental analysis be conducted on the experiment activities to determine if grave danger to marine mammals or ethical issues would result. Activities and sound transmissions associated with the Fram Strait acoustic tomography experiment were initially analyzed in a 2009 Environmental Assessment Report (EAR, December 2009). This document, Environmental Assessment Report No. 2 (EAR-2), is an ensuing effort to confirm the predicted potential impacts in the first EAR now that the experiment has been completed. Though the EU is beginning to address the issue of the potential effects of underwater sound on the environment in the Marine Strategy Framework Directive 2008/56/EC, there are no existing EU standards with which to evaluate risk of ethical concerns. Therefore, reference to existing U.S. regulations, including the Endangered Species Act and the Marine Mammal Protection Act, and the best available practices for estimating risk of potential environmental effects under those regulations, were utilized in this document. Under the Marine Strategy Framework Directive, impulsive and ambient noise indicators and their implementation are being developed by the EU Technical Subgroup on Underwater Noise (Van der Graaf et al. 2012), though these two categories would not include the underwater acoustic sources utilized in the ACOBAR Experiment.

The ACOBAR Experiment was conducted in a triangular-shaped experiment area located in Fram Strait between Greenland and Svalbard, lying wholly outside any country's territorial seas (Figure 1-1). The experiment area was defined by the locations of the active sources at each of the three corners (Table 1-1), with the Simple Tomographic Acoustic Receiver (STAR) array located roughly in the center of the area. Covering roughly 26,000 square kilometers (km^2) (7,580 square nautical miles [nmi^2]), the dimensions of the ACOBAR Experiment area were approximately 190 km (103 nmi), 275 km (149 nmi), and 304 km (164 nmi) for the western, northern, and southern sides, respectively. Water depths in the experiment area ranged from about 1,400 m to over 5,000 m. The easternmost source mooring in the experiment area was located approximately 83 km (45 nmi) from the nearest point of land on Svalbard, while the westernmost mooring in the experiment area was located about 313 km (169 nmi) from the nearest point of land on Greenland.

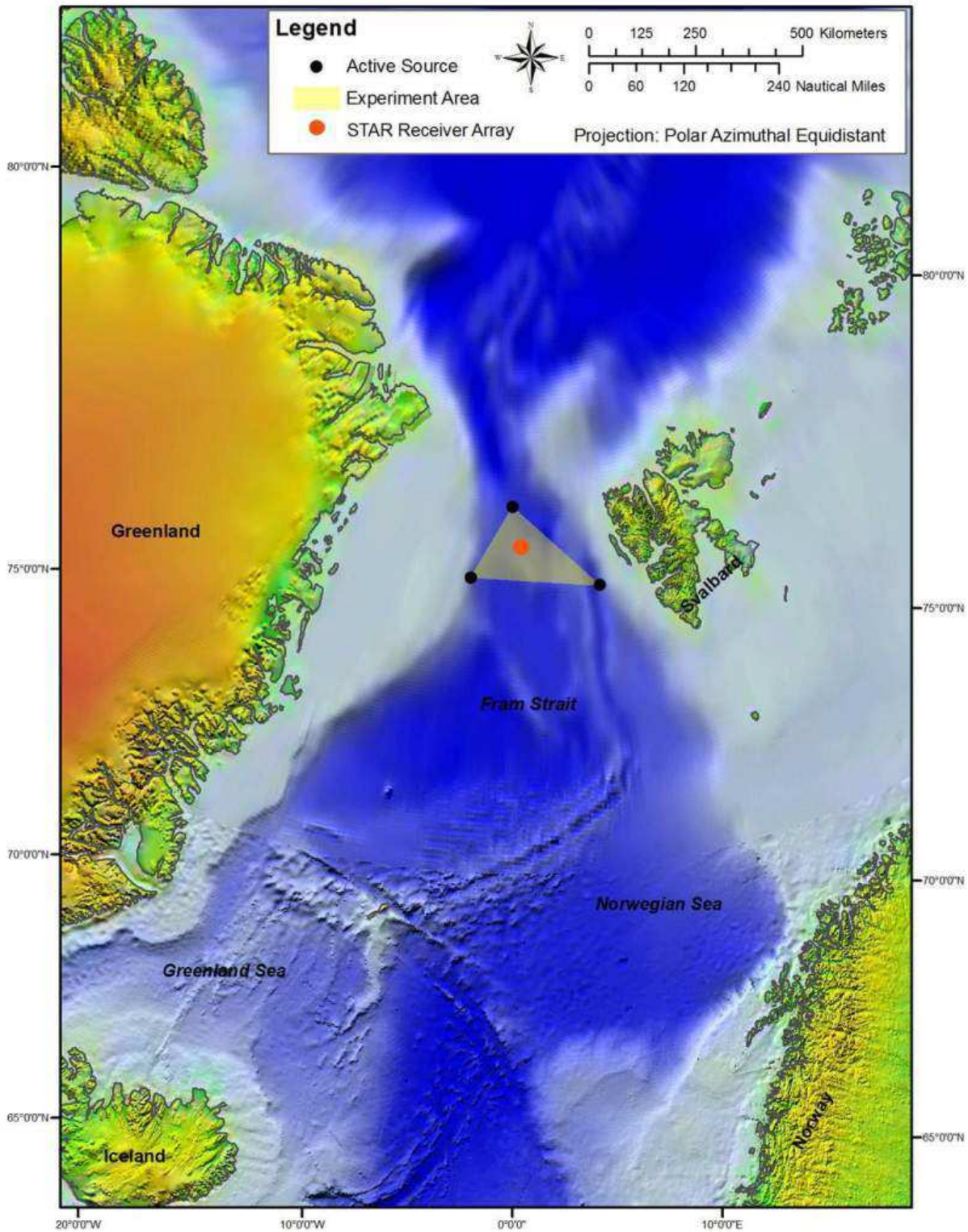| Table 1-1. Geographic coordinates of the ACOBAR experiment area, as defined by the locations of the active acoustic sources and location of the receiver array within the experimental area. |
|---|
| Mooring (A): 77.8999°N / 8.7469°E |
| Mooring (B): 78.1609°N / 4.2430°W |
| Mooring (C): 79.6664°N / 0.2368°W |
| STAR receiver array (2010-2011): 78.8962°N / 2.3456°E |
| STAR receiver array (2011-2012): 78.8951°N / 2.3283°E |

Figure 1-1. Experiment area for NERSC's ACOBAR acoustic tomography experiment including active source and receiver array locations in Fram Strait.

1.1 PURPOSE AND NEED

Long-term monitoring of sea ice and sea temperature in the Arctic Ocean and Fram Strait is an essential component for understanding climate variability, detecting global warming, and predicting the effect on water mass outflow into the North Atlantic Ocean. In September 2012, the extent of Arctic sea ice showed a record minimum, which has not been observed since satellite monitoring of sea ice began in 1978. The September 2012 minimum was 760,000 km^2 (221,581 nmi^2) below the previous record minimum extent in the satellite record, which occurred on September 18, 2007; and is an area about one-third the size of Greenland (National Snow and Ice Data Center 2013). The September 2012 minimum was 3.29 million km^2 (959,211 nmi^2) below the 1979 to 2000 average minimum, representing an area nearly twice the size of Iran; the September 2012 minimum was 18% below 2007 minimum and 49% below the 1979 to 2000 average minimum (National Snow and Ice Data Center 2013).

Although the International Arctic Buoy Program maintains a network of ice buoys that provide meteorological and oceanographic data in real-time to the Applied Physics Laboratory, University of Washington, the reduction in multi-year sea ice introduces a bias in the data from the buoys toward the Canadian and Greenland sectors of the Arctic. Other viable data collection methods that are not affected by sea ice are needed and solutions include the use of underwater gliders and underwater acoustic systems. While gliders can travel autonomously over large distances to collect data, they are limited due to navigation issues in regions where the speed of the glider is of the same order as the ambient current velocities and where ice cover impedes the use a global positioning system (GPS) for navigation when gliders surface. While a glider will spend 8 to 14 days covering 200 km (108 nmi), sound pulses travel the same distance within 138 seconds (sec). Together, with appropriate inversion techniques, underwater acoustic tomography systems can provide unique, synoptic, and integrated measures of internal temperature with an accuracy of 0.01 degrees (^{0}) Celsius (C) along the acoustic tracks. Acoustic tomography has previously been successfully used in the Arctic to study ocean processes in the Greenland, Barents, and Labrador Seas. The ACOBAR Experiment and Program built on the research and systems developed during previous experiments in the Fram Strait and Arctic Ocean regions including the Acoustic Monitoring of Ocean Climate (AMOC) and DAMOCLES Programs. The goal of the ACOBAR Experiment was to develop and install an ocean acoustic tomography system in Fram Strait to provide the data needed to monitor the changing Arctic heat flux and circulation as well as to understand the effects of climate variability on water mass transport and sea ice exchange through the Strait.

1.2 EXPERIMENTAL ACTIVITIES

Low frequency acoustic signals in the ocean travel fast (approximately 1,500 m/sec) with little attenuation. The speed at which these signals travel through the ocean varies with changes in temperature, salinity, pressure, and currents as they propagate through different water masses. Thus, the signal travel time can measure the water temperature and current of the ensonified water volume, when used in conjunction with appropriate signal processing techniques (e.g., inversion schemes) (Munk et al. 1995). This is the fundamental principle of acoustic tomography, which can provide measurements of internal ocean temperatures to an accuracy of 0.001ºC over a 200 km (108 nmi) range (Munk et al. 1995). To measure water mass properties this way, two-way travel times are necessary, which require a minimum of two transceivers in the tomography array. Acoustic tomography can be used in any oceanic area, including very deep and ice-covered regions.

The ACOBAR Experiment deployed equipment in August 2010. Three ACOBAR tomography system moorings were deployed in Fram Strait, including three Webb Research Corporation (WRC) sources, one located at each corner of the experiment area, and one STAR receiver array deployed in the approximate center of the experiment area (Table 1-1; Figure 1-1). The WRC sources transmitted tomographic and RAFOS signals while deployed (Table 1-2). The STAR receiver array deployed in 2010 remained operational until 2011, when it was retrieved and a second STAR receiver array was deployed in roughly the same area (Table 1-1). The tomography system collected data for two years. Two of the three WRC

sources (transceivers) and the STAR array were recovered in September 2012. The third WRC source has not been recovered yet. After approximately two weeks of successful transmissions, its transmissions were no longer received. It is believed that the subsurface buoy holding the mooring in the water column collapsed and the mooring fell to the ocean floor. Attempts will be made to dredge the sea floor in the area and attempt to locate and recover the mooring during the summer of 2013.

With the exception of standard expendable oceanographic equipment and expendable mooring lines and anchors, all other equipment, arrays, and sources were retrieved from their moorings upon conclusion of the experiment's data collection.

1.3   RESEARCH VESSEL SUPPORT

Two research vessels were used during the ACOBAR Experiment: the RV *Håkon Mosby*, a 47-m vessel owned and managed by the Norwegian Institute of Marine Research (IMR); and the KV *Svalbard*, a 104-m Norwegian Coast Guard icebreaker and offshore patrol vessel (OPV).

1.4   EXPERIMENTAL EQUIPMENT

During the ACOBAR Experiment, active acoustic sources and other oceanographic equipment were deployed in Fram Strait. No "experimental" acoustic sources were deployed. All sources are commercially available. The RV and OPV are outfitted with hull-mounted standard active transducers, including echosounders and depth sounders. Additionally, the ACOBAR project scientists used a variety of standard commercial off-the-shelf (COTS) instruments, such as Acoustic Doppler Current Profiler (ADCP) and acoustic modems (Table 1-3). Since these acoustic instruments were unmodified and were used for their intended function, they were not included in the acoustical analysis in this EAR. Additional non-acoustic, standard oceanographic equipment, such as conductivity, temperature, and depth (CTD) instruments, were also deployed to measure other parameters of the physical oceanic environment during the experiment.

The WRC moored tomography sound source (Figure 1-2), which was used to generate the tomographic and RAFOS signals, is a swept frequency underwater acoustic projector that is not gas-compensated, with 50% efficiency, and a directivity index (DI) of 3 decibels (dB) in the horizontal direction (Table 1-2). The WRC projector is a micro-tunable organ pipe with a symmetrical Tonpliz transducer. The unit is free-flooded, with a 36 centimeter (cm) (14 in) diameter. Its controller is a 32-bit Motorola MC68CK338 micro-controller, programmable via external SAIL connector, integrated with a 4-channel STAR system (Scripps Institution of Oceanography), with a hybrid Rubidium low-power clock and underwater acoustic navigation. Long-term stability is estimated to be 3 msec for one year. Power is generated from standard alkaline

Figure 1-2. WRC acoustic source to be deployed during the ACOBAR Experiment.

"D" cell batteries. Endurance is estimated to be up to 3,000 acoustic transmissions, and maximum operating depth is 6,000 m for the electronic housing. The WRC projector is built from aluminum 6061-T6, end-caps are hard anodized, and weight in air is 1,000 kilograms (kg). A WRC source was located at 420 m (Mooring A), 515 m (Mooring B), and 559 m (Mooring C) on the mooring string at each corner of the experimental area (Figure 1-3). The WRC sources transmitted tomographic signals (row 1 of Table 1-2) and RAFOS signals (row 2 of Table 1-2).

A vertical line array of STAR (Figures 1-4 and 1-5), developed by Scripps Institution of Oceanography (SIO), was deployed and moored roughly in the center of the ACOBAR Experiment area. A standard

Table 1-2. Active acoustic sources, including their characteristics, used in the ACOBAR acoustic tomography experiment in Fram Strait for which potential impacts have been analyzed.									
SOURCE/ QUANTITY	TYPE OF SIGNAL	FRE-QUENCY (HZ)	SOURCE LEVEL (dB re 1uPa @ 1 m)	SIGNAL TYPE[3] (HZ)	SIGNAL DURATION (SEC)	SIGNAL INTERVAL	% TIME SOURCE TRANSMITTED (%)	BEAM PATTERN	REMARKS
Webb Research Corp. (WRC) tomography source / 3	Tomo-graphy	205 to 305	184	100 Hz LFM sweep	60	3 hr every day (Moorings B and C) or every other day (Mooring A)	0.56	Dipole at 231.8 Hz	Depths of 420 (A), 515 (B), and 559 (C) m
	RAFOS	260	188	1.5 Hz LFM sweep	80	6 hr	0.37		

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[3] LFM = Linear frequency modulation

Table 1-3. Additional acoustic sources, including their relevant characteristics, used in the ACOBAR Experiment in Fram Strait, for which potential impacts have not been analyzed.								
SOURCE	FREQUENCY (Hz)	SOURCE LEVEL (dB re 1uPa @ 1 m)	SIGNAL TYPE[4] (Hz)	SIGNAL DURATION (SEC)	SIGNAL INTERVAL	% TIME SOURCE TRANSMITTED	BEAM PATTERN	REMARKS
Aquatec AQUAmodem 1000	7,500 to 11,700	185	FSK	0.01[5]	Variable	0.01	Hemispher-ical	One modem co-located with each WRC source and the STAR receiver array.
HAM Module Modem	2,500 to 4,500	180	FSK				Omnidi-rectional	Deployed at depth of 750 m from July 2009 through summer 2010; mooring locations: 78°50'N, 7°E; 78°50'N,6°E; 78°50'N, 5°E

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[4] FSK = Frequency shift key
[5] During data queries, total transmission duration may last 10 to 60 sec.
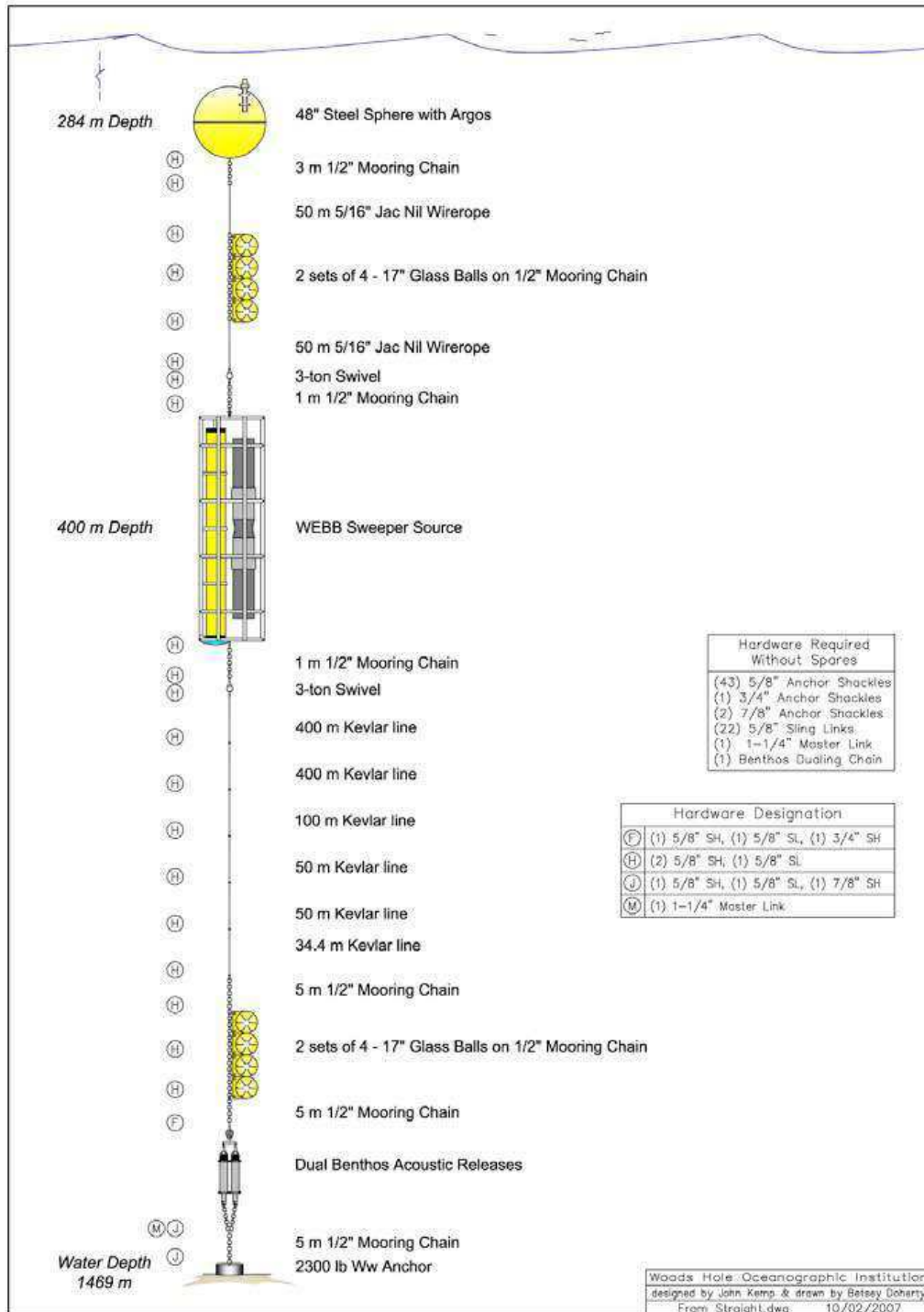
Figure 1-3. WRC source mooring string showing WRC deployed at 400-m in the water column of Fram Strait.

STAR comes in a tube containing the electronics, lithium batteries, and cable with hydrophones spaced at 1.5 wavelengths. The standard STAR includes a precise clock that uses a two-oscillator system (MCXO plus Rubidium) that provides a precision/stability better than 3 msec over a year. Four transponders were deployed 0.5 to 1 km away from the anchor position of the STAR array mooring. The four acoustic transponders surrounding each mooring location provide a long-baseline acoustic navigation system to measure the position of the control unit with an accuracy of 0.5 to 1 m.

Figure 1-4. SIO STARs being deployed in array configuration.
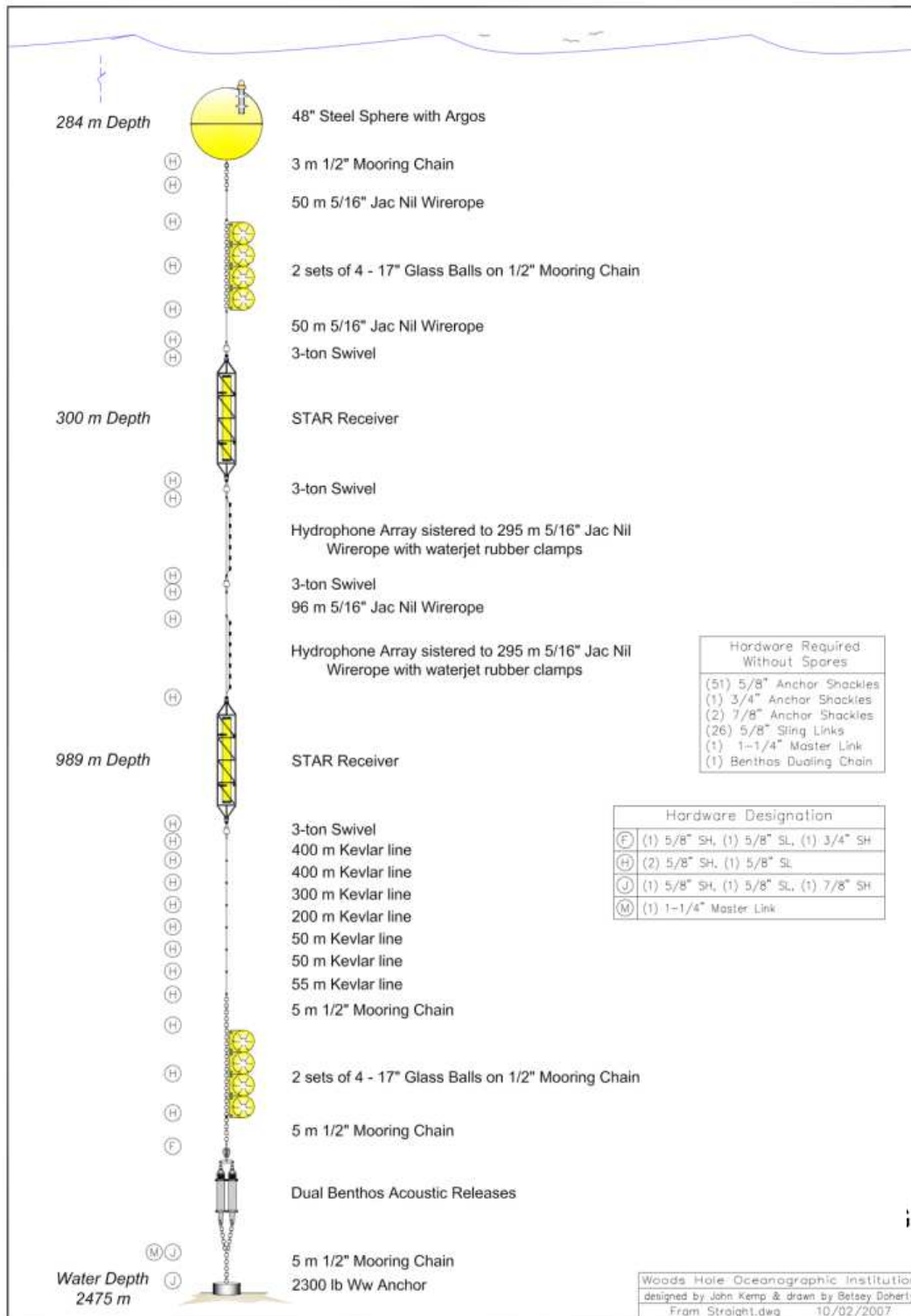
Figure 1-5. Configuration for STAR vertical line array, which was located approximately in the center of the ACOBAR Experiment area.

2 AFFECTED ENVIRONMENT

This chapter describes the pertinent existing physical, biological, and economic environments of the area in which the ACOBAR Experiment was conducted. The chapter's focus is on those resource areas relevant to evaluating potential effects resulting from the ACOBAR Experiment activities and use of acoustic tomography. Resource areas such as coral reefs, protected fish habitat, as well as recreational diving or boating activities are not considered in this assessment, as these resources do not occur in the Fram Strait experimental area. The waters of Fram Strait are much too cold or deep to support coral reef development or recreational activities, and no fish habitat is protected within Fram Strait. The water temperatures of Fram Strait are also below the thermal tolerance of sea turtles, so no sea turtles are reasonably expected to occur in the experimental area, and thus, are not considered in this assessment report.

For marine species, conservation status in this assessment is reported in the classifications designated under the United States (U.S.) Endangered Species Act (ESA) and the International Union for Conservation of Nature (IUCN), as appropriate. The critical ESA classifications are those of endangered or threatened species, while the IUCN designates critically endangered, endangered, and vulnerable categories as species that are considered threatened with extinction.

2.1 PHYSICAL ENVIRONMENT

The ACOBAR Experiment occurred in Fram Strait between Svalbard to the east and northern Greenland to the west (Figure 2-1), just at the region where the width of the Strait begins to narrow. Svalbard, the northernmost Norwegian territory, is an archipelago of many islands, of which Spitsbergen is the largest. Fram Strait connects the Greenland and Norwegian Seas to the Arctic Ocean and is the only deepwater connection to the Arctic.

Figure 2-1. Patterns of circulation in Fram Strait (Joiris et al. 2011).

As an important passageway between ocean basins, Fram Strait influences the world's hydrography and Arctic climate, principally due to the heat and water mass exchange associated with the two primary water masses in the Strait, the West Spitsbergen Current (WSC) and the East Greenland Current (EGC) (Figure 2-1). Ninety percent of the heat exchange and 75% of the water mass exchange between the Arctic Ocean and all other oceans occurs in Fram Strait (Hop et al. 2006). The WSC flows north along the eastern continental shelf and slope margin of the Strait, transporting warmer North Atlantic water poleward. The EGC sweeps south along eastern Greenland, transporting very cold, low-salinity Polar Water and ice southward. The EGC and WSC transport a large volume of ice and water through Fram Strait, with net southward transport by the EGC of 1.7 to 3.2 Sverdrups (Sv)[6], ice flux volume of approximately 0.06 to 0.11 Sv, and mean annual ice flux of about 866,000 km^2 per year (Hop et al. 2006). In the experiment area of Fram Strait, mean annual transport northward ranges from 9 to 10 Sv while southern transport is from 12 to 13 Sv (Schauer et al. 2004). Oceanographic fronts, such as the Polar Front to the west and the Arctic Front to the east, are formed along the boundaries of the Arctic Water, Polar Water, and Atlantic Water masses. The Polar Front largely coincides with the ice edge off Greenland, where significant upwelling can occur during favorable wind conditions (Joiris et al. 2011). Arctic Water is characterized by the occurrence of

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[6] One Sverdrup (Sv) is equal to water volume transport of one million m^3/sec

mesoscale eddies, likely shedding from instabilities in the WSC (Schauer et al. 2004; Hop et al. 2006). Water temperatures at the surface of Fram Strait are variable, but the maximum water temperature depends upon the intensity of the WSC; water temperatures are a relatively constant 1 to 1.3°C at 200 to 300 m, dropping to -0.90 to -0.95°C below 1,000 m (Hop et al. 2006).

Ice covers much of the waters over the Greenland shelf and ice cover extends into Fram Strait from the Arctic Ocean in winter through spring. The typical annual ice cycle in the Arctic begins with maximum ice extent in March followed by the minimum occurring in September (Hop et al. 2006). The extent and thickness of the ice cover in the Arctic has decreased steadily over the last century, with the sea ice extent declining significantly in all months, for an approximate 3% reduction in ice area per decade (Hop et al. 2006; Sagen et al. 2008). During the summer of 2012, Arctic sea ice reached a record minimum level. In September 2012, the extent of Arctic sea ice showed a record minimum, which has not been observed since satellite monitoring of sea ice began in 1978. The September 2012 minimum was 760,000 km^2 (221,581 nmi^2) below the previous record minimum extent in the satellite record, which occurred on September 18, 2007; and is an area about one-third the size of Greenland (National Snow and Ice Data Center 2013). The September 2012 minimum was 3.29 million km^2 (959,211 nmi^2) below the 1979 to 2000 average minimum, representing an area nearly twice the size of Iran; the September 2012 minimum was 18% below 2007 minimum and 49% below the 1979 to 2000 average minimum (National Snow and Ice Data Center 2013).

2.1.1 PHYSIOGRAPHY AND BATHYMETRY
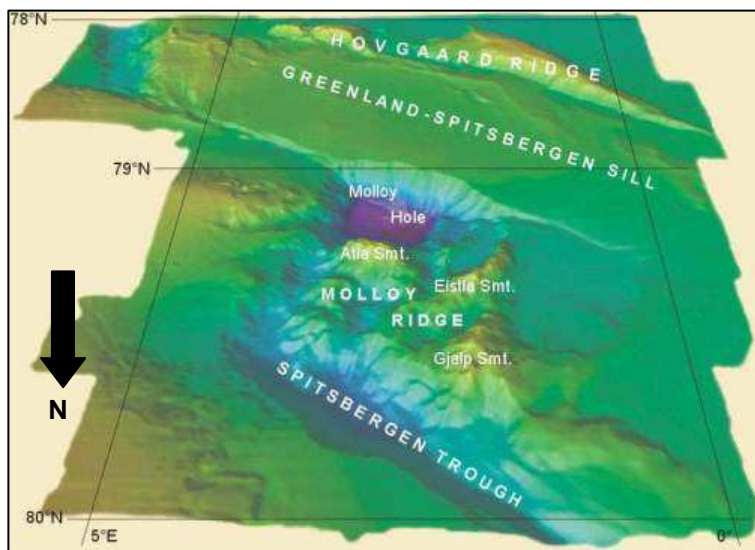
Figure 2-2. Distinctive physiographic features of Fram Strait viewed from the north looking south (AWI 2009).

Fram Strait is a deepwater passage that reaches water depths of over 5,600 m in the Molloy Deep or Molloy Hole region (Figures 2-2 and 2-3) (AWI 2009). The seafloor of Fram Strait is part of a complex system of faults and spreading centers forming a series of troughs, sills, ridges, and deep depressions that primarily are oriented in a northwest to southeast direction (Thiede et al. 1990; AWI 2009). A series of three seamounts are located in central Fram Strait at Molly Ridge, rising 1,600 m off the seafloor.

The ACOBAR Experiment area is located in waters that range from about 1,400 to over 5,000 m in depth and is situated above some

of the most complex topography in the Strait.

2.1.2 ACOUSTICAL CONDITIONS

In general, the acoustic environment of Fram Strait area is complex due to: a) the rapid changes in bathymetry; b) influx from the south of warm North Atlantic waters; c) cold less-saline water outflows from the Arctic Ocean; d) strong vertical gradient in temperature occurs at depth, and e) the potential for surface ice coverage in the area seasonally. Overall, the underwater acoustic propagation mode that exists in the experiment area is that of an upward refracting, convergence zone, although surface and near-surface ducts can commonly develop during much of the year (Figure 2-4), especially when the

temperature of the upper water column is near constant and close to freezing. Surface ducts trap much of the acoustic energy close to the sea surface while ice cover both absorbs and scatters sound energy. Sound waves pass more slowly through the upper, colder water masses than through the deeper, warmer water masses, which is the reason there is such a difference in sound speed travel times in the winter and summer in the experiment area (Figure 2-5).

Increased interaction of the ice-ocean interface as well as the meso- and micro-scale oceanographic features that exist in the region will increase transmission loss due to scattering and reflection losses. If an acoustic source is placed in the water column (below any potential surface ducts), only a relatively small portion of the sound from that fixed source could eventually be trapped in near-surface ducts, as illustrated in Figure 2-4. Although some transmitted sound may eventually be trapped in surface ducts, that sound has already traveled a great distance (80 to 100 km) and has been greatly reduced in sound level (>80 dB) before reaching the duct.

2.2 BIOLOGICAL ENVIRONMENT

The biological environment of Fram Strait is a pelagic and ice-associated ecosystem strongly influenced by oceanography and sea-ice conditions. With advection and ice-associated upwelling playing such key roles in the dynamics of the Strait, species retention is low and highly variable and the environment can be considered a transitional or temporary habitat for many

Figure 2-3. Bathymetry in the Fram Strait and adjacent regions (International Bathymetric Chart of the Arctic Ocean) (Image courtesy of AWI 2009).

species. Zooplankton are seasonally abundant in the region from spring through summer and are dominated by calanoid copepods (Hop et al. 2006), the favored food of the critically endangered bowhead whale. Surprisingly, for such an important oceanographic and climatologic region, the biota of Fram Strait have been little studied and surveyed. This section of the assessment provides information on the megafauna species of the Fram Strait ecosystem that could potentially be impacted by the ACOBAR Experiment. Information and data are provided in this section against which experimental impacts will be assessed in the following section.

Figure 2-4. Sound speed profiles and predicted rays in Fram Strait during September 2008 from the TOPAZ model and data collected by CTD (Sagen et al. 2009).
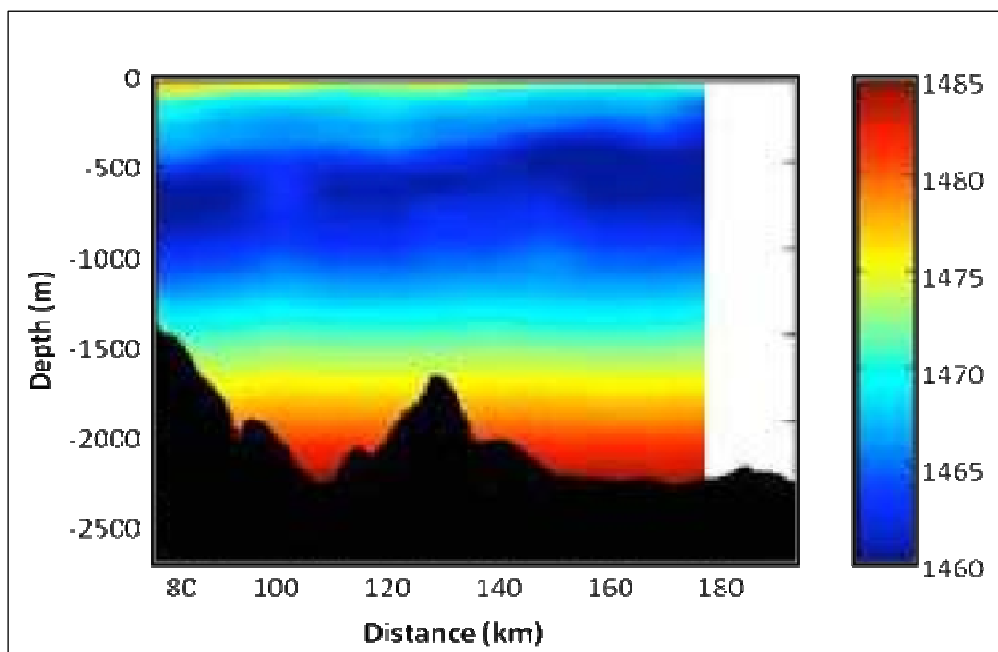
Figure 2-5. Eastern Fram Strait sound velocity fields from CTD data, corresponding to Figure 2-4 (Sagen et al. 2009).

2.2.1 MARINE MAMMALS

As many as 21 species of marine mammals potentially occur in Fram Strait (Table 2-1). The marine mammal species include fourteen cetacean (whales, dolphins, and porpoises) species of which six species are baleen or mysticete whales and eight species are toothed or odontocete whales. Six specie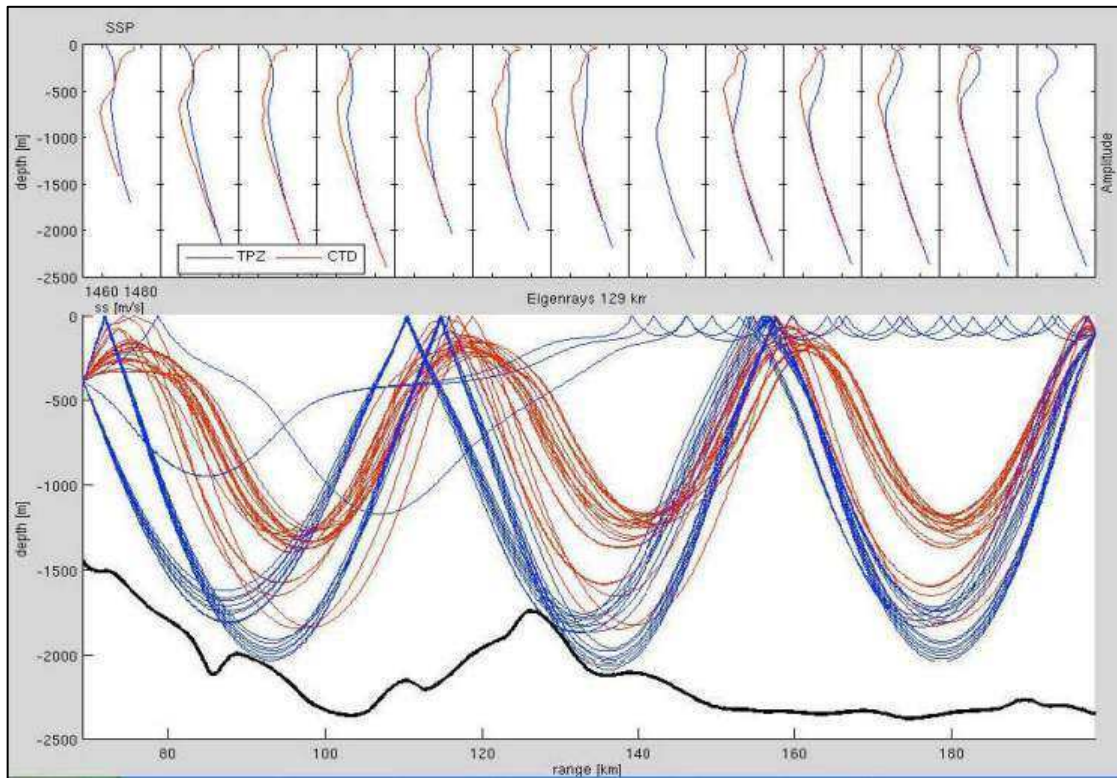s of pinnipeds (walrus, seals, and sea lions) as well as the polar bear may also occur in the experiment area. Of the marine mammals potentially occurring in Fram Strait, eight are listed under the U.S. ESA as either threatened or endangered, and seven of the species are listed in the IUCN's Red List as vulnerable, endangered, or critically endangered species.

All available sources of information and data were queried to compile a representative assemblage of the marine mammals that may occur in the experiment area for the ACOBAR Experiment. Since so few data were available on the occurrence of marine mammals in the Fram Strait region, seasonal estimates were not possible; density estimates are representative of the entire year. Density estimates could not be derived from existing literature or data for seven of the possible 21 marine mammal species. For these species (Table 2-1), a density of <0.00001 was used so that impacts on these species could be estimated. This low density value is realistic, however, as available occurrence information for these species indicates that they have historically occurred in very low levels in the Fram Strait region. Densities for the remaining species were derived from a multitude of regional sources; in some cases where only abundance estimates were given, areas of the Fram Strait regions where the species had been surveyed were taken from Øien (2009) so that densities could be estimated. In some cases, a correction factor was applied to account for the amount of the experiment area that had been included in the survey area from which the density was derived.

2.2.1.1 Mysticetes

Six species of baleen or mysticete whales potentially occur in Fram Strait throughout the year (Table 2-1). All baleen whales that may be found in the ACOBAR Experiment area except the minke and humpback whales are considered to be endangered or critically endangered under the ESA and IUCN. The minke whale is the most common baleen whale in the region and is commercially hunted.

Hearing and sound production is highly developed in all studied marine mammal species. Mysticetes, like other marine mammals, rely heavily on sound and hearing for communication and sensing their environment (Norris, 1969; Watkins and Wartzok, 1985; Frankel, 2009). Cetaceans have the broadest acoustic range and the only fully specialized ears adapted for underwater hearing. Little information, however, is available on the individual hearing capabilities of many marine mammals; no direct measurements of mysticete hearing sensitivity have been conducted (Ketten, 1994 and 2000; Thewissen, 2002).

➢ **Blue Whale (*Balaenoptera musculus*)**

Blue whales are the largest living animal, growing to lengths of 27 m (Reeves et al. 2002). Blue whales are classified as endangered under both the ESA and by the IUCN. In the northern hemisphere, the IWC recognizes two stocks of blue whales: the North Atlantic and the North Pacific. There are no current reliable abundance estimates for the North Atlantic stock (Waring et al. 2013), though it is believed blue whales number in the hundreds in the northeast Atlantic (Pike et al. 2009). Blue whales are primarily found in deeper, offshore waters and are rare in shallower, shelf waters (Wenzel et al. 1988). These large baleen whales are distributed from the ice edge to the subtropics in both hemispheres (Reeves et al. 2002). Blue whales occur from Baffin Bay and the Greenland Sea to the waters of Northern Norway and Svalbard (Mizroch et al. 1984a). In two year-long, passive acoustic studies of Fram Strait, blue whale sounds were recorded June to November (Klinck et al. 2012; Moore et al. 2012) and not during the rest of the year. These long-term studies demonstrate that blue whales follow the traditional baleen pattern of summer residency at northern latitudes, migrating to southern latitudes for the winter (Reeves et al. 2002).

Common Name	Scientific Name	Status Under ESA	Status Under IUCN	Density (animals/km^2)	Density Reference
Table 2-1. Marine mammals potentially occurring in Fram Strait and their status under the ESA and IUCN as well as their densities.					
Cetaceans–Mysticetes					
Blue Whale	*Balaenoptera musculus*	Endangered	Endangered	0.00001	4
Bowhead Whale	*Balaena mysticetus*	Endangered	Critically Endangered	0.00002	1
Common Minke Whale	*Balaenoptera acutorostrata*		Least Concern	0.03206	2, 3
Fin Whale	*Balaenoptera physalus*	Endangered	Endangered	0.00574	4
Humpback Whale	*Megaptera novaengliae*	Endangered	Least Concern	0.00009	4
Sei Whale	*Balaenoptera borealis*	Endangered	Endangered	0.00001	4
Cetaceans–Odontocetes					
Atlantic White-sided Dolphin	*Lagenorhynchus acutus*		Least Concern	<0.00001	
Beluga Whale	*Delphinapterus leucas*	*	Near Threatened	<0.00001	
Killer Whale	*Orcinus orca*		Data Deficient	<0.00001	
Long-finned Pilot Whale	*Globicephala melas*		Data Deficient	<0.00001	
Narwhal	*Monodon monoceros*		Near Threatened	0.00004	10
Northern Bottlenose Whale	*Hyperoodon ampullatus*		Data Deficient	<0.00001	
Sperm Whale	*Physeter macrocephalus*	Endangered	Vulnerable	0	4
White-beaked Dolphin	*Lagenorhynchus albirostris*		Least Concern	<0.00001	
Carnivora					
Polar Bear	*Ursus maritimus*	Threatened	Vulnerable	0.00500	5
Pinnipeds					
Arctic Ringed Seal	*Pusa hispida hispida*	Threatened	Least Concern	0.03355	9
Bearded Seal	*Erignathus barbatus*	**	Least Concern	0.01050	11
Harbor Seal	*Phoca vitulina*		Least Concern	0.00089	8
Harp Seal	*Pagophilus groenlandica*		Least Concern	0.07043	6
Hooded Seal	*Cystophora cristata*		Vulnerable	0.00811	6
Walrus	*Odobenus rosmarus*		Data Deficient	<0.00001	7

1. Wiig et al. 2007
2. Skaug et al. 2004
3. Bøthun et al. 2008
4. Øien 2009
5. Aars et al. 2009
6. Haug et al. 2007
7. Gjertz and Wiig 1994
8. Gjertz and Borset 1992
9. Krafft et al. 2006
10. Øien incidental sighting data
11. Bengston et al. 2005

*Only the Cook Inlet, Alaska population is listed as Endangered under the ESA

**Only the Beringia and Sea of Okhotsk bearded seal DPSs are listed as threatened under the ESA

Blue whales are lunge feeders and prey almost exclusively on krill (Reeves et al. 2002). The typical duration of blue whale dives is 3 to 20 minutes (min) (Jefferson et al. 2008). Croll et al. (2001) determined that blue whales dove to 140.0 $\pm$ 46.01 m and for 7.8 $\pm$ 1.89 min when foraging and to 67.6 $\pm$ 51.46 m and for 4.9 $\pm$ 2.53 min when not foraging. Dives as deep as 300 m have been recorded (Calambokidis et al. 2003). Blue whale vocalizations are long, patterned low frequency sounds with durations up to 36 sec (Thomson and Richardson 1995), repeated every 1 to 2 min (Mellinger and Clark 2003). The frequency range of their vocalizations is 12 to 400 Hz, with dominant energy in the infrasonic range at 12 to 25 Hz (Ketten 1998; Mellinger and Clark 2003). Source levels of blue whale calls are up to 188 decibels relative to one micro-Pascal measured at one meter from center of source (dB re 1 µPa @ 1 m) (Ketten 1998; McDonald et al. 2001).

➢ **Bowhead Whale** *(Balaena mysticetus)*

Bowhead whales can grow to 15.2 to 18.3 m in length and possess a thick blubber layer. Classified as endangered under the ESA, the Svalbard subpopulation is classified as critically endangered under the IUCN. The bowhead whale population declined due to whaling exploitation. Bowheads are separated into five distinct breeding stocks: the Okhotsk Sea, Bering-Chukchi-Beaufort Sea, Davis Strait, Hudson Bay, and Spitsbergen stocks (Rugh et al. 2003). The Spitsbergen stock ranges from eastern Greenland to the Barents and Kara Seas and was estimated to be the largest pre-whaling stock with 25,000 to over 50,000 individuals (Allen and Keay 2006). Population estimates currently place the stock at possibly tens of animals based on limited sightings (Wiig et al. 2007). Records of bowhead sightings in the Svalbard area have been sporadically documented, with forty-two sightings between 1940 and 2008, though only three of those occurred prior to 1980 (Wiig et al. 2010). During dedicated surveys in Fram Strait during 2006 and 2008, eight and zero sightings, respectively, were observed (Wiig et al. 2010).

Bowheads associate with pack ice, preferring sea ice cover of 40 to 70%, and are capable of breaking thick ice (Moore and Laidre 2006). Bowheads migrate south in autumn to winter feeding grounds near the edge of the pack ice and return north as the ice retreats in the spring (Moore and Reeves 1993). A female was tagged and tracked continuously from 30 April 2010 to 24 July 2010; initially remaining in Fram Strait, the animal then moved south (70-73°N) for the summer, with winter positions (27 Nov-20 Dec 2010) back north (80°N) (Lydersen et al. 2012). This type of seasonal movement reflects those described in traditional whaling records (Lydersen et al. 2012).

Bowheads are skim feeders, foraging primarily on euphausiids and copepods (Braham 1984; Moore and Laidre 2006). Adults can dive to 200 m with average dive times of 22.3 min and a maximum of 41 min (Finley 2001). Bowheads produce low frequency sounds similar to other baleen whales but possess a more complex repertoire, producing several different types of calls including tonal FM calls, pulsed tone calls, tonal AM calls, and complex calls or songs (Clark and Johnson 1984). Vocalizations of bowhead whales were recorded year-round in Fram Strait (Moore et al. 2012), with songs recorded daily, often hourly, from the end of November until early March in western Fram Strait (Stafford et al. 2012). The diversity and intensity of song suggests that western Fram Strait is a wintering ground, if not breeding ground, for the Spitsbergen stock (Stafford et al. 2012). Bowhead whale calls or "moans" have been estimated at source levels of about 129 to 178 dB re 1 µPa @ 1 m, perhaps reaching as high as 189 dB re 1 µPa @ 1 m (Cummings and Holliday 1987; Richardson et al. 1995). Singing by bowhead whales has been recorded during the spring migration through ice leads in Alaska; bowhead songs cover a wider frequency range than do typical calls with greater modulation variability (Richardson et al. 1995). The song diversity recorded in Fram Strait closely approached that of songbirds, certainly unprecedented for baleen whales (Stafford et al. 2012).

➢ **Common Minke Whale (**Balaenoptera acutorostrata**)**

The common minke whale is the smallest baleen whale in the Northern Hemisphere with adults reaching lengths of about 10.7 m (Reeves et al 2002). In the North Atlantic, the International Whaling Commission

(IWC) recognizes four stocks of common minke whales: Canadian East Coast, West Greenland, Central North Atlantic, and Northeastern North Atlantic (NAMMCO 2004a). The most recent abundance estimate for the Northeastern North Atlantic stock was computed at 103,000 whales (Bøthun et al. 2008). Common minke whales are distributed throughout the North Atlantic Ocean but are found predominantly along the continental shelf margin. In the Fram Strait area, minke whales are the most common baleen whale and have frequently been observed along the shelf break region of eastern Fram Strait off Svalbard (Skaug et al. 2004).

Common minkes migrate seasonally, but their movement patterns are not as well defined as those of other baleen whales. Minke whales are lunge feeders that usually feed at depth on krill and fish. The general dive pattern of minke whales is that of four surfacings that are interspersed with short duration dives of less than 38 sec (Stern 1992). After the fourth surfacing, there is a longer-duration dive ranging from approximately 2 to 6 min. Recordings of minke whale sounds indicate the production of both high and low-frequency sounds (range: 0.06 to 20 kHz) in two basic forms of pulse trains (Thomson and Richardson 1995; Mellinger et al. 2000). Source levels for this species have been estimated to range from 151 to 175 dB re 1 µPa @ 1 m (Ketten 1998), but some minke whale sounds have been calculated to range from 150 to 165 dB re 1 µPa @ 1 m (Gedamke et al. 2001).

➢ **Fin Whale (*Balaeanoptera physalus*)**

Fin whales are the second largest whale species (Reeves et al. 2002) reaching lengths of 22 m (Gambell 1985). Fin whales are classified as endangered under ESA and by the IUCN. Within the North Atlantic Ocean, the IWC has designated six stocks of fin whales: the Western North Atlantic, West Greenland, East Greenland-Iceland, North Norway, West Norway, and the Faroe Islands (NAMMCO 2004b). Two stocks occur in the Fram Strait region, the North Norway and East Greenland-Iceland stocks. The most recent abundance estimates for the North Norway and East Greenland-Iceland stocks were 3,946 and 25,352, respectively (NAMMCO 2004b). A recent abundance estimate for the Fram Strait region resulted in an estimate of 6,409 animals (Øien 2009).

Fin whales occur in coastal and continental shelf waters as well as deep offshore waters, with higher densities occurring beyond the slope (Aguilar 2002). In the North Atlantic, fin whales occur from the Gulf of Mexico and the Mediterranean Sea north to approximately 80°N in the summer and southwestern Norway in the winter (Harwood and Wilson 2001). Fin whales undergo a seasonal migration pattern similar to other baleen whales; however, their migrations are believed to be more complex (NAMMCO 2004b). This has been shown to be true from year-round passive acoustic monitoring of northern latitude regions. In Davis Strait, between Greenland and Canada, and along the mid-Atlantic Ridge, the peak power in the frequency band of fin whales occurred in November to December (Simon et al. 2010; Nieukirk et al. 2012). Furthermore, Moore et al. (2012) recorded fin whales in Fram Strait from August to March, with no detected vocalizations in spring or early summer. A similar pattern was identified by Klinck et al. (2012), with calls from August to April and an energy peak in early December.

Fin whales are lunge feeders, mainly feeding at depth on euphausiids and small schooling fish (Croll et al. 2001). Dive depths typically correlate with prey depths. Croll et al. (2001) determined that fin whales dove to about 100 m with a duration around 6 min when foraging and to about 60 m with a duration of around 4 min when not foraging. Maximum dive duration was about 17 min (Croll et al. 2001). Fin whales produce a variety of sounds with a frequency range up to 150 Hz (Thomson and Richardson 1995), including a 20 Hz infrasonic pulse (actually an FM sweep from about 23 to 18 Hz) with durations of about 1 sec (Watkins et al. 1987) and can reach source levels of 184 to 186 dB re 1 µPa @ 1 m (maximum up to 200) (Charif et al. 2002).

➢ **Humpback Whale (*Megaptera novaeangliae)***

Humpback whale adults are 11 to 16 m in length. Humpback whales are listed as endangered under the ESA and as least concern under the IUCN. Humpback whales are globally distributed in all major oceans

and most seas. These whales are generally found during the summer on high-latitude feeding grounds and during the winter in the tropics and subtropics around islands, over shallow banks, and along continental coasts, where calving typically occurs. Most humpback whale sightings are in nearshore and continental shelf waters. During recent summer surveys (1996 through 2001) covering an area that included Fram Strait, the Norwegian and Greenland Seas, and part of the Barents Sea, an abundance of 1,450 humpback whales was estimated (Øien 2009).

Humpbacks feed in the North Atlantic waters during spring and summer on small schooling fish and krill; most of the north Atlantic population migrates during the winter to calving grounds in the West Indies region (Whitehead and Moore 1982). The migratory routes taken during the southbound and northbound migrations are not known. Little is known about humpback hearing, but Houser et al. (2001) produced the first predicted audiogram for the humpback, which indicates hearing sensitivity at frequencies from 700 Hz to 10 kHz, with maximum relative sensitivity between 2 and 6 kHz. Humpback whales are known to produce three classes of vocalizations: (1) "songs" in the late fall, winter, and spring by solitary males; (2) sounds made within groups on the wintering (calving) grounds; and (3) sounds made on the feeding grounds (Thomson and Richardson 1995). Au et al. (2001) recorded high-frequency harmonics (to 13.5 kHz) and source level (between 171 and 189 dB re 1 μPa @ 1 m) of humpback whale songs.

➢ **Sei Whale (*Balaenoptera borealis*)**

Adult sei whales grow up to 18 m in length. Sei whales are listed as endangered under the ESA and the IUCN. The IWC recognizes three sei whale stocks in the North Atlantic: Nova Scotia, Iceland-Denmark Strait, and Northeast Atlantic (Perry et al. 1999). Sei whales are most often found in deep, oceanic waters over areas of steep bathymetric relief (Best and Lockyer 2002). Sei whales have a worldwide distribution but are found primarily in cold temperate to subpolar latitudes. These whales spend the summer months feeding in the subpolar higher latitudes and return to the lower latitudes to calve in the winter. In the western North Atlantic, sei whales occur primarily from Georges Bank north to Davis Strait (Perry et al. 1999). Five sei whales were recently observed during surveys in the Fram Strait region (Øien 2009).

The sei whale is atypical of rorquals as they primarily "skim" their food of small fishes and zooplankton. Sei whale vocalization recordings from the North Atlantic consisted of paired sequences (0.5 to 0.8 sec, separated by 0.4 to 1.0 sec) of 10 to 20 short (4 msec) FM sweeps between 1.5 and 3.5 kHz; source level was not known (Thomson and Richardson 1995). These mid-frequency calls are distinctly different from low-frequency tonal and frequency-swept calls recently recorded in the Antarctic; the average duration of the tonal calls was 0.45±0.3 sec, with an average frequency of 433±192 Hz and a maximum source level of 156 ± 3.6 dB re 1 μPa @ 1 m (McDonald et al. 2005).

2.2.1.2   Odontocetes

➢ **Atlantic White-sided Dolphin (*Lagenorhynchus acutus*)**

Adult white-sided dolphins are 2.5 to 2.8 m in length (Jefferson et al. 2008). Atlantic white-sided dolphins are listed as least concern by the IUCN and are considered to be abundant in number throughout their range, with worldwide numbers estimated at 150,000 to 300,000 individuals (Kaschner 2004). Schools of 2,000 to 4,000 dolphins have been observed. This species is distributed in cold temperate to subpolar waters of the North Atlantic from France to southern Greenland, Iceland, and southern Svalbard, primarily occurring in outer continental shelf and slope waters although they are sometimes observed in shallow, coastal and deeper, oceanic waters (Jefferson et al. 2008). Mass strandings of this species are common in the North Atlantic. Atlantic white-sided dolphins feed on small schooling fishes, shrimp, and squid. The longest recorded dive of a tagged Atlantic white-sided dolphin was 4 min (Jefferson et al. 2008). The only information available on Atlantic white-sided vocalizations is that the dominant frequency is 6 to 15 kHz (Thomson and Richardson 1995). Life history, biology, and physiology of this dolphin species are not well known; no hearing data are available for this species.

➢ **Beluga** *(Delphinapterus leucas)*

The beluga, or white whale, is a medium-sized whale that reaches a length of 3.6 to 5 m (Jefferson et al. 2008). Belugas are listed as vulnerable under the IUCN. There are well over 100,000 belugas in the circumpolar Arctic (Reeves et al. 2002). Stocks are defined primarily on the basis of summering grounds, most of which are centered on estuaries where animals molt (Reeves et al. 2002). There are approximately 12 stocks within eastern Canada, western Greenland, Norway (Svalbard) and the Kara Sea (NAMMCO 2004c). The beluga has a nearly Arctic circumpolar distribution, being found in arctic and subarctic waters within Canada, Alaska, Russia, Norway (Svalbard), and western Greenland (Gurevich 1980; NAMMCO 2004c). Distribution is centered mainly between 50ºN and 80ºN (Reeves et al. 2002) and the St. Lawrence estuary is at the southern limit of the distribution of this species (Lesage and Kingsley 1998). Belugas occur in to warmer shallow waters in coastal estuaries, bays, and rivers for molting and calving (NAMMCO 2004c). During the winter, they are pushed out of the shallower waters by ice into deeper waters. Belugas winter primarily in polynyas, near the edges of pack ice, or in areas of shifting, unconsolidated ice (NAMMCO 2004c). In the coastal waters of Svalbard, belugas also occur commonly in near glacier fronts (Lydersen et al. 2001). Calls from odontocetes, primarily from belugas and narwhals, were recorded throughout most of the year in Fram Strait (Moore et al. 2012). Long migrations (thousands of kilometers) are a normal part of beluga behavior in some locales (Reeves 1990). These movements are probably a response to a combination of coastal ice formations, offshore feeding opportunities, and the affinity for estuarine conditions during the summer calving period (Brodie 1989).

Belugas prey on a wide range of benthic and pelagic fishes, invertebrates (Gurevich 1980), and sometimes cephalopods (Reeves et al. 2002) and crustaceans (Boltunov and Belikov 2002). Primary prey species depends on region and seasonal availability (Reeves et al. 2002). Belugas are generalist feeders, but arctic cod and polar cod are the most important prey species throughout their range (Finley et al. 1990; Boltunov and Belikov 2002). They are capable of diving to extreme depths; free ranging belugas have been documented to dive to depths of over 450 m (Martin et al. 1998). Average dive time for belugas is 13 min (Martin and Smith 1999), but the maximum dive duration recorded is 25 min (Martin et al. 1998). Scientists have documented as many as 50 call types of belugas (O'Corry-Crowe 2002). Whistle and pulsed calls are typically made at frequencies between 0.4 and 20 kHz (Thomson and Richardson 1995). Belugas have demonstrated echolocation abilities with frequencies of 40 to 60 kHz and 206 to 225 kHz; with a source level of 206 to 225 dB re 1 µPa @ 1 m (Thomson and Richardson 1995). This species has good high-frequency hearing, with high sensitivities from 32 kHz to 108 kHz (Klishin et al. 2000). Hearing extends at least as low as 40 to 75 Hz; however, sensitivity at these low frequencies appears to be poor (Awbrey et al. 1988; Klishin et al. 2000). Ridgway et al. (2001) determined that beluga hearing is not attenuated at depth (which means that zones of audibility occur throughout the depths to which these whales dive).

➢ **Killer Whale (*Orcinus Orca*)**

This is probably the most instantly-recognizable of all the cetaceans with their distinct black and white coloration and tall dorsal fin. Killer whales range throughout the North Atlantic Ocean and have been observed in virtually every marine habitat from the tropics to the poles and from shallow, inshore waters (and even rivers) to deep, oceanic regions (Dahlheim and Heyning 1999). In the northeast Atlantic Ocean, Norwegian and Icelandic killer whales are recognized, both of which specialize in foraging on herring (Similä et al. 1996). In the Fram Strait area, killer whales are known in the Norwegian and Barents Seas, where their population is estimated at 3,000 whales; these whales also occur in the waters of Svalbard during the summer (Kovacs and Lydersen 2008). Within the Svalbard region, killer whales are rarely seen inshore, preferring to stay near the areas of productivity, primarily the continental slope (Kovacs and Lydersen 2008). The occurrence and prevalence of killer whales in the Arctic region has grown exponentially as the extent of sea ice decreases (Higdon 2007; Higdon et al. 2012).

Though a generalist species that can feed on bony fishes, elasmobranchs, cephalopods, seabirds, sea turtles, and other marine mammals (Katona et al. 1988; Jefferson et al. 1991; Fertl et al. 1996), the distribution of Norwegian and Icelandic killer whales has been correlated with that of herring (Similä and Ugarte 1993, Similä et al. 1996). Norwegian killer whales participate in a cooperative feeding behavior called carousel feeding or tail slapping in which herring are herding into tight balls close to the surface and stunned by underwater tail slaps (Similä and Ugarte 1993). Icelandic killer whales participate in a similar cooperative feeding strategy which is often preceded by a pulsed call that is hypothesized to aid in herding herring (Simon et al. 2006). Killer whales use echolocation as a primary means of locating prey and use different echolocation patterns for different hunting strategies (Barrett-Lennard et al. 1996; Eskesen et al. 2011). Adults reach lengths of 9 m (Dahlheim and Heyning 1999). The maximum average recorded depths for killer whales diving off British Columbia and Washington was 141 m with the deepest dive to 330 m and most dives <250 m; most of the whales in the tagged pod spent the majority of time in the upper 15 m of the water column (Baird et al. 2005). The longest duration of a recorded dive from a radio-tagged killer whale was 17 min (Dahlheim and Heyning 1999).

The killer whale produces three types of underwater vocalizations: echolocation clicks, whistles, and pulsed calls (Simon et al. 2006; Eskesen et al. 2011). Source levels of echolocation signals range between 195 and 224 dB re 1 µPa @ 1 m (Au et al. 2004; Eskesen et al. 2011). The killer whale has the lowest frequency of maximum hearing sensitivity and one of the lowest high-frequency limits among toothed whales (Szymanski et al. 1999) with an upper limit of 100 kHz. The most sensitive frequency, in both behavioral and in auditory brainstem response audiograms, has been determined to be 20 kHz (Szymanski et al. 1999).

➢ **Long-finned Pilot Whale (*Globicephala melas*)**

Pilot whales are among the largest members of the dolphin family, possibly reaching up to 6.7 m in length. Fullard et al. (2000) proposed a stock structure for long-finned pilot whales in the North Atlantic that is correlated with sea surface temperature: a cold-water population west of the Labrador/North Atlantic Current and a warm-water population that extends across the North Atlantic in the warmer water of the Gulf Stream. As many as 780,000 long-finned pilot whales were estimated in the eastern North Atlantic (Jefferson et al. 2008). Genetic studies have demonstrated that pods are defined by matrilineal related individuals with offspring (Bloch et al. 2003). Tagging studies of four individuals from one pod also provide evidence that the spatio-temporal cohesiveness suggested for long-finned pilot whale pods is less than and different from the strong affinity previously hypothesized (Bloch et al. 2003). During the annual mating season, two or more pods meet and cross-mating occurs. Long-finned pilot whales occur in temperate and subpolar oceanic and some coastal waters of the North Atlantic.

Pilot whale species feed primarily on squid and other mesopelagic cephalopods, but also take fish. Long-finned pilot whales are considered deep divers (Croll et al. 1999).The deepest dive reported by Heide-Jørgensen et al. (2002) for tagged long-finned pilot whales off the Farœ Islands was 828 m, however 60% of their time was spent above 7 m and more than 60% of dives lasted less than three minutes. Pilot whales echolocate with a precision similar to bottlenose dolphins and vocalize with other school members (Olson 2009; Eskesen et al. 2011). Vocalizations recorded from both pilot whale species (long and short-finned) include clicks and whistles. Long-finned pilot whale whistles and clicks have dominant frequency ranges of 1.6 to 6.7 kHz and 6 to 11 kHz, respectively (Ketten 1998). Echolocation clicks were recorded with a source level of 196 dB re 1 µPa @ 1 m (peak-to-peak), a duration of 23 µsec, and a centroid frequency of 55 kHz (Eskesen et al. 2011). Although little information is available on the hearing sensitivity of the long-finned pilot whale, a recent study by Pacini et al. (2010) measured the first audiogram of this species. The AEP-derived audiogram of a rehabilitated stranded long-finned pilot whale showed the U-shaped curve common in other mammals. The audiogram results found best hearing between 11.2 and 50 kHz with thresholds below 70 dB, while best hearing sensitivity was found at 40 kHz with a 53.1 dB threshold (Pacini et al. 2010).

➢ **Narwhal (*Monodon monoceros*)**

This toothed whale can obtain 4.6 m in length. Narwhals are listed as near threatened under the IUCN and little is known about their stock structure. In the Arctic regions of the North Atlantic, they form a metapopulation of several smaller subpopulations showing high site fidelity to summering grounds (Heide-Jørgensen et al. 2010). Jefferson et al. (2008) estimates that approximately 50,000 narwhals exist throughout their distributional range, which includes the Arctic Ocean (above the Arctic Circle), Davis Strait, Baffin and Hudson Bays, and the Greenland and Barents Seas (Heide-Jorgensen 2002). Aerial surveys of major narwhal hunting grounds in East Greenland in 2008 estimated 6,444 narwhals, corrected for diving animals, with a density estimate in the coastal water summer habitats of eastern Greenland was approximately 0.0920 animals/km^2 (Heide-Jørgensen et al. 2010). Narwhals associate with ice and are usually found within heavy pack ice (Heide-Jørgensen et al. 2002). During the annual period of heavy ice, narwhals occur within deep waters of 1,000 m or more; in the summer, fjords and bays are the preferred habitat where calving and molting occurs (Heide-Jørgensen et al. 2002; Laidre et al. 2003).

Narwhals exhibit low prey diversity, possibly due to the restricted environment that they inhabit. Primary prey species are arctic and polar cod in the summer and Greenland halibut and squid in the winter (Laidre and Heide-Jørgensen 2005). The deepest narwhal dives occur within the pack ice to depths over 1,500 m (Dietz et al. 2001; Heide-Jorgensen et al. 2002; Laidre et al. 2003). Average dive duration is 20 to 25 min (Heide-Jorgensen 2002). Two types of calls dominate narwhal vocalizations: clicks and pulsed-tone calls (Finley et al. 1990). Clicks are between 3 and 7 kHz with regular, slow repetition rates (Finley et al. 1990). Pulsed-tone calls range from slower, lower frequency growls to high-pitched creaks (Finley et al. 1990). No data are available on the hearing capability of this species.

➢ **Northern Bottlenose Whale *(Hyperoodon ampullatus)***

Northern bottlenose whales are 7 to 9 m in length. The IUCN classifies the status of northern bottlenose whales as data deficient. Currently there are no reliable population estimates for the northern bottlenose whale. Survey estimates from 1987 indicated there were over 5,800 individuals around Iceland and the Faroe Islands (Gunnlaugsson and Sigurjonsson 1990). The northern bottlenose whale is distributed in areas with cold, deep water along and seaward of the edge of the continental shelf (Reeves et al. 1993). Bottlenose whales prefer deep waters (Reeves et al. 2002) and occur in greater abundances in waters more than 1,000 m deep (Reeves et al. 1993). This whale sometimes occurs within or near pack ice (Reeves et al. 2002). Northern bottlenose whales occur in the North Atlantic from Nova Scotia to about 70°N in the Davis Strait, along the east coast of Greenland to 77°N and from England to the West Coast of Svalbard (Mead 1989).

Dive depths correlate with the depths at which the main prey, primarily cephalopods, is located (Santos et al. 2001). Dives fall into two discrete categories: short-duration (mean=11.7 min) shallow dives and long-duration (mean=36.98 min) deep dives (Hooker and Baird 1999). Tagged northern bottlenose whales off Nova Scotia dive approximately every 80 min to over 2,625 ft (800 m; with a maximum of 1,453 m and up to 70 min in duration (Hooker and Baird 1999). Very little information is available on characteristics of sound produced by beaked whales such as the northern bottlenose whale. Vocalizations produced at depth and on the surface were predominately clicks with frequencies of 2 to 26 kHz (Hooker and Whitehead 2002). Clicks produced at depth have higher peak frequencies and are more consistent (20 to 25 kHz) than clicks produced at the water's surface (4 to 21 kHz) (Hooker and Whitehead 2002). There is no direct information available on the hearing abilities of beaked whales (MacLeod 1999), although beaked whale ears are predominantly adapted to hear ultrasonic (> 20 kHz) frequencies (MacLeod 1999).

➢ **Sperm Whale *(Physeter macrocephalus)***

The sperm whale is the largest toothed whale species. Adults can reach 18 m in length (Jefferson et al. 2008). Sperm whales are classified as endangered under the ESA and as vulnerable under the IUCN.

Stock structure for sperm whales in the North Atlantic is not known (Dufault et al. 1999). Sperm whales show a strong preference for deep waters (Rice 1989). Sperm whales are found from tropical to polar waters in all oceans of the world between approximately 70°N and 70°S (Jefferson et al. 2008). Sperm whale distribution is associated with waters over the continental shelf edge, over the continental slope, and into deeper waters; worldwide, females rarely enter the shallow water over the continental shelf (Whitehead 2003). Sperm whale echolocation clicks were detected up to 60% of the time from July to September and 10% of the time from November to January in Fram Strait (Klinck et al. 2012). There was one occurrence of sperm whale clicks in the Greenland Sea on February 5, 2010.

Sperm whales prey on large mesopelagic squid and other cephalopods, as well as demersal fishes and occasionally benthic invertebrates (Clarke 1996; Jefferson et al. 2008). Sperm whales are capable of dives to depths of over 2,000 m with durations of over 60 min (Watkins et al. 1993). Sperm whales spend up to 83% of daylight hours under water (Jaquet et al. 2000; Amano and Yoshioka 2003). Males do not spend extensive periods of time at the surface (Jaquet et al. 2000). In contrast, females spend prolonged periods of time at the surface (1 to 5 hours [hrs] daily) without foraging (Whitehead and Weilgart 1991; Amano and Yoshioka 2003). Dive descents averaged 11 min at a rate of 1.52 m/sec, and ascents averaged 11.8 min at a rate of 1.4 m/sec (Watkins et al. 2002). Sperm whales produce short-duration (generally less than 3 sec), broadband clicks. These clicks range in frequency from 100 Hz to 30 kHz, with dominant energy in two bands (2 to 4 kHz and 10 to 16 kHz). Generally, most of the acoustic energy is present at frequencies below 4 kHz, although diffuse energy up to and past 20 kHz has been reported (Thode et al. 2002). The source levels can be up to 236 dB re 1 µPa @ 1 m (Møhl et al. 2003). The anatomy of the sperm whale's ear indicates that it hears high-frequency sounds (Ketten 1992). Anatomical studies also suggest that the sperm whale has some ultrasonic hearing but at a lower maximum frequency than many other odontocetes (Ketten 1992). Auditory brainstem response in a neonatal sperm whale indicated highest sensitivity to frequencies between 5 and 20 kHz (Ridgway and Carder 2001).

> **White-beaked Dolphin (*Lagenorhynchus albirostris*)**

Adult white-beaked dolphins reach lengths of 3.2 m (Jefferson et al. 2008). The white beaked dolphin is classified as a least concern (lower risk) species under the IUCN. At least two separate stocks of this species have been identified in the North Atlantic: one in the eastern and one in the western North Atlantic. White-beaked dolphins occur only in cold-temperate and subarctic waters of the North Atlantic and appear to be more common in the eastern than western Atlantic waters (Lien et al. 2001). In the western North Atlantic Ocean, the white-beaked dolphin occurs from eastern Greenland through the Davis Strait and south to the northern U.S. waters (Lien et al. 2001). White-beaked dolphins are found near the northern limits of their range between spring and late fall, apparently wintering to the south where they may remain until late spring or early summer.

The principal prey items of white-beaked dolphins are clupeids (e.g., herrings), gadids (e.g., Atlantic cod, haddock), whiting, hake, and squids (Reeves et al. 1999). White-beaked dolphins produce sounds such as clicks and squeals. Maximum source levels of clicks are 219 dB re 1 µPa @ 1 m (Rasmussen et al. 2002). Squeals range from 6.5 to 15 kHz (noted in Lien et al. 2001). Nachtigall et al. (2008) performed AEP measurements on the white beaked dolphin. An adult male was measured to have a hearing threshold near 100 dB at 152 kHz, and 121 dB at 181 kHz (Nachtigall et al. 2008).

2.2.1.3 Carnivora

> **Polar Bear *(Ursus maritimus)***

Polar Bears are the largest of all the bear species. Males grow to 2.4 to 3.4 m in length. Polar bears were listed in May of 2008 as threatened under the ESA wherever they occur and as vulnerable under the IUCN. There are 19 recognized stocks of polar bears, with the largest, the Arctic Basin stock, being the least known. Information is scarce regarding many of the stocks due to inaccessibility of the habitat, low

population densities, and extensive movement of bears over international boundaries. The estimated population size for all 19 stocks is 20,000 to 25,000 individuals (Marz 2006; Crockford 2008).

Polar bears rely upon the sea ice for a number of purposes including hunting, breeding, long distance travel, and, for some, denning (Marz 2006). Most remain upon the ice for the entire year or at most spend limited time on land (Crockford 2008). Polar bears are abundant along the coastline and southern edge of the pack ice but occur throughout the Arctic Basin (Marz 2006). Their distribution is closely associated with prey distribution (primarily ringed seals), with polar bears distributed throughout the ice-covered arctic waters. As ice retreats in the late spring/early summer, polar bears will either move farther north toward the year-round ice or south to land and the shorefast ice (Crockford 2008). Bears choosing a more pelagic lifestyle spend the summers on the offshore ice floes near the North Pole, whereas nearshore bears utilize the shorefast ice and are sometimes forced onto land in the northern parts of Canada, Greenland, Russia, Norway, and Alaska. Polar bears are not considered a migratory species; instead they have home ranges that can be rather extensive. They continually move throughout their range based on prey concentrations and ice conditions, although movement is more frequent in the summer due to the lack of "pack ice" (Born et al. 1997; Wiig et al. 2003). Home ranges of polar bears in the region of the Northeast Polynya (northern Fram Strait) were estimated to be as large as 72,263 km^2 (Born et al., 1997). Unlike other bear species, polar bears do not undergo a true hibernation in the winter; instead they enter a "walking hibernation" where their metabolism alters to a hibernation-like state (Marz 2006; Crockford 2008).

Primary prey species for polar bears are ringed and bearded seals, but they will also feed upon walrus, beluga, and narwhal, and scavenge large whale carcasses (Marz 2006; Crockford 2008). Polar bears are also very capable swimmers and can swim speeds of up to 6 miles per hour (mph). These bears are shallow divers, only typically diving to no more than a maximum of 5 m (16 ft) for less than 1 min. Few studies exist with threshold hearing data, but polar bears have good hearing sensitivity from 11.2 to 22.5 kHz in air; absolute thresholds were lower than 27 to 30 dB (Nachtigall et al. 2007). The highest tested frequency was 22.5 kHz so it can be inferred from these data and other studies that polar bears have a much wider range of hearing (Nachtigall et al. 2007).

2.2.1.4   Pinnipeds

➢ **Arctic Ringed Seal** *(Pusa hispida hispida)*

Ringed seals are the smallest seal, reaching lengths up to 1.5 m, and most common seal in the Arctic. Arctic ringed seals, a recognized subspecies, were listed in December 2012 as threatened under the ESA, but ringed seals (*P. hispida*) are listed as least concern by the IUCN. Currently, there is no reliable estimate of population size, however it is believed that there may be approximately 7 million ringed seals in the Arctic (Crockford 2008). The ringed seal is closely associated with ice and will occupy both the seasonal shorefast ice and the more permanent ice to the north (Kingsley 1990; Marz 2006; Crockford 2008). Ringed seals can be characterized as either "nearshore" or "offshore" dwelling, based on habitat preference. As ice coverage decreases in the spring, ringed seals either choose to stay nearshore on the unstable ice floes or move further north to the more stable ice near the pole, thus widely dispersing the population (Crockford 2008). They are a circumpolar species occurring from 35°N to the North Pole and occur within all seas of the Arctic Ocean and will remain in contact with the ice for most of the year.

Ringed seals feed on a variety of amphipods, euphausiids, mysids, shrimps, cephalopods, and fish (Weslawski et al. 1994). Median dive duration is less than 10 min for ringed seals (Lydersen 1991; Teilmann et al. 1999; Gjertz et al. 2000), although they will occasionally dive for up to 50 min or longer (Gjertz et al. 2000). Ringed seals will sometimes dive to depths of more than 250 m (Teilmann et al. 1999), though most dives are shallower than 100 m (Lydersen 1991; Teilmann et al. 1999; Gjertz et al. 2000). They produce clicks with a fundamental frequency of 4 kHz and varying harmonics up to 16 kHz (Schevill et al. 1963). Vocally, ringed seals produce several different types of sounds; low pitched barks,

high pitched yelps, high and low pitch growls and short chirps. Terhune and Ronald (1976) found that ringed seals are capable of hearing frequencies of 8 to 60 kHz.

➢ **Bearded Seal (*Erignathus barbatus*)**

Unlike other species, bearded seals are considered to be one stock due to the lack of geographic separation in their range and genetic data. They are concerned least concern by the IUCN. The global population of bearded seals has not been assessed, but probably numbers in the hundreds of thousands (Kovacs et al. 2011). The Arctic distribution of the bearded seal is not well studied, perhaps because they appear to be present in low densities throughout most of the Arctic. Bearded seal vocalizations were recorded in Fram Strait, primarily in the spring and summer, during a year-long passive acoustic monitoring project (Moore et al. 2012).

Bearded seals have a circumpolar but patchy distribution throughout the Arctic and rarely occur north of 80°N. Principally occurring in coastal waters less than 200 m (650 ft) or less because they are benthic feeders, bearded seals are also found in the drifting pack ice over shallow water. Bearded seals can be observed in the landfast ice and thick ice where they maintain breathing holes. Bearded seals avoid densely packed ice unless open-water leads are available, and prefer unconsolidated pack ice (Chambellant et al. 2012). During the ice-covered season, bearded seals are typically associated with moving pack ice, open water leads and polynyas (Stephenson and Hartwig 2010). As with other arctic species most individuals will undergo migrations based on sea ice build-up and retreat. Most bearded seals will move north to stay with the broken pack ice and ice floes, (Kovacs et al. 2011). Some individuals will choose not to migrate and stay in open-ocean as well as heavy pack ice.

The maximum dive time for a pup bearded seal is 5.5 min to a maximum depth of 84 m (275 ft) (Lydersen et al. 1994). Bearded seal females off Svalbard displayed a bi-modal dive behavior, with peaks of activity that were shallower than 10 m or from 50 to 70 m (Gjertz et al. 2000a).There are no data on hearing capability for this species. Bearded seals can be vocal animals, especially males during the breeding season. All bearded seals are known to make several different types of calls: long, spiraling trills; shorter, sweep calls; flat, tonal grunts; and short, low frequency moans. All calls range from 0.02 to 11 kHz. Trills are the most prevalently used calls and are dominate during the breeding season of March to July (Terhune 1999). There are three different types of trills: high pitch trills; slow drop trills; and fast drop trills (Terhune 1999). These are varied between in order to prevent masking suggesting that they are used for communication and locating other individuals (Cleator et al. 1989; Terhune 1999). All three trills spanned five octaves and centered around 1 kHz (Terhune 1999). Cleator et al. (1989) found that the trills were heard 30 km from the individuals (the farthest placed hydrophone); to be heard at that distance, bearded seals must produce sound pressure levels of at least 100 dB referenced to 1 dB re 1 µPa @ 1 m (Cleator et al., 1989).

➢ **Harbor Seal (*Phoca vitulina*)**

The harbor seal is a small- to medium-sized seal, with adult males attaining a maximum length of 1.9 m. They are listed as least concern by the IUCN. The global population of harbor seals is estimated to be between 300,000 and 500,000 seals (Jefferson et al. 2008). Harbor seals, while primarily aquatic, also utilize the coastal terrestrial environment, where they haul out of the water periodically. They are a coastal species, rarely found more than 20 km (10.8 nmi) from shore, and frequently occupying bays, estuaries, and inlets (Baird 2001). The harbor seal is one of the most widespread of the pinniped species and are found in temperate to subarctic nearshore waters. Its distribution ranges from the east Baltic, west across the Atlantic and Pacific Oceans to southern Japan (Stanley et al. 1996).

Harbor seals are opportunistic feeders that adjust their feeding patterns to take advantage of locally and seasonally abundant prey (Payne and Selzer 1989; Baird 2001; Bjørge 2002). Diet consists of fish and invertebrates (Bigg 1981); but generally, schooling or bottomfish species. Harbor seals are generally shallow divers. About 50% of their diving is shallower than 40 m, and 95% is shallower than 250 m (Gjertz

et al. 2001; Krafft et al. 2002). Dive durations are shorter than 10 min, with about 90% lasting less than 7 min (Gjertz et al. 2001). Adult males produce low frequency vocalizations underwater during the breeding season (Hanggi and Schusterman 1994; Van Parijs et al. 2003) in the frequency range of 100 to 1,000 Hz (Thomson and Richardson 1995). The harbor seal hears almost equally well in air and under water (Kastak and Schusterman 1998) and hears best at frequencies from 1 to 180 kHz; the peak hearing sensitivity is at 32 kHz in water and 12 kHz in air (Terhune and Turnball 1995; Kastak and Schusterman 1998; Wolski et al. 2003). Kastak and Schusterman (1996) observed a temporary threshold shift (TTS) of 8 dB at 100 Hz, with complete recovery approximately one week following exposure. Kastak et al. (1999) determined that underwater noise of moderate intensity (65 to 75 db re 1 µPa @ 1 m) and duration (20 to 22 min) is sufficient to induce TTS in harbor seals

➢ **Harp Seal** *(Pagophilus groenlandica)*

Harp seals are medium-sized phocids that can reach 1.7 m in length. They are listed as least concern by the IUCN. They are differentiated by three separate breeding stocks: the White Sea (Barents Sea), the Greenland Sea (West Ice), and the Northwest Atlantic (Reeves et al. 2002). Harp seals are distributed in the pack ice of the North Atlantic and Arctic Oceans, from Newfoundland and the Gulf of St. Lawrence to northern Russia (Reeves et al. 2002). The Greenland Sea breeding stock occurs from the eastern coast of Greenland to Svalbard (Folkow et al. 2004) with reproduction occurring on the pack ice edge of the "West Ice" north of Jan Mayen, in the White Sea, and in the northwest Atlantic (Joiris and Falck 2011). After breeding, harp seals disperse north, foraging on polar cod under the pack ice. In Fram Strait, harp seals are very abundant in mixed Polar/Arctic waters, either at the front between the water masses or in small-scale eddies. Depending on the location of the ice edge, changes in distribution will result from changes in water masses (Joiris and Falck 2011). The Greenland Sea breeding stock was estimated at 756,200 seals in 2007 and is the largest population estimate to date (Haug et al. 2007; ICES 2008). All harp seal stocks are hunted commercially and for subsistence within Canada, Greenland, Norway, and Russia. They are closely associated with drifting pack ice, preferring rough pack ice that is at least 0.25 m thick (Ronald and Healey 1981; Ronald and Gots 2003). In the Greenland Sea, harp seals spend almost 25% of their time in open ocean (<4/10 ice coverage) (Folkow et al. 2004).

Primary prey species are small fish (such as capelin) and invertebrates (Lawson et al. 1995; Lawson and Stenson 1997), although the prey variety depends on age, season, location, and year (Lavigne 2002). Harp seals are capable of diving to depths of over 450 m; however, the majority of the dives are 300 m or less, and depths usually coincide with where the target prey species occur (Folkow et al. 2004). The harp seal's vocal repertoire consists of at least 27 underwater and two aerial call types (Serrano 2001). Terhune and Ronald (1986) measured source levels of underwater vocalizations of 140 dB re 1 µPa @ 1 m. Vester et al. (2001) recorded ultrasonic clicks with a frequency range of 66 to 120 kHz, with the main energy at 93±22 kHz and average source levels of 143+ dB re 1 µPa @ 1 m in conjunction with live fish hunting. Behavioral audiograms have been obtained for harp seals (Terhune and Ronald 1972), revealing underwater hearing between 0.76 to 100 kHz, with areas of increased sensitivity at 2 and 22.9 kHz (Terhune and Ronald 1972).

➢ **Hooded Seals** *(Cystophora cristata)*

Adult male hooded seals grow to approximately 2.5 m in length. They are listed as vulnerable by the IUCN. Hooded seals are divided into two separately managed stocks: Northwest Atlantic and Greenland Sea (NMFCA 2008). The Greenland Sea stock is managed by both Norway and Russia and breeding occurs on the West Ice, north of the Greenland Sea near Jan Mayen Island (NMFCA 2008). Stock estimates are hard to obtain due to hooded seals being widely dispersed and inhabiting an inaccessible environment. Surveys in 2007 resulted in a stock estimate of 82,380 (ICES 2008), which is only 10 to 15% of the size estimated 60 years ago (NMFCA 2008). Hooded seals occur in the Atlantic and Arctic Oceans from the Davis Strait, Newfoundland and Gulf of St. Lawrence in the west to Norway (Svalbard) in the east (Campbell 1987). There are four distinct breeding areas: Newfoundland (the "Front"), Gulf of St.

Lawrence (the "Gulf"), Davis Strait (all three belong to the Northwest Atlantic stock) and the "West Ice" near Jan Mayen Island (Greenland Sea stock) (Haug et al. 2007). The Greenland Sea stock is believed to move offshore into deeper waters during autumn and winter (Reeves et al. 2002) and individuals will generally stay between eastern Greenland and Svalbard Island; however, range may be considerably influenced by changes in ice cover and climate (Campbell 1987). Hooded seals are closely associated with ice and annual migrations follow the ice edge (Campbell 1987; Kovacs 2002). They are known to inhabit the edge of the heavy pack ice for breeding and molting (Campbell 1987), and after molting, they are believed to move offshore into deep ocean waters (Reeves et al. 2002) spending approximately 90% of their time submerged (Folkow and Blix 1999). The hooded seal can make extensive movements and shows a great tendency toward wandering, with extralimital sightings as far south as Puerto Rico in the western North Atlantic Ocean (Mignucci-Giannoni and Odell 2001).

Hooded seals primarily prey upon a variety of fishes (Kovacs and Lydersen 2008A). Average dive depths are 100 to 600 m, however, hooded seals are capable of diving to >965m (Folkow and Blix 1999). Shallow dives are more common in partially ice covered waters, which is usually the breeding and molting grounds. Average dive times are approximately 20 min, although hooded seals can stay submerged for > 50 min (Folkow and Blix 1999). Hooded seals emit eight different call types, although it is suspected that the repertoire is more varied (Ballard and Kovacs 1995). The calls of hooded seals are primarily aerial with energy produced from 0.1 to 1.2 kHz (Terhune and Ronald 1973) and underwater calls are probably only produced by males (Terhune and Ronald 1973; Ballard and Kovacs 1995). Males produce low frequency sounds in air; however, there are no data on underwater hearing capability for this species. The generic underwater hearing range for phocids is a peak sensitivity ranging between 10 and 30 kHz, with a functional high frequency limit of about 60 kHz (Wartzok and Ketten 1999), and low frequency functional limits underwater are not yet well established for phocids (Wartzok and Ketten 1999).

➢ **Walrus** *(Odobenus rosmarus)*

The walrus is one of the largest pinnipeds, with Atlantic males attaining lengths of 3 m. There are believed to be eight breeding stocks of the Atlantic walrus *(Odobenus rosmarus rosmarus)*, a recognized subspecies (Stewart 2008). It is known that animals in Svalbard and Franz Joseph Land belong to the same population that is differentiated from Greenlandic animals (Lydersen et al. 2008). The abundance of the Atlantic walruses is approximately 18,500, although this estimate is poor and it is unknown if the population is increasing, decreasing or stable (NAMMCO 2004d). All known terrestrial haul-out sites in Svalbard were surveyed 1-3 August 2006 (Lydersen et al. 2008). 657 walruses were counted, which when corrected for time at sea (75%), results in an estimate of 2,629 animals. The walrus has a disjunct circumpolar distribution in the Northern Hemisphere. Atlantic walruses occur in northeastern Canada, Greenland, Svalbard, and northern Russia (NAMMCO 2004d). Walruses are generally found in the shallower waters of the continental shelf. Most walruses stay within waters less than 100 m deep and with large ice floes (Marz 2006). Walrus movement and association with ice depend largely on the seasonal advance and retreat of the ice (Fay 1993; Marz 2006). During the winter, walrus will move south closer to the edge of the pack ice where they will overwinter in areas of divergent ice flows or along the margins of persistent polynyas (Marz 2006). In the summer, they will move north once again either using the traditional haul-out sites on land near feeding grounds (NAMMCO 2004d) or staying at the southern edge of the pack ice; moving further into the pack during stormy weather (Marz 2006).

They are highly specialized benthic feeders, feeding almost exclusively on bivalves at depths of 80 to 100 m or less (Fay 1993; Fisher and Stewart 1997; Born et al. 2003). The deepest recorded dive for this species was to 133 m and the longest recorded dive was 25 min (Reeves et al. 2002). Feeding walruses tend to dive for approximately 5 min and then remain at the surface for 1 to 2 min (Born et al. 2003). They produce both aerial and underwater vocalizations; these are in the 0.5 to 8 kHz frequency range (Kastelein et al. 2002). The only source level measurement of walrus vocalizations is of rutting whistles, which were 120 db re 1 µPa @ 1 m (Verboom and Kastelein 1995). The large variety of aerial calls are believed to serve a social function, whereas the many underwater calls are assumed to be mainly from

males for courtship and establishment of territory (Kastelein et al. 2002). During the breeding season, mature males will produce underwater songs (Stirling et al. 1983) which are predominately coda songs and diving vocalization songs (Sjare et al. 2003). Walrus hearing is adapted more to low frequency sound with a range of best hearing from 1 to 12 kHz; maximum hearing sensitivity is at 12 kHz (Kastelein et al. 2002).

2.2.2 FISHES

The fish species that occur in Fram Strait are a mixture of boreal and Arctic demersal and pelagic species. Boreal fishes such as Atlantic cod, herring, and blue whiting extend their range into Fram Strait with the flow of the WSC. Boreal species' ranges overlap with arctic fish species, such as polar cod. The majority of fish species in Fram Strait are small, benthic Arctic species, with the exceptions of the Greenland shark and Greenland halibut (Hop et al. 2006). The Greenland shark (*Somniosus microcephalus*) also known as the "sleeper shark," is the largest member of the dogfish family and can grow to over 6.4 m in length and weigh up to 907 kg. Primarily, this shark species inhabits the deep waters around Greenland and Iceland to depths of 2,000 m. No other shark resides at the high northern latitudes that the Greenland shark is found.

One fish species that potentially occurs in the ACOBAR Experiment area is the Atlantic cod, which is listed under IUCN's vulnerable category. No fish habitat is specifically protected under Norwegian or IUCN regulations in the Fram Strait area.

➢ **Atlantic Cod (*Gadus morhua*)**

Atlantic cod are listed as vulnerable under the IUCN (Sobel 1996). Atlantic cod are demersal cold-temperate fish that are distributed in the North Atlantic Ocean waters from Greenland to the southeastern United States (Penttila 2007). Oceanic populations of Atlantic cod are highly migratory and travel thousands of kilometers to spawn in generally the same areas each year (Jørgensen et al. 2008). The northeastern Arctic cod stock migrates from oceanic feeding grounds to spawning areas in coastal waters annually (Jørgensen et al. 2008). The Atlantic cod populations during the 18th and 19th centuries were severely over-fished and fishing in some regions of the North Atlantic was closed to cod harvest (Fu and Fanning 2004). Atlantic cod are still a main fishery today for various northern Atlantic coastal countries.

2.2.3 MARINE PROTECTED AREAS

The IUCN (2009) defines a protected area as "an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means." Marine Protected Areas (MPAs) in the Fram Strait region include national parks, nature reserves, wetlands of international importance, plant protected areas, and bird sanctuaries located in Svalbard, Norway, and eastern Greenland (Governor of Svalbard 2008). These areas are protected because they are considered to be areas of significant environmental and biological importance.

While four MPAs are located along Greenland's eastern coast bordering Fram Strait, only one, the Northeast Greenland National Park, was designated specifically to protect marine species, including marine mammals; the others were designated to protect coastal wetlands. This large MPA, designated in 1974, is 972,000 km^2 in size, of which 110,600 km^2 of the area is strictly marine (Table 2-2) (Figure 2-6) (Wood 2007, Hoyt 2011). The Northeast Greenland National Park is the world's largest national park, and although once known for its large cetacean population, due to exploitation of this resource, the number of marine mammals is now significantly decreased (Hoyt 2011).

The Norwegian government has protected the ecology and outstanding wildlife populations of Svalbard, as it is considered one of the last "true" Arctic wildlife areas. A network of more than 13 MPAs protect over 41,000 km^2 of Svalbard's coastal waters (Hoyt 2005, Wood 2007). The largest of the Svalbard MPAs, at 36,691km^2, is Northeast Svalbard National Reserve (Table 2-2).

In 2003, the maritime boundaries of Svalbard were extended from 7.4 km to 22.2 km, adding some 41,000 km^2 of additional protected marine waters for a total estimated at more than 72,000 km^2 of marine protected areas (Hoyt 2011). In the waters of the Svalbard MPAs, cetaceans cannot be hunted, although migrating marine mammal species, such as minke whales and harp seals, are not included in this protection and can be hunted (Hoyt 2005).

2.3 ECONOMIC ENVIRONMENT

Only the economic resources that were potentially affected by the ACOBAR Experiment's activities have been included in this assessment.

2.3.1 COMMERCIAL SHIPPING

No commercial shipping lanes traverse Fram Strait itself, but two key marine routes or navigation lanes to Greenland, the Arctic, and Svalbard are located in proximity to Fram Strait (Figure 2-7). One traverses a route roughly parallel to the eastern shoreline of Greenland northward into the Arctic Ocean while the second is located along the western side of Svalbard, terminating in the ports along western Svalbard (Ellis 2008). The major port located in eastern Greenland is Sisimuit (CIA 2009a), and the major shipping ports in western Svalbard are Barentsburg, Longyearbyen, Ny-Alesund, and Pyramiden (CIA 2009b). A commercial coal mine is located in Barentsburg.

Table 2-2. Designated Marine Protected Areas (MPAs) of Greenland and Svalbard relevant to marine species and that are adjacent to the Fram Strait experimental area for the ACOBAR Experiment (Wood 2007, NDNM 2010, Hoyt 2011).				
Country/Area	**MPA**	**Designation**	**Date Designated**	**Total Marine Area (km^2)**
Greenland (Denmark)	Northeast-Greenland	National Park	1974	110,600
Svalbard (Norway)	Bjørnøoya	Nature Reserve	2002	2,805
	Forlandet	National Park	1973	4,018
	Nordenskiöld Land	National Park	2003	1,207
	Nordre Isfjorden	National Park	2003	904
	Northwest Spitsbergen	National Park	1973	6,189
	South-Spitsbergen	National Park	1973	8,198
	Indre Wijdefjorden	National Park	2005	382
	Sassen-Bünsow Land	National Park	2003	73
	Moffen	Nature Reserve	1983	4
	Northeast Svalbard	Nature Reserve	1973	36,691
	Southeast Svalbard	Nature Reserve	1973	25,436
	Hopen	Nature Reserve	2003	3,140
	Festningen	Geotope Protection Area	2003	3
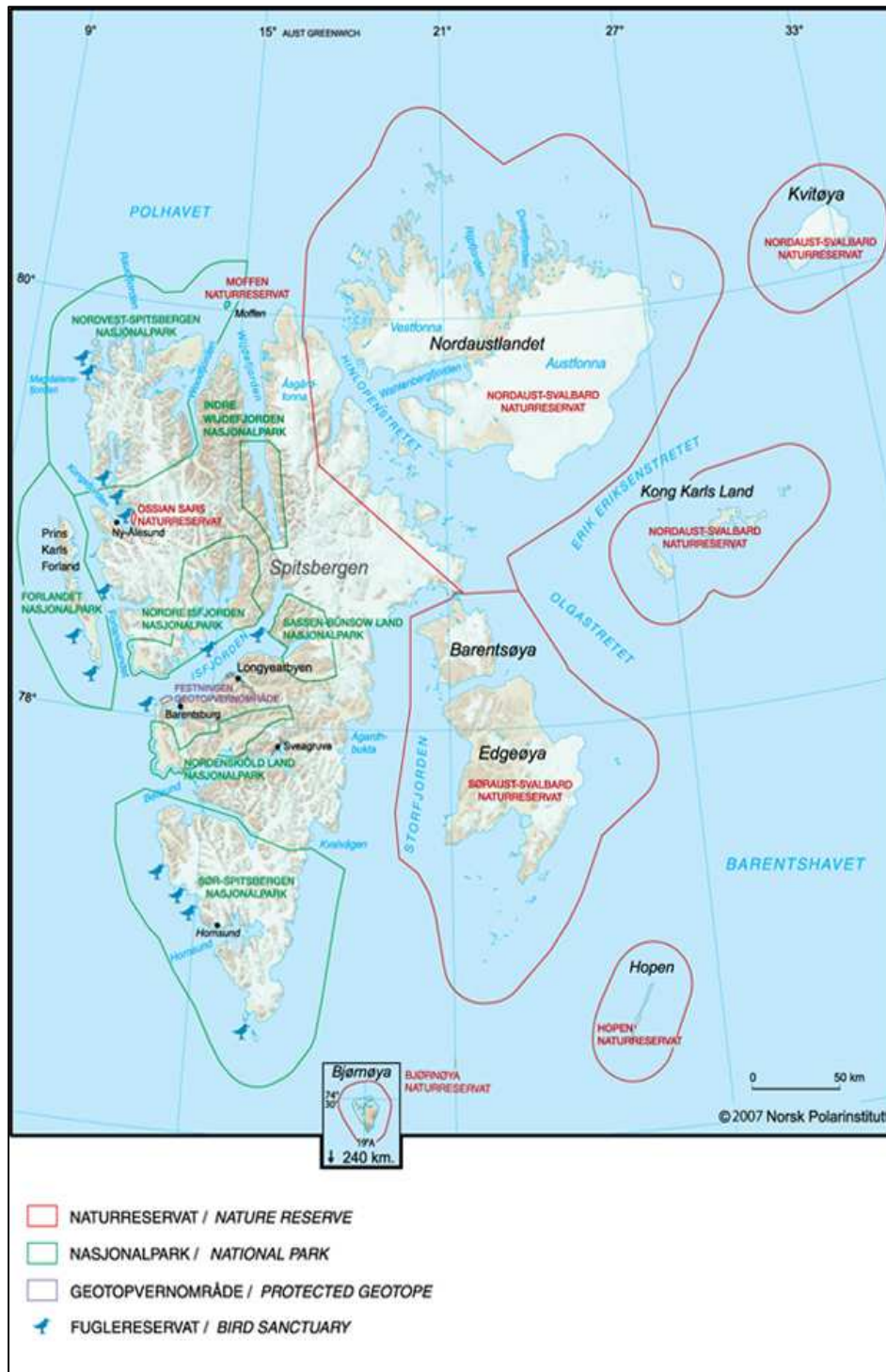
Figure 2-6. Marine Protected Areas of Svalbard (NDNM 2010).
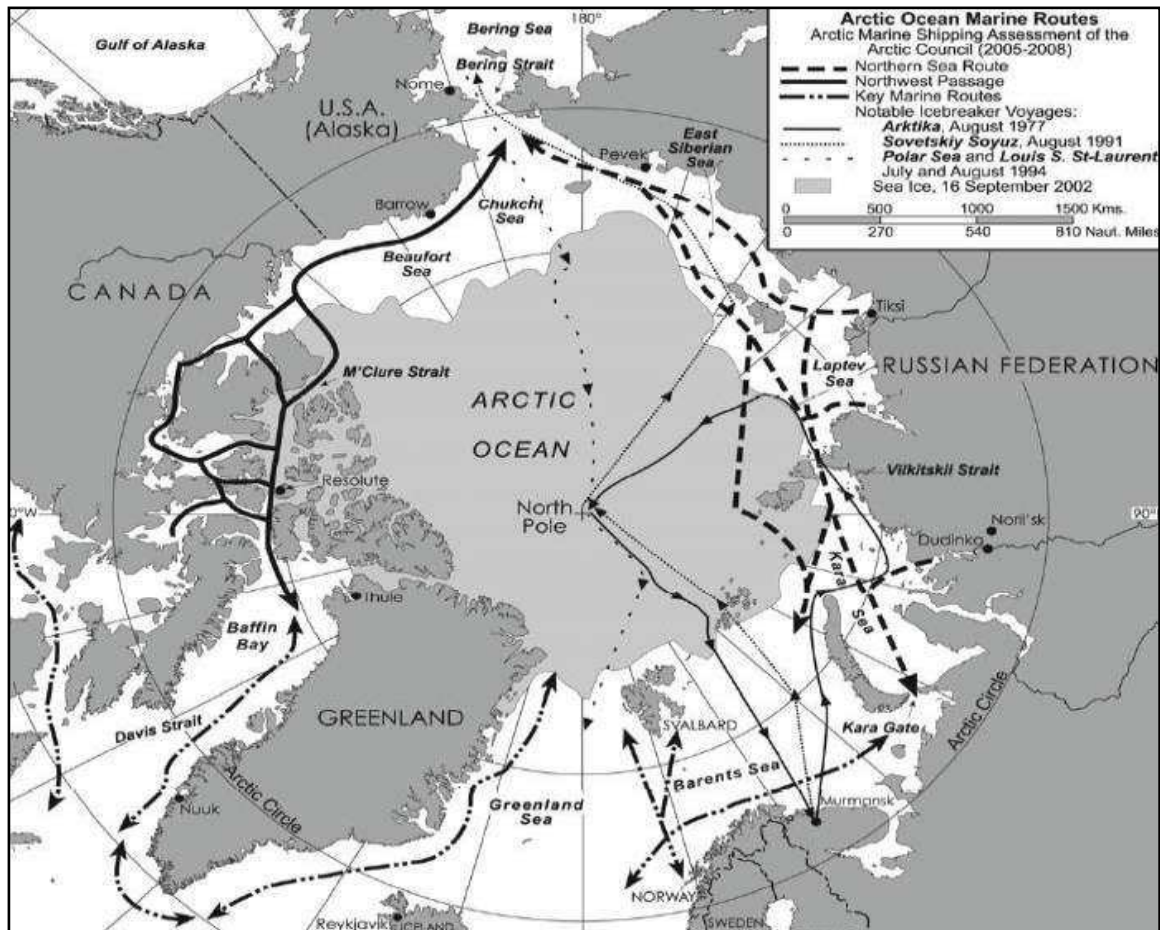
Figure 2-7. Major shipping lanes or routes in the Fram Strait area (Ellis 2008a).

During the summer months, there are many commercial fishing vessels in the southern Fram Strait due to the high level of fishing effort (Ellis 2007) and several commercial cruise lines voyage through the Svalbard archipelago on sightseeing trips (CruiseNorway 2009).

2.3.2 COMMERCIAL FISHERIES

Commercial fishing in the lower Arctic is an important part of the Norwegian and Greenland economies, bringing in significant revenue. Norway established a fishery protection zone around Svalbard in 1977, in which fish stocks are protected and only those individuals who have been given permission by the Norwegian government are allowed to fish in those waters (NMFCA 2013). Although aquaculture activities take place in the waters of mainland Norway, no aquaculture activities occur in Svalbard (NMFCA 2013) and no aquaculture occurs in the waters of Greenland.

2.3.2.1 Norwegian Commercial Fisheries

Fisheries have been one of Norway's central components of business and industry because of the rich fishing grounds that Norway controls (FAO 2012). Norway controls the North Sea, Norwegian coast, Barents Sea, and the Polar Front in the Norwegian Sea, which are some of the most productive fishing grounds in the world. Today, Norway is one of the top exporters of fish and fishery products, placing 2nd in the world in 2010 with over US$8.8M in export goods (FAO 2012). In 2011, Norway landed 2,298,907 m tons of seafood worth just over 16 billion Norwegian Kroner (NOK) (Statistics Norway 2013).

Almost 90% of Norway's fisheries are conducted on stocks that are shared with other states (NMFCA 2013). Norway has fishing quota and fishing location agreements with Russia, the EU, Iceland, the Faroe Islands, and Greenland. Greenland and Norway have a reciprocal agreement that allows each country to fish in the Exclusive Economic Zone (EEZ) of the other (NMFCA 2013). Herring was the most landed fish species in the Norwegian fishery, with landings of 633,103 tons in 2011, worth 3.33 billion NOK (Table 2-3) (Statistics Norway 2013). However, the most valuable fish caught in the Norwegian fishery is cod. In 2011, the cod fishery landed 340,167 tons with a value of 3.96 billion NOK (Statistics Norway 2013).

Table 2-3. Top five Norwegian fish species landed in 2011 (Statistics Norway 2013).		
Fish Species	**2011 live weight (tons)**	**Value (1000 NOK)**
Herring	633,103	3,333,322
Capelin	362,368	786,105
Cod	340,167	3,959,421
Mackerel	207,955	2,560,516
Saithe	190,344	1,492,686

2.3.2.2 Greenland Commercial Fisheries

Like Norway, one of Greenland's most important businesses is commercial fisheries (Statistics Greenland 2010). Greenland is surrounded by productive waters that are home to hundreds of species of fish. In 2006, 65,000 Greenlanders were employed by the fishing industry (Statistics Greenland 2007). There were no statistics found specifically for the eastern coast of Greenland, near the Fram Strait.

The largest fishing industry in Greenland is the shrimp industry. In 2008, over 65,000 tons of shrimp were landed with a value of about 395 million Greenland Danish Kroner (DKK) (Table 2-4) (Statistics Greenland 2010). Although the shrimp fishery originated in western Greenland waters, a profitable shrimp fishing area where unusually large shrimp were harvested, now most of Greenland's shrimp fishing takes place in eastern Greenland waters (FAO 2004). Four other species dominate Greenland's fisheries (Table 2-4), including the large Greenland halibut fishery that landed nearly 20,000 tons in 2008 (Statistics Greenland 2010).

Table 2-4. Greenland's top fishery landings (Statistics Greenland 2010).		
Fish Species	**2010 live weight (tons)**	**Value (1000 DKK)**
Shrimp (Prawns)	67,157	394,884
Greenland halibut	19,524	149,946
Cod	12,266	83,160
Lumpsucker	6,436	14,417
Crabs	2,169	28,810

3 POTENTIAL ENVIRONMENTAL IMPACTS AND CONSEQUENCES

An evaluation of the predicted potential effects of the ACOBAR Experiment on the physical, biological, and economic environment is addressed in this section. No coral reefs are found in or near the experiment area, as the environmental conditions (near-arctic, deepwater, typically >500 m) could not possibly support reef growth. Further, due to the cold water temperatures and surface ice conditions, no sea turtles are expected to occur in these polar waters and have thus not been evaluated further in this assessment. Since the ACOBAR Experiment area was located in the Fram Strait, between Greenland and Svalbard, the likelihood is negligible that any recreational diving, boating, or fishing occurred during the experiment. Thus, no descriptions of impacts to these activities are included in this assessment.

3.1 POTENTIAL IMPACTS OF THE ACTION

3.1.1 POTENTIAL IMPACTS TO THE PHYSICAL ENVIRONMENT

Descriptions of the acoustic and oceanographic sources and acoustic receivers as well as the other equipment that were used in the ACOBAR Experiment were provided in Section 1 (see Tables 1-2 and 1-3). Three WRC transceiver moorings and one STAR receiver array (one STAR array was deployed for a one-year period and then replaced during the second year) were deployed in Fram Strait. Two of the three WRC transceivers and the STAR array were recovered in September 2012. The third WRC source has not yet been recovered. After approximately two weeks of successful transmissions, the transmissions of the third WRC were no longer received. It is believed that the subsurface buoy holding the mooring in the water column collapsed and the mooring fell to the ocean floor. Attempts will be made to dredge the region and recover the mooring during the summer of 2013.

With the exception of standard expendable oceanographic equipment and expendable mooring lines and anchors, all other equipment, arrays, and sources were retrieved from their moorings upon conclusion of the experiment's data collection. The remaining systems' components will either corrode or meld with the ocean bottom. Although this constitutes a very minor, temporary impact to the environment, these sensors and/or mooring materials will ultimately function as artificial hard bottom habitats. Essentially, their potential impact is negligible and their presence may be beneficial to the benthic community.

3.1.2 POTENTIAL IMPACTS TO THE BIOLOGICAL ENVIRONMENT

3.1.2.1 Marine Mammals

Potential effects on marine mammals from active acoustic sources are:

- **Non-auditory injury**: This includes the potential for resonance of the lungs/organs, tissue damage, and mortality. For the purposes of the ACOBAR Experiment, there was no potential for non-auditory injury since this is expected to occur for marine mammals exposed to underwater sound ≥215 decibels relative to 1 microPascal squared per second (dB re 1 µPa^2-sec) sound energy level (SEL) (Level A "incidental harassment" under the U.S. MMPA) (Southall et al. 2007), which is greater than the source levels of the signals that were transmitted.

- **Auditory effects:**

  o **Permanent threshold shift (PTS)**: A severe situation occurs when sound intensity is very high or of such long duration that permanent hearing loss results, which is referred to as permanent threshold shift (PTS). PTS is a consequence of the death of the sensory hair cells of the auditory epithelia of the ear with a resultant loss of hearing ability in the general vicinity of the frequencies of stimulation (Richardson et al. 1995a). PTS results in a permanent elevation in the hearing threshold—an unrecoverable reduction in hearing sensitivity. The intensity and duration of an

underwater sound that will cause PTS varies across marine mammal species and even among individual animals. For the purposes of the ACOBAR Experiment, there was no potential for PTS effects on cetaceans since PTS would be expected to occur when exposed to underwater sound ≥215 dB re 1 µPa^2-sec SEL (Level A "incidental harassment" under the U.S. MMPA) (Southall et al. 2007). For pinnipeds, a very small potential existed for PTS to occur from the 80-sec RAFOS signals, which have an SEL SL of 207 dB re 1 µPa^2-sec. PTS may occur in pinnipeds at received levels ≥203 dB re 1 µPa^2-sec SEL (Southall et al. 2007). However, it is very unlikely that any of the two species of potentially occurring seals capable of deep diving, hooded and harp seals, dove to the depth at which the WRC sources (400 to 560 m) were located and then remained within 1.6 m of the sources for the entire 80-sec duration of the RAFOS signal required for PTS to occur.

o **Temporary threshold shift (TTS):** Underwater sounds of sufficient loudness can cause a transient condition known as temporary threshold shift (TTS), in which an animal's hearing is impaired for a limited period of time. After termination of the sound, normal hearing ability returns over a period that may range anywhere from minutes to days, depending on many factors, including the intensity and duration of exposure to the intense sound. Hair cells may be temporarily affected by exposure to the sound, but they are not permanently damaged or killed. Thus, TTS is not considered an injury (Richardson et al. 1995; Southall et al. 2007), although during a period of TTS, animals may be at some disadvantage in terms of detecting predators or prey. For the purposes of the ACOBAR Experiment, cetaceans and pinnipeds exposed to underwater sound ≥195 dB re 1 µPa^2-sec and 183 dB re 1 µPa^2-sec SEL, respectively, were evaluated as if they experienced TTS (Level B "incidental harassment" under the U.S. MMPA) (Southall et al. 2007).

o **Behavioral change:** Various vertebrate species are affected by the presence of intense sounds in their environment (Richardson et al. 1995). Behavioral responses to these sounds vary from subtle changes in surfacing and breathing patterns to cessation of vocalization or even active avoidance or escape from regions of high sound levels (Wartzok et al. 2004). Sub-TTS Level B "incidental harassment" under the MMPA is defined as any act that disturbs or is likely to disturb a marine mammal by causing disruption of natural behavioral patterns to a point where the patterns are abandoned or significantly altered. Behaviors include migration, surfacing, nursing, breeding, feeding, and sheltering. In a discussion on biologically significant behaviors and possible effects, the National Research Council (NRC) noted that an action or activity becomes biologically significant to an individual animal when it affects the ability of the animal to grow, survive, and reproduce; these are the effects on individuals that can have population-level consequences and affect the viability of the species (NRC 2005). For the purposes of the ACOBAR Experiment, marine mammals exposed to underwater sound ≥190 dB re 1 µPa^2-sec SEL were evaluated as if they may be affected (i.e., have a behavioral reaction; Level B "incidental harassment" under the MMPA). More discussion of this criterion is provided below.

o **Masking:** The presence of intense sounds in the environment can potentially interfere with an animal's ability to hear relevant sounds. This effect, known as "auditory masking," could interfere with the animal's ability to detect biologically-relevant sounds, such as those produced by predators or prey. Thus, during auditory masking, an animal may not be able to locate food or escape predacious attack. The potential for masking from acoustic transmissions during the ACOBAR Experiment are discussed further below.

➢ **Behavioral change**

Ridgway et al. (1997) is one of the first in a series of comprehensive studies to evaluate the effect of acoustic noise on marine mammals. During the Ridgway et al. (1997) study, researchers observed behavioral modifications and temporary shifts in the hearing sensitivity of bottlenose dolphins exposed to

1-sec tones at frequencies between 3 and 75 kHz. Work by Schlundt et al. (2000) used masking noise to create a consistent ambient noise environment and extended the frequency range at which behavior and hearing were affected to 400 Hz. The results of these studies showed that changes in behavior and temporary shifts in the hearing levels of odontocetes were observed at the average received levels of 186 dB and 195 dB, respectively, between the frequencies of 3 and 20 kHz.

Finneran et al. (2001, 2003, and 2005) conducted TTS experiments with bottlenose dolphins exposed to 3 kHz tones with durations of 1, 2, 4, and 8 sec. Results were consistent with the data collected by Schlundt et al. (2000) and confirmed that total received energy or SEL is a more appropriate metric for determining the received levels (RLs) at which behavioral changes, TTS, and PTS occur. Using a total received energy approach accounts for both pulse length and multiple received pulses.

There is an extreme degree of group, species, and individual variability in behavioral responses in various contexts and conditions (Southall et al. 2007, Ellison et al. 2011). Given this variability, a single metric is unlikely to capture the range of behavioral responses that may occur under different scenarios. However, to bound the potential for a behavioral response, the U.S. Navy developed acoustic criteria (Table 3-1) to determine if a proposed action rises to a level of "may affect" (the environment) (US Navy 2006, 2007). Besides the thresholds, the Navy policies also direct that: a) no mitigation be applied in the "no-effect" determination calculations, b) for a "no-effect" determination, takes of threatened or endangered species must be <0.05, and c) takes of non-threatened or endangered species must be <0.5. Even though these policies were initially written for mid-frequency sources (i.e., sources between 1 to 10 kHz), they are also applied to low frequency (LF) and high frequency (HF) sources (i.e., sources between 0.1 and 1.0 kHz and 10 and 100 kHz, respectively). These thresholds and policies were used in the impact analyses of the active sources employed during the ACOBAR Experiment.

Table 3-1. Acoustic criteria for potential effects from active acoustic sources.		
POTENTIAL EFFECT	**ACOUSTIC CRITERIA (dB RE 1 μPA^2 - SEC)**	
	CETACEANS	**PINNIPEDS**
Permanent Threshold Shift	215	203
Temporary Threshold Shift	195	183
Behavioral Change	190	190

The zone of influence (ZOI), or region around each active source where the RL equals or exceeds the acoustic thresholds, is an essential element in the calculation of potential impacts from acoustic sources. The derivation of ZOIs involves the convolution of the acoustic thresholds with the known SEL for each source. The SEL for each source is determined by adding the SLs to a factor of ten times the log (base 10) of the signal's duration and ten times the log (base 10) of the number of signals per second.

The equation governing the maximum RL is:

RL = SEL – TL

where RL is received level (dB), SEL is sound exposure level (dB), and TL is transmission loss (dB).

The RL can be predicted using the following TL equation, which is dominated by spherical spreading loss:

TL = 20 * LOG (R)

where TL is transmission loss (dB) and R is range (m).

The maximum ZOI radius around the WRC source is about 15.9 m (Table 3-2), assuming an animal remains within the ZOI for the entire 80-sec RAFOS signal duration.

Table 3-2. Maximum zones of influence (ZOIs) for the active acoustic sources used in the ACOBAR Experiment.						
ACTIVE ACOUSTIC SIGNALS	**ZOI RADIUS (M) FOR THE THREE RELEVANT IMPACT LEVELS***					
	PTS/LEVEL A HARASSMENT		**TTS ***		**BEHAVIOR/LEVEL B HARASSMENT**	
	Cetaceans	Pinnipeds	Cetaceans	Pinnipeds	Cetaceans	Pinnipeds
WRC – 60 sec tomographic signal	< 1.0	< 1.0	2.2	8.7	3.9	3.9
WRC – 80 sec RAFOS signal	< 1.0	1.6	4.0	15.9	7.1	7.1

   *   TTS is provided for information purposes only and was not used in harassment calculations.

  **   Assumes that the maximum signal duration is used in the ZOI calculation.

In reality, given the small area of the ZOIs, the depth of the sound sources, the animal movements in three-dimensions, and the surface and sub-surface current structure in the Fram area, it would be impossible for an animal to remain within a source's ZOI for the entire duration of the signals. An iterative analysis was performed, accounting for the size of the ZOI, the total "virtual" water area ensonified during a single transmission (as the current moves the water past the source), and the length of time it would take an animal to move across an entire ZOI diameter, as controlled by the combined animal and current speed. The result of this analysis was that the tomographic and RAFOS signals had "effective" transmission durations (i.e., the time that an animal would be inside the ZOI and have the source's acoustic energy contributing to potential impacts) of about 10 sec and 2.5 sec, respectively. This is even more conservative when the depth of the sources in the water column (400 to 560 m) is compared to the average dive depth of most of the marine mammals in the region. However, to be conservative, the full durations of the signals were used for the harassment (take) estimates.

To determine the potential impacts to the marine mammal species possibly occurring in the ACOBAR Experiment area, the following assumptions, many of which are conservative, were made:

- Each transmission by each source was treated as a separate event due to the spatial and temporal separation of the sources (i.e., the ZOIs are very small and do not overlap with each other because the sources were separated by many kilometers, and typically hours separate the various transmissions);
- The sources operated/transmitted as described in Table 1-2;
- WRC Mooring C did not operate after the first two weeks of its deployment;

- The two-dimensional water area ensonified by a transmission was estimated as a circle with radius equal to the ZOI distance;

- The ZOI distance was calculated with a spherical spreading transmission loss equation that does not include any attenuation or scattering losses. This is very conservative and more complex transmission loss modeling that includes these losses (which would reduce the ZOI distances) may want to be considered in subsequent analyses;

- Animals were assumed to be within the region of the ACOBAR Experiment year-round for the entire duration of the experiment (i.e., there was no correction factor for migratory movements or ice cover over the sources);

- Animals were assumed to be in the water diving during the entire duration of the experiment (i.e., there was no correction factor for haul-out time by pinnipeds or polar bears);

- Potential effects included a correction for each species' ability to dive to the depth of the sources, calculated as the percentage of dives that include or reach the source depth (the shallowest source was at a depth of 420 m). The following are the estimated percentages of dives that reach 400 m depth: fin and sei whales 10%, beluga whale 100%, long finned pilot whale 50%, narwhal 50%, northern bottlenose whale 75%, sperm whale 95%, harbor seal 5%, harp seal 2%, and hooded seal 10%. The remaining species typically do not dive deeper than 150 m, with many not exceeding 250 m depth. Therefore, a conservative 1% value was used for these species in the very remote chance they may dive to 400 m depth; and
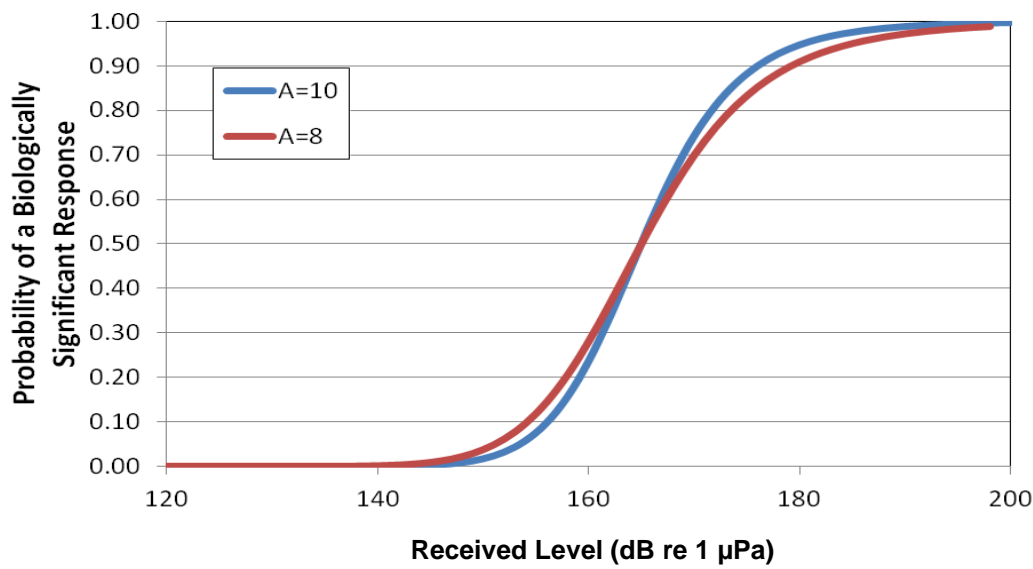
- No mitigation was applied.

Based on these assumptions, the two-dimensional area ensonified by each signal was then calculated for each ZOI and multiplied by the number of transmissions of each signal type. The final step in estimating potential impacts (takes) is to multiply the ensonified areas by the marine mammal densities and the percentage of dives to 400 m. The potential effects were summed across the two-year duration of the ACOBAR Experiment (Table 3-3).

The precision with which a probability of environmental impact might occur is largely determined by the precision with which the marine mammal densities are estimated for the selected experiment area and season. While the marine mammal densities used in this analysis (Table 3-3) represent the best available data for the waters of Fram Strait, they are based on very limited population-level survey data. An additional difficulty is that densities are not available for all species of marine mammals known to occur in the waters of the ACOBAR Experiment. In such cases, a density estimate of <0.00001 was used so that an estimated harassment value could be computed.

The possibility of injurious impacts (i.e., PTS, U.S. MMPA Level A) resulting from the experiment is negligible for all marine mammal species (Table 3-3). For all ESA- or IUCN -listed species (i.e., the polar bear, and blue, bowhead, fin, humpback, sei, and sperm whales; and the Arctic ringed and hooded seals), the probability of behavior impacts (U.S. MMPA Level B) occurring is also very low, with the highest potential behavioral impacts occurring with hooded seals, with an estimated 0.00861 animals potentially impacted; all other ESA- or IUCN-listed species have probabilities less than this value. For all other marine mammal species potentially occurring in the experiment area (i.e., non-threatened or endangered), the next highest estimated potential for behavioral impacts is 0.00150 for the harp seal, with all other species' potential for change in behavior being substantially below this impact level. Based on the analysis of potential acoustic impacts on marine mammals, the proposed experiment will not result in any injurious or behavioral (U.S. MMPA Level A or Level B, respectively) incidental harassment (Table 3-3).

It should be emphasized that the preceding analysis methodology and Level A and B thresholds are typically used in preliminary U.S. ESA analyses to determine if there is a "may affect" from the proposed

Table 3-3. Marine mammal density estimates for the Fram Strait area and the potential harassment of marine mammals estimated as a result of the active acoustic sources transmitting during the two years of the ACOBAR Experiment.			
MARINE MAMMAL SPECIES	**DENSITY ESTIMATES (ANIMALS/KM^2)**	**HARASSMENT ESTIMATES**	
		INJURY (U.S. MMPA LEVEL A)	**BEHAVIOR CHANGES (U.S. MMPA LEVEL B)**
Mysticetes			
Blue Whale	0.00001	<0.00001	<0.00001
Bowhead Whale	0.00002	<0.00001	<0.00001
Common Minke Whale	0.03206	0.00002	0.00034
Fin Whale	0.00574	0.00002	0.00030
Humpback Whale	0.00009	<0.00001	<0.00001
Sei Whale	0.00001	<0.00001	<0.00001
Odontocetes			
Atlantic White-sided Dolphin	<0.00001	<0.00001	<0.00001
Beluga Whale	<0.00001	<0.00001	0.00001
Killer Whale	<0.00001	<0.00001	<0.00001
Long-finned Pilot Whale	<0.00001	<0.00001	0.00001
Narwhal	0.00004	<0.00001	0.00002
Northern Bottlenose Whale	<0.00001	<0.00001	0.00001
Sperm Whale	0.0	<0.00001	<0.00001
White-beaked Dolphin	<0.00001	<0.00001	<0.00001
Carnivora			
Polar Bear	0.00500	<0.00001	0.00005
Pinnipeds			
Arctic Ringed Seal	0.03355	0.00002	0.00036
Bearded Seal	0.01050	0.00002	0.00011
Harbor Seal	0.00089	<0.00001	0.00005
Harp Seal	0.07043	0.00007	0.00150
Hooded Seal	0.08111	0.00043	0.00861
Walrus	<0.00001	<0.00001	<0.00001

Figure 3-1. Behavioral response functions for mysticetes (red) and odontocetes and pinnipeds (blue).

action. Based on resultant potential impact values for each species, the proposed action addressed in this EAR does not exceed the "may affect" threshold. Thus, no further analysis would normally be conducted.

When the U.S. ESA "may affect" threshold is exceeded and a more thorough analysis is required, the current methodology is to apply a behavioral response function or risk continuum (Figure 3-1) in which the probability of a behavioral response is determined by the sound pressure received level (SPL RL). While behavioral response is almost certainly determined by more factors than exposure level, it is also likely that in the limited situation of exposure to acoustic energy when all other contextual factors are known and held constant, received sound level can be used as a proxy for behavioral response. The probability of a behavioral response is greater than 0.0001 at a received level of approximately 140 dB re 1 µPa. The distances from the WRC sources (transmitting tomographic and RAFOS signals) to this received level are 158.5 and 251.2 m, respectively, which would occur at depths of approximately 260 and 170 m, respectively. Thus, an animal would need to be within a ZOI of one of the signals, while the signal had been transmitted, to potentially be affected. Since the sources were at a depth of 400 to 560 m, it is highly unlikely that an animal would have been within either ZOI during the limited time that these sources were transmitting (i.e., 60 sec every 3 hr or 80 sec every 6 hr). Thus, the preliminary analysis that concluded that the "may affect" threshold is not exceeded and no change in animal behavior is expected, is further supported by this additional analysis based on a more conservative SPL RL of 140 dB re 1 µPa.

➤ **Masking**

Anthropogenic underwater noise has the potential to mask marine mammal vocalizations and communication. However, in the case of the ACOBAR Experiment, the following transmission duty cycles are germane to this discussion:

- For the WRC tomography signals, on for 60 sec, off for 10,740 sec, every day or every other day, the duty cycle was 0.56% or 0.28%, respectively.

- For the RAFOS signals, on for 80 sec, off for 21,520 sec, the duty cycle was 0.37%.

Furthermore, the location of the experiment was in the vicinity of the marginal ice zone (MIZ) so it is expected that the local ambient noise in these waters was slightly elevated due to wave and ice

interactions and movement. In the 205 to 305 Hz frequency band (i.e., the transmit frequency for the tomographic and RAFOS signals), Sagen (1998) measured ambient noise spectra in the MIZ for interior ice packs, grease ice and compact ice at 75 to 80 dB re 1 μPa^2/Hz, whereas in open ocean (near the MIZ) and in diffused ice, ambient noise was approximately 80–85 dB re 1 μPa^2/Hz. For the ACOBAR signals to decrease due to transmission loss to these ambient noise levels, the signals would have needed to travel several tens of kilometers. Within these distances, the potential for masking would be considered possible. Of the marine mammals present in the experiment area, mysticetes are the primary users of frequencies near the 205 to 305 Hz band of the ACOBAR sources, and normally this is a small percentage (i.e., 10-20%) of the frequency band of their signals. Therefore, mysticetes would be expected to have had the highest potential to experience masking during the experiment, and only for a portion of the acoustic spectrum they use. Additionally, this could only occur during those infrequent times when the sources were actually transmitting. Moreover, even though the sound field of the ACOBAR sources may have covered tens of kilometers, those signals would be below 130 dB re 1 μPa RL beyond 1 km (0.54 nmi) from the source. All of the above factors combine to minimize the potential and duration of any masking of mysticete vocalizations for the limited period when the sources were actually transmitting. Therefore, the potential for any masking of marine mammals, including mysticetes, is so minute that it must be considered to be negligible.

3.1.2.2 Fishes

Fish can be classified by their hearing capabilities. A number of fish, found in widely diverse groups, have physiological adaptations that enhance their hearing capabilities. These fish, often called "hearing specialists," can hear a wider range of sound frequencies and sounds of lower intensities than fishes that are "hearing generalists" and do not possess the adaptations (Popper and Fay 1993).

The upper frequency limit for hearing generalists varies by fish species. The upper frequency for a hearing generalist may be as low as 200 Hz in a flatfish or perch and as high as 800 Hz in some salmon, but best hearing is generally in the center of the hearing range. Hearing specialists hear a wider range of hearing frequencies, with the upper range most often reaching 2,500 to 4,000 Hz. Best sensitivity in hearing specialists generally ranges from 200 to 800 Hz. Hearing ability in fish is also affected by the duration of the sound stimulus. As the stimulus begins to decrease in duration, the hearing threshold (generally defined as the minimum sound level detectable at a particular frequency) begins to increase. In other words, as a signal gets shorter, it is harder for fish to detect.

The potential effects of high-intensity underwater sounds on fishes may include TTS, increased stress levels (Smith et al. 2004a, b), and/or damage to other organ systems such as the circulatory system and the swim bladder (Hastings and Popper 2005). There is also the potential for behavioral effects, including movement away from the source and alterations in feeding and mating (Slotte et al. 2004). Recent research on rainbow trout (a hearing generalist closely related to salmon) exposed to high-intensity (RL of 193 dB re 1 μPa rms), low-frequency (170 to 320 Hz) signals of 324 or 648 sec duration found no effect on non-auditory tissues and no indication of damage to sensory hearing cells (Popper et al. 2007). However Popper et al. (2007) did find that some trout experienced 20 to 25 dB of TTS at 400 Hz up to 48 hr post-exposure. Smith et al. (2004a, b) found that goldfish, a hearing specialist, experienced 5 dB of TTS after 10 min of exposure to 0.1 to 10 kHz band-limited noise at approximately 170 dB RL overall spectral sound pressure level. In contrast, tilapia, a hearing generalist, showed no TTS after up to 21 days of similar exposure at 170 dB.

Data on shark hearing are very limited and in need of replication and expansion to include more species and more specimens. Some representative data indicate that hammerhead sharks are able to detect sounds below 750 Hz, with best sensitivity from 250 to 275 Hz (Olla, 1962). Kritzler and Wood (1961) reported that the bull shark responded to signals at frequencies between 100 and 1,400 Hz, with the band of greatest sensitivity occurring at 400 to 600 Hz. Lemon sharks responded to sounds varying in frequency from 10 to 640 Hz, with the greatest sensitivity at 40 Hz; however, the lowest frequency may

not accurately represent the lower limit of lemon shark hearing due to limitations in the range of frequencies that could be produced in the test tank due to the nature of the tank acoustics (Nelson 1967). Moreover, lemon sharks may have responded at higher frequencies, but sounds of sufficiently high intensity that could not be produced to elicit attraction responses (Nelson, 1967). Banner (1972) reported that the lemon sharks he studied responded to sounds varying from 10 to 1,000 Hz. In a conditioning experiment with horn sharks, Kelly and Nelson (1975) discovered the sharks responded to frequencies of 20 to 160 Hz, and the lowest particle motion threshold was at 60 Hz. The most recent study was that of the little skate, *Raja erinacea* (Casper et al., 2003), with results suggesting that this species is able to detect sounds from 100 to over 800 Hz, with best hearing up to and possibly slightly greater than 500 Hz. However, these authors, as several others working with elasmobranchs, report thresholds in terms of pressure, whereas it is highly likely that all of these species are detecting particle motion (van den Berg and Schuijf, 1983), and so the thresholds are possibly quite different than those reported since particle motion was not calibrated.

Researchers doing field studies on shark behavior found that several shark species appear to exhibit withdrawal responses to broadband noise (500 to 4,000 Hz, although it is not clear that sharks heard the higher frequencies in this range). Lemon sharks exhibited withdrawal responses to broadband noise raised 18 dB at an onset rate of 96 dB/sec, to a peak amplitude of 123 dB RL from a continuous level just masking broadband noise (Klimley and Myrberg, 1979). Myrberg et al. (1978) reported that a silky shark withdrew 10 m from a speaker broadcasting a 150 to 600 Hz sound with a sudden onset and a peak SPL of 154 dB SL.

One caveat with all data collected on sharks is that they are generally obtained from studies of a single animal, and it is well known that sound detection ability (both sensitivity and hearing bandwidth) varies considerably among different species, and even among members of the same species. Moreover, it is known that hearing ability changes with age, health, and many other variables.

The acoustic sources that were used during the ACOBAR Experiment operate between 205 and 305 Hz, nominally in the hearing range of fish hearing generalists and hearing specialists. Due to the nature of the experiment (i.e., the locale in near-Arctic waters, the distance from shore, the source placement in the water column [at 420 to 559 m of a 5,000+ m water column]), the relatively low source levels, and the long periods between transmissions, the potential for acoustic impacts on fishes from the active acoustic source transmissions analyzed in this EAR is negligible. This includes a negligible potential for any acoustic impacts on the one IUCN-listed fish species found in the ACOBAR experiment area, the Atlantic cod.

3.1.3   POTENTIAL IMPACTS TO MARINE PROTECTED AREAS

The closest MPA to the ACOBAR Experimental area was Forlandet National Park in Svalbard, which was about 33 km (18 nmi) from the closest ACOBAR Experiment source. The closest MPA to the experimental area in Greenland was the Northeast Greenland National Park, which was located greater than 185 km (100 nmi) from the closest ACOBAR Experiment source. The low SL of the sources, combined with the placement in relationship to MPAs and the long intervals between transmissions, preclude the ACOBAR Experiment from impacting any resources of MPAs.

3.1.4   POTENTIAL OF ECONOMIC IMPACT

3.1.4.1   Commercial Shipping

No commercial shipping lanes traverse Fram Strait itself but the two key marine routes or navigation lanes in the area are located on the perimeters of the Strait along Greenland and Svalbard's continental shelves. The experimental equipment were not located at the sea surface but were deployed at 400 to 560 m depth in the water column. No effects on commercial shipping activities or shipping routes were reasonably expected in association with the ACOBAR Experiment.

3.1.4.2 Commercial Fisheries

The major fishing industry in Greenland is the shrimp industry, which mainly takes place off the East Greenland coast. In 2010, 67,157 tons of shrimp were harvested (Statistics Greenland 2010). The major fishing industry in Svalbard/Norway is the herring industry, and in 2011, 633,103 tons were landed (Statistics Norway 2013). The low level of the ACOBAR acoustic sources combined with the long intervals between transmissions, placement of the sources in the water column, and geography preclude the ACOBAR Experiment from impacting any commercial fishing activities.

3.1.5 POTENTIAL OF DIRECT AND INDIRECT IMPACTS

Based on the analysis of the potential acoustic impacts conducted for the ACOBAR Experiment, there are no identified direct or indirect impacts that resulted from the experiment activities, including the acoustic transmissions that occurred during the experiment. No lasting direct or indirect physical impacts resulted from the experiment.

3.1.6 POTENTIAL FOR CUMULATIVE IMPACTS

Cumulative impacts are defined by the U.S. Council on Environmental Quality as impacts on the environment that result from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions. The ACOBAR Experiment took place over two years, from 2010 to 2012. Prior to the ACOBAR Experiment, the Fram Strait Tomography Experiment, part of the DAMOCLES Project, installed a prototype acoustic tomography system in Fram Strait. One source and one receiver were deployed in August 2008 for a duration of one year. The source transmitted 60-sec signals from 205 to 305 Hz every three hours (http://acobar.nersc.no/). NERSC has just been awarded a research grant from the Norwegian government for the UNDER ICE project, which is part of a larger Eurpoean Union funded research initiative called AROMOS. The tomography portion of the research project will replicate the work done in the ACOBAR Experiment with three WRC sources installed for two years (2014 to 2016) in a triangular arrangement. The east and westernmost sources will be deployed in approximately the same area as during ACOBAR (Moorings A and B), however, the northernmost source will be north of the ACOBAR Mooring C, closer to the Gakkel Ridge. It is not anticipated that these small research projects with deep active acoustic sources transmitting very infrequently will combine to cause cumulative impacts.

During the past few years, two pilot studies measuring the ambient noise in Arctic environments have been conducted. One study deployed two passive acoustic recorders, one in the Fram Strait and one in the Chukchi Sea, from autumn 2008 to autumn 2009 to compare the Atlantic and Pacific Arctic acoustic habitats, respectively (Moore et al. 2012). Airgun signals were detected year-round in Fram Strait, including every day from July to September, 80 to 95% of days per month from March to June, and 30 to 65% of days per month from October to February. With only a single recorder, distances to the seismic surveys could not be calculated, but the signals appeared to be from sources located at great distances (Moore et al. 2012).

The second study deployed two autonomous receivers, one in the Fram Strait and one in the Greenland Sea, from June 2009 through June 2010 (Klinck et al. 2012). Ambient noise levels for the frequency band of 15 to 840 Hz were calculated. During the summer months (May to September), airgun signals were detected almost every hour per month at both deployment locations. Ship noise was also recorded during summer months in Fram Strait, whereas it was recorded year-round in the Greenland Sea, though at relatively low levels. Monthly median spectral levels at 50 Hz were significantly correlated with airgun activity whereas spectral levels at 300 Hz were correlated with average surface wind speeds (Klinck et al. 2012). Fin whale vocalizations were a major contributor to ambient noise levels in the 19 to 24 Hz frequency band (Klinck et al. 2012).

Increased ocean noise due to anthropogenic as well as natural sources has led to concern and scientific study, especially as the noise affects protected marine species. There is a recognized need for a new

approach to understanding how multiple sources contribute to the cumulative noise environment from the perspective of marine animals (Moore et al. 2012a). Since the ACOBAR Experiment used active acoustic sources with relatively low SLs for relatively short durations, there is no reasonable expectation that the experiment added to or resulted in any significant increase in the ambient noise environment of the Fram Strait area. The experiment, thus, did not cause cumulative effects on the biota, marine habitats and environment, or other resources in the surrounding waters.

3.2   MITIGATION MEASURES

To further reduce the possibility of physical impacts to marine mammals in the ACOBAR Experiment area, the RV and OPV that participated in the experiment were prepared to maneuver to avoid visible marine mammals. They successful avoided marine mammals (whales) that were seen in the eastern part of Fram Strait during the deployment cruise.

3.3   ANALYSIS SUMMARY

In summary, the ACOBAR Experiment did not affect marine mammal species and no takes of marine mammals occurred as a result of this experiment, including those marine mammals designated as endangered or threatened under the U.S. ESA or the IUCN. The relatively low power of the acoustic sources and relatively short transmission period, followed by long periods with no transmissions, resulted in small acoustic ZOIs (<15.9 m), which are indicative of the negligible potential impact to any marine mammal species. The ACOBAR Experiment had no effects on the water column and only a transitory, non-permanent effect on the benthic environment due to the mooring anchors. There was limited potential for acoustic impacts on fish species; thus, potential impacts on fish, including the IUCN-listed Atlantic cod, were considered negligible. Thus, no impacts occurred to commercial fisheries in the region. Further, the ACOBAR Experiment did not affect the habitats or resources of designated MPAs since they were located so far from the experiment area. Since no commercial shipping lanes are located in the experiment area, shipping was not impacted by the experiment, especially since most of the deployed equipment resided at depths well beyond potential interaction with ships. It should be noted that the impacts analysis performed for this EAR pertains only to the underwater sound sources cited in Table 1-2 and should not be construed to relate to any other underwater sound sources (e.g., acoustic deterrent devices).

4   CONCLUSIONS

Based on the execution of the ACOBAR Experiment and the scientific analysis of the underwater active acoustic sources included in this EAR, the experiment had a negligible potential for impacts to the environment of Fram Strait. The experiment did not affect marine species listed as endangered or threatened under the U.S. ESA or IUCN Red List. No reasonably foreseeable injury or behavioral harassment of marine mammals (under U.S. MMPA criteria) occurred as a result of this experiment. In addition, the potential for impacts to fishes and fisheries was considered negligible. The low source level of the sources, combined with the placement in relationship to MPAs and the long intervals between transmissions, precluded the activities or transmissions of the experiment from impacting any MPA. Commercial shipping was in no way affected by the experiment. It is further concluded from the scientific analysis provided in this EAR that the ACOBAR Experiment had no potential to cause grave danger to marine mammals in the Fram Strait area, which could lead to ethical concerns.

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