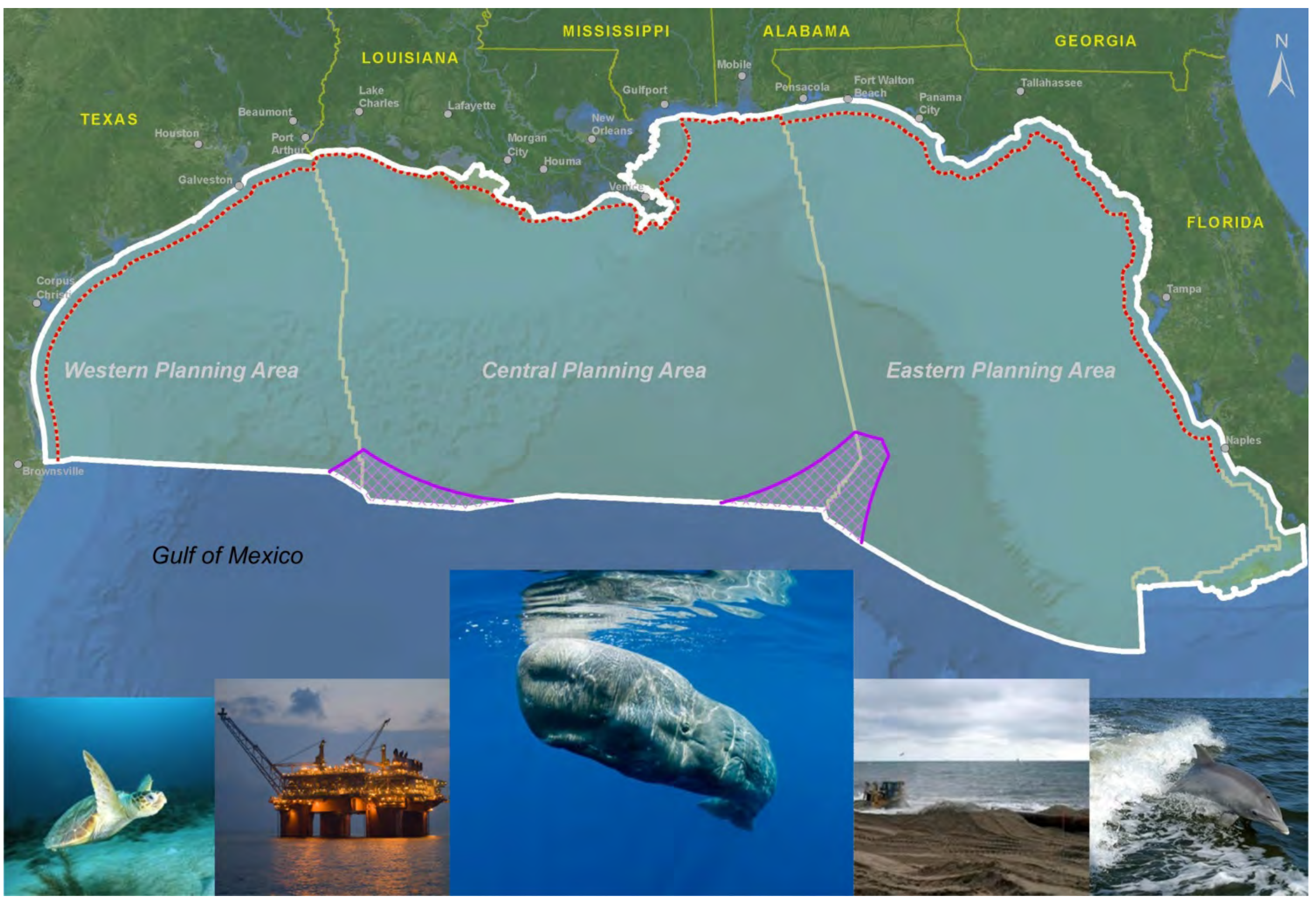
OCS EIS/EA
BOEM 2016-049

Gulf of Mexico OCS
Proposed Geological and Geophysical Activities

Western, Central, and Eastern Planning Areas

Draft Programmatic Environmental Impact Statement

Volume III: Appendices E-L



U.S. Department of the Interior
Bureau of Ocean Energy Management
Gulf of Mexico OCS Region

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Author

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Gulf of Mexico OCS Region

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ABBREVIATIONS AND ACRONYMS

μg	microgram
μm	micrometer
μPa	micropascal
μs	microsecond
μV	microvolt
ABR	auditory brainstem response
ac	acre
AEP	auditory evoked potential
AOI	Area of Interest
ATOC	Acoustic Thermometry of Ocean Climate
AWOIS	Automated Wreck and Obstruction Information System
B.P.	before present
BCR	Bird Conservation Region
BOEM	Bureau of Ocean Energy Management
BP	British Petroleum
BSEE	Bureau of Safety and Environmental Enforcement
CAA	Clean Air Act
CEI	Coastal Environments, Inc.
CI	confidence interval
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CO_2	carbon dioxide
CV	coefficient of variation
dB	decibel
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DOSS	dioctyl sodium sulfoscuccinate
DPS	distinct population segment
DTRU	Dry Tortugas Recovery Unit (loggerhead turtles)
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
Eh	oxidation reduction potential
EIS	Environmental Impact Statement
ENC	Electronic Navigational Charts (NOAA)
EO	Executive Order
EPAct	Energy Policy Act of 2005
ESA	Endangered Species Act
EWTA	Eglin Water Test Area
FDEP	Florida Department of Environmental Protection
FDHR	Florida Division of Historical Resources
FGB	Flower Garden Bank
FGBNMS	Flower Garden Banks National Marine Sanctuary
FKNMS	Florida Keys National Marine Sanctuary
FM	frequency modulation
FMC	Fishery Management Council

FMP	Fishery Management Plan
FR	*Federal Register*
ft	foot
FWC	Florida Fish and Wildlife Conservation Committee
FWRI	Fish and Wildlife Research Institute
FWS	Fish and Wildlife Service (USDOI)
G&G	geological and geophysical
GDP	gross domestic product
GIS	geographic information systems
GMFMC	Gulf of Mexico Fishery Management Council
GMWD	Global Maritime Wrecks Database
GOM	Gulf of Mexico
GOMESA	Gulf of Mexico Energy Security Act
ha	hectare
HAPC	Habitat Area of Particular Concern
HCB	hexachlorobenzene
HCH	hexachlorocyclohexane
Hz	hertz
IBA	Important Bird Area
IUCN	International Union for Conservation of Nature
kHz	kilohertz
km	kilometer
kn	knot
L	liter
LNG	liquid natural gas
LOOP	Louisiana Offshore Oil Port
m	meter
mg	milligram
mm	millimeter
MMPA	Marine Mammal Protection Act
MMS	Minerals Management Service
MPA	Marine Protected Area
mph	miles per hour
ms	millisecond
MSA	Metropolitan Statistical Area
MSFCMA	Magnuson-Stevens Fisheries Conservation and Management Act
MWA	Military Warning Area
NAAQS	National Ambient Air Quality Standards
NABCI	North American Bird Conservation Initiative
NavAids	NOAA Aids to Navigation
NAVFAC	Naval Facilities Engineering Command
NEPA	National Environmental Policy Act
NERR	National Estuarine Research Reserve
NGMCS	Northern Gulf of Mexico Continental Slope (study)
NGMRU	Northern Gulf of Mexico Recovery Unit (loggerhead turtles)
NMFS	National Marine Fisheries Service

nmi	nautical mile
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
NTL	Notice to Lessees and Operators
NWA	National Wilderness Area
NWR	National Wildlife Refuge
O_3	ozone
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act
ODMDS	ocean dredged material disposal site
OSAT	Operational Science Advisory Team
OSP	optimum sustainable population
P.L.	Public Law
PAH	polycyclic aromatic hydrocarbon
PBDE	polybrominated diphenyl ether
PBR	potential biological removal
PCB	polychlorinated biphenyl
PDARP	Programmatic Damage Assessment and Restoration Plan
PFRU	Peninsular Florida Recovery Unit (loggerhead turtles)
pH	potential of hydrogen
PM	particulate matter
ppb	parts per billion
ppm	parts per million
PSD	Prevention of Significant Deterioration
RESTORE Act	Resource and Ecosystem Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act
RL	receiving level
SAFMC	South Atlantic Fishery Management Council
SAR	Stock Assessment Report
SE	standard error
SEMARNAT	Secretariat of Environment & Natural Resources
SL	source level
SO_2	sulfur dioxide
TAMU	Texas A&M University
TED	turtle excluder device
TEWG	Turtle Expert Working Group
TNASS	Trans-North Atlantic Sighting Survey
TPH	total petroleum hydrocarbons
TPY	tons per year
UME	unusual mortality event
U.S.	United States
U.S.C.	United States Code
USACE	U.S. Army Corps of Engineers

USCG	U.S. Coast Guard
USDOC	U.S. Department of Commerce
USDOI	U.S. Department of the Interior
USEPA	U.S. Environmental Protection Agency
VK	Viosca Knoll
VOC	volatile organic compound
YONAH	Years of the North American Humpback

1 INTRODUCTION

The affected environment descriptions in **Chapter 4** of this Programmatic Environmental Impact Statement (EIS) succinctly describe and summarize the existing environment of the Area of Interest (AOI) (**Figure E-1**) in sufficient yet concentrated detail necessary to support the impact analysis of the alternatives. The succinct descriptions avoid an encyclopedic Programmatic EIS and promote an analytic approach to the document. This appendix provides expanded, more comprehensive information, including additional details regarding the affected environment resources, and was indirectly considered during the preparation of this Programmatic EIS.

As described in **Chapter 4.1.1** and shown in **Table 4.1-2** of this Programmatic EIS, preliminary screening was conducted to identify the resources at risk of impact from the proposed and anticipated geological and geophysical (G&G) activities in the Gulf of Mexico (GOM). Screening allows for completion of a focused impact analysis by eliminating (from detailed analysis) resources with no potential for adverse or significant impact. This approach focuses the analysis on the resources at greatest risk for impact, which resulted in the identification of 12 resources carried forward for detailed analysis. The comprehensive affected environment information for those 12 resources is provided in **Sections 2 through 13**. To further describe the environmental setting, affected environment descriptions for additional resources (those that did not receive a detailed impact analysis) are provided in **Sections 14 through 21**.

In October 2015, the National Oceanic and Atmospheric Administration (NOAA) released a Draft Programmatic Damage Assessment and Restoration Plan and Draft Programmatic EIS (PDARP/PEIS) (USDOC, NOAA, 2015a). In February 2016, the Final PDARP/PEIS was released (Deepwater Horizon Natural Resource Damage Assessment Trusstees, 2016). The PDARP/PEIS considers programmatic alternatives to restore natural resources, ecological services, and recreational use services damaged or lost because of the 2010 *Deepwater Horizon* explosion, oil spill, and response (including the sinking of the drilling unit), oil spill, and response. The PDARP/PEIS includes an assessment of “injury” to natural resources resulting from the *Deepwater Horizon* explosion, oil spill, and response. Resources screened out of the impact analysis (**Sections 14 through 21**) have summarized information therein.

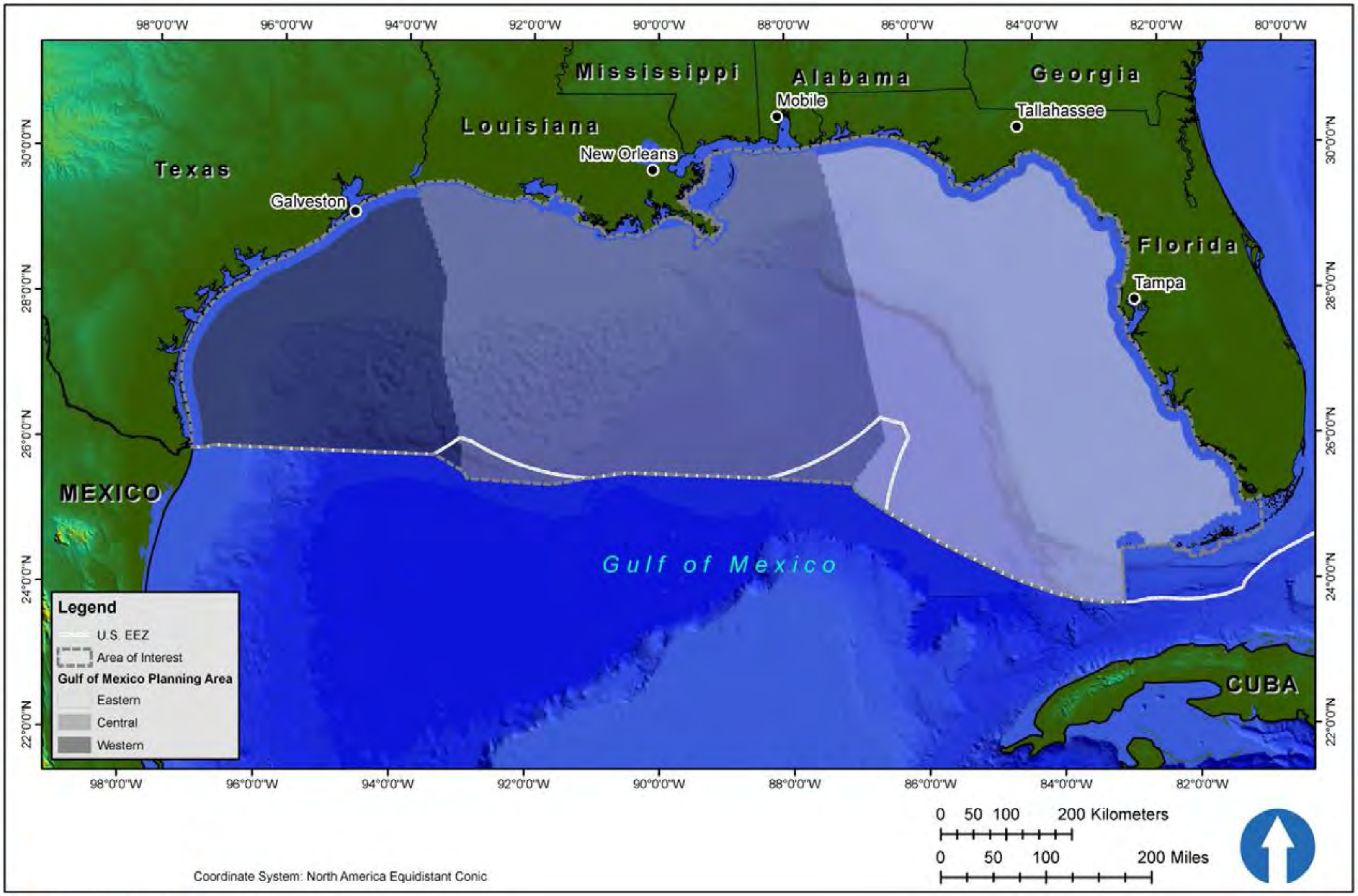

Figure E-1. Geographic Boundary of the Gulf of Mexico G&G Programmatic EIS Area or Interest.

2 MARINE MAMMALS

Chapter 4.2.1 of this Programmatic EIS provides the succinct description of the affected environment for marine mammals in sufficient detail to support the impact analyses. Mammals potentially occurring in the AOI are listed and described in **Table 4.2-1** of this Programmatic EIS. The following descriptions provide additional information on marine mammal life histories. Information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trusstees, 2016) is included below where appropriate. Information on each species is separated into the following subsections: population; distribution and abundance; habitat; behavior; vocalization and hearing; threats; and status.

2.1 CETACEANS – MYSTICETES

2.1.1 Bryde's Whale

Bryde's whales (*Balaenoptera edeni*) are large animals (considered medium-sized for balaenopterids) with a sleek body that is dark gray in color and white on the ventral side (USDOC, NMFS, 2015a). They can reach lengths ranging from 13 to 16.5 m (43 to 54 ft) and weigh up to approximately 40,000 kg (90,000 lb). Males are usually slightly smaller than females.

2.1.1.1 Population

The species complex includes one species, *Balaenoptera edeni* (Bryde's whale), that occurs in the Pacific, Indian, and Atlantic Oceans between approximately 40° N. and 40° S. latitude, and two subspecies that occur within the Indian and Pacific Oceans: *B. e. edeni* (Eden's whale) and *B. e. brydei* (offshore Bryde's whale) (Committee on Taxonomy, 2013). For management purposes, Bryde's whales inhabiting U.S. waters have been divided into three stocks: the Eastern Tropical Pacific stock; Hawaiian stock; and Northern GOM stock (USDOC, NMFS, 2015a). It is possible that Bryde's whales found in the GOM may represent a resident stock (Schmidly, 1981; Leatherwood and Reeves, 1983); however, no information on stock differentiation is available. Rosel and Wilcox, (2014) characterized genetic diversity and phylogenetic relationships of GOM resident whales to other members of the Bryde's whale complex. Their low abundance in the region was consistent with extremely low levels of genetic diversity found in both mitochondrial DNA and nuclear genomes, and places these whales at risk from decreased fitness and evolutionary potential, and demographic stochasticity (Rosel and Reeves, 2000). The high level of genetic divergence of GOM Bryde's whales, when compared with the two recognized Bryde's whale subspecies (*B. e. edeni* and *B. e. brydei*) and other balaenopterids, suggests that they have been isolated for a relatively long period of time. The combination of low genetic diversity, low population size, restricted distribution, and multiple potential sources for human-induced mortality elevates the level of concern for this population (Rosel and Wilcox, 2014).

2.1.1.2 Distribution and Abundance

Bryde's whales are distributed globally in tropical and subtropical waters of the world (Omura, 1959; Kato, 2002). In the western Atlantic Ocean, Bryde's whales are reported to occur in waters with average temperatures of 16.3°C (61.3°F) from the southeastern U.S. and the southern West Indies to Brazil, or roughly between 40° N. and 40° S. latitude (Leatherwood and Reeves, 1983; Kato, 2002). Bryde's whales occur in coastal and pelagic waters and often are sighted in shelf break waters or near topographic features such as the De Soto Canyon or Florida Escarpment in the GOM (Mullin et al., 1994; Davis et al., 2000). **Figure 4.2-3** of this Programmatic EIS shows the distribution of Bryde's whale sightings in the AOI. The Bryde's whale is considered the most common mysticete in the GOM and appears to occur in the GOM year-round (Würsig et al., 2000), although only rarely.

The CetMap abundance estimate for GOM Bryde's whales is 44 individuals (Roberts et al., 2016). Similarly, from the National Marine Fisheries Service's (NMFS) Stock Assessment Report's (SAR) data, the best current abundance estimate available for northern GOM Bryde's whales is 33 individuals (CV = 1.07). This estimate was based on results from a summer 2009 oceanic survey covering waters from the 200-m (168-ft) isobath to the seaward extent of the U.S. Exclusive Economic Zone (EEZ) (Waring et al., 2014). Historically, the estimate from surveys within oceanic waters was 35 individuals (CV = 1.10) between 1991 and 1994 (Hansen et al., 1995), 40 individuals (CV = 0.61) between 1996 and 2001 (Mullin and Fulling, 2004), and 15 individuals (CV = 1.98) between 2003 and 2004 (Mullin, 2007).

2.1.1.3 Habitat

Shipboard and aerial surveys conducted by the NMFS in oceanic waters of the northern GOM at various times throughout all seasons only observed Bryde's whales between the 100- and 300-m (328- and 984-ft) isobaths (maximum depth, 302 m [991 ft]; in the eastern Gulf of Mexico from south of Pensacola (head of De Soto Canyon) to northwest of Tampa Bay, Florida (Maze-Foley and Mullin, 2006; Waring et al., 2013; Rosel and Wilcox, 2014). Additionally, Rice et al. (2014) recorded sounds associated with Bryde's whales from several autonomous recording units deployed south of Panama City, Florida, from June through October 2010. An area has been designated as a Biologically Important Area for GOM Bryde's whales, based on extensive expert review and synthesis of published and unpublished information (LaBrecque et al., 2015).

2.1.1.4 Behavior

Bryde's whales typically are seen alone or in pairs (Tershy, 1992) but have been observed in groups of up to 10 individuals (Miyazaki and Wada, 1978). In the GOM, they occur alone or in groups of up to seven individuals (Mullin and Hoggard, 2000). Bryde's whales have been recorded swimming at speeds of 10.8 kn (12.4 mph) (Cummings, 1985) with dives lasting as long as 20 minutes; dive depths are not known. Bryde's whales feed primarily on euphausiids, copepods, and schooling fish such as sardines, herring, pilchard, and mackerel (Best, 1960; Nemoto and Kawamura, 1977; Cummings, 1985; Tershy, 1992; Tershy et al., 1993).

2.1.1.5 Hearing and Vocalizations

Bryde's whales are classified within the low-frequency, cetacean functional, marine mammal hearing group (7 Hz to 30 kHz) (Au et al., 2006; Lucifredi and Stein, 2007; Southall et al., 2007; Ketten and Mountain, 2009; Tubelli et al., 2012). There is no direct measurement of auditory threshold for Bryde's whales (Ketten, 2000; Theweissen, 2002). They are known to produce a variety of low-frequency sounds in the 20- to 900-Hz band (Cummings, 1985; Edds et al., 1993; Oleson et al., 2003). A pulsed moan has been recorded in frequencies ranging from 100 to 900 Hz. Oleson et al. (2003) reported call types with a fundamental frequency below 60 Hz. These lower frequency call types have been recorded from Bryde's whales in the Caribbean, eastern tropical Pacific, and off the coast of New Zealand. Calves produce discrete pulses at 700 to 900 Hz (Edds et al., 1993). The function of these sounds is unknown, but it is assumed to be used for communication. Source levels (SLs) range between 152 and 174 dB re 1 μPa at 1 m (Frankel, 2002).

2.1.1.6 Threats

Annual human-caused mortality and serious injury is unknown for the Northern GOM stock of Bryde's whales. There is no documented mortality or serious injury associated with commercial fishing. In 2009, there was one known Bryde's whale mortality as a result of a ship strike. The species is currently hunted outside the U.S. (Japanese whalers) and artisanal whalers have hunted and taken Bryde's whales off the coasts of Indonesia and the Philippines. The Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) quantified the impacts from the 2010 *Deepwater Horizon* oil spill on Bryde's whales. Forty-eight percent of the population was impacted by *Deepwater Horizon* oil, resulting in an estimated 22 percent maximum decline in population size. Due to their already small population size, Bryde's whales are highly susceptible to any threats that can reduce productivity and resiliency to perterbations.

2.1.1.7 Status

The Bryde's whale is currently protected under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) as well as the MMPA and is classified as data deficient by the International Union for Conservation of Nature (IUCN). In 2014, the Natural Resources Defense Council (NRDC) petitioned the Secretary of Commerce, through the NMFS, to list the Gulf of Mexico population of the Bryde's whale as an endangered species and to designate critical habitat to ensure its recovery pursuant to Section 4(b) of the Endangered Species Act (ESA). In the petition, it is argued that the Bryde's whale in the Gulf of Mexico is significant because of its unique genetic characteristics, its behavior and morphology, and because it is the only resident baleen whale population in the Gulf of Mexico (NRDC, 2014). The genetic differentiation of the Gulf of Mexico Bryde's whale makes it evolutionarily significant (Rosel and Wilcox, 2014). Based on criteria specified in 50 CFR § 424.14(b)(2), the petition cites the following threats as contributing to the present or threatened destruction, modification, or curtailment of habitat or range of the Gulf of Mexico Bryde's whale: ship strikes; acoustic impacts; oil spills; other toxic chemicals; ocean acidification; entanglement in fishing gear; and trophic impacts due to overfishing. The current status of Bryde's whales in the northern GOM, relative to its optimum sustainable population (OSP), is unknown. There are insufficient data to determine the population trends for this stock. Total human-caused mortality and serious injury for this stock is not known; however, one human-caused mortality was documented in 2009. Population modeling from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) indicates that the ability of the GOM population to recover from the *Deepwater Horizon* injury is unknown. The northern GOM Bryde's whale is a strategic stock because the average annual human-caused mortality and serious injury exceeds potential biological removal (PBR) (PBR = 0.16) (Waring et al., 2014).

2.2 Cetaceans – Odontocetes

2.2.1 Sperm Whale

The sperm whale (*Physeter macrocephalus*) is the largest odontocete, with adult lengths ranging from 12 to 18 m (40 to 60 ft). Sperm whales also are the most sexually dimorphic whale in terms of body length and weight, with adult males being up to approximately 50 percent larger than females (Whitehead, 2002; Jefferson et al., 2008). Sperm whales are mostly dark gray, though some individuals have white patches on the ventral side, with an extremely large head that takes up approximately one-third of its total body length. The most distinctive feature of the sperm whale is this massive head and specialized nasal complex, which functions as a pneumatic sound generator (Madsen et al., 2002).

2.2.1.1 Population

There is no clear understanding of the global population structure of sperm whales (Dufault et al., 1999). Recent ocean-wide genetic studies indicate low, but statistically significant, genetic diversity and no clear geographic structure, but strong differentiation between social groups (Lyrholm et al., 1996; Lyrholm and Gyllensten, 1998; Lyrholm et al., 1999). Sperm whale populations appear to be structured socially at the clan level rather than geographically (Whitehead, 2003; Whitehead et al., 2008).

The International Whaling Commission currently recognizes four sperm whale stocks: North Atlantic, North Pacific, northern Indian Ocean, and Southern Hemisphere (Reeves and Whitehead, 1997; Dufault et al., 1999). Genetic studies indicate that movements of both sexes through expanses of ocean basins are common, and that males, but not females, often breed in different ocean basins than the ones in which they were born (Whitehead, 2003). Matrilinear groups in the eastern Pacific share nuclear DNA within broader clans, but North Atlantic matrilinear groups do not share this genetic heritage (Whitehead et al., 2012). Genetic studies of GOM sperm whales found significant genetic differentiation in matrilineally inherited mitochondrial DNA among whales examined from the northern GOM and animals examined from the western North Atlantic Ocean, North Sea, and Mediterranean Sea. However, similar comparisons of biparentally inherited nuclear DNA showed no significant difference between GOM whales and whales from the other areas of the North Atlantic. The overall results from these studies indicate that some mature male sperm whales move in and out of the GOM (Engelhaupt et al., 2009). Results from satellite tagging studies of individual GOM sperm whales found no evidence of seasonal migrations of groups outside of the GOM but documented Gulfwide movements, primarily along the northern continental slope and (in a few cases) into the southern GOM. Only one sperm whale (an adult male) tagged during this study left the GOM for the North Atlantic and returned after a period of approximately 2 months (Jochens et al., 2008).

Sperm whale vocalization patterns called "codas" have distinct patterns and are believed to be culturally transmitted. Coda patterns have been examined and, based on the degree of social affiliation of these patterns, can be used to place mixed groups of sperm whales worldwide in discrete "acoustic clans" (Watkins and Schevill, 1977; Whitehead and Weilgart, 1991; Rendell and Whitehead, 2001; Rendell and Whitehead, 2003). These vocal dialects indicate parent-offspring transmission that suggests differentiation in populations (Rendell et al., 2011). Coda patterns from mixed groups of sperm whales in the GOM were compared with those from other areas of the Atlantic and suggest that GOM sperm whales may constitute a distinct acoustic clan. However, the study also found variation in coda patterns between sperm whales in the north-central GOM and the northwest GOM. From these results, it was suggested that groups of sperm whales from other acoustic clans (e.g., from the North Atlantic) may occasionally enter the northern GOM (Gordon et al., 2008).

On average, the total length of GOM sperm whales is 1.5 to 2 m (5 to 7 ft) smaller than sperm whales measured in other areas (Waring et al., 2013). Older males, which (based on tagging data) may enter the GOM only for breeding, are larger than the younger males that have not yet migrated out of the GOM (78 FR 68032). Sperm whale group size in the GOM is smaller on average than in other oceans; however, group size is variable throughout the global range of sperm whales. For example, female/immature sperm whale group size in the GOM is one-quarter to one-third that found in the Pacific Ocean but similar to group sizes observed in the Caribbean (Richter et al., 2008; Jaquet and Gendron, 2009).

In summary, although movements between the North Atlantic and GOM have been documented, GOM sperm whales are genetically distinct from their Mediterranean and North Atlantic relatives (Engelhaupt, 2004; Waring et al., 2013). The acoustic dialect used by this group is also different from sperm whales in the North Atlantic (Waring et al., 2013). For these and other reasons (e.g., average size, photo identification studies), sperm whales in the GOM constitute a stock that is distinct from other Atlantic Ocean stocks, considered as the Northern GOM stock (Waring et al., 2013).

2.2.1.2 Distribution and Abundance

Sperm whales are cosmopolitan in their distribution, ranging from tropical latitudes to pack ice edges in both hemispheres. Mature males in the Atlantic range between 70° N. and 70° S. latitude (Reeves and Whitehead, 1997; Perry et al., 1999), whereas mature females and immature individuals of both sexes are seldom found higher than 50° N. or 50° S. latitude (Reeves and

Whitehead, 1997). In winter, sperm whales migrate closer to equatorial waters, primarily to breed (Kasuya and Miyashita, 1988; Waring et al., 1993).

In the GOM, systematic aerial and ship surveys indicate that sperm whales are widely distributed during all seasons in continental slope and oceanic waters, particularly along and seaward of the 1,000-m (3,280-ft) isobaths and within areas of steep depth gradients (**Figure 4.2 1** of this Programmatic EIS) (Mullin et al., 1991, 1994, and 2004; Hansen et al., 1996; Jefferson and Schiro, 1997; Davis et al., 1998; Mullin and Hoggard, 2000; Ortega Ortiz, 2002; Fulling et al., 2003; Mullin and Fulling, 2004; Maze Foley and Mullin, 2006; Mullin, 2007; Jefferson et al., 2008). The spatial distribution of sperm whales within the GOM is also strongly correlated with mesoscale physical features such as Loop Current eddies that locally increase primary production and the availability of prey (Biggs et al., 2005).

The CetMap abundance estimate for northern GOM sperm whales is 2,128 individuals (Roberts et al., 2016). From NMFS SAR data, the best abundance estimate available for northern GOM sperm whales, derived from a summer 2009 oceanic survey, is 763 individuals (CV = 0.38) (Waring et al., 2013). The minimum population estimate resulting from these data is 560 sperm whales. From 1991 through 1994 and from 1996 through 2001 (excluding 1998), annual surveys were conducted within oceanic waters during spring along a fixed plankton-sampling trackline. Due to the limited number of surveys in any given year, the survey effort-weighted estimated average abundance of sperm whales for all surveys was combined. From 1991 to 1994, the estimate was 530 individuals (CV = 0.31) (Hansen et al., 1996), and for 1996 to 2001, the estimate was 1,349 individuals (CV = 0.23) (Mullin and Fulling, 2004). During summer 2003 and spring 2004, surveys dedicated to estimating cetacean abundance were conducted along a grid of uniformly spaced transect lines from a random start. The abundance estimate for sperm whales, pooled from 2003 to 2004, was 1,665 individuals (CV = 0.20) (Mullin, 2007).

Jochens et al. (2006) estimated the number of sperm whales off the Mississippi River Delta to be 398 individuals (CI = 253 to 607). Mullin et al. (2004) estimated the number of whales in the north-central and northwestern GOM at 87 individuals (95% CI = 52 to 146).

2.2.1.3 Habitat

Sperm whales have a strong preference for waters deeper than 1,000 m (3,280 ft) (Watkins, 1977; Reeves and Whitehead, 1997) and are rarely found in waters <300 m (984 ft) deep (Clarke, 1956; Rice, 1989). Sperm whales are frequently found in locations of high productivity resulting from upwelling or steep underwater topography, such as continental slopes, seamounts, or canyon features (Jaquet and Whitehead, 1996; Jaquet et al., 1996). Cold-core eddy features are also attractive to sperm whales in the GOM, likely because of the large numbers of squid that are drawn to the high concentrations of plankton associated with these features (Biggs et al., 2000; Davis et al., 2000 and 2002; Wormuth et al., 2000).

2.2.1.4 Behavior

Reproduction and Social Behavior

Female sperm whales become sexually mature at an average of 9 years or 8.2 to 8.8 m (27 to 29 ft) (Kasuya, 1991). Males reach lengths of 10 to 12 m (33 to 39 ft) at sexual maturity and take 9 to 20 years to become sexually mature, but they require another 10 years to become large enough to successfully breed (Kasuya, 1991; Würsig et al., 2000). Mean age at physical maturity is 45 years for males and 30 years for females (Waring et al., 2004). Adult females give birth after roughly 15 months of gestation and nurse their calves for 2 to 3 years (Waring et al., 2004). The calving interval is estimated to be every 4 to 6 years between the ages of 12 and 40 (Kasuya, 1991; Whitehead et al., 2008). It has been suggested that some mature males may not migrate to breeding grounds annually during winter, and instead may remain in higher latitude feeding grounds for >1 year at a time (Whitehead and Arnbom, 1987).

Sperm whale age distribution is unknown, but sperm whales are believed to live at least 60 years (Rice, 1978). Stable, long-term associations among females form the core of sperm whale societies (Christal et al., 1998). Up to a dozen females usually live in such groups, accompanied by their female and young male offspring. Young individuals are subject to alloparental care by members of either sex and may be suckled by non-maternal individuals (Gero et al., 2009). Groups may be stable for long periods, such as for 80 days in the Gulf of California (Jaquet and Gendron, 2009). Males start leaving these family groups at approximately 6 years of age, after which they live in “bachelor schools,” but this may occur more than a decade later (Pinela et al., 2009). The cohesion among males within a bachelor school declines with age. During their breeding prime and old age, male sperm whales are essentially solitary (Christal and Whitehead, 1997).

Diving

Sperm whales are probably the deepest and longest diving mammalian species, with dives to a depth of 3 km (1.9 mi) and durations in excess of 2 hours (Clarke, 1976; Watkins et al., 1985; Watkins et al., 1993). However, dives are generally shorter (25 to 45 minutes) and shallower (400 to 1,000 m [1,312 to 3,280 ft]). Dives are separated by 8- to 11-minute rests at the surface (Gordon, 1987; Papastavrou et al., 1989; Würsig et al., 2000; Jochens et al., 2006; Watwood et al., 2006). Sperm whales typically travel approximately 3 km (1.9 mi) horizontally and 0.5 km (0.3 mi) vertically during a foraging dive (Whitehead, 2003). Differences in night and day diving patterns are not known for this species, but, like most diving air-breathers for which there are data (rorquals, fur seals, and chinstrap penguins), sperm whales probably make relatively shallow dives at night when prey are closer to the surface.

Feeding

Sperm whales appear to feed regularly throughout the year (USDOC, NMFS, 2006). It is estimated they consume approximately 3 to 3.5 percent of their body weight daily (Lockyer, 1981). They seem to forage mainly on or near the seafloor, often ingesting stones, sand, sponges, and other non-food items (Rice, 1989). A large proportion of a sperm whale’s diet consists of low-fat, ammoniacal, or luminescent squids (Clarke, 1980 and 1996; Martin and Clarke, 1986). While sperm whales feed primarily on large and medium-sized squids, the list of documented food items is fairly long and diverse. Prey items include other cephalopods, such as octopuses, and medium- and large-sized demersal fishes, such as rays, sharks, and many teleosts (Berzin, 1972; Clarke, 1977; Clarke, 1980; Rice, 1989; Angliss and Lodge, 2004). The diet of large males in some areas, especially in high northern latitudes, is dominated by fish (Rice, 1989).

2.2.1.5 Vocalization and Hearing

Sound production and reception by sperm whales are better understood than in most cetaceans. Sperm whales produce broadband clicks in the 100 Hz to 20 kHz range that can be extremely loud for a biological source (200 to 236 dB re 1 μPa at 1 m), although lower SL energy has been suggested at approximately 171 dB re 1 μPa at 1 m (Weilgart and Whitehead, 1993 and 1997; Goold and Jones, 1995; Møhl et al., 2003). Most of the energy in sperm whale clicks is concentrated at approximately 2 to 4 kHz and 10 to 16 kHz (Weilgart and Whitehead, 1993; Goold and Jones, 1995; USDOC, NMFS, 2006). The highly asymmetric head anatomy of sperm whales is likely an adaptation to produce the unique clicks recorded from these animals (Norris and Harvey, 1972; Cranford, 1992). Long, repeated clicks are associated with feeding and echolocation (Weilgart and Whitehead, 1993 and 1997; Goold and Jones, 1995). However, clicks are also used in short patterns (codas) during social behavior and intragroup interactions (Weilgart and Whitehead, 1993). They may also aid in intraspecific communication. Another class of sound, “squeals,” are produced at frequencies of 100 Hz to 20 kHz (e.g., Weir et al., 2007).

The understanding of sperm whale hearing stems largely from the sounds they produce. The only direct measurement of hearing was from a young stranded individual from which auditory evoked potentials were recorded (Carder and Ridgway, 1990). From this whale, responses support a hearing range of 2.5 to 60 kHz. Sperm whales therefore are classified within the mid-frequency, cetacean functional, marine mammal hearing group (150 Hz to 160 kHz) (Southall et al., 2007). However, behavioral responses of adult, free-ranging individuals also provide insight into hearing range; sperm whales have been observed to frequently stop echolocating in the presence of underwater pulses made by echosounders and submarine sonar (Watkins and Schevill, 1975; Watkins et al., 1985). They also stop vocalizing for brief periods when codas are being produced by other individuals, perhaps because they can hear better when not vocalizing themselves (Goold and Jones, 1995). Because they spend large amounts of time at depth and use low-frequency sound, sperm whales are likely to be susceptible to low-frequency sound in the ocean (Croll et al., 1999).

2.2.1.6 Threats

Natural

Sperm whales are known to be occasionally preyed upon by killer whales (Jefferson et al., 1991; Pitman et al., 2001) and large sharks (Best et al., 1984) as well as harassed by pilot whales (Arnbom et al., 1987; Rice, 1989; Whitehead, 1995; Palacios and Mate, 1996; Weller et al., 1996). Whitt et al. (2015) reported a prolonged interaction between killer whales and sperm whales in the

GOM during 2011. Strandings are relatively common events, with one to dozens of individuals beaching themselves and dying during any single event. Although several hypotheses have been proposed, such as navigation errors, illness, and anthropogenic stressors (Goold et al., 2002; Wright, 2005), direct widespread causes of strandings remain unclear. An additional natural threat to humback whales includes calcivirus and papillomavirus pathogens (Smith and Latham, 1978; Lambertsen et al., 1987).

Anthropogenic

Sperm whales historically faced severe depletion from commercial whaling operations. From 1800 to 1900, the International Whaling Commission estimated that nearly 250,000 sperm whales were killed by whalers, with another 700,000 killed from 1910 to 1982. However, other estimates have included 436,000 individuals killed between 1800 and 1987 (Carretta et al., 2005). However, all of these estimates are likely underestimates due to illegal and inaccurate killings by Soviet whaling fleets between 1947 and 1973. Additionally, Soviet whalers disproportionately killed adult females in any reproductive condition (pregnant or lactating) as well as immature sperm whales of either gender. Following a moratorium on whaling by the International Whaling Commission, significant whaling pressures on sperm whales were eliminated.

There were eight sperm whale strandings in the northern GOM between 2006 and 2010 (Waring et al., 2013). For one stranding, no evidence of human interaction was detected; for the remaining seven strandings, it could not be determined if there was evidence of human interactions. During June 2010, one dead sperm whale was found floating 124 km (77 mi) due south of the *Deepwater Horizon* spill site. It was not found in oiled waters; however, the location of its death is unknown. The cause of death is also unknown; the animal did not appear oily. The Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) summarized injuries to GOM sperm whales and stated that 16 percent of the population was exposed to *Deepwater Horizon* oil and 6 percent of the population was killed as a result. In addition, 7 percent of females likely experienced reproductive failure, and 6 percent of the population has experienced adverse health effects. Stranding data probably underestimate the extent of human related mortality and serious injury because (1) not all marine mammals that die or are seriously injured in human interactions wash ashore; (2) not all that wash ashore are discovered, reported, or investigated; and (3) not all that wash ashore show signs of entanglement or other human interaction. Sperm whales (and other oceanic species) that die in waters greater than 20-m (66-ft) depth are extremely unlikely (<1%) to be found as beached carcasses in the GOM (Deepwater Horizon Marine Mammal Injury Quantification Team, 2015). Finally, the level of technical expertise among stranding network personnel varies widely as does the ability to recognize signs of fishery interactions. Two sperm whale deaths have been considered to be part of the ongoing GOM cetacean unusual mortality event (UME).

In U.S. waters, sperm whales are known to have been incidentally captured in drift gillnet operations (Barlow et al., 1997), resulting in serious injury and mortality. Interactions between longline fisheries and sperm whales have been reported, primarily in Alaskan fisheries (Rice, 1989;

Hill and Demaster, 1998), and observers have documented sperm whales feeding on fish caught in longline gear. The available evidence does not indicate sperm whales are being killed or seriously injured as a result of these interactions, although the nature and extent of interactions between sperm whales and longline gear is not yet clear. In the GOM, sperm whales are most likely to interact with pelagic longlines. No fishing-related mortality or serious injury of a sperm whale was reported in the GOM between 1998 and 2010. However, in 2008, there was one sperm whale released alive with no serious injury after an entanglement interaction with the pelagic longline fishery and one mortality due to entanglement in the sea anchor (parachute anchor and lines) of a longline fishing vessel (Garrison et al., 2009).

Contaminants have been identified in sperm whales but vary widely in concentration based on life history and geographic location, with northern hemisphere individuals generally carrying higher burdens (Evans et al., 2004). Contaminants include dieldrin, chlordane, DDT, DDE, PCBs, HCB, and HCHs as well as several heavy metals in a variety of body tissues (Aguilar, 1983; Law et al., 1996; Evans et al., 2004). However, unlike other marine mammals, females appear to bioaccumulate toxins at greater levels than males, which may be related to possible dietary differences between females who remain at relatively low latitudes compared wirh more migratory males (Aguilar, 1983; Wise et al., 2009). Ingestion of trash and debris can have fatal consequences even for large whales, with multiple instances of stranded sperm whales found having ingested plastic debris (e.g., Lambertsen, 1990; Viale et al., 1992; USDOC, NMFS, 2009a; de Stephanis et al., 2013).

There have not been any recent documented ship strikes involving sperm whales, although there are a few records of ship strikes in the 1990s. The lack of recent evidence should not lead to the assumption that no mortality or injury from collisions with vessels occurs as carcasses that do not drift ashore may go unreported, and those that do strand may show no obvious signs of having been struck by a ship (USDOC, NMFS, 2009a). Worldwide, sperm whales are known to have been struck 17 times out of a total record of 292 strikes of all large whales, 13 of which resulted in mortality (Laist et al., 2001; Jensen and Silber, 2004). One sperm whale mortality, possibly resulting from a vessel strike, has been documented for the GOM. The incident occurred in 1990 in the vicinity of Grand Isle, Louisiana. Deep cuts on the dorsal surface of the whale indicated the ship strike was probably pre-mortem (Jensen and Silber, 2004). Given the current number of reported cases of injury and mortality, it does not appear that ship strikes are a significant threat to sperm whales (Whitehead, 2003).

2.2.1.7 Status

Sperm whales were originally listed as endangered in 1970 (35 FR 18319), and this status remains under the ESA. The IUCN has classified the sperm whale as vulnerable. Sperm whales are designated as depleted because of the species' listing under the ESA, and the Northern GOM stock is classified as strategic under the MMPA. The current PBR for GOM sperm whales is 1.1 individuals (Waring et al., 2013). The NMFS has not designated critical habitat for sperm whales. Sperm whales were widely harvested from the northeastern Caribbean (Romero et al.,

2001) and the GOM, where sperm whale fisheries operated during the late 1700s to the early 1900s (Townsend, 1935; USDOC, NMFS, 2006). Presumably from the effects of whaling pressure, sperm whale populations remain small. Because of their small population size, small changes in reproductive parameters, such as the loss of adult females, may significantly affect the growth of sperm whale populations (Chiquet et al., 2013). No population trends can be interpreted from data available for the GOM; however, recent information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) suggests that sperm whales in the GOM have experienced a population decline (6%) as a result of injury from the spill. Changes in abundance will be difficult to interpret without a Gulfwide understanding of sperm whale abundance. Studies based on abundance and distribution surveys restricted to U.S. waters are unable to detect temporal shifts in distribution beyond U.S. waters that might account for any changes in abundance (Waring et al., 2013).

2.2.2 Pygmy and Dwarf Sperm Whales

Pygmy (*Kogia breviceps*) and dwarf (Kogia sima) sperm whales are in the family Kogiidae. Pygmy sperm whales reach lengths of approximately 3.5 m (11 ft) and weigh between 315 and 450 kg (700 and 1,000 lb). Dwarf sperm whales can reach lengths of approximately 2.7 m (9 ft) and weigh between 135 and 270 kg (300 and 600 lb). Females may be slightly smaller than males.

2.2.2.1 Population

For management purposes, pygmy and dwarf sperm whales inhabiting U.S. waters have been divided into four stocks: the California/Oregon/Washington stock; the Hawaiian stock; the Northern GOM stock; and the Western North Atlantic stock. Although GOM populations of the two Kogia species are provisionally being considered as separate stocks for management purposes, there is currently no information to differentiate these stocks from the Atlantic Ocean stock(s) (Waring et al., 2012).

2.2.2.2 Distribution and Abundance

Pygmy and dwarf sperm whales are distributed worldwide, primarily in temperate to tropical oceanic waters from 40° S. to 60° N. latitude. Both Kogia species are believed to occur year-round in the GOM (Würsig et al., 2000). Dwarf and pygmy sperm whales are difficult to differentiate at sea, and sightings usually are categorized as Kogia spp. (Waring et al., 2012). Sightings of this category were documented in all seasons during GulfCet aerial surveys of the northern GOM from 1992 to 1998 (Hansen et al., 1996; Mullin and Hoggard, 2000). They have been known to strand along the coast of the GOM, especially in fall and winter, which may be associated with the calving season (Würsig et al., 2000). Dwarf sperm whales do not strand as frequently as pygmy sperm whales (Würsig et al., 2000). Breeding areas for both species include waters off Florida (Evans, 1987). There is little evidence of whether pygmy and dwarf sperm whales have a seasonal migration pattern (McAlpine, 2002).

The CetMap abundance estimate for dwarf and pygmy sperm whale (combined) is 2,234 individuals (Roberts et al., 2016). From NMFS SAR data, the best abundance estimate available for northern GOM dwarf and pygmy sperm whales is 186 individuals (CV = 1.04). This estimate is from a summer 2009 oceanic survey covering waters from the 200-m (656-ft) isobath to the seaward extent of the U.S. EEZ (Waring et al., 2012). Historically, for surveys conducted in oceanic waters from 1991 to 1994, the estimate was 547 individuals (CV = 0.28); for 1996 to 2001 (excluding 1998), 742 individuals (CV = 0.29); and from 2003 to 2004, the estimate was 453 individuals (CV = 0.35) (Waring et al., 2012).

2.2.2.3 Habitat

Dwarf sperm whales generally have been sighted in warmer waters than pygmy sperm whales (Caldwell and Caldwell, 1989). Pygmy sperm whales typically are sighted in water depths of 100 to 2,000 m (328 to 6,562 ft) while dwarf sperm whales are thought to be more pelagic and deeper divers (Barros et al., 1998).

2.2.2.4 Behavior

Dwarf sperm whales are found at the surface in groups of up to 10 individuals while pygmy sperm whales are found in smaller groups of 1 to 6 individuals (Caldwell and Caldwell, 1989). These groups can vary based on age and sex, but little else is known about the social organization of these species. Kogia are rarely active or aerial at the surface, and it is very uncommon for them to approach boats. Usually they are seen slowly swimming (3 kn; 3.5 mph) or “logging” (floating motionless) at the surface, showing only a small portion of their body. Before diving, they will slowly roll or sink and disappear from view without displaying their flukes. This species is very difficult to visually spot at sea given their timid behavior, lack of a visible blow, and low profile in the water. They usually are only detected in ideal (i.e., calm) sea state and weather conditions (e.g., low wind speeds and little or no swells) (USDOC, NMFS, 2015a). Swim speeds vary and were found to reach up to 5.9 kn (6.8 mph) (Scott et al., 2001). In the GOM, the maximum dive time for dwarf sperm whales was recorded as 43 minutes (Breese and Tershy, 1993; Willis and Baird, 1998). Their diet consists of cephalopods (e.g., squids and octopuses), crustaceans (e.g., crabs and shrimp), and fish. Based on the structure of their lower jaw and analysis of stomach contents, these animals forage and feed in mostly mid-water and deepwater environments as well as near the seafloor. Pygmy sperm whales may feed in slightly deeper waters than dwarf sperm whales (USDOC, NMFS, 2015a).

Dwarf sperm whales become sexually mature at 2.5 to 5 years of age, whereas pygmy sperm whales become sexually mature at 4 to 5 years of age. Gestation is estimated to be 9 to 11 months, and newborn pygmy sperm whale calves are approximately 1.2 m (4 ft) in length and weigh 50 kg (110 lb); newborn dwarf sperm whale calves are approximately 1 m (3 ft) in length and weigh 40 to 50 kg (88 to 110 lb). Calves probably are weaned after 1 year. Females may give birth to calves in consecutive years. The estimated lifespan for these species is 22 to 23 years (USDOC, NMFS, 2015a).

2.2.2.5 Vocalizations and Hearing

Sparse data are available on the hearing sensitivity for pygmy or dwarf sperm whales. An auditory brainstem response (ABR) study on a rehabilitating pygmy sperm whale indicated that this species has an underwater hearing range that is most sensitive between 90 and 150 kHz (Carder et al., 1995; Ridgway and Carder, 2001). Thomas et al. (1990) recorded a low-frequency sweep between 1,300 and 1,500 Hz from a captive pygmy sperm whale in Hawaii. Richardson et al. (1995) reported pygmy sperm whale click frequency ranging from 60 to 200 kHz, with the dominant frequency at 120 kHz. Recent recordings from captive and stranded pygmy sperm whales indicate that they produce sounds between 60 and 200 kHz with peak frequencies at 120 to 130 kHz, while echolocation pulses were documented with peak frequencies at 125 to 130 kHz (Marten, 2000; Ridgway and Carder, 2001). No geographical or seasonal differences in sounds have been documented. No information is available on sound production in dwarf sperm whales.

2.2.2.6 Threats

The commercial fishery that could interact with the Northern GOM stock is the large pelagic longline fishery. Total human-caused mortality and serious injury for this stock is not known. There is insufficient information available to determine whether the total fishery-related mortality and serious injury for this stock is insignificant and approaching zero mortality and serious injury rate. The Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) summarized injuries to GOM pygmy and dwarf sperm whales from the *Deepwater Horizon* oil spill. Fifteen percent of the population was exposed to *Deepwater Horizon* oil and 5 percent of the population was killed as a result. In addition, 7 percent of the females likely experienced reproductive failure, and 6 percent of the population has experienced adverse health effects.

2.2.2.7 Status

Both Kogia species are protected under the MMPA and classified as least concern by the IUCN. The species are not listed as threatened or endangered under the ESA. The status of Kogia in the northern GOM, relative to OSP, is unknown. There are insufficient data to determine the population trends for the two species; however, recent information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) suggests that they have experienced a population decline (5%) as a result of injury from the *Deepwater Horizon* oil spill. They are not considered strategic stocks because it is assumed that average annual human-related mortality and serious injury does not exceed combined PBR (PBR = 0.9). However, the continuing inability to distinguish between species of Kogia raises concerns about the possibility of mortalities of one stock or the other exceeding PBR (Waring et al., 2012).

2.2.3 Cuvier's Beaked Whale

Cuvier's beaked whales (*Ziphius cavirostris*) are members of the beaked whale family Ziphiidae. They can reach lengths of 4.5 to 7 m (15 to 23 ft) and weigh 1,845 to 3,090 kg (4,000 to 6,800 lb). There is no significant sexual dimorphism in regards to body size for this species (USDOC, NMFS, 2015a).

2.2.3.1 Population

For management purposes, Cuvier's beaked whales inhabiting U.S. waters have been divided into five stocks: the Alaska stock; the California/Oregon/Washington stock; the Hawaiian stock; the Northern GOM stock; and the Western North Atlantic stock. The Northern GOM stock is provisionally being considered a separate stock for management purposes, although there is currently no information to differentiate this stock from the Western North Atlantic stock (Waring et al., 2012).

2.2.3.2 Distribution and Abundance

Cuvier's beaked whales are found in deep offshore waters of all oceans from 60° N. to 60° S. latitude (Jefferson et al., 1993) but are more common in subtropical and temperate waters (Evans, 1987). Cuvier's beaked whales are reported in the GOM from strandings and live individuals sighted during surveys. Strandings records are primarily from the eastern GOM along the Florida coast. Sightings of live individuals were made primarily within the central and western GOM, in areas with water depths of approximately 2,000 m (6,562 ft) (Würsig et al., 2000). During GulfCet surveys, they were sighted only during spring (Davis and Fargion, 1996).

The CetMap abundance estimate for GOM beaked whales, including Cuvier's, Gervais', and Blainville's (combined) is 2,910 individuals (Roberts et al., 2016). From NMFS SAR data, the best abundance estimate available for Cuvier's beaked whales in the northern GOM is 74 individuals (CV = 1.04). This estimate is from a summer 2009 oceanic survey covering waters from the 200-m (656-ft) isobath to the seaward extent of the U.S. EEZ. This abundance estimate is negatively biased because only sightings of beaked whales that could be positively identified to species were used, and estimates for undifferentiated beaked whales (Mesoplodon spp. and unidentified Ziphiidae) made during the same time period may also include an unknown number of Cuvier's beaked whales (Waring et al., 2012). Historically, for surveys conducted in oceanic waters from 1991 to 1994, the estimate was 30 individuals (CV = 0.50); for 1996 to 2001 (excluding 1998), the estimate was 95 individuals (CV = 0.47); and from 2003 to 2004, the estimate was 65 individuals (CV = 0.67) (Waring et al., 2012).

2.2.3.3 Habitat

Cuvier's beaked whales can be found in temperate, subtropical, and tropical waters. They prefer deepwater habitats (usually >1,000 m [3,280 ft]) of the continental slope and edge as well as steep underwater geologic features like banks, seamounts, and submarine canyons. Recent surveys suggest that Cuvier's beaked whales, like other beaked whale species, may favor oceanographic features such as currents, current boundaries, and core ring features (USDOC, NMFS, 2015a).

2.2.3.4 Behavior

Mullin and Hoggard (2000) reported that Cuvier's beaked whales have been sighted in groups of 1 to 4 individuals, but Mullin et al. (2004) and MacLeod and D'Amico (2006) later reported that Cuvier's beaked whales may occur in groups ranging from 1 to 15 individuals. Swimming speeds of Cuvier's beaked whales have been recorded between 2.7 and 3.3 kn (3.1 and 3.8 mph) (Houston, 1991). Dive durations range between 20 and 87 minutes, with an average dive time of approximately 30 minutes (Heyning, 1989; Jefferson et al., 1993; Baird et al., 2004). Baird et al. (2004 and 2006) recorded Cuvier's beaked whales diving as long as 87 minutes to depths up to 1,990 m (6,529 ft). Cuvier's beaked whales consume squids and deep-sea fishes (Clarke, 1996).

2.2.3.5 Vocalization and Hearing

The hearing sensitivity of Cuvier's beaked whales has not been determined (Ketten, 2000; Thewissen, 2002). Cuvier's beaked whales have been recorded producing high-frequency clicks between 13 and 17 kHz and lasting for 15 to 44 seconds (Frantzis et al., 2002). These sounds were recorded during diving activity and may be associated with echolocation. Whistle frequencies have been measured at 2 to 12 kHz and pulsed sounds range in frequency from 300 Hz to 135 kHz. However, it is possible that higher frequencies could not be recorded due to equipment limitations (MacLeod and D'Amico, 2006). No data are available regarding seasonal or geographical variation in the sound production of Cuvier's beaked whales. Beaked whales are capable of producing SLs of 200 to 220 dB re 1 μPa at 1 m (peak peak) (Johnson et al., 2004).

Zimmer et al. (2005) also studied Cuvier's beaked whales and their echolocation clicks. The highest measured SL was 214 dB re 1 μPa at 1 m (peak-peak). It is possible that Cuvier's beaked whales cannot produce higher SLs, but it is more likely that the full capabilities of the Cuvier's beaked whales are underestimated by this study. Therefore, the maximum SL shown in this study may be the result of the whales reducing the volume when ensonifying each other (Zimmer et al., 2005).

2.2.3.6 Threats

Threats to Cuvier's beaked whales include entanglement in fishing gear, ship strikes, and anthropogenic noise (USDOC, NMFS, 2015a). The commercial fishery that could interact with the Northern GOM stock in the GOM is the large pelagic longline fishery. Stranding data probably underestimate the extent of human-related mortality and serious injury because (1) not all marine mammals that die or are seriously injured in human interactions wash ashore; (2) not all that wash ashore are discovered, reported, or investigated; and (3) not all that wash ashore show signs of entanglement or other fishery interaction (Waring et al., 2012). Total human-caused mortality and serious injury for this stock is not known; however, the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) summarized injuries from the *Deepwater Horizon* oil spill to GOM beaked whales (Cuvier's, Gervais', and Blainesville's) and stated that 12 percent of the population was exposed to *Deepwater Horizon* oil and 4 percent of the population was killed as a result. In addition, 5 percent of females likely experienced reproductive failure and 4 percent of the population has experienced adverse health effects There is insufficient information available to determine whether the total fishery-related mortality and serious injury for this stock is insignificant and approaching zero mortality and serious injury rate. Disturbance by anthropogenic noise may prove to be an important habitat issue in some areas of this population's range, notably in areas of oil and gas activities or where shipping or naval activities are high (USDOC, NMFS, 2015a).

2.2.3.7 Status

The Cuvier's beaked whale is currently classified as data deficient by the IUCN and is protected under the MMPA. The species is not listed as threatened or endangered under the ESA. Abundance estimates of the global population size for this species are unknown. The status of Cuvier's beaked whales and other beaked whales in the northern GOM, relative to OSP, is unknown. There are insufficient data to determine the population trends for this species; however, recent information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) suggests that the beaked whale complex (Cuvier's, Gervais', and Blainesville's) have experienced a population decline (4%) as a result of injury from the *Deepwater Horizon* oil spill. This is not a strategic stock because it is assumed that the average annual human-related mortality and serious injury does not exceed PBR (PBR = 0.4) (Waring et al., 2012).

2.2.4 Mesoplodon Beaked Whales

Two species of Mesoplodon beaked whales may occur in the GOM: Blainville's beaked whale (*M. densirostris*) and Gervais' beaked whale (*M. europaeus*). Many species of beaked whales (especially those in the genus Mesoplodon) are very difficult to distinguish from one another due to their cryptic and skittish behavior, low profile, and small inconspicuous blow at the water's surface; therefore, much of the available characterization for beaked whales is to genus level only. Uncertainty regarding species identification of beaked whales often exists because of a lack of easily discernable or distinct physical characteristics (USDOC, NMFS, 2015a).

2.2.4.1 Population

For management purposes, Blainville's beaked whales inhabiting U.S. waters have been divided into three stocks (i.e., Hawaiian stock, Northern GOM stock, and Western North Atlantic stock) and Gervais' beaked whales have been divided into two stocks (i.e., Western North Atlantic stock and Northern GOM stock).

2.2.4.2 Distribution and Abundance

Mesoplodon whales are distributed in offshore pelagic waters between 72° N. and 60° S. latitude (Leatherwood and Reeves, 1983; Jefferson et al., 1993; Wade and Gerrodette, 1993; Carlström et al., 1997). Along the East Coast of the U.S., beaked whales may be associated with the Gulf Stream and warm core eddies (Waring et al., 1992). Globally, beaked whales typically inhabit the continental slope and deep oceanic waters (>200 m [656 ft]) (Cañadas et al., 2002; Pitman, 2002; MacLeod et al., 2004; Ferguson et al., 2006; MacLeod and Mitchell, 2006). In the GOM, beaked whales have been sighted during all seasons and in waters depths ranging from 420 to 3,487 m (1,378 to 11,440 ft) (Ward et al., 2005; Waring et al., 2009).

Blainville's beaked whales appear to be widely but sparsely distributed in temperate and tropical waters of the world's oceans (Leatherwood et al., 1976). Blainville's beaked whales appear to be pelagic and mainly found in deep waters but also occur in some coastal areas (Davis et al., 1998). They generally are sighted in water depths >200 m (656 ft) and have also been frequently sighted in water depths >1,000 m (3,280 ft) (Ritter and Brederlau, 1999; Gannier, 2000; MacLeod et al., 2004; Ferguson, 2005; MacLeod and Zuur, 2005). Blainville's beaked whales have been reported as far north as Nova Scotia and as far south as Florida, the Bahamas, and the GOM (Leatherwood et al., 1976; Mead, 1989; Würsig et al., 2000; MacLeod et al., 2006). There have been two sightings and four documented strandings of Blainville's beaked whales in the northern GOM (Hansen et al., 1995; Würsig et al., 2000).

Gervais' beaked whales appear to be primarily oceanic and sparsely distributed in temperate and tropical waters. Strandings of this species have occurred along the U.S. East Coast from Cape Cod, Massachusetts, south to Florida as well as in the Caribbean Sea and GOM (Leatherwood et al., 1976; Mead, 1989; MacLeod et al., 2006), with 16 strandings occurring in the GOM (Würsig et al., 2000). The strandings may coincide with calving, which takes place in shallow water (Würsig et al., 2000).

Differentiated abundance estimates for Blainsville and Gervais' beaked whales in the northern GOM are not available. The CetMap abundance estimate for GOM beaked whales, including Cuvier's, Gervais', and Blainville's (combined) is 2,910 individuals (Roberts et al., 2016). From NMFS SAR data, the best available abundance estimate of Blainville's and Gervais' beaked whales is 149 individuals (CV = 0.91) (Waring et al., 2014). Historically, for surveys conducted in oceanic waters from 1996 to 2001 (excluding 1998), the estimate was 106 individuals (CV = 0.41); and from 2003 to 2004, the estimate was 57 individuals (CV = 0.1.4) (Waring et al., 2012).

2.2.4.3 Habitat

Blainville's beaked whales occur in tropical to temperate waters worldwide, generally within deep offshore waters of the continental shelf. This species is often associated with steep underwater geologic structures such as banks, submarine canyons, seamounts, and continental slopes (USDOC, NMFS, 2015a). Gervais' beaked whales prefer deep tropical, subtropical, and warm temperate waters of the Atlantic Ocean, but they are occasionally found in colder temperate seas (USDOC, NMFS, 2015a).

2.2.4.4 Behavior

Blainville's beaked whales typically are found in groups of 1 to 11 individuals (Mullin and Fulling, 2004), whereas other Mesoplodon species are found alone or in groups of up to 15 individuals (MacLeod and D'Amico, 2006). General swimming speeds for beaked whales average 2.7 kn (3.1 mph) (Kastelein and Gerrits, 1991). Dives of Blainville's beaked whales average 7.5 minutes during social interactions at the surface (Baird et al., 2004). Dives longer than 45 minutes have been recorded for some Mesoplodon species (Jefferson et al., 1993).

Gervais' beaked whales usually are found individually or in small closely associated social groups (USDOC, NMFS, 2015a). Females may become sexually mature at 4.5 m (15 ft) and will give birth to a single newborn calf that is approximately 1.5 to 2 m (5 to 7 ft) long and weighs approximately 80 kg (176 lb). The estimated lifespan of this species is at least 27 years, but it may be up to 48 years (Reeves et al., 2002).

Mesoplodon whales are deep-diving species that consume small cephalopods and bentho-pelagic fish (Sullivan and Houck, 1979; Leatherwood et al., 1988; Mead, 1989; Jefferson et al., 1993; MacLeod et al., 2003). Blainville's beaked whales diving to depths near 900 m (2,625 ft) for 20 minutes or longer are most likely foraging (Leatherwood et al., 1988; Baird et al., 2004). Barlow (1999) and Baird et al. (2006) have recorded dive durations of >20 minutes for Mesoplodon species.

2.2.4.5 Vocalizations and Hearing

No direct measurements of the hearing sensitivity of Mesoplodon species have been made (Ketten, 2000; Thewissen, 2002). There are sparse data available on sound production of Mesoplodon species and no data regarding seasonal or geographical variation in sound production. A stranded Blainville's beaked whale in Florida produced chirps and whistles from <1 to 6 kHz (Caldwell and Caldwell, 1971a). Johnson et al. (2004) found that Blainville's beaked whales started clicking at an average depth of 400 m (1,312 ft), ranging from 200 to 570 m (656 to 1,870 ft), and stopped clicking when they started their ascent at an average depth of 720 m (2,362 ft), with a range of 500 to 790 m (1,640 to 2,592 ft). The intervals between regular clicks were approximately 0.4 seconds. Trains of clicks often end in a rapid increase in the click rate, which is also called a buzz. The Cuvier's beaked whale and the Blainville's beaked whale have a somewhat flat spectrum that was accurately sampled by Johnson et al. (2004) between 30 and 48 kHz. There may be a slight decrease in the spectrum above 40 kHz, but the 96-kHz sampling rate was not sufficient to sample the full frequency range of clicks from either species (Johnson et al., 2004).

2.2.4.6 Threats

Mesoplodon species have been incidentally taken in the pelagic drift gillnet fishery off the U.S. Atlantic Coast. Blainville's beaked whales have been incidentally taken by Japanese fishing boats (Jefferson et al., 2008). This species occasionally has been taken in hunts targeting small cetaceans. Gervais' beaked whales have been incidentally taken as bycatch in fishing gear, such as pound nets, driftnets, and gillnets, off the U.S. Atlantic Coast. This species may be hunted in the Caribbean Sea for food (USDOC, NMFS, 2015a).

Beaked whales may be sensitive to underwater sounds and anthropogenic noise. Recently, strandings of Blainville's beaked whales in the Bahamas, due to acoustic trauma, have been associated with active sonar during Naval military activities and exercises.

2.2.4.7 Status

Mesoplodon species currently are classified as data deficient by the IUCN and are protected under the MMPA. The status of beaked whales in the northern GOM, relative to OSP, is unknown. The species are not listed as threatened or endangered under the ESA. There are insufficient data to determine the population trends for these species; however, recent information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) suggests that the beaked whale complex (i.e., Cuvier's, Gervais', and Blainesville's) have experienced a population decline (4%) as a result of injury from the *Deepwater Horizon* oil spill. Total human-caused mortality and serious injury for the stocks are not known. The Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) summarized injuries from the *Deepwater Horizon* spill to GOM beaked whales (i.e., Cuvier's, Gervais', and Blainesville's) and stated that 12 percent of the population was exposed to *Deepwater Horizon* oil and 4 percent of the population was killed. In addition, 5 percent of females likely experienced reproductive failure and 4 percent of the population has experienced adverse health effects. There is insufficient information available to determine whether the total fishery-related mortality and serious injury for these stocks is insignificant and approaching zero mortality and serious injury rate. They are not strategic stocks because it is assumed that the average annual human-related mortality and serious injury does not exceed PBR (Waring et al., 2012).

2.2.5 Rough-Toothed Dolphin

The rough-toothed dolphin (*Steno bredanensis*) is a relatively robust dolphin that can grow to 2.7 m (9 ft) in length (Jefferson et al., 2008). It is characterized by a long, conical head with no demarcation between the melon and beak.

2.2.5.1 Population

The GOM population of rough-toothed dolphin is provisionally being considered one stock for management purposes, although there currently is no information to differentiate this stock from the Atlantic Ocean stock(s) nor is there information on whether more than one stock may exist in the GOM. Additional morphological, genetic, and behavioral data are needed to provide further information on stock delineation (Waring et al., 2013).

2.2.5.2 Distribution and Abundance

The rough-toothed dolphin is distributed within deep tropical and subtropical waters between 40° N. and 35° S. latitude. Records from the Atlantic are mostly from between the southeastern U.S. and southern Brazil (Jefferson, 2002a). In the GOM, rough-toothed dolphins occur in oceanic and, to a lesser extent, continental shelf waters (Fulling et al., 2003; Mullin and Fulling, 2004; Maze-Foley and Mullin, 2006). Rough toothed dolphins were recorded in all seasons during GulfCet aerial surveys of the northern GOM between 1992 and 1998 (Hansen et al., 1996; Mullin and Hoggard, 2000).

The CetMap abundance estimate for northern GOM rough-toothed dolphins is 4,853 individuals (Roberts et al., 2016). From NMFS SAR data, the current population size for the rough-toothed dolphin in the northern GOM is estimated to be 624 individuals (CV = 0.99) (Waring et al., 2012). This estimate is from a summer 2009 oceanic survey covering waters from the 200-m (656-ft) isobath to the seaward extent of the U.S. EEZ. Historically, for surveys conducted in oceanic waters from 2000 to 2001, the estimate was 1,145 individuals (CV = 0.83); and from 2003 to 2004, the estimate was 1,508 individuals (CV = 0.39 (Waring et al., 2012).

2.2.5.3 Habitat

Rough-toothed dolphins prefer deeper areas of tropical and warmer temperate waters, which is where their prey are concentrated (USDOC, NMFS, 2015a; Würsig et al., 2000).

2.2.5.4 Behavior

Rough-toothed dolphins are not known to be fast swimmers, instead skimming the surface at a moderate speed, and they have a distinctive splash (Jefferson, 2002b). Swim speeds of this species vary from 3 to 8.6 kn (3.5 to 10 mph). Rough-toothed dolphins can dive to depths between 30 and 70 m (98 and 230 ft) (Croll et al., 1999). The dive duration ranges from 0.5 to 3.5 minutes (Ritter, 2002). The maximum dive depth recorded was 70 m (230 ft); however, due to their morphology, it is believed that they are capable of diving much deeper. Dives up to 15 minutes have been recorded for groups of dolphins (Croll et al., 1999). Rough-toothed dolphins feed mainly on cephalopods and fish, including large fish like dolphinfish (*Coryphaena hippurus*) (Miyazaki and Perrin, 1994; Reeves et al., 1999; Pitman and Stinchcomb, 2002).

2.2.5.5 Vocalization and Hearing

There are no direct measurements of auditory threshold for the hearing sensitivity of rough-toothed dolphins (Ketten, 2000; Thewissen, 2002); however, Cook et al. (2005) performed auditory tests on 5 of 36 stranded rough-toothed dolphins in Florida. The amplitude modulation rate used in auditory evoked potential (AEP) measurements was 1.5 kHz to determine the evoked-potential hearing thresholds between 5 and 80 kHz. The results of these tests show that the rough-toothed dolphin can hear sounds in this frequency range and most likely can hear frequencies much higher than 80 kHz as well (Cook et al., 2005).

Rough-toothed dolphins produce vocalizations ranging from 0.1 to 200 kHz (Popper, 1980; Miyazaki and Perrin, 1994; Richardson et al., 1995; Yu et al., 2003). Clicks have peak energy at 25 kHz, while whistles have a maximum energy between 2 and 14 kHz (Norris and Evans, 1967; Norris, 1969; Popper, 1980). There are no available data regarding seasonal or geographical variation in the vocalization production of this species.

2.2.5.6 Threats

The commercial fishery that could interact with this stock in the GOM is the Atlantic Ocean, Caribbean, GOM large pelagic longline fishery (Waring et al., 2012). However, there is no reported bycatch from U.S. fisheries, but they are known to take bait in commercial and recreational fisheries in the Hawaiian Islands. Strandings are moderately common; two in the GOM region are thought to be related to fishery interactions. A mass stranding of 62 animals occurred off Marathon, Florida, in March 2005 (USDOC, NMFS, 2015a). Information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessement Trustees, 2016) summarized injuries from the *Deepwater Horizon* oil spill to rough-toothed dolphins and stated that 41 percent of the population was exposed to *Deepwater Horizon* oil and 14 percent of the population was killed as a result. In addition, 15 percent of females likely experienced reproductive failure and 19 percent of the population has experienced adverse health effects.

2.2.5.7 Status

Rough-toothed dolphins are currently classified as data deficient under the IUCN and are protected under the MMPA. The status of rough-toothed dolphins in the northern GOM, relative to OSP, is unknown. The species is not listed as threatened or endangered under the ESA. There are insufficient data to determine the population trends for this species; however, recent information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) suggests that rough-toothed dolphins in the GOM have experienced a population decline (14%) as a result of injury from the *Deepwater Horizon* oil spill. This is not a strategic stock because it is assumed that the average annual human-related mortality and serious injury does not exceed PBR (PBR = 3.1) (Waring et al., 2012).

2.2.6 Common Bottlenose Dolphin

Adult common bottlenose dolphins (*Tursiops truncatus*) are medium-sized dolphins that range in length from 1.9 to 3.8 m (6 to 12 ft), with much variation among populations (Würsig et al., 2000; Jefferson et al., 2008). Male bottlenose dolphins may be somewhat larger than females in some populations (Jefferson et al., 2008). Two genetically distinct geographic varieties (ecotypes) of bottlenose dolphins are known to occur in the western North Atlantic and GOM: a “coastal” ecotype and an “offshore” ecotype (Hersh and Duffield, 1990; LeDuc and Curry, 1998). The coastal ecotype differs from the offshore ecotype mainly in features of the skull associated with feeding, and suggests that it may feed on larger and tougher prey than the offshore ecotype. Other morphological differences may reflect differences in diving behavior and sound production, and may indicate evolutionary adaptation to different physical environments (Perrin et al., 2011). The two bottlenose dolphin ecotypes are genetically distinct according to mitochondrial and nuclear markers (Hoelzel et al., 1998).

2.2.6.1 Population

Bottlenose dolphins inhabiting the northern GOM are currently divided into 37 management stocks (from Waring et al., 2013):

- Northern GOM Oceanic stock;
- Northern GOM Continental Shelf stock;

- GOM Coastal stocks (comprising 3 individual stocks); and
- Northern GOM Bay, Sound, and Estuary Stocks (comprising 32 individual stocks).

Details of each stock or stock group, including their distribution in the GOM, are described in the following subsections.

Northern GOM Oceanic Stock

The Northern GOM Oceanic stock encompasses the waters from the 200-m (656-ft) isobath to the seaward extent of the U.S. EEZ. This stock is considered separate from Atlantic Ocean stocks of bottlenose dolphins for management purposes. The Northern GOM Oceanic stock is thought to be composed entirely of individuals of the “offshore” ecotype.

Northern GOM Continental Shelf Stock

The Northern GOM Continental Shelf stock of bottlenose dolphins inhabits waters from 20 to 200 m (66 to 656 ft) deep from the U.S.-Mexico border to the Florida Keys. This stock probably includes a mixture of both coastal and offshore ecotypes. It is believed that Bay, Sound, and Estuary stocks; Coastal stocks; and the Oceanic stock are separate from the Continental Shelf stock. However, the Continental Shelf stock may overlap with the other stocks in some areas and so may be genetically indistinguishable (Sellas et al., 2005).

GOM Coastal Stocks

Bottlenose dolphins inhabiting northern GOM coastal waters (defined as water depths <20 m [66 ft]) have been divided for management purposes into the following three separate stocks:

- Eastern Coastal stock – Florida coastal waters from 84° W. longitude to Key West;
- Northern Coastal stock – coastal waters from 84° W. longitude (Florida) to the Mississippi River Delta (Louisiana); and
- Western Coastal stock – Mississippi River Delta (Louisiana) to the Texas-Mexico border.

It is assumed that the dolphins occupying GOM coastal habitats with dissimilar climatic, coastal, and oceanographic characteristics may be restricted in their movements between these habitats, and so constitute separate stocks. Portions of the three coastal stocks may also occur with the Northern GOM Continental Shelf stock and Bay, Sound, and Estuary stocks. The seaward boundary for GOM Coastal stocks (the 20-m [66-ft] isobath) generally corresponds to historical survey strata (Scott, 1990; Blaylock and Hoggard, 1994; Fulling et al., 2003) and so represents a management boundary rather than an actual ecological boundary for these stocks. The GOM Coastal stocks may include coastal and offshore ecotypes of bottlenose dolphins.

Northern GOM Bay, Sound, and Estuary Stocks

Distinct stocks of bottlenose dolphins are currently identified in 32 areas of contiguous, enclosed, or semi-enclosed bodies of water adjacent to the northern GOM, based on descriptions of relatively discrete dolphin “communities” in some of these areas. A “community” in this case has been defined by the NMFS as a group of resident dolphins that regularly share large portions of their ranges, exhibit similar distinct genetic profiles, and interact with each other to a much greater extent than with dolphins in adjacent waters (Waring et al., 2013). The geographic nature of these areas and long-term stability of residency patterns suggest that many of these communities exist as functioning units and under the MMPA are being maintained as separate management stocks. The Northern GOM Bay, Sound, and Estuary stocks are listed in **Table 4.2 2** of this Programmatic EIS. The relative distributions of the 32 stocks, as referenced to NMFS’ Southeast Fisheries Science Center logistical aerial survey areas, are shown in **Figure 4.2-4** of this Programmatic EIS.

2.2.6.2 Distribution and Abundance

The common bottlenose dolphin is distributed worldwide in tropical and temperate waters, mostly between 50° S. to 45° N. latitude (Croll et al., 1999). It is the most widespread and common cetacean species in coastal waters of the GOM. During GulfCet surveys, bottlenose dolphins were, in almost all cases, sighted in areas with water depths <1,000 m (3,280 ft) (Würsig et al., 2000). Common bottlenose dolphins in the northern GOM are divided into 37 separate stocks. Details of each stock, including their relative distributions in the northern GOM, are discussed below.

The CetMap abundance estimate for all northern GOM bottlenose dolphin stocks is 138,602 individuals (Roberts et al., 2016). From NMFS SAR data, estimates of abundance for each separate stock are presented in **Table 4.2 2** of this Programmatic EIS.

2.2.6.3 Habitat

Common bottlenose dolphins are found in temperate and tropical waters around the world. There are coastal populations that migrate into bays, estuaries, and river mouths as well as offshore populations that inhabit pelagic waters along the continental shelf (USDOC, NMFS, 2015a).

2.2.6.4 Behavior

In the GOM, common bottlenose dolphins show seasonal and diel patterns in their behavior, such as feeding, socializing, and traveling. During the summer months, they feed primarily during the morning and for a short time in the afternoon. Social behaviors increase as feeding decreases, with socializing peaking in the afternoon. In the fall, they feed throughout the day and spend less time socializing and traveling (Bräger, 1993). Bottlenose dolphins feed primarily on fish in the summer and on cephalopods and crustaceans in the winter (Bräger, 1993). The diet of the bottlenose dolphin is diverse, as they are opportunistic feeders, and ranges from various fishes (with a preference for sciaenids, scombrids, and mugilids), cephalopods, and shrimp (Wells and Scott, 1999 and 2002).

Different age classes and sexes may feed in different localities. Lactating females and calves have been reported foraging in the nearshore zone, while adolescents feed farther offshore. Male adults and females without young may feed still farther offshore (Wells and Scott, 2002). Bottlenose dolphins appear to be active during the day and at night. Their activities are influenced by the season, time of day, tidal state, and physiological factors such as reproductive seasonality (Wells and Scott, 2002). Bottlenose dolphins also have recurrent feeding behaviors in the northern GOM. They are known to feed on fishes dumped from the decks of shrimp boats; herd schools of fishes by encircling and charging; crowd small fishes onto shoals or banks and then drive the fish onto shore, sliding on the banks to retrieve them; and feed individually (Würsig et al., 2000).

Bottlenose dolphins can sustain swimming speeds between 2 and 11 kn (2.3 and 12.7 mph). Speeds commonly range from 4 to 6 kn (4.6 to 6.9 mph) and may reach speeds as high as 16 kn (18.4 mph) for 7.5 seconds (Croll et al., 1999). Dive times range from 38 seconds to 1.2 minutes, but they have been known to last as long as 10 minutes (Mate et al., 1995; Croll et al., 1999). The dive depth of a bottlenose dolphin in Tampa Bay was measured at 98 m (322 ft) (Mate et al., 1995). The deepest dive recorded for a bottlenose dolphin is 535 m (1,755 ft), reached by a trained individual (Ridgway, 1986).

2.2.6.5 Vocalizations and Hearing

Common bottlenose dolphins are known to use active echolocation and to listen for the sounds that their prey produce, which is called “passive listening” (Barros and Myrberg, 1987; Gannon et al., 2005). Bottlenose dolphins hear underwater sounds in the range of 150 Hz to 135 kHz (Johnson, 1967; Ljungblad et al., 1982). Their best underwater hearing occurs at 15 kHz, where the threshold level range is 42 to 52 dB (Sauerland and Dehnhardt, 1998). Bottlenose dolphins also have good sound location abilities and are most sensitive when sounds arrive from the front (Richardson et al., 1995).

Bottlenose dolphins produce vocalizations as low as 0.05 kHz and as high as 150 kHz with dominant frequencies at 0.3 to 14.5 kHz, 25 to 30 kHz, and 95 to 130 kHz (Johnson, 1967; Popper, 1980; McCowan and Reiss, 1995; Schultz et al., 1995; Croll et al., 1999; Oswald et al., 2003). The maximum SL is 228 dB re 1 μPa at 1 m (Croll et al., 1999). Bottlenose dolphins produce a variety of whistles, echolocation clicks, and burst-pulse sounds. Echolocation clicks with peak frequencies from 40 to 130 kHz are hypothesized to be used in navigation, foraging, and predator detection (Au, 1993; Houser et al., 1999 and 2004; Jones and Sayigh, 2002). According to Au (1993), sonar clicks are broadband, ranging in frequency from a few kHz to >150 kHz, with a 3-dB bandwidth of 30 to 60 kHz (Croll et al., 1999). The echolocation signals usually have a 50- to 100-μs duration with peak frequencies ranging from 30 to 100 kHz and fractional bandwidths between 10 and 90 percent of the peak frequency (Houser et al., 1999). Electrophysiological experiments with bottlenose dolphins suggest that their brain has a dual analysis system: one specializing in ultrasonic clicks and the other for lower frequency sounds like whistles (Ridgway, 2000).

Burst-pulses, or squawks, are commonly produced during social interactions. These sounds are broadband vocalizations that consist of rapid sequences of clicks with inter-click intervals of <5 ms. Burst-pulse sounds typically are used during escalations of aggression. Each individual bottlenose dolphin has a fixed unique FM pattern, or contour whistle, called a signature whistle. These signal types have been well studied and are presumably used for recognition, but they may have other social contexts (Frankel, 2002; Sayigh, 2002). Up to 52 percent of whistles produced by mother calf pairs in the group can be classified as signature whistles (U.S. Department of the Navy, 2007). Stereotypically, signature whistles have a narrow-band sound with the frequency between 4 and 20 kHz, duration between 0.1 and 3.6 seconds, and an SL of 125 to 140 dB re 1 μPa at 1 m (Croll et al., 1999).

McCowan et al. (1999) discussed bottlenose dolphins and their structure and organization of communication mathematically. Zipf's law is applied, which examines the first-order entropic relation and evaluates the signal composition of a repertoire by examining the frequency of use of signals in a relationship to their ranks. It measures the potential capacity for information transfer at the repertoire level by examining the optimal amount of diversity and redundancy necessary for communication transfer across a noisy channel. The results from this experiment suggest that Zipf's statistic can be applied to animal vocal repertoires, in this case dolphin whistle repertoires, and their development. Zipf's statistic may be an important comparative measure of repertoire complexity, both interspecies, and as an indicator for vocal acquisition or learning of vocal repertoire structure within a species. The results also suggest that dolphin whistles contain some higher-order internal structure, enough to begin to predict statistically what whistle types might immediately follow the same or another whistle type. A greater knowledge of the higher-order entropic structures could allow the reconstruction of dolphins' whistle sequence structure, independent of additional data inputs such as actions and non-vocal signaling (McCowan et al., 1999).

In contrast to the signature whistle theory, McCowan and Reiss (2001) stated that predominant whistle types produced by isolated dolphins were the same whistle types that were predominant for all adult subjects and for infant subjects by the end of their first year in socially interactive and separation contexts. No evidence for individually distinctive signature whistle contours was found in the bottlenose dolphins studied. Ten of 12 individuals produced one shared whistle type as their most predominant whistle during contexts of isolation. The two other individuals produced two other predominant whistle types that could not be considered signature whistles because both whistle types were shared among many different individuals within and across independent captive social groups (McCowan and Reiss, 2001).

Jones and Sayigh (2002) reported geographic variations in behavior and in the rates of vocal production. Whistles and echolocation varied between Southport, North Carolina; the Wilmington North Carolina Intracoastal Waterway; the Wilmington, North Carolina coastline; and Sarasota, Florida. Dolphins at the Southport site whistled more than the dolphins at the Wilmington site, who whistled more than the dolphins at the Intracoastal Waterway site, who whistled more than the dolphins at the Sarasota site. Echolocation production was higher at the Intracoastal Waterway site than all of the other sites. Dolphins in all three North Carolina sites spent more time in large groups than the dolphins at the Sarasota site. Echolocation occurred most often when dolphins were socializing (Jones and Sayigh, 2002).

2.2.6.6 Threats

Worldwide, threats to bottlenose dolphins include incidental injury and mortality from fishing gear such as gillnets, seines, and trawls and from longline commercial and recreational operations; exposure to pollutants and biotoxins; viral outbreaks; and direct harvest in Japan and Taiwan (USDOC, NMFS, 2015a). According to Waring et al. (2012), the commercial fisheries that could interact with bottlenose dolphins in the GOM are listed by management stock group:

- Northern GOM Bay, Sound, and Estuary stocks: shrimp trawl, blue crab trap/pot, stone crab trap/pot, menhaden purse seine, gillnet, and Atlantic Ocean commercial passenger fishing vessel (hook and line) fisheries;
- Northern GOM Continental Shelf stock: Southeastern U.S. Atlantic, GOM shark bottom longline fishery; Southeastern U.S. Atlantic, GOM shrimp trawl fishery; Southeastern U.S. Atlantic, GOM, Caribbean snapper-grouper and other reef fish fishery; and the GOM butterfish trawl fishery;
- Eastern, Northern, and Western Coastal stocks: shark bottom longline, shrimp trawl, blue crab trap/pot, stone crab trap/pot, spiny lobster trap/pot, and Atlantic Ocean commercial passenger fishing vessel (hook-and-line) fisheries; and
- Northern GOM Oceanic stock: Atlantic Ocean, Caribbean, GOM large pelagic longline fishery; and the GOM butterfish trawl fishery.

The Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) identified 13 GOM stocks (i.e., 9 BSE stocks, 2 coastal stocks, 1 shelf stock, and 1 oceanic stock) that were found in areas within the *Deepwater Horizon* oil-spill footprint.

2.2.6.7 Status

The bottlenose dolphin is classified as data deficient by the IUCN and is protected under the MMPA. The Northern GOM Oceanic, Northern GOM Continental Shelf, and the Eastern Coastal stocks are classified as non-strategic. The Western and Northern Coastal stocks of bottlenose dolphins currently are classified as strategic due to the ongoing UME that began on February 1, 2010. The NMFS considers each of these stocks to be strategic because most of the stock sizes are currently unknown but likely small, so relatively few mortalities and serious injuries would exceed PBR. The stocks also are considered strategic because stock areas in Louisiana, Mississippi, Alabama, and the western Florida Panhandle have been impacted by the aforementioned UME (Waring et al., 2013). In addition to the UME, bottlenose dolphins in the GOM (13 of 37 stocks) were negatively impacted by the *Deepwater Horizon* oil spill. Impacts included increased mortality, increased reproductive failure, and adverse health effects. Information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) summarizes injuries (refer to **Table 4.9-12**) for marine mammal stocks affected by the spill. It builds from the measured injuries in Barataria Bay and Mississippi Sound bottlenose dolphins to other BSE stocks of bottlenose dolphins, and then to the coastal and oceanic stocks of bottlenose dolphins (and other cetacean species) within the *Deepwater Horizon* oil-spill footprint. Depending on the stock, up to 59 percent of the population was killed, 46 percent of females likely experienced reproductive failure, and 37 percent of the population has experienced adverse health effects.

The current PBR estimates for the Northern GOM stocks of bottlenose dolphins are listed in **Table 4.2-2** of this Programmatic EIS.

2.2.7 Pantropical Spotted Dolphin

The pantropical spotted dolphin (*Stenella attenuata*) varies significantly in size and coloration throughout its range. There is one species recognized in the GOM and Northern Atlantic Ocean. One subspecies (*S. a. graffmani*) is recognized and occurs only in coastal waters of the eastern tropical Pacific. Adults range in length from 1.6 to 2.4 m (5.2 to 7.9 ft).

2.2.7.1 Population

The GOM population of pantropical spotted dolphins is provisionally being considered a separate stock for management purposes; however, there currently is no information to differentiate this stock from the Atlantic Ocean stock(s). Additional morphological, genetic, and behavioral data are needed to provide further information on stock delineation (Waring et al., 2013).

2.2.7.2 Distribution and Abundance

Pantropical spotted dolphins are primarily distributed within offshore (oceanic) tropical zones. It is the most common cetacean within deep GOM waters, with most sightings between the 100- and 2,000-m (328- and 6,562-ft) depth contours (Würsig et al., 2000). During the GulfCet surveys, average group sizes of 46.2 and 55.1 individuals were estimated from ship and aircraft, respectively (Davis and Fargion, 1996). Seasonally, pantropical spotted dolphin densities peaked during spring and were lowest during fall.

The CetMap abundance estimate for northern GOM pantropical spotted dolphins is 84,014 individuals (Roberts et al., 2016). From NMFS SAR data, the best abundance estimate available for northern GOM pantropical spotted dolphins is 50,880 individuals (Waring et al., 2013). This estimate is from a summer 2009 oceanic survey covering waters from the 200-m (656-ft) isobath to the seaward extent of the U.S. EEZ. Historically, for surveys conducted in oceanic waters from 1991 to 1994, the estimate was 31,320 individuals (CV = 0.20); from 1996 to 2001 (excluding 1998), the estimate was 91,321 individuals (CV = 0.16); and from 2003 to 2004, the estimate was 34,067 individuals (CV = 0.18) (Waring et al., 2012).

2.2.7.3 Habitat

Pantropical spotted dolphins spend the majority of the daytime in shallower water between 90 and 300 m (295 and 984 ft) deep. At night, they dive into deeper waters to search for prey (USDOC, NMFS, 2015a).

2.2.7.4 Behavior

Pantropical spotted dolphins commonly are observed in large groups of up to thousands of individuals. Groups may segregate according to sex and age. They are fast swimmers and often engage in acrobatics (Jefferson et al., 2008). Pantropical spotted dolphins feed primarily on small epipelagic and mesopelagic fishes, squids, and crustaceans that associate with deep scattering layers.

2.2.7.5 Vocalizations and Hearing

Pantropical spotted dolphins produce sounds that range from 0.1 to 160 kHz (Richardson et al., 1995). As a group, Stenella are classified within the mid-frequency cetacean functional marine mammal hearing group (150 Hz to 160 kHz) (Southall et al., 2007). There is no direct measurement of auditory threshold for the hearing sensitivity of the pantropical spotted dolphin.

The results of a study on pantropical spotted (and spinner) dolphins conducted by Lammers et al. (2003) revealed that the whistles and burst pulses of the two species span a broader frequency range than traditionally reported for delphinids. The fundamental frequency contours of whistles occur in the human hearing range, but the harmonics typically reach 50 kHz and beyond. Pantropical spotted dolphin whistles range in frequency from 3.1 to 21.4 kHz (Thomson and Richardson, 1995). Clicks typically are bimodal, meaning they have two frequency peaks, one at 40 to 60 kHz and another at 120 to 140 kHz, with an estimated SL of up to 220 dB re 1 μPa at 1 m (peak-peak) (Schotten et al., 2004).

There are no available data regarding seasonal variation in the sound production of Stenella dolphins, although geographic variation is evident. SLs as high as 210 dB re 1 μPa at 1 m (peak-peak) have been measured for echolocation clicks (Au et al., 1998; Au and Herzing, 2003).

2.2.7.6 Threats

Stocks of pantropical spotted dolphins have been the targets of the tuna purse seine fishery within the eastern tropical Pacific that uses the dolphins' locations to find tuna. Many dolphins used to be caught in the nets and drowned. Currently, fishing methods for tuna imported into the U.S. under the Dolphin Safe program do not allow such destructive fishing practices. The commercial fishery that could interact with this stock in the GOM is the Atlantic Ocean, Caribbean, GOM large pelagic longline fishery (Waring et al., 2012). Interactions with tourists are a growing issue for the Hawaiian stock (USDOC, NMFS, 2015a). Information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) summarized injuries from the *Deepwater Horizon* spill to pantropical dolphins and stated that 20 percent of the population was exposed to *Deepwater Horizon* oil and 7 percent of the population was killed as a result. In addition, 9 percent of females likely experienced reproductive failure and 7 percent of the population has experienced adverse health effects.

2.2.7.7 Status

The GOM population of pantropical spotted dolphins is provisionally considered a separate stock (Northern GOM stock) for management purposes; however, there currently is no information to differentiate this stock from the Atlantic Ocean stock(s). The status of pantropical spotted dolphins in the northern GOM is unknown. The species is not listed as threatened or endangered under the ESA, and there are insufficient data to determine the population trends for this stoc; however, recent information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) suggests that pantropical dolphins in the GOM have experienced a population decline (7%) as a result of injury from the *Deepwater Horizon* oil spill. It is not a strategic stock because it is assumed that the average annual human-related mortality and serious injury does not exceed PBR. The current PBR for the Northern GOM stock of pantropical spotted dolphins is 407 individuals (Waring et al., 2013).

2.2.8 Clymene Dolphin

The Clymene dolphin (*Stenella clymene*) is the smallest member of the genus Stenella. Adult individuals are known to reach 2.0 m (6.5 ft) (males) and 1.9 m (6.2 ft) (females) in length.

2.2.8.1 Population

The GOM population is provisionally being considered a separate stock for management purposes; however, there currently is no information to differentiate this stock from the Atlantic stock. Additional morphological, genetic, and behavioral data are needed to provide further information on stock delineation (Waring et al., 2013).

2.2.8.2 Distribution and Abundance

The Clymene dolphin is restricted to tropical and warm temperate waters of the Atlantic Ocean, including the Caribbean Sea and GOM. It is a deepwater oceanic species and is considered relatively common in oceanic waters (Würsig et al., 2000; Jefferson, 2002b; Jefferson et al., 2008). Clymene dolphins were sighted offshore Louisiana in every season during the GulfCet surveys. Sightings made during these surveys occurred almost exclusively beyond the 100-m (328-ft) isobath.

The CetMap abundance estimate for northern GOM Clymene dolphins is 11,000 individuals (Roberts et al., 2016). From NMFS SAR data, the best abundance estimate available for northern GOM Clymene dolphins is 129 individuals (Waring et al., 2013). This estimate is from a summer 2009 oceanic survey covering waters from the 200-m (656-ft) isobath to the seaward extent of the U.S. EEZ. Historically, for surveys conducted in oceanic waters from 1991 to 1994, the estimate was 5,571 individuals (CV = 0.37); from 1996 to 2001 (excluding 1998), the estimate was

17,355 individuals (CV = 0.65); and from 2003 to 2004, the estimate was 6,575 individuals (CV = 6.0) (Waring et al., 2012).

2.2.8.3 Habitat

Clymene dolphins prefer deep tropical, subtropical, and warm temperate waters in the Atlantic Ocean, including the GOM. This species generally occurs in oceanic waters in depths of 250 to 5,000 m (820 to 16,400 ft).

2.2.8.4 Behavior

Clymene dolphins commonly are observed in groups of 60 to 80 individuals within the GOM. These groups often appear to be segregated by age group and sex, and they often occur with other cetacean species such as spinner dolphins. Very little is known about the ecology of Clymene dolphins. Based on few examinations of stomach contents, the species feeds mostly on mesopelagic fishes and squids, presumably at night (Jefferson et al., 2008).

2.2.8.5 Vocalizations and Hearing

Stenella species produce sounds that range from 0.1 to 160 kHz (Richardson et al., 1995). As a group, Stenella species are classified within the mid-frequency cetacean functional marine mammal hearing group (150 Hz to 160 kHz) (Southall et al., 2007). There is no direct measurement of auditory threshold for the hearing sensitivity of the Stenella dolphins, except for striped dolphins (Ketten, 2000; Thewissen, 2002). There are very little data on Clymene dolphin acoustics and hearing. Their whistles generally are higher in frequency, ranging from approximately 6.3 to 19.2 kHz (Mullin et al., 1994). Striped dolphin (also a Stenella species) whistles range from 6 to >24 kHz, with dominant frequencies ranging from 8 to 12.5 kHz (Thomson and Richardson, 1995). There are no available data regarding seasonal variation in the sound production of Stenella dolphins, although geographic variation is evident. The SLs as high as 210 dB re 1 μPa at 1 m (peak-peak) have been measured for echolocation clicks (Au et al., 1998; Au and Herzing, 2003).

2.2.8.6 Threats

Throughout their range, threats to Clymene dolphins include incidental take (as bycatch) in fisheries such as gillnets in Venezuela and possibly tuna purse seine nets off the coast of West Africa, and harvesting by artisan whalers using harpoons in the Caribbean Sea. The commercial fishery that could interact with this stock in the GOM is the Atlantic Ocean, Caribbean, GOM large pelagic longline fishery (Waring et al., 2013). Information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) summarized injuries from the *Deepwater Horizon* oil spill to Clymene dolphins and stated that 7 percent of the population was exposed to *Deepwater Horizon* oil and 2 percent of the population was killed as a result. In addition, 3 percent of females likely experienced reproductive failure and 3 percent of the population has experienced adverse health effects.

2.2.8.7 Status

The GOM population is considered a separate stock (Northern GOM stock) for management purposes; however, there currently is no information to differentiate this stock from the Atlantic Ocean stock(s). The status of Clymene dolphins in the northern GOM is unknown. The species is not listed as threatened or endangered under the ESA, and there are insufficient data to determine species population trends; however, recent information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) suggests that clymene dolphins in the GOM have experienced a population decline (2%) as a result of injury from the *Deepwater Horizon* oil spill. It is not a strategic stock because average annual human-related mortality and serious injury does not exceed PBR. The current PBR for the Northern GOM stock of Clymene dolphins is 0.6 individuals (Waring et al., 2013).

2.2.9 Striped Dolphin

Striped dolphins (*Stenella coeruleoalba*) are similar in general body shape to other small oceanic dolphins but are easily distinguished by their robust body and coloration (Archer, 2002). Average body length is 2.5 m (8.2 ft) for males and 2 m (6.6 ft) for females, but there is geographical variation in adults from different populations (Jefferson et al., 2008).

2.2.9.1 Population

The GOM population is provisionally being considered a separate stock for management purposes; however, there currently is no information to differentiate this stock from the Atlantic Ocean stock(s). Additional morphological, genetic, and behavioral data are needed to provide further information on stock delineation (Waring et al., 2013).

2.2.9.2 Distribution and Abundance

Striped dolphins are widely distributed, ranging from tropical to cool temperate waters within the Atlantic, Pacific, and Indian Oceans. They are restricted to oceanic regions and are commonly associated with convergence zones and regions of upwelling (Archer, 2002). Sightings of these animals in the northern GOM also occur in oceanic waters (Mullin and Fulling, 2004; Maze-Foley and Mullin, 2006). Striped dolphins were seen in all seasons during GulfCet aerial surveys of the northern GOM between 1992 and 1998 (Hansen et al., 1996; Mullin and Hoggard, 2000).

The CetMap abundance estimate for northern GOM striped dolphins is 4,914 individuals (Roberts et al., 2016). From NMFS SAR data, the best abundance estimate available for northern GOM striped dolphins is 1,849 individuals (Waring et al., 2013). This estimate is from a summer 2009 oceanic survey covering waters from the 200-m (656-ft) isobath to the seaward extent of the U.S. EEZ. Historically, for surveys conducted in oceanic waters from 1991 to 1994, the estimate was 4,858 individuals (CV = 0.44); from 1996 to 2001 (excluding 1998), the estimate was 6,505 individuals (CV = 0.43); and from 2003 to 2004, the estimate was 3,325 individuals (CV = 0.48) (Waring et al., 2012).

2.2.9.3 Habitat

Striped dolphins prefer highly productive tropical to warm temperate (10°C to 26°C [52°F to 84°F]) deep oceanic waters. These dolphins often are linked to upwelling areas and convergence zones (USDOC, NMFS, 2015a).

2.2.9.4 Behavior

Striped dolphins usually are observed in groups of 10 to 30 individuals but may be seen in aggregations of up to 500 individuals. As with other oceanic dolphins, these groups may be segregated by age and sex, with individuals moving between groups. Striped dolphins perform a variety of aerial behaviors (Archer, 2002). Striped dolphins feed on a variety of pelagic and benthopelagic fishes (e.g., lanternfish and cod) as well as squids at depths of 200 to 700 m (656 to 2,297 ft) (Jefferson et al., 2008).

2.2.9.5 Vocalizations and Hearing

Stenella produce sounds that range in frequency from 0.1 to 160 kHz (Richardson et al., 1995). Striped dolphin whistles range from 6 to >24 kHz, with dominant frequencies ranging from 8 to 12.5 kHz (Thomson and Richardson, 1995). As a group, Stenella are classified within the mid-frequency cetacean functional marine mammal hearing group (150 Hz to 160 kHz) (Southall et al., 2007). Based on ABRs, striped dolphins hear sounds ≥120 dB in the range of <10 to >100 kHz (Popper, 1980). The behavioral audiogram developed by Kastelein et al. (2003) shows hearing capabilities from 0.5 to 160 kHz. The best underwater hearing of the species appears to be from 29 to 123 kHz (Kastelein, et al., 2003). Striped dolphins have relatively less hearing sensitivity below 32 kHz and above 120 kHz. There are no available data regarding seasonal variation in the sound production of Stenella dolphins, although geographic variation is evident. SLs as high as 210 dB re 1 µPa at 1 m (peak-peak) have been measured for echolocation clicks (Au et al., 1998; Au and Herzing, 2003).

2.2.9.6 Threats

Striped dolphins are taken as bycatch or interact with several fisheries such as in pelagic trawls, gillnets, driftnets, purse seine nets, and hand harpoons. They have been subjected to drive hunts in Japan and taken in the Caribbean and Sri Lanka. During the mid-20th century, it is estimated that as many as 21,000 striped dolphins were caught and killed each year. The commercial fishery that could interact with this stock in the GOM is the Atlantic Ocean, Caribbean, GOM large pelagic longline fishery (Waring et al., 2013). Information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) summarized injuries from the *Deepwater Horizon* oil spill to striped dolphins and stated that 13 percent of the population was exposed to *Deepwater Horizon* oil and 5 percent of the population was killed as a result. In addition, 6 percent of females likely experienced reproductive failure and 5 percent of the population has experienced adverse health effects.

2.2.9.7 Status

The GOM population is considered a separate stock (Northern GOM stock) for management purposes; however, there currently is no information to differentiate this stock from the Atlantic Ocean stock(s). The status of striped dolphins in the northern GOM is unknown. The species is not listed as threatened or endangered under the ESA, and there are insufficient data to determine the population trends for this species; however, recent information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) suggests that striped dolphins in the GOM have experienced a population decline (5%) as a result of injury from the *Deepwater Horizon* oil spill. It is not a strategic stock because average annual human-related mortality and serious injury does not exceed PBR. The current PBR for the Northern GOM stock of striped dolphins is 10 individuals (Waring et al., 2013).

2.2.10 Atlantic Spotted Dolphin

The Atlantic spotted dolphin (*Stenella frontalis*) is highly variable geographically, leading to much taxonomic confusion and misidentification of individuals (Perrin et al., 1994a). There is significant variability in osteological characteristics and color patterns in this species (Jefferson et al., 2008). Adults range from 1.7 to 2.3 m (5.6 to 7.5 ft) in length (Perrin, 2002a).

2.2.10.1 Population

The GOM population is being considered a separate stock for management purposes. Adams and Rosel (2005) presented strong genetic support for differentiation between GOM and western North Atlantic management stocks using mitochondrial and nuclear markers. However, this study did not test for further population subdivision within the GOM (Waring et al., 2013).

2.2.10.2 Distribution and Abundance

The Atlantic spotted dolphin is endemic and common in tropical and temperate waters of the Atlantic Ocean. In the western Atlantic, they generally occur on the OCS and upper continental slope, usually between the 20- to 200-m (66- to 656-ft) depth contours (Jefferson et al., 2008). This species may conduct seasonal nearshore-offshore movements in response to the availability of prey species (Würsig et al., 2000). During GulfCet surveys, Atlantic spotted dolphins were sighted near the 100-m (328-ft) isobath, throughout the length of the survey area and during all seasons (Davis and Fargion, 1996). The current population size for the Atlantic spotted dolphin in the northern GOM is unknown (survey data are >8 years old).

The CetMap abundance estimate for northern GOM Atlantic spotted dolphins is 47,488 individuals (Roberts et al., 2016). From NMFS SAR data, the most recent best abundance estimate for the Atlantic spotted dolphin in the northern GOM is 37,611 individuals, which is a combined estimate of abundance for animals sighted in OCS (fall surveys, 2000-2001) and oceanic waters (spring and summer surveys, 2003-2004) (Waring et al., 2013). Historically, for surveys conducted in OCS waters from 2000 to 2001, the estimate was 37,611 individuals (CV = 0.28) and for surveys conducted in oceanic waters from 2003 to 2004, the estimate was 0 (CV = n/a) (Waring et al., 2013).

2.2.10.3 Habitat

Atlantic spotted dolphins prefer the tropical to warm temperate waters along the continental shelf of the Atlantic Ocean, occurring in water depths of 20 to 250 m (66 to 820 ft), but occasionally can be found in deeper oceanic waters (USDOC, NMFS, 2015a).

2.2.10.4 Behavior

Atlantic spotted dolphins have been observed in small to moderate-sized groups of <50 individuals (Jefferson et al., 2008). These groups may be segregated by age and sex (Perrin, 2002a). They may interact with bottlenose dolphins, sometimes aggressively (Jefferson et al., 2008). Atlantic spotted dolphins feed on a variety of epipelagic and mesopelagic fishes and squids as well as benthic invertebrates. They forage at depths between 40 and 60 m (131 and 197 ft), but most time is spent at depths <10 m (33 ft) (Perrin, 2002a).

2.2.10.5 Vocalizations and Hearing

Stenella produce sounds that range from 0.1 to 160 kHz (Richardson et al., 1995). As a group, Stenella are classified within the mid-frequency cetacean functional marine mammal hearing group (150 Hz to 160 kHz) (Southall et al., 2007). There is no direct measurement of auditory threshold for the hearing sensitivity of the Stenella dolphins, except for striped dolphins (Ketten, 2000; Thewissen, 2002). Atlantic spotted dolphins produce a variety of sounds, including whistles, whistle-squawks, buzzes, burst pulses, synch pulses, barks, screams, squawks, tail slaps, and echolocation clicks. Like other odontocetes, they produce broadband, short-duration echolocation signals. Most of these signals have a bimodal frequency distribution. They project relatively high-amplitude signals with a maximum SL of approximately 223 dB re 1 μPa at 1 m (Au and Herzing, 2003). Their broadband clicks have peak frequencies between 60 and 120 kHz. Atlantic spotted dolphins produce whistles with frequencies below 20 kHz, with multiple harmonics extending to approximately 100 kHz (Lammers et al., 2003). Burst pulses consist of frequencies above 20 kHz (Lammers et al., 2003). Many of the vocalizations from Atlantic spotted dolphins have been associated with foraging behavior (Herzing, 1996). Thomson and Richardson (1995) reported that squawks, barks, growls, and chirps typically range from 0.1 to 8 kHz. Echolocation clicks have two dominant frequency ranges, one at 40 to 50 kHz and the other at 110 to 130 kHz, depending on the SL (lower SLs typically correspond to lower frequencies, and vice versa) (Au and Herzing, 2003). There are no available data regarding seasonal variation in the sound production of Stenella dolphins, although geographic variation is evident. SLs as high as 210 dB re 1 μPa at 1 m (peak peak) have been measured for echolocation clicks (Au et al., 1998; Au and Herzing, 2003).

2.2.10.6 Threats

Throughout their range, Atlantic spotted dolphins have been incidentally taken as bycatch in fisheries using gillnets and purse seines. This species has been observed interacting with various fishing vessels, often following vessels and feeding on discarded catch. The commercial fisheries that could interact with this stock in the GOM are the Atlantic Ocean, Caribbean, GOM large pelagic longline fishery and the Southeastern U.S. Atlantic/GOM shrimp trawl fishery (Waring et al., 2013). A few Atlantic spotted dolphins have been harpooned in the Caribbean, South America (e.g., Brazil), West Africa, and other offshore islands for food and bait. Information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) summarized injuries from the *Deepwater Horizon* oil spill to "continental shelf" dolphins, which included both Atlantic spotted and shelf bottlenose dolphins. It stated that 13 percent of the population was exposed to *Deepwater Horizon* oil and 4 percent of the population was killed as a result. In addition, 6 percent of females likely experienced reproductive failure and 5 percent of the population has experienced adverse health effects.

2.2.10.7 Status

The GOM population of Atlantic spotted dolphins is considered a separate stock (Northern GOM stock) for management purposes. Adams and Rosel (2005) presented strong genetic support for differentiation between GOM and Western North Atlantic management stocks using mitochondrial and nuclear markers but did not test for further population subdivision within the GOM. The status of Atlantic spotted dolphins in the northern GOM is unknown. The species is not listed as threatened or endangered under the ESA, and there are insufficient data to determine population trends for this species; however, recent information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) suggests that continental shelf dolphins (this includes Atlantic spotted) in the GOM have experienced a population decline (4%) as a result of injury from the *Deepwater Horizon* oil spill. It is not a strategic stock because previous estimates of population size have been large compared to the number of cases of documented human-related mortality and serious injury. The current PBR for the Northern GOM stock of striped dolphins is 10 individuals (Waring et al., 2013).

2.2.11 Spinner Dolphin

Like other dolphins of the genus Stenella, spinner dolphins (*Stenella longirostris*) are relatively small. Adults range in length between 1.4 and 2.0 m (4.6 and 6.6 ft) (females) and 1.6 and 2.1 m (5.2 and 6.9 ft) (males) (Jefferson et al., 2008). They weigh approximately 59 to 77 kg (130 to 170 lb) at adulthood. They have long, slender beaks, and there is a lot of color variation based on region (USDOC, NMFS, 2015a).

2.2.11.1 Population

There are four recognized subspecies of spinner dolphins: *S. l. longirostris* (Gray's spinner dolphin); *S. l. orientalis* (eastern spinner dolphin); *S. l. centroamericana* (Central American spinner dolphin); and *S. l. roseiventris* (dwarf spinner dolphin) (Committee on Taxonomy, 2013). The Gray's spinner dolphin is the typical form of spinner dolphin that is found in most areas of the world, including the GOM. The GOM population is provisionally being considered a separate stock for management purposes; however, there currently is no information to differentiate this stock from the

Atlantic Ocean stock(s). Additional morphological, genetic, and behavioral data are needed to provide further information on stock delineation (Waring et al., 2013).

2.2.11.2 Distribution and Abundance

Spinner dolphins are distributed worldwide in tropical to temperate oceanic waters. Much of their range is oceanic. Sightings of the Gray's spinner dolphin in the northern GOM occur in oceanic waters, generally east of the Mississippi River (Mullin and Fulling, 2004; Maze-Foley and Mullin, 2006). Spinner dolphins were recorded in all seasons during GulfCet aerial surveys of the northern GOM between 1992 and 1998 (Hansen et al., 1996; Mullin and Hoggard, 2000).

The CetMap abundance estimate for northern GOM spinner dolphins is 13,485 individuals (Roberts et al., 2016). From NMFS SAR data, the best abundance estimate available for northern GOM spinner dolphins is 11,441 individuals (Waring et al., 2013). This estimate is from a summer 2009 oceanic survey covering waters from the 200-m (656-ft) isobath to the seaward extent of the U.S. EEZ. Historically, estimates within oceanic waters for 1991 to 1994 was 6,316 individuals (CV = 0.43); from 1996 to 2001 (excluding 1998), the estimate was 11,971 individuals (CV = 0.71); and from 2003 to 2004, the estimate was 1,989 individuals (CV = 0.48) (Waring et al., 2013).

2.2.11.3 Habitat

In most places, spinner dolphins are found in the deep ocean where they likely track prey. The Hawaii population has a more coastal distribution. There, the animals rest in bays and protected areas during the day and then fuse into larger groups at night to feed on fish and squid in deeper water (USDOC, NMFS, 2015a).

2.2.11.4 Behavior

Spinner dolphins are highly gregarious and form groups ranging in size from a few individuals to several thousand (Perrin, 2002b; Jefferson et al., 2008). They commonly school with other cetacean species (Perrin, 2002b). The social organization of these groups is fluid and may be composed of temporary (days or weeks) associations of family units (Perrin, 2002b). Adult males may form groups of approximately 12 individuals; the function of these groups is unknown (Perrin, 2002b). Spinner dolphins are one of the most aerial of all dolphin species. Spinner dolphins feed on small midwater fishes, squids, and crustaceans, usually at night and at depths of 600 m (1,969 ft) or greater (Perrin, 2002b).

2.2.11.5 Vocalizations and Hearing

Stenella produce sounds that range from 0.1 to 160 kHz (Richardson et al., 1995). As a group, Stenella are classified within the mid-frequency cetacean functional marine mammal hearing group (150 Hz to 160 kHz) (Southall et al., 2007). There is no direct measurement of auditory threshold for the hearing sensitivity of the Stenella dolphins, except for striped dolphins (Ketten, 2000; Thewissen, 2002). Spinner dolphins produce burst-pulse calls, echolocation clicks, whistles, and screams (Norris et al., 1994; Bazúa-Durán and Au, 2002). Pulses and whistles have a dominant frequency range of 5 to 60 kHz and 8 to 12 kHz, respectively (U.S. Department of the Navy, 2007). Their whistles range in frequency from 16.9 to 17.9 kHz, with a maximum frequency for the fundamental component of 24.9 kHz (Bazúa Durán and Au, 2002; Lammers et al., 2003). Ketten (1998) stated that clicks from spinner dolphins have a dominant frequency of 60 kHz, and Lammers et al. (2003) reported that burst-pulses are predominantly ultrasonic with little or no energy below 20 kHz. Schotten et al. (2004) reported that spinner dolphin clicks have SLs ranging from 195 to 222 dB re 1 μPa at 1 m. The results of a study on pantropical spotted dolphins and spinner dolphins conducted by Lammers et al. (2003) revealed that the whistles and burst-pulses of the two species span a broader frequency range than traditionally reported for delphinids. The fundamental frequency contours of whistles occur in the human hearing range, but the harmonics typically reach 50 kHz and higher. Pantropical spotted dolphin whistles range in frequency from 3.1 to 21.4 kHz (Thomson and Richardson, 1995). Clicks typically are bimodal, with frequency peaks at 40 to 60 kHz and at 120 to 140 kHz, with an estimated SL of up to 220 dB re 1 μPa at 1 m (peak peak) (Schotten et al., 2004). There are no available data regarding seasonal variation in the sound production of Stenella dolphins, although geographic variation is evident. SLs as high as 210 dB re 1 μPa at 1 m (peak-peak) have been measured for echolocation clicks (Au et al., 1998; Au and Herzing, 2003).

2.2.11.6 Threats

The Eastern Tropical Pacific stock of spinner dolphins has been used by the purse seine fishery to locate tuna. Dolphins can become trapped in the nets and drown. Stress from being encircled in purse seines has been documented as a very serious threat to dolphins. Currently, fishing methods for tuna imported into the U.S. under the Dolphin-Safe program do not allow such fishing practices (USDOC, NMFS, 2015a). The commercial fishery that could interact with this stock in the GOM is the Atlantic Ocean, Caribbean, GOM large pelagic longline fishery (Waring et al., 2013). Interactions with tourists are a growing threat to the Hawaiian stock; because the species is active at night, daytime interactions with tourists inhibit necessary rest and sleep time. Information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) summarized injuries from the *Deepwater Horizon* oil spill to spinner dolphins and stated that 47 percent of the population was exposed to *Deepwater Horizon* oil and 16 percent of the population was killed as a result. In addition, 21 percent of females likely experienced reproductive failure and 17 percent of the population has experienced adverse health effects.

2.2.11.7 Status

The GOM population of spinner dolphins is considered a separate stock (Northern GOM stock) for management purposes; however, there currently is no information to differentiate this stock from the Atlantic Ocean stock(s). The status of spinner dolphins in the northern GOM is unknown. The species is not listed as threatened or endangered under the ESA, and there are insufficient data to determine the population trends for this species; however, recent information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) suggests that spinner dolphins in the GOM have experienced a population decline (16%) as a result of injury from the *Deepwater Horizon* oil spill. This is not a strategic stock because it is assumed that the average annual human-related mortality and serious injury does not exceed PBR (current PBR for the northern GOM spinner dolphin is 62 individuals) (Waring et al., 2013).

2.2.12 Fraser's Dolphin

The Fraser's dolphin (*Lagenodelphis hosei*) is easily identified by its stocky body, short beak, and small triangular or slightly falcate dorsal fin (Dolar, 2002). They grow to lengths of approximately 2.7 m (9 ft) (Jefferson et al., 2008).

2.2.12.1 Population

The GOM population is provisionally being considered a separate stock for management purposes; however, there currently is no information to differentiate this stock from the Atlantic Ocean stock(s). Additional morphological, genetic, and behavioral data are needed to provide further information on stock delineation (Waring et al., 2013).

2.2.12.2 Distribution and Abundance

The Fraser's dolphin is a pantropical species, distributed in oceanic waters between 30° N. and 30° S. latitude in the Atlantic, Pacific, and Indian Oceans (Dolar, 2002; Jefferson et al., 2008). Sightings in the northern GOM have been recorded during all seasons in water depths >200 m (656 ft) (Leatherwood et al., 1993; Hansen et al., 1996; Mullin and Hoggard, 2000; Maze Foley and Mullin, 2006).

The CetMap abundance estimate for northern GOM Fraser's dolphins is 1,665 individuals (Roberts et al., 2016). From NMFS SAR data, the best abundance estimate available for northern GOM Fraser's dolphins is unknown. Recent surveys (summer 2009) estimated zero abundance for Fraser's dolphins in oceanic waters in 2009. Because sightings of Fraser's dolphins have been uncommon to rare in the past, it is probable that Fraser's dolphins were not encountered during this survey (Waring et al., 2013). Historically, for surveys conducted in oceanic waters from 1991 to 1994, the estimate was 127 individuals (CV = 0.9); from 1996 to 2001 (excluding 1998), the estimate was 726 individuals (CV = 0.70); and from 2003 to 2004, the estimate was 0 individuals (CV = n/a) (Waring et al., 2013).

2.2.12.3 Habitat

Fraser's dolphins occur in warm temperate, subtropical, and tropical pelagic waters worldwide, usually deeper than 1,000 m (3,280 ft). They often are associated with areas of upwelling (USDOC, NMFS, 2015a).

2.2.12.4 Behavior

Fraser's dolphins are observed in large groups of hundreds to thousands of individuals, often mixed with other cetacean species such as melon-headed whales, pilot whales, Risso's dolphins, spotted dolphins, and spinner dolphins (Jefferson et al., 2008). Swimming speeds of Fraser's dolphins have been recorded between 2 and 4 kn (2.3 to 4.6 mph) with speeds up to 15 kn (17.3 mph) when escaping predators (Croll et al., 1999). According to Watkins et al. (1994), Fraser's dolphins herd when they feed, swimming rapidly to an area, diving for 15 seconds or more, surfacing, and splashing in a coordinated effort to surround the school of fish. Dive durations are not known, but several foraging depths have been recorded (250 to 500 m [820 to 1,640 ft]) (Perrin et al., 1994b). Fraser's dolphins feed on mesopelagic fish (particularly Myctophidae and Stomiidae), crustaceans (particularly Oplophoridae), and cephalopods (Croll et al., 1999; Dolar, 2002).

2.2.12.5 Vocalizations and Hearing

Fraser's dolphins produce sounds that range from 6.6 to 23.5 kHz (Oswald, 2006). They are classified within the mid-frequency cetacean functional marine mammal hearing group (150 Hz to 160 kHz) (Southall et al., 2007). There is no direct measurement of auditory threshold for the hearing sensitivity of Fraser's dolphins (Ketten, 2000; Thewissen, 2002). Echolocation clicks are described as short broadband sounds without emphasis at frequencies below 40 kHz, while whistles are FM tones concentrated between 4.3 and 24 kHz. Whistles have been suggested as communicative signals during social activity (Watkins et al., 1994). There are no available data regarding seasonal or geographical variation in the sound production of Fraser's dolphins.

2.2.12.6 Threats

Threats to Fraser's dolphins throughout their range include incidental catch in fisheries operating in pelagic waters using driftnets, gillnets, and trap nets as well as harvest by fisheries for meat and oil (Jefferson et al., 2008). Specifically, Fraser's dolphins have been incidentally captured in tuna purse seine fisheries in the eastern tropical Pacific and the Philippines (USDOC, NMFS, 2015a). The commercial fishery that could interact with this stock in the GOM is the Atlantic Ocean, Caribbean, GOM large pelagic longline fishery (Waring et al., 2013). Fraser's dolphins are harvested in Indonesia, Japan, the Lesser Antilles, the Philippines, and Sri Lanka (USDOC, NMFS, 2015a). There was not enough information for Fraser's dolphins in the GOM to assess potential impacts of the *Deepwater Horizon* oil spill (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016).

2.2.12.7 Status

Fraser's dolphin is classified as data deficient by the IUCN and is protected under the MMPA. The species is not listed as threatened or endangered under the ESA, and there are insufficient data to determine the population trends for this species. There were not enough data to make a determination about the overlap between the *Deepwater Horizon* oil-spill footprint and the ranges of Fraser's dolphins in the GOM; therefore, the potential injuries to this population are unknown. Total human-caused mortality and serious injury for this stock is not known, but none has been documented. The PBR for the northern GOM Fraser's dolphin is undetermined. Despite an undetermined PBR, this is not a strategic stock because there is no documented human-related mortality and serious injury (Waring et al., 2013).

2.2.13 Risso's Dolphin

The Risso's dolphin (*Grampus griseus*) is a medium-sized dolphin with a characteristic blunt head and light coloration. Adults are covered with white scratches, spots, and blotches that may, in conjunction with dorsal fin scars, be used to identify individuals. It is thought that this scarring may be from the beaks and suckers of squid (their primary prey) and the teeth of other Risso's dolphins (Jefferson et al., 2008). Adults of both sexes reach body lengths of more than 3.8 m (12 ft).

2.2.13.1 Population

The GOM population is provisionally being considered a separate stock for management purposes; however, there currently is little information to differentiate this stock from the Atlantic Ocean stock(s). Additional morphological, genetic, and behavioral data are needed to provide further information on stock delineation.

2.2.13.2 Distribution and Abundance

Risso's dolphins are distributed worldwide in tropical to warm temperate waters (Leatherwood and Reeves, 1983). They occur throughout oceanic waters of the northern GOM but are concentrated in areas of the continental slope (Baumgartner, 1997; Maze-Foley and Mullin, 2006). Risso's dolphins were documented in all seasons during GulfCet aerial surveys of the northern GOM between 1992 and 1998 (Hansen et al., 1996; Mullin and Hoggard, 2000). Average group size during GulfCet surveys was 7.5 individuals (Davis and Fargion, 1996).

The CetMap abundance estimate for northern GOM Risso's dolphins is 3,137 individuals (Roberts et al., 2016). From NMFS SAR data, the best abundance estimate available for northern GOM Risso's dolphins is 2,442 individuals (CV = 0.57) (Waring et al., 2014). Historically, for surveys conducted in oceanic waters from 1991 to 1994, the estimate was 2,749 individuals (CV = 0.27); from 1996 to 2001 (excluding 1998), the estimate was 2,169 individuals (CV = 0.32); and from 2003 to 2004, the estimate was 1,589 individuals (CV = 0.27) (Waring et al., 2012).

2.2.13.3 Habitat

Risso's dolphins are found in temperate, subtropical, and tropical waters with a temperature range of 10°C to 30°C (50°F to 86°F) and in depths >1,000 m (3,280 ft) seaward of the continental shelf. The species may be limited by water temperature, as individuals are more common in waters of 15°C to 20°C (59°F to 68°F). In the northern GOM, Risso's dolphins may prefer habitats on the continental slope where the seafloor topography is steeper. In the waters off northern Europe, they are known to inhabit shallower coastal areas (USDOC, NMFS, 2015a).

2.2.13.4 Behavior

Risso's dolphins often are observed in groups of 10 to 100 individuals, but larger aggregations have been reported (Jefferson et al., 2008). In the GOM, pod sizes typically range from 3 to 30 individuals (Würsig et al., 2000). They commonly associate with other cetacean species, including other delphinids and large whales (Baird, 2002a). They are thought to feed primarily on squid but are known to eat fishes and crustaceans (Würsig et al., 2000). Behavioral research suggests that Risso's dolphins primarily feed at night (Baird, 2002a). Swimming speeds for Risso's dolphins have been recorded at 1 to 7 kn (1.2 to 8.1 mph) off Santa Catalina Island (Shane, 1995). There currently are no known studies on diving behavior, but Risso's dolphins have been known to dive for up to 30 minutes and as deep as 600 m (1,969 ft) (DiGiovanni et al., 2005). They have been noted to demonstrate aggressive behavior toward other cetacean species. No data on breeding grounds are available, and Risso's dolphins have been known to calve year-round, peaking in winter (Baird, 2002a).

2.2.13.5 Vocalization and Hearing

The species is classified within the mid-frequency cetacean functional marine mammal hearing group (150 Hz to 160 kHz) (Southall et al., 2007). Audiograms for Risso's dolphins indicate hearing thresholds ≤65 to 125 dB in frequencies ranging from 1.6 to 110 kHz (Nachtigall et al., 1995). Philips et al. (2003) reported that Risso's dolphins are capable of hearing frequencies up to 80 kHz, with best underwater hearing occurring between 4 and 80 kHz at threshold levels from 64 to 74 dB re 1 µPa. Other audiograms obtained on Risso's dolphins confirm previous measurements and demonstrated a hearing threshold of 140 dB re 1 µPa for a 1-second, 75-Hz signal (Au et al., 1997; Croll et al., 1999).

Au et al. (1997) studied the hearing sensitivities of false killer whales and Risso's dolphins to the Acoustic Thermometry of Ocean Climate (ATOC) signal. The ATOC program transmitted 75 Hz, phase modulated, 195 dB re 1 µPa at 1 m SL signals from two locations in the North Pacific to study ocean temperatures. The hearing thresholds for Risso's dolphins were 142 ± 2 dB re 1 µPa receiving level (RL) for a 75 Hz pure tone signal and 141 ± 1 dB re 1 µPa RL for the ATOC signal. The results of this study concluded that small cetaceans, such as false killer whales and Risso's dolphins, swimming directly over the ATOC source would not be able to hear the transmitted sound unless the animals dove to a depth of approximately 400 m (1,312 ft). If these animals were at a horizontal range >0.5 km (0.3 nmi) from the source, the level of the ATOC signal would be below their hearing threshold at any depth.

Risso's dolphins produce vocalizations as low as 0.1 kHz and as high as 65 kHz. Their dominant frequencies are between 2 and 5 kHz and at 65 kHz (Watkins, 1967; Au, 1993; Croll et al., 1999; Philips et al., 2003). The maximum SL, with dominant frequencies at 2 to 5 kHz, is approximately 120 dB re 1 µPa at 1 m (peak-to-peak) (Au, 1993). In one experiment conducted by Philips et al. (2003), clicks were found to have a peak frequency of 65 kHz and durations ranging from 40 to 100 ms. In a second experiment, Philips et al. (2003) recorded clicks with peak frequencies up to 50 kHz with durations ranging from 35 to 75 ms. Estimated SLs of echolocation clicks can reach up to 216 dB re 1 µPa at 1 m (Philips et al., 2003). Bark vocalizations consisted of highly variable burst-pulses and have a frequency range of 2 to 20 kHz. Buzzes consisted of a short burst-pulse of sound approximately 2 seconds in duration with a frequency range of 2.1 to 22 kHz. Low-frequency, narrow-band grunt vocalizations ranged between 400 and 800 Hz. Chirp vocalizations were slightly higher in frequency than the grunt vocalizations, ranging in frequency from 2 to 4 kHz. There are no available data regarding seasonal or geographical variation in the sound production of Risso's dolphin.

2.2.13.6 Threats

Threats to Risso's dolphins throughout their range include bycatch in fishing gear, including gillnets, longlines, and trawls, as well as tuna purse seine fishing (in the eastern tropical Pacific Ocean); harvest for meat and oil in Indonesia, Japan (drive fishery), the Caribbean (the Lesser Antilles), and the Solomon Islands; and small numbers of Risso's dolphins have been captured from the wild for the purpose of public display in aquariums and oceanariums (USDOC, NMFS, 2015a). The commercial fishery that could interact with this stock in the GOM is the Atlantic Ocean, Caribbean, GOM large pelagic longline fishery (Waring et al., 2013). Information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) summarized injuries from the *Deepwater Horizon* oil spill to Risso's dolphins and stated that 8 percent of the population was exposed to *Deepwater Horizon* oil and 3 percent of the population was killed as a result. In addition, 3 percent of females likely experienced reproductive failure and 3 percent of the population has experienced adverse health effects.

2.2.13.7 Status

Risso's dolphin is classified as data deficient by the IUCN and is protected under the MMPA. The status of Risso's dolphins in the northern GOM is unknown; however, recent information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) suggests that Risso's dolphins in the GOM have experienced a population decline (3%) as a result of injury from the *Deepwater Horizon* oil spill. The species is not listed as threatened or endangered under the ESA, and there are insufficient data to determine the population trends for this species. The stock is classified as non-strategic under the MMPA. The current PBR for the Northern GOM stock of Risso's dolphins is 16 individuals (Waring et al., 2014).

2.2.14 Melon-Headed Whale

The melon-headed whale (*Peponocephala electra*) is a small, slender whale that reaches a maximum length of approximately 2.8 m (9.2 ft) (Jefferson et al., 2008).

2.2.14.1 Population

The GOM population is provisionally being considered as one stock for management purposes; however, there currently is no information to differentiate this stock from the Atlantic Ocean stock(s). Additional morphological, genetic, and behavioral data are needed to provide further information on stock delineation (Waring et al., 2013).

2.2.14.2 Distribution and Abundance

Melon-headed whales are distributed worldwide in tropical to subtropical waters (Jefferson et al., 2008). They generally are found in oceanic waters with nearshore sightings limited to areas where deep waters are found near the coast (Perryman, 2002). Sightings in the northern GOM generally have occurred in water depths >800 m (2,625 ft) and usually offshore Louisiana to west of Mobile Bay, Alabama (Mullin et al., 1994; Mullin and Fulling, 2004; Maze-Foley and Mullin, 2006). Melon-headed whales were sighted in all seasons during GulfCet surveys of the northern GOM between 1992 and 1998 (Davis and Fargion, 1996; Hansen et al., 1996; Mullin and Hoggard, 2000).

The CetMap abundance estimate for northern GOM melon-headed whales is 6,733 individuals (Roberts et al., 2016). From NMFS SAR data, the best abundance estimate available for northern GOM melon-headed whales is 2,235 individuals (CV = 0.75) (Waring et al., 2012). Historically, for surveys conducted in oceanic waters from 1991 to 1994, the estimate was 3,965 individuals (CV = 0.39); from 1996 to 2001 (excluding 1998), the estimate was 3,451 individuals (CV = 0.55), and from 2003 to 2004, the estimate was 2,283 individuals (CV = 0.76) (Waring et al., 2012).

2.2.14.3 Habitat

Melon-headed whales prefer deeper areas of warmer tropical waters where their prey are concentrated (USDOC, NMFS, 2015a).

2.2.14.4 Behavior

Melon-headed whales are highly social animals and usually are observed in groups of 100 to 500 individuals. Average group sizes reported from the GOM during GulfCet surveys were 140.7 individuals (ship surveys) and 311.7 individuals (aircraft surveys) (Davis and Fargion, 1996). Melon-headed whales often are observed swimming with other delphinid species such as Fraser's dolphins, spinner dolphins, and spotted dolphins, occasionally forming "super pods" of thousands of individuals. Melon-headed whales are known to feed mainly on deepwater squid, but fish and shrimp have been found in melon-headed whale stomachs as well (Perryman, 2002). Little is known of this species' life history or reproductive biology. No swimming speeds, dive depths, or dive times are available for the melon-headed whale.

2.2.14.5 Vocalization and Hearing

Melon-headed whales are classified within the mid-frequency cetacean functional marine mammal hearing group (150 Hz to 160 kHz) (Southall et al., 2007). There is no direct measurement of auditory threshold for the hearing sensitivity of melon-headed whales (Ketten, 2000; Thewissen, 2002). They produce sounds between 8 and 40 kHz (Watkins et al., 1997). Individual click bursts have frequency emphases between 20 and 40 kHz (Watkins et al., 1997). Dominant frequencies of whistles are 8 to 12 kHz, with FM upsweeps and downsweeps (Watkins et al., 1997). There are no available data regarding seasonal or geographical variation in the sound production of this species.

Maximum SLs are estimated at 155 dB re 1 μPa at 1 m for whistles and 165 dB re 1 μPa at 1 m for click bursts (Watkins et al., 1997).

2.2.14.6 Threats

Throughout their range, threats to melon-headed whales include bycatch in some fisheries. There has been some take of this species in the past by small cetacean fisheries in the Caribbean (Caldwell et al., 1976). The commercial fishery that could interact with this stock in the GOM is the Atlantic Ocean, Caribbean, GOM large pelagic longline fishery (Waring et al., 2013). Information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) summarized injuries from the *Deepwater Horizon* oil spill to melon-headed whales and stated that 15 percent of the population was exposed to *Deepwater Horizon* oil and 5 percent of the population was killed as a result. In addition, 7 percent of females likely experienced reproductive failure and 6 percent of the population has experienced adverse health effects.

2.2.14.7 Status

Melon-headed whales are categorized as least concern by the IUCN and are protected under the MMPA. The species is not listed as threatened or endangered under the ESA. The status of melon-headed whales in the northern GOM is unknown; however, recent information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) suggests that melon-headed whales in the GOM have experienced a population decline (5%) as a result of injury from the *Deepwater Horizon* oil spill. This is not a strategic stock because it is assumed that the average annual human-related mortality and serious injury does not exceed PBR. The current PBR for the Northern GOM stock of melon-headed whales is 13 individuals (Waring et al., 2014).

2.2.15 Pygmy Killer Whale

The pygmy killer whale (*Feresa attenuata*) is a relatively small odontocete of the family Delphinidae. Adult pygmy killer whales can reach body lengths of 2.6 m (8.5 ft) (Jefferson et al., 2008).

2.2.15.1 Population

The GOM population of pygmy killer whales is provisionally being considered a separate stock for management purposes; however, there currently is no information to differentiate this stock from the Atlantic Ocean stock(s). Additional morphological, genetic, and behavioral data are needed to provide further information on stock delineation (Waring et al., 2013).

2.2.15.2 Distribution and Abundance

The pygmy killer whale is distributed worldwide in tropical to subtropical oceanic waters. They are rarely seen in nearshore waters, except in areas where deep water is close to shore (Jefferson et al., 2008). Historic sightings of these animals in the northern GOM are within oceanic waters (Mullin and Fulling, 2004; Maze-Foley and Mullin, 2006). Through the GulfCet program, BOEM (formerly the Minerals Management Service [MMS]) had data collaboratively collected by external partners, including the NMFS, on the distribution and abundance of marine mammals in the northern GOM. Sightings of pygmy killer whales (in low numbers) were documented in all seasons during GulfCet aerial surveys of the northern GOM between 1992 and 1998 (Hansen et al., 1996; Mullin and Hoggard, 2000). No data are available to confirm seasonal migration patterns for pygmy killer whales, and there are no available data on breeding and calving grounds.

The CetMap abundance estimate for northern GOM pygmy killer whales is 2,126 individuals (Roberts et al., 2016). From NMFS SAR data, the best abundance estimate available for northern GOM pygmy killer whales is 152 individuals (CV = 1.02), based on data collected from a summer 2009 survey covering waters from the 200-m (656-ft) isobath to the seaward extent of the U.S. EEZ (Waring et al., 2013). Historically, for surveys conducted in oceanic waters from 1991 to 1994, the estimate was 518 individuals (CV = 0.81); from 1996 to 2001 (excluding 1998), the estimate was 408 individuals (CV = 0.60); and from 2003 to 2004, the estimate was 323 individuals (CV = 6.0) (Waring et al., 2012).

2.2.15.3 Habitat

Pygmy killer whales prefer deeper areas of warm tropical and subtropical waters where their prey are concentrated (USDOC, NMFS, 2015a).

2.2.15.4 Behavior

Little is known about the biology of the pygmy killer whale. Groups generally contain approximately 12 to 50 individuals, although pods of several hundred individuals have been reported (Würsig et al., 2000). Existing information indicates that pygmy killer whales feed on fishes and squids (Ross and Leatherwood, 1994). They have shown aggressive behavior with other animals, based on attacks on animals while in captivity or individual dolphins incidentally caught in tuna nets in the eastern tropical Pacific (Jefferson et al., 2008).

2.2.15.5 Vocalizations and Hearing

The pygmy killer whale is classified within the mid-frequency cetacean functional marine mammal hearing group (150 Hz to 160 kHz) (Southall et al., 2007). Little is known of the auditory range and sound production of the species. Pryor et al. (1965) described pygmy killer whales producing low-frequency “growls.” Pygmy killer whales emit echolocation clicks with centroid frequencies between 70 and 85 kHz, with bimodal peak frequencies between 45 and 117 kHz and an estimated SL between 197 and 223 dB re 1 μPa at 1 m (Madsen et al., 2004).

2.2.15.6 Threats

Throughout their range, few pygmy killer whales are caught in drive and gillnet fisheries. There has been some take of this species in the past by small cetacean fisheries in the Caribbean (Caldwell and Caldwell, 1971b). The commercial fishery that could interact with this stock in the

GOM is the Atlantic Ocean, Caribbean, GOM large pelagic longline fishery (Waring et al., 2013). However, there is no reported bycatch from U.S. fisheries. Information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) summarized injuries from the *Deepwater Horizon* oil spill to pygmy killer whales and stated that 15 percent of the population was exposed to *Deepwater Horizon* oil and 5 percent of the population was killed as a result. In addition, 7 percent of females likely experienced reproductive failure and 6 percent of the population has experienced adverse health effects.

2.2.15.7 Status

Pygmy killer whales are classified as data deficient by the IUCN and are protected under the MMPA. The species is not listed as threatened or endangered under the ESA, and there are insufficient data to determine the population trends for this species or total human-caused mortality and serious injury for this stock. The status of pygmy killer whales in the northern GOM is unknown; however, recent information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) suggests that pygmy killer whales in the GOM have experienced a population decline (5%) as a result of injury from the *Deepwater Horizon* oil spill. The GOM stock is not classified under the MMPA as a strategic stock. The current PBR for the Northern GOM stock of pygmy killer whales is 0.8 individuals (Waring et al., 2014).

2.2.16 False Killer Whale

The false killer whale (*Pseudorca crassidens*) is a medium-sized odontocete of the family Delphinidae. Males can reach 6 m (20 ft) in length and females can reach 5 m (16 ft) (Jefferson et al., 2008).

2.2.16.1 Population

The GOM population is provisionally being considered a single stock for management purposes; however, there currently is no information to differentiate this stock from the Atlantic Ocean stock(s). Additional morphological, genetic, and behavioral data are needed to provide further information on stock delineation (Waring et al., 2013).

2.2.16.2 Distribution and Abundance

The false killer whale is distributed worldwide throughout warm temperate and tropical oceans, generally in relatively deep offshore waters from 60° S. to 60° N. latitude (USDOC, NMFS, 2015a; Stacey et al., 1994; Odell and McClune, 1999; Baird, 2002b; Waring et al., 2013). They are reported to occur over the continental shelf and may move into very shallow waters on occasion (Jefferson et al., 2008). Historic sightings of this species in the northern GOM are from oceanic waters (Mullin and Fulling, 2004; Maze Foley and Mullin, 2006). False killer whales were observed only during spring and summer during GulfCet aerial surveys between 1992 and 1998 (Hansen et al., 1996; Mullin and Hoggard, 2000) and in the spring during vessel surveys (Mullin and Fulling, 2004). Sightings during the GulfCet surveys were not concentrated in any particular portion of the study area (Davis and Fargion, 1996).

The CetMap abundance estimate for northern GOM killer whales is 3,204 individuals (CV = 0.32) (Roberts et al., 2016). From NMFS SAR data, the current estimate of abundance and the minimum population estimate of false killer whales in the GOM are unknown (existing estimates are >8 years old); the best population estimate is unknown (Waring et al., 2013). Historically, for surveys conducted in oceanic waters from 1991 to 1994, the estimate was 381 individuals (CV = 0.62); from 1996 to 2001 (excluding 1998), the estimate was 1,038 individuals (CV = 0.71); and from 2003 to 2004, the estimate was 777 individuals (CV = 0.56) (Waring et al., 2012).

2.2.16.3 Habitat

False killer whales prefer tropical to temperate waters that are deeper than 3,300 ft (1,000 m) (USDOC, NMFS, 2015a).

2.2.16.4 Behavior

False killer whales are highly social and commonly observed in groups of 10 to 60 individuals, although larger groups have been documented (Würsig et al., 2000; Baird, 2002b). During GulfCet surveys, observed group sizes ranged from 2 to 35 individuals and averaged 3.5 and 27.5 individuals estimated from ship and aerial platforms, respectively (Davis and Fargion, 1996). Details of false killer whale social organizations are not available; however, because of their propensity to strand in groups, it is assumed that there are strong bonds between individuals within groups (Baird, 2002b). They primarily feed on fishes and cephalopods, although they are known to attack other cetaceans. False killer whales have an approximate swimming speed of 2 kn (2.3 mph), although a maximum swimming speed of 15.5 kn (17.8 mph) (Brown et al., 1966; Rohr et al., 2002). Dive depths of 500 m (1,640 ft) have been recorded for this species (Odell and McClune, 1999). There are no available data on specific breeding grounds. Calving season may be considered year-round with a peak in late winter (Baird, 2002b). The calving interval for one group was reported as almost 7 years, and calving may occur year-round (Baird, 2002b).

2.2.16.5 Vocalizations and Hearing

False killer whales are classified within the mid-frequency, cetacean functional marine mammal hearing group (150 Hz to 160 kHz) (Southall et al., 2007). They hear underwater sounds in the range of <1 to 115 kHz (Johnson, 1967; Awbrey et al., 1988; Au, 1993). Their best underwater hearing occurs at 17 kHz, where the threshold level ranges between 39 and 49 dB re 1 µPa (Sauerland and Dehnhardt, 1998). Behavioral audiograms, supported by ABR studies that had similar results, show that the range of best hearing sensitivity is between 16 and 24 kHz, with peak sensitivity at 20 kHz (Yuen et al., 2005). Au et al. (1997) studied the hearing sensitivities of false killer whales and Risso's dolphins to the ATOC signal. The ATOC program transmitted 75 Hz, phase-modulated, 195 dB SL signals from two locations in the North Pacific to study ocean temperatures. The hearing thresholds for false killer whales were 141 ± 1 dB re 1 µPa RL for a 75-Hz pure tone signal and 139 ± 1 dB re 1 µPa RL for the ATOC signal. The results of this study concluded that small cetaceans, such as false killer whales and Risso's dolphins, swimming directly over the ATOC source, would not be able to hear the transmitted sound unless the animals dove to a depth of approximately 400 m (1,312 ft). If these animals were at a horizontal range >0.5 km (0.3 mi) from the source, the level of the ATOC signal would be below their hearing threshold at any depth.

False killer whales produce a wide variety of sounds from 4 to 130 kHz, with dominant frequencies between 25 and 30 kHz and 95 and 130 kHz (Busnel and Dziedzic, 1968; Kamminga and van Velden, 1987; Thomas and Turl, 1990; Murray et al., 1998). Most signal types are whistles, burst-pulses, and click trains (Murray et al., 1998). Whistles generally range between 4 and 9.5 kHz (Thomson and Richardson, 1995). False killer whales echolocate using highly directional clicks ranging between 20 and 60 kHz and 100 and 130 kHz (Kamminga and van Velden, 1987; Thomas and Turl, 1990). The SL of clicks has been measured to range from 200 to 228 dB re 1 μPa at 1 m (Thomas and Turl, 1990; Ketten, 1998). There are no available data regarding seasonal or geographical variation in the sound production of false killer whales.

2.2.16.6 Threats

Throughout their range, threats to false killer whales include bycatch and other fishery interactions, such as the Hawaii longline fishery and bottomfish fishery off the northwestern Hawaiian Islands, and hunting in Indonesia, Japan, and the West Indies (USDOC, NMFS, 2015a). The commercial fishery that could interact with this stock in the GOM is the large pelagic longline fishery (Waring et al., 2013). Pelagic swordfish, tunas, and billfish are the targets of the longline fishery operating in the northern GOM (Waring et al., 2013). Information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) summarized injuries from the *Deepwater Horizon* oil spill to false killer whales and stated that 18 percent of the population was exposed to *Deepwater Horizon* oil and 6 percent of the population was killed as a result. In addition, 8 percent of females likely experienced reproductive failure and 7 percent of the population has experienced adverse health effects.

2.2.16.7 Status

False killer whales are classified as least concern by the IUCN and are protected under the MMPA. The species is not listed as threatened or endangered under the ESA. The status of false killer whales in the northern GOM is unknown, and there are insufficient data to determine population trends for this species; however, recent information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) suggests that false killer whales in the GOM have experienced a population decline (6%) as a result of injury from the *Deepwater Horizon* oil spill. The species is not a strategic stock. The current PBR for the Northern GOM stock of false killer whales is undetermined (Waring et al., 2013).

2.2.17 Killer Whale

The killer whale (*Orcinus orca*) is the largest member of the ocean dolphin family Delphinidae (Würsig et al., 2000). Adults reach body lengths of 9.8 m (32 ft) for males and 8.5 m (28 ft) for females (Jefferson et al., 2008). In addition to body length, adult male killer whales possess disproportionally larger appendages (pectoral flippers, dorsal fin, and tail flukes) than females (Ford, 2002). They are easily recognizable by their large size and characteristic black-and-white coloration.

2.2.17.1 Population

A single species is recognized; however, genetic, morphological, and ecological evidence suggest separate forms that may represent distinct species (Jefferson et al., 2008). Currently, two unnamed subspecies of *O. orca* are recognized: killer whale unnamed subspecies (resident killer whale) and killer whale unnamed subspecies (transient killer whale, Bigg's killer whale) (Committee on Taxonomy, 2013). The GOM population is provisionally being considered a separate stock for management purposes; however, there currently is no information to differentiate this stock from the Atlantic Ocean stock(s). Additional morphological, genetic, and behavioral data are needed to provide further information on stock delineation (Waring et al., 2013).

2.2.17.2 Distribution and Abundance

The killer whale's distribution is cosmopolitan. Within the North Atlantic, its range extends from the Arctic ice-edge to the Caribbean Sea and includes the GOM. Historic sightings of killer whales in the northern GOM from 1921 to 1995 occurred primarily in oceanic waters ranging from 256 to 2,652 m (840 to 8,700 ft) deep (averaging 1,242 m [4,075 ft]), primarily in the north-central region (O'Sullivan and Mullin, 1997).

Killer whales are characterized as uncommon or rare in waters of the U.S. Atlantic EEZ (Katona et al., 1988). Most sightings of this species within the GOM have been on the continental shelf edge and slope. Very few sightings of killer whales in the GOM have been made within continental shelf waters other than those reported in 1921, 1985, and 1987 (Katona et al., 1988). During GulfCet surveys conducted between 1992 and 1998, killer whales were seen near the continental shelf edge and slope only in the summer (Hansen et al., 1996; Mullin and Hoggard, 2000). During shipboard surveys, killer whales were reported in the GOM from May through September and in November (Whitt et al., 2015; O'Sullivan and Mullin, 1997; Mullin and Fulling, 2004; Maze-Foley and Mullin, 2006).

The CetMap abundance estimate for northern GOM killer whales is 185 individuals (Roberts et al., 2016). From NMFS SAR data, the best abundance estimate available for northern GOM killer whales is 28 individuals (CV = 1.02) (Waring et al., 2012). Historically, for surveys conducted in oceanic waters from 1991 to 1994, the estimate was 277 individuals (CV = 0.42); from 1996 to 2001 (excluding 1998), the estimate was 133 individuals (CV = 0.49); and from 2003 to 2004, the estimate was 49 individuals (CV = 0.77) (Waring et al., 2012).

2.2.17.3 Habitat

Killer whales are most abundant in polar waters; however, they can be fairly abundant in temperate waters. Killer whales also occur, though at lower densities, in tropical, subtropical, and offshore waters (USDOC, NMFS, 2015a).

2.2.17.4 Behavior

Killer whales usually are observed in groups of 5 to 20 individuals. In the GOM, group sizes averaged 11.2 individuals (Davis and Fargion, 1996). Killer whale groups appear to be temporally stable (Ford, 2002) and usually contain adults of both sexes, but adult females and young will sometimes segregate to form their own groups. Groups are highly cooperative and function as a unit when hunting (Würsig et al., 2000). In the northeastern Pacific Ocean, killer whales exhibit dietary specialization within different sympatric populations. In this region, these populations maintain social isolation from each other and differ in genetic structure, morphology, behavior, distribution patterns, and ecology. One population (referred to as residents) feed primarily on fish, whereas a second population (termed transients) are primarily mammal hunters (Ford, 2002). Evidence suggests that similar degrees of specialization may exist in other areas within their range. Whitt et al. (2015) reported a prolonged interaction between killer whales and sperm whales in the GOM during 2011.

Killer whale swimming speeds usually range from 3 to 5 kn (3.5 to 5.8 mph), but they can achieve speeds up to 20 kn (23 mph) in short bursts (Lang, 1966; LeDuc, 2002). In southern British Columbia and northwestern Washington, killer whales spend 70 percent of their time in the upper 20 m (66 ft) of the water column but can dive to 100 m (328 ft) or more, with a maximum recorded depth for a wild individual of 201 m (660 ft) (Baird et al., 1998). The deepest dive recorded by a killer whale is 265 m (870 ft), reached by a trained individual (Ridgway, 1986). Recorded dive durations range from 1 to 10 minutes (Norris and Prescott, 1961; Lenfant, 1969; Baird et al., 1998).

2.2.17.5 Vocalization and Hearing

Killer whales are classified within the mid-frequency, cetacean functional marine mammal hearing group (150 Hz to 160 kHz) (Southall et al., 2007). Killer whales hear underwater sounds from <500 Hz to 120 kHz (Bain et al., 1993; Szymanski et al., 1999). Their best underwater hearing occurs between 15 and 42 kHz, where the threshold level is 34 to 36 dB re 1 μPa (Hall and Johnson, 1972; Szymanski et al., 1999). Killer whales produce sounds as low as 80 Hz and as high as 85 kHz, with dominant frequencies at 1 to 20 kHz (Schevill and Watkins, 1966; Diercks et al., 1971 and 1973; Evans, 1973; Steiner et al., 1979; Awbrey et al., 1982; Ford and Fisher, 1983; Ford, 1989; Miller and Bain, 2000). An average of 12 different call types (range 7 to 17), mostly repetitive discrete calls, exist for each pod in coastal waters of the eastern North Pacific (Ford, 2002). Pulsed calls, whistles, and called dialects carry information hypothesized as geographic origin, individual identity, pod membership, and activity level. Vocalizations tend to be between 500 Hz and 10 kHz and may be used for group cohesion and identity (Ford, 2002; Frankel, 2002). Whistles and echolocation clicks are included in killer whale repertoires as well but are not a dominant signal type of the vocal repertoire compared with pulsed calls (Miller and Bain, 2000). Erbe (2002) recorded received broadband sound pressure levels of orca burst-pulse calls ranging between 105 and 124 dB re 1 μPa RL at an estimated distance of 100 m (328 ft). Clicks and whistles range from 0.5 to 25 kHz, with a dominant frequency range of 1 to 6 kHz (Thomson and Richardson, 1995). Au et al. (2004) recorded echolocation clicks at SLs ranging from 195 to 224 dB re 1 μPa at 1 m (peak-peak), with dominant frequencies ranging from 20 to 60 kHz and durations of 80 to 120 μs. Average SLs for other sounds were 140 dB re 1 μPa at 1 m for whistles, 147 dB re 1 μPa at 1 m for variable calls, and 153 dB re 1 μPa at 1 m for stereotyped calls (Veirs, 2004). Killer whales modify their vocalizations depending on the social context or ecological function; for example, short-range (<10 km [6.2 mi]) vocalizations typically are associated with social and resting behaviors and long-range (10 to 16 km [6.2 to 9.9 mi]) vocalizations are associated with travel and foraging (Miller, 2006).

2.2.17.6 Threats

Throughout their range, threats to killer whales include commercial hunting; live capture for aquarium display, particularly of the southern resident stock (some live capture still occurs in Russia); culling due to depredation of fisheries; contaminants (e.g., PCBs); depletion of prey due to overfishing and habitat degradation; ship strikes; oil spills; noise disturbance from industrial and military activities; interactions with fishing gear; and whale watching (USDOC, NMFS, 2015a). There was not enough information for killer whales in the GOM to assess the potential impacts of the *Deepwater Horizon* oil spill (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016).

2.2.17.7 Status

The killer whale is classified as lower risk (data deficient) by the IUCN and is protected under the MMPA. The species is not listed as threatened or endangered under the ESA, and the Northern GOM stock is not classified as a strategic stock under the MMPA. There were not enough data to make a determination about the overlap between the *Deepwater Horizon* oil-spill footprint and the ranges of killer whales in the GOM; therefore, potential injuries to this population are unknown. The current PBR for the Northern GOM stock of killer whales is 0.1 individuals (Waring et al., 2014).

2.2.18 Short-Finned Pilot Whale

The short-finned pilot whale (*Globicephala macrorhynchus*) is a medium-sized whale with a characteristic bulbous head and broad-based dorsal fin. Adult short-finned pilot whales attain a body length of 7.2 m (24 ft) for males and 5.5 m (18 ft) for females (Jefferson et al., 2008). In addition to greater length, male pilot whales exhibit larger dorsal fins and a more pronounced melon than females (Olson and Reilly, 2002).

2.2.18.1 Population

The GOM population is being considered a separate stock for management purposes; however, there currently is no information to differentiate this stock from the Atlantic Ocean stock(s).

Additional morphological, genetic, and behavioral data are needed to provide further information on stock delineation.

2.2.18.2 Distribution and Abundance

The short-finned pilot whale is distributed worldwide in tropical to subtropical waters, generally on the continental shelf break and in deep oceanic waters (Leatherwood and Reeves, 1983; Jefferson et al., 2008). Historical sightings of these animals in the northern GOM have been primarily on the continental slope, west of 89° W. longitude (Mullin and Fulling, 2004; Maze-Foley and Mullin, 2006). During GulfCet aerial and ship surveys of the northern GOM between 1992 and 1998, short-finned pilot whales were recorded in all seasons, with sightings primarily offshore Louisiana and almost evenly distributed throughout the seasons (Davis and Fargion, 1996; Hansen et al., 1996; Mullin and Hoggard, 2000). Although seasonal movements for this species are reported for the Caribbean Sea, there is no evidence of migration in the GOM (Würsig et al., 2000).

The CetMap abundance estimate for northern GOM short-finned pilot whales is 1,981 individuals (Roberts et al., 2016). From NMFS SAR data, the best abundance estimate available for northern GOM short-finned pilot whales is 2,415 individuals (CV = 0.66) (Waring et al., 2014). Historically, for surveys conducted in oceanic waters from 1991 to 1994, the estimate was 353 individuals (CV = 0.89); from 1996 to 2001 (excluding 1998), the estimate was 2,388 individuals (CV = 0.48); and from 2003 to 2004, the estimate was 716 individuals (CV = 0.34) (Waring et al., 2012).

2.2.18.3 Habitat

Short-finned pilot whales prefer warmer tropical and temperate waters and can be found at varying distances from shore but typically in deeper waters. Areas with a high density of squid are their primary foraging habitats (USDOC, NMFS, 2015a).

2.2.18.4 Behavior

Short-finned pilot whales generally are found in aggregations of 10 to 60 individuals, but larger groups of several hundred individuals are not infrequent (Davis and Fargion, 1996; Würsig et al., 2000). Studies suggest that these aggregations are relatively stable and maternally based, and strong social bonds may be a reason why pilot whales are one of the species most often associated with mass strandings. A variety of group behaviors have been documented (Olson and Reilly, 2002). Aggregations of short-finned pilot whales are commonly associated with other cetacean species such as other delphinids and large whales (Jefferson et al., 2008). There are accounts of aggressive behavior of pilot whales toward other cetacean species (Olson and Reilly, 2002). Short-finned pilot whales have swimming speeds ranging between 4 to 5 kn (4.6 to 5.8 mph) (Norris and Prescott, 1961). Short-finned pilot whales are considered deep divers (deepest recording at 610 m [2,000 ft]), feeding primarily on fish and squid (Ridgway, 1986; Croll et al., 1999). They may stay submerged for up to 40 minutes (Mate et al., 2005).

2.2.18.5 Vocalization and Hearing

Short-finned pilot whales are classified within the mid-frequency, cetacean functional marine mammal hearing group (150 Hz to 160 kHz) (Southall et al., 2007). There is no direct measurement of auditory threshold for the hearing sensitivity of short-finned pilot whales (Ketten, 2000; Thewissen, 2002). Pilot whales echolocate with a precision similar to bottlenose dolphins and also vocalize with other pod members (Olson and Reilly, 2002). Short-finned pilot whales produce vocalizations as low as 280 Hz and as high as 100 kHz, with dominant frequencies between 2 and 14 kHz and 30 and 60 kHz (Caldwell and Caldwell, 1969; Fish and Turl, 1976; Scheer et al., 1998). Vocalizations produced by this species average 7.87 kHz, higher than that of a long-finned pilot whale (Olson and Reilly, 2002). Echolocation abilities have been demonstrated during click production (Evans, 1973). The SLs of clicks have been measured as high as 180 dB re 1 μPa at 1 m (Fish and Turl 1976; Richardson et al., 1995). There are few available data regarding seasonal or geographical variation in the vocalizations production of the short finned pilot whale, although there is evidence of group-specific call repertoires (Olson and Reilly, 2002).

2.2.18.6 Threats

Throughout their range, threats to short-finned pilot whales include bycatch in fishing gear such as gillnets, longlines, and trawls, and drive fisheries that specifically target pilot whales in Japan and the Lesser Antilles (USDOC, NMFS, 2015a). The commercial fishery that could interact with this stock in the GOM is the Atlantic Ocean, Caribbean, GOM large pelagic longline fishery (Waring et al., 2013). Ship strikes may pose a threat in the Hawaii Islands as propeller scarred whales have been documented there. Information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) summarized injuries from the *Deepwater Horizon* oil spill to short-finned pilot whales and stated that 6 percent of the population was exposed to *Deepwater Horizon* oil and 2 percent of the population was killed as a result. In addition, 3 percent of females likely experienced reproductive failure and 2 percent of the population has experienced adverse health effects.

2.2.18.7 Status

The short-finned pilot whale is classified as a lower risk (data deficient) species by the IUCN and is protected under the MMPA. The species is not listed as threatened or endangered under the ESA. The status of the short-finned pilot whale in the northern GOM is unknown (Waring et al., 2013). There are insufficient data to determine population trends; however, recent information from the Final PDARP/PEIS (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016) suggests that short-finned pilot whales in the GOM have experienced a population decline (2%) as a result of injury from the *Deepwater Horizon* oil spill. It is not classified as a strategic stock under the MMPA. The current PBR for the Northern GOM stock of short-finned pilot whales is 15 individuals (Waring et al., 2014).

2.3 Sirenians – West Indian Manatee

The West Indian manatee (*Trichechus manatus*), the only sirenian found in the AOI and listed under the ESA, is divided into two subspecies: *T. m. manatus* (Antillean manatee) and *T. m. latirostris* (Florida manatee) (Committee on Taxonomy, 2013). The West Indian manatees can reach lengths of 4 m (13 ft), with females slightly larger than males.

2.3.1 Population

Studies of the Florida manatee identified four regional management units (formerly referred to as subpopulations), including two units within the GOM: a Northwest unit that occupies the Florida Panhandle south to Hernando County; and a Southwest unit that occurs from Pasco County to Whitewater Bay in Monroe County (USDOI, FWS, 2001 and 2007). While the Florida manatee population has been separated into these management units, the FWS identifies the Florida manatee population as a single stock. Significant genetic differences between the manatees of Florida and Puerto Rico do exist and, as a result, these populations are identified as separate stocks (Vianna et al., 2006).

2.3.2 Distribution and Abundance

The West Indian manatee is distributed from Virginia, U.S. to Espiritu Santo, Brazil (Shoshani, 2005). The Florida manatee subspecies is found throughout the southeastern U.S., with individuals sighted as far north as Massachusetts and as far west as Texas (Rathbun et al., 1982; Schwartz, 1995; Fertl et al., 2005). Locations of manatee sightings within the AOI are shown in **Figure 4.2-2** of this Programmatic EIS. The Antillean manatee subspecies is found in the southern GOM (eastern Mexico and Central America), northern and eastern South America, and in the Greater Antilles (Lefebvre et al., 1989); therefore, its range is outside of the AOI.

The best available count of GOM manatees is based on an annual synoptic survey of warm-water refuges along the Florida west coast (at sites from the Wakulla River to the Everglades). The Florida Fish and Wildlife Conservation Commission (FWC) coordinates an interagency team that conducts broad, synoptic surveys from one to three times each year (weather permitting). The synoptic surveys are conducted in winter and cover all of the known wintering habitats of manatees in Florida. Surveys conducted in February 2015 recorded 2,730 individuals on the west coast of Florida. Historic estimates of manatee abundance off west Florida as generated from these synoptic surveys over the last decade are provided below (State of Florida, Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, 2015a):

- 2014 – 2,509 individuals;
- 2011 – 2,402 individuals;
- 2010 – 2,297 individuals;
- 2009 – 1,654 individuals;

- 2007 – 1,403 individuals;
- 2006 – 1,474 individuals; and
- 2005 – 1,549 individuals.

2.3.3 Habitat

Manatees are a subtropical species with little tolerance for cold water. As a result, the Florida manatee is generally restricted to the inland and coastal waters of peninsular Florida during the winter when individuals shelter in or near warm-water springs, industrial effluents, and other warm-water sites (Hartman, 1979; Lefebvre et al., 2001; Stith et al., 2006). In warmer months, manatees leave these sites and can disperse great distances. Manatees tend to show strong fidelity to specific ranges. Most individual Florida manatees within the southeastern U.S. migrate seasonally between a summer range and a more southern winter range. The presence of warm-water sources, such as coastal power plant outfalls, has affected their normal migration patterns.

2.3.4 Behavior

Florida manatees typically are seen alone or in groups of up to six individuals. These groups are "loosely knit" and the species generally is not behaviorally gregarious (Würsig et al., 2000). Florida manatees prefer shallow seagrass beds, especially areas with access to deep channels. Preferred coastal and riverine habitats (e.g., near the mouths of coastal rivers) are used for resting, mating, and calving (USDOI, FWS, 2001 and 2007). Manatees are aquatic herbivores that feed exclusively on vegetation such as turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), and water hyacinth (*Eichhornia crassipes*). They appear to prefer submerged vegetation, followed by floating and emergent vegetation (Würsig et al., 2000). Manatees typically dive for 2 to 3 minutes or less at a time but can remain underwater for more than 20 minutes. Their dives typically are shallow, based on where aquatic vegetation is able to grow (Reynolds and Powell, 2002). There is no defined breeding season; calves are born year-round (O'Shea et al., 1995).

2.3.5 Vocalizations and Hearing

Manatees produce sounds, particularly squeaks and squeals, mostly in the 3- to 5-kHz range (Reynolds and Powell, 2002), with a full range of 0.6 to 12 kHz and sound durations of 0.18 to 0.9 seconds (Steel and Morris, 1982; Thomson and Richardson, 1995; Niezrecki et al., 2003; O'Shea and Poche, 2006). Frisch and Frisch (2003) recorded vocalizations below 0.1 kHz (U.S. Department of the Navy, 2007). Average SLs range from 90 to 138 dB re 1 μPa at 1 m (Nowacek et al., 2003; Phillips et al., 2004). Gerstein et al. (1999) studied the underwater audiogram of the Florida manatee. Research was conducted at the Lowry Park Zoo in Tampa, Florida, in an acoustically insulated test pool. The results showed that the two manatees tested exhibited a typical mammalian U-shaped audiogram, with frequency sensitivity increasing from 0.4 kHz to a maximum sensitivity between 6 and 20 kHz (9 dB from maximum sensitivity). Based on this study, Gerstein et al. (1999) estimated the maximum hearing range for the West Indian manatee to be from 0.4 to

46 kHz. Hearing sensitivity "dropped approximately 40 dB per octave above 26 kHz and approximately 20 dB per octave below 0.8 kHz" (Gerstein et al., 1999).

2.3.6 Threats

Sources of human-caused manatee mortality and injury include watercraft-related strikes (direct impact and propeller strikes), water control structures (entrapment in flood gates and navigation locks), recreational and commercial fishing gear (entanglement or ingestion), among others (Waring et al., 2013). From 2010 through 2014, 2,477 manatee carcasses were salvaged in Florida; 760 of those animals died of undetermined causes and 707 were natural mortalities and perinatal deaths (State of Florida, Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, 2015b). Additional causes of deaths were as follows:

- vessel collisions – 343 individuals;
- cold stress – 428 individuals; and
- water control structures (including flood gates and navigation locks) – 14 individuals.

Natural threats include exposure to cold water and red tides (algal blooms). Mortality associated with these natural threats includes cold stress syndrome and brevetoxicosis, respectively (Waring et al., 2013). While the distribution of West Indian manatees overlaps with the *Deepwater Horizon* oil footprint, none were sighted in oil and no injury assessment was completed for this marine mammal species (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016).

2.3.7 Status

The Florida manatee currently is listed as endangered under the ESA and by the IUCN, and as a strategic stock under the MMPA. The species also is protected under the Florida Manatee Sanctuary Act. The majority of the Atlantic population of the Florida manatee is located in eastern Florida and southern Georgia (Waring et al., 2013) and is managed within four distinct regional management units: Atlantic Coast (northeast Florida to the Florida Keys); Upper St. Johns River (St. Johns River, south of Palakta); Northwest (Florida Panhandle to Hernando County); and Southwest (Pasco County to Monroe County) (USDOI, FWS, 2001 and 2007). The Northwest and Southwest units are the most relevant to the AOI. Critical habitat was designated for the Florida manatee on September 24, 1976 (41 FR 41914). The current, revised critical habitat designation includes inland waterways in four northeastern Florida coastal counties (Brevard, Duval, St. Johns, and Nassau Counties) that are not within the AOI.

3 SEA TURTLES

Chapter 4.3.1 of this Programmatic EIS provides the succinct description of the affected environment for sea turtles in sufficient detail to support the impact analyses. The following descriptions provide additional information on sea turtle life histories. Of the seven extant species of sea turtle, the following five occur in the AOI (**Table 4.3-1** of this Programmatic EIS):

- green turtle (*Chelonia mydas*);
- hawksbill turtle (*Eretmochelys imbricata*);
- Kemp's ridley turtle (*Lepidochelys kempii*);
- loggerhead turtle (*Caretta caretta*); and
- leatherback turtle (*Dermochelys coriacea*).

The leatherback turtle is under the family Dermochelyidae, whereas the other four species are classified as hard-shelled turtles in the family Cheloniidae.

All sea turtles are protected under the ESA. Because sea turtles use terrestrial and marine environments at different life stages, the FWS and NMFS share jurisdiction under the ESA. The FWS has jurisdiction over sea turtles when they come ashore to nest, and the NMFS has jurisdiction over sea turtles in the marine environment. The hawksbill, Kemp's ridley, and leatherback turtles are listed as endangered throughout their ranges under the ESA. As a species, the green turtle is listed as threatened under the ESA, but the Florida and Mexico Pacific breeding populations are listed as endangered. Loggerhead turtles recently have been divided into nine distinct population segments (DPSs); the Northwest Atlantic Ocean, South Atlantic Ocean, Southeast Indo-Pacific Ocean, and Southwest Indian Ocean DPSs are listed as threatened under the ESA, while the Northeast Atlantic Ocean, Mediterranean Sea, North Indian Ocean, North Pacific Ocean, and South Pacific Ocean DPSs are listed as endangered. A DPS is a population that is discrete from other populations of a species and significant in relation to the entire species. The GOM is part of the Northwest Atlantic Ocean DPS; therefore, loggerhead turtles occurring in the AOI are considered threatened. The ESA-designated critical habitat for the loggerhead turtle occurs within or adjacent to the AOI. Nearshore reproductive critical habitat for the Northwest Atlantic Ocean loggerhead turtle DPS has been designated in the State waters of Mississippi, Alabama, and Florida (79 FR 39856). Farther offshore in the AOI, a large portion of the northern GOM has been designated as *Sargassum* critical habitat for the Northwest Atlantic Ocean loggerhead turtle DPS (**Figure 4.3-3** of this Programmatic EIS) (79 FR 39856). In March 2015, the NMFS published a proposed rule to revise the listing for the green turtle to list 11 green turtle DPSs, with 3 population segments to be listed as endangered and 8 as threatened (80 FR 15272). The North Atlantic DPS, which includes the individuals that occur in the GOM, is proposed to be listed as threatened. The NMFS is currently compiling comments on the proposed rule, with a final rule expected to be published in late 2016.

Loggerhead, Kemp's ridley, and leatherback turtles commonly occur in the GOM; green and hawksbill turtles are rarer. During aerial surveys conducted in 1980 to 1981, Fritts et al. (1983a and 1983b) observed loggerhead, green, Kemp's ridley, and leatherback turtles across the northern GOM. Only loggerhead, Kemp's ridley, and leatherback turtles were observed during the aerial and ship surveys conducted during the GulfCet I (central and northwestern GOM) and II (northern GOM) programs (Davis and Fargion, 1996; Mullin and Hoggard, 2000). The greatest abundance of sea turtles in the GOM has been observed in continental shelf waters east of Mobile Bay (Lohoefener et al., 1990; Mullin and Hoggard, 2000). McDaniel et al. (2000) conducted aerial surveys for sea turtles over a broad area of the eastern GOM nearshore zone. Although the aerial surveys were unable to differentiate between species and likely missed smaller individuals, they found a pattern of increasing sea turtle abundance in nearshore waters as they moved from the northern GOM offshore of Louisiana and Mississippi (0.05 to 0.10 turtle observations per transect kilometer) to the Florida coastal waters, with the highest abundance recorded in the waters offshore of the Florida Keys (0.35 to 1.0 observations per transect kilometer). Inwater Research Group (2014) conducted 2,300 km (1,429 mi) of vessel-based transect surveys for sea turtles in the near coastal waters of eastern Louisiana. These surveys were able to differentiate between species and estimated overall sea turtle abundance at 0.27 observations per transect kilometer (obs/km). Observations were dominated by Kemp's ridleys (0.12 obs/km) and loggerheads (0.11 obs/km), with considerably lower numbers of leatherbacks (0.04 obs/km) and green turtles (0.006 obs/km).

Swimming loggerhead, leatherback, Kemp's ridley, and green turtles are commonly found within the AOI at certain periods (e.g., nesting season) and life stages. Each of the species has a juvenile stage thought to be distributed almost exclusively in offshore pelagic habitats. These juvenile stages, which include post-hatchlings leaving nesting beaches and small oceanic-stage juveniles, are most often found in close association with *Sargassum* drift algae habitats, which they use as developmental habitat before making a transition to shallow-water habitats at 1-3 years of age (Bolten and Witherington, 2003). Witherington et al. (2012) conducted vessel-based transect surveys from five Florida ports from Pensacola to Key West extending up to 120 km (62 mi) offshore to evaluate the abundance, species composition, and behavior of oceanic-stage juvenile sea turtles in the eastern GOM. They found that 89 percent of all turtle observations occurred within 1 m (3.3 ft) of floating *Sargassum* and that turtle density estimates in *Sargassum* habitats were nearly 100 times higher than in open-water areas where *Sargassum* was not present. Ninety captures of oceanic-stage juvenile turtles revealed a species composition dominated by green turtles (49%) and Kemp's ridleys (42%) and lower abundances of hawksbills (7%) and loggerheads (2%). In addition, large numbers of post-hatchling sea turtles were observed, but only during hatching season on the adjacent Florida nesting beaches (July-October). On a broader scale, Putman et al. (2013) generated predicted distributions for the distribution of oceanic-stage Kemp's ridley turtles throughout the GOM basin using simulated particle dispersal with ocean circulation models. They found that the predicted highest abundance for Kemp's ridley oceanic-stage juveniles was in the far western GOM, with 50 percent of the individuals expected to remain west of 90° W. longitude.

The northern GOM possesses a diverse array of juvenile developmental and adult foraging habitats (from shallow-water habitats such as seagrass beds and coral reefs to deeper water habitats such as artificial reef [including oil and gas] structures and canyons, as well as open ocean *Sargassum* habitat) (Carr et al., 1982). Sea turtles often use the dominant currents of the northern GOM, such as the Loop and Florida Currents, for transport to distant areas of the northern Atlantic Ocean or Caribbean Sea (Fritts et al. 1983a and 1983b; Turtle Expert Working Group [TEWG], 1998). Important marine habitats for sea turtles in and near the AOI include nesting beaches, estuaries and embayments, and nearshore hard substrate areas.

Nesting of all five species of sea turtles has been documented along the coasts of western Florida, Mississippi, Alabama, and southern Texas adjacent to the AOI **(Table 4.3-1 and Figure 4.3-1** of this Programmatic EIS). With the exception of Florida, sea turtle nesting in the Northern GOM is often not systematically documented. Texas beaches support significant nesting by Kemp's ridley turtles, mostly on North and South Padre Islands. An average of 136 Kemp's ridley nests per year were documented from Texas from 2010 through 2014 (Shaver, official communication, 2015). In Louisiana and Mississippi, no regular surveys are conducted so nesting reports are anecdotal. Louisiana supports low levels of nesting by loggerhead and possibly Kemp's ridley turtles, mostly on Breton and Chandeleur Islands and in Grand Isle. One leatherback turtle was observed nesting on Chandeleur Island in 1989 (Lauritsen, official communication, 2015). Mississippi beaches support low levels (zero to 15 nests per year) from loggerheads and possibly Kemp's ridley turtles, primarily on Petit Bois and Horn Islands (Lauritsen, official communication, 2015). Alabama has documented an average of 68 loggerhead and 1 Kemp's ridley nest per year from 2002 to 2014 (Ingram, official communication, 2015). While nesting of all five species has occurred historically along the beaches of the northern GOM, nesting occurs most dominantly along western Florida and south Texas/Padre Island beaches (**Table 4.3-1** of this Programmatic EIS). Most sea turtle species move seasonally between nesting and foraging or developmental habitats (Mansfield et al., 2009; Hawkes et al., 2011).

While nesting beaches adjacent to the AOI are subject to human impacts such as the presence of artificial lighting or man-made structures on beaches, natural events such as tropical cyclones (including hurricanes and tropical storms) also impact sea turtle nests. Studies suggest that tropical cyclones are a significant factor in observed sea turtle nesting declines (van Houtan and Bass, 2007). It is anticipated that the frequency of these storm events is likely to increase with changes in global climate (Webster et al., 2005; Pike and Stiner, 2007). Generally, storm-induced impacts to nesting beaches include beach flooding and the displacement of large volumes of sand (Pike and Stiner, 2007). Sea turtle eggs lose and gain water quickly depending on nest conditions, and nests exposed to seawater may be lost because of inhibited oxygen exchange or rapid freshwater loss to saline seawater (Packard, 1999). Displacement of sand during storm events may expose and destroy established nests or may alter beach morphology to where it is not suitable nesting habitat. Factors that may affect nesting success during storm seasons include the distance of the nest from shore, nest depth, and nesting season.

Most sea turtles exhibit differential distributions throughout their various life stages (hatchling, juvenile, adult) (Márquez-M, 1990; Hirth, 1997; Musick and Limpus, 1997). Hatchling sea turtles typically spend the first years of life in the oceanic environment, drifting in convergence zones and *Sargassum* rafts where they find refuge and food (USDOC, NMFS and USDOI, FWS, 2008; Hirth, 1997). Post-hatchling sea turtles spend nearly a decade growing in the pelagic "early juvenile nursery habitat" before migrating to distant feeding grounds, which are known as the "later juvenile developmental habitat" (Musick and Limpus, 1997). Shallow nearshore and inshore waters represent the later juvenile developmental habitat most often used by hard-shelled sea turtles. For leatherback turtles, however, the later developmental habitat can be a coastal feeding area in temperate waters or an offshore feeding area in tropical waters depending on the season (Frazier, 2001).

Sea turtles undergo complex seasonal movements that are influenced by changes in ocean currents, turbidity, salinity, and food availability (Musick and Limpus, 1997). Migratory behavior of adult sea turtles is much better understood than that of hatchlings and juveniles due to the development and use of satellite telemetry. Many female sea turtles have been tracked after nesting. Some species have been tracked to a neritic environment (defined as a shallow-water environment or the nearshore marine zone extending from the low-tide level to a depth of approximately 200 m [656 ft] or the shelf break) where they sometimes stay for 1 to 4 years. Juvenile and subadult sea turtles may actively move across the GOM to neritic developmental habitats and adult foraging habitats, respectively. Adult foraging habitats may be, in some populations, geographically distinct from juvenile developmental habitats (Musick and Limpus, 1997).

3.1 Loggerhead Sea Turtle

Loggerhead sea turtles are the most commonly occurring sea turtle species in U.S. waters, including the AOI. The loggerhead sea turtle is a large hard-shelled sea turtle, with adults reaching a carapace length of approximately 1 m (3 ft) and a weight of 116 kg (256 lb) in the U.S. Atlantic and GOM region (USDOC, NMFS and USDOI, FWS, 2008).

3.1.1 Range and Spatial Distribution

The loggerhead sea turtle has a circumglobal distribution in tropical and temperate waters and occurs throughout the GOM (USDOC, NMFS and USDOI, FWS, 2008). Loggerhead sea turtles nest almost exclusively in warm temperate regions throughout the world, with a major nesting population located in peninsular Florida that produces >1,000 nests per year; a smaller nesting subpopulation exists in the Florida Panhandle region of the northern GOM and produces <1,000 nests annually (TEWG, 2009). In the remainder of the northern GOM, a much smaller amount of loggerhead nesting occurs in Alabama, Mississippi, and Texas, but principally in Alabama (Conant et al., 2009; TEWG, 2009).

Loggerhead sea turtles are highly migratory, making seasonal and annual long-distance migrations between foraging and nesting sites (Godley et al., 2003). Moncada et al. (2010) reported that it is common for loggerhead sea turtles to make extended transoceanic journeys and then return to specific nesting beaches. Female loggerhead sea turtles tagged after nesting on GOM beaches traveled in shallow nearshore waters as well as deep offshore waters to an area between the Dry Tortugas and Cape San Blas, Florida, where many resided for up to a year, while others migrated out of the GOM (TEWG, 2009) or into the western GOM (Hart et al., 2014). Satellite tracking of tagged post-nesting loggerhead sea turtles in the northern GOM has shown the year-round use of northern GOM habitat and five foraging areas for female loggerheads that nest along the northern GOM coast (Hart et al., 2014).

3.1.2 Population Status

Overall, the population structure of the loggerhead sea turtle is complex and difficult to evaluate (Bolten and Witherington, 2003). According to the Loggerhead Biological Review Team, there are nine DPSs of loggerhead sea turtles (Conant et al., 2009). The Northwest Atlantic Ocean DPS occurs in an area bounded by 60° N. latitude and the equator, with 40° W. longitude as the eastern boundary, and includes the GOM (76 FR 58868). Collectively, the Northwest Atlantic Ocean DPS hosts the most significant nesting assemblage of loggerhead sea turtles in the western hemisphere and is one of the two largest loggerhead nesting assemblages in the world (Conant et al., 2009). Within the most recent recovery plan for the Northwest Atlantic DPS of the loggerhead sea turtle, the NMFS has identified five recovery units, four of which are located in U.S. waters (USDOC, NMFS and USDOI, FWS, 2009) (**Figure 4.3-2** of this Programmatic EIS). A recovery unit is defined as a management sub-unit of the listed entity (in this case, species), geographically or otherwise identifiable, that is essential to the recovery of the entire listed entity or conserves genetic or demographic robustness, important life history stages, or other feature for long-term sustainability of the entire listed entity. Three loggerhead sea turtle recovery units are located within the AOI: the Dry Tortugas Recovery Unit (DTRU), extending throughout the islands west of Key West, Florida; the Northern Gulf of Mexico Recovery Unit (NGMRU), extending from Franklin County on the northwest Gulf Coast of Florida through Texas; and the Peninsular Florida Recovery Unit (PFRU), which extends from the Florida-Georgia border through Pinellas County on the west coast of Florida, excluding the islands off Key West, Florida (USDOC, NMFS and USDOI, FWS, 2009).

Estimating sea turtle populations is difficult, and the status of the population often is estimated based on the number of annual nests at different locations within a region, anthropogenic threats, and mortality estimates (Conant et al., 2009). Nest counts always underestimate the population of sea turtles because they only include reproductively active females and do not take into account males, juveniles, or non-reproductive females. The PFRU represents approximately 87 percent of all nesting that occurs in the Northwest Atlantic Ocean DPS (Ehrhart et al., 2003). In recent years, the counts of loggerhead nests in Peninsular Florida were highly variable, with a decline of more than 40 percent between 1998 and 2007 (Witherington et al., 2009), which was followed by a more recent increase in the number of loggerhead nests (State of Florida, Fish and Wildlife Conservation Commiission, Fish and Wildlife Research Institute, 2015c). The most current loggerhead nesting trend for the Northwest Atlantic Ocean DPS, from 1989 to 2010, is very slightly negative, but the rate of decline is not statistically different from zero (76 FR 58868). Recent aerial surveys of northwest Atlantic waters from Cape Canaveral, Florida, to the Gulf of St. Lawrence provided an abundance estimate of 801,000 loggerhead sea turtles in U.S. Atlantic waters; this estimate did not include loggerhead sea turtles in the northern GOM (76 FR 58868). The number of loggerhead sea turtles nesting in the NGMRU is the third largest of the four U.S. recovery units (USDOC, NMFS and USDOI, FWS, 2009). The most recent recovery plan reported that the number of nests in the PFRU averaged 64,513 annually between 1989 and 2007, with nesting during this period declining by 1.6 percent (USDOC, NMFS and USDOI, FWS, 2009). The DTRU averaged 246 nests per year, though only 9 years were surveyed and no trend was detected with such as small dataset. The NGMRU averaged 906 nests per year from 1995 through 2007, with analysis of western Florida nesting showing a declining trend of 42 percent annually during this period (USDOC, NMFS and USDOI, FWS, 2009). In 2014, loggerhead nest counts for the PFRU were approximately 47,000 nests, which was slightly higher than the highest nest count in 1998 (State of Florida, Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, 2015c).

3.1.3 Ecology and Life History

Loggerhead sea turtles use three different types of marine habitats during their life (i.e., terrestrial [beaches], neritic [nearshore waters], and oceanic [open ocean]) and feed primarily on mollusks and crustaceans (USDOC, NMFS and USDOI, FWS, 2009). Loggerhead sea turtle nesting generally occurs from April to September for the Northwest Atlantic Ocean DPS, with peak nesting occurring in June and July (Weishampel et al., 2006); females nest every 2.5 to 3.7 years (USDOC, NMFS and USDOI, FWS, 2009). Age at sexual maturity is late in life at approximately 35 years of age; average clutch size is between 100 and 126 eggs, and incubation is between 42 and 75 days. The mean number of clutches per laying female is 3 to 5.5 per breeding season, with inter-nesting intervals ranging from 12 to 15 days (USDOC, NMFS and USDOI, FWS, 2009). The lifespan of the loggerhead sea turtle is 57 years or more.

Immediately after loggerhead sea turtle hatchlings emerge from the nest, they actively swim offshore into oceanic areas of local convergence zones and major gyre systems, often characterized by accumulations of floating *Sargassum*. The duration of this oceanic post-hatchling juvenile stage is variable but generally ranges from 7 to 12 years (Bolten and Witherington, 2003). Afterward, oceanic juveniles actively migrate to nearshore (neritic) developmental habitats. Within the western North Atlantic, including the AOI, some neritic juveniles make seasonal foraging migrations into temperate latitudes as far north as New York. Most juveniles are south of Cape Hatteras, North Carolina, by January (Musick and Limpus, 1997). Neritic juvenile loggerhead sea turtles are likely to occupy shallow-water developmental habitats in nearshore areas of the AOI.

Information about daily movement and dive behaviors of loggerheads in the open ocean is limited, but new technology has recently allowed researchers to study this type of behavior in the sea turtles' natural environment (Sobin, 2008). Houghton et al. (2000) recorded observations of loggerhead sea turtles around the Greek island of Kefalonia and discovered that these individuals made frequent shorter duration dives than previously reported in the literature; on average, four loggerhead sea turtles made 96 dives over 29 days, with dive durations ranging from 1 to 5 minutes. Off Hawaii, the dive depth distributions of four sea turtles (2 loggerhead sea turtles and 2 olive ridley sea turtles [*Lepidochelys olivacea*]) were monitored to understand how mitigation measures could be implemented for longline fisheries (Polovina et al., 2003). Based on the research, Polovina et al. (2003) found that there were diurnal and species differences in dive profiles. Overall, the researchers found that the sea turtles spent more time at the surface and dove deeper during the day than at night. Most (70%) of the dives were no deeper than 5 m (16 ft), and the deepest dive recorded for one of the loggerhead sea turtles was 178 m (584 ft); loggerhead sea turtles generally dive to depths less than 100 m (328 ft). Loggerhead diving behavior has been investigated off Japan by Hatase et al. (2007), who found that diving behavior is somewhat size dependent. In southwest Florida, Sobin (2008) reported that loggerhead sea turtles spent more time near the surface in the morning than in the evening, which was different than previous studies.

3.1.4 Threats

Threats to the loggerhead population are similar to those for other sea turtles and include numerous anthropogenic threats such as commercial fisheries, habitat loss (nesting beaches), climate change (e.g., sea-level rise, shifts in prey availability, and increasing temperature), pollution, boat strikes, and disease (Conant et al., 2009; Hawkes et al., 2009; Witt et al., 2010a).

3.1.5 Current Status

The loggerhead turtle was listed as a threatened species on July 28, 1978 (43 FR 32800). In 2011, the NMFS and FWS listed nine DPSs of loggerhead sea turtles under the ESA (76 FR 58868). Loggerhead sea turtles found in the GOM are part of the Northwest Atlantic Ocean DPS, which is listed as threatened under the ESA. In July 2014, the NMFS designated ESA critical habitat for the Northwest Atlantic Ocean DPS, which includes nearshore reproductive habitat, winter areas, breeding areas, constricted migratory corridors, and *Sargassum* habitat (79 FR 39856). Nearshore reproductive and *Sargassum* critical habitat for the loggerhead sea turtle are located in the northern GOM, but only the *Sargassum* habitat is located in the AOI (**Figure 4.3-3** of this Programmatic EIS).

3.2 GREEN SEA TURTLE

The green sea turtle is the largest cheloniid sea turtle. Adults can reach 1 m (3 ft) in carapace length and weigh 136 to 159 kg (300 and 350 lb) (USDOC, NMFS and USDOI, FWS, 2015). During the recent 5-year status review, 11 DPSs were identified, including the North Atlantic DPS, which encompasses animals found in the GOM (USDOC, NMFS and USDOI, FWS, 2015).

3.2.1 Range and Spatial Distribution

The green sea turtle is a circumglobal species found in the Mediterranean Sea and the Pacific, Indian, and Atlantic Oceans (Seminoff et al., 2015). The green sea turtle can be found in tropical and subtropical waters between 30° N. and 30° S. latitude, and to a lesser extent in temperate waters (Seminoff et al., 2015). Satellite tagging data indicate that, like other sea turtles, green sea turtles display highly migratory behavior, making vast seasonal coastal and annual transoceanic migrations (Godley et al., 2003, 2008, and 2010). Green sea turtles are vulnerable to cold temperatures, so in many locations they are found only seasonally within the AOI (Foley et al., 2007). Based on satellite tagging research by Hart and Fujisaki (2010), green sea turtles display daily and seasonal movement patterns that are associated with foraging strategies. Hart and Fujisaki (2010) indicated that locations with optimal habitats (e.g., sources of marine algae) are likely where small juvenile green sea turtles may be found. Based on this study, it is possible that juvenile green sea turtles may be found in various shallow-water inshore areas in the AOI where macroalgae is reported. Green sea turtles nest infrequently along the Gulf Coast on Florida, Alabama, and Texas beaches, with the most important nesting sites located outside of the AOI along the Atlantic Coast of Florida (USDOC, NMFS and USDOI, FWS, 2007a and 2015).

3.2.2 Population Status

The green sea turtle population is considered severely depleted in comparison to its estimated historical levels (USDOC, NMFS and USDOI, FWS, 2007a). Currently, there is no reliable green sea turtle population estimate, but inferences have been attempted using age-based survivability models and nesting data (Bjorndal et al., 2003). Nesting data indicate that between 200 and 1,100 females nest annually on continental U.S. beaches, mostly outside of the AOI.

3.2.3 Ecology and Life History

Hatchling green sea turtles swim offshore to areas of convergence zones characterized by driftlines and patches of *Sargassum*. Musick and Limpus (1997) experiments with post-hatchling green sea turtles in the laboratory suggest that they are more open-water animals than loggerhead or hawksbill sea turtles and may avoid floatlines of *Sargassum*. In addition, their strong counter-coloration suggest that they spend more time swimming in open water. Data also suggest that recruitment of green sea turtles into neritic developmental habitats occurs at smaller body sizes (30 to 40 cm [12 to 16 in]) than for loggerhead sea turtles (Bjorndal and Bolten, 1988). Neritic developmental habitats in the western North Atlantic range from Long Island Sound to southern Florida, the GOM, and the tropics. Within the AOI, these habitats include shallow nearshore hard substrate, embayments, and other inshore habitats along the west coast of Florida, Alabama, and southern Texas.

In the GOM, green sea turtle nesting generally occurs from June to mid-September; females nest at 2- to 4-year intervals. The majority of North Atlantic DPS nesting occurs on the east coast of Florida where a mean of 5,055 nests were deposited each year from 2001 to 2005 and 10,377 nests each year from 2008 to 2012 (USDOC, NMFS and USDOI, FWS, 2015). Nesting occurs in all coastal counties of Florida except the Big Bend area of west-central Florida. Nesting totals for the west coast of Florida in 2014 included 73 green sea turtle nests and 54 non-nesting emergences (State of Florida, Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, 2015d). Nesting also has been documented in Padre Island National Seashore and South Padre Island, Texas (USDOI, NPS, 2015), and in Alabama prior to 2003, though not confirmed by hatchling identification (USDOI, FWS, 2008a). Similar to other sea turtles, age at sexual maturity is not reached until late in life at approximately 20 to 50 years of age; clutch size ranges from 75 to 200 eggs, and incubation is between 20 and 50 days. Female green sea turtles usually deposit three to five clutches per breeding season, with inter-nesting intervals of 12 to 14 days every 2 to 3 years (USDOC, NMFS and USDOI, FWS, 2007a and 2015).

Hazel et al. (2009) documented various daily diving behaviors of green sea turtles in nearshore foraging habitats in Australia. The researchers found that the majority of the sea turtles spent most of time (89 to 100%) at depths (<5 m [16 ft]) near the surface. They also found that dives were shorter and shallower during the day than at night, suggesting that green sea turtles rest at night and forage during the day. Hazel et al. (2009) also indicated that this phenomenon was consistent with the requirement to surface more often during increased activity (daytime foraging). In addition, Hazel et al. (2009) found that green sea turtle dives became longer as water temperatures decreased. Despite the ability for sea turtles to dive to deep depths, Hazel et al. (2009) postulated that green sea turtles chose not to dive to deeper depths at night given the distance (3 or 6 km [1.9 or 3.7 mi]) it was from shallow (foraging areas) to deeper waters. Off the Hawaiian Islands, Rice and Balazs (2008) documented the diving behavior of two adult green sea turtles in the open-ocean environment. Findings demonstrated that green sea turtles also displayed a shallow daytime and deeper nighttime dive pattern. In general, the two green sea turtles spent the day near the surface taking shallow and short duration dives and made dives to 35 to 55 m (115 or 180 ft) at night, with mean dive duration ranging from 33 to 44 minutes. The maximum depths recorded were two dives deeper than 135 m (445 ft) by one female and one dive to 100 m (328 ft) by one male (Rice and Balazs, 2008).

3.2.4 Threats

Green sea turtles have various anthropogenic threats such as commercial fishery interactions, habitat loss, global climatic changes, and fibropapillomatosis (USDOC, NMFS and USDOI, FWS, 2007a). Fibropapillomatosis is a disease characterized by the presence of internal and external tumors (fibropapillomas) that may grow large enough to hamper swimming, vision, feeding, and potential escape from predators (Herbst, 1994). While reported in all sea turtle species, the frequency of infection is much higher in green sea turtles for unknown reasons. Despite the uncertainty of population-level impacts of fibropapillomatosis to green sea turtles, a high percentage of strandings have been attributed to the disease (USDOC, NMFS and USDOI, FWS, 2007a). Given these inadvertent impacts, there are numerous global research priorities that focus on understanding these threats and how to reduce their negative impacts to sea turtle populations (Hamann et al., 2010).

3.2.5 Current Status

The green sea turtle was listed as a threatened species on July 28, 1978, with all populations listed as threatened except for the breeding populations of Florida and the Pacific Coast of Mexico, which are endangered (43 FR 32800). Currently, 11 DPSs of the green sea turtle are proposed for listing under the ESA, with the North Atlantic DPS proposed as threatened (80 FR 15272).

The green sea turtle is protected and managed by the NMFS and FWS. Under the leadership of these Federal agencies, various conservation and recovery strategies have been implemented since green sea turtles were listed under the protection of the ESA. Some of these management measures include international and domestic environmental policies, which include numerous laws, rules, and regulations. Conservation measures include establishing various conservation programs under the green sea turtle recovery plan and implementing a variety of restrictions on commercial fishery activities (e.g., requiring the use of circle hooks in pelagic longline fisheries and sea turtle excluder devices [TEDs] in trawls) to prevent serious injury and mortality to sea turtles; the NMFS has also developed a strategy for sea turtle conservation and recovery for Atlantic and Gulf of Mexico fisheries (gear-based approach). Moreover, there are various other restrictions to protect sea turtles such as beach lighting restrictions during the sea turtle nesting season, which is generally from late spring to late summer, and offshore hopper dredging restrictions.

In 1998, the NMFS and FWS jointly designated critical habitat for the green sea turtle as the waters of Culebra Island, Puerto Rico, and its outlying keys (63 FR 46693). Under the designation process, the NMFS identified critical habitat for green sea turtles as specific geographical areas that have the physical or biological features essential to the conservation of the green sea turtle that may require special management considerations.

3.3 Hawksbill Sea Turtle

The hawksbill sea turtle is a medium-weight cheloniid sea turtle. Adults can reach a carapace length of 1.1 m (3.5 ft) and weight of 82 kg (180 lb) (USDOC, NMFS and USDOI, FWS, 2013a).

3.3.1 Range and Spatial Distribution

The hawksbill sea turtle is distributed circumglobally in the Pacific, Indian, and Atlantic Oceans (USDOC, NMFS and USDOI, FWS, 2013a). The hawksbill sea turtle can be found in tropical and subtropical waters between 30° N. and 30° S. latitude (USDOC, NMFS and USDOI, FWS, 2013a). Hawksbill sea turtles display highly migratory behavior, with satellite tagging data demonstrating that these sea turtles undergo short and long migrations from nesting to foraging grounds (Blumenthal et al., 2009; USDOC, NMFS and USDOI, FWS, 2013a). In the western North Atlantic, hawksbill sea turtles are widely distributed throughout the Caribbean Sea and occur regularly in southern Florida, the GOM, the Greater and Lesser Antilles, and along the Central American mainland south to Brazil. However, hawksbill sea turtle nesting on GOM beaches is extremely rare; one nest was documented on Padre Island, Texas, in 1998 (Mays and Shaver, 1998). Hawksbill sea turtles use a wide range of habitats during their lifetime but have a foraging habitat preference for coral reefs, which are found in only a few isolated locations of the AOI. Limited information on home ranges of hawksbill sea turtles suggests they are smaller than for other sea turtle species (Witt et al., 2010b). In addition to offshore and reef habitats, hawksbill sea turtles are known to use mangrove-fringed bays, estuaries, and Caribbean seagrass habitats (Carr, 1952; Bjorndal and Bolten, 1988 and 2010).

3.3.2 Population Status

The hawksbill sea turtle population is severely depleted and continues to be threatened (Bjorndal, 1999). Although there is no reliable hawksbill sea turtle population estimate, conclusions have been made from nesting data. There are no nesting estimates for hawksbill sea turtles within the AOI, but the number of nesting females per season in the Caribbean ranges from 5 to 18 in Bonaire, Netherlands Antilles, to 400 to 833 in Cuba (USDOC, NMFS and USDOI, FWS, 2013a).

The recent 5-year status review (USDOC, NMFS and USDOI, FWS, 2013a) reported that, of 63 nesting sites for which historic trends could be assessed, all 63 (100%) showed a decline during the long-term period of 20 to 100 years. Among 41 nesting sites for which recent trend data (past 20 years) are available, 10 (24.4%) are increasing, 3 (7.3%) are stable, and 28 (68.3%) are decreasing. Although greatly depleted from historic levels, nesting populations in the Atlantic Ocean in general are doing better than in the Indo-Pacific. Limpus and Miller (2008) reported that the hawksbill sea turtle nesting population in north Queensland, Australia, has declined 3 percent in recent time. However, in Barbados, West Indies, hawksbill sea turtle nesting data show that the population may be improving (Beggs et al., 2007). Beggs et al. (2007) reported increases from 316 nests and 77 females in 1992 to 2,016 nests and 492 females in 2004. Based on these data, Beggs et al. (2007) indicated that the hawksbill sea turtle population in Barbados could be the second largest rookery in the wider Caribbean; the largest rookery is in Mexico. Despite showing some signs of recovery, the hawksbill sea turtle population has not reached a level that warrants delisting or reclassification (USDOC, NMFS and USDOI, FWS, 2013a).

3.3.3 Ecology and Life History

Hatchling hawksbill sea turtles emerge from the nest and actively swim offshore at night to areas of water-mass convergence. Hawksbill post-hatchlings in the laboratory appear to be attracted to patches of floating *Sargassum*, which they use as protective cover (Musick and Limpus, 1997). Data suggest that juvenile (or post-hatchling) hawksbill sea turtles move into neritic developmental habitats at a smaller size than loggerhead and green sea turtles; neritic developmental habitats include shallow coral reefs and mangrove estuaries (Witzell, 1983).

Adult hawksbill sea turtles specialize on a diet of sponges and feed very selectively on specific species in the class Demospongiae (Bjorndal, 1997). They may also consume other food items such as algae and other benthic invertebrates (Márquez-M, 1990). In the Caribbean, hawksbill sea turtles often are seen feeding among coral reefs and hard bottom communities (Blumenthal et al., 2009). Hawksbill sea turtles primarily nest on Mexican (Yucatán Peninsula) and Caribbean (Puerto Rico [Culebra, Mona, and Vieques Islands] to Barbados) beaches; some nesting has been reported in South Florida and the Florida Keys, but this is rare (USDOC, NMFS and USDOI, FWS, 1993). Depending on the location, nesting season occurs during various summer and fall months (USDOC, NMFS and USDOI, FWS, 1993). For example, hawksbill sea turtle nesting occurs from July to October on Buck Island (U.S. Virgin Islands) and from August to October on Mona Island (Puerto Rico), with females nesting at 2- or 3-year intervals. In Barbados, Beggs et al. (2007) reported that nesting occurred year-round from 1997 through 2004, with peak months of June to August. Beggs et al. (2007) also discovered that the nesting interval ranged from 2 to 6 years, with a mean of 2.5 years. Overall, the average nesting season for the hawksbill sea turtle (6 months) is longer than for other sea turtles (USDOC, NMFS and USDOI, FWS, 1993). Female hawksbill sea turtles usually deposit three to five clutches per breeding season (at approximately 14-day intervals) (Beggs et al., 2007; USDOC, NMFS and USDOI, FWS, 2013a). Age at sexual maturity is between 20 and 40 years; average clutch size is approximately 135 eggs, and incubation is approximately 60 days.

There is some information about the diving behavior of hawksbill sea turtles. In Milman Island, Australia, Bell and Parmenter (2008) recorded the diving behavior of nine female hawksbill sea turtles that had previously laid eggs and two females that had not successfully laid eggs. Results from the study showed that the nine hawksbill sea turtles primarily spent their time near the surface but occasionally made deeper dives. The maximum depth recorded was 21.5 m (71 ft), and the researchers did not find any significant difference between day and night diving behavior. On average, the dive time and surface interval for the sea turtles were 31.2 and 1.6 minutes, respectively. On the reefs of Mona Island, Puerto Rico, van Dam and Diez (1997) reported the diving patterns of five juvenile hawksbill sea turtles. Results showed that mean dive behavior associated with foraging ranged from 8 to 10 m (26 to 33 ft), dive durations ranged from 19 to 26 minutes, and surface intervals ranged from 37 to 64 seconds. Night dives ranged from 7 to 10 m (23 to 33 ft), dive durations ranged from 35 to 47 minutes, and surface intervals ranged from 36 to 60 seconds (van Dam and Diez, 1997).

3.3.4 Threats

The recovery of the hawksbill sea turtle population is threatened by many ongoing anthropogenic threats, including commercial fishery interactions, habitat loss (e.g., coral reefs), global climatic changes (e.g., sea-level rise), and fibropapillomatosis (USDOC, NMFS and USDOI, FWS, 2013a). The continued overutilization of hawksbill sea turtles for commercial, recreational, scientific, or educational purposes is another major threat to the recovery of the species (USDOC, NMFS and USDOI, FWS, 2013a).

3.3.5 Current Status

The hawksbill sea turtle was listed as endangered on June 2, 1970 (35 FR 8491), and is considered critically endangered by the IUCN based on global population declines of more than 80 percent during the last 3 generations (105 years) (Meylan and Donnelly, 1999). The conservation and recovery of the hawksbill sea turtle is administered through various regulatory mechanisms such as designating critical habitat and implementing conservation regulations. Critical habitat for the hawksbill sea turtle was designated in 1982 and additional critical habitat was designated in 1998 (63 FR 46693). Critical habitat for the hawksbill sea turtle includes Mona, Culebrita, and Culebra Islands in Puerto Rico, as well as the waters surrounding the islands of Mona and Monito (3 to 5 km [1.9 to 3.1 mi]). Critical habitat also includes specific beaches on Culebra Island (Playa Resaca, Playa Brava, and Playa Larga). Other conservation measures governed by Federal agencies include implementing various recovery plan and commercial fishery measures to prevent further serious injury and mortality to sea turtles. The agencies also support several international agreements for the conservation of sea turtles, such as the South-East Asian Marine Turtle Memorandum of Understanding in the Indian Ocean. Campbell et al. (2009) indicated that co-management by local communities and government agencies is a strategy to improve fisheries management that has the potential to reduce adverse interactions between sea turtles and fisheries.

3.4 Kemp's Ridley Sea Turtle

The Kemp's ridley is one of the smallest species of sea turtles; adults reach approximately 60 to 65 cm (24 to 26 in) in carapace length and weigh 39 to 49 kg (86 to 108 lb) (USDOC, NMFS; USDOI, FWS; and SEMARNAT, 2011).

3.4.1 Range and Spatial Distribution

The distribution of the Kemp's ridley sea turtle is restricted to the North Atlantic Ocean, principally in the GOM, with moderate numbers recorded along the U.S. Atlantic Coast from Florida to New England and up to the Grand Banks and Nova Scotia (Bleakney, 1955; Márquez-M., 1994; Watson et al., 2004). The primary habitat for adult Kemp's ridley sea turtles is nearshore waters of 37 m (121 ft) depth or shallower, with GOM survey data showing that the majority of Kemp's ridley sea turtles occur in continental shelf waters. Juvenile and adult Kemp's ridley sea turtles typically are found in shallow waters, especially in seagrass areas (Márquez-M., 1990; Ernst et al., 1994).

Historical data show that adult females have been seasonally abundant in prey-rich waters such as the mouth of the Mississippi River and the Campeche Banks, migrating toward Rancho Nuevo during the nesting season (Carr, 1963; Pritchard, 1969; Pritchard and Márquez-M., 1973; Hildebrand, 1995; Shaver et al., 2013). Shaver et al. (2013) reported that most areas defined as high-use foraging areas for Kemp's ridley sea turtles in the GOM were relatively close to shore (mean distance of 2.2 km [1.4 mi] from shore) in water depths less than 68 m (223 ft) and within a narrow temperature range (24.1°C to 27.6°C [75.4°F to 81.7°F]). The concentration of these areas, particularly along the coast of Louisiana, suggests that the areas represent critical foraging hotspots. Females have been tracked to foraging areas from the Yucatan Peninsula to southwest Florida (USDOC, NMFS and USDOI, FWS, 2007b). Key foraging areas within the AOI include Sabine Pass, Texas; Caillou Bay and Calcasieu Pass, Louisiana; Bug Gulley, Alabama; Cedar Keys, Florida; and Ten Thousand Islands, Florida (USDOC, NMFS and USDOI, FWS, 2007b). Kemp's ridley sea turtles display some seasonal and coastal migratory behavior; satellite tagging data indicate that Kemp's ridley sea turtles transit between nearshore and offshore waters from spring/summer to fall/winter, which coincides with seasonal water temperature changes (USDOC, NMFS; USDOI, FWS; and SEMARNAT, 2011).

Kemp's ridley sea turtles primarily nest on beaches in Mexico (i.e., Tamaulipas [Rancho Nuevo, Tepehuajes, and Playa Dos] and Veracruz [Lechuguillas and Tecolutla]) and to a lesser extent in Texas (i.e., South Padre Island, North Padre Island, and Boca Chica Beach). Nesting by Kemp's ridley sea turtles has also been documented in Alabama and Florida (USDOC, NMFS; USDOI, FWS; and SEMARNAT, 2011).

3.4.2 Population Status

The Kemp's ridley sea turtle population is severely depleted, and it is considered the most endangered sea turtle species (USDOI, FWS, 1999). The nesting population of Kemp's ridley sea turtles has increased exponentially, which is indicative of a corresponding increasing trend in the overall population. From 1988 to 2003, the number of nests observed at Rancho Nuevo and nearby beaches increased 15 percent per year (Heppell et al., 2005), and by 2009, the total number of nests recorded at Rancho Nuevo and adjacent beaches exceeded 20,000, which represents approximately 8,000 females nesting during the nesting season (USDOC, NMFS; USDOI, FWS; and SEMARNAT, 2011). From 2002 to 2010, 911 Kemp's ridley nests were documented along the Texas coast, principally along the southernmost part of the coast, which is more than 11 times the 81 nests recorded over the previous 54 years (1948 to 2001) (Shaver and Caillouet, 1998; Shaver et al., 2005). These increases in nest counts were a likely indication that the population is on its way to recovery. However, scientists reported at the Second International Kemp's Ridley Sea Turtle Symposium in Texas that the total number of nests had declined during 2011 to 2013, with 12,000 nests reported in 2013, and a similar decline reported for 2014 (Caillouet, 2014; Cavazos-Lliteras and Gerardo-Cardenas, 2014; Shaver et al., 2014; Virata, 2014).

3.4.3 Ecology and Life History

Hatchling Kemp's ridley sea turtles leave the nest at night and actively swim offshore into the anticyclonic Mexican Current and into the northern GOM. Some oceanic post-hatchling and juvenile Kemp's ridley sea turtles remain in the northern GOM until they migrate inshore to neritic developmental habitats, while others may be swept into the Loop Current and then into the Gulf Stream (Collard, 1990). Neritic developmental habitats include shallow coastal areas in the GOM and areas of the western North Atlantic as far north as Long Island Sound. Neritic juvenile Kemp's ridley sea turtles undergo seasonal migrations within the AOI.

The Kemp's ridley sea turtle is a carnivore throughout its life cycle (Márquez-M, 1990). Adult and subadult Kemp's ridley sea turtles are benthic feeders that primarily feed on crabs. Other preferred food items include shrimps, mollusks, sea urchins, and fishes (opportunistically) (USDOC, NMFS; USDOI, FWS; and SEMARNAT, 2011). Kemp's ridley sea turtles primarily nest on GOM beaches in Mexico from April through July during daylight hours (Márquez-M., 1990). The mean clutch number is 2.5 per breeding season (14 to 28 days), average clutch size is approximately 100 eggs, and incubation is between 45 and 58 days; females nest at 2-year intervals (USDOC, NMFS; USDOI, FWS; and SEMARNAT, 2011). Age at sexual maturity for wild Kemp's ridleys has been reported to be between 10 and 16 years.

Available information about Kemp's ridley sea turtles in the open ocean is limited. Dive times have been documented to range from a few seconds to a maximum of 167 minutes, with routine dives lasting between 16.7 and 33.7 minutes (Mendonca and Pritchard, 1986; Renaud, 1995). Over a 12-hour period, Kemp's ridleys may spend 89 to 96 percent of the time submerged (Byles, 1989; Gitschlag, 1996). In the GOM, Schmid et al. (2002) reported a surface interval of 1 to 88 seconds and a mean submergence duration of 8.4 minutes; overall, these researchers did not find any differences between day and night surface activities but did find a diel difference in some years (1994 vs. 1995). The data also showed that the mean submergence interval at the night was longer than during the day (Schmid et al., 2002).

3.4.4 Threats

The Kemp's ridley sea turtle is threatened by many activities such as commercial fishery interactions (entrapment in shrimp trawl nets), ongoing habitat loss, disease, climatic changes, pollution, and ecosystem alterations (USDOC, NMFS; USDOI, FWS; and SEMARNAT, 2011). Given that the majority of the population nests in one location in Mexico, human population growth and urban development are serious threats to Kemp's ridley nesting beaches (USDOI, FWS, 1999). Mexico and the U.S. (NMFS) collaborate to conserve and restore the species under the Kemp's Ridley Restoration and Enhancement Program (Head Start) in Rancho Nuevo, Tamaulipas, Mexico. This government program and the expansion of the Rancho Nuevo Natural Reserve to include the state of Veracruz protects more than 200 km (124 mi) of nesting sites (Márquez-M, 2001). In addition to international collaboration efforts, the NMFS continues to implement various conservation regulations in commercial fisheries such as the use of TEDs to protect all sea turtles, including the Kemp's ridley sea turtle (USDOC, NMFS, 2015b). Other threats to sea turtles include dredging operations, and hopper dredging activities occur throughout the AOI on a regular basis.

3.4.5 Current Status

The Kemp's ridley was listed as endangered on December 2, 1970 (35 FR 18319). The conservation and recovery of the Kemp's ridley sea turtle is conducted through various regulatory mechanisms such as habitat protection efforts, protecting nesting females, and maintaining or increasing hatchling production levels. Other conservation measures include restrictions on commercial fishery activities to prevent serious injury and mortality to sea turtles as well as several international agreements such as CITES. Critical habitat has not been designated for the Kemp's ridley sea turtle, but the NMFS and FWS were petitioned on February 17, 2010, to designate Kemp's ridley critical habitat under the ESA (USDOC, NMFS, 2011); no decision on critical habitat designation has been forthcoming. The agencies continue to evaluate data and consider whether the scientific information warrants designating the proposed areas (i.e., nesting beaches along the Texas coast and marine habitats in the Gulf of Mexico and Atlantic Ocean to water depths of 40 m [131 ft]) as critical habitat.

3.5 Leatherback Sea Turtle

The leatherback sea turtle is the largest species of sea turtle and the largest reptile; adults reach up to 1.8 m (6 ft) in carapace length and can weigh as much as 907 kg (2,000 lb) (Ernst et al., 1994). They are easily distinguished from all other sea turtle species by their large spindle-shaped, leathery, and unscaled carapaces that possess a series of parallel dorsal ridges, or keels (Márquez-M, 1990).

3.5.1 Range and Spatial Distribution

The leatherback sea turtle is the most oceanic of all sea turtle species and is a cosmopolitan species, occurring in the Mediterranean Sea and Indian, Pacific, and Atlantic Oceans, including the GOM (USDOC, NMFS and USDOI, FWS, 2013b). The leatherback sea turtle is the most abundant sea turtle in oceanic waters of the northern GOM, especially over the continental slope (Mullin and

Hoggard, 2000), but nesting on GOM beaches is rare. Leatherback nesting in the western North Atlantic Ocean is restricted to subtropical to tropical latitudes from Brazil to the southeastern U.S. and throughout the West Indies, with significant nesting occurring in French Guiana, Suriname, and Costa Rica (Ernst et al., 1994). Within the Atlantic Ocean, excluding Africa, 470 nesting sites have been identified (Dow Piniak and Eckert, 2011). Along the northern GOM, nesting of leatherback sea turtles is only known from Florida beaches; in 2014, four leatherback nests were documented along the west coast of Florida (USDOC, NMFS and USDOI, FWS, 1992; State of Florida, Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institue, 2015d). Once nesting season is over, most leatherback sea turtles leave the waters adjacent to their nesting beaches and travel to feeding grounds in more temperate waters.

Leatherback sea turtles appear to use continental shelf and slope waters in the GOM (Fritts et al., 1983a and 1983b; Collard, 1990; Davis and Fargion, 1996). GulfCet I and II surveys suggest that the region from Mississippi Canyon to De Soto Canyon, especially near the shelf edge, appears to be an important habitat area for leatherback sea turtles (Mullin and Hoggard, 2000). Temporal variability in leatherback sea turtle distribution and abundance suggests that specific areas may be important to this species. During the GulfCet I and II surveys, leatherback sea turtles were sighted in significant numbers during summer and winter surveys. High variability in the relative numbers of leatherback sea turtles sighted within specific areas of the GOM suggests that their distribution and densities are likely associated with opportunistic foraging opportunities (Mullin and Hoggard, 2000). Leatherback sea turtles use the deep offshore waters of the northern GOM, particularly in the De Soto Canyon and Mississippi Canyon areas, for foraging, resting, and as migratory corridors (Davis et al., 2000).

Leatherback sea turtles are highly migratory (Shillinger et al., 2008) and migrate farther than any other reptile (USDOC, NMFS and USDOI, FWS, 2013b). Satellite tagging data demonstrate that leatherback sea turtles display wide-ranging coastal and transoceanic movements (Hays et al., 2006; USDOC, NMFS and USDOI, FWS, 2013b) and have the largest distribution of any sea turtle. Leatherback sea turtles appear to adapt quickly to local environmental conditions as they do not display any restricted distributional or movement behaviors that characterize other sea turtle species (Hays et al., 2006; USDOC, NMFS and USDOI, FWS, 2013b). James et al. (2005a and 2005b) described only a few high-use areas for leatherback sea turtles in the Atlantic compared with the total area traveled through, suggesting low fidelity to any particular area. Eckert (2006) reported that leatherback sea turtles tagged in Trinidad were later located off Newfoundland (Flemish Cap), Canada, and then in Mauritanian waters. Hays et al. (2006) concluded that leatherback sea turtles do not display highly migratory behavior to forage at specific “hotspots” but instead continuously feed as they travel. Leatherback sea turtles did remain in specific areas for short durations to forage, and their diving patterns were correlated with prey distribution and abundance (Hays et al., 2006).

Genetic techniques have distinguished five populations of leatherback sea turtles in the western North Atlantic Ocean: Florida; Northern Caribbean; Western Caribbean; Southern Caribbean (includes northern Brazil); and Southern Brazil (USDOC, NMFS and USDOI, FWS, 2013b). Genetic studies support the natal homing hypothesis, which has been reported for other sea turtles (Godley et al., 2010).

The distribution and developmental habitats of juvenile leatherback sea turtles are poorly understood. In an analysis of available sightings (Eckert, 2002), researchers found that leatherback sea turtles smaller than approximately 1 m (3 ft) in carapace length were only sighted in waters 26°C (79°F) or warmer, while adults were found in waters as cold as 0°C to 15°C (32°F to 59°F) off Newfoundland.

3.5.2 Population Status

Similar to other sea turtles, the leatherback sea turtle population is depleted; however, the population is considered stable or slightly increasing (USDOC, NMFS and USDOI, FWS, 2013b). The most recent population estimate for adult leatherback sea turtles in the Atlantic Ocean is 34,000 to 94,000 individuals (TEWG, 2007). The leatherback sea turtle is found in Florida's coastal waters, and a small number (30 to 60 individuals per year) nest in the state. The index of leatherback nesting in Florida from 1989 to 2014 indicates that there were 27 to 641 nests at core index nesting beaches in 2014. In Florida, the number of leatherback sea turtle nests has been increasing by 10.2 percent (range 3.1 to 16.3%) annually since 1979 (USDOC, NMFS and USDOI, FWS, 2013b). In 2014, four leatherback nests were reported in western Florida (State of Florida, Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, 2015d).

3.5.3 Ecology and Life History

Like other sea turtle species, hatchling leatherback sea turtles leave the nest and actively swim offshore. However, post-hatchling and oceanic juvenile leatherback sea turtles are more active than other sea turtle species (Wyneken and Salmon, 1992). Oceanic juveniles virtually disappear for 4 years (Musick and Limpus, 1997). Their requirements for gelatinous prey (i.e., jellyfish) suggest that they may search for areas of major upwelling. Juvenile (as well as adult) leatherback sea turtles recruit seasonally to temperate and boreal coastal habitats to feed on concentrations of jellyfish (Lutcavage and Lutz, 1986). In the western North Atlantic, juveniles appear in these habitats at a body length of 110 to 120 cm (43 to 47 in) (Musick and Limpus, 1997). It is likely that post-hatchling and oceanic juvenile leatherback sea turtles may be present within offshore and coastal waters of the AOI.

Leatherback sea turtles have a wide-ranging distribution and apparently are able to adapt and tolerate cold water temperatures, thus they are the most far-ranging and most northerly occurring sea turtle species. Coles (1999) indicated that sea turtle distribution may not be random but instead may be associated with specific water temperature ranges. Adult leatherback sea turtles have been reported to migrate from equatorial to temperate waters to forage, which is unique for sea turtles (USDOC, NMFS and USDOI, FWS, 2013b). Leatherback sea turtles primarily feed on pelagic gelatinous invertebrates such as scyphomedusae (jellyfish) and pelagic tunicates (USDOC, NMFS and USDOI, FWS, 1992; Bjorndal, 1997), and seasonal movements appear to be correlated with jellyfish seasonal abundance (State of South Carolina, Dept. of Natural Resources, 2005). Unlike other sea turtles, leatherback sea turtles may begin nesting much earlier in the year. Leatherback sea turtles have been reported to nest as early as February or March, with peak nesting in July; females nest at 2- or 3-year intervals. In Atlantic Outer Continental Shelf (OCS) waters and within the AOI, the leatherback sea turtle is reported to nest mainly on Florida beaches. Age at sexual maturity has been reported to be much younger than for other sea turtles, at approximately 6 to 10 years. The average clutch size is approximately 100 eggs, and incubation is between 60 and 65 days; females deposit 5 to 7 clutches per breeding season, with inter-nesting intervals of approximately 8 to 12 days (USDOC, NMFS and USDOI, FWS, 2013b).

Leatherback sea turtles are the deepest diving sea turtles, diving as deep as 1,200 m (3,937 ft) (Eisenberg and Frazier 1983; Davenport, 1988). Average dive depths from tagged leatherback sea turtles off the continental shelf of St. Croix ranged from 35 to 122 m (115 to 400 ft), with estimated maximum depths of more than 1,000 m (3,280 ft) (Eckert et al., 1989); typical dive durations averaged 6.9 to 14.5 minutes per dive, with a maximum of 42 minutes (Eckert et al., 1986 and 1989). The St. Croix studies of leatherback sea turtle diving patterns suggested nocturnal foraging on the deep scattering layer was taking place (Eckert et al., 1989). Off South Africa, Sale et al. (2006) investigated leatherback sea turtle diving behavior during oceanic movements and found that leatherback sea turtles primarily dove to depths less than 200 m (656 ft), with maximum dive durations between 30 and 40 minutes. Leatherback sea turtles displayed differences in dive patterns by time of day, with the longest dive times for most individuals being recorded at night. Using tagging data from nine leatherback sea turtles, Hays et al. (2006) recorded seasonal north and south movements between the Caribbean and northeastern U.S. coast; leatherback sea turtle dive depths lessened and dive durations became progressively shorter as the sea turtles moved northward. Mean dive duration ranged from 3 to 30 minutes, and mean dive depth ranged from surface waters to almost 250 m (820 ft). The overall distance traveled ranged from 2.5 to 82.5 km (1.6 to 51.3 mi) per day; however, most leatherback sea turtles traveled between 32.5 and 42.5 km (20 and 26 mi) per day (Hays et al., 2006).

3.5.4 Threats

Leatherback sea turtles have various anthropogenic threats to their recovery, including incidental capture by commercial fisheries; habitat loss (nesting); climatic change (e.g., sea-level rise, and shifts in prey availability); pollution; overutilization for commercial, recreational, scientific, or education purposes (e.g., egg harvesting); and disease (USDOC, NMFS and USDOI, FWS, 2013b).

3.5.5 Current Status

The leatherback sea turtle was listed as endangered on June 2, 1970 (35 FR 8491). Critical habitat was designated for the leatherback sea turtle in the U.S. Virgin Islands in 1979 (44 FR 17710). Critical habitat is defined as a strip of land 0.2-mi (0.3-km) wide at Sandy Point Beach, St. Croix, and the waters adjacent to the site (shore to 100-fathom curve [183-m; 600-ft]). In 2010, there were two petitions to designate additional critical habitat in Puerto Rico; both petitions were denied by the NMFS after the 12-month determination (77 FR 32909). There is no critical habitat designation for leatherback sea turtles in the GOM (44 FR 17710).

The conservation and recovery of the leatherback sea turtle is governed through various regulatory mechanisms such as attempting to meet specific recovery plan objectives, habitat protection efforts, and protecting nesting females. Other conservation measures include imposing restrictions on commercial fishery activities to prevent serious injury and mortality to sea turtles (e.g., circle hook requirements in the pelagic longline fishery and the use of TEDS in trawls) and supporting several international agreements such as the Inter-American Convention for the Protection and Conservation of Sea Turtles. Moreover, the NMFS has developed and is attempting to implement a strategy for sea turtle conservation and recovery in relation to Atlantic and Gulf of Mexico fisheries, which focuses on specific commercial fishing gear related criteria.

3.6 Summary of Sea Turtle Hearing Capabilities

A brief overview of sea turtle hearing is presented in this section; more information can be found in **Appendix I**. Few studies have examined the role acoustic cues play in the ecology of sea turtles (Mrosovsky, 1972; Cook and Forrest, 2005; Samuel et al., 2005; Nunny et al., 2008). There is evidence that sea turtles may use sound to communicate, but the few vocalizations described for sea turtles are restricted to the grunts and gular pumps of nesting females (Mrosovsky, 1972; Cook and Forrest, 2005). These low-frequency sounds are relatively loud (peak frequency recorded from nesting females were between 300 and 500 Hz), thus leading to speculation that nesting females use sounds to communicate with conspecifics (Mrosovsky, 1972; Cook and Forrest, 2005). Very little is known about the extent to which sea turtles use their auditory environment (“soundscape”) for navigation, environmental assessment, or identification of predators and prey. The passive acoustic environment for sea turtles changes with life cycle stages. In the inshore environment where juvenile and adult sea turtles generally reside, the ambient environment is noisier than the open ocean environment of the hatchlings and is dominated by low-frequency sound (Hawkins and Myrberg, 1983). Moreover, in highly trafficked inshore areas, virtually constant low-frequency noises from shipping and recreational boating compound the potential for acoustic impact (Hildebrand, 2009) and might prevent the animal from hearing signals from biologically important stimuli (Fay, 2009).

Much of the research on the hearing capacity of sea turtles is limited to gross morphological dissections (Wever, 1978; Lenhardt et al., 1985). Based on the functional morphology of the ear, it appears that sea turtles receive sound through the standard vertebrate tympanic middle-ear path. The sea turtle ear appears to be a poor receptor for aerial sounds but is well adapted to detect underwater sound. The dense layer of fat under the tympanum acts as a low-impedance channel for underwater sound (similar to the pathway found in odontocetes [Ketten et al., 1999]). Furthermore, the retention of air in the middle ear of sea turtles suggests that they are able to detect sound pressures (Hetherington, 2008).

Electrophysiological studies on hearing have been conducted on juvenile green sea turtles (Ridgway et al., 1969; Bartol and Ketten, 2006; Dow Piniak et al., 2012a); juvenile Kemp’s ridley sea turtles (Bartol and Ketten, 2006); post-hatchling, juvenile, and adult loggerhead sea turtles (Bartol et al., 1999; Lavender et al., 2012 and 2014; Martin et al., 2012); and hatchling leatherback sea turtles (Dow Piniak et al., 2012b). Electrophysiological responses, specifically AEPs, are the most widely accepted measurement for hearing in situations in which normal behavioral testing is impractical. The AEPs reflect the synchronous discharge of large populations of neurons within the auditory pathway and thus are useful for monitoring the functionality of the auditory system. Some AEP research has concentrated the responses occurring within the first 10 ms following presentation of click or brief tone burst stimuli. This response is the ABR, which consists of a series of five to seven patterned and identifiable waves. These techniques are non-invasive and often are performed on conscious subject animals (Bullock, 1981; Corwin et al., 1982; Bartol et al., 1999).

Ridgway et al. (1969) measured auditory cochlear potentials of green sea turtles using aerial and vibrational stimuli. Thresholds were not measured; instead, cochlear response curves of 0.1-microvolt (μV) potential were plotted for frequencies ranging from 50 to 2,000 Hz. Green sea turtles detect a limited frequency range (200 to 700 Hz) with best sensitivity in the low tone region of approximately 400 Hz. Though this investigation examined two separate modes of sound reception (i.e., air and bone conduction), sensitivity curves were relatively similar, suggesting that the inner ear is the main structure for determining frequency sensitivity. To measure electrophysiological responses to sound stimuli, Bartol et al. (1999) collected ABRs from juvenile loggerhead sea turtles. Thresholds were recorded for tonal and click stimuli. Best sensitivity was found in the low-frequency range of 250 to 1,000 Hz. The decline in sensitivity was rapid above 1,000 Hz, and the most sensitive threshold tested was 250 Hz.

More recently, Bartol and Ketten (2006) collected underwater ABRs from hatchling and juvenile loggerhead sea turtles and juvenile green sea turtles using speakers suspended in air while the sea turtle's tympanum remained submerged. All tested sea turtles responded to sounds in the low-frequency range, from at least 100 Hz (lowest frequency tested) to no more than 800 Hz. Hearing sensitivity of green sea turtles varied with size; smaller green sea turtles had a broader range of hearing (100 to 800 Hz; greatest sensitivity at 600 to 700 Hz at 95 dB re 1 μPa) than that detected in larger subadult subjects (100 to 500 Hz, greatest sensitivity 200 to 400 Hz at 93 to 97 dB re 1 μPa). Dow Piniak et al. (2012a) recorded both in air and in water AEP responses from juvenile green sea turtles. The AEP signal signature recorded from green sea turtles was similar to that seen in studies of fish evoked potentials, with a frequency-doubling response (i.e., where response waves oscillate at twice the stimulus frequency). Juvenile green sea turtles responded to stimuli between 50 and 1,600 Hz in water and 50 and 800 Hz in air. Ranges of maximum sensitivity were between 50 and 400 Hz in water and 300 and 400 Hz in air. Though these animals responded to an expanded range of frequencies compared with those previously studied, sensitivity decreased sharply for frequencies above 400 Hz in both media.

Lavender et al. (2011, 2012 and 2014) have recorded underwater AEPs from post-hatchling to juvenile loggerhead sea turtles. The experiments involved submerging a restrained, fully conscious loggerhead sea turtle just below the air-water interface and presenting sound using a J-9 underwater speaker. Under these conditions, post-hatchling and juvenile loggerhead sea turtles were found to respond to frequencies between 50 and 1,100 Hz. Post-hatchling sea turtles responded with the greatest sensitivity at 200 Hz (116 dB re 1 μPa), and juveniles were most sensitive at 50, 100, and 400 Hz (117 to 118 dB re 1 µPa). Martin et al. (2012) acquired AEPs from a submerged adult loggerhead using an underwater pool speaker and reported thresholds between 100 and 1,131 Hz, with highest sensitivity occurring at 100 to 400 Hz (threshold levels approximately 109 dB re 1 µPa).

Only one study has looked at the hearing of leatherback sea turtles (Dow Piniak et al., 2012b). This study measured hearing of hatchlings (immediately post-emergence) in water and in air. These animals reacted to low-frequency sounds, responding to stimuli between 50 and 1,600 Hz in air and 50 and 1,200 Hz in water (lowest sensitivity recorded was 93 dB re 1 µPa at 300 Hz). Finally, Bartol and Ketten (2006) recorded hearing from Kemp's ridley sea turtles using the same methods described for juvenile and subadult green sea turtles. The two juvenile sea turtles tested had a restricted hearing range (100 to 500 Hz) with their most sensitive hearing between 100 and 200 Hz (110 dB re 1 µPa) (Bartol and Ketten, 2006).

4 FISH RESOURCES AND ESSENTIAL FISH HABITAT

Chapter 4.4.1 of this Programmatic EIS provides the succinct description of the affected environment for fish resources and Essential Fish Habitat (EFH) in sufficient detail to support the impact analyses. The following descriptions provide additional information on fish resources and EFH.

The AOI encompasses demersal (zone directly above and influenced by the benthic zone [seafloor]) and pelagic (the open water environment) habitats from the shoreline to the open ocean that support a large diverse group of fish families and species. Fish species distributions vary relative to major environmental factors such as water depth, salinity, temperature, and habitat type. Many commercial fish species spend all or part of their life cycle in the AOI, resulting in the majority of the AOI designated as EFH. The EFH is the habitat necessary for managed fish to complete their life cycle, thus contributing to a fishery that can be harvested sustainably; specifically defined by 16 U.S.C. § 1801(10) as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity". The following sections describe the listed species (**Section 4.1**), candidate species and species of concern (**Section 4.2**), non-listed species (**Section 4.3**), and a brief summary of EFH (**Section 4.4**). **Appendix I** reviews the physics of underwater sound, mechanics of fish hearing, sources of anthropogenic sound and sound metrics, mechanisms of injury to fish from exposure to anthropogenic sound, and criteria for the protection of fish from exposure to injurious levels of G&G survey sounds.

4.1 LISTED SPECIES

The proposed AOI includes critical habitat for two endangered fish species that are managed by the NMFS and FWS under the ESA: smalltooth sawfish and Gulf sturgeon. Another endangered species, the largetooth sawfish *Pristis perotteti* (formerly *P. pristis*), was historically documented in the AOI; however, the population has been extirpated from the GOM and no critical habitat is designated for the species.

4.1.1 Smalltooth Sawfish

4.1.1.1 Distribution and Abundance

The smalltooth sawfish (*Pristis pectinata*) of the family Pristidae is a member of the cartilaginous class of fishes Chondrichthyes. The historic range of smalltooth sawfish extended throughout the GOM and north to Long Island Sound in the Atlantic but has contracted considerably in U.S. coastal waters over the past 200 years. Currently, the core of the U.S. smalltooth sawfish population is surviving and reproducing in the waters of southwest Florida and Florida Bay, primarily within the jurisdictional boundaries of Everglades National Park where important habitat features are still present and less fragmented than in other parts of the species' historic range (Simpfendorfer and Wiley, 2005; USDOC, NMFS, 2009b). This area includes most of the critical habitat shown in **Figure 4.4-1** of this Programmatic EIS. The smalltooth sawfish normally inhabits shallow waters (<10 m [33 ft]), often near river mouths or in estuarine lagoons over sandy or muddy substrates, but it may also occur in deeper waters (<50 m [164 ft]) of the continental shelf. Young sawfish generally prefer shallow water where the substrate is muddy and the shore is lined with mangrove trees (USDOC, NMFS, 2009b).

4.1.1.2 Behavior

Smalltooth sawfish grow slowly and mature at approximately 10 years of age. Females bear live young, and litters reportedly range from 1 to 20 embryos (USDOC, NMFS, 2009b). Smalltooth sawfish feed on fishes and benthic invertebrates. The toothed rostrum, or saw, has been considered a trophic apparatus, used to herd and even impale shallow-water schooling fishes such as herring and mullet (Breder, 1952). More recent research suggests that the saw is used to rake the seafloor to uncover partially buried invertebrates. Small juvenile sawfishes may be susceptible to predation from bull sharks (*Carcharhinus leucas*) and lemon sharks (*Negaprion brevirostris*) that inhabit similar water depths as the smalltooth sawfish.

4.1.1.3 Status

In response to a petition from the Ocean Conservancy, the NMFS conducted a status review of the smalltooth sawfish in 2000 (USDOC, NMFS, 2000). The status review determined that smalltooth sawfish in U.S. waters comprise a DPS that is in danger of extinction throughout its range. On April 1, 2003, the NMFS published a final rule (68 FR 15674) listing the U.S. DPS as endangered under the ESA.

Over the past 200 years, smalltooth sawfish populations have declined considerably, primarily because of incidental capture by fishing gear as well as destruction of habitat. The ESA listing was based on the following considerations: threatened destruction, modification, or curtailment of habitat or range; overutilization for commercial, recreational, scientific, or educational purposes; inadequacy of existing regulatory mechanisms; and other natural and man-made factors affecting the continued existence of the species. Critical habitat for the smalltooth sawfish includes two units on the southwest coast of Florida, within and adjacent to the Eastern Planning Area (**Figure 4.4-1** of this Programmatic EIS): the Charlotte Harbor Estuary Unit and the Ten Thousand

Islands/Everglades Unit (50 CFR § 226.218). Recent studies indicate that key habitat features (particularly for immature individuals) are shallow water, especially near mangroves, with estuarine conditions (Simpfendorfer and Wiley, 2005; Simpfendorfer 2006; USDOC, NMFS, 2009b).

4.1.2 Gulf Sturgeon

4.1.2.1 Distribution and Abundance

The Gulf sturgeon (*Acipenser oxyrinchus desotoi*) is a geographical subspecies of the Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) and is a member of the family Acipenseridae within the ray finned fishes (Class Actinopterygii). Gulf sturgeon occur in most major tributaries of the northeastern GOM from Lake Pontchartrain and the Mississippi River east to Florida's Suwannee River, and in the central and eastern GOM waters as far south as Charlotte Harbor, Florida (Wooley and Crateau, 1985). Gulf sturgeon are currently found in the Pearl, Pascagoula, Escambia, Yellow, Blackwater, Choctawhatchee, Apalachicola, Ochlockonee, and Suwannee Rivers (Reynolds, 1993). Critical habitat for Gulf sturgeon is shown in **Figure 4.4-1** of this Programmatic EIS.

Five genetically based stocks have been identified by the FWS and NMFS: (1) Lake Pontchartrain and Pearl River; (2) Pascagoula River; (3) Escambia and Yellow Rivers; (4) Choctawhatchee River; and (5) Apalachicola, Ochlockonee, and Suwannee Rivers. Mitochondrial DNA analyses of individuals from subpopulations indicate that adults return to natal river areas for feeding and spawning (Stabile et al., 1996; Sulak and Clugston, 1999; USDOI, FWS and USDOC, NMFS, 2009c).

4.1.2.2 Behavior

Gulf sturgeon are anadromous, meaning adults spend most of their lives in estuarine and marine waters and migrate into freshwater rivers and streams to spawn during the spring and early summer. As a result of this reproduction cycle, critical habitat for this species includes nearshore bays and estuaries from Louisiana to Florida, including the following river systems: the Apalachicola, Choctawhatchee, Escambia, Suwannee, Pascagoula, Pearl, and Yellow Rivers (50 CFR § 226.214). Free-jumping adult fish produce sounds during summer months but the adaptive significance of these sounds is unknown (Sulak et al., 2002).

Gulf sturgeon stop feeding while migrating upstream to spawn. Individuals only feed while in the GOM during winter. Sturgeons are bottom suction feeders that have ventrally located, highly extrudable mouths and primarily feed on benthic invertebrates. The sturgeon head is dorsoventrally compressed (flattened) with eyes dorsal, so they detect benthic prey using sensitive barbels. The barbels are also useful for navigation at night and in high-order streams if visibility is low.

Lovell et al. (2005) and Meyer et al. (2012) studied the hearing of lake sturgeon. Lovell et al. (2005) found that lake sturgeon are responsive to sounds ranging in frequency from 100 to 500 Hz. The lowest hearing thresholds from both species were acquired at frequencies between 200 and

300 Hz, with higher thresholds at 100 and 500 Hz. Sulak et al. (2002) hypothesized that sturgeons jump as a means of communication and found that the sounds produced from jumping sturgeon were distinct from other sounds; however, other studies suggest that jumping may occur for a number of other reasons. **Appendix I** provides a synopsis of fish hearing and the sensitivity of fish to hearing loss and injury.

4.1.2.3 Status

The FWS and NMFS listed the Gulf sturgeon as a threatened species on September 30, 1991. A recovery plan was developed to ensure the preservation and protection of Gulf sturgeon spawning habitat (USDOI, FWS and Gulf States Marine Fisheries Commission, 1995). Critical habitat was designated on March 19, 2003 (68 FR 13370) (**Figure 4.4-2** of this Programmatic EIS).

4.2 Candidate Species and Species of Concern

On September 2, 2014, the NMFS announced a 12-month finding and listing determination on a petition to list the Nassau grouper (*Epinephelus striatus*) as threatened or endangered under the ESA (79 FR 51929). The Nassau grouper is a moderately large grouper (Family Epinephelidae) known to occur within the AOI only at the Flower Garden Banks (FGBs) off Texas and off the Dry Tortugas and Key West, Florida (77 FR 61559). Nassau grouper generally are found near high-relief coral reefs and rocky bottoms from inshore to a maximum depth of approximately 100 m (328 ft). The Alabama shad (*Alosa alabamae*) is undergoing a status review to determine if the petition to list it as threatened or endangered is warranted (78 FR 57611).

The NMFS also has evaluated the dusky shark (*Carcharhinus obscurus*) (78 FR 29100) for ESA listing, but announced on May 17, 2013, that a status review of the GOM population of dusky shark is needed. The great hammerhead shark (*Sphyrna mokarran*) is also currently under status review by the NMFS (78 FR 24701). Species of concern in the AOI include dusky shark, sand tiger shark (*Carcharhinus taurus*), speckled hind (*Epinephelus drummondhayi*), and Warsaw grouper (*Epinephelus nigritus*).

4.3 Non-Listed Species

The GOM's marine habitats range from coastal marshes to the deep-sea abyssal plain and support a varied and abundant fish fauna. Within the AOI, distinctive fish assemblages are described using the following broad habitat categories: soft bottom fishes, hard bottom fishes, and coastal pelagic fishes on the continental shelf; and epipelagic, midwater fishes, and demersal fishes in oceanic waters (>200-m [656-ft] water depths).

4.3.1 Continental Shelf Fishes

4.3.1.1 Soft Bottom Fishes

The demersal, or bottom-dwelling, fish fauna of the continental shelf separates broadly into soft bottom and hard bottom assemblages. Soft bottom fish fauna vary along (east to west) and across the GOM shelf (Chittenden and McEachran, 1976; Darnell et al., 1983; Darnell and Kleypas, 1987). Major environmental factors influencing the distribution and abundance of soft bottom fishes include sedimentary characteristics, water temperature, dissolved oxygen, salinity, and water depth (e.g., Switzer et al., 2006).

In the eastern GOM (primarily the expansive West Florida Shelf), relatively clear water and coarse carbonate sediments on the open shelf support seabasses, mojarras, porgies, grunts, and sand flounders. Numerically dominant species include sand perch (*Diplectrum formosum*), silver jenny (Eucinostomus gula), dusky flounder (*Syacium papillosum*), and pigfish (*Orthopristis chrysoptera*). The West Florida Shelf also has vast areas of soft bottom covered by seagrasses and macroalgae. The Big Bend area and Florida Bay to the south support most of the seagrass acreage. Complex seagrass habitats attract diverse assemblages of fishes composed of herrings, pipefishes, snappers, grunts, porgies, drums, gobies, smooth puffers, and filefishes. Individual species characteristic of shelf seagrass meadows are false pilchard (*Harengula jaguana*), lane snapper (*Lutjanus synagris*), gray snapper (*Lutjanus griseus*), red drum (*Sciaenops ocellatus*), pinfish (*Lagodon rhomboides*), spotted seatrout (*Cynoscion nebulosus*), and spot (*Leiostomus xanthurus*).

West of the Florida Panhandle to the central GOM, carbonate sediments of the open shelf give way to coarser sand and shell hash. In water depths ranging from 20 to 40 m (66 to 131 ft) from Alabama to west of the Mississippi River Delta, soft bottom fish assemblages are composed of searobins, seabasses, porgies, flatfishes, goatfishes, and snake eels. Common species include longspine porgy (*Stenotomus caprinus*), leopard searobin (*Prionotus scitulus*), horned searobin (*Bellator miliaris*), and red goatfish (*Mullus aratus*). This particular horizon extends semicontinuously to the West Texas Shelf (Chittenden and McEachran, 1976). In water depths from 20 m (66 ft) to the shoreline, sediments become fine and muddy due to the massive discharges of Mobile Bay, the Mississippi River, and the Atchafalaya River. This region, centered on the Mississippi River Delta and often called the “fertile crescent,” supports a dense assemblage of catfishes, drums, cutlassfish, croakers, and seatrouts. Numerically dominant species are Atlantic croaker (*Micropogonias undulatus*), star drum (*Stellifer lanceolatus*), Atlantic cutlassfish (*Trichiurus lepturus*), sand seatrout (*Cynoscion arenarius*), silver seatrout (*Cynoscion nothus*), Atlantic threadfin (*Polydactylus octonemus*), and hardhead catfish (*Ariopsis felis*) (Chittenden and McEachran, 1976; Darnell et al., 1983). In some areas of the central and western GOM, sediments form mosaics of mud, sand, and shell hash. Fishes will segregate among sediment types (Wells et al., 2009). Larger deposits of sediment may form shoals that rise gradually above the surrounding seafloor. Fishes associating with shell hash include dwarf sand perch (*Diplectrum bivittatum*), least puffer (*Sphoeroides parvus*), and juvenile red snapper (*Lutjanus campechanus*). Muddy substrates attract silver jenny, silver seatrout, and largescale lizardfish (*Saurida undosquamis*) (Wells et al., 2009).

Few soft bottom fish species are of fishery importance; however, because of prevalence of shrimping over soft bottom habitats in all regions of the GOM, incidentally caught fish that are not discarded at sea end up as unclassified landings (Gulf and Atlantic Fisheries Foundation, 2009). The species most common in the bycatch include Atlantic croaker, anchovy (*Anchoa mitchilli*), hardhead catfish, and Gulf menhaden (*Brevoortia patronus*). Examples of economically important species caught incidentally by shrimp trawls include red snapper, flounder (*Paralichthys lethostigma*), and blue crabs (*Callinectes sapidus*). Bycatch reduction devices that allow non-target fishes to escape the trawl net are required by shrimpers working in the Gulf of Mexico EEZ (Gulf and Atlantic Fisheries Foundation, 2009).

4.3.1.2 Hard Bottom Fishes

Hard bottom habitats in the GOM are composed mostly of rock (or clay) derived from ancient shorelines, bioherms, or other sedimentary features hardened into rock over time. Where rock surfaces are exposed, algae, sponges, octocorals, stony corals, hydrozoans, and tunicates attach and grow, creating a complex habitat for fishes. Water temperature, clarity, salinity, light penetration, and depth influence biological dynamics of hard bottom communities.

Hard bottom habitat is most extensive in the eastern GOM where relatively low-relief (<1 m [3 ft]) rock characterizes much of the West Florida Shelf. Although much of the exposed hard bottom habitat is low relief, several high-relief areas occur in the region, including the Florida Middle Grounds, Steamboat Lumps, and Pulley Ridge (**Sections 5.2 and 7.2**). Shallow-water (10 to 50 m [33 to 164 ft]) hard bottom habitats support common reef fishes: snappers, seabasses, grunts, porgies, angelfishes, damselfishes, butterflyfishes, surgeonfishes, wrasses, triggerfishes, and filefishes. Seabasses and groupers are the most species rich families of reef fish in the area (Smith, 1976; Bullock and Smith, 1991; Coleman et al., 2011).

In water depths exceeding 30 m (98 ft) where reduced light penetration excludes most plants and therefore herbivores, a distinctive deep-reef or "mesophotic" assemblage occurs (Koenig et al., 2000; Weaver et al., 2002 and 2006a). Conspicuous mesophotic reefs are found on the Florida, Mississippi, and Alabama continental shelves. The Mississippi-Alabama Pinnacle Trend represents a series of mounds, ledges, and high-relief features in water depths ranging from 70 to 100 m (230 to 328 ft) (Continental Shelf Associates, Inc. and Texas A&M University [TAMU], 2001; Weaver et al., 2002). Fish assemblages on mesophotic reefs are composed of seabasses, snappers, wrasses, bigeyes, butterflyfishes, angelfishes, jacks, and other reef-dwelling species (Koenig et al., 2000; Continental Shelf Associates, Inc. and TAMU, 2001; Weaver et al., 2002). Red snapper, snowy grouper (*Hyporthodus niveatus*), scamp (Mycteroperca phenax), gag (*Mycteroperca microlepis*), speckled hind, and goldface tilefish (*Caulolatilus chrysops*), which are found at mesophotic reefs in the GOM, are not only large predatory fish but are members of the Gulf of Mexico Fishery Management Council's (GMFMC's) reef fish management unit. **Table 4.4-1** of this Programmatic EIS provides information on hard bottom species with essential fish habitat identified within the AOI.

Other species prevalent on the mesophotic reefs do not have direct fishery importance but do contribute to the mesophotic food web. These generally are small species that feed on invertebrates (attached or motile) living on the reefs or on plankton transported from surrounding areas. Species that feed mainly near or on the reef structure include short bigeye (*Pristigenys alta*), wrasse bass (*Liopropoma eukrines*), tattler (*Serranus phoebe*), bank butterflyfish (*Prognathodes* *aya*), red hogfish (*Decodon puellaris*), and greenband wrasse (*Halichoeres bathyphilus*). Planktivorous fishes are abundant and are represented by small-bodied species such as the roughtongue bass (*Pronotogrammus martinicensis*), red barbier (*Hemanthia vivanus*), and yellowtail reeffish (*Chromis enchrysura*). These species form an important prey base for the larger predatory species (Weaver et al., 2002).

Offshore of Louisiana and Texas, a series of topographic features (called "banks") created by subsurface salt intrusions dot the outer shelf (refer to **Section 5.2.4**). The portion of the banks closest to the surface (shallowest water depth) varies among the banks and greatly influences fish faunal composition. Two of the best known banks are the East and West FGBs, a pair of features rising from almost 100 m (328 ft) to within 25 m (82 ft) of the surface (Gardner et al., 1998). Because of the relatively shallow depth, the fish fauna at the East and West FGBs is similar to that of a southern Florida or Caribbean coral reef. Damselfishes, wrasses, parrotfishes, groupers, snappers, and other reef species occupy the mostly living coral reef that caps the East and West FGBs (Rooker et al., 1997). The deeper (>50 m [164 ft]) sloping sides of the banks provide sponge and rubble habitat for a suite of mesophotic reef fishes including wrasse bass, tattler, roughtongue bass, bank seabass, bank butterflyfish, and marbled grouper (*Epinephelus inermis*) (Dennis and Bright, 1988; Weaver et al., 2006b).

Deep reef fishes occur on hard bottom features in water depths of 50 to 100 m (164 to 328 ft) off southwest Florida, the Mississippi-Alabama Pinnacle Trend, the Texas-Louisiana shelf edge, and the south Texas carbonate banks.

In water depths >320 m (1,050 ft), deep coral reefs composed of *Lophelia pertusa* and other invertebrates harbor a different fish assemblage that includes barrelfish (*Hyperoglyphe perciformis*), black seabass (*Centropristis striata*), alfonsino (*Beryx decadactylus*), scorpionfish (*Scorpaena plumieri*), and conger eel (*Conger oceanica*) (Sulak et al., 2007).

Hard bottom fishes in the GOM often associate with artificial habitat, including oil and gas structures, artificial reefs, shipwrecks, and other debris. The approximately 2,900 oil and gas structures in the northern GOM may be grouped into coastal, offshore, and, blue water categories with respect to environmental conditions and species composition (Gallaway and Lewbel, 1982). Coastal platforms are found in water depths <30 m (98 ft) and are characterized by variable water column conditions (e.g., temperature, salinity, and turbidity). Typical fish assemblages at coastal platforms include sheepshead (*Archosargus probatocephalus*), Atlantic spadefish (*Chaetodipterus faber*), gray snapper, and gray triggerfish (*Balistes capriscus*).

The offshore platform assemblage is found in water depths of 30 to 60 m (98 to 197 ft) with variable but more stable water column conditions. Red snapper, gray triggerfish, Atlantic spadefish, sergeant major (*Abudefduf saxatilis*), cocoa damselfish (*Stegastes variabilis*), blue tang (*Acanthurus coeruleus*), blue angelfish (*Holacanthus bermudensis*), orangespotted filefish (*Cantherhines pullus*), and many other species reside near offshore platforms. Reef fish assemblages associated with offshore platforms are not particularly species rich when compared with natural reefs and lack conspicuous components, including most parrotfishes, grunts, porgies, goatfishes, gobies, and others, that depend on more than just the presence of hard substrate (Rooker et al., 1997).

The blue water platform assemblage occurs along the outer margin of the continental shelf and upper continental slope in water depths >60 m (197 ft). Unlike natural hard bottom, oil and gas platforms span the entire water column providing shallow-water habitat over the OCS and upper continental slope where ambient water depths exceed 300 m (984 ft). This vertical structure combined with blue water conditions creates an environment conducive to the settlement (and attraction) of shallow-water tropical reef fishes in the upper water column and mesophotic species in depths greater than 30 m (98 ft). Reef fishes tend to distribute vertically based on species-specific, water-depth preferences with a general range from near the surface to approximately 60 m (197 ft) (Stanley and Wilson, 1998). Most species remain relatively near or under the structures (Stanley and Wilson, 2000 and 2003). Blue water platforms support assemblages consisting of all the species mentioned previously as well as Spanish hogfish (*Bodianus rufus*), scamp, rock hind (*Epinephelus adscensionis*), creole fish (*Paranthias furcifer*), redlip blenny (*Ophioblennius macclurei*), tessellated blenny (*Hypsoblennius invemar*), cocoa damselfish, sergeant major, spotfin butterflyfish (*Chaetodon ocellatus*), rock beauty (*Holacanthus tricolor*), blue angelfish, bluehead wrasse (*Thalassoma bifasciatum*), spotfin hogfish (*Bodianus pulchellus*), scrawled filefish (*Aluterus scriptus*), and orangespotted filefish. Most of these species feed on algae and invertebrates growing on the platform legs and cross members.

4.3.1.3 Coastal Pelagic Fishes

The primary water column fish assemblage found in coastal and shelf waters of the GOM is termed coastal pelagic. **Table 4.4-2** of this Programmatic EIS provides information on coastal migratory pelagic species with EFH identified within the AOI. Major coastal pelagic fishes occurring in the GOM are sharks, rays, ladyfish, anchovies, herrings, mackerels, jacks, mullets, bluefish, and cobia. In general, coastal pelagic species are distributed across the entire GOM with little east-west differences; however, some species form distinct subpopulations. For example, king mackerel (*Scomberomorus cavalla*) appears to have eastern and western subpopulations. The eastern subpopulation migrates from near the Mississippi River Delta then southeast around the Florida peninsula for the winter (Sutter et al., 1991). The western subpopulation travels to waters off the Yucatan Peninsula during winter. In summer, both populations migrate to the northern GOM, where they intermix to an unknown extent (Johnson et al., 1994). Spanish mackerel (*Scomberomorus maculatus*), cobia (*Rachycentron canadum*), bluefish (*Pomatomus saltatrix*), crevalle jack (*Caranx hippos*), blacktip shark (*Carcharhinus limbatus*), Atlantic sharpnose shark (*Rhizoprionodon terraenovae*), bonnethead (*Sphyraena tiburo*), and smooth dogfish (*Mustelus canis*) are migratory, but their routes or potential population structure have not been well studied. Spanish mackerel, bluefish, and crevalle jack generally migrate westward along the shelf in warm months and back towards Florida during cold months (Barry A. Vittor and Associates, 1985). Gulf menhaden, thread herring (*Opisthonema oglinum*), Atlantic Spanish mackerel, and ladyfish (*Elops saurus*) form large schools, but other species such as cobia and bull shark travel alone or in small groups. The distribution of most species depends on water column structure in temperature, salinity, and dissolved oxygen, which vary spatially and seasonally.

While migrating, many coastal pelagic species will associate with offshore oil and gas platforms (Gallaway and Lewbel, 1982). **Table 4.4-3** of this Programmatic EIS provides information on highly migratory species with EFH identified within the AOI. Coastal platforms in water depths <20 m (66 ft) attract Spanish mackerel, bluefish, blue runners (*Caranx crysos*), and lookdowns (*Selene vomer*). Offshore platforms (20 to 60 m [66 to 197 ft]) are visited by blue runner, king mackerel, greater amberjack, jack crevalle, cobia and little tunny (*Euthynnus alletteratus*). Some coastal pelagic fishes, mostly jacks, frequent blue water platforms in water depths exceeding 60 m (197 ft). These species swim within a zone ranging from 10 to 50 m (33 to 164 ft) horizontally from the structure and vertically down to approximately 100 m (328 ft) (Stanley and Wilson, 2000). Blue runner form large schools that feed on surface plankton near platforms (Brown et al., 2010; Keenan et al., 2003). The vertical structure of a platform can slow the surface water flow, creating eddies that retain plankton in a way that may facilitate water column feeding. In addition, platform lights attract plankton at night and provide enough illumination to allow blue runners (and presumably other visual water column feeders) to forage day and night.

Coastal pelagic fishes form dynamic trophic interactions among different sized members of the assemblage. The larger predatory species such as coastal sharks, king mackerel, cobia, and little tunny feed on smaller fishes, including Spanish mackerel, bluefish, herrings, scads, and mullets. These smaller species typically form schools, undergo migrations, grow rapidly, mature early, and exhibit high fecundity. Species in the lower group in the trophic web are the planktivorous Gulf menhaden, thread herring, Spanish sardine, round scad, and anchovies, which are fed upon by all of the previously mentioned species.

The species discussed thus far are inhabitants of the open shelf in water depths >10 m (33 ft). Another component of the coastal pelagic assemblage occurs regularly along sandy beaches from the shoreline to the swash zone (<5 m [16 ft]) (e.g., Ross, 1983). This habitat occurs along the seaward shore of barrier islands off all Gulf Coast States. Fish species commonly occurring in this shallow habitat include scaled sardine (*Harengula clupeola*), Florida pompano (*Trachinotus carolinus*), sand drum (*Umbrina coroides*), kingfishes (*Menticirrhus* spp.), mullets (*Mugil* spp.), and various anchovies (*Anchoa* spp.). Nearshore fish assemblages show considerable seasonal structuring in the northern GOM. The lowest abundance of all species occurs in winter, with peak numbers found during summer and fall. Larger predatory species (particularly bluefish, Spanish mackerel, and blue runner) may be attracted to large concentrations of anchovies, herrings, and silversides, which congregate in nearshore areas.

4.3.2 Oceanic Fishes

4.3.2.1 Epipelagic Fishes

Epipelagic fishes inhabit the upper 200 m (656 ft) of the water column and include several sharks, billfishes, tunas, dolphins, flyingfishes, halfbeaks, opahs, oarfishes, jacks, remoras, pomfrets, butterfishes, molas, and triggerfishes. **Table 4.4-4** of this Programmatic EIS provides information on shark species with EFH identified within the AOI. Several of these species, such as dolphinfish (*Coryphaena hippurus*), sailfish (*Istiophorus platypterus*), white marlin (*Kajikia albida*), blue marlin (*Makaira nigricans*), and tunas (*Thunnus* spp.), are important to commercial and recreational fisheries (refer to **Sections 9 and 10**). Most epipelagic species migrate great distances within or outside the GOM. Whale sharks (*Rhincodon typus*) aggregate periodically in predictable locations offshore of Louisiana (Hoffmayer et al., 2007). Blue marlin migrate across the entire GOM in response to seasonal changes in sea surface temperature and productivity (Kraus et al., 2011). Bluefin tuna migrate from outside the GOM to spawn in the eastern GOM (Rooker et al., 2008). Yellowfin tuna (*Thunnus albacares*) migrate across the northern GOM in response to temperature and food availability. Many of the oceanic species associate with flotsam, which provides forage areas and nursery refuge.

Floating seaweed (*Sargassum*) (**Section 8**), jellyfishes, siphonophores, logs, and other debris attract juvenile and adult epipelagic fishes. Many species such as young jacks, filefishes, chubs, driftfishes, and dolphinfish associate with drifting objects, and larger predators forage around flotsam. Many fish species are closely associated with floating *Sargassum* at some point in their life cycle, but only two spend their entire lives there: the sargassumfish (*Histro histrio*) and the *Sargassum* pipefish (*Syngnathus pelagicus*). Most fish associated with *Sargassum* are temporary residents, such as juveniles of species that reside in shelf or coastal waters as adults (e.g., jacks, triggerfishes, and filefishes). However, several larger species of recreational or commercial importance, including dolphinfish (*Coryphaena hippurus*), yellowfin tuna (*Thunnus albacares*), blackfin tuna (*Thunnus atlanticus*), skipjack tuna (*Katsuwonus pelamis*), Atlantic bonito (*Sarda sarda*), little tunny (*Euthynnus alletteratus*), and wahoo (*Acanthocybium solandri*), feed on the small fishes and invertebrates attracted to *Sargassum* (Dooley, 1972; Bortone et al., 1977; Wells and Rooker, 2004a and 2004b).

As with coastal pelagic fishes, many of the epipelagic species associate with fixed or moored oil and gas platforms. Several other pelagic species such as shortfin mako (*Isurus oxyrinchus*), longfin mako (*Isurus paucus*), silky shark (*Carcharhinus falciformis*), oceanic whitetip shark (*Carcharhinus longimanus*), dolphinfish, blackfin tuna, yellowfin tuna, blue marlin, sailfish, and wahoo are known to occur around blue water platforms (Gallaway and Lewbel, 1982; Franks, 2000; Stanley and Wilson, 2000). Most of these species associate with offshore structures in a transient fashion, usually in response to the availability of prey.

4.3.2.2 Midwater Fishes

Below the epipelagic zone the water column may be layered into mesopelagic (200 to 1,000 m [656 to 3,280 ft]) and bathypelagic (>1,000 m [3,280 ft]) zones. Taken together, these two zones and their inhabitants may be referred to as midwater. In the mesopelagic zone of the GOM, fish assemblages are numerically dominated by lanternfishes, bristlemouths, and hatchetfishes (Gartner et al., 1987; Hopkins et al., 1997; Bangma and Haedrich, 2008). Lanternfishes are small silvery fishes that can be extremely abundant, often responsible for the deep scattering layer in sonar images of the deep sea. Lanternfishes and other mesopelagic fishes spend the daytime in depths of 200 to 1,000 m (656 to 3,280 ft) but migrate vertically at night into food-rich, near-surface waters. Mesopelagic fishes, while less commonly known, are important ecologically because they transfer significant amounts of energy between mesopelagic and epipelagic zones over each daily cycle. Lanternfishes are important prey for meso- and epipelagic predators (e.g., tunas), and particularly the mesopelagic dragonfishes (Hopkins et al., 1997).

Deeper dwelling bathypelagic fishes inhabit the water column at depths >1,000 m (3,280 ft). This group is composed of little known species such as snipe eels, slickheads, deep-sea anglers, bigscales, and whalefishes (McEachran and Fechhelm, 1998). Most species are capable of producing and emitting light (bioluminescence) to aid in communicating in an environment devoid of sunlight. Little scientific information is available on bathypelagic fishes of the GOM.

4.3.2.3 Demersal Fishes

Demersal fishes are those that are in direct contact with the substrate or hover above it from the shelf-slope transition down to the abyssal plain. The deep-sea demersal fish fauna in the GOM includes approximately 300 species. The most diverse group is the cod-like fishes (e.g., hakes and grenadiers), followed by eels, cusk-eels, sharks, and flatfishes, as summarized by Pequegnat (1983), Gallaway (1988), and Powell et al. (2003). In general, fish species diversity decreases with increasing water depth. The highest diversity and density of demersal fishes is found along the continental slope in the eastern GOM. Deep-sea demersal fishes consume a wide variety of organisms, including other fishes as well as epifaunal, infaunal, meiofaunal, and planktonic invertebrates.

4.4 Essential Fish Habitat

The Magnuson-Stevens Fisheries Conservation and Management Act (MSFCMA) (16 U.S.C. § 1801-1882) established regional Fishery Management Councils (FMCs) and mandated that Fishery Management Plans (FMPs) be developed to responsibly manage exploited fish and invertebrate species in U.S. Federal waters. When Congress reauthorized the MSFCMA in 1996 as the Sustainable Fisheries Act, several reforms and changes were made. One change was to charge the NMFS with designating and conserving EFH for species managed under existing FMPs. This is intended to minimize, to the extent practicable, any adverse effects on habitat caused by fishing or non-fishing activities, and to identify other actions to encourage the conservation and enhancement of such habitat.

The EFH is defined as “those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity” (16 U.S.C. § 1801(10)). The EFH final rule summarizing EFH regulation (50 CFR part 600) outlines additional interpretation of the EFH definition. Waters, as defined previously, include “aquatic areas and their associated physical, chemical, and biological properties that are used by fish, and may include aquatic areas historically used by fish where appropriate.” Substrate includes “sediment, hard bottom, structures underlying the waters, and associated biological communities.” Necessary is defined as “the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem." "Fish" includes "finfish, mollusks, crustaceans, and all other forms of marine animal and plant life other than marine mammals and birds," whereas "spawning, breeding, feeding or growth to maturity" covers the complete life cycle of those species of interest.

The AOI covers a broad geographic and bathymetric region that features a dynamic mix of fishery species. Fishery resources within the AOI are primarily managed by the GMFMC utilizing seven FMPs. The seven FMPs manage 182 fishery species grouped as follows: reef fish (31), coastal migratory pelagic fish (3), red drum (1), shrimp (4), spiny lobster (1), and corals (142). The EFH for managed fisheries is described in the respective FMPs.

Migratory pelagic fish species are jointly managed by the GMFMC and South Atlantic Fishery Management Council (SAFMC). In addition to these FMPs, 39 highly migratory fishery species (tunas [5], billfishes [5], sharks [28], and swordfish [1]) occurring in the GOM are managed by the Highly Migratory Species Management Unit within the Office of Sustainable Fisheries under the NMFS.

BOEM, the Bureau of Safety and Environmental Enforcement (BSEE), and NMFS are under a programmatic EFH consultation. Pursuant to section 305(b) of the MSFCMA, Federal agencies are required to consult with the NMFS on any action that may result in adverse effects on EFH. In March 2000, BOEM consulted with the NMFS' Southeast Regional Office, resulting in the preparing of a NMFS regional finding for the GOM that allows BOEM to incorporate the EFH assessments into National Environmental Policy Act (NEPA) documents as an appendix.

The programmatic EFH consultation was initiated during the 2012-2017 WPA/CPA Multisale EIS review process, continued with the NMFS' conservation recommendations, and formally concluded with BOEM's response to the NMFS' conservation recommendations. The EFH assessment, which can be found in Appendix D of the 2012-2017 WPA/CPA Multisale EIS (USDOI, BOEM, 2012a), describes the OCS proposed activities, analyzes the effects of the proposed activities on EFH, and identifies proposed mitigation measures. It also includes an evaluation of the G&G activities described in this Programmatic EIS.

The programmatic consultation continues with active coordination among the NMFS, BOEM, and BSEE. This coordination includes annual reports from BOEM to the NMFS, meetings with GOM staff, discussions of mitigation, and other relevant topics.

5 BENTHIC COMMUNITIES

Chapter 4.5.1 of this Programmatic EIS provides the succinct description of the affected environment for benthic communities in sufficient detail to support the impact analyses. The following descriptions provide additional, expanded information.

The benthic environment of the AOI is complex, with bathymetry and biological, geological, and geophysical features varying widely (Rowe and Kennicutt, 2009). The AOI encompasses several habitats within water depths ranging from <200 m (656 ft) near State boundaries along the northern edge of the AOI to depths of nearly 3,500 m (11,483 ft) in the south-central GOM. It is important to note that the AOI extends beyond the planning areas to account for the acoustic energy that could propagate beyond BOEM jurisdictional boundaries; as such, the description of benthic communities in the AOI includes benthic communities within the Florida Keys, Dry Tortugas National Park, Tortugas Ecological Reserve, and other sensitive shallow-water habitats within State waters (3 or 9 nmi [5.6 or 16.7 km; 3.5 or 10.6 mi] from shore).

The benthic faunal assemblages of the GOM can be loosely grouped by depth. Biological diversity is relatively low on the continental shelf, where a small number of species are locally abundant in high densities (Rowe and Kennicutt, 2009). Benthic fauna at water depths >200 m (656 ft) are dominated by infaunal (living in bottom sediments) worms, crustaceans (e.g., crabs, lobsters, shrimps), and mollusks (e.g., clams, scallops, oysters). Deposit-feeding polychaetes (segmented marine worms) are the most abundant organisms on the continental shelf (USDOI, BOEM, 2012a, 2013a, and 2013b).

The deepwater GOM can be separated into the continental slope and abyssal plain. The continental slope is unique, being influenced by the hydrographic processes of both the shelf and the abyssal plain. The continental slope includes varying ranges of productivity and, consequently, several different faunal assemblages. Across the GOM, the slope consists of fine muddy sediments that support high-diversity, low-density benthic communities (Rowe and Kennicutt, 2009). Demersal fishes, gastropods (snails), polychaetes, asteroids (sea stars), and other echinoids (i.e., sand dollars, sea cucumbers) are common in this zone (USDOI, BOEM, 2013a).

The abyssal plain (>1,000 m [3,280 ft]) contains the majority of benthic habitat within the AOI. The number of invertebrate species is higher and the number of fish species lower in the abyssal plain compared with shelf or slope habitats. In waters deeper than 2,300 m (7,546 ft), fishes are rare and echinoderms (i.e., sea stars, sand dollars, and sea cucumbers) are the dominant megafauna.

Although the GOM is dominated by soft bottom communities (**Section 5.1**), hard bottom (**Section 5.2**) and chemosynthetic (**Section 5.3**) communities are scattered throughout. **Section 5.4** provides a discussion of listed and candidate coral species.

5.1 Soft Bottom Communities

The seafloor of the GOM is composed primarily of muddy and sandy sediments. Sediments in the eastern GOM consist primarily of sand, while sand, silt, and clay are the dominant constituents of sediment in the central and western GOM (Jenkins, 2011). Grain size is the most important substrate characteristic affecting the distribution of benthic fauna (Vittor, 2000) and is often used to categorize faunal assemblages. Vittor (2000) divided the northern GOM continental shelf into the following four assemblages:

- **Assemblage I:** Nearshore sandy bottom with <5 percent silt/clay. This assemblage is found across the GOM and is dominated by filter- and deposit-feeding mollusks and crustaceans as well as carnivorous polychaetes and mollusks.
- **Assemblage II:** Silty, sandy bottoms in shallower areas (<100 m [328 ft]) that are spread across the continental shelf. These areas contain >5 percent silt and generally are found in areas with terrigenous (land-based) sediments such as Mobile Bay. Dominant fauna are detritivores, especially polychaetes. Suspension and filter feeders, including crustaceans and polychaetes, are present as well.
- **Assemblage III:** Patchy areas with coarse sand and shell hash. These areas are found in shallow and deep waters and are dominated by motile benthic megafauna, filter feeders, and epibenthic deposit and suspension feeders.
- **Assemblage IV:** Fine sandy/silty sediments in waters deeper than 100 m (328 ft). This assemblage is dominated by demersal and burrowing deposit-feeding polychaetes and mollusks as well as carnivorous polychaetes.

The continental slope is a complex transitional zone with varying ranges of productivity and faunal assemblages. Faunal assemblages of the continental slope and abyssal zone are described in BOEM's 2012-2017 WPA/CPA Multisale EIS as follows:

- **Shelf-Slope Transition Zone** (150 to 450 m [490 to 1,475 ft]): A highly productive zone dominated by demersal fishes, asteroids, gastropods, and polychaetes.
- **Archibenthal Zone Horizon A** (475 to 740 m [1,560 to 2,430 ft]): Sea cucumbers become more abundant in this zone and demersal fishes become less abundant. Gastropods and polychaetes are also numerous.
- **Archibenthal Zone Horizon B** (775 to 950 m [2,545 to 3,120 ft]): Demersal fishes, asteroids, and echinoids are found in large numbers. Gastropods and polychaetes are also common.
- **Upper Abyssal Zone** (1,000 to 2,000 m [3,280 to 6,560 ft]): This zone has fewer fishes than are found in shallower depths. The number and types of invertebrate species increase, especially sea cucumbers and galatheid crabs.
- **Mesoabyssal Zone** (2,300 to 3,000 m [7,545 to 9,840 ft]): Few fish species are found in this deepwater zone. Echinoderms dominate the fauna.

- **Lower Abyssal Zone** (3,200 to 3,800 m [10,500 to 12,470 ft]): The large asteroid *Dytaster insignis* is the dominant megafaunal species.

Fauna of the GOM can be divided into megafauna, macrofauna, meiofauna, and microbiota. Each of these groups is described briefly in the following subsections.

5.1.1 Megafauna

Megafauna are classified as organisms large enough to be easily distinguished with the naked eye. In the GOM, most megafauna are crustaceans, echinoderms, or demersal fishes (USDOI, BOEM, 2012a). Megafaunal distributions in the GOM traditionally have been described by depth, as discussed previously. It should be noted that, among other sampling issues, the methods used to sample megafauna may be selective and otherwise uncalibrated, which will result in variation in the estimates of species composition and abundances reported in literature. For example, in the Northern Gulf of Mexico Continental Slope (NGMCS) study of the 1980s, bottom-trawl samples were dominated by decapod crustaceans, but seafloor photographs showed that sea cucumbers, bivalves, and sea pens were the most common seafloor megafauna (Gallaway et al., 2003). Gallaway et al. (2003) found that the composition of megafauna changes continuously with depth, resulting in gradual changes in the occurrence and abundance of species between the discrete zones used to describe the distribution of megafauna. Upper slope fauna is found to a depth of approximately 1,200 m (3,937 ft) (mostly decapods and fishes), and a distinct deepwater faunal assemblage is found deeper than 2,500 m (8,202 ft) (mostly echinoderms). A transition zone between 1,200 and 2,500 m (3,937 and 8,202 ft) typically has low faunal abundances and low diversity (Gallaway et al., 2003).

5.1.2 Macrofauna

Macrofauna are described as organisms larger than 0.3 millimeters (mm) but smaller than megafauna (USDOI, BOEM, 2012a). The NGMCS study (Gallaway et al., 2003) obtained 69,933 individual macrofauna from 1,548 taxa. Further processing of samples by taxonomic experts resulted in classification of individual animals to 1,107 species. Some of the animals collected could not be classified to species. Polychaetes were the most common organism found in the study and included 407 species. Other macrofauna obtained in samples (in order of abundance) were nematodes (roundworms), ostracods and harpacticoid copepods (small crustaceans), bivalves (clams, oysters), tanaids (small shrimp-like animals), bryozoans (moss animals), isopods (crustaceans with seven pairs of legs), amphipods (small crustaceans), and others (Gallaway et al., 1988). Density of benthic macrofauna ranged from 518 to 5,369 individuals/m^2, though transects in the central GOM had a higher mean density of macrofauna (4,938 individuals/m^2) than transects in the eastern (4,869 individuals/m^2) or western GOM (3,389 individuals/m^2) (Gallaway et al., 2003).

5.1.3 Meiofauna

Meiofauna are small (0.063 to 0.3 mm) organisms. The most numerically abundant meiofauna in the GOM are nematodes and harpacticoid copepods, and those present in the greatest biomass are polychaetes and ostracods (Gallaway et al., 2003). Nematodes, harpacticoid copepods, polychaetes, ostracods, and kinorhynchs (segmented wormlike invertebrates) made up 98 percent of the meiofauna identified in samples taken by Gallaway et al. (2003) in the NGMCS study. Meiofauna are considerably more abundant than macrofauna or megafauna, with an overall density of 707,000 individuals/m^2 in the area of study (Gallaway et al., 1988). Like megafauna and macrofauna, meiofaunal abundance appears to decrease with increasing depth. There is evidence that meiofaunal abundance can be locally high at greater depths concurrent with the presence of deepwater chemosynthetic communities (Gallaway et al., 2003).

5.1.4 Microbiota

Microbiota are organisms smaller than 0.063 mm. This poorly understood group consists primarily of bacteria with a small contribution from other microbenthos. Little data are available on the density of microbiota in the deepwater GOM. Cruz-Kaegi (1998) estimated the density of bacteria sampled from the GOM continental slope by counting (with epifluorescence microscopy techniques) the number of dyed bacteria in subsamples. The biomass of bacteria in samples was estimated using image processing of dyed bacteria photographs to estimate the volume of bacteria, literature estimates of bacterial carbon content (Bratbak and Dundas, 1984), bacteria density estimates, and adjustment for subsample volume. Estimates of bacterial biomass were 2.37 grams of carbon per square meter (g C/m^2) for the GOM slope and 0.37 g C/m^2 for the abyssal plain. Cruz-Kaegi (1998) found that bacteria, meiofauna, and macrofauna contributed on average 67, 13, and 20 percent, respectively, to total benthic biomass.

5.2 Hard Bottom Communities

While less common than ubiquitous soft bottom environments in the GOM, hard bottom environments are scattered across the GOM (**Figure 4.5-1** of this Programmatic EIS). This section focuses on deepwater benthic communities; for discussion of benthic chemosynthetic communities in the GOM, refer to **Section 5.3**.

The GMFMC manages GOM corals through a coral management unit that encompasses 142 species of stony and soft corals, including fire or stinging corals, stony corals, and black corals. The EFH for the coral management unit includes the total distribution of coral species and life stages throughout the GOM, including coral reefs in the North and South Tortugas Ecological Reserves, East and West FGBs, McGrail Bank, and the southern portion of Pulley Ridge. Additionally, EFH includes hard bottom areas on the scattered pinnacles and banks from Texas to Mississippi, the shelf edge at the Florida Middle Grounds, the southwest tip of the Florida Reef Tract, and hard bottom offshore of Florida from approximately Crystal River south to the Florida Keys (GMFMC, 2005).

5.2.1 Deepwater Coral Communities

Corals that rely on photosynthetic zooxanthellae (algae in the genus Symbiodinium) cannot live below the euphotic zone (where sunlight penetrates). Although the deepwater benthic environment of the GOM consists primarily of mud and silt, occasional carbonate hard bottom exists that supports ahermatypic (non-reef building) corals. Moore and Bullis (1960) first described a deepwater coral community in the GOM and retrieving >136 kg (300 lb) of *Lophelia pertusa*. Deepwater coral reefs are now known to exist throughout the GOM. To help determine where such reefs may exist, BOEM has examined seismic data to identify areas of high reflectivity that indicate hard bottom areas. As of 2012, the database included >28,000 areas of anomalous (higher than typical) reflectivity that indicate possible hard bottom where deepwater reefs could exist (Shedd et al., 2012). These estimates suggest that deepwater reefs in the GOM may not be as rare as once thought (Shedd et al., 2012). Hard bottom areas of the GOM are thought to have been created by the precipitation of calcium carbonate by chemosynthetic bacteria. Although only a small number of the overall hard bottom patches have been investigated, those that have been studied suggest that most of the hard bottom areas available in the GOM have been colonized by chemosynthetic coral reefs created by bacteria living off hydrocarbon seepages (Shedd et al., 2012). Colonies of *L. pertusa*, as found in the Moore and Bullis (1960) trawls, are most commonly found in the upper shelf, but colonies have been found as deep as 3,000 m (9,842 ft) (USDOI, BOEM, 2012a and 2013a). These findings suggest that suitable hard bottom areas exist throughout the AOI that could harbor deepwater coral communities as well as non-reef forming deepwater corals.

As discussed in **Chapter 4.5.1** of this Programmatic EIS, at least one deepwater gorgonian coral community in Mississippi Canyon Block 294 is known to have been affected by the *Deepwater Horizon* explosion, oil spill, and response. White et al. (2012) documented highly localized damage to a coral community where 86 percent of corals showed signs of impact. Tests of flocculent oil-based material collected from the community confirmed that the oil was from the *Deepwater Horizon* explosion and oil spill. Other continental shelf coral communities are discussed further in **Sections 5.2.2 through 5.2.4**.

5.2.2 Live Bottoms (Pinnacle Trend)

Vertical, high-relief, hard bottom features with extensions up to 15 m (49 ft) above the surrounding seafloor in the Gulf of Mexico OCS were reported by Ludwick and Walton (1957). These “pinnacles” are known to exist in 74 OCS lease blocks in a 64 x 16 mi (103 x 26 km) area of the northeastern CPA, particularly in parts of the Main Pass, Viosca Knoll, and Destin Dome Areas (**Figure 4.5-2** of this Programmatic EIS). In Notice to Lessees and Operators (NTL) 2009-G39, BOEM (formerly the MMS) describes the Pinnacle Trend as “small, isolated low to moderate relief carbonate reef features or outcrops of unknown origin or hard substrates exposed by erosion that provide surface area for the growth of sessile invertebrates and attract large numbers of fish.

The Pinnacle Trend comprises several loosely organized hard bottom habitats of high and low relief (USDOI, BOEM, 2012a). The low-relief areas may rise only 1 to 2 m (3 to 7 ft) from the seafloor; however, both low- and high-relief areas provide usable hard bottom habitat. Low-relief hard bottom areas are discussed in **Section 5.2.3**. The Pinnacle Trend contains a variety of geologic features that provide a suitable environment for hard bottom biota, including patch reefs, flat-top reefs, reef-like mounds, ridges, scarps, and depressions (USDOI, BOEM, 2012a).

High-relief pinnacles can rise as much as 20 m (66 ft) from the surrounding seafloor and be 500 m (1,640 ft) in diameter (Thompson et al., 1999), though most are <200 m (656 ft) wide at their base (Gittings et al., 1992). Ludwick and Walton (1957) hypothesized that the pinnacles might be coral reefs that were gradually drowned to unsuitable depths with sea-level rise, a theory supported by Brooks (1991). The pinnacles are located in depth ranges of 74 to 82 m (243 to 269 ft) and 105 to 120 m (344 to 394 ft). The relatively steep sides and tops of the pinnacles provide prime hard bottom habitat for coralline algae, sponges, octocorals (sea fans and sea whips), crinoids (sea lilies), byrozoans, and demersal fishes. Ahermatypic corals may be present in deeper waters (Continental Shelf Associates, Inc., 1992). Hermatypic (reef-building) coral typically do not live at the depth associated with the Pinnacle Trend due to a lack of available light. However, a hermatypic reef was observed with up to 60 percent live coral cover in 60 to 75 m (197 to 246 ft) of water near Pulley Ridge, on the southwest Florida platform margin (Jarrett et al., 2005).

The biological diversity of the fauna on the pinnacles has been found to be directly related to the height of the pinnacle feature (Gittings et al., 1992; Thompson et al., 1999). Biological diversity also increases with greater distance from the Mississippi River Delta as water turbidity decreases (Gittings et al., 1992). Biological diversity is highest on the tops of high-relief pinnacles. Near the seafloor, a persistent nepheloid (turbidity) emanating from the Mississippi River outflow precludes the colonization of most sessile organisms. Only a few upright invertebrate species such as sea whips and sea fans can withstand the high turbidity. High turbidity-tolerant fauna include comatulid crinoids, the ahermatypic coral *Rhizopsammia manuelensis*, and black coral (*Antipathes* spp.; deepwater tree-like coral) (Gittings et al., 1992). Roughtongue bass is the dominant fish species in the higher turbidity region near the base of high-relief pinnacles (Weaver et al., 2002).

The walls of pinnacles provide habitat supporting higher biological diversity. Continental Shelf Associates, Inc. (1992) reported at least 34 species of epifauna on the walls of a high-relief pinnacle, including black corals *R. manuelensis* and *Antipathes* spp., wire coral (*Cirrhipathes leukeni*), and soft coral and sea whips (*Ellisella* sp.). The crests of pinnacles also show high diversity with species assemblages similar to those on the pinnacle walls, though the gorgonian coral *Bebryce* sp. was most common (Gittings et al., 1992). High-relief pinnacles also provide habitat for fishes. Roughtongue bass, red barbier, greenband wrasse, and yellowtail reeffish are the more frequent members of the fish assemblages found near pinnacle crests (Weaver et al., 2002).

5.2.3 Live Bottoms (Low Relief)

Low-relief hard bottom habitats are found in the CPA and WPA. Low-relief live bottom habitats are found in the extreme northeastern corner of the CPA but are much broadly distributed in the EPA. BOEM has instituted a Live Bottom (Low Relief) Stipulation to protect low-relief hard bottom habitats from impact by OCS energy exploration activities. NTL 2009-G39 defines low-relief habitat as “seagrass communities, areas that contain biological assemblages consisting of sessile invertebrates living upon and attached to naturally occurring hard or rocky formations with rough, broken, or smooth topography; and areas where a hard substrate and vertical relief may favor the accumulation of sea turtles, fishes, or other fauna.” In addition, BOEM conducts case-by-case reviews of plans, pipeline applications, structure removal applications, and ancillary activity applications in order to prevent routine bottom-disturbing activities from occurring within adequate distances from live bottom (low relief) areas.

Live Bottoms of the Mississippi-Alabama Shelf

Hard bottom areas made of sedimentary rock are found in shallow waters (18 to 40 m [60 to 130 ft]) along the inner and middle Mississippi-Alabama Shelf and at the head of the De Soto Canyon. These hard bottom areas include many different habitat types, including reef-like structures, rubble fields, flat rocks, limestone ledges, rocky outcrops, and clustered reefs (Schroeder, 2000). Organisms that inhabit these shallow-water features include ahermatypic corals, soft corals, sponges, bryozoans, crinoids, fishes (Thompson et al., 1999), and algal communities (Brooks, 1991; Gittings et al., 1992). Schroeder et. al. (1988) described four low-relief, live bottom areas west of De Soto Canyon: Southeast Bank; Southwest Rock; Big Rock/Trysler Grounds; and 17 Fathom Hole. Common fauna in low-relief habitats included the colorful sea whip (*Leptogorgia virgulata*), regal sea fan (*Lophogorgia hebes*), hydroids (stalked predators related to jellyfish), and byrozoans (Schroeder et al., 1988). Various other small patches of hard bottom have been identified on the Mississippi-Alabama Shelf (Shipp and Hopkins, 1978; Benson et al., 1997). Fauna observed at these small sites were similar to those described by Brooks (1991), including sponges, non-reef-building hard corals such as the diffuse ivory bush coral (*Oculina diffusa*), soft corals/sea fans, black and wire corals, and tropical fishes.

Live Bottoms of the West Florida Shelf

Most of the low-relief hard bottom in the GOM is found on the West Florida Shelf. Live bottoms are widely scattered on the West Florida Shelf, and BOEM has designated all OCS lease blocks on the West Florida Shelf out to 100-m (328-ft) depth as Live Bottom (Low Relief) Stipulation Blocks. The West Florida Shelf is flat, stable karst limestone covered in places by carbonate sand. Ephemeral hard bottom exists in many areas due to seasonally shifting sands that periodically expose the underlying bedrock. Faunal cover usually is limited on these ephemeral hard bottom patches, but some species of sea whips and sea fans can grow quickly enough and survive despite occasional partial burial (USDOI, BOEM, 2012a and 2013a). These patches usually are dominated by various algae species, including green algae (*Chlorophyta*) species such as *Halimeda* spp., *Anadyomene menziesii*, and *Caulerpa* spp.; coralline algae *Cryptonemiales* and *Pessyonnelia simulans*; and various brown (*Phaeophyceae*) and red (*Rhodophyta*) algae (Woodward-Clyde and Continental Shelf Associates, Inc., 1983).

Other portions of the West Florida Shelf have higher relief areas that are permanently exposed hard bottom. The NMFS has designated the following areas on the West Florida Shelf as Habitat Areas of Particular Concern (HAPCs): Madison Swanson Marine Reserve; Florida Middle Grounds; and Pulley Ridge. Other areas of permanent hard bottom on the West Florida Shelf include Steamboat Lumps Marine Reserve and Sticky Ground Mounds. Each of these areas is briefly discussed in the following subsections.

Madison Swanson Marine Reserve

A detailed discussion of the Madison-Swanson Marine Reserve can be found in **Section 7.2**. Briefly, the reserve is the 400 km^2 (155 mi^2) of protected area approximately 80 km (50 mi) south of Apalachicola, Florida, that consists of small outcrops as well as a few higher relief pinnacles (up to 9 m [30 ft] high) (USDOI, BOEM, 2013a) at depths between 60 and 140 m (197 and 459 ft). Sponges, sea fans, corals (including bush/tree corals [*Oculina* spp.]), echinoderms, and crabs reside within the reserve (USDOI, BOEM, 2013a).

Florida Middle Grounds

The Florida Middle Grounds are a complex series of carbonate hard bottom outcroppings located approximately 138 km (86 mi) south of Apalachee Bay, Florida. The outcroppings are spread over an area of approximately 1,193 km^2 (460 mi^2), with relief up to 17 m (56 ft). The Florida Middle Grounds are the northernmost extent of hermatypic corals in the U.S. (Puglise and Kelty, 2007), and the fauna most closely resemble that found at tropical reefs. The branching fire coral (*Millepora alcicornis*), pineapple coral (*Dichocoenia stokesii*), and ten-ray star coral (*Madracis decactis*) are common, as are octocorals, sea fans of the genus Muricea, and the giant barrel sponge (*Xestospongia muta*) (Naar et al., 2007). Other fauna include hydroids, anemones, mollusks, crustaceans, echinoderms, polychaetes, and fishes (Hopkins et al., 1977; Coleman et al., 2004a). It should be noted that the Florida Middle Grounds are not considered a true coral reef because the lack of abundance of hermatypic corals does not allow for the successful accretion of a carbonate reef (USDOI, BOEM, 2013a).

Pulley Ridge

Pulley Ridge is a submerged shoal colonized by reef-building organisms after sea-level rise left it submerged (Jaap and Halley, 2008). Pulley Ridge is approximately 300 km (185 mi) long, trending north-south, with carbonate hard bottom ranging in depth from 60 to 90 m (197 and 295 ft) approximately 250 km (155 mi) west of Cape Sable, Florida. Vertical relief is approximately 10 m (33 ft) (Puglise and Kelty, 2007). The southernmost end of Pulley Ridge supports a unique coral reef system that harbors traditional reef-building corals containing zooxanthellae and is one of the deepest reefs on the North American continental shelf. The most common corals at the site are the lettuce corals *Leptoseris cucullata* and *Agaricia* sp. (Jaap and Halley, 2008). Red and green algae are prevalent in deeper portions of Pulley Ridge. Pulley Ridge is also a significant area for commercial fishing, with >90 fish species present in appreciable numbers (Jaap and Halley, 2008).

Steamboat Lumps Marine Reserve

A detailed discussion of the Steamboat Lumps Marine Reserve can be found in **Section 7.2**. Briefly, the Steamboat Lumps Marine Reserve is located 161 km (100 mi) south-southwest of Cape San Blas, Florida, and approximately 32 km (20 mi) southwest of the Florida Middle Grounds. Steamboat Lumps Marine Reserve encompasses approximately 357 km^2 (138 mi^2) and consists of a relic reef (Hine and Locker, 2008) in water depths of 60 to 140 m (197 to 459 ft). Fauna in the

Steamboat Lumps Marine Reserve is typical of a deepwater reef and includes sponges, sea fans, black corals, bush/tree corals, echinoderms, and crustaceans (USDOI, BOEM, 2013a).

Sticky Ground Mounds

The Sticky Ground Mounds are a series of mounds located 185 km (115 mi) west of Tampa, Florida, in 120 to 130 m (394 to 427 ft) of water (USDOI, BOEM, 2013a). The mounds form a narrow 2-km (1.2-mi) wide band of patch reefs that may have originated from carbonate sedimentation caused by methane seeps, though this hypothesis has not been proven (Hine and Locker, 2008). The mounds range in size, but they are approximately 20 m (66 ft) in diameter with a vertical relief of 10 m (33 ft). Fauna on the mounds are similar to other deepwater reefs, with biota dominated by sponges, sea fans, black corals, corals, echinoderms, and crustaceans (USDOI, BOEM, 2012a and 2013a).

Florida Reef Tract

The portion of the Florida Reef Tract that is part of the AOI includes the Florida Keys, Dry Tortugas National Park, and Tortugas Ecological Reserve (North and South Areas). Detailed discussions of the protected areas within the Florida Reef Tract are discussed in **Section 7.1**. Unlike many of the other low-relief hard bottom habitats previously discussed, much of the Florida Reef Tract is shallow, mostly with water depths of <3 m (10 ft) (Chiappone and Sullivan, 1994). Octocorals Palmer’s eunicea (*Eunicea palmeri*), porous sea rods (*Pseudoplexaura jiagellosa*), and corky sea finger (*Briareum asbestinum*) are dominant, but red algae (*Laurencia intricata*) and green algae (*Halimeda opuntia*); sponges, including ethereal sponge (*Dysidea etheria*), scattered pore rope sponge (*Aplysina fulva*), and chicken liver sponge (*Chondrilla nucula*); and stony corals such as the lesser starlet coral (*Siderastrea radians*), clubtip finger coral (*Porites porites*), smooth stone coral (*Solenastrea bournoni*), knobby star coral (*Solenastrea hyades*), golfball coral (*Favia fragum*), and diffuse ivory bush coral are also common (Chiappone and Sullivan, 1994), along with the branching fire corals. In recent years, the diversity and abundance of corals has significantly declined within the Florida Reef Tract as a result of numerous factors such as disease, tropical storms, agricultural runoff, coastal development, and overfishing of keystone species (Donahue et al., 2008).

5.2.4 Topographic Features

In the GOM, the term “topographic features” specifically refers to the 37 submerged banks that are protected from oil and gas activities and described in NTL 2009-G39 as “isolated areas of moderate to high relief that provide habitat for hard bottom communities of high biomass and diversity and large numbers of plant and animal species, and support, as shelter or food, large numbers of commercially and recreationally important fisheries.” These banks are located in the WPA (21 banks) and CPA (16 banks) (**Figure 4.5-2** of this Programmatic EIS). The topographic features are a result of a thick stratum of salt that is present beneath the GOM seafloor that formed during periods of lower sea level in geologic history (USDOI, BOEM, 2012a). When subjected to high pressures, salt can liquefy and protrude up through seafloor faults, causing rock layers to project above the seafloor. These formations are known as salt diapirs. This process forms hard bottom habitat that can be colonized by reef organisms in areas that usually are dominated by soft bottom communities (USDOI, BOEM, 2012a). BOEM has mandated “No Activity Zones” around major topographic features in the GOM (USDOI, MMS, 2008) to protect these submerged banks from anchoring and other disturbances that may occur during oil and gas exploration and production activities.

Table 4.5-1 of this Programmatic EIS lists the topographic features in the GOM that are protected by BOEM as described in NTL 2009 G39. The MMS (USDOI, MMS, 2008) presented maps of all 37 protected areas and graphically displayed the protected zones around each bank. True coral reefs are found at the East and West FGBs in the WPA, McGrail Bank in the CPA, and Pulley Ridge in the EPA (USDOI, BOEM, 2012a and 2013a). The other topographic features listed in **Table 4.5-1** of this Programmatic EIS have varying degrees of biological diversity and reef development, depending on depth, sedimentation rates, and habitat complexity. Although many of the banks are too deep to harbor true hermatypic coral reefs, they feature vast biological diversity including gorgonians, black corals, soft corals, sponges, echinoderms, crustaceans, polychaetes, and other invertebrates, as well as complex fish assemblages (USDOI, BOEM, 2012a and 2013a). Unlike the shallow, easily damaged Caribbean coral reefs, deep reefs (>70 m [230 ft]) of the GOM are influenced by only the strongest tropical storms, and even then usually only by increased turbidity near the seafloor (Rezak et al., 1990).

Detailed descriptions of the East and West FGBs, as well as other topographic features that are managed areas (i.e., Alderdice Bank, Bright Bank, Geyer Bank, McGrail Bank, Stetson Bank, and Sonnier Bank), are fully discussed in **Sections 7.1 and 7.2**. The topographic features of the GOM have been grouped based on location on the shelf (refer to Rezak et al., 1983). Following this grouping, banks of the three major shelf locations are summarized in the following subsections. A more complete discussion of these banks can be found in the Multisale EISs published by BOEM (USDOI, BOEM, 2012a and 2013a).

Shelf Edge Banks

The best examples of shelf edge banks are the East and West FGBs. These banks are at depths between 100 and 150 m (328 and 492 ft) and are within 12 km (7.5 mi) of each other. Vertical relief extends to approximately 116 m (380 ft) at the East FGB and approximately 130 m (425 ft) at the West FGB, making the water shallow (<20 m [66 ft]) at the crest of the banks (Rezak et al., 1983). The banks were formed by salt diapirs, as described previously. This allows for the development of a coral reef system that thrives in clear warm waters. Most of the reef-building corals are in water depths of <50 m (164 ft) primarily because deeper waters can fall below 19°C (66°F) in the winter months. Coral species of the reef-building zone include lobed star coral (*Orbicella annularis*), symmetrical brain coral (*Diploria strigosa*), great star coral (*Montastraea cavernosa*), stony/brain coral (*Colpophyllia* spp.), and mustard hill coral (*Porites astreoides*). The endangered elkhorn coral (*Acropora palmata*) was discovered at the West FGB in 2001 (Precht et al., 2006) and at the East FGB in 2005 (Precht et al., 2008). In deeper portions of the FGBs, the biota is dominated by coralline algae, octocorals, sponges, echinoderms, leafy algae, and ahermatypic corals (Rezak et al., 1983).

Mid-Shelf Banks

Rezak et al. (1983) defined mid-shelf banks as those that are located in 80 m (262 ft) or less of water and have vertical relief of 15 to 50 m (49 to 164 ft). There are eight mid-shelf banks within the AOI (i.e., 29 Fathom Bank, 32 Fathom Bank, Claypile Lump Bank, Coffee Lump Bank, Stetson Bank, Fishnet Bank, Sackett Bank, and Sonnier Bank). Stetson Bank has a different species composition than other nearby banks, likely due to its geographic location near the northern limit for hermatypic corals (USDOI, BOEM, 2012a and 2013a). Reef-building corals at Stetson Bank include symmetrical brain coral, blushing star coral (*Stephanocoenia intersepta*), ten-ray star coral, yellow pencil coral (*Madracis mirabilis*), and fragile saucer coral (*Agaricia fragilis*) (DeBose et al., 2008). DeBose et al. (2008) identified >180 species of reef and schooling fishes as well as 644 species of invertebrates at Stetson Bank.

South Texas Banks

The South Texas Banks are unique because they were not formed by salt diapirs as is likely for banks with similar features elsewhere in the GOM. The South Texas Banks are most likely drowned reefs originating in the late Pleistocene to early Holocene Epochs, approximately 18,000 to 10,580 years ago (Rezak et al., 1983). Typical species assemblages for the South Texas Banks include black corals (*Cirrhipathes* spp.), vase sponges (*Ircinia campana*), feather stars (comatulid crinoids), sea fans, deepwater alcyonarians (sea pens), small solitary corals, basket stars, American thorny oyster (*Spondylus americanus*), brachiopods (*Argyrotheca barrettiana*), arrow crabs (*Stenorhynchus seticornis*), hermit crabs, black urchin (*Diadema antillarum*), sea cucumber (*Isostichopus* spp.), and fireworms (*Hermodice* spp.). A diverse fish fauna is also present on these banks, including yellowtail reeffish, roughtongue bass, spotfin hogfish, reef butterflyfish (*Chaetodon sedentarius*), wrasse bass, tattler, gobies (Family Gobiidae), and blue angelfish (Rezak et al., 1983). A variety of migratory game and commercially fished species inhabit South Texas Banks, including red snapper, vermilion snapper (*Rhomboplites aurorubens*), greater amberjack (*Seriola dumerili*), great barracuda (*Sphyraena barricuda*), and cobia (Rezak et al., 1983).

5.2.5 Artificial Reefs

In addition to natural hard bottom habitats, artificial reefs provide suitable substrate for the proliferation of live bottom communities (SAFMC, 2009) and associated fish assemblages. **Figure 4.5-3** of this Programmatic EIS shows locations of artificial reefs in the AOI. Under the existing regulations, when oil and gas platforms reach the end of their useful life, they must be decommissioned and dismantled. The USDOI's Rigs-to-Reefs policy, implemented by the BSEE and BOEM, is a process by which operators of decommissioned oil and gas platforms donate the material to coastal states for use as artificial reefs. The platforms are prepared for decommissioning and can be toppled in place, partially removed near the surface, or towed to existing reef sites with proper permits obtained by the State from the U.S. Army Corps of Engineers (USACE) and in accordance with applicable guidelines to ensure navigational safety, infrastructure security, and environmental protection. Recreational diving and fishing, as well as commercial fisheries, benefit from artificial reefs, which provide an additional option for conserving, managing, and developing fishery resources and which can provide potential habitats for endangered or threatened species. As of 2013, there are >500 sites that have been approved by BSEE as artificial reef sites on the OCS (USDOI, BSEE, 2013).

Artificial reef habitats are an integral part of the coastal and shelf ecosystem in the GOM and support a diverse and special biological community (Steimle and Zetlin, 2000). Artificial reefs typically are composed of objects that provide hard surfaces such as metal, wood, and concrete that can support algae, barnacles, sponge, tubeworms, hydroids, anemones, oysters, and tunicates (Steimle and Figley, 1996; Steimle and Zetlin, 2000). The communities often are similar to those occurring on natural hard bottoms, though the size, composition, location, and age affect the structure and habitat value of these reefs (Steimle and Zetlin, 2000; Wilson et. al., 2003).

The presence of oil and gas platforms (active, decommissioned, and sunken) adds areas of hard bottom to the dominantly soft bottom AOI (Stanley and Wilson, 2000). Artificial reefs can help enhance the amount of available hard bottom and create habitat for hard and soft corals and associated fauna. Wilson et al. (2003) concluded that free-standing oil and gas platforms supported significantly higher fish biomass and densities than those found around dismantled rigs or natural reefs. Artificial reefs created by dismantled rigs were found to have similar fish biomass as the upper terrace of a natural reef at the West FGB. The fish species composition at the West FGB was found to be composed of more reef-dependent species, while the species at artificial reefs generally were more pelagic in nature. Fish densities tended to be 10 to 1,000 times greater around artificial reefs than was found in surrounding open water soft bottom habitats (Wilson et al., 2003). Boswell et al. (2010) found similarly high fish densities around the Freeport Sulphur Mine Artificial Reef in the northern GOM. Wilson et al. (2003) provided support for the hypothesis that dismantled oil and gas platforms can create effective hard bottom habitat for reef organisms.

A more recent study has identified reef-building corals (mostly ten-ray star coral, symmetrical brain coral, and great star coral) and non-reef-building corals (mostly diffuse ivory bush coral and hidden cup coral [*Phyllangia americana*]) on 48 oil and gas platforms near the FGBs (Sammarco et al., 2008). Corals were more commonly found on platforms at the shelf edge than inshore, and brooding coral species were more effective than broadcasters at colonizing the extremely patchy hard bottoms created by oil and gas platforms (Sammarco et al., 2008). It is important to note that the majority of corals on decommissioned platforms are invasive cup corals (*Tubastrea* sp.), which can number in the hundreds of thousands of colonies on a single structure (Sammarco, 2008). These invasives do not contribute to reef building, and it is not known if these species are opportunists taking advantage of an open ecological niche or if they are excluding other native species from using available habitat (Sammarco et al., 2010). Sammarco (2014) showed that some *Tubastrea* species were existing at greater depths than in its native range and appears to readily outcompete native sessile epibenthic organisms. Artificial reefs created by existing and future oil and gas infrastructure may contribute alternative habitat for corals and associated reef fauna by creating a complex habitat in a mostly featureless, soft bottom seafloor.

5.3 Chemosynthetic Communities

Chemosynthetic organisms are unique in that they use a carbon source other than the photosynthesis-based food webs that support all other life on Earth. Chemosynthetic bacteria have the ability to oxidize the chemicals present in seafloor vents (often hydrogen sulfide, hydrogen gas, or ammonia) into organic molecules used to produce biomass (often sugars). Since they were first discovered at the base of the Florida Escarpment in 1983 (Paull et al., 1984), more than 70 chemosynthetic communities have been found in the GOM (USDOI, BOEM, 2012a and 2013a) and it is likely that many more exist (**Figure 4.5-1** of this Programmatic EIS). All known chemosynthetic communities in the GOM are found in deep water (>300 m [984 ft]), well beyond the boundary of the continental shelf (USDOI, BOEM, 2012a). There is a relationship between commercial hydrocarbon discoveries in the GOM and the presence of chemosynthetic communities (Sassen et al., 1993). Most of the oil present in the GOM is found in geologic layers originating from the Upper Jurassic to Upper Cretaceous Periods (Sassen et al., 1993), while most hydrocarbon seeps are in areas where there is little sediment cover over underlying strata (USDOI, BOEM, 2012a and 2013a). Seeps occur where hydrocarbons can vertically migrate through faults or other conduits to the surface, a process which occurs slowly on the geologic time scale. Many areas that fit these general descriptions have been seismically surveyed, and more than 28,000 seismic amplitude anomalies have been identified (Shedd et al., 2012), some of which have been proven to harbor chemosynthetic communities (USDOI, BOEM, 2013a).

Chemosynthetic communities have been classified into four general types based on the dominant seep organism (MacDonald et al., 1990): those dominated by vestimentiferan tube worms (*Lamellibrachia* cf. *brahma* and *Escarpia* sp.), mytilid mussels (*Bathymodiolus* spp.), vesicomyid clams (*Vesicomya cordata*), and infaunal lucinid or thyasirid clams (*Lucinoma* sp. or *Thyasira* sp.). Each of these dominant organisms creates unique seep communities based on differing faunal density, chemical usage, and associated heterotrophic (non-carbon fixing) fauna (USDOI, BOEM, 2012a). Powell (1995) found that, after a disturbance event where a large percentage of the dominant fauna were killed, the same chemosynthetic species recolonized the site.

Growth rates of many organisms in these communities are extremely slow, averaging approximately 2.5 mm per year for tube worms of the genus Lamellibrachia (Fisher, 1995). However, mytilid mussels have been found to reach reproductive age relatively quickly, with growth rates slowing in adulthood (Fisher, 1995). These factors lead to long-lived individuals and communities; Powell (1995) estimated that some clam and mussel communities at chemosynthetic sites have been present in the same location for 500 to 4,000 years. Powell (1995) noted that many sites stayed biologically and geologically, with most communities showing no evidence of changes in the dominant faunal organisms over time. Other heterotrophic organisms that are often found at chemosynthetic sites include a variety of mollusks, crustaceans, and echinoderms (Carney, 1994), as well as autotrophic (carbon-fixing) and non-chemosynthetic bacterial mats (MacDonald, 2002).

5.4 Listed and Candidate Species

Two coral species were listed under the ESA as threatened in 2006: elkhorn coral (*Acropora palmata*) and staghorn coral (*A. cervicornis*). Following a petition in 2009 from the Center for Biological Diversity (2009) to list 83 species of reef-building corals under the ESA, the NMFS issued a Final Rule (79 FR 67356), listing five additional Caribbean corals as threatened under the ESA: pillar coral (*Dendrogyra cylindrus*); lobed star coral (*Orbicella annularis*); mountainous star coral (*Orbicella faveolata*); star coral (*Orbicella franksi*); and rough cactus coral (*Mycetophyllia ferox*). This brings the total number of listed coral species in the wider Caribbean to seven. All of the threatened Caribbean species of coral are found within the AOI (Puglise and Kelty, 2007). Most are limited to the patch reefs surrounding the Florida Keys, off the southwest coast of Florida, on the East and West FGBs (USDOC, NOAA, 2013a and 2013b), and on the 18 Fathom and Bright Bank reefs in the northwest GOM (Rezak et al., 1983 and 1990). Elkhorn coral was documented at the West and East FGBs in 2003 and 2005, respectively (Zimmer et al., 2006).

6 MARINE AND COASTAL BIRDS

Chapter 4.6.1 of this Programmatic EIS provides the succinct description of the affected environment for marine and coastal birds in sufficient detail to support the impact analyses. The following descriptions provide additional, expanded information.

The GOM supports a diverse avifauna assemblage and includes a variety of coastal habitats that are important to the ecology of coastal and marine bird species, including the following:

- Sandwich Terns – the Breton National Wildlife Refuge off the Louisiana coast supports one of the world's largest colonies of Sandwich Terns. The northern Gulf Coast harbors about 75 percent of the population of Sandwich Terns in the southeastern United States.
- Brown Pelican – nearly half the southeastern population of Brown Pelicans lives in the northern Gulf Coast, generally nesting on protected islands. The Brown Pelican is Louisiana's State bird and has made a comeback in this region since Hurricanes Katrina and Rita in 2005. It was recently removed from the Endangered Species List.
- Wilson's Plover – the northern Gulf Coast is home to about 25 percent of the southeast's Wilson's Plover population.
- Black Skimmer – 35 percent of the southeastern Black Skimmer population is found along the Gulf Coast.
- Forster's Tern – 41 percent of the southeastern population is found along the Gulf Coast.
- Gull-Billed Terns – 16 percent of the southeastern population is found along the Gulf Coast.

- Laughing Gulls – 25 percent of the southeastern population is found along the Gulf Coast.
- Least Terns – 42 percent of the southeastern population is found along the Gulf Coast.
- Royal Terns – 36 percent of the southeastern population is found along the Gulf Coast.
- Snowy Plover – 22 percent of the southeastern population are found along the Gulf Coast.

This discussion focuses on three distinct taxonomic and ecological groups: seabirds, waterfowl, and shorebirds. Seabirds are defined here as species that live in the marine environment and feed at sea (Schreiber and Burger, 2002). Seabirds may be categorized by the marine zones in which they tend to forage. Pelagic birds forage in the open ocean away from the coastal zone, and shorebirds forage in coastal waters; other seabirds use coastal and open ocean zones (Michel, 2013). Seabirds within the AOI include members from five taxonomic orders: Charadriiformes (gulls, terns); Gaviiformes (loons); Pelecaniformes (pelicans, frigatebirds, gannets, boobies, tropicbirds, cormorants); Podicipediformes (grebes); and Procellariiformes (petrels, storm-petrels, shearwaters).

Certain waterfowl taxa commonly termed sea ducks (Order Anseriformes) feed and rest within coastal (nearshore and inshore) waters outside of their breeding seasons. They typically form large flocks and are often observed in large rafts on the sea surface. Members of the order Gaviiformes (loons) may also be present in coastal waters.

Shorebirds utilize coastal environments for nesting, feeding, and resting. They are included within the order Charadriiformes (with gulls and terns). The shorebird group consists of four families and includes sandpipers, plovers, oystercatchers, and stilts.

6.1 Listed Species

Under the ESA, there are three threatened species of marine and coastal birds present within the AOI that were analyzed within this Programmatic EIS: Piping Plover (50 FR 50726); Roseate Tern (52 FR 42064); and Red Knot (79 FR 73705). Although there are additional threatened and endangered species that occur in the coastal areas of the AOI, they are not considered marine or coastal birds based on their reliance on more terrestrial habitats or they are not documented in the AOI.

Piping Plover (*Charadrius melodus*)

The Piping Plover is a small, migratory shorebird that inhabits coastal sandy beaches and mudflats. They use open, sandy beaches close to the primary dune of barrier islands or along shores of rivers for breeding, preferring sparsely vegetated open sand, gravel, or cobble for nesting sites. They forage along the wrack zone, or line, where dead or dying seaweed, marsh grass, and other debris are left on the upper beach by the high tide (USDOI, FWS, 2011). Piping Plovers are very sensitive to human activities, and disturbances from anthropogenic activities can cause the parents to abandon their nests (USDOI, FWS, 2009).

The population of Piping Plovers that breeds in the Great Lakes States is listed as endangered, as amended (66 FR 36038). The Great Lakes Piping Plover wintering population is distributed along the Atlantic and GOM coastlines (Stucker and Cuthbert, 2006). The population of Piping Plovers that breeds in the Great Plains is listed as threatened (50 FR 50726). All Piping Plovers are considered threatened species under the ESA when on their wintering grounds (66 FR 36038). Individuals from the Great Plains population have been reported in coastal counties in all Gulf Coast States except Mississippi; however, individuals from the endangered population (those that breed in Great Lakes States) have been reported in the coastal counties of Mississippi (USDOI, FWS, 2011).

The FWS first designated critical habitat for wintering Piping Plovers in 142 critical habitat conservation areas, including the coasts of Florida, Alabama, Mississippi, Louisiana, and Texas within the AOI on July 10, 2001 (66 FR 36038). Critical habitat conservation areas were subsequently revised in Texas in 2009 (74 FR 23476). Critical wintering habitat has been designated in each of the Gulf Coast States for all three breeding populations (i.e., Atlantic Coast, Great Lakes, and Northern Great Plains) (66 FR 36038). Specifically, there are 30 parcels of land designated as critical habitat in the panhandle and west coast of Florida within the AOI; 3 areas in Alabama; 15 in Mississippi; 7 in Louisiana; and 18 in Texas (66 FR 36038). Thirty-three percent of these designated critical habitat areas are known to be used by Great Lakes breeding population of Piping Plovers (Stucker and Cuthbert, 2006).

Roseate Tern (*Sterna dougallii*)

The Roseate Tern is medium-sized and is primarily pelagic along seacoasts, bays, and estuaries, going to land only to nest and roost (Sibley, 2000). They often forage up to 30 km (19 mi) offshore and roost in flocks near tidal inlets in late July to mid-September. They nest on islands on sandy beaches, open bare ground, and grassy areas, typically near areas with cover or shelter.

Roseate Terns forage mainly by plunge-diving and contact-dipping (in which the bird’s bill briefly contacts the water) or surface dipping over shallow sandbars, reefs, or schools of predatory fish. They are adapted for fast flight and relatively deep diving and often submerge completely when diving for fish (USDOI, FWS, 2010).

Only one subspecies of Roseate Tern (*S. d. dougallii*) is located in the AOI. A population breeds on islands around the Caribbean Sea from the Florida Keys to the Lesser Antilles; this population, which is listed as threatened, is known to occur within the AOI in scattered colonies along the Florida Keys (USDOI, FWS, 2010). No critical habitat has been designated for the Roseate Tern.

Red Knot (*Calidris canutus rufa*)

The Red Knot (*Calidris canutus rufa*) is a medium-sized shorebird that migrates in large flocks long distances between breeding grounds in the mid- and high-arctic areas and wintering grounds primarily in southern South America along the coast of Patagonia, but with smaller populations wintering in northeast Brazil and in the southern U.S. along the Gulf Coast of Florida, Texas, and between Georgia and South Carolina. The largest concentrations of the birds that overwinter in the U.S. are found along the southwestern coast of Florida (Harrington, 2001; Morrison et al., 2001a; USDOI, FWS, 2013a; Normandeau Associates, Inc., 2011). They migrate northward through the contiguous U.S. in April to June and southward in July to October.

Within the AOI, Red Knots forage along sandy beaches, tidal mudflats, salt marshes, and peat banks. They also use mangrove and brackish lagoons in Florida and beaches, oyster reefs, and exposed bay bottoms in Texas (USDOI, FWS, 2013a). The Red Knot was added to the list of threatened species under the ESA (79 FR 73705) on January 12, 2015.

6.2 Non-Listed Species

Within the AOI, there are numerous marine and coastal bird species present, including resident and migratory species. Resident species are present throughout the year; migratory species may be present only during breeding or wintering seasons or they may only migrate through the AOI. The trans-Gulf migrant birds include various species of shorebirds, wading birds, and terrestrial birds.

Marine and coastal birds present within the AOI include seabirds, waterfowl, and shorebirds within 17 taxonomic families (**Table 4.6-1** of this Programmatic EIS). Bird species within a family share common physical and behavioral characteristics. Because of these commonalities, birds will be presented by family rather than individual species in this document as the potential for exposure to G&G activities will be similar for species within a family.

6.2.1 Seabirds

Four taxonomic orders of seabirds (broadly defined as birds that spend a large portion of their lives on or over water), including 11 families, are found in offshore and coastal waters of the AOI during their annual life cycle. Many species are present throughout the entire AOI and can be grouped into four categories according to their spatial and temporal residence: summer migrant pelagics, summer residents, wintering marine species, or permanent residents. Other species are present in only portions of the AOI (Peterson, 1980; Clapp et al., 1982a, 1982b, and 1983).

Seabirds generally feed on localized concentrations of prey in single- or mixed-species aggregations. Modes of prey acquisition include picking from the sea surface, shallow diving below the sea surface, and diving to depths of several meters (Shealer, 2002). Species that dive below the sea surface may be exposed to underwater noise produced during G&G surveys. Seabird species from the Procellariidae (petrels, prions, and shearwaters), Pelecanoididae (diving petrels), Sulidae (gannets and boobies), Phalacrocoracidae (cormorants and shags), and Laridae (gulls or seagulls) families occur within the AOI and regularly dive below the sea surface, and some species are known to deep dive for long durations.

Seabirds within the northern GOM were surveyed from ships during the GulfCet II program. Hess and Ribic (2000) reported that terns (*Sterna* spp.), Storm-Petrels (Family Hydrobatidae), shearwaters (*Puffinus* spp.), and jaegers (*Stercorarius* spp.) were the most frequently sighted seabirds in the deepwater area. During these surveys, seabirds in four ecological categories were observed in the deepwater areas of the GOM: (1) summer migrants (shearwaters, storm-petrels, and boobies [*Sula* spp.]); (2) summer residents that breed in the GOM (Sooty Tern [*Sterna fuscata*], Least Tern [*Sternula antillarum*], Sandwich Tern [*Sterna sandvicensis*], and Magnificent Frigatebird [*Fregata magnificens*]); (3) winter residents (gannets, gulls, and jaegers); and (4) permanent resident species (Laughing Gulls [*Larus atricilla*], Royal Terns [*Sterna maxima*], and Bridled Terns [*Sterna anaethetus*]) (Hess and Ribic, 2000). The GulfCet II study did not estimate bird population densities; however, Powers (1987) indicated that seabird densities over the open ocean are typically <10 birds/km^2.

The distribution and relative densities of seabird species within the deepwater areas of the GOM vary temporally (i.e., seasonally) and spatially. In the GulfCet II studies, seabird species diversity and densities were found to vary with the hydrographic environment, particularly the presence and location of mesoscale features such as Loop Current eddies that may enhance nutrient levels and productivity of surface waters where seabirds forage (Hess and Ribic, 2000).

In general, seabirds tend to occur at low densities over much of the ocean and are patchily distributed in relatively higher densities at *Sargassum* lines, upwellings, convergence zones, thermal fronts, salinity gradients, and areas of high planktonic productivity (Ribic et al., 1997; Hess and Ribic, 2000).

6.2.2 Waterfowl

Waterfowl that may occur within coastal and inshore waters of the AOI include species within the subfamilies Aythyinae (diving ducks) and Merginae (sea ducks) (Sibley, 2000). Diving ducks include the Canvasback (*Aythya valisineria*), Ring-Necked Duck (*Aythya collaris*), Lesser Scaup (*Aythya affinis*), Greater Scaup (*A. marila*), Bufflehead (*Bucephala albeola*), and Common Goldeneye (*Bucephala clangula*). Diving ducks are gregarious and mainly found in freshwater or estuarine environments, although species such as the Greater Scaup move to marine environments during the winter. Diving ducks feed on aquatic vegetation, mollusks, and crustaceans. Of the sea ducks in the AOI, the Hooded Merganser (*Lophodytes cucullatus*) is the most commonly occurring species.

Depending on species, all waterfowl feed on fishes, mollusks, and small invertebrates (Sibley, 2000). Similar to diving seabirds, sea ducks and some diving ducks may be vulnerable to underwater noise produced during G&G activities because they dive beneath the water surface in coastal waters for feeding. However, most diving ducks and sea ducks are located in bays and estuaries, which are outside of the AOI.

6.2.3 Shorebirds

The term shorebird applies to a large group of birds commonly called sandpipers and plovers but also includes oystercatchers, avocets, and stilts. Shorebirds found along the coastline of the AOI include species within four families: Charadriidae (plovers), Haematopodidae (oystercatchers), Recurvirostridae (avocets and stilts), and Scolopacidae (sandpipers). Fifty-three species of shorebirds regularly occur in the U.S. (Brown et al., 2001) with 43 species occurring during migrational or wintering periods in the AOI. Six shorebird species breed in the GOM: American Oystercatcher (*Haematopus palliates*), Snowy Plover (*Charadrius alexandrines*), Wilson's Plover (*Charadrius wilsonia*), Willet (*Catoptrophorus semipalmatus*), Killdeer (*Charadrius vociferous*), and Black-necked Stilt (*Himantopus mexicanus*) (Helmers, 1992). Recent trend analyses of shorebird abundance in various parts of the U.S. indicate that many species are declining, including species that are present along the shores adjacent to the AOI (Morrison et al., 2001b and 2006). This decline in shorebird abundance is believed to be from multiple factors, including the environmental degradation of the shoreline habitats, industrial and recreational development of multiple habitats (i.e., breeding and wintering), climate change affecting Arctic breeding sites, and alterations to coastal areas from sea-level rise. In addition, global climate change may alter prevailing wind patterns, which may affect ocean upwelling and productivity, subsequently affecting shorebird abundance and distribution (Morrison et al., 2001b). The Lower Mississippi/Western Gulf Coast Region is rich with a variety of shorebird habitats and the Gulf Coast has some of the most important shorebird habitat in North America, particularly the Laguna Madre ecosystem along the south Texas coast (Brown et al., 2001; Withers, 2002). Resident shorebirds primarily rely on the shorelines adjacent to the AOI for life functions; however, some shorebird species cross the AOI during their annual migration.

6.3 MIGRATION

A migratory bird is any species of bird that migrates and lives or reproduces within or across international borders at some point during its annual life cycle. Migratory birds and their nests are protected under the Migratory Bird Treaty Act (16 U.S.C. §§ 703-712). Migratory movements of most marine and coastal birds across North America are known only in general terms (Harrington and Morrison, 1979). Many North American birds seasonally migrate long distances between northern habitats in the high Arctic, New England, and Canada and southern habitats in Florida, Central America, and South America, traveling as far as 12,000 km (7,457 mi) from breeding to wintering grounds (Helmers, 1992). There are significant differences between species in migratory routes (Rappole, 1995). Many marine and coastal birds, as well as terrestrial birds, use the Mississippi Flyway, which runs through the peninsula of southern Ontario, Canada, across the U.S. to the mouth of the Mississippi River (**Figure 4.6-1** of this Programmatic EIS). The longest bird migration route in the Western Hemisphere ranges from the Arctic Coast of Alaska to Patagonia (Brown et al., 2001; Morrison et al., 2001a; Nutty Birdwatcher, 2015). Many North American terrestrial birds migrating to the tropics follow the Mississippi Flyway and take a shortcut across the

GOM (Nutty Birdwatcher, 2015). During migration, stopover areas provide resting and feeding opportunities needed by migrating birds to sustain them during their migration (Brown et al., 2001; McWilliams and Karasov, 2005). Disturbance along the shoreline where migrating birds forage can deny them the rest and food needed to complete their migration in good health (Helmers, 1992).

6.4 Bird Conservation Regions and Birds of Conservation Concern

The Fish and Wildlife Coordination Act was amended in 1988 to mandate the FWS to "identify species, subspecies, and populations of all migratory nongame birds that, without additional conservation actions, are likely to become candidates for listing" under the ESA. The FWS (USDOI, FWS, 2008b) prepared a document to identify birds of conservation concern to comply with this mandate. The goal of the document was to identify all migratory and non-migratory bird species with high conservation priorities in addition to species already designated as federally threatened or endangered. The development of the birds of conservation concern took into account variable geographic scales addressed by three bird conservation initiatives: North American Bird Conservation Initiative (NABCI) Bird Conservation Regions (BCRs), FWS Regions, and National (USDOI, FWS, 2008b).

The NABCI Bird Conservation Regions were developed by a mapping team with members from the U.S., Mexico, and Canada to provide a consistent spatial framework for bird conservation in North America. The mapping team developed a hierarchical framework of nested ecological units, or BCRs (**Figure 4.6-2** of this Programmatic EIS). There are four land-based BCRs located adjacent to the AOI: BCR 26, Mississippi Alluvial Valley; BCR 27, Southeastern Coastal Plain; BCR 31, Peninsular Florida; and BCR 37, Gulf Coastal Prairie (U.S. NABCI Committee, 2000). The FWS (USDOI, FWS, 2008b; Tables 24, 25, 33 and 35) listed all birds of conservation concern that may be present in BCRs (except for the Red Knot, which has only recently been listed) that include portions of the AOI. Shorebirds are, in general, of high conservation concern, with nearly half of the species in the U.S. designated as conservation concern (U.S. NABCI Committee, 2009 and 2014).

The BCR 26 (Mississippi Alluvial Valley) has 26 bird species of conservation concern, of which 5 species are marine or coastal birds. The BCR 27 (Southeastern Coastal Plain) has 53 bird species of conservation concern, of which 19 species are marine and coastal birds. The BCR 31 (Peninsular Florida) has 49 bird species of conservation concern, of which 18 species are marine and coastal birds. The BCR 37 (Gulf Coastal Prairie) has 44 bird species of conservation concern, of which 21 species are marine and coastal birds.

6.5 Important Bird Areas

The Important Bird Area (IBA) Program was developed by the National Audubon Society as a global effort to identify and conserve areas that are vital to birds and other biodiversity. The IBAs are sites that provide essential habitat for one or more species of birds and include sites for breeding, wintering, and migrating birds. By definition (National Audubon Society, 2011), IBAs are sites that support

- species of conservation concern (e.g., threatened or endangered species);
- restricted-ranges species (species vulnerable because they are not widely distributed);
- species that are vulnerable because their populations are concentrated in one general habitat type or biome; and
- species or groups of similar species (such as waterfowl or shorebirds) that are vulnerable because they occur at high densities due to congregatory behavior.

The IBAs are located throughout the U.S. including along the coast, in nearshore waters, and offshore (**Figure 4.6-3** of this Programmatic EIS). Five of the Louisiana IBAs include nearshore waters within the AOI: Chenier Plain, Atchafalaya Delta, Barataria Terrebonne, Active Delta, and Chandeleur Islands (**Figure 4.6-4** of this Programmatic EIS). Additional offshore sites include Dry Tortugas National Park, Key West National Wildlife Refuge (NWR), and Great White Heron NWR. Furthermore, the GOM includes NWRs (**Chapter 4.7.1.2** of this Programmatic EIS), some of which include coastal habitat within the AOI. These NWRs (7 in Texas, 2 in Louisiana, 1 in Mississippi, 1 in Alabama, and 13 in Florida) are primarily managed for the protection and conservation of migratory birds (USDOI, FWS, 2013b).

7 MARINE PROTECTED AREAS

Chapter 4.7.1 of this Programmatic EIS provides the succinct description of the affected environment for marine protected areas in sufficient detail to support the impact analyses. The following descriptions provide additional, expanded information.

A Marine Protected Area (MPA) is defined by Executive Order (EO) 13158 as "any area of the marine environment that has been reserved by Federal, State, territorial, Tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein." In practice, MPAs are defined areas where natural and cultural resources are given greater protection than the surrounding waters. In the U.S., MPAs span a range of habitats, including the open ocean, coral reefs, deepwater habitats, coastal areas, intertidal zones, and estuaries, and can include freshwater and terrestrial areas. The MPAs are designed to achieve a variety of goals, generally falling within six categories: (1) conservation of biodiversity and habitat; (2) fishery management; (3) research and education; (4) enhancement of recreation and tourism; (5) maintenance of marine ecosystems; and (6) protection of cultural heritage.

Section 5 of EO 13158 specifically states, "In implementing this section, each Federal agency shall refer to the MPAs identified under subsection 4(d) of this order." Section 4(d) states that the Secretary of Commerce and the Secretary of the Interior "shall also publish and maintain a list of MPAs that meet the definition of MPA for the purposes of this order." In accordance with Section 4(d), a National System of MPAs was established in 2009 for the effective stewardship, conservation, restoration, sustainable use, understanding, and appreciation of marine resources. The information presented herein was obtained from the Marine Protected Areas Inventory (i.e., the

National System of MPAs) maintained through a partnership between NOAA and the USDOI. For the purpose of this analysis, National System MPAs are presented; however, it is recognized in **Section 5** that additional areas are afforded protection by other management systems (e.g., GMFMC) (Simmons et al., 2015) and that specific management areas (e.g., banks and topographic features) may be included within boundaries of existing National System MPAs.

It is important to note that the AOI extends beyond the planning areas to account for the acoustic energy that could propagate beyond BOEM jurisdictional boundaries; as such, the description of MPAs in the AOI include the Florida Keys, Dry Tortugas National Park, Tortugas Ecological Reserve, and other sensitive shallow-water habitats within State waters (3 or 9 nmi [5.6 or 16.7 km; 3.5 or 10.6 mi] from shore). The offshore MPAs within the AOI are listed in **Table 4.7-1** of this Programmatic EIS, and their locations are shown in **Figure 4.7-1** of this Programmatic EIS. Coastal MPAs are shown in **Figure 4.7-2** of this Programmatic EIS and include numerous MPAs that, while outside of BOEM's planning areas, are included to account for potential effects that may extend beyond the AOI boundary. **Table 4.7-1** of this Programmatic EIS contains sites that are currently designated as "members" of the National System of MPAs as well as the sites listed as "eligible" for inclusion. All sites listed are afforded some degree of protection based on their associated management plans. The following discussion focuses on marine sanctuaries, deepwater sites, and fishery management areas within the AOI, followed by a brief summary of coastal MPAs completely or partially within the AOI.

Table 4.7-1 of this Programmatic EIS includes the following additional categories of information for the respective MPAs:

- government level of management (State or Federal);
- managing agency (a State or Federal agency, and in a few cases, partnerships);
- primary conservation focus;
- areas of MPA within the AOI;
- total area of the MPA; and
- percentage of the MPA falling within the AOI.

7.1 National Marine Sanctuaries

Two National Marine Sanctuaries have been established in the AOI: the Florida Keys National Marine Sanctuary (FKNMS) and the Flower Garden Banks National Marine Sanctuary (FGBNMS), the latter of which is located in the northwestern GOM (**Figure 4.7-1** of this Programmatic EIS). They are administered by NOAA's Office of National Marine Sanctuaries.

7.1.1 Florida Keys National Marine Sanctuary

The FKNMS protects 9,947 km^2 (2,900 nmi^2) of waters surrounding the Florida Keys, from south of Miami west to encompass the Dry Tortugas, excluding Dry Tortugas National Park. This FKNMS is administered by NOAA and jointly managed with the State of Florida. It spans a shallow-water interface between the GOM and the Atlantic Ocean and is adjacent to most of the relatively shallow estuarine waters of South Florida, including Florida Bay and Biscayne Bay. The sanctuary surrounds >1,700 islands, which constitute most of the limestone island archipelago of the Florida Keys. This archipelago extends from the Florida peninsula south and westward more than 354 km (220 mi), terminating at the islands of Dry Tortugas National Park. The sanctuary contains components of five distinct physiographic regions: (1) the Florida Bay, (2) the Southwest Continental Shelf, (3) the Florida Reef Tract, (4) the Florida Keys, and (5) the Straits of Florida. The regions are environmentally and lithologically unique, and together they form the framework for the FKNMS' diverse terrestrial and aquatic habitats. The oceanic boundary of the FKNMS is the 300-ft (91-m) depth contour, beyond which the Florida Straits separate the Florida Keys from Cuba and the Bahamas. The waters northwest of the Florida Keys are within the eastern GOM. The FKNMS' GOM region is important as a fisheries resource as the area serves as the nursery grounds for many recreationally and commercially important species of fishes and invertebrates, including groupers, snappers, pink shrimp, spiny lobster, and stone crab.

The sanctuary supports approximately 6,000 marine species and contains the world's third largest barrier reef, extensive seagrass meadows, and mangrove-fringed islands. A variety of plants, invertebrates, fishes, reptiles, birds, and mammals that use or contribute to sanctuary resources in the Florida Keys are protected at the Federal or State level. Each species is a valuable natural resource that contributes to the ecological balance of the FKNMS. Animal species at risk depend on the FKNMS' diverse habitats, including mangroves, beaches (below high water mark), seagrass beds, and coral reefs. State and federally listed threatened and endangered marine and aquatic fauna include elkhorn coral, staghorn coral, pillar coral, all five species of sea turtles found in the western Atlantic (i.e., loggerhead, green, hawksbill, Kemp's ridley, and leatherback), American alligator (*Alligator mississippiensis*), American crocodile (*Crocodylus acutus*), smalltooth sawfish, Roseate Tern, Least Tern (*Sterna antillarum*), and the West Indian manatee. The FKNMS is also in the migratory range of three species of whales: humpback whale, fin whale, and North American right whale. The FKNMS also protects elements of history such as shipwrecks and other archeological treasures, including 669 historic artificial reefs that have been documented to date. As of January 2016, 14 shipwrecks and 2 lighthouses within the FKNMS are listed in the National Register of Historic Places.

The AOI includes most of the FKNMS (approximately 58% of the total area), from the area just south of Long Key to beyond the Dry Tortugas to the southwest.

7.1.2 Flower Garden Banks National Marine Sanctuary

The FGBNMS is located in the northwestern GOM and consists of three distinct areas: the East FGB, West FGB, and Stetson Bank. The East FGB covers 65.86 km^2 (19.20 nmi^2; 25.43 mi^2)

and is located approximately 222 km (120 nmi) south southwest of Cameron, Louisiana. The West FGB covers 77.54 km^2 (22.61 nmi^2; 29.94 mi^2) and is located approximately 200 km (108 nmi; 124 mi) southeast of Galveston, Texas. Stetson Bank covers 2.18 km^2 (0.64 nmi^2; 0.84 mi^2) and is located approximately 110 km (61 nmi; 68 mi) southeast of Galveston, Texas.

Structurally, the FGB coral reefs are composed of large, closely spaced heads 3 m (10 ft) or more in diameter and height. The FGB reefs are the northernmost living coral reefs on the U.S. continental shelf. Isolated from other coral reef systems by more than 556 km (300 nmi; 345 mi), the East and West FGBs favor hard corals and support at least 21 species. Eight species of coral are found on Stetson Bank, where the cooler water temperatures favor non-reef-building corals and sponges. The East FGB is also home to the only known oceanic brine seep in GOM continental shelf waters. The super-saline water flowing from under the seafloor has created a concentrated brine lake and channel in which only salt-tolerant bacteria are able to live. This “lake” and “river” are only approximately 25.4 cm (10 in) deep.

The East FGB is a pear-shaped dome capped by 1 km^2 (0.4 mi^2) of coral reef, termed “coral cap,” that rises to within 17 m (56 ft) of the surface. The West FGB is an oblong-shaped dome that includes 0.4 km^2 (0.15 mi^2) of coral reef area starting 18 m (59 ft) below the water surface. Brain and star corals dominate the coral caps of the East and West FGBs, with a few coral heads exceeding 6 m (20 ft) in diameter. On average, 45 to 52 percent of the bottom surfaces of the East and West FGBs coral caps are covered by coral species to depths of 30 m (98 ft), and exceeding 70 percent coral cover in depths of at least 43 m (141 ft) (Hickerson and Schmal, 2005). The coral caps do not contain some species commonly found in the Caribbean, such as many of the branching corals, sea whips, or sea fans. The deepwater habitat of the FGBs that makes up more than 98 percent of the area within the FGBNMS boundaries is not as well known. Habitats below recreational SCUBA limits (approximately 40 m [131 ft]) include algal-sponge zones, “honeycomb” reefs (highly eroded outcroppings), mud flats, mounds, mud volcanoes, and at least one brine seep system. Different assemblages of sea life reside in these deeper habitats, including extensive beds of coralline algae, pavements and algal nodules, colorful sea fans, sea whips, black corals, deep reef fish, batfish, searobins, basket sea stars, and feather stars (USDOI, BOEM, 2012a).

Depths at Stetson Bank range from approximately 17 to 52 m (55 to 170 ft). Environmental conditions at Stetson Bank include more extreme fluctuations in temperature and turbidity than at the East and West FGBs and do not support the growth of reef-building corals like those found at the FGBs. Stetson Bank contains a low-diversity coral community in addition to prominent sponge (*Phylum porifera*) fauna. The outcrops of Stetson Bank are dominated by the branching fire coral (*Millepora alcicornis*) and sponges, with cover exceeding 30 percent (Bernhardt, 2000). There are at least nine coral species at Stetson Bank, but most colonies are small and sparsely distributed, with the exception of a large area of ten-ray star coral (Hickerson et al., 2008).

Located in the general region of the East and West FGBs are other reefs and banks designated through NMFS’ essential fish habitat legislation as HAPCs, including Sonnier Bank, McGrail Bank, Bright Bank, Geyer Bank, and Alderdice Bank. These designated deepwater habitats contain outcroppings populated with benthic invertebrates, coralline algae, deep coral biota, and a variety of fish species. All HAPCs have protective measures from certain fishing operations and vessel anchoring and are identified as areas for special consideration during individual species assessments.

More than 300 different fish species and 3 species of sea turtles (i.e., hawksbill, leatherback, and loggerhead) inhabit FGBNMS waters. Macroalgae, crustaceans, sharks, skates, rays, many different types of benthic invertebrates, and a variety of seabirds thrive in the protected waters around the FGBs (Showalter and Schiavinato, 2003).

The entirety of the FGBNMS falls within the AOI. Expansion of the FGBNMS is proposed following several years of scientific assessment and public input. The proposed expansion was determined as one of the top priority issues that emerged during the management plan review process completed in 2012. The FGBNMS' advisory council recommended expanding from 145.6 km^2 (56.2 mi^2) to 725.9 km^2 (280.3 mi^2) to include up to nine additional reefs and banks, which support essential habitat for commercial and recreational fish species (USDOC, NOAA, 2015b).

7.2 Other Federal Fishery Management Areas

The Pulley Ridge HAPC, the deepest hermatypic (or reef-building) coral reef in the continental U.S., is located off the southwest coast of Florida. Pulley Ridge is a drowned barrier island approximately 100 km (62 mi) long by 5 km (3.1 mi) wide running parallel to the Florida peninsula northwest of the Dry Tortugas. The entirety of the Pulley Ridge HAPC (344 km^2 [132.8 mi^2]) is located within the AOI. Live corals dominated by *Agaricia* sp. have been located between the 60- and 70-m (197- and 230-ft) isobaths on the reef along with a diverse assemblage of fish species consisting of shallow-water and deepwater species.

Some fishing activities have been restricted in the Pulley Ridge HAPC, but growing concern for hermatypic corals in the area may lead to future management options. The GMFMC deepwater coral working group has expressed concern over ongoing damage to Pulley Ridge habitat by fishing operations and is considering additional protective measures. In May 2015, the Joint Coral Scientific and Statistical Committee and Coral Advisory Panel (Coral SSC/AP) recommended extended boundaries for the Pulley Ridge HAPC, stating specific concerns over the golden crab fishery (Coral SSC/AP, 2015).

While there are substantial areas of cold-water coral habitat in the GOM, it appears to be more scattered and less extensive than such habitats in the Atlantic Ocean off the southeastern U.S. Much of the research into the cold-water coral communities of the GOM has taken place along the northern continental slope. There, several studies have found coral habitat consisting of hermatypic coral species such as *Lophelia pertusa* and zigzag coral (*Madrepora oculata*). The most extensive cold-water coral communities found to date in the GOM occur at the Viosca Knoll, located on the upper De Soto Slope, approximately 120 km (65 nmi) south of Mobile Bay, Alabama. The main Viosca Knoll site (named the VK 826 Coral Habitat) is an isolated feature that rises 90 m (295 ft) from the seafloor, providing high relief for an array of suspension feeders, including scleractinian, gorgonian, and anthipatharian corals. The VK 862 *Lophelia* and Black Coral Habitat is located approximately 40 km (25 mi) west of the VK 826 Coral Habitat.

Numerous Federal fishery management areas have been designated by the NMFS and GMFMC. Other federally protected areas, with different degrees of management and protection, include reserves such as the Tortugas Ecological Reserve and the Reef Fish Stressed Area. The following MPAs listed in this section are not members of the national system of MPAs but are eligible to become members. These areas have restrictions on certain types of fishing activities and are briefly discussed here.

The De Soto Canyon Closed Area, located off the east coast of Florida, is a Federal Fishery Management Zone and has been managed by the NMFS since its designation in 2000. The MPA is closed year-round to all pelagic longline gear in order to protect tunas, swordfish, and other billfish and sharks (USDOC, NOAA, n.d.-a). The entire close area (86,854 km^2 [33,534.5 mi^2]) falls within the AOI.

The East Florida Coast Closed Area, as the name implies, is located primarily along Florida's east coast, but a small portion of it wraps under the southern end of the Florida peninsula. The area is closed to fishing gear, such as longline gear, that could indiscriminately catch non-target species. This MPA is closed year-round and is primarily focused on alleviating impacts to select species of fish and all sea turtles (USDOC, NOAA, n.d.-a). Only a small fraction (0.01%; 12.3 km^2 [4.7 mi^2]) of the MPA falls within the AOI.

The Florida Middle Grounds are a complex series of carbonate hard bottom outcropping located approximately 138 km (86 mi) south of Apalachee Bay, Florida. The outcroppings are spread over an area of approximately 1,193 km^2 (461 mi^2), with relief of up to 17 m (56 ft). The Florida Middle Grounds are the northernmost extent of hermatypic coral growth in the U.S. (Puglise and Kelty, 2007), and the fauna most closely resemble a tropical reef. Branching fire coral, elliptical star coral, and ten-ray star coral are common, as are octocorals, sea fans of the genus Muricea, and the giant barrel sponge (Naar et al., 2007). Other fauna include hydroids, anemones, mollusks, crustaceans, echinoderms, polychaetes, and fishes (Hopkins et al., 1977; Coleman et al., 2004a). The Florida Middle Grounds are not considered a true coral reef because the lack of abundance of hermatypic corals does not allow for the successful accretion of a carbonate reef (USDOI, BOEM, 2013a). All of the Florida Middle Grounds HAPC (1,159.6 km^2 [447.7 mi^2]) falls within the AOI.

Two marine reserves have been established to help manage gag grouper populations in the GOM: Madison-Swanson Marine Reserve and Steamboat Lumps Marine Reserve.

Madison-Swanson Marine Reserve is 400 km^2 (155 mi^2) of small outcrops and a few higher relief pinnacles (up to 9 m [30 ft]) roughly 80 km (50 mi) south of Apalachicola, Florida in water depths between 60 and 140 m (197 and 459 ft) (USDOI, BOEM, 2013a). The site is home to sponges, sea fans, corals (including bush/tree corals), echinoderms, and crabs (USDOI, BOEM, 2013a). The entire reserve falls within the AOI.

Steamboat Lumps Marine Reserve is located 161 km (100 mi) south-southwest of Cape San Blas, Florida, and approximately 32 km (20 mi) southwest of the Florida Middle Grounds. The reserve encompasses approximately 365 km^2 (138 mi^2) and comprises a relic reef in 60 to 140 m (197 to 459 ft) of water (Hine and Locker, 2008). Fauna in Steamboat Lumps Marine Reserve is typical of a deepwater reef, with sponges, sea fans, black corals, bush/tree corals, echinoderms, and crustaceans (USDOI, BOEM, 2013a). The entirety of Steamboat Lumps Marine Reserve falls within the AOI.

McGrail Bank (formerly known as 18 Fathom Bank) was mentioned but not described in the discussion of the FGBNMS. It is one of several named banks found across the continental shelf of the northwestern GOM and appears to be biologically and geologically connected to the FGBNMS. The top of McGrail Bank lies 46 m (151 ft) beneath the sea surface. Deeper reef habitat includes extensive coralline algae and deep coral assemblages at McGrail Bank, which is designated as a Coral HAPC. This designation protects the bottom habitat from fish traps and anchoring (USDOC, NOAA, National Ocean Service, 2014). McGrail Bank is located approximately 46 km (30 mi) east-northeast of Geyer Bank and 97 km (60 mi) east-northeast of the East FGB. It consists of a pair of ridges separated by a valley. McGrail Bank has the shallowest crest of any of the shelf-edge GOM banks west of the Mississippi River Delta, excluding the FGBs. There has been discussion about expanding the boundaries of the FGBNMS to include areas such as McGrail Bank (USDOC, NOAA, 2015b). The entirety of McGrail Bank (48 km^2 [18.5 mi^2]) falls within the AOI. Stetson Bank is described in **Section 7.1**, as it is part of the FGBNMS; however, it is also a designated HAPC.

The Pelagic Sargassum Habitat Restricted Area, which extends along the southeast coast of the U.S. from Virginia to a narrow region along the Florida Keys. A small portion of this restricted area extends into the AOI. This area has seasonal restrictions on the harvest of pelagic *Sargassum* (68 FR 18942). Only a fraction of the total restricted area (0.01%; 63 km^2 [24 mi^2]) falls within the AOI.

The Reef Fish Longline and Buoy Gear Restricted Area extends along all of the Gulf Coast States and restricts commercial fishing using longline gear within its boundaries (USDOC, NOAA, n.d.-b). The entirety of this restricted area (177, 935 km^2 [68,701 mi^2]) falls within the AOI.

The Reef Fish Stressed Area extends along all of the Gulf Coast States and contains commercial fishing restrictions within its boundaries (U.S. Government Publishing Office, 2002). The entirety of this restricted area (98,557 km^2 [38,053 mi^2]) falls within the AOI.

The Tortugas Marine Ecological Reserve, created in 2001, consists of two regions covering a total of 151 nmi^2 (200 mi^2; 518 km^2) at the western extent of the FKNMS. The reserve is closed to all consumptive use, including fishing and anchoring, and a portion of it is only open to permitted marine research (Jeffrey et al., 2012). The entirety of the reserve (229.4 km^2 [88.6 mi^2]) falls within the AOI.

The West and East FGBs HAPC is described in **Section 7.1.2**. The entirety of the HAPC (220.5 km^2 [85.1 mi^2]) falls within the AOI.

7.3 COASTAL MARINE PROTECTED AREAS

Coastal MPAs within the AOI include national seashores, NWRs, National Estuarine Research Reserves (NERRs), and State-designated MPAs (**Figure 4.7-2 and Table 4.7-1** of this Programmatic EIS).

7.3.1 National Park System (National Seashores)

There are four coastal national parks within the boundary of the AOI that are administered by the National Park Service (NPS). The NPS lands along the coast or in coastal areas of the AOI include the Dry Tortugas National Park, Everglades National Park, Gulf Islands National Seashore, and Padre Island National Seashore (**Figure 4.7 2** of this Programmatic EIS).

The Dry Tortugas National Park is located approximately 113 km (70 mi) west of Key West. The 261.4-km^2 (101-mi^2) park is mostly open water with seven small islands and is accessible only by boat or seaplane. The park's Fort Jefferson is a National Monument, and the designation as a National Park protects this monument. Almost 99 percent (258 km^2 [99.6 mi^2]) of the park falls within the AOI.

The Everglades National Park encompasses nearly 6,216 km^2 (2,400 mi^2) and includes the southern portion of mainland Florida, Florida Bay, and portions of the upper Florida Keys. The park contains approximately 2,280 km^2 (880 mi^2) of marine habitat, including open water, shallow waters, and mangrove-fringed shorelines and islands. Approximately 12.5 percent (775.3 km^2 [299 mi^2]) of the park falls within the AOI.

The Gulf Islands National Seashore spans two island chains off the coast of Mississippi and the Florida Panhandle. The Gulf Islands consist of seven barrier islands, five in Mississippi and two in Florida, making it the Nation's largest national seashore, covering more than 240 km (150 mi) of the Gulf Coast. Two of these islands (Horn and Petit Bois) are designated as Wilderness Areas under the Wilderness Act. The park encompasses 526 km^2 (203 mi^2) of barrier island and coastal waters. Approximately 42.2 percent (775 km^2 [299 mi^2]) of the park falls within the AOI.

Padre Island National Seashore lies along the Gulf Coast of Texas and stretches 180 km (112 mi), making it the longest barrier island in the U.S. Padre Island separates the GOM from the Laguna Madre, one of only a few hypersaline lagoons in the world. The park encompasses approximately 529 km^2 (204 mi^2). Approximately 12.1 percent (64 km^2 [24.7 mi^2]) of the park falls within the AOI.

7.3.2 National Wildlife Refuges

The National Wildlife Refuge system of U.S. lands and waters is managed by the FWS specifically for the enhancement of wildlife. There are 19 NWRs located within the AOI (**Table 4.7 1 and Figure 4.7 2** of this Programmatic EIS).

All terrestrial and aquatic resources within the NWR system are managed with the goals of conservation, management, and where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the U.S. for the benefit of present and future generations. Management approaches and conservation methods differ among NWRs but typically include managing and rehabilitating wildlife habitat, controlling invasive species, and assisting in the recovery of rare wildlife species (USDOI, FWS, 2002).

The Anahuac National Wildlife Refuge, established in 1963, borders Galveston Bay in southeast Texas and is a region of coastal marsh and prairie. The management focus of the NWR is to protect and manage the coastal marsh for migrating, wintering, and breeding waterfowl, shorebirds, and waterbirds as well as provide crucial nesting areas for neotropical migratory songbirds migrating across the GOM (USDOI, FWS, 2012). Less than 1 km^2 (0.4 mi^2) of the 137 km^2 (53 mi^2) of this NWR falls within the AOI.

The Aransas National Wildlife Refuge, established in 1937, includes two upland components and the shoreline of Matagorda Island along the Texas coast. Matagorda Island is a significant natural area that stretches 61 km (37.9 mi) long and 1.2 to 7.2 km (0.7 to 4.5 mi) wide, covering 229 km^2 (88 mi^2). Approximately 121 km^2 (47 mi^2) are uplands and the remaining 105 km^2 (41 mi^2) are salt marsh, tidal flats, and beaches. Matagorda Island's orientation is northeast-southwest with the GOM on one side and Espiritu Santo Bay on the other (USDOI, FWS, 2013c). Approximately 4.6 percent (21.8 km^2 [8.4 mi^2]) of this NWR falls within the AOI.

The Breton National Wildlife Refuge, established in 1904, is the second oldest wildlife refuge in existence. The NWR consists of barrier islands, including the Chandeleurs, located in the GOM off the southeast coast of Louisiana. According to the FWS, this NWR has one of the larger known nesting colonies of Royal and Sandwich Terns. This NWR also serves as an important area for Reddish Egrets (*Egretta rufescens*) and provides nesting habitat for various other colonial seabirds. This NWR has a large non-breeding concentration of Magnificent Frigatebirds as well as a large winter concentration of Redhead Ducks (*Aythya americana*) with a smaller number of Canvasbacks and Lesser Scaups (*Aythya affinis*). It also serves a large nesting colonies of several thousand Eastern Brown Pelicans (*Pelecanus occidentalis*) and provides wintering migration habitat for Piping Plover and other shorebirds (USDOI, FWS, n.d.-a). The entirety of this NWR (30.5 km^2 [11.8 mi^2]) falls within the AOI.

The Cedar Keys National Wildlife Refuge, established in 1929, is located in coastal Levy County, Florida. This NWR is composed of 12 offshore islands around the town of Cedar Key, ranging in size from a few acres to 120 ac. This NWR contains one of the largest colonial bird nesting sites in northern Florida. A wide variety of birds nest on Cedar Key (USDOI, FWS, n.d.-b). The entirety of this NWR (3.3 km^2 [1.3 mi^2]) falls within the AOI.

The Chassahowitzka National Wildlife Refuge, established in 1941, consists of more than 125 km^2 (48 mi^2) of saltwater bays, estuaries, and brackish marshes at the mouth of the Chassahowitzka River, Florida. According to the FWS, this NWR was established primarily to protect waterfowl habitat and is home to >250 species of birds, >50 species of reptiles and amphibians, and at least 25 different species of mammals, including the endangered West Indian Manatee (USDOI, FWS, 2013d). Approximately 48 percent (71.5 km^2 [27.6 mi^2]) of this NWR falls within the AOI.

The Crystal River National Wildlife Refuge, established in 1983, was specifically created for the protection of the endangered Florida manatee (a subspecies of the West Indian Manatee). This NWR protects important wintering habitat for manatees located in Kings Bay, Florida, which includes King Spring and Three Sisters Spring (USDOI, FWS, 2014). Approximately 11.5 percent (3.9 km^2 [1.5 mi^2]) of this NWR falls within the AOI.

The Delta National Wildlife Refuge, established in 1935, is composed of marsh habitat located just south of Venice, Louisiana, and is part of the Mississippi River Delta. This NWR was established as a bird sanctuary and provides wintering habitat and sanctuary for waterfowl and other migratory birds (USDOI, FWS, n.d.-c). Approximately 5.2 percent (10.7 km^2 [4.1 mi^2]) of this NWR falls within the AOI.

The Great White Heron National Wildlife Refuge, established in 1938, is located in the lower Florida Keys and consists of approximately 809 km^2 (312 mi^2) of open water and islands that are north of Marathon Key, and it is part of the Florida Keys National Wildlife Refuges Complex. The islands account for approximately 31 km^2 (12 mi^2) and consist primarily of mangroves, with some larger islands containing pine rockland and tropical hardwood hammock habitats. This NWR provides important habitat for migratory birds, sea turtles, and other wildlife (USDOI, FWS, n.d.-d). The entirety of this NWR (837.8 km^2 [323.5 mi^2]) falls within the AOI.

The J.N. Ding Darling National Wildlife Refuge, established in 1945, is located on Sanibel Island, in Lee County, Florida. Approximately 2,800 acres (ac) (1,133 hectares [ha]) of the refuge are designated as a Federal Wilderness Area. This NWR is composed of several habitat types: estuarine habitat consisting of open water, seagrass beds, mud flats and mangrove islands; and interior freshwater habitats consisting of open water ponds, *Spartina* swales, and West Indian hardwood hammocks/ridges. Two brackish water impoundments totaling 800 ac (324 ha) are used extensively by wading birds and other water birds (USDOI, FWS, n.d.-e). Approximately 3.4 percent (1 km^2 [0.4 mi^2]) of this NWR falls within the AOI.

The Key West National Wildlife Refuge, established in 1908, is almost entirely within the marine environment and is part of the Florida Keys National Wildlife Refuges Complex. This NWR consists of coral reef and seagrass communities as well as mangrove islands with limited sandy beach and dune habitat and regions of large sand flats. There are some areas of saltmarsh and coastal berm hammocks. This NWR supports critical nesting, roosting, wading, and loafing habitat to more than 250 bird species, particularly wading birds (USDOI, FWS, n.d.-f). The entirety of this NWR, approximately 760 km^2 (293.4 mi^2), falls within the AOI.

The Laguna Atascosa National Wildlife Refuge, established in 1946 in southeast Texas, includes South Padre Island and the waters of the Bahia Grande. It provides habitat for wintering waterfowl and other migratory birds, principally Redhead Ducks as well as endangered species conservation and management for shorebirds. This NWR also has the largest population of the endangered ocelot (*Leopardus pardalis*) in the U.S. (USDOI, FWS, 2013e). Less than 1 percent (7.5 km^2 [2.9 mi^2]) of this NWR falls within the AOI.

The Lower Rio Grande Valley National Wildlife Refuge, established in 1979 in southeastern Texas, is a fairly unusual region where four climates (temperate, desert, coastal, and subtropical) converge, resulting in a great diversity of plants and wildlife. This NWR was established to protect the biodiversity from over development from agriculture (USDOI, FWS, 2013f). This NWR provides habitat to 18 federally listed threatened and endangered species. Less than 1 percent (17 km^2 [6.5 mi^2]) of this NWR falls within the AOI.

The Lower Suwannee National Wildlife Refuge, established in 1979 in Dixie and Levy Counties, Florida, consists of lands located along the lower reaches of the of the Suwanee River, beginning at Yellow Jacket and continuing for 20 mi (32 km) until the river flows in the GOM. From the mouth of the river, this NWR extends northward along the GOM for 10 mi (16 km). This NWR consists of 146 km^2 (56 mi^2) of wetlands and 65 km^2 (25 mi^2) of uplands, providing important habitat for wading and shore birds, migratory songbirds, and raptors (USDOI, FWS, n.d.-g). Approximately 16.3 percent (55.3 km^2 [21.4 mi^2]) of this NWR falls within the AOI.

The National Key Deer Refuge, established in 1957 in Monroe County, Florida, consists of upland forest, shrub wetland, and wetland marsh habitat, and is part of the Florida Keys National Wildlife Refuges Complex. This NWR encompasses the truncated historical range of the endangered Key deer (*Odocoileus virginianus clavium*), including critical habitat. This NWR also serves as home to tropical hardwood hammock habitat and 22 federally listed endangered and threatened species of plants and animals, 5 of which are unique to the NWR (USDOI, FWS, n.d.-h). The entirety of this NWR (557.1 km^2 [215.1 mi^2]) falls within the AOI.

The San Bernard National Wildlife Refuge, established in 1969 near Freeport, Texas, consists of beaches, dunes, bay estuaries, and salt marsh habitat. Freshwater marsh and bottomland hardwood forest habitats of the Brazos and San Bernard River basins are found farther inland. This NWR supports a large diversity of coastal wildlife, including 320 species of birds, 95 species of reptiles and amphibians, and 130 species of butterflies and dragonflies (USDOI, FWS, 2013g). Less than 1 percent (0.02 km^2 [0.007 mi^2]) of this NWR falls within the AOI.

The Shell Keys National Wildlife Refuge, established in 1907, consists of a small group of dynamic shell fragment islets located south of Marsh Island and west of Greenwich, Louisiana. The boundary of the NWR has been interpreted to be the areas in this vicinity that are above mean high tide. This NWR is an important area for wading and shore birds. Recent hurricanes and storms have eroded the islets to such an extent that no nesting has occurred since 1992 (USDOI, FWS, 2008c). The entirety of this small NWR (0.02 km^2 [0.007 mi^2]) falls within the AOI.

The St. Marks National Wildlife Refuge was established in 1931 along the Florida Panhandle. The NWR includes coastal marshes, islands, tidal creeks, and estuaries of seven north Florida rivers and is home to a diverse community of plant and animal life. This NWR has more than 69 km^2 (27 mi^2) protected under the Federal Wilderness Act (USDOI, FWS, 2015). Approximately 24.1 percent (107.6 km^2 [41.5 mi^2]) of this NWR falls within the AOI.

The St. Vincent National Wildlife Refuge was established in 1968 in Franklin and Gulf Counties, Florida. The NWR is a coastal barrier island consisting of open water, wetlands, forest, shrub, and sand dune habitat. This NWR serves as a stop-over for migratory birds, red wolf (*Canis rufus*) propagation, nesting raptors, and nesting loggerhead sea turtles (USDOI, FWS, n.d.-i). Less than 1 percent (0.08 km^2 [0.03 mi^2]) of this NWR falls within the AOI.

The Ten Thousand Islands National Wildlife Refuge was established in 1996 in Collier County, Florida. The NWR consists of a diverse wetland habitat supported by freshwater flow from the Fakahatchee Strand and Picayune Strand watersheds. This NWR provides habitat for large concentrations of wading birds, shorebirds, waterfowl, and other water birds. Ten percent of Florida's manatee population utilizes the NWR and adjacent waters (USDOI, FWS, n.d.-j). Approximately 12.8 percent (18 km^2 [6.9 mi^2]) of this NWR falls within the AOI.

7.3.3 National Estuarine Research Reserves

The National Estuarine Research Reserve System (NERRS) is a partnership between NOAA and the coastal states that protects more than 1.3 million ac (526,091 ha) of coastal and estuarine habitat in a network of 28 reserves located in 22 states and Puerto Rico. The reserves consist of relatively pristine estuarine areas that contain key habitat for purposes of long-term research, environmental monitoring, education, and stewardship and are protected from significant ecological change or developmental impacts (USDOC, NOAA, NERRS, 2011). The NERRs containing portions within the AOI are the Apalachicola Bay, the Rookery Bay, and the Mission-Aransas Reserves (**Table 4.7-1 and Figure 4.7-2** of this Programmatic EIS).

The Apalachicola Bay Reserve is a lagoon and barrier complex consisting of a 99,553-ha (246,000-ac) reserve located on the Florida Panhandle. The reserve's management area includes two barrier islands and a portion of a third, the lower 52 mi (84 km) of the Apalachicola River and its floodplain, portions of adjoining uplands, and the Apalachicola Bay estuarine, riverine, and floodplain systems. Major estuarine habitats found within the reserve include oyster bars, submerged vegetation, tidal flats, soft sediment, marshes, and open water (USDOC, NOAA, NERRS, 2009a).

The reserve supports forage habitat for migratory bird species and for economically important fish species.

The Mission-Aransas Reserve, located along western Gulf Coast, consists of a 75,154-ha (185,708-ac) contiguous complex of wetland, terrestrial, and marine environments. The wetland component consists of riparian habitat and freshwater and salt water marshes. The open water component consists of bays with tidal flats, seagrass meadows, mangroves, and oyster reefs (USDOC, NOAA, NERRS, 2009b). The reserve supports forage habitat for migratory bird species and for economically import fish species.

The Rookery Bay Reserve is located south of Naples along Florida's Gulf Coast. The reserve is a coastal subtropical mangrove forested estuary consisting of approximately 44,516 ha (110,000 ac), 28,328 ha (70,000 ac) of which is open water. The remaining 16,188 ha (40,000 ac) are primarily composed of mangroves, fresh to brackish water marshes, and upland habitats, including upland hammocks and scrub. The reserve provides important habitat to more than 150 species of birds, economically important fish species, and threatened and endangered species, including the Florida panther (USDOC, NOAA, NERRS, 2009c).

7.3.4 State-Designated Marine Protected Areas

There are numerous State-designated coastal MPAs along the coastal boundary of the AOI that include State parks, resource conservation areas (e.g., nature preserves, aquatic preserves, natural areas, and wildlife management areas), sanctuaries, water quality protection areas, and historical areas (**Figure 4.7-2** of this Programmatic EIS). In addition, there are areas in State-designated MPAs where fishery activities are prohibited or controlled (**Table 4.7 1** of this Programmatic EIS). In total, there are 53 State-designated MPAs within the AOI. The portion of the MPA that falls within the AOI is provided in **Table 4.7-1** of this Programmatic EIS.

Florida has 48 State-designated eligible MPAs, grouped by managing agency. The Florida Department of Environmental Protection (FDEP) manages 36 of these MPAs; the majority were designated for protection of natural heritage areas and one was designated for sustainable production. The vast majority of these MPAs are Outstanding Florida Waters, although many are also State parks and aquatic preserves. Outstanding Florida Waters are water features designated by FDEP as worthy of special protection because of their natural attributes and have special restrictions on any new activity that would lower water quality or otherwise degrade the body of water. **Table 4.7-1** of this Programmatic EIS lists the FDEP-managed eligible MPAs, the total area that falls within the AOI, and the portion of the MPA that falls within the AOI.

The FWC manages eight MPAs; four are wildlife management areas and the other four are designated protection zones for the Florida manatee (**Table 4.7-1** of this Programmatic EIS). Collectively, the manatee protection areas located within the AOI cover approximately 20.6 km^2 (8.0 mi^2), which makes 3.2 percent of the total collective region designated with some form of manatee protection. The remaining four FWC-managed MPAs have coastal portions of their total area that fall within the AOI.

The Florida Division of Historical Resources (FDHR) manage four MPAs that were designated to preserve underwater archaeological regions of cultural significance, primarily shipwrecks. **Table 4.7-1** of this Programmatic EIS lists the FDHR-managed eligible MPAs, the total area that falls within the AOI, and the portion of the MPA that falls within the AOI.

Louisiana has five State-designated eligible MPAs, including a refuge and four wildlife management areas, three of which are also game preserves. All of these MPAs are managed by the Louisiana Department of Wildlife and Fisheries and are listed in **Table 4.7-1** of this Programmatic EIS.

Texas, Alabama, and Mississippi currently do not have any MPAs within the AOI.

8 *SARGASSUM* AND ASSOCIATED COMMUNITIES

Chapter 4.8.1 of this Programmatic EIS provides the succinct description of the affected environment for *Sargassum* and associated communities in sufficient detail to support the impact analyses. The following descriptions provide additional, expanded information.

Sargassum mats comprise two species of brown algae: *Sargassum natans* and *S. fluitans*. Each species is entirely pelagic, spending its entire life cycle on the ocean surface. *Sargassum* reproduces by vegetative fragmentation (LaPoint, 1995), and its movement is controlled by surface winds and currents. *Sargassum* can be found alone or aggregated into large mats or long windrows, and it can be randomly spread across the ocean surface or found along current or wind-driven boundaries. *Sargassum* mats also merge with natural and anthropogenic flotsam like terrestrial vegetation, seagrass, and trash (Witherington et al., 2012). *Sargassum* mats can grow to a few acres in extent and 1 to 1.5 m (3 to 5 ft) thick. The size of the mats is variable, depending on local physical (e.g., currents and winds) and physicochemical (e.g., dissolved oxygen, salinity, and temperature) oceanographic conditions (USDOI, BOEM, 2012a). Individual plants can grow up to 50 cm (20 in) in length and are characterized by a bushy, highly branched thallus (stem) with elongated toothed blades containing numerous spherical pneumatocysts (air bladders) (Littler et al., 1989; Coston-Clements et al., 1991). Pelagic *Sargassum* mats provide habitat for fauna, including more than 100 species of fish; more than 100 species of invertebrates, including crabs, shrimp, and mollusks; 4 species of sea turtles; and many species of marine birds (Coston Clements et al., 1991). Epiphytic algae (a group of microscopic algae that grow on the surface of marine plants), encrusting hydroids, bryozoans, and tube worms are also associated with these communities. *Sargassum* provides areas of high biological productivity in otherwise featureless waterbodies, supporting a diverse community during all life stages for foraging, protection from predators, and as nursery habitat.

8.1 *SARGASSUM* DISTRIBUTION

Analysis of satellite imagery from 2003 to 2007 suggests that *Sargassum* grows in the northwest GOM during the spring of each year and is then adverted into the Atlantic Ocean during fall and winter by the Loop Current and Gulf Stream (Gower and King, 2011). As the Loop Current penetrates northward into the GOM, large anticyclonic (clockwise-rotating) eddies (rings) are shed (**Section 18**); these eddies provide the surface energy needed to move the *Sargassum* to the near coastal waters of the Mexico and Texas Gulf Coasts (Webster and Linton, 2013). Models are being developed for coastal managers to predict *Sargassum* mat movement, especially prediction of when and where large amounts will come ashore (Webster and Linton, 2013). Estimates suggest that 0.6 to 6 million tons of *Sargassum* are present annually in the GOM, with an additional 100 million tons or more exported to the Atlantic (Gower and King, 2008 and 2011; Gower et al., 2013). Rapid growth of *Sargassum* ensures that the species are resilient and able to recover rapidly. Frazier et al. (2015) uses NASA's Landsat satellite imagery and data from ocean monitoring devices for use in the *Sargassum* Early Advisory predictive model. Frazier et al. (2015) observed the presence and abundance of *Sargassum* through the satellite imagery stating that it can take 2 to 5 months to reach the Texas Coast from the Sargasso Sea.

8.2 FISH HABITAT

The habitat provided by *Sargassum* mats is important to the life histories of many species of pelagic, littoral, and benthic fishes, as the mats provide substrate, protection from predation, and access to food in the open sea (Dooley, 1972). Two fish species are endemic to *Sargassum*, spending nearly their entire lives within *Sargassum* habitat: sargassumfish and *Sargassum* pipefish (**Chapter 4.3.2.1** of this Programmatic EIS). Other species, such as the Atlantic tripletail (*Lobotes surinamensis*) and various species of filefish (especially *Stephanolepis* spp.), appear to completely depend on drifting algae for refuge as juveniles (Hemphill, 2005). Some of the large pelagic, economically important fish utilizing *Sargassum* habitats include all life stages of tuna (*Thunnus* spp.), dolphinfish, wahoo, and several species of billfish that temporarily associate with *Sargassum*. Wells and Rooker (2004b) documented the abundance of estuarine and pelagic fish species in *Sargassum* mats, indicating that *Sargassum* may serve as an important means of transport of larval and juvenile species between offshore and inshore waters. Larval and juvenile fish have been documented within, adjacent to, and below *Sargassum*, with the highest abundance and greatest diversity being documented in waters adjacent to *Sargassum* mats (Hoffmayer et al., 2005). Eggs and larvae of species associated with *Sargassum* include gray triggerfish, lesser amberjack (*Seriola fasciata*), almaco jack (*Seriola rivoliana*).

8.3 SEA TURTLE HABITAT

Four species of sea turtles (i.e., loggerhead, green, hawksbill, and Kemp's ridley) have been documented in association with *Sargassum* in the GOM, specifically post-hatchling and early juvenile life stages. The four species of sea turtles have been observed actively foraging within the mats, resting and drifting while concealed by the mats, and diving below the mats (Witherington et al., 2012). Similar observations of hatchling and juvenile sea turtles' utilization of *Sargassum* as transport via passive drifting and foraging is reported in Carr and Meylan (1980) for green sea turtles and in Collard and Ogren (1990) for Kemp's ridley sea turtles. These observations suggest that sea turtles may complete their pelagic developmental life stage within *Sargassum* communities and then transition to neritic zone habitats as subadults.

Sargassum habitat in the offshore waters of the EPA, as well as most of the CPA and WPA, was designated as critical habitat in July 2014 (79 FR 39856) for hatchling loggerhead sea turtles (**Figure 4.3-3** of this Programmatic EIS). The designation was established because the survival of loggerhead sea turtles, in particular the post-hatchling and small oceanic juvenile stages, depends on suitable foraging and shelter habitat, which are provided by *Sargassum* in the Atlantic and GOM (79 FR 39856).

8.4 Invertebrate Habitat

The invertebrate community that inhabits *Sargassum* includes motile and sessile species. Common invertebrates include hydroids, anthozoans, flatworms, bryozoans, polychaetes, gastropods, nudibranchs, bivalves, cephalopods, pycnogonids, isopods, amphipods, copepods, decapod crustaceans, insects, and tunicates. Shrimps and crabs make up the bulk of invertebrates and are a major food source for *Sargassum*-associated fishes (Dooley, 1972).

9 COMMERCIAL FISHERIES

Chapter 4.9.1 of this Programmatic EIS provides the succinct description of the affected environment for commercial fisheries in sufficient detail to support the impact analyses. The following descriptions provide additional, expanded information.

The AOI supports regionally and nationally important commercial fisheries. The NMFS' Fisheries Statistics Division has automated data summary programs that can be used to rapidly and easily summarize U.S. commercial fisheries landings (USDOC, NMFS, 2015c). For the purposes of this Programmatic EIS, it is not practicable to report specific fisheries landings using the statistics queries because data are updated weekly; therefore, this characterization of commercial fisheries is primarily summarized from the most recently published Fisheries Economics Report (USDOC, NMFS, 2014).

In 2012, the seafood industry in the five coastal states adjacent to the AOI supported nearly 160,000 jobs (**Table 4.9-1** of this Programmatic EIS). Commercial fisheries support numerous directly related jobs (fishing crews) as well as many indirectly related industries such as seafood distributors, restaurants, and suppliers of commercial fishing gear. Commercial fishing ports often support entire coastal fishing communities and local businesses; thus, the fishing industry is an important component to the economy of the GOM. In 2012, the GOM region's seafood industry generated a total of approximately $22 billion in sales impacts, with Louisiana generating $1.9 billion of that total. Florida generated the largest employment, income, and value added impacts, generating 82,000 jobs, $3.1 billion, and $5.5 billion, respectively. Louisiana and Texas had the highest landings revenue in the region in 2012, $331 million and $194 million, respectively; the next greatest landings revenue came from Florida with $142 million (USDOC, NMFS, 2014).

9.1 Commercial Landings

Table 4.9-2 of this Programmatic EIS shows commercial landings in thousands of pounds of key species or species groups within the GOM, including blue crab, crawfish, groupers, menhaden, mullets, oysters, red snapper, shrimp, stone crab, and tunas (USDOC, NMFS, 2014). Fishers in the GOM region landed 1.7 billion lb of finfish and shellfish in 2012. Finfish landings contributed 82 percent of total landings in the GOM region (1.3 billion lb) in 2012.

Commercial fisheries in the AOI target a variety of fish and invertebrate species in State and Federal waters. Landings data do not indicate actual areas where particular species were caught; to accurately interpret fishing activity within the AOI from landings data for the coastal states, inferences must be made using knowledge of broad habitat use by species represented in the dataset. For example, 2012 landings data (**Table 4.9-2** of this Programmatic EIS) indicate that blue crab is an important fishery species (54.5 million lb in 2012), but blue crabs live primarily in inshore waters and would not be part of the fisheries for the AOI. The eastern oyster is a similar example of an inshore species making substantial contributions to landings data that should not be used to characterize fisheries in the AOI.

9.2 Commercial Fishing Gears

The main commercial fishing gears used within the AOI and along the Gulf Coast are bottom trawls, purse seines, gill nets, pots/traps, and longlines (bottom and pelagic). **Table 4.9-3** of this Programmatic EIS provides the species sought, seasons, and general areas fished with each gear type; a summary of the gear types is provided here.

Bottom trawls are large bag-shaped nets constructed with natural fibers or synthetic materials that typically have rectangular mouth openings. Trawls are towed at specific water depths (surface, mid water, or bottom), depending on the target species. Trawls are classified by their function, bag construction, or method of maintaining the mouth opening (Stevenson et al., 2004). Bottom trawls are designed to be towed along the seafloor to catch a variety of demersal fish and invertebrate species (e.g., shrimps, Gulf flounder [*Paralichthys albigutta*], or Atlantic croaker).

Purse seines are a type of net constructed with natural fibers or synthetic materials that are used to encircle a school of fish. Once the net has captured a school of fish, it is then cinched closed. Purse seines are primarily used to target Gulf menhaden within the inner shelf of the AOI during spring and summer months.

Gill nets are constructed of long panels of monofilament netting (mesh size approximately 3 to 4 in [8 to 10 cm]) with lead line at the bottom and float line at the surface. Nets are set perpendicular to shore or encircling a target school of fish. Gill nets are used to catch Spanish mackerel, mullet, black drum, and other coastal species by entanglement in coastal waters offshore Alabama, Mississippi, and Louisiana; gill nets are prohibited in Florida and Texas.

Pots/traps are rectangular, square, or cylindrical-enclosed devices with one or more gates set on the bottom to target benthic invertebrates (e.g., blue crab, stone crab, spiny lobster, and deep-sea red crab). Pots/traps usually are marked at the surface with a buoy that is attached to the pot or trap by a rope. This type of gear is usually set in strings near natural or artificial structure or hard bottom. Pots are connected by “mainlines” that float or sink to the bottom (Stevenson et al., 2004). This method is primarily used offshore Florida.

Longlines typically consist of 1.6 to 64.4 km (1 to 40 mi) of monofilament mainline with leaders attached to baited hooks (gangions) clipped at regular intervals. The mainline is attached to a series of floats equipped with radar reflectors and with radio beacons. Longlines are classified by where the gear is set in the water column; longline gear is set at the surface in open waters of the GOM or on the seafloor in OCS waters from Florida to Texas on suitable bottom type. Longlines drift with the currents or are anchored to the bottom and are used to target benthic (e.g., tilefish and large coastal sharks), coastal pelagic (e.g., dolphinfish and wahoo), and pelagic (e.g., tunas, swordfish, or pelagic sharks) species (Stevenson et al., 2004).

9.3 Time and Area Closures and Gear Restrictions

One method that FMCs use to control commercial fishing effort or protect specific habitats is to designate closed areas or to close fisheries (temporarily, seasonally, or permanently). To notify the public of fishery or site closures, the NMFS publishes the regulations, which are usually associated with an FMP amendment or management action, in the *Federal Register*. When a closure has been approved, the FMCs, in cooperation with the NMFS, announce these closures by posting them to their websites, sending emails and faxes, or holding public meetings. In addition to closing fisheries or areas for fish conservation management reasons, regulatory agencies use closed areas to protect marine mammals and sea turtles (e.g., from entanglement in discarded fishing gear).

Permanent commercial fishing closures can also consist of prohibiting various types of commercial fishing gears or fishing techniques. **Table 4.9-4** of this Programmatic EIS summarizes areas where certain commercial fishing activities are prohibited or where gear restrictions apply during all or part of the year; however it is important to note that regulations fluctuate on a regular basis and current information on rules must be obtained from the NMFS or GMFMC. **Figure 4.9-1** of this Programmatic EIS shows the locations of most of these closure areas.

10 RECREATIONAL FISHERIES

Chapter 4.10.1 of this Programmatic EIS provides the succinct description of the affected environment for recreational fisheries in sufficient detail to support the impact analyses. The following descriptions provide additional, expanded information.

Recreational fishing is an important social and economic activity. Nationally, 8.9 million saltwater recreational anglers made 86 million trips and spent $10.3 billion in 2011 (USDOI, FWS and USDOC, Census Bureau, 2014). Saltwater recreational fisheries in states adjacent to the AOI are among the most valuable in the U.S. In 2012, total fishing trip and durable equipment expenditures were $10 billion, and major expenditures included boat expenses ($4.8 billion), fishing tackle ($1.4 billion), vehicle expenses ($1.2 billion), second home expenses ($896 million), and other equipment ($558 million). In 2012, west Florida ranked first ($9.1 billion) and Louisiana ranked third ($2 billion) nationally in sales impacts from total expenditures related to recreational fishing (USDOC, NMFS, 2014). Among the Gulf Coast States, the number of trips, jobs, sales, income, and value-added impacts from recreational fishing were highest in Florida (west coast) in 2012 (**Table 4.10-1** of this Programmatic EIS).

In 2011, Florida ranked first nationally for total expenditures and durable goods expenditures related to recreational fishing (Lovell et al., 2013). Among the Gulf Coast States, sales, income, and employment impacts created by recreational fishing were highest in Florida (west coast), while the impacts generated from shore-based fishing were highest in Texas (Lovell et al., 2013). In 2011, Federal taxes generated by angler purchases ranged from $8.5 million (Mississippi) to $661 million (Florida), while revenue received by State/local governments ranged from $10.9 million (Mississippi) to $534 million (Florida) (Lovell et al., 2013).

In their comprehensive national analysis of recreational fishing, Coleman et al. (2004b) estimated that saltwater fishing accounted for approximately 4 percent of the total marine fish landed in 2002. However, recreational fishing accounts for a much larger percentage of the total landings for populations of concern in the GOM (64%) (Coleman et al., 2004b). Worldwide, increases in recreational fishing activity may threaten some already overfished populations (Cooke and Cowx, 2004); in 2002, recreational fishing activities landed approximately 23 percent of the overfished stocks in the U.S. (Coleman et al., 2004b).

10.1 Recreational Fishing Effort

The annual number of recreational angler trips is a measure of recreational fishing effort that is monitored by the NMFS via the Marine Recreational Information Program, which is an automated data query system that maintains a searchable database of recreational saltwater fishing catch, effort, and participation data and statistics. For the purposes of this Programmatic EIS, characterization of commercial fisheries is primarily summarized from the most recently published Fisheries Economics Report (USDOC, NMFS, 2014).

Recreational fishing effort within the GOM in 2012 consisted of more than 3.1 million recreational anglers taking 23 million trips (**Table 4.10-1** of this Programmatic EIS); anglers were primarily (>91%) residents of the Gulf Coast. Recreational fishing is a year-round activity throughout the AOI and can be classified as a nearshore or offshore effort depending on the size of the vessel and its fishing location (distance from shore). Nearshore recreational fishing (<4.8 km [3.0 mi]) consists of anglers fishing from private vessels and along beaches, marshes, or man-made structures (e.g., jetties, docks, and piers), whereas offshore fishing consists of anglers fishing from larger vessels (i.e., private, rental, charter, or party) in offshore waters (>4.8 km [3.0 mi]). According to the USDOC, NMFS (2014), recreational fishing trips in the AOI (Louisiana, Mississippi, Alabama, and Florida) during 2012 were primarily from private/rental boats (55%), shore (41%), and charter vessels (4%). In 2013, the majority of recreational fishing trips were from Florida (60%), while other Gulf Coast States accounted for 18 percent (Louisiana), 11 percent (Alabama), 7 percent (Mississippi), and 4 percent (Texas) of the total number of trips (USDOC, NMFS, 2014).

10.2 Recreational Fishing Locations

Marine fishes depend on and utilize many different types of habitats (e.g., seagrass, salt marsh, soft bottom, hard bottom) for feeding, spawning, and nursery grounds. Given the importance of these areas to the fish, recreational anglers have many opportunities to target various species in these habitats. For example, anglers targeting reef fishes (groupers and snappers) target offshore structure (natural and artificial reefs or ledges) (**Chapter 4.5.5.2** of this Programmatic EIS), while anglers pursuing inshore fishes (spotted seatrout and redfish) target seagrass habitat (**Section 20**).

10.3 Recreational Catch Characteristics

Recreational fishing is a year-round activity, but many anglers target specific species at certain times, and recreational fishing effort is often weather-dependent; more recreational fishing effort occurs during spring through summer when the weather is ideal for anglers fishing from small watercraft. The choice of fish species targeted by recreational anglers depends on the season, fishing location, and seasonal movement of the target species. For example, one of the best times to target pelagic species such as dolphinfish and sailfish in the GOM is during late summer and early fall. Bottom fishing for snapper, grunts, and porgies increases during the summer, while grouper fishing is best during winter.

The types and numbers of fishes caught by recreational anglers vary by state within the AOI. Of the Gulf of Mexico OCS Region's key species and species groups, spotted seatrout (33 million fish), red drum (9 million fish), sand and silver seatrout (7.4 million fish) and Atlantic croaker (5.2 million fish) were the most often caught by anglers in 2012 (**Table 4.10-3** of this Programmatic EIS).

10.4 Recreational Fishing Tournaments

Organized saltwater fishing tournaments are held throughout the AOI and are popular amateur and professional events that can range in participation from approximately 50 to more than 2,050 vessels from throughout the U.S. Tournaments can draw large spectator crowds onshore, which contributes to the local economy; tournament prizes can be more than $1 million and involve corporate sponsors and non-profit beneficiaries. Recreational fishing tournaments are held year-round but most take place in summer. In general, many fishing tournaments are held at the same time and place each year; local communities often rely on fishing tournaments to stimulate the local economy (e.g., restaurants, hotels, fuel, and supplies). Depending on the fishing tournament and its rules, participants have the option to participate in inshore (e.g., red drum, spotted seatrout, snook) or offshore (e.g., dolphinfish, wahoo, kingfish) categories, or enter both categories. Every fishing tournament has its own set of rules for classes of eligible fish, size limits, time limits, and specific geographical boundaries. Based on the tournament's rules and eligible fish, participant teams choose fishing sites and tactics according to their fishing experience and local knowledge. Throughout the AOI, there are many fishing tournaments that are annual events; however, it is difficult to identify all tournaments given that some are one-time events and sponsorships can change from year to year. Overall, saltwater fishing tournaments in the AOI are a traditional community-based pastime and important local tradition; there is at least one tournament every weekend somewhere between Texas and Florida during the spring/summer months (**Table 4.10-4** of this Programmatic EIS).

11 ARCHAEOLOGICAL RESOURCES

Chapter 4.11.1 of this Programmatic EIS provides the succinct description of the affected environment for archaeological resources in sufficient detail to support the impact analyses. The following descriptions provide additional, expanded information.

Submerged cultural resources within the AOI include shipwrecks that occurred as early as the 16th and 17th centuries during exploration and settlement of North America by Europeans. Submerged prehistoric sites dating between 12,000 and 3,500 before present (B.P.) may also be present within the AOI, depending on regional landform variation.

The AOI includes State and Federal waters (outside of estuaries) from the Florida Keys in the east to the Rio Grande Estuary, Texas, in the west, extending from the coastline to the EEZ, 200 nmi (230 mi; 370 km) seaward from the mean high water line. BOEM's guidelines state that the maximum depth for renewable energy development is 40 m (131 ft) and for marine minerals development is 30 m (98 ft). In this discussion, "nearshore" refers to waters from the shoreline to the 40-m (131-ft) isobath, the maximum limit for G&G activities. "Offshore" refers to the zone extending from the 40-m (131-ft) isobath to the outer boundary of the AOI.

11.1 HISTORIC SHIPWRECKS

European explorers have been active in the GOM since the late 16th century, but it was not until the second decade of the 17th century that explorers reached the northern GOM within the AOI. Shipwrecks within the AOI date from the 16th century until modern times.

The number of shipwrecks and obstructions in the AOI were estimated using information from various databases, including the NOAA Automated Wreck and Obstruction Information System (AWOIS) (updated January 2015), the NOAA Aids to Navigation (NavAids), the NOAA Electronic Navigational Charts (ENC) Direct (updated January 2015), the U.S. Coast Guard (USCG) Hazards to Navigation, and the Global GIS Data Services, LLC Global Maritime Wrecks Database (GMWD). Information from the AWOIS database includes position (latitude/longitude), feature description, and any known historic or descriptive details. Positional accuracy of AWOIS wrecks and obstructions is highly variable and can have an error of as much as a 1 km (0.5 nmi; 0.6 mi) or more. The NOAA NavAids database identifies wreck locations, obstructions, platforms, submerged pilings, navigational aids, and light/channel markers. The NOAA ENCDirect contains limited information, mainly describing wrecks as dangerous or non-dangerous and identifying source date and chart number. The USCG Hazards to Navigation database identifies obstructions, wreck locations, buoys, and unidentified object locations. The GMWD provides a range of information for each site, including wreck name, wreck nationality, date of sinking, depth of wreck, vessel category, gross tons, sinking agent, nominal accuracy of wreck location, source of wreck, nationality of the vessel that sunk the wreck if applicable, and more.

A variety of secondary sources with information about shipwrecks in the AOI were reviewed, including Berman (1973), Lytle and Holdcamper (1975), and Marx (1987). Lytle and Holdcamper (1975) compiled a comprehensive registry (known as the Lytle-Holdcamper List) of most steam vessels in the U.S. from 1790 to 1868. This list was originally compiled in 1952 and reprinted in 1975. The primary sources, collected and compiled by William M. Lytle, include abstracts of registers, licenses, and enrollment documents sent or surrendered to the Bureau of Navigation. The list also includes a section titled "Losses of United States Merchant Vessels, 1790-1868" that provides vessel name, tonnage, year built, nature of wreck, date, place, and lives lost. More than 3,800 vessels are listed as lost between 1790 and 1868. While the reference is general in nature and only covers American steam vessels through the Civil War, it provides an indication of the potential number and location of shipwrecks within the AOI. Berman's work includes approximately 13,000 shipwrecks within American waters (excluding vessels <50 gross tons). Berman's encyclopedia includes shipwrecks in coastal waters and inland waterways dating from the pre-Revolutionary era to modern times.

Many of the shipwreck databases and secondary sources overlap, generating repetitiveness in the data. Additionally, these sources are far from comprehensive. They tend to focus on large merchant vessels and omit the smaller coastal trading, fishing, and other locally built watercraft that may be present as shipwrecks in the nearshore zone of the AOI. Omission of smaller coastal watercraft from shipwreck databases would underestimate the number of shipwrecks in the nearshore zone.

Review of all databases and secondary sources identified 12,485 known wrecks, obstructions, archaeological sites, occurrences, or sites marked as "unknown" in the AOI (**Figure 4.11-1** of this Programmatic EIS). Of these sites, 10,410 (83%) are within the 40-m (131-ft) depth contour (nearshore zone) and 2,075 (17%) are in deeper waters (offshore zone). The number of offshore zone losses, however, should be considered underrepresented as there were undoubtedly many more sinkings that were not recorded because there were no survivors to report the loss. Although many obstructions identified as "unknown" are eventually identified through diver investigation as modern debris, those that have not been investigated cannot be ruled out as potential submerged cultural resources.

Three studies sponsored by the NPS and BOEM included models to identify areas in the GOM where shipwrecks may occur. The first of these studies, conducted by Coastal Environments, Inc. (CEI) in 1977, estimated that there were 2,500 to 3,000 wrecks within the GOM. The authors concluded that approximately two-thirds of those wrecks lie within 1.5 km (0.8 nmi; 0.9 mi) of the coast and that most of the remainder could be found within 10 km (5.4 nmi; 6.2 mi) of the coast (CEI, 1977). The study also concluded that shipwrecks are likely to be concentrated around areas of intensive maritime activity such as the approaches and entrances to ports as well as the mouths of navigable rivers and straits, and around natural maritime hazards such as reefs and shoals. Garrison et al. (1989) expanded upon CEI's work, utilizing statistical analysis to examine five factors that affect shipwreck locations: historic shipping routes; port locations; natural hazards (reefs, shoals, etc.); ocean currents and winds; and historic hurricane routes. This study concluded that a large percentage of wrecks occurred in the open seas, a reflection of changes in shipping routes during the late-19th to early-20th century (Garrison et al., 1989). Garrison et al. (1989) divided the GOM into zones ranked by the potential for shipwrecks and the preservation potential of shipwrecks to help the MMS (BOEM's predecessor) identify OCS lease blocks that would require archaeological surveys. However, remote-sensing surveys conducted since 1989 and new shipwreck discoveries in the GOM have revealed deficiencies in the 1989 model. As a consequence, the MMS authorized an additional study to reevaluate and refine the work of that study as well as previous studies.

Pearson et al. (2003) conducted the reevaluation study, utilizing geographic information systems (GIS) and nearly 15 years of new data from high-resolution oil and gas shallow hazard surveys to refine the previous models of shipwreck distribution and probability of shipwrecks in the GOM. By incorporating new variables and quantitative measures in the analysis, Pearson et al. (2003) increased the number of OCS lease blocks designated as having a high probability for shipwreck resources. Several of the new OCS lease blocks were located in deepwater regions, notably in areas of heavy maritime traffic such as the approaches to the Mississippi River. BOEM and BSEE have published guidelines (NTL 2005-G07 and NTL 2008-G20 [superseded by NTL 2011-JOINT-G01]) for performing archaeological surveys and, as a result of the information from the cited studies, have revised the guidance and gradually increased the number of OCS lease blocks requiring archaeological surveys. As a result of BOEM's requirements for archaeological surveys in the OCS, at least 39 potential historic shipwreck sites have been identified since the implementation of the guidelines in 2005. Furthermore, within the last 6 years, a dozen potential shipwrecks have been discovered by oil industry surveys in water depths up to 2,987 m (9,800 ft) (USDOI, BOEM, 2012a). Nine of the potential sites have been visually confirmed as shipwrecks (USDOI, BOEM, 2012a).

11.2 PREHISTORIC RESOURCES

Submerged cultural resources include prehistoric archaeological sites. Based on previous research, sea levels were approximately 90 to 130 m (295 to 427 ft) lower than present at the end of the last glacial period approximately 20,000 B.P. and did not reach current levels until approximately 3,500 B.P. (Pearson et al., 1986). Archaeological evidence indicates that the GOM region was occupied by prehistoric people as long ago as 12,000 B.P. Sea-level curves produced by CEI

(1977, V1) indicate that sea level was approximately 45 to 60 m (148 to 197 ft) below present level at that time. Therefore, the continental shelf shoreward of this range of depth contours has the potential for containing prehistoric sites. Due to uncertainties in the rate of sea-level rise and in the time of entry of native populations into North America, BOEM has set the 60-m (197-ft) depth contour as the seaward extent of potential submerged prehistoric sites on the continental shelf.

Research conducted by CEI (1977, V1) identified several geomorphic features that could contain prehistoric sites, including barrier islands, back-barrier embayments, river channels and associated floodplains, terraces, and salt domes. The possibility of locating submerged prehistoric sites would be greatest in the nearshore zone (<60-m [197-ft] water depth) because portions of this area would have been exposed land during the period of human occupation. Survival of sites on the OCS is attributed to several factors, including degree of sediment overburden, presence of low wave energy environments, and speed of sea-level rise. In the AOI, Holocene deposits are thicker in west Texas and the Mississippi River Delta region. Due to its complex of overlapping deltaic lobes, sites in the Mississippi River Delta can be buried by up to 91 m (300 ft) of Holocene sediment (USDOI, BOEM, 2012a). In western Louisiana and eastern Texas, Holocene sediments generally are thin and late Pleistocene deposits lie only a few meters below the seafloor. The McFaddin Beach site (Texas Historical Commission site number 41JF50) in Jefferson County, Texas, is an example of a site in this region. Artifacts dating between 11,500 and 400 B.P. have been found along the current shoreline and are thought to have resulted from redeposition of material from a now-submerged but eroding shoreline (Stright et al., 1999, V1). East of the Mississippi River, sediments are sandier and the general environment is more energetic. Farther to the east along the western coast of Florida, the area is dominated by karst formations, and although located in a relatively low-energy environment, the region is sediment starved. Sites in this region typically are found exposed on rocky outcrops above karstic river channels (Faught and Gusick, 2011).

Until recently, the earliest material culture that has been identified in the Paleo-Indian period in the U.S., called Clovis, is represented by distinctly basal fluted projectile points that date back to 12,500 B.P. This Paleo-Indian settlement pattern is described as semi-nomadic within a defined territory, reliant on reliable freshwater sources and cryptocrystalline raw material sources, exploiting large and small game as well as wild plants. As a result of a semi-nomadic settlement pattern, Paleo-Indian sites that are most visible in the archaeological record would most likely be located in proximity to freshwater sources that would have been visited repeatedly. Clovis culture material can be found throughout most of the U.S.

Recently, there have been sites discovered that could pre-date the Clovis culture. Sites such as Cactus Hill and Saltville in Virginia show evidence of Clovis and what appears to be pre-Clovis occupation. In central Texas, ongoing excavations at the Debra L. Friedkin Site are revealing a distinct assemblage of multifaceted flake tools that may indicate a pre-Clovis occupation (Waters et al., 2011). Material from the site indicates an occupation from 13,200 to 15,500 B.P. It has been hypothesized that the original routes taken by migrants that eventually populated the U.S. might have followed a coastal migration.

Conditions necessary for preservation of Paleo-Indian sites along the Gulf of Mexico OCS are variable and depend on geomorphological conditions and the rate of sea-level rise. Current research on regional geology, relative sea-level change, and marine transgression are providing useful data concerning the possibility that there may be intact Paleo-Indian sites submerged along the Gulf of Mexico OCS. These submerged Paleo-Indian sites would most likely be found in the vicinity of paleochannels or river terraces that offer the highest potential of site preservation.

12 OTHER MARINE USES

Chapter 4.12.1 of this Programmatic EIS provides the succinct description of the affected environment for other marine uses in sufficient detail to support the impact analyses. The following descriptions provide additional, expanded information.

Other uses of the marine environment in the AOI include shipping and other marine traffic; military warning areas that are used for military exercises, training, and other military activities; sand and gravel mining; renewable energy development; ocean dredged material disposal; and oil and gas exploration and production. Commercial and recreational fishing are described in **Sections 9 and 10**, respectively. Recreational resources and tourism are described in **Section 15** and human resources are described in **Section 16**.

The Multipurpose Marine Cadastre, a web-based tool developed by BOEM, NOAA's Coastal Services Center, and other partners, was used to identify the uses of the AOI. The Multipurpose Marine Cadastre is an integrated marine information system that provides legal, physical, ecological, and cultural information in a common GIS framework. The Multipurpose Marine Cadastre is used by Federal agencies and others who are evaluating renewable energy sites and other offshore activities as well as others working on regional and State coastal and marine spatial planning efforts. At its core, the Multipurpose Marine Cadastre contains the official U.S. marine cadastre and is the only utility where users can see all of the official U.S. boundaries on one map. Similar to the Nation's land-based parcel system, a marine cadastre provides information about the spatial extent, rights, restrictions, and responsibilities of those wanting access to U.S. waters. All data come from the authoritative organizations responsible for data maintenance. In addition to data available from the Multipurpose Marine Cadastre, data from BOEM and the Naval Facilities Engineering Command (NAVFAC) was used to identify other uses of the marine environment within the AOI.

12.1 SHIPPING AND MARINE TRANSPORTATION

The USCG designates shipping fairways and establishes traffic separation schemes that control movement of vessels as they approach ports (**Figure 4.12-1** of this Programmatic EIS) (33 CFR part 166). Each port is serviced by a navigation channel maintained and regulated by the USACE. Traffic fairways and the buoys and beacons that serve as navigation aids are identified on NOAA's Office of Coast Survey's navigation charts.

Vessels operating in the AOI include commercial shipping vessels, military vessels, commercial business craft (e.g., support vessels, tug boats, fishing vessels, and ferries), commercial recreational craft (e.g., cruise ships and fishing/sightseeing/diving charters), research vessels, and personal craft (e.g., fishing boats, house boats, yachts and sailboats, and other pleasure craft).

Seven deepwater commercial ports that can handle fully laden Panamax ships (pre-Panama Canal expansion) are located along the Gulf Coast adjacent to the AOI:

- Houston, Texas;
- Corpus Christi, Texas;
- Beaumont, Texas;
- Galveston, Texas;
- New Orleans, Louisiana;
- Mobile, Alabama; and
- Tampa, Florida.

The Port of Houston ranks first in the U.S. in foreign waterborne tonnage, first in U.S. imports, first in U.S. export tonnage, and second in the U.S. in total tonnage. It is also the Nation's leading breakbulk port, handling 65 percent of all major U.S. project cargo (Port of Houston Authority, 2015). The Port of South Louisiana located on the Mississippi River ranks first in total tonnage. These deepwater ports are discussed further in **Section 12.6.1**. Large commercial vessels (i.e., cargo ships, tankers, and container ships) use these ports to access overland rail and road routes to transport goods throughout the U.S. In 2011, Gulf ports (from Brownsville, Texas, to Key West, Florida) accounted for 34.1 percent of U.S. vessel calls of oceangoing vessels >10,000 deadweight tons (U.S. Department of Transportation, Maritime Administration, 2013). Additional information regarding ports within the AOI is provided in **Section 16.1**.

Commercial business craft include support vessels, fishing vessels, and ferries. The primary types of OCS support vessels include anchor handling, towing, and supply vessels; offshore supply vessels; and marine platform supply vessels. The level and locations of activity are irregular, and the ports utilized vary based on the activity.

Commercial recreational craft include cruise ships, fishing charters (**Section 10**), sightseeing charters, and diving charters (**Section 15**). Major cruise ship terminals in the AOI include Galveston, Texas; New Orleans, Louisiana; and Tampa, Florida. Numerous coastal cities host smaller charters, which typically operate near the coasts.

12.2 MILITARY WARNING AREAS AND OTHER MILITARY USES

Military Warning Areas (MWAs) are established in the AOI to allow military forces to conduct training and testing activities. Most of the AOI is within an MWA, as shown in **Figure 4.12-2** of this

Programmatic EIS. Military activities can include air-to-air, air-to-surface, and surface-to-surface Naval fleet training, submarine and antisubmarine training, and Air Force exercises.

The GOM includes 12 MWAs and 6 Eglin Water Test Areas (EWTAs) (**Figure 4.12-2** of this Programmatic EIS) (NTL 2014-BOEM-G04). Military operations and oil and gas exploration and production have coexisted for many years in these multi-use areas. The MWAs and EWTAs cumulatively include 75 percent of the total acreage of the WPA, 31 percent of the total acreage of the CPA, and 91 percent of the total acreage of the EPA. The U.S. Department of the Navy has issued a standard Military Areas Stipulation that is applied to all lessees and operators in the GOM, which includes the following provisions:

- **Hold and Save Harmless**: Lessee assumes all risks of damage or injury to persons or property in connection with activity performed by the lessee.
- **Electromagnetic Emissions:** Lessee agrees to control its own electromagnetic emissions and must coordinate with appropriate military installation command headquarters.
- **Operational:** Lessee must enter into an agreement with the appropriate military command headquarters.

In addition, the following provisions are applied to lessees and operators with activities within an EWTA:

- **Evacuation Stipulation:** Lessee is required to evacuate, upon receipt of a directive from BOEM's Regional Director, all personnel from structures on the lease. Lessee must also shut-in and secure all wells and other equipment, including pipelines, on the lease.
- **Coordination Stipulation:** Lessee is required to consult with the appropriate military command headquarters regarding the location, density, and planned periods of operation of surface structures on the lease, and to maximize exploration while minimizing conflicts with U.S. Department of Defense activities prior to approval of an exploration plan by BOEM's Regional Director.

Portions of the AOI are further classified as danger zones, which can be closed or subject to limited public access during intermittent periods. Danger zones and restricted areas are defined in 33 CFR § 334.2 and are described as follows:

- **Danger Zone:** A defined water area used for target practice, bombing, rocket firing, or other especially hazardous operations, normally for the armed forces. Danger zones may be closed to the public on a full-time or intermittent basis, as stated in the regulations.

- **Restricted Area:** A defined water area for the purpose of prohibiting or limiting public access to the area. Restricted areas generally provide security for government property and protection to the public from the risks of property damage or injury arising from the U.S. Government's use of that area.

Military vessels operating in the AOI are associated with training and testing activities. The Naval Surface Warfare Center Panama City Division conducts activities involving a variety of Naval assets including vessels, aircraft, and underwater systems that support eight primary research, development, test, and evaluation capabilities: air, surface, subsurface, sonar, laser, electromagnetic, live ordnance, and projectile firing. Vessel movements will be disclosed following standard operating procedures associated with test planning, and a Notice to Mariners will be released 24 hours prior to a scheduled test event that requires a secured test area, providing other vessels ample time to plan accordingly.

Unexploded Ordnances

The GOM has 26 sites that contain unexploded ordnances, submerged explosives, depth charges, torpedoes, or other obstructions, or that are identified as discontinued dump sites for explosives or other wastes (**Figure 4.12-2** of this Programmatic EIS). These hazard areas, ranging in size from approximately 0.006 to 3,877 km^2 (0.002 to 1,497 mi^2), are distributed across the AOI, cumulatively covering 8,943 km^2 (3,453 mi^2) of seafloor.

12.3 SAND AND GRAVEL MINING

BOEM may offer and enter into a noncompetitive negotiated agreement (lease) for sand, shell, or gravel resources following the 1994 amendments to the Outer Continental Shelf Lands Act (OCSLA) (Public Law [P.L.] 103-426) for certain types of projects funded in whole or part by, or authorized by, the Federal Government. The Shore Protection Provisions of the Water Resource Development Act of 1999, which amended P.L. 103-426, prohibits charging State and local governments a fee for using OCS sand. For all other uses, a competitive bidding process is required under Section 8(k)(1) of the OCSLA. The Marine Minerals Program, which is administered by BOEM, primarily centers on the identification and use of OCS sand for tax-funded beach nourishment and coastal restoration projects (USDOI, BOEM, 2015a). Offshore sand resources in the GOM are limited in coastal areas where sand is needed for nourishment and restoration projects. Compounding this scarcity of sand is that vast areas of these relatively small offshore sand resources are not extractable because of the presence of oil and gas infrastructure, archaeologically sensitive areas, and biologically sensitive areas. BOEM's Marine Minerals Program is implementing several measures to help safeguard the most significant OCS sediment resources, reduce multi-use conflicts, and minimize interference with oil and gas operations under existing leases and rights-of-way. **Figure 4.12-3** of this Programmatic EIS shows the OCS lease blocks with significant sediment resources (USDOI, BOEM, 2015b), including those listed in **Table E-1**.

Table E-1. OCS Lease Blocks with Significant Sediment Resources

Lease Area	OCS Lease Blocks
Breton Sound Area	41, 42, 43, 44, 53, 54, 55, and 56
Chandeleur Area	30 to 34
Main Pass Area	42 to 44, 86 to 90, 92 to 114, and 118 to 120
Main Pass Area, South and East Addition	161, 162, 180, and 181
High Island Area	38, 39, 45 to 48, 71 to 76, 88, 89, 114, 199, 200, and 202
Sabine Pass Area	11 to 15
West Cameron Area	20 to 22, 43 to 45, 56 to 58, 90 to 93, 113 to 118, 128 to 134, 147 to 149, and 168 to 172
West Cameron West Area	155, 156, and 162
Vermilion Area	11, 30, 51 to 54, 68 to 72, 74 to 76, 87 to 96, and 108 to 111
South Marsh Island Area, North Addition	207 to 237, 241 to 249, 259, and 260
Eugene Island Area	10, 18 to 35, 37 to 69, and 71 to 93
Ship Shoal Area	64, 71, 84 to 100, and 107 to 110
South Pelto Area	11 to 14 and 17 to 20
West Delta Area	20 to 31, 43 to 50, and 56 to 61
Mobile Area	816 to 821, 856 to 865, and 902 to 909

Table 4.12-1 of this Programmatic EIS provides the recent projects in Florida and Louisiana, the cubic yards of sand, and the miles of restored shoreline. Some projects were done on an emergency basis, where imminent breaching of barrier islands was prevented by the rapid placement of OCS sand. Most projects used sand that was identified by BOEM (USDOI, BOEM, 2015a) through its cooperative sand evaluation program with coastal states. P.L. 109-234, enacted in June 2006, appropriates funds to support coastal restoration efforts in Alabama, Mississippi, Louisiana, and Texas to assist in the restoration of the coastal areas damaged by Hurricanes Katrina and Rita in 2005. All four states have received funding for surveys, studies, database development, or analysis that will be conducted in collaboration with State agencies and universities. Sand resource volumes needed to repair the damaged coastlines and barrier islands of the four states is estimated to be 191 to 229 million m^3 (250 to 300 million yd^3); in Louisiana alone, >518 km^2 (200 mi^2) of coastal land was lost due to the hurricanes (USDOI, BOEM, 2015c). **Table 4.12-1** of this Programmatic EIS provides the recent projects in Florida and Louisiana, the cubic yards of sand, and the miles of restored shoreline (USDOI, BOEM, 2015d).

As a result of the *Deepwater Horizon* explosion, oil spill, and response, the Resources and Ecosystem Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act (RESTORE Act) created a trust fund for restoration activities. The Gulf Coast Ecosystem Restoration Council is responsible for developing and overseeing implementation of a comprehensive plan for ecosystem restoration, economic recovery, and tourism promotion in the Gulf Coast region. Currently, the plan outlines the goals, objectives, and evaluation criteria for selecting projects for funding but it does not identify specific projects (Gulf Coast Ecosystem Restoration Council, 2013); however, it is expected that the major restoration efforts will require the use of OCS sand resources in order to restore coastal wetlands and barrier islands along the Gulf Coast (USDOI, BOEM, 2015a).

12.4 RENEWABLE ENERGY DEVELOPMENT

The Energy Policy Act of 2005 (EPAct) was signed into law by President George W. Bush on August 8, 2005. The EPAct authorized the USDOI to grant leases, easements, and rights-of-way in the OCS for the development of energy resources other than traditional hydrocarbons on the OCS. The *Programmatic Environmental Impact Statement for Alternative Energy Development and Production and Alternative Use of Facilities on the Outer Continental Shelf, Final Environmental Impact Statement* was published in 2007 (USDOI, MMS, 2007a) leading the way for BOEM to develop an alternative energy program, which was published as a final rule on April 29, 2009 in 30 CFR part 285.

Wind Energy

Offshore wind energy is seen as the most technologically mature option for a marine renewable energy source. As of January 2015, there were 74 operational offshore wind farms, including 2,488 turbines in use offshore Europe (European Wind Energy Association, 2015). Globally, there is a cumulative capacity of 7,046 megawatts installed in offshore waters as of the end of 2013 (Global Wind Energy Council, 2014). Offshore wind energy is a promising renewable energy due to its environmental friendliness, renewability, and predictability. Some major hurdles remain for widespread use in the U.S., including the following (USDOI, BOEM, 2015e):

- environmental concerns related to impacts to marine mammals, birds, sea turtles, and other species from vessel or turbine strikes, disturbance of nesting areas, alteration of key habitat, or low-probability large spills of fuel or lubricating oil or dielectric fluids;
- multiple-use conflicts between wind energy projects and marine transportation, fishing, and military activities; and
- cost-effectiveness, and technical challenges regarding turbine installation and hook-up to the electrical grid.

As of 2013, there are no operational wind farms within the AOI, and no Wind Energy Areas have been identified by the USDOI within the AOI. A licensed wind platform operated by Coastal Point Energy is currently the site of a meteorological monitoring tower used to track winds offshore Galveston, Texas (Coastal Point Energy, 2015). A 150-megawatt wind farm is scheduled to be built on the site, which is located in Texas State waters and also within the AOI.

12.5 OCEAN DREDGED MATERIAL DISPOSAL SITES

Regulated by the U.S. Environmental Protection Agency (USEPA), ocean dredged material disposal sites (ODMDSs) are composed of materials from maintenance dredging and are available for potential beneficial uses to restore and create habitat, for beach nourishment projects, and for industrial and commercial development. There are 19 ODMDSs within the AOI (40 CFR § 228.15), ranging in size from 1.4 to 164.8 km^2 (0.42 to 48 nmi^2; 0.5 to 63.6 mi^2) and located offshore of the following areas (**Figure 4.12 4** of this Programmatic EIS) (40 CFR § 228.15; USEPA, 2015a):

- Tampa, Florida;
- Pensacola, Florida (nearshore and offshore);
- Mobile, Alabama;
- Pascagoula, Mississippi;
- Gulfport, Mississippi (east and west);
- Mississippi River Gulf Outlet, Louisiana;
- Southwest Pass, Mississippi River, Louisiana;
- Barataria Bay Waterway, Louisiana;
- Houma Navigation Channel, Louisiana;
- Atchafalaya River (east and west) and Bayous Chene, Boeuf, and Black, Louisiana (2 sites);
- Calcasieu, Louisiana (3 sites);
- Sabine-Neches, Texas (8 sites);
- Galveston, Texas;
- Freeport Harbor, Texas (2 sites);
- Matagorda Ship Channel, Texas;
- Corpus Christi Ship Channel, Texas;
- Homeport Project, Port Aransas, Texas;
- Port Mansfield, Texas; and
- Brazos Island Harbor, Texas (2 sites).

The USACE is the permitting authority for dredged material disposal. When issuing a permit, the USACE must obtain the USEPA's concurrence, use the USEPA's developed dumping criteria, and use USEPA-designated ODMDSs to the maximum extent feasible. Virtually all ocean dumping in the U.S. today is of dredged material (USEPA, 2015a).

12.6 OIL AND GAS EXPLORATION, PRODUCTION, AND DEVELOPMENT

Under the authority of the OCSLA, BOEM manages the leasing program for the 1.76 billion ac of the OCS. These Federal lands are organized into 26 planning areas, approximately 80 percent of which have been unavailable for leasing because of Congressional moratoria and administrative withdrawals. The Gulf of Mexico OCS is divided into the WPA, CPA, and EPA, encompassing approximately 159.38 million ac and approximately 29,100 leasable blocks. As of June 1, 2016, there were 3,998 active leases in the Gulf of Mexico OCS, covering approximately 21.44 million ac (USDOC, BOEM, 2016). The majority of the active leases are located in the WPA and CPA; only 46 active leases are located in the EPA. The Gulf of Mexico OCS Region currently oversees approximately 3,400 offshore oil and natural gas facilities, accounting for nearly 30 percent of the Nation's domestic oil production and approximately 11 percent of domestic natural gas production (USDOI, BSEE, 2014).

The Gulf of Mexico Energy Security Act (GOMESA) was signed into law by President George W. Bush on December 20, 2006. Among other provisions, GOMESA banned oil and gas leases within 125 mi (201 km) of the Florida coastline in the EPA until at least 2022. The GOMESA also banned new oil and gas leases from all areas in the EPA east of the Military Mission Line (86°41' W. longitude) and areas in the CPA within 100 mi (161 km) of the Florida coastline (**Figure 4.12-5** of this Programmatic EIS).

12.6.1 Gas Hydrates

Gas hydrates are an energy-rich but poorly understood class of chemical compounds where ice forms an open lattice that encloses methane molecules in a cage-like structure (USDOI, BOEM, 2012b). Methane hydrates are only stable under high pressure, which makes studying and extracting them especially challenging. Several research cruises have been performed in the GOM to characterize the presence of gas hydrates, and several test wells have been drilled. The MMS (USDOI, MMS, 2008) provided a geological and technical assessment of gas hydrates in the GOM, concluding that an estimated mean volume of 607 trillion m^3 of methane was present in hydrate form. There are no existing plans for gas hydrate mining in the GOM; however, the 2012-2017 WPA/CPA Multisale EIS (USDOI, BOEM, 2012a) estimated that the first production of gas hydrates from U.S. waters could be from the GOM due to the advantageous working environment and existing pipeline infrastructure that would make development more efficient.

12.6.2 Offshore Deepwater Ports

According to U.S. Department of Transportation's Maritime Administration, the Louisiana Offshore Oil Port (LOOP) is the only operational offshore deepwater port in the GOM with offshore marine terminal facilities. The LOOP has been in operation since 1981 and serves as an unloading and distribution center for incoming supertankers for the entire GOM. With a current operating flow of approximately 1.2 million bbl of crude oil per day, the LOOP carries 13 percent of all imported oil to the U.S. via subsea pipelines transporting it onshore to Lafourche Parish, where it is stored and piped to markets throughout the country via onshore pipelines.

Several permits have been issued for deepwater port facilities within the AOI; these permits (1) have been approved and then the application for permit withdrawn, (2) have been approved and then surrendered, or (3) the facility has been decommissioned. Of the licenses for deepwater port facilities in the GOM, one facility is currently operational (LOOP), three licenses (Gulf Landing, Port Pelican, and Port Dolphin) were voluntarily surrendered after issuance, two licenses were approved but withdrawn prior to license issuance (Bienville and Main Pass), and one facility has been decommissioned (Gulf Gateway).

12.6.3 Pipeline and Cable Infrastructure

There is an extensive network of pipelines in the GOM that carry produced oil and gas from the offshore field to refineries and terminals onshore (**Figure 4.12-6a to c** of this Programmatic EIS). Most of the pipelines that make landfall along the Gulf Coast were installed in the 1960s and 1970s. Thereafter, most new pipelines tied into the existing network of underused pipelines rather than making new landfalls in order to minimize cost and environmental impacts (USDOI, MMS, 2007b).

As of 2015, there are 14 OCS-related pipelines that make landfall in Texas and 122 OCS-related pipelines that make landfall in Louisiana (Smith, official communication, 2015). All gas production and >99 percent of OCS oil production is transported to shore through the pipeline infrastructure. As drilling has moved into deeper waters in the GOM, methods for laying pipeline in deep water have been developed. As of 2012, the deepest pipeline in the Gulf of Mexico OCS was in approximately 2,700 m (8,858 ft) of water. More than 500 pipelines are in water depths of >400 m (1,312 ft), and 400 of those pipelines are in water depths of >800 m (2,625 ft) (USDOI, BOEM, 2012a).

In order to provide reliable communications from platforms to shore, British Petroleum (BP) started a project in 2005 to engineer and construct a fiber optic communication system in the GOM extending to deepwater assets from landing sites in Pascagoula, Mississippi, and Freeport, Texas. The fiber optic backbone was laid on the seafloor in 2007 and was operational in 2008, connecting seven of BP's platforms with the BP enterprise. The cable system is 1,216 km (756 mi) long, in water depths of almost 2,000 m (6,562 ft). Branching cables (i.e., spurs) extend out perpendicular to the main trunk and can be up to 100 km (62 mi) in length (BP, 2008). In addition, there are several other submarine power cables and umbilicals associated with oil and gas platforms and field development within the GOM (**Figure 4.12-7** of this Programmatic EIS).

13 HUMAN RESOURCES AND LAND USE

The onshore portion of the AOI extends along the GOM coastline from the southwestern tip of the Florida Keys to the southern coast of Texas. The area encompasses 133 counties/parishes in 23 BOEM-designated Economic Impact Areas. The G&G activities in the GOM have a concurrent impact on the human environment onshore, including land use and coastal infrastructure, environmental justice, demographics, and socioeconomic aspects of the communities along the Gulf Coast. Activities in the OCS are supported by onshore facilities, which can impact the human environment.

13.1 LAND USE AND COASTAL INFRASTRUCTURE

The coastal areas of the GOM are not homogenous in terms of physical characteristics or socioeconomic attributes; they are divided into counties and parishes, each with unique histories and characteristics. Major cities near the study area include Houston, Texas; Baton Rouge and New Orleans, Louisiana; Pascagoula, Mississippi; Mobile, Alabama; and Tampa, Florida. Land uses in the study area range from urban areas in and around the cities previously mentioned to rural agricultural areas. Coastal land uses range from large areas of recreational beaches, wetlands, and barrier islands to deepwater ports and oil and gas production infrastructure. In addition, residential, commercial, farming/ranching, and other industrial uses are scattered along the coast.

The energy industry has a long history of operating in the GOM and, as a result, coastal infrastructure has been built to accommodate and service this sector. The G&G activities have been conducted for years in the GOM; therefore, companies that provide goods and services to support G&G activities are numerous and well established. For example, companies that provide shipbuilding and repair services, ports, and equipment and material suppliers are all part of the coastal infrastructure (**Table 4.13-2** of this Programmatic EIS).

According to the *OCS-Related Infrastructure Fact Book* completed in 2011 (Dismukes, 2011), 28 major shipbuilding yards are located along the GOM, with the majority of these yards being topside repair yards. The yards mostly are clustered between New Orleans, Louisiana, and Mobile, Alabama (Dismukes, 2011).

Numerous ports and ports facilities that could be used to support G&G activities on the OCS are located throughout the GOM region. Ports that support activities on the OCS typically fall into one of two categories: (1) smaller facilities that are privately owned and are designed and used to support energy development activities in the GOM; or (2) larger facilities that support a wide spectrum of maritime activities, including oil and gas exploration, as well as bulk container traffic and maritime transportation. The top 50 offshore support ports in the GOM identified in the *OCS-Related Infrastructure Fact Book* are primarily located around the New Orleans/Mobile area or in the Houston area (Dismukes, 2011).

The two primary ports that support G&G activities in the GOM are Port Fourchon in Lafourche Parish, Louisiana, and the Port of Galveston in Texas, according to G&G permit application forms submitted to BOEM. Port Fourchon is the largest port serving oil and gas production in the GOM. More than 250 companies utilize the port as a base of operation, and >90 percent of the GOM's deepwater oil production is serviced by Port Fourchon (Greater Lafourche Port Commission, n.d.). The Port of Galveston serves cruise ships, cargo ships, research vessel, barges, lay barges, and rigs. In 2013, a total of 912 ship calls occurred in the port, including 317 cargo ships, 85 research vessels, and 179 cruise ships. Pipe-laying vessels and drill rigs accounted for 96 ship calls, while pipe-laying barges accounted for an additional 229 ship calls. Cargo barges accounted for six ship calls in 2013 (Port of Galveston, n.d.).

13.2 ENVIRONMENTAL JUSTICE

EO 12898 ("Federal Actions to Address Environmental Justice in Minority Populations and Low Income Populations") was signed by President Clinton on February 11, 1994. This EO requires each Federal agency to identify and address, as appropriate, disproportionately high and adverse human health or environmental impacts of its programs, policies, and activities on minority and low-income populations, including Native American populations. The USEPA and the Council on Environmental Quality emphasize the importance of incorporating environmental justice review in the analyses conducted by Federal agencies under NEPA and of developing protective measures that avoid disproportionate environmental impacts on minority and low-income populations.

President Clinton issued EO 13045 ("Environmental Health Risks and Safety Risk to Children") on April 21, 1997. This EO requires each Federal agency to "make it a high priority to identify and assess environmental health risks and safety risks that may disproportionately affect children and shall . . . ensure that its policies, programs, activities, and standards address disproportionate risks to children." This EO was issued because a growing body of scientific knowledge demonstrates that children may suffer disproportionately from environmental health and safety risks.

The Council on Environmental Quality has issued the following guidance to Federal agencies on the terms used in EO 12898:

- **Low-Income Population:** Low-income populations in an affected area should be identified using the annual statistical poverty thresholds from the U.S. Census Bureau.
- **Minority:** An individual who is a member of the following population groups: American Indian or Alaskan Native; Asian or Pacific Islander; Black, not of Hispanic origin; or Hispanic.
- **Minority Population:** Minority populations should be identified where (1) the minority population of the affected area exceeds 50 percent or (2) the minority population percentage of the affected area is meaningfully greater than the minority population percentage in the general population or other appropriate unit of geographic analysis.
- **Children:** Individuals under the age of 18.

Table 4.13-3 of this Programmatic EIS shows the percent of the population that are considered minorities in the geographic areas around Port Fourchon and the Port of Galveston. Totals for the U.S. and for Louisiana and Texas are shown for comparison purposes. Port Fourchon is located within the Houma-Bayou Cane-Thibodaux Metropolitan Statistical Area (MSA). The Port of Galveston is located in the Houston-Sugar Land-Baytown MSA. As shown in **Table 4.13-3** of this Programmatic EIS, the areas surrounding Port Fourchon have smaller percentages of minorities than Louisiana or the U.S. as a whole. In contrast, Galveston and the Houston-Sugar Land-Baytown

MSA have greater percentages of racial minorities than Texas or the U.S. as a whole. The areas surrounding the Port of Galveston have smaller percentages of Hispanic or Latino populations than the statewide total but larger percentages than the national level (USDOC, Census Bureau, 2012). For environmental justice purposes, Galveston and the Houston-Sugar Land-Baytown MSA are considered to have meaningfully greater minority populations.

Table 4.13-4 of this Programmatic EIS shows the low-income populations in the same geographic areas. As shown in the table, the Houma-Bayou Cane-Thibodaux MSA has a slightly greater percentage of residents defined as low income compared with the nationwide average and a smaller percentage than the total for Louisiana. In contrast, Lafourche Parish has a smaller percentage of residents defined as low income compared to State and national levels. During the same time period, 24.7 percent of all residents in the City of Galveston were considered low income compared with 18.1 percent in Texas and 15.7 percent in the U.S., making this a difference that was meaningfully greater for environmental justice purposes. The Houston-Sugar Land-Baytown MSA around the Port of Galveston had a smaller percentage of low-income residents than the State and Nation (USDOC, Census Bureau, 2012).

13.3 Demographics

The population living in the coastal communities along the GOM has experienced a dramatic increase over the last 40 years. As of 2010, approximately 24.2 million people lived in communities influenced by activities in the GOM, more than double the number of individuals who lived in the same communities 40 years ago. In 2010, approximately 7.8 percent of the total population of the U.S. lived in communities along the GOM (USDOC, Census Bureau, 2012; USDOC, NOAA, n.d.-c). However, this increase in population is not uniformly distributed throughout the region.

Because the GOM region is so diverse, some areas have experienced rapid growth while other areas have not kept up with national growth rates. Florida has experienced the most rapid population growth in the region, with its total and Gulf Coast populations nearly doubling between 1970 and 1990. From 1990 to 2010, an additional 3.1 million people moved to the coastal areas of the GOM in Florida alone.

In contrast, population growth rates in the coastal areas of Alabama and Louisiana have not kept up with national growth rates. Between 1970 and 1990 and from 1990 to 2010, the U.S. experienced population growth rates of 22.4 and 24.1 percent, respectively (USDOC, Census Bureau, 2002 and 2012), whereas populations in the coastal areas of Louisiana increased by 18.0 and 7.9 percent, respectively, during the two time periods, and populations in the Alabama coastal areas increased by only 20.5 and 19.45 percent, respectively (**Table 4.13-1** of this Programmatic EIS).

Total population around Port Fourchon and the Port of Galveston is shown in **Table 4.13-3** of this Programmatic EIS. There were 208,178 residents living in the Houma-Bayou Cane-Thibodaux MSA and 96,318 residents living in Lafourche Parish in 2010. The area surrounding the Port of

Galveston is much more populous. In 2010, there were >5.9 million people living in the Houston-Sugar Land-Baytown MSA. More than 47,000 residents lived in the City of Galveston (**Table 4.13-3** of this Programmatic EIS).

13.4 SOCIOECONOMICS

The communities along the GOM are a diverse group that range from the large urban areas like Houston and New Orleans, which have well-integrated economies, to the smaller rural areas that are more dependent on a few industries.

The GOM has a great economic impact on the local and regional economies of coastal communities from Florida to Texas. In total, approximately 25,100 business enterprises generated nearly $161.2 billion in local gross domestic product (GDP) and $33.9 billion in wages and salaries, supporting nearly 581,100 jobs in 2012 as a result of activities associated with the GOM. Offshore mineral extraction was the largest sector in terms of GDP and wages, accounting for 81.3 percent of the total economic activity and 57.5 percent of the total wages and salaries associated with the GOM. In contrast, the tourism and recreation sector accounted for >51.4 percent of all jobs associated with the GOM but generated only 16.7 percent of the total wages and salaries and only 7.4 percent of the local GDP tied to activities in the GOM. Marine transportation and shipbuilding were large employment sectors as well. The marine construction sector and the living resources sector (e.g., commercial fishing) generated the smallest portion of GOM-related employment in 2010 (**Table 4.13-2** of this Programmatic EIS) (USDOC, NOAA, n.d.-c).

The energy industry has a long history in the Gulf Coast States; the industry is mature and it is fully integrated into all aspects of the local and regional communities. Numerous companies offer G&G services in the GOM. According to an economic study on the oil services contract industry in the GOM region completed for BOEM in June 2011, the G&G services' industry employs between 5,870 and 6,128 workers in the GOM region and contributes at least $2.94 billion to the regional economy. A total of 79 companies were identified as providing G&G prospecting services in the GOM and range from large, publicly owned multinational companies to small, privately owned companies (Eastern Research Group, Inc., 2011).

A total of 79 companies were identified as providing G&G prospecting services in the GOM (Eastern Research Group, Inc., 2011). The firms ranged from large, publicly owned multinational companies to small, privately owned companies. Employment at the publicly owned companies ranged from 80,000 workers at Schlumberger to only 36 workers at GETECH, Inc. Some of these companies perform services in addition to G&G prospecting services; therefore it cannot be assumed that all of their employees work in the G&G prospecting field. The majority of the privately held companies employed <25 workers. There were, however, a few notable exceptions, including Fairfield Industries that employed 400 workers, Paradigm that employed 950 workers, and Willis Group that employed 286 workers, which were large privately owned enterprises (Eastern Research Group, Inc., 2011).

Much of the onshore portion of the G&G industry is located in Harris County, Texas, the county that encompasses much of greater Houston. Approximately 68 percent of all firms offering G&G services in the GOM are located in Harris County, 84 percent of the total employees working in the G&G industry are assigned to offices in Harris County, and 95 percent of the total revenues earned in the industry are attributed to companies in Harris County. Other areas with large concentrations of personnel engaged in G&G activities included Lafayette Parish, Louisiana, and Fort Bend County, Texas (Eastern Research Group, Inc., 2011).

In addition to the oil and gas industry, G&G services and activities in the GOM are utilized by a wide variety of scientific, research, educational, governmental, and commercial enterprises. Studies into geomorphology, cartology, and climate change; cultural resource surveys; fisheries research; military and USCG activities; and BOEM's Marine Minerals Program all require G&G services. As a result, G&G services support these multimillion-dollar industries that employ thousands of workers throughout the Gulf Coast.

14 RECREATIONAL RESOURCES AND TOURISM

The GOM has become a popular tourist destination for domestic and foreign travelers. The mild climate and coastal waters provide numerous venues for recreation. Beach-going, recreational fishing, boating and diving, and nature watching, as well as other water-based activities, are among the primary tourist attractions.

The GOM encompasses 2,625 km (1,631 mi) of coastline. As shown in **Table E-2**, in a typical year, beaches along the Gulf Coast accommodate nearly 22 million visitors during nearly 207 million annual visitor days. Beaches in Florida account for the vast majority of these visits with >15 million visitors annually. Beaches in Texas accounted for nearly 4 million visitors annually, while Alabama, Louisiana, and Mississippi each hosted approximately 1 million visitors annually (USDOC, NOAA, 2008).

Table E-2. Number of Public Beaches, Number of Visitors, and Number of Visitor Days in Coastal Areas of the Gulf of Mexico (From: USDOC, NOAA, 2008)

State/Area	Number of Public Beaches (2010)	Number of Visitors Annually (millions)	Number of Visitor Days (millions)
Alabama	25	1.2	11.8
Florida[1]	556	15.2	177.2
Louisiana	28	0.6	4.0
Mississippi	22	1.0	8.7
Texas	169	3.9	5.2
Total	615	21.9	206.9

[1] Florida data include beaches and beach use for both Gulf Coast and Atlantic Coast beaches.

In addition to the beaches, numerous Federal, State, and local parks and wildlife refuges (**Section 7**); public and private boat docks and marinas; boat launches; and equipment rental and tour boat companies provide access to the GOM for tourists. The tourism industry has a large economic impact on the region. In 2013, >1.7 million workers were employed in the travel and tourism industry in the Gulf Coast States. During the same time, total industry spending was approximately $165.1 billion, which supported $43.4 billion in wages and salaries. Nearly $24.2 billion in tax revenue was generated by this industry (U.S. Travel Association, 2015a-e). **Table E-3** provides a breakdown of tourism economic statistics by state.

Table E-3. Selected Economic Statistics for the Tourism Industry for 2013 (From: U.S. Travel Association, 2015a-e).

State/Area	Travel Industry Spending (in $ billion)	Employment	Wages and Salaries (in $ million)	Tax Receipts[1] (in $ billion)
Alabama	8.5	80,050	1,500	0.9
Gulf Coast Area[2]	1.9	16,470	285	[1]
Florida	78.7	826,210	21,200	11.5
Gulf Coast Area[2]	28.7	305,892	6,425	[1]
Louisiana	10.6	107,660	2,100	1.3
Gulf Coast Area[2]	8.0	81,643	1,626	[1]
Mississippi	6.1	85,070	1,800	1.0
Gulf Coast Area[2]	1.9	27,587	619	[1]
Texas	61.2	609,220	16,800	9.5
Gulf Coast Area[2]	4.6	43,858	1,027	[1]
State Total	165.1	1,708,210	43,400	24.2
Gulf Coast Area Total[2]	45.1	475,450	9,982	[1]

[1]Tax receipt data are only provided at a statewide level.
[2]Gulf Coast Area is defined as U.S. Congressional Districts whose boundaries are adjacent to the GOM.

In Congressional Districts along the Gulf Coast, total travel industry spending was estimated to be $45.1 billion in 2013; during the same year, tourism provided 475,450 jobs with an annual payroll of $10.0 billion. Congressional Districts in Florida accounted for the majority of this economic impact. In 2013, it was estimated that total travel industry spending in Congressional Districts along the Gulf Coast of Florida reached $28.7 billion, while travel industry employment in the same area accounted for 305,892 jobs with an associated annual payroll of $6.4 billion. In contrast, during the same time period, Gulf Coast Congressional Districts in Alabama accounted for only $1.9 billion in travel industry spending, 16,470 travel industry jobs, and $285 million in associated payroll (U.S. Travel Association, 2015a-e). **Table E-3** above presents Gulf Coast travel industry economic statistics broken down by state.

Deepwater Horizon **Explosion, Oil Spill, and Response**

The *Deepwater Horizon* explosion, oil spill, and response impacted the GOM tourism industry. The impacts of the *Deepwater Horizon* explosion, oil spill, and response, both real and perceived, to recreational resources along the Gulf Coast curtailed tourism spending immediately after the explosion and oil spill. According to a study conducted by Oxford Economics (2010) in December 2010 for the State of Louisiana, concern that the *Deepwater Horizon* explosion, oil spill, and response had impacted water quality, the GOM shoreline, and seafood quality led to a high rate of trip cancellations from April to December 2010 by leisure travelers. The Oxford Economics (2010) study also found that the influx of media, relief workers, and government officials into the region during the response and cleanup phase of the incident helped offset some, but not all, of the lost economic activity caused by the reduction in the number of leisure travelers (Oxford Economics, 2010).

Because most economic data are released after a time lag and, due to restrictions placed on the disclosure of data specific to the *Deepwater Horizon* explosion, oil spill, and response related to ongoing litigation, only limited information is currently available to estimate the long-term impacts to the tourism industry. The concurrence of the *Deepwater Horizon* explosion, oil spill, and response and the U.S. national economic recession make analysis of the economic impacts of the oil spill to specific industries such as tourism more complex. Several ongoing economic studies are being conducted to estimate the long-term impacts of the *Deepwater Horizon* explosion, oil spill, and response on tourism in the GOM.

15 AIR QUALITY

The National Ambient Air Quality Standards (NAAQS) were established by the Clean Air Act of 1970 (CAA) to serve as the primary standards to protect public health and welfare. Secondary standards were created to protect public welfare, including protection of air clarity, and to prevent damage to crops and other vegetation. Air quality typically is defined by the concentration of specific pollutants established by the USEPA under the NAAQS. The current NAAQS specifically address six pollutants considered harmful to public health and the environment: carbon monoxide (CO); lead (Pb); nitrogen dioxide (NO_2); particulate matter (PM); ozone (O_3); and sulfur dioxide (SO_2). Particulates are divided into two categories: coarse (between 2.5 and 10 μm [PM_{10}]) and fine (<2.5 μm [$PM_{2.5}$]). The USEPA periodically reviews and updates the allowable levels of the pollutants covered under the NAAQS. A new 8-hour O_3 NAAQS of 0.075 parts per million (ppm) was enacted in 2008 by the USEPA. In December 2006, the USEPA reduced the $PM_{2.5}$ standard from 65 to 35 micrograms per cubic meter (μg/m_3). Other recent changes to the NAAQS include a revision of the NO_2 NAAQS to a 1-hour standard of 100 parts per billion (ppb), a new 1-hour standard of average SO_2 of 75 ppb, and the revocation of the 24-hour SO_2 NAAQS. The current NAAQS are shown in **Table E-4**.

Table E-4. USEPA's National Ambient Air Quality Standards for the Six "Criteria" Pollutants (From: USEPA, 2015b)

Pollutant [final rule cite]		Primary/ Secondary	Averaging Time	Level	Form
Carbon monoxide (CO) [76 FR 54294, Aug 31, 2011]		Primary	8-hour	9 ppm	Not to be exceeded more than once per year
			1-hour	35 ppm	
Lead (Pb) [73 FR 66964, Nov 12, 2008]		Primary and Secondary	Rolling 3-month average	0.15 $\mu g/m^3$(1)	Not to be exceeded
Nitrogen dioxide (NO_2) [75 FR 6474, Feb 9, 2010] [61 FR 52852, Oct 8, 1996]		Primary	1-hour	100 ppb	98^{th} percentile, averaged over 3 years
		Primary and Secondary	Annual	53 ppb(2)	Annual mean
Ozone (O_3) [73 FR 16436, Mar 27, 2008]		Primary and Secondary	8-hour	0.075 ppm(3)	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
Particle pollution Dec 14, 2012	$PM_{2.5}$	Primary	Annual	12 $\mu g/m^3$	Annual mean, averaged over 3 years
		Secondary	Annual	15 $\mu g/m^3$	Annual mean, averaged over 3 years
		Primary and Secondary	24-hour	35 $\mu g/m^3$	98^{th} percentile, averaged over 3 years
	PM_{10}	Primary and Secondary	24-hour	150 $\mu g/m^3$	Not to be exceeded more than once per year on average over 3 years
Sulfur dioxide (SO_2) [75 FR 35520, Jun 22, 2010] [38 FR 25678, Sept 14, 1973]		Primary	1-hour	75 ppb(4)	99^{th} percentile of 1-hour daily maximum concentrations, averaged over 3 years
		Secondary	3-hour	0.5 ppm	Not to be exceeded more than once per year

(1) Final rule signed October 15, 2008. The 1978 lead standard (1.5 $\mu g/m^3$ as a quarterly average) remains in effect until 1 year after an area is designated for the 2008 standard, except in areas designated nonattainment for the 1978 standards, in which case the 1978 standard remains in effect until implementation plans to attain or maintain the 2008 standard are approved.

(2) The official level of the annual NO_2 standard is 0.053 ppm, equal to 53 ppb, which is shown here for the purpose of clearer comparison to the 1-hour standard.

(3) Final rule signed March 12, 2008. The 1997 O_3 standard (0.08 ppm, annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years) and related implementation rules remain in place. In 1997, the USEPA revoked the 1-hour O_3 standard (0.12 ppm, not to be exceeded more than once per year) in all areas, although some areas have continued obligations under that standard ("anti-backsliding"). The 1-hour O_3 standard is attained when the expected number of days per calendar year with maximum hourly average concentrations >0.12 ppm is ≤1 day.

(4) Final rule signed June 2, 2010. The 1971 annual and 24-hour SO_2 standards were revoked in the same ruling. However, the standards remain in effect until 1 year after an area is designated for the 2010 standard, except in areas designated nonattainment for the 1971 standards, in which case the 1971 standards remain in effect until implementation plans to attain or maintain the 2010 standard are approved.

The OCS sources within 25 mi (40 km) of the States' seaward boundaries are subject to the same Federal and State requirements as those that would apply if the source were located onshore. The OCS sources beyond 25 mi (40 km) of the States' boundaries are subject to Federal requirements for Prevention of Significant Deterioration (PSD). The PSD Class I air quality areas (where almost no change from current air quality is allowed) are designated under the CAA as areas that are protected under strict air quality standards. Incremental standards have been established for four pollutants: NO_2, SO_2, PM_{10}, and $PM_{2.5}$. The maximum allowable increases over baseline concentrations for these pollutants in a PSD Class I area are 2.5 μg/m^3 annual arithmetic mean for NO_2; 25 μg/m^3 3-hour maximum increment, 5 μg/m^3 24-hour maximum increment, and 2 μg/m^3 annual arithmetic mean for SO_2; 8 μg/m^3 24-hour maximum increment and 4 μg/m^3 annual arthmetic mean for PM10; and 2 μg/m^3 24-hour maximum increment and 1 μg/m^3 annual arthmetic mean for $PM_{2.5}$ (40 CFR § 51.21). Coastal areas of the GOM that are designated as PSD Class I are Breton NWR and National Wilderness Area (NWA), Chassahowitzka NWR, St. Marks NWA, Bradwell Bay NWA, and Everglades National Park (**Figure E-2**). A 2008 Agency-funded study showed that impacts to the Breton NWR caused by routine OCS activities were well within the PSD Class I allowable increment (Wheeler et al., 2008).

BOEM's *Year 2011 Gulfwide Emissions Inventory Study* (Wilson et al., 2014) estimated emissions for criteria pollutants produced by oil and gas platforms and non-platform sources located in the GOM in 2011 (**Table E-5**). Included in the estimates were emissions from survey vessels in reference to non-platform emission sources, total source emissions from OCS oil and gas production sources, total emissions for OCS non-platform sources, and overall total emissions from all oil and gas sources. In 2011, survey vessels in the GOM were estimated to emit 1,760 tons per year (TPY) of CO; 7,851 TPY of nitrogen oxides (NO_x); 290 TPY of PM_{10}; 281 TPY of $PM_{2.5}$; 97 TPY of SO_2; and 105 TPY of volatile organic compounds (VOCs). These numbers were calculated assuming 238,821 total annual hours of survey vessel operation used in emission calculation formulae.

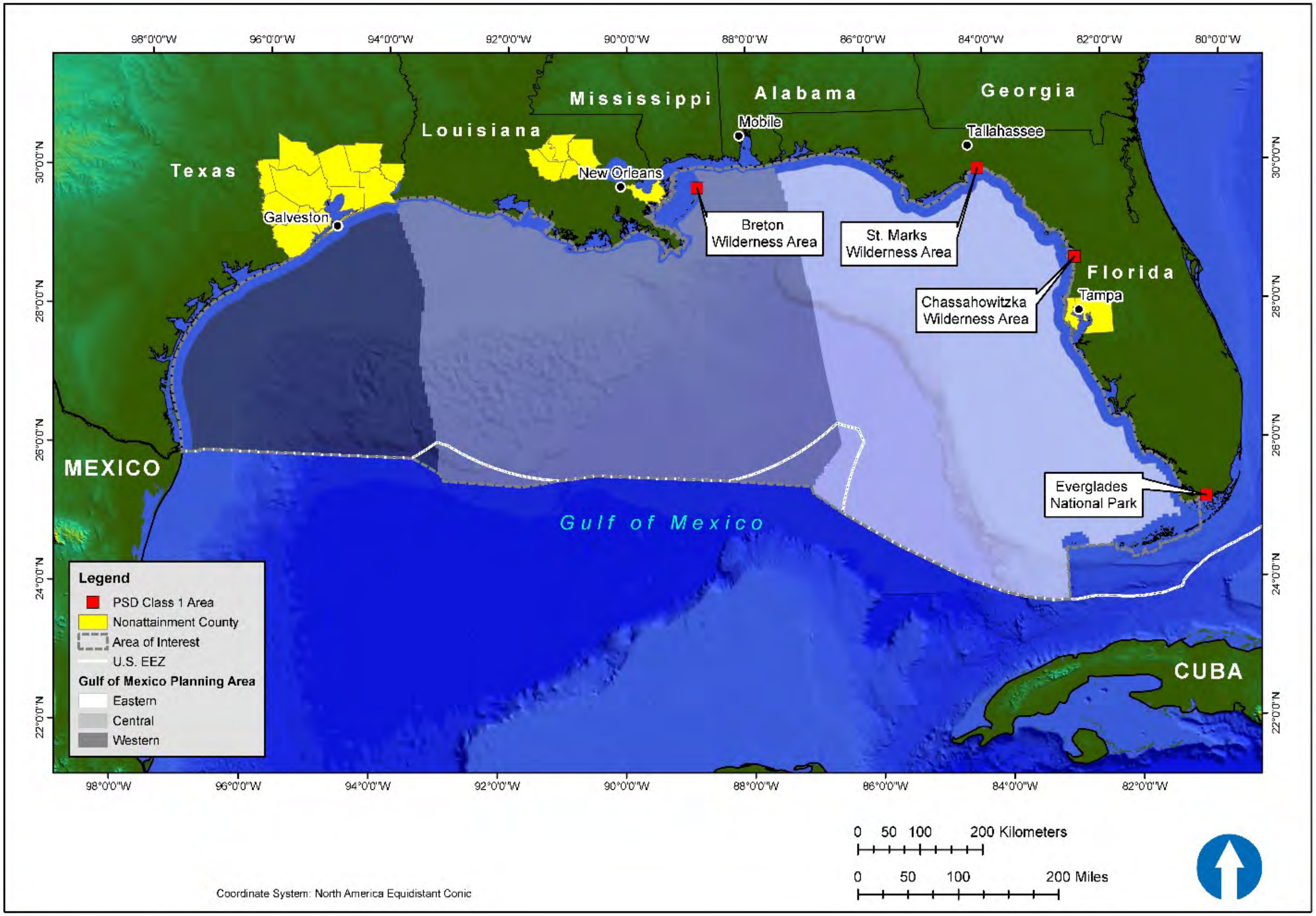

Figure E-2. Coastal Areas Designated as PSD Class I and Counties Designated as Nonattainment Areas Adjacent to the Area of Interest.

Table E-5. Total Platform and Non-Platform Emission Estimates for Criteria Pollutants

Equipment/Source Category	Emission Type (TPY)					
	CO	NO_x	PM_{10}	$PM_{2.5}$	SO_2	VOCs
Total Platform Emissions	70,753	84,415	760	759	3,197	54,724
Drilling Rigs	6,248	69,135	2,634	2,407	20,863	2,750
Pipelaying Operations	2,124	9,480	350	338	117	128
Support Helicopters	2,163	753	23	22	112	1,624
Support Vessels	35,686	175,558	6,435	6,242	2,157	4,016
Survey Vessels	1,760	7,851	290	281	97	105
Total OCS Oil/Gas Production Source Emissions	118,734	347,192	10,492	10,049	26,543	63,347
Total Non-OCS Oil/Gas Production Source Emissions	13,008	131,094	4,973	4,569	36,283	37,063
Total Emissions[1]	131,742	478,287	15,465	14,618	62,827	100,410

[1] Totals may not sum due to rounding.

Attainment Status

The CAA, as amended, established classification increments for pollutants based on ongoing monitoring of regional air quality. The CAA, as amended, identified timetables and requirements for attaining and maintaining air quality criteria. After the USEPA designates primary or secondary NAAQS, they must designate areas as "attainment" (meets standards), "nonattainment" (does not meet standards), or "unclassifiable" (insufficient data). The attainment statuses are determined after air quality monitoring by State or local governments. Once a particular area has a nonattainment designation, an implementation plan must be developed by State and local governments to plan how the area will achieve attainment status.

The CAA, as amended, does not identify attainment status for OCS waters (similarly, OCS waters are not classified as to the presence of criteria pollutants under the NAAQS); only areas within State boundaries are classified with an attainment status. Counties with GOM coastline that are designated as nonattainment areas (based on the 1997 standards) include Brazoria County, Texas (for 8-hour ozone); Galveston County, Texas (for 8-hour ozone); Chambers County, Texas (for 8-hour ozone); St. Bernard Parish, Louisiana (for SO_2); and Hillsborough County, Florida (for lead and SO_2) (USEPA, 2015b) (**Figure E-2**). The CAA also updated jurisdiction for air quality policy making and enforcement. The OCS waters east of 87.5° W. longitude fall under the USEPA's jurisdiction, while waters west of 87.5° W. longitude fall under BOEM's jurisdiction.

***Deepwater Horizon* Explosion, Oil Spill, and Response**

After the *Deepwater Horizon* explosion, oil spill, and response, the USEPA, NOAA, and other agencies measured air quality to determine any effects of the oil spill on coastal air quality. These measurements indicated that air quality impacts were minor and generally below the health standards set by the USEPA (USDOI, BOEM, 2012a). Middlebrook et al. (2011) analyzed air quality data acquired after the *Deepwater Horizon* explosion, oil spill, and response. Along with computer modeling, the data indicated that, as a result of the spill, evaporating hydrocarbons were the most significant source of air pollution. Ozone pollution was limited to the area immediately downwind of the spill, but NO_x, CO, and black carbon were emitted from in-situ burning of oil (Middlebrook et al., 2011). Because the *Deepwater Horizon* explosion, oil spill, and response was an acute non-recurring incident, the impact on air quality was limited (Middlebrook et al., 2011). It is unlikely that any future data will reveal information that alter conclusions (of minimal air quality impact) caused by the *Deepwater Horizon* explosion, oil spill, and response (USDOI, BOEM, 2012a).

16 WATER QUALITY

Water quality refers to the chemical, physical, biological, and radiological characteristics of water. For the purposes of this Programmatic EIS, water quality is discussed as a measure of the condition of water relative to the ability of a waterbody to maintain the ecosystems it supports or influences. In the case of coastal and marine environments, water quality is influenced by the rivers that drain into the area, the quantity and composition of wet and dry atmospheric deposition, and the influx of constituents from sediments. In addition to natural inputs, human activity can contribute to water quality through discharges, runoff, dumping, air emissions, burning, and spills. Also, mixing or circulation of the water can improve water quality through flushing or be the source of factors contributing to its decline.

Evaluation of water quality is done by measuring factors considered important to the health of an ecosystem. The primary factors influencing coastal and marine environments are temperature, salinity, dissolved oxygen, nutrients, pH, oxidation reduction potential (Eh), pathogens, and turbidity or suspended load. Trace constituents such as metals and organic compounds can affect water quality. Water and sediment quality may be closely linked. Contaminants, which are associated with the suspended load, may ultimately reside in the sediments rather than in the water column.

The USEPA (Regions 4 and 6) regulates all waste streams generated from offshore oil and gas activities. Section 403 of the Clean Water Act requires that National Pollutant Discharge Elimination System (NPDES) permits be issued for discharges to the territorial seas (shore to 3 nmi [3.5 mi; 5.6 km]), the contiguous zone, and the open ocean in compliance with the USEPA's regulations for preventing unreasonable degradation of the receiving waters. Water quality standards consist of the waterbody's designated uses, water quality criteria to protect those uses and determine if they are being attained, and antidegradation policies to help protect high quality waterbodies. Discharges from offshore activities within State waters must comply with all applicable State water quality standards. In general, waste streams that can be discharged overboard include water-based drilling fluids and drill cuttings, synthetic-based fluid-wetted drill cuttings, cement slurries, various treated waters (including produced water) and sanitary wastes, and uncontaminated freshwater and seawater, provided they meet the criteria of the applicable NPDES permit.

Some areas of the GOM have heavy shipping traffic and may experience localized impacts from ships, especially from bilge water, domestic wastewater, and tank washings. Ship discharges are regulated under the USEPA's NPDES vessels program, along with the USCG's bilge and ballast water regulations based on the MARPOL Annex I, Regulations for the Prevention of Pollution by Oil.

The primary means of regulation is the Vessel General Permit, which applies to discharges incidental to the normal operation of all non-recreational, non-military vessels 24 m (79 ft) or longer that discharge in U.S. waters (USEPA, 2013a).

The AOI is divided into coastal and marine waters for the following water quality discussion. Coastal waters include all bays and estuaries from the Rio Grande River to the Florida Bay. Offshore water includes both State offshore water and Federal OCS waters extending from outside the barrier islands to the EEZ. Marine waters are divided into three regions: the continental shelf west of the Mississippi River; the continental shelf east of the Mississippi River; and deep water (USDOI, BOEM, 2012b).

***Deepwater Horizon* Explosion, Oil Spill, and Response**

The *Deepwater Horizon* explosion, oil spill, and response released an estimated 4.9 million bbl of oil (Operational Science Advisory Team [OSAT], 2010) and 200,000 to 500,000 tons of hydrocarbon gases (predominantly methane) (Joye et al., 2011a; Reddy et al., 2011) into the GOM. According to the Federal Interagency Solutions Group's Oil Budget Calculator (2010), of the 4.9 million bbl of oil released from the well, approximately 820,000 bbl were directly recovered through a riser insertion tube tool and "top hat," resulting in approximately 4.1 million bbl being released into the environment. Valentine et al. (2010) reported that 2 months after the spill, methane, ethane, propane, and butane gases at depth (>799 m [2,621 ft]) were the major gases driving rapid respiration by bacteria. An initial report by Kessler et al. (2011a) stated that released methane was rapidly consumed by methanotrophic bacteria in GOM deep waters over a 4-month period. However, at present, the extent to which the bacteria consumed the methane is under dispute (Joye et al., 2011b; Kessler et al., 2011b).

With respect to the spilled oil, 1.4 million bbl were estimated to be naturally or chemically dispersed and 1.8 to 2.2 million gal of dispersants were applied to the spill (combined for surface and depth) (OSAT, 2010; Allan et al., 2012; Joung and Shiller, 2013; Paul et al., 2013; Spier et al., 2013) and consequently into the marine environment. The dispersants used contained anionic surfactant dioctyl sodium sulfoscuccinate (DOSS) that lowered the interfacial tension between oil and water to hamper the formation of large surface oil slicks. The DOSS acts conservatively in the water column, is not significantly removed by biodegradation or sedimentation, and has been found to be persistent in subsurface waters following the *Deepwater Horizon* oil spill. Under certain conditions, DOSS can persist in the environment for up to 4 years (White et al., 2014).

After the *Deepwater Horizon* oil spill, the USEPA, NOAA, other agencies, and academic institutes collected water quality measurements to determine any effects of the oil spill on coastal and deepwater water quality. Results from many of the studies have only recently been published or are still in the process of being published; therefore, a summary of available data will be provided.

The OSAT (2010) of the Unified Area Command summarized water and sediment quality data measuring concentrations of oil- and dispersant-related chemicals collected from the start of the

Deepwater Horizon explosion, oil spill, and response through October 2010. The OSAT (2010) established a suite of sediment and water quality indicators to determine whether oil- and dispersant-related chemicals were in concentrations high enough to cause impacts to human health and aquatic life. Samples were collected in nearshore (shoreline to 3 nmi), offshore (3 nmi to 200 m [3.5 mi/5.6 km to 656 ft] depth), and deepwater (beyond 200 m [656 ft] depth) environments. Results revealed that concentrations of oil- and dispersant-related chemicals in water and sediment samples did not exceed the benchmark for impacting human health; <1 percent of water samples and approximately 1 percent of sediment samples exceeded concentrations, resulting in impacts to aquatic life with respect to oil-related chemicals (e.g., polycyclic aromatic hydrocarbons [PAHs]); however, none of the water sample exceedances were consistent with the *Deepwater Horizon* spill signature, and the sediment exceedances were limited to within 3 km (1.6 nmi; 1.7 mi) of the wellhead.

Camilli et al. (2010) conducted a subsurface hydrocarbon survey to track the hydrocarbon plume associated with the *Deepwater Horizon* spill. They found a continuous plume of dispersed oil at a depth of approximately 1,100 m (3,609 ft) that extended 35 km (19 nmi; 22 mi) from the spill. The plume consisted of monoaromatic petroleum hydrocarbon concentrations in excess of 50 micrograms per liter (μg/L), and the plume persisted for months with no substantial biodegradation. Additional water column concentration measurements revealed similarly high concentrations of hydrocarbons in the upper 100 m (328 ft) of the water column. Similarly, Diercks et al. (2010) reported PAH concentrations reaching 189 mg/L (ppb) at depths between 1,000 and 1,400 m (3,280 and 4,595 ft) near the wellsite and concentrations considered to be toxic to marine organisms in the same depth range up to 13 km (7 nmi; 8 mi) from the spill site.

Allan et al. (2012) monitored bioavailable concentrations of PAHs in coastal waters of Louisiana, Mississippi, Alabama, and Florida and observed significant increases following the spill. Boehm et al. (2011) reviewed total PAH concentrations in water samples collected through Natural Resource Damage Assessment efforts between April and October 2010 in offshore waters ≥4.8 km (2.6 nmi; 3.0 mi) from shore. Boehm et al. (2011) found that total PAH concentrations in 85 percent of samples were at or near background levels and concentrations attenuated rapidly with distance from the wellhead due to dilution and biodegradation. Edwards et al. (2011) reported higher rates of microbial respiration within the surface oil slick; however, no increase in microbial abundances or biomass was observed within the slick, which was attributed to a lack of available nutrients.

The distribution and chemical composition of hydrocarbons within a 45-km (28-mi) radius of the spill were investigated by Spier et al. (2013), who discovered that the distribution of hydrocarbons was over a wider area in subsurface waters than previously predicted or reported (e.g., Diercks et al., 2010; Valentine et al., 2010). The deepwater hydrocarbon plume predicted by models at 1,175 m (3,855 ft) was verified, and additional plumes were identified at water depths of 25,265 and 865 m (82,889 and 2,838 ft). Furthermore, benzene concentrations were found at potentially toxic levels outside of areas previously reported to contain hydrocarbons, and the application of subsurface dispersants was found to increase hydrocarbon concentration in subsurface waters.

Paul et al. (2013) collected water samples in the northeast GOM and along the West Florida Shelf to measure the general toxicity and mutagenicity of waters in the upper water column. Analysis of water samples revealed that 21 percent of samples were toxic to bacteria, 34 percent were toxic to phytoplankton, and 43 percent showed DNA-damaging activity. Additionally, the degree of toxicity in samples was correlated to total petroleum hydrocarbons (TPH) concentration, and mutagenicity persisted for 1.5 years after capping of the well.

Sammarco et al. (2013) examined the geographic extent of petroleum hydrocarbon contamination in sediment, seawater, biota, and seafood during and after the *Deepwater Horizon* spill by collecting samples from coastal waters between the Florida Keys and Galveston, Texas. Concentrations of TPH in seawater were relatively high and peaked offshore Pensacola, Florida. Average concentrations of TPH and PAHs in sediment samples were high throughout the study region.

Trace element distributions in the water column near the *Macondo* well were examined by Joung and Shiller (2013). In surface waters, barium, cobalt, copper, iron, manganese, and nickel were relatively well correlated with salinity, suggesting mixing with river water was the main influence on metal distributions in the area. Conversely, at depths of 1,000 to 1,400 m (3,280 to 4,593 ft) within oil/gas plumes, elevated concentrations of cobalt and barium were observed. Cobalt concentrations were linked to the *Deepwater Horizon* oil signature, while barium concentrations were attributed to drilling muds used in the attempts to stop the spill.

16.1 COASTAL WATER QUALITY

Including the shore of all barrier islands, wetlands, inland bays, and inland bodies of water, the combined coastlines of the Gulf Coast States span more than 75,639 km (47,000 mi) (USDOI, BOEM, 2012a). The GOM coastal areas comprise more than 750 bays, estuaries, and sub-estuary systems (USEPA, 2012). While the bays and estuaries are outside of the AOI, their influence on coastal water quality is not.

More than 60 percent of U.S. drainage, including outlets from 33 major river systems and 207 estuaries, flows into the GOM (USEPA, 2014). Three major estuarine drainage areas (Texas, Mississippi, and West Florida) and three fluvial drainage areas (also Texas, Mississippi, and West Florida) have a large influence on water quality in the GOM. Additional freshwater inputs originate in Mexico, the Yucatán Peninsula, and Cuba. The river deltas emptying into the GOM bring freshwater and sediment into coastal waters, affecting the water quality of receiving waters (Gore, 1992). Rivers carry excess nutrients (e.g., nitrogen and phosphorus) and contaminants from industrial wastewater discharge, urban runoff, and agriculture to downstream receiving waters.

Population growth in coastal areas can impact water quality. Since 1960, the population of the coastal counties of the Gulf Coast States has increased by >100 percent. From 2000 to 2004, the population expanded by 6.7 percent. Population growth results in additional land clearing, excavation, construction, expansion of paved surface areas, and drainage controls (U.S.

Commission on Ocean Policy, 2004a and 2004b). These activities alter the quantity, quality, and timing of freshwater runoff. Stormwater runoff, which flows across impervious surfaces such as parking lots, is more likely to be warmer and to transport contaminants associated with urbanization, including suspended solids, heavy metals, pesticides, oil and grease, and nutrients.

In coastal waters of the GOM, water quality is controlled primarily by the anthropogenic inputs of land runoff, land point-source discharges, and atmospheric deposition. With increasing distance from shore, oceanic circulation patterns play an increasingly larger role in dispersing and diluting anthropogenic contaminants and determining water quality. Due primarily to the influence of the GOM's extensive estuary system and input from the Mississippi River, areas of the AOI closer to shore show regional variation (USEPA, 2012).

Within the GOM, coastal waters are divided into two biogeographical provinces: (1) Louisiana Province and (2) West Indian Province (USEPA, 2012).

Within the AOI, the Louisiana Province extends from the Texas-Mexico border to Anclote Key, Florida, and the West Indian Province extends from Tampa Bay to Florida Bay, Florida. The overall condition of coastal waters within the AOI is rated as fair with an index score of 2.4 (USEPA, 2012). This assessment is based on an evaluation of five indices: water quality, sediment, benthic, coastal habitat, and fish tissue contaminants. More specifically, the water quality index for the GOM's coastal waters was rated fair, the benthic index was rated fair to poor, the sediment quality and coastal habitat indices were rated poor, and the fish tissue contaminants index was rated good (USEPA, 2012). Of the evaluation indices listed, sediment quality (ranked as poor) poses an impact risk to coastal water quality as contaminants in sediments may be re-suspended into the water by anthropogenic activities, storms, or other natural events. Sediments in the GOM coastal region have been found to contain pesticides, metals, PCBs, and occasionally PAHs (USEPA, 2012).

Outside of anthropogenic inputs and the GOM's estuarine and river systems, storm events have had a significant impact on the water quality of the coastal waters of the AOI. Hurricanes Katrina and Rita in 2005 resulted in impacts on water quality conditions in the GOM from damage caused to oil and gas pipelines, oil refineries, manufacturing and storage facilities, sewage treatment facilities, and other infrastructure. Hurricane Katrina reportedly damaged 100 pipelines, resulting in approximately 211 minor pollution reports; Hurricane Rita damaged 83 pipelines, resulting in 207 minor pollution reports (USDOI, MMS, 2006). In total, 113 platforms were destroyed and an additional 52 platforms incurred extensive damage (Moore, 2006). Furthermore, 50 oil spills were reported in the nearshore environment, ranging from 13,000 to 3.78 million gal (Pine, 2006).

16.2 MARINE WATER QUALITY

Marine water composition in the GOM has two primary influences: (1) the configuration of the basin, which controls the influx of water from the Caribbean Sea and the output of water through the Straits of Florida; and (2) runoff from land masses, which controls the quantity of freshwater input into the GOM from the estuarine and fluvial drainage areas. As noted previously, there are three major estuarine drainage areas (Texas, Mississippi, and West Florida) and three fluvial drainage areas (also Texas, Mississippi, and West Florida) that together drain a total of 60 percent of the continental U.S. and have a large influence on water quality in the GOM. The large amount of freshwater runoff mixes into the GOM's surface water, producing a different composition on the continental shelf than that in the open ocean. Marine waters are divided into three regions: the continental shelf west of the Mississippi River; the continental shelf east of the Mississippi River; and deep water (USDOI, BOEM, 2012b).

16.2.1 Continental Shelf West of the Mississippi River

Water quality on the continental shelf west of the Mississippi River is predominantly influenced by the input of sediment, nutrients, and pollutants from the Mississippi and Atchafalaya Rivers (USDOI, BOEM, 2012b). There is a surface turbidity layer associated with the freshwater plume from the two rivers. During summer months, shelf stratification results in a large hypoxic zone on the Louisiana-Texas Shelf in bottom waters (Turner et al., 2005). Hypoxia, the condition of having low dissolved oxygen concentration in the water (<2 mg/L), is caused by excessive nutrients and other oxygen demanding contaminants. Hypoxia often occurs when the water column becomes vertically stratified and mixing between oxygenated surface waters and bottom waters cannot occur. Hypoxia is a widespread phenomenon in the AOI (**Figure E-3**), and the largest hypoxic zone in the western Atlantic occurs there (Rabalais et al., 2002; Turner et al., 2005 and 2012; Obenour et al., 2013). The hypoxic zone in the GOM occurs seasonally and is influenced by the timing of the Mississippi and Atchafalaya Rivers discharge, and formation of the zone is attributed to nutrient influxes and shelf stratification; the zone persists until wind-driven circulation mixes the water column. Recent estimates of the area of low oxygen by the USDOC, NOAA (2015b) as of August 3, 2015, measured 6,474 mi^2 (16,760 km^2), an increase from the size measured in 2014 (5,052 mi^2; 13,085 km^2) and larger than the estimated size (5,838 mi^2; 15,120 km^2) forecast by the Louisiana Universities Marine Consortium (2015) in June 2015. The size of the hypoxic zone has been shown to be directly correlated with the flux of nitrogen from the Mississippi River (Turner et al., 2012).

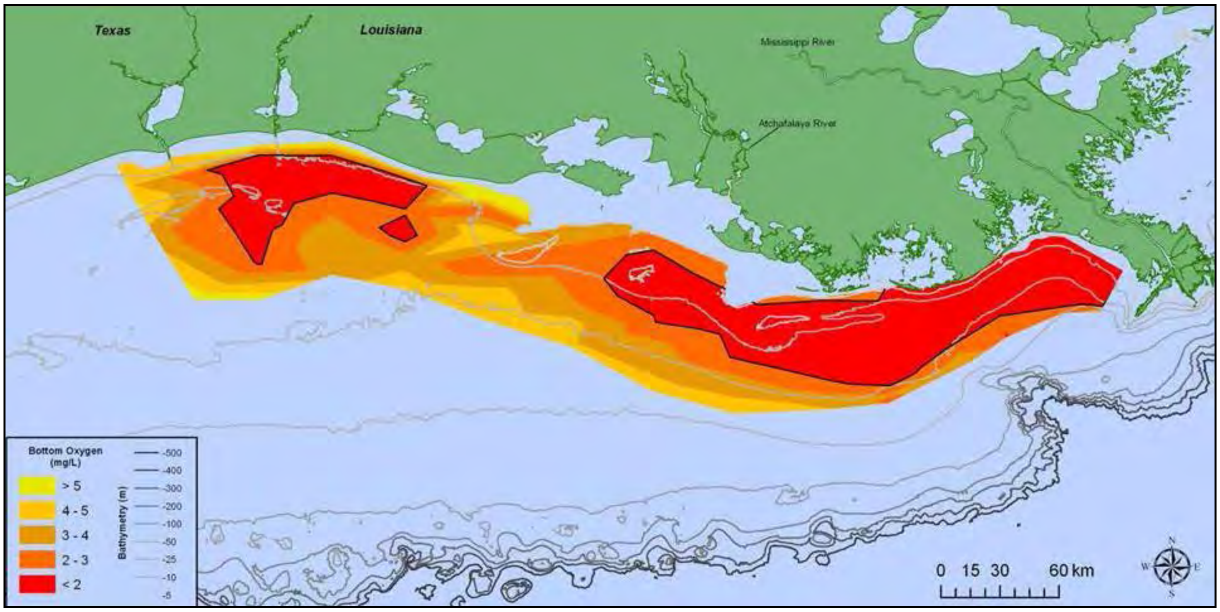

Figure E-3. Distribution of Bottom-Water Dissolved Oxygen July 27-August 1 (West of the Mississippi River Delta), 2014. Black line indicates dissolved oxygen level of 2 mg/L. (From: USDOC, NOAA, 2015b).

Turner et al. (2003) found trace organic pollutants, including PAHs, PCBs, and trace inorganic metals, in shelf sediments offshore Louisiana that were attributed to river discharge. Additional input of hydrocarbons associated with natural seeps and oil and gas activity in the region were found farther offshore (Turner et al., 2003). Pelagic tar is a common form of hydrocarbon contamination present in the offshore environment (Van Vleet et al., 1983a and 1983b; Farrington, 1987) of the GOM. Higher tar concentrations were closely correlated with proximity to the Loop Current (Van Vleet et al., 1983b; Farrington, 1987). Van Vleet et al. (1983a) estimated that approximately 7,112,323 kg (7,000 tons) of pelagic tar are discharged annually from the GOM into the North Atlantic and that approximately half of the oil may be brought into the GOM from the Caribbean via the Loop Current, while the remainder appears to originate in the GOM.

16.2.2 Continental Shelf East of the Mississippi River

Water quality on the continental shelf east of the Mississippi River is influenced by river discharge, coastal runoff, and the Loop Current and its associated eddies. The Loop Current and its associated eddies intrude on the shelf at irregular intervals and mix the water column. Warm-core eddies bring clear, low-nutrient water onto the shelf and entrain and transport high turbidity shelf waters farther offshore into deeper waters while cold-core eddies introduce nutrient-rich waters onto the shelf through upwelling. Waters in the area generally are turbid from the input of fine sediments discharged from the Mississippi River, but water clarity improves closer to Florida out of the influence of the river outflow.

Multiple studies (Dames & Moore, Inc., 1979; Brooks and Giammona, 1990; Brooks, 1991) analyzed water, sediments, and biota for hydrocarbons in the Mississippi, Alabama, and Florida area. Results indicated the area showed only minor influence of anthropogenic and petrogenic hydrocarbons from river sources and natural seeps, and analysis of trace metal contamination indicated no contamination sources.

16.2.3 Deep Water

Water quality of the deepwater GOM may be closely tied to sediment quality, and the two can affect each other. For example, a contaminant may react with the mineral particles in the sediment and be removed from the water column (e.g., adsorption). Thus, under appropriate conditions, sediments can serve as sinks for contaminants such as metals, nutrients, and organic compounds. However, if sediments are (re)suspended (e.g., due to dredging, a storm event, or in conjunction with seasonal mixing and circulation patterns), the resuspension can lead to a temporary redox flux, including a localized and temporal release of any formally sorbed metals as well as nutrient recycling (USDOI, BOEM, 2012a).

Limited information is available with respect to the deepwater environment of the GOM. Few studies analyzing concentrations of trace metals and hydrocarbons in sediments have been conducted, and water column measurements have been primarily limited to oxygen, salinity, temperature, and nutrients (Trefry, 1981; Gallaway, 1988; Continental Shelf Associates, Inc., 2006; Rowe and Kennicutt, 2009). Two studies (Continental Shelf Associates, Inc., 2006; Rowe and Kennicutt, 2009) have been completed that measured concentrations of organics, metals, and nutrients in sediments in the deepwater zone relative to oil and gas operations and benthic habitats. Continental Shelf Associates, Inc. (2006) found that concentrations of barium, mercury, and PAHs were elevated in sediment samples near exploratory drilling sites. Rowe and Kennicutt (2009) observed elevated PAH and barium concentrations in deepwater sediments at stations in proximity to drilling operations. Resuspension of sediments through dredging, trawling, or storm events could result in impacts to deepwater water quality, but these events are infrequent.

Deepwater water and sediment quality are most directly impacted by natural hydrocarbon seeps, which have been estimated to contribute 1 to 1.4 million bbl of hydrocarbons per year into the GOM (Kvenvolden and Cooper, 2003; National Research Council, 2003). Natural seeps are extensive throughout the continental slope of the GOM and are the highest contributor of petroleum hydrocarbons to the marine environment.

17 GEOGRAPHY AND GEOLOGY

The AOI encompasses the northern GOM waters along the coasts of Texas, Louisiana, Mississippi, Alabama, and Florida from the shoreline (excluding estuaries) out to the maritime boundary between the U.S. and Mexico in accordance with the 1978 Treaty on Maritime Boundaries. This section provides a regional geologic description, the geologic history, and a characterization of sediments of the AOI.

***Deepwater Horizon* Explosion, Oil Spill, and Response**

The *Deepwater Horizon* explosion, oil spill, and response did not alter or impact the geology of the GOM. While the benthic biological resources (**Section 5**) and the sediments of the GOM may have been affected by the spill, the purpose of this document is to analyze the impacts of G&G activities to the baseline conditions within the AOI, and geology has been screened out from the impacts discussion.

17.1 REGIONAL GEOLOGIC DESCRIPTION

The northern GOM is distinguished by an enormous river delta (Mississippi River), limestone islands, expansive and relatively flat continental shelf areas, submarine canyons (De Soto, Mississippi, Alaminos, Rio Perdido, and Keathley Canyons), steep escarpments, sea fans, and a central flat basin where water depths reach 3,750 to 4,400 m (12,303 to 14,436 ft) (Moretzsohn et al., 2013).

The width of the continental shelf in the AOI is variable, ranging from extremely narrow (approximately 10 km [6 mi]) near the mouth of the Mississippi River to more than 200 km (124 mi) off west Florida (Shepard, 1973) (**Figure E-4**). The shelf has a gentle gradient (approximately 1°), while the gradient of the continental slope ranges from 1° to 4° and extends from the shelf edge at 20 m (66 ft) water depth off southern Florida to approximately 200 m (656 ft) depth in the northern GOM, down to the Sigsbee and Florida Escarpments at approximately 3,000 m (9,842 ft) depth. Bathymetry in the GOM is shown in **Figure E-4**.

The continental shelf of the northwestern GOM is divided into four physiographic regions: the Rio Grande Delta; the south Texas intra-deltaic ramp; the Colorado-Brazos Delta complex; and the western Louisiana shelf (Holmes, 2011). The Rio-Grande Delta portion of the inner shelf features a northeast trending ridge system formed by faulting; the central shelf is terraced due to erosion and deposition, while the shelf break has linear features associated with slumping from sediment loading. The south Texas intra-deltaic ramp is gently sloping with a gradient of 2.8 m/km (9.2 ft/mi), features carbonate reefs as high as 15 m (49 ft) above the seafloor, and is predominantly silty-clay except near the reefs. The Colorado-Brazos Delta complex is characterized by sets of linear low ridges and a sediment cover of mud and sand. The western Louisiana shelf is a featureless plain. The eastern portion of the shelf is characterized by the presence of four large offshore sand shoals (Trinity Shoal, Ship Shoal, Outer Shoal, and St. Bernard Shoal). The shelf edge features numerous banks with relief of 3 m (10 ft) or more that are often capped with carbonate reefs, the most predominant of which are the FGBs. The majority of the Mississippi-Alabama shelf is flat with a gradient of only 40 cm/km (16 in/mi), and the continental shelf and shoreline of the north-central GOM are the products of fluvial sedimentation and sea-level change (Flocks et al., 2011). The Florida shelf ranges from 25 to 250 km (16 to 155 mi) wide and features a broad range of seafloor morphologies, bathymetric gradients, sediment types, benthic communities, hard bottom exposures, and reef structures with gradients that range from 0.2 to 4 m/km (0.7 to 13 ft/mi) (Hine and Locker, 2011).

Topography of the continental slope off of the Florida panhandle is relatively smooth and featureless aside from the De Soto Canyon, whereas the slope off western Florida is distinguished by steep gradients and irregular topography (**Figure E-4**). In the central and western GOM, the continental slope is underlain by salt and characterized by canyons, troughs, minibasins, and salt structures (e.g., small diapiric domes [domelike rock structures formed beneath Earth's surface by the upward movement of a mass of salt, often associated with oil and gas accumulations]) with higher relief than surrounding areas. In the central and western GOM, the Sigsbee Escarpment defines the southern limit of the Texas-Louisiana slope and was formed by a large system of salt ridges that underlie the region (**Figure E-5**). In the eastern GOM, the Florida Escarpment represents the ancient shelf edge during the Cretaceous Period (**Figure E-5**).

In addition to De Soto Canyon off the coast of Florida, the AOI contains four canyons on or near the Texas-Louisiana continental slope: Mississippi Canyon (Trough) (**Figure E-4**), located southwest of the Mississippi River Delta; Alaminos Canyon (**Figure E-5**), located on the western end of the Sigsbee Escarpment; Keathley Canyon, also located on the western end of the Sigsbee Escarpment; and Rio Perdido Canyon, located between the Texas-Louisiana continental slope and the East Mexico continental slope.

Located between the Sigsbee Escarpment and Sigsbee Abyssal Plain, the continental rise (**Figure E 5**) is composed of sediments transported to the area from the north. The Sigsbee and Florida Escarpments terminate in the Sigsbee and Florida Abyssal Plains. The abyssal plains are the deepest portions of the GOM and are characterized as relatively uniform flat areas where the Sigsbee Knolls (**Figures E-4 and E-5**) and other small salt domes represent the only major topographical features.

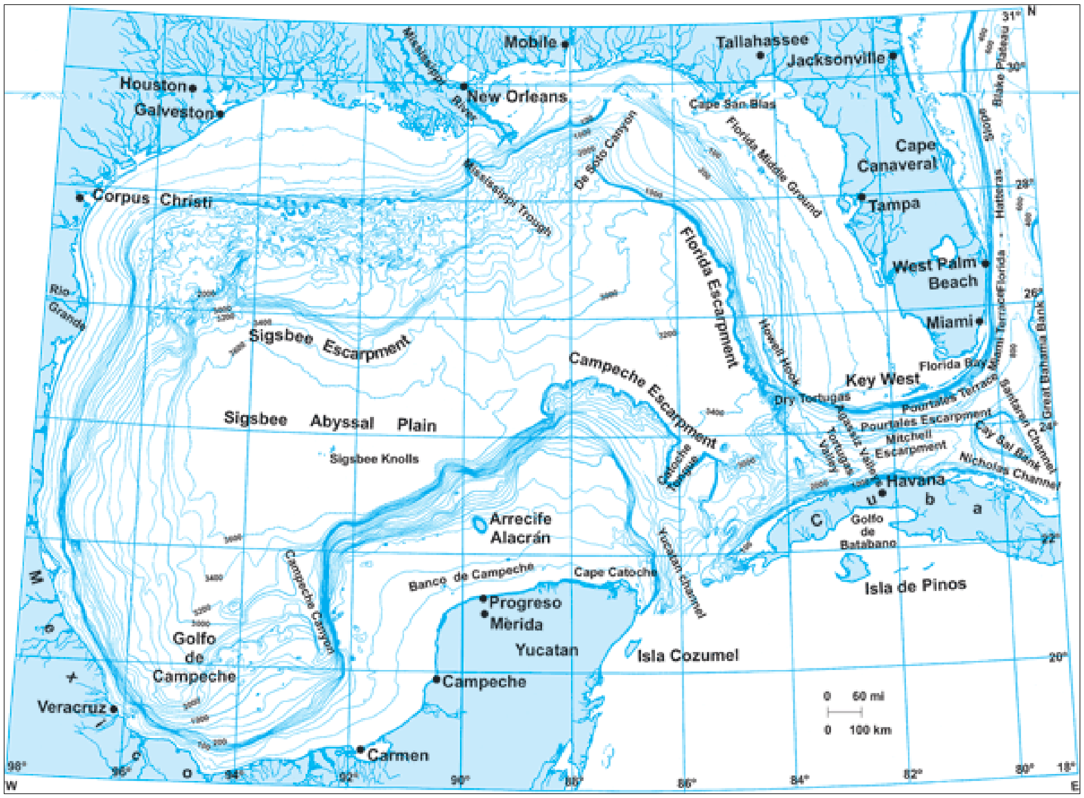

Figure E-4. Bathymetry (shown in meters) in the Gulf of Mexico (From: Maul, 2014).

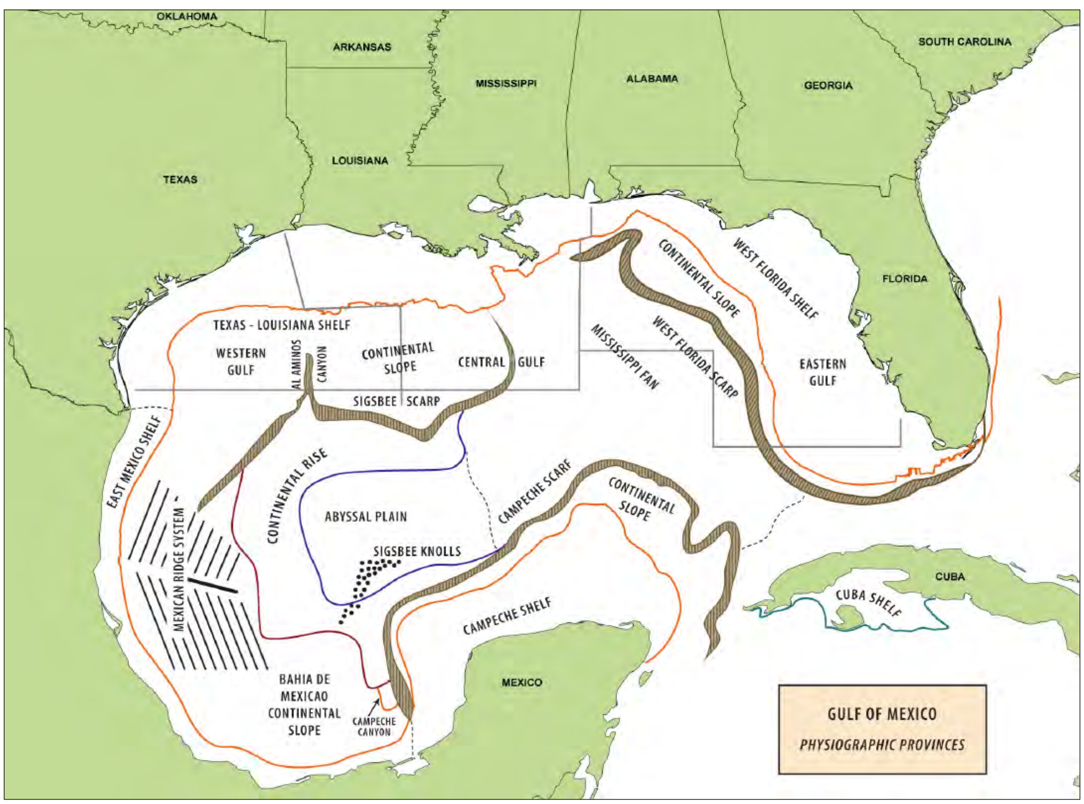

Figure E-5. Physiographic Provinces in the Gulf of Mexico (From: The Encyclopedia of Earth, 2011).

17.2 GEOLOGIC HISTORY AND SEDIMENTARY BASINS

The GOM is a passive continental margin (Martin, 1978) that was formed during the Triassic-Jurassic breaking apart of the supercontinent Pangea approximately 200 million years ago. During the Late Triassic, rifting occurred between the North American plate and the African/South American and Eurasian plates, the GOM basin was formed as the North American plate separated from the South American plate.

The GOM's geologic history resulted in the development of three distinct geologic provinces: a carbonate province, a salt province, and a canyon to deep-sea fan province (ten Brink et al., 2009) (**Figure E-6**). Seawater flowed intermittently into the GOM, evaporated, and deposited a thick widespread salt bed (Louann salt) during the Late-Middle Jurassic (Continental Shelf Associates, Inc., 2000). During the Late Jurassic, the basin-center crust cooled, subsided, and gradually filled with deeper water in which carbonate (i.e., limestone, chalk, and reefs) deposition was dominant (Bryant et al., 1991). During the Middle Cretaceous, slow subsidence of the carbonate shelves with little elastic input resulted in a reef system being built that extended from southern Texas to southern Louisiana, the shelf edge of Florida, and then south to the eastern Campeche Escarpment (**Figure E-6**). In the Late Cretaceous, detrital sediments started to flux into the northern and western GOM and accumulate on top of the salt (Continental Shelf Associates, Inc., 2000), causing it to flow southward into the northern GOM to the Sigsbee Escarpment (Bryant et al., 1991). Sediments were supplied to the deep GOM through submarine canyons and resulted in a series of deepsea fans. The GOM was inactive during the Late Eocene; in the Oligocene and Miocene, extensive sedimentation occurred and faulting molded the relief that exists presently with the GOM. During the mid-late Cenozoic, the total thickness of sediments was estimated to be up to 15 km (9.3 mi) in the northwestern GOM (Moretzsohn et al., 2013). In the southern and eastern GOM, carbonate deposition remained active since the Late Jurassic-Early Cretaceous, which limited the terrigenous influence seen in other areas of the GOM (Gallaway, 1988). Only small amounts of detrital sediments were deposited during the Quaternary.

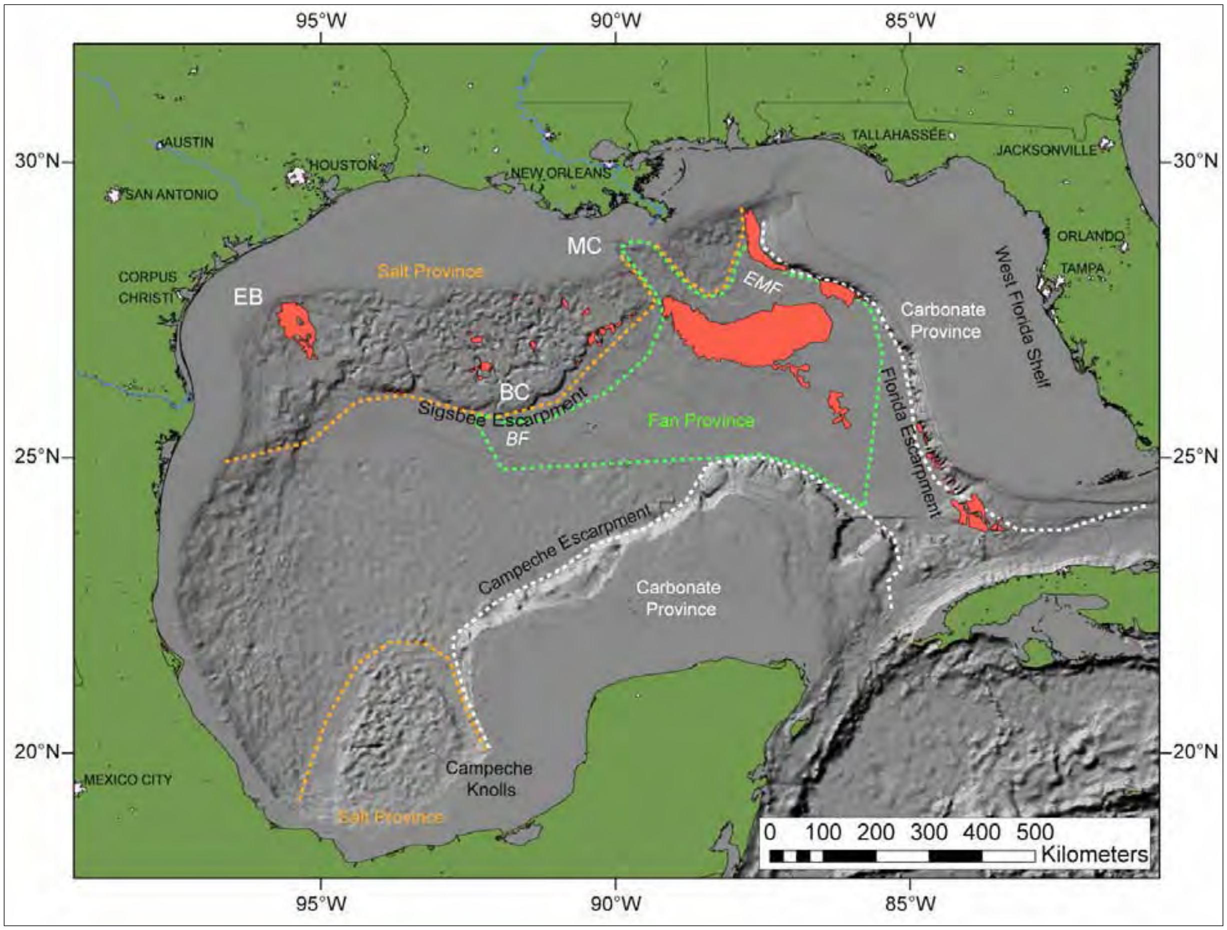

Figure E-6. *Primary Geologic Provinces of the Gulf of Mexico as Indicated by the Dashed Lines (From: ten Brink et al., 2009). Landslide deposits are marked in red. BC = Bryant Canyon; BF = Bryant Fan; EB = East Breaks Landslide; EMF = East Mississippi Fan; MC = Mississippi Canyon; MF = Mississippi Fan.*

17.3 SEDIMENTS

There are two major sedimentary provinces in the GOM: the younger Cenozoic Province in the western and central GOM, and the older Mesozoic Province in the eastern GOM. The Cenozoic Province is a clastic regime, characterized by thick deposits of sand, silt, clay, and mud underlain by carbonate rocks (i.e., limestone, chalk, and reefs). The Mesozoic Province is a largely carbonate (i.e., limestone and reef buildups) regime that extends eastward from the Cretaceous Shelf Edge off the coast of Mississippi, Alabama, and Florida towards the coastline of Florida (Salvador, 1991; Continental Shelf Associates, Inc., 2000; USDOI, BOEM, 2012a).

The seafloor of the GOM continental shelf consists primarily of muddy to sandy sediments. Pequegnat (1983) constructed a GOM sediment distribution map that indicated fine-grained sediments dominate in the central and western portions of the northern GOM continental slope, but coarser-grained sediments intrude in the eastern portion. More recently, Balsam and Beeson (2003) showed that the eastern portion of the shelf is primarily sand to 100 m (328 ft) depth; the western and central shelf consists of a mixture of sand, silt, and clay; and sediments offshore Mississippi and Louisiana are silt and clay of terrigenous origin from the Mississippi River (**Figure E-7**).

Offshore sand resources in the GOM are extremely scarce in coastal areas where sand is needed for nourishment and restoration projects. The OCS lease blocks in the GOM with significant sediment resources are discussed in **Section 12** and are shown in **Figure 4.12-3** of this Programmatic EIS.

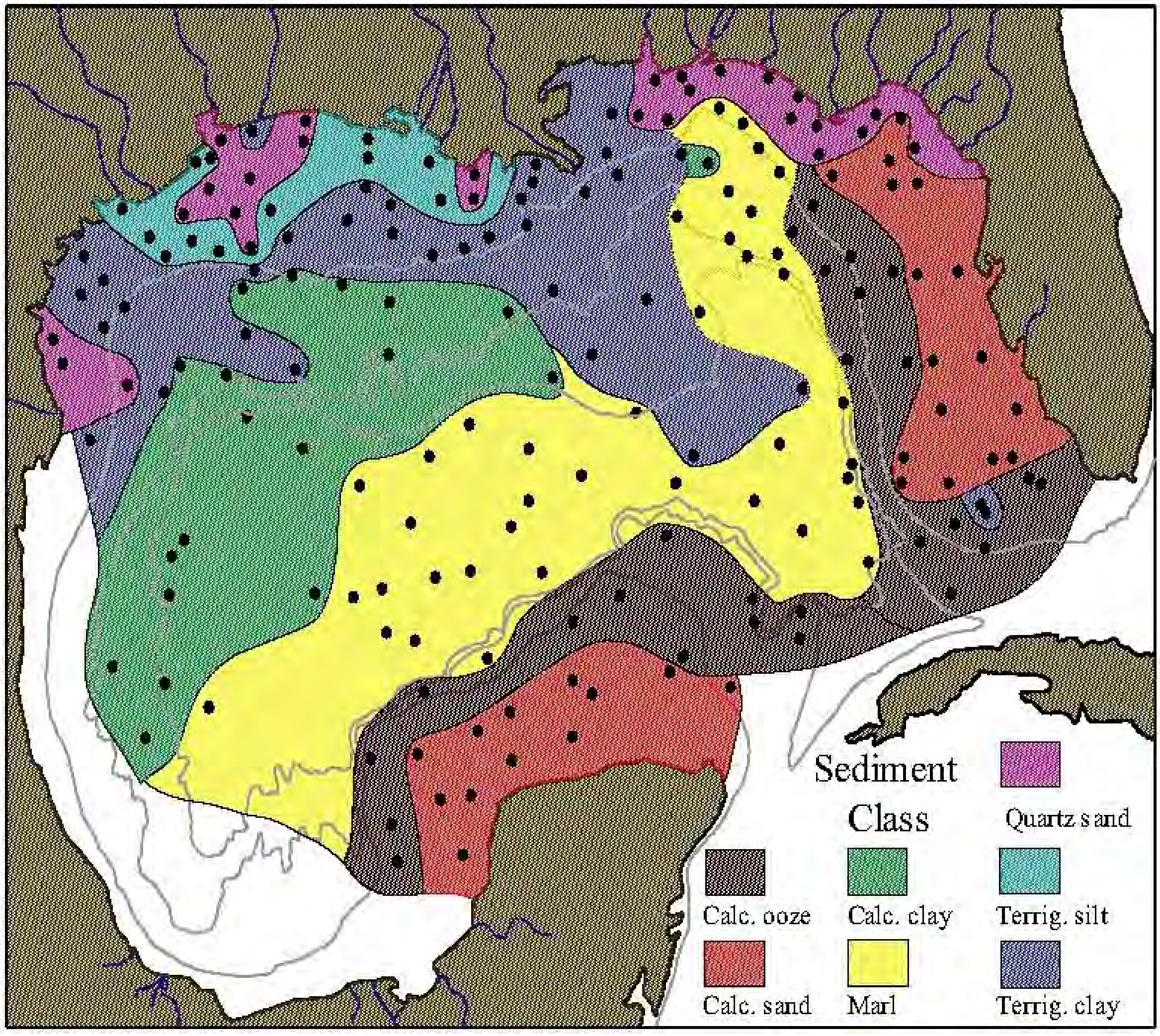

Figure E-7. Sediment Distribution Map Showing the Distribution of the Primary Classes of Sediment (From: Balsam and Beeson, 2003).

18 PHYSICAL OCEANOGRAPHY

The GOM is a semi-enclosed, subtropical sea encompassing an area of approximately 1.5 million km^2 (371 million ac) (Moretzsohn et al., 2015) and is the ninth largest waterbody in the world. The GOM opens to the Atlantic Ocean through the Straits of Florida and to the Caribbean Sea through the Yucatán Channel. The origins of the principal water masses in the GOM include Subtropical Underwater, Sargasso Sea Water, Tropical Atlantic Central Water, Antarctic

Intermediate Water, and a deepwater mixture of water masses (USDOI, BOEM, 2012a). Water masses identified in the eastern and western GOM are highly variable and strongly influenced by the presence of cyclonic and anticyclonic rings (Nowlin and McLellan, 1967; Vidal et al., 1994).

The GOM is one of the few seas in the world where diurnal tides (single high and low tide per day) dominate over semidiurnal tides (two high and low tides per day), resulting in a complex tidal regime (**Figure E-8**). The tidal regime is mixed but dominantly semidiurnal on most of the east coast of Florida, becomes dominantly diurnal from the Florida Panhandle through Alabama, is strongly diurnal at the Mississippi River Delta, becomes mixed in western Louisiana, and is dominantly diurnal through most of south Texas and the Yucatán (Flick et al., 2003). Tidal ranges in the GOM are generally microtidal and smaller than those found on the east and west coasts of the U.S. The tidal range throughout the GOM varies from approximately 0.5 m (1.6 ft) along the coastline to approximately 0.03 m (0.10 ft) or less within coastal bays (Flick et al., 2003; Davis, 2011).

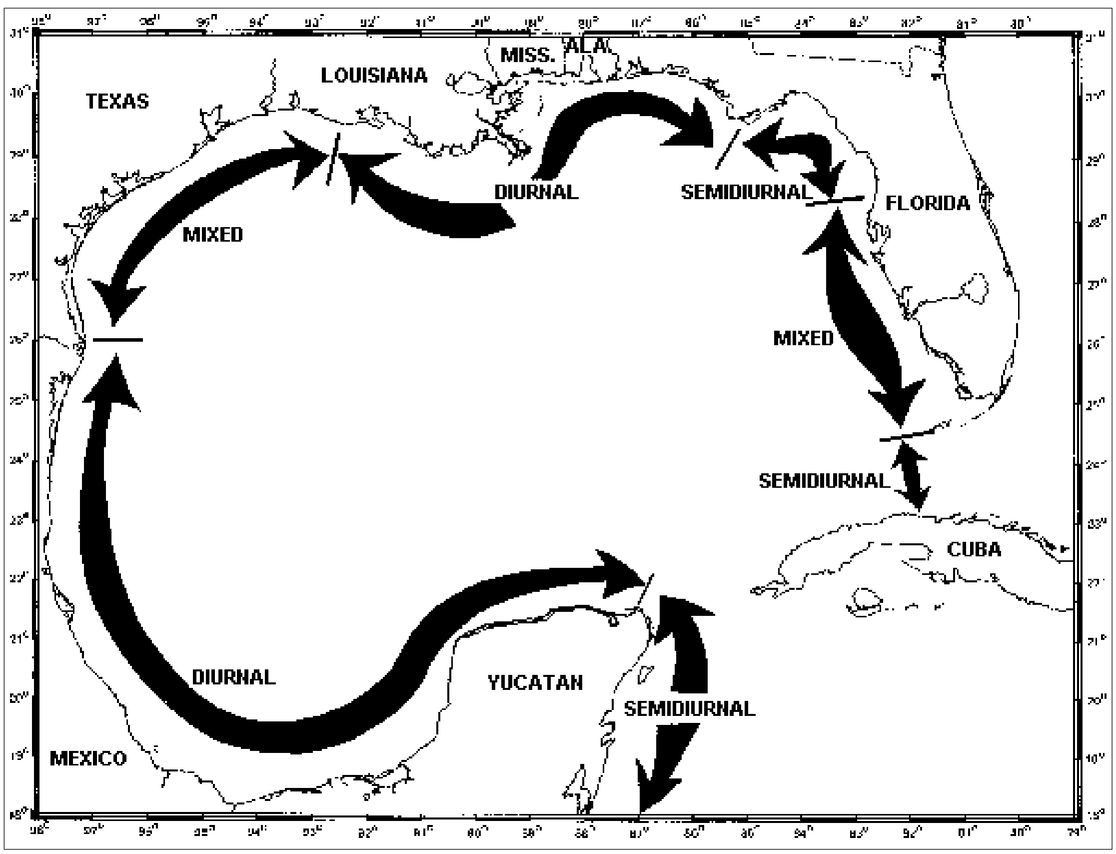

Figure E-8. Tidal Regimes of the Gulf of Mexico (From: Eleuterius and Beaugez, 1979).

Water flow known as the Loop Current enters the GOM through the Yucatán Channel, turns clockwise, and then exits the GOM through the Straits of Florida, to become the Florida Current and later part of the Gulf Stream (**Figure E-9**). The Loop Current is the principal current driving circulation in the AOI. Position of the current is variable throughout the year; it may be confined to the southeastern GOM or it may extend well into the northeastern or north-central GOM, with intrusions of Loop Current water interacting with the shelf edge off Louisiana and the Florida Panhandle (Huh et al., 1981; Paluszkiewicz et al., 1983; He and Weisberg, 2003; Vukovich, 2005).

As the Loop Current penetrates northward into the GOM, large (400 km [249 mi] or more in diameter) anticyclonic eddies (clockwise-rotating rings) are shed (Wiseman and Sturges, 1999) (**Figure E-9**). These anticyclonic eddies are also called warm-core eddies because they surround a central core of warm Loop Current water. The eddies propagate westward or west-southwestward across the GOM prior to decaying on the Mexican and Texas shelves. Loop Current penetration into the northern GOM and the shedding of eddies occurs at an average rate of once per 11 months. The cycle can take as few as 5 months or as long as 19 months (Vukovich, 2005). As the eddies interact with the shelves of the western and northern GOM, they entrain water from the shelf and generate a cyclonic (counterclockwise-rotating) eddy (also called a cold-core eddy because it surrounds a central core of seawater that is cooler and fresher than adjacent waters), resulting in the transport of nutrient-rich water off the shelf to deeper waters. Currents within the Loop Current and its associated eddies extend to depths of 700 m (2,297 ft) or more. The large anticyclonic ring is a semipermanent feature in the western GOM and dominates circulation in the area.

Eddies shed from the Loop Current can persist for a year or longer, and as they decay, they generate smaller (30 to 150 km [19 to 93 mi] in diameter) cyclonic and anticyclonic eddies that spread throughout the GOM (Hamilton, 1992). Warm-core (anticyclonic) eddies bring clear, low nutrient water onto the shelf and entrain and transport high turbidity shelf waters farther offshore into deeper waters. Cold-core (cyclonic) eddies introduce nutrient-rich waters onto the shelf through upwelling. Both warm-core and cold-core eddies eddies can dominate local circulation in regions removed from the direct impacts of the Loop Current and large-scale rings, such as over the northeastern slope of the GOM (Hamilton et al., 2000).

Shelf circulation in the GOM is complex and strongly influenced by discharges of the Mississippi and Atchafalaya Rivers as well as intrusions of the Loop Current and its eddies. Horizontal circulation, water temperature, and salinity on the shelf are affected by season, freshwater input, solar heating, wind-induced mixing, and upwelling and downwelling related to Loop Current eddies that reach the shelf. Overall, salinity is generally lower near shore due to freshwater input from the Mississippi and Atchafalaya Rivers, but the freshwater can extend into deeper waters as it is entrained in the Loop Current (Weisberg et al., 2005).

The Louisiana-Texas Shelf is generally dominated by a large cyclonic cell for most of the year (Cochrane and Kelly, 1986); however, seasonal reversal of this pattern occurs due to changes in wind patterns. Inner-shelf currents on the Louisiana-Texas Shelf flow in the downcoast (south or west) direction during non-summer months, reversing to upcoast flow in the summer (Cochrane and Kelly, 1986; Nowlin et al., 2005). The Mississippi-Alabama Marine Ecosystems Study (Brooks, 1991) concluded that four primary forcing mechanisms drive the continental shelf and slope waters of that portion of the shelf: synoptic scale wind stress, Loop Current-related intrusions, river discharges, and tropical cyclones. Estimates of the flow direction and speed on this portion of the shelf indicate a mean cyclonic surface circulation with inner shelf circulation influenced by wind.

Circulation on the continental shelf of the northeastern GOM tends to follow a cyclonic pattern with westward currents prevailing on the inner and middle shelf and eastward flow on the outer shelf (Brooks, 1991). Circulation on the West Florida Shelf tends to be to the southeast along the coast during the winter and northwest during the summer due to seasonal winds and heat flux forcing. The West Florida Shelf circulation is dominated by tides, winds, mesoscale perturbations, and the Loop Current. The outer shelf offshore Florida is a transitional area between deepwater currents over the continental slope and the shelf regime.

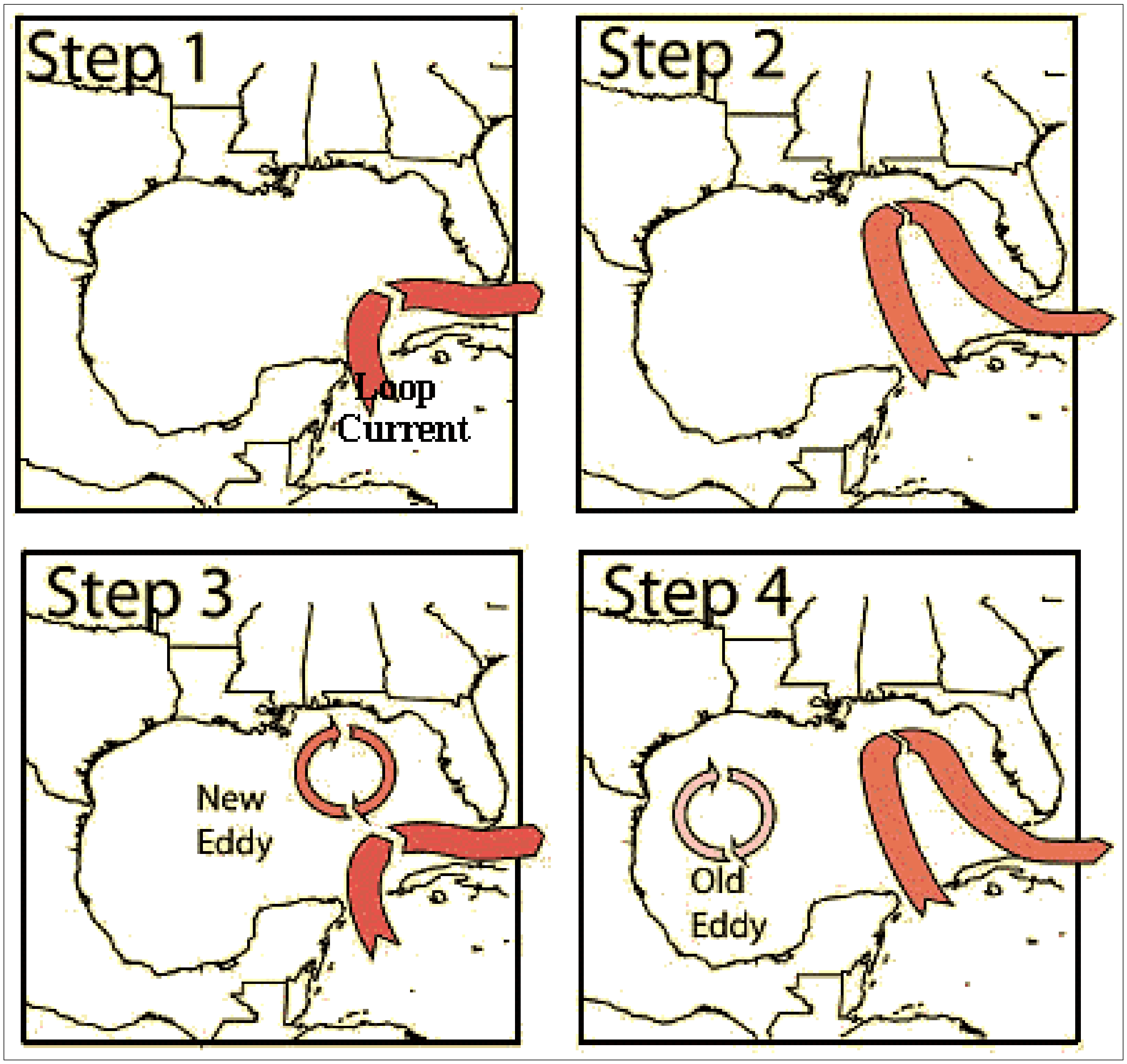

Figure E-9. Strong Loop Current in the Eastern Gulf of Mexico. It can be a short loop (Step 1), or stretched very long (Step 2), which often pinches off a spinning body of water called an eddy (Step 3). These eddies drift westward over many weeks (Step 4). They slowly lose energy in the western GOM. This cycle repeats itself several times a year (From: USDOC, NOAA, OER, 2002).

Deepwater Horizon Explosion, Oil Spill, and Response

The *Deepwater Horizon* explosion, oil spill, and response did not alter or impact the physical oceanography of the GOM. While the physical oceanography of the GOM influenced the transport, distribution, and weathering of the spill, the purpose of this document is to analyze the impacts of G&G activities to the baseline conditions within the AOI, and physical oceanography has been screened out from the impacts discussion.

19 COASTAL BARRIER ISLAND BEACHES

Coastal restoration projects are often necessary to replace coastal resources impacted by natural processes and eroded by human activities (USDOI, BOEM, 2013a and 2015a). Beach renourishment projects (described in **Section 12.3**) are needed to replace eroded sediments along coastal beaches and to stabilize the shoreline (Khalil et al., 2013; Sherwood et al., 2014). **Table 4.12-1** of this Programmatic EIS describes recent and future beach renourishment projects and estimated yards of sand replaced. Coastal barrier islands are important resources that protect the mainland from harsh environmental conditions that may cause shoreline deterioration (Byrnes et al., 2013; Khalil et al., 2013; State of Louisiana, Coastal Protection and Restoration Authority [CPRA], 2014; Ford, 2014; USDOI, BOEM, 2015a).

Barrier islands are long narrow islands that usually run parallel to shore and are composed largely of sand or other unconsolidated soils (Bagur, 1978; Zhang and Leatherman, 2011). The U.S. shoreline in the GOM runs from the Mexican border to southern Florida, approximately 2,623 km (1,630 mi) (National Atlas, 2013), and barrier islands are present on more than half of the coastline (LaRoe, 1976; USDOI, BOEM, 2015a). Barrier island beaches usually consist of a shoreface, foreshore, and backshore (Frey and Howard, 1969; USDOI, BOEM, 2012a; Society for Sedimentary Geology, 2013), though this discussion is limited to the shoreface and foreshore up to the mean high water line of the barrier island beaches within the AOI. The shoreface consists of the submerged substrate seaward of the low tide water line; the foreshore is the unvegetated beach landward of the low tide water line up to the beach berm crest (USDOI, BOEM, 2012a).

Wave, wind, and tidal energy are environmental conditions that shape barrier islands and create a dynamic system (LaRoe, 1976; Zhang and Leatherman, 2011; USDOI, BOEM, 2012a). Storms can have dramatic impacts on low-lying barrier island beaches, often inducing overwash events even with small surges (Sherwood et al., 2014; USDOI, BOEM, 2015a). Most of the geographic changes experienced by barrier islands are due to storms, subsidence, deltaic influence, longshore drift, or anthropogenic stressors (USDOI, BOEM, 2012a). Longshore movements of barrier island sand are important due to their role in creating estuarine environments in the lagoons between the island and the mainland. Most of the barrier islands in the GOM are migrating laterally to some extent (USDOI, BOEM, 2012a), though some of the beaches on the west coast of Florida are stable or slowly accreting due to low wave energy and frequent renourishment projects (Morton et al., 2005). Most GOM barrier islands are migrating landward, resulting in the accumulation of marine sediments on top of terrestrial sediments (Khalil et al., 2013). These transgressive islands are usually low-profile, narrow, and sparsely vegetated, and they often have frequent washover channels (USDOI, BOEM, 2012a). Landward migration of barrier islands is an inexact and discontinuous process that depends on numerous factors, including storm frequency and intensity, cold front passage, and the intensity of seasons (Williams et al., 1992).

This discussion briefly describes the barrier island beaches within and adjacent to the AOI. The barrier island chain is well developed and nearly continuous from Brownsville to Galveston, Texas (**Figure E-10**). The five major barrier islands of this region (Padre Island, Mustang Island, San Jose Island, Matagorda Island, and Galveston Island) are generally narrow, low relief, and sediment starved due the localized nature of currents and the resulting sediment transport scheme (Paine et al., 2014). As sea level rises, the shorelines along this section of the Gulf Coast have been transformed into transgressive landforms, effectively causing erosion and landward movement of the sediment (USDOI, BOEM, 2012a; Paine et al., 2014). In eastern Texas and western Louisiana, the coastline is dominated by expansive marshlands with inland lakes, left by erosion during the last glaciations (USDOI, BOEM, 2012a). This stretch, east to Atchafalaya Bay, Louisiana, is primarily marshland with no barrier island beaches.

The barrier islands of the northern GOM stretch from Atchafalaya Bay, Louisiana, to Mobile Bay, Alabama (USDOI, BOEM, 2012a and 2013a) (**Figure E-11**). Beaches along this stretch of coast are generally eroding, and deterioration of barrier islands occurs as a result of reduced sediment availability and transport, sea-level rise, frequent tropical and winter storms, and topographic and geomorphic features (McBride et al., 1992; Otvos and Carter, 2008; USDOI, BOEM, 2012a and 2013a; Byrnes et al., 2013; Khalil et al., 2013; State of Louisiana, CPRA, 2014). Barrier islands off the coast of Louisiana (the Isle Dernieres chain, Timbalier Island, Grand Isle, and the Chandeleur Islands) are highly influenced by the Mississippi River Delta (State of Louisiana, CPRA, 2014). Channelization of the Mississippi River deposits much of the available sediment offshore, where it cannot be used to replace eroded beaches (USDOI, BOEM, 2012a). The major barrier islands of Mississippi and Alabama are Cat Island, Ship Island, Horn Island, Petit Bois Island, and Dauphin Island. These islands generally do not migrate landward as they accrete sediment; instead, they are migrating westward by means of shoal-bar accretion due to the dominant westward littoral drift in the area (USDOI, BOEM, 2012a). This shoal-bar accretion results in islands with high beaches and broad dunes. A noticeable exception is Dauphin Island, Alabama, a 12-km (7.5-mi) long, low-profile transgressive island that is slowly migrating landward as a result of frequent storm overwash that results in the deposition of sediment on the lee side of the island (Morton, 2008).

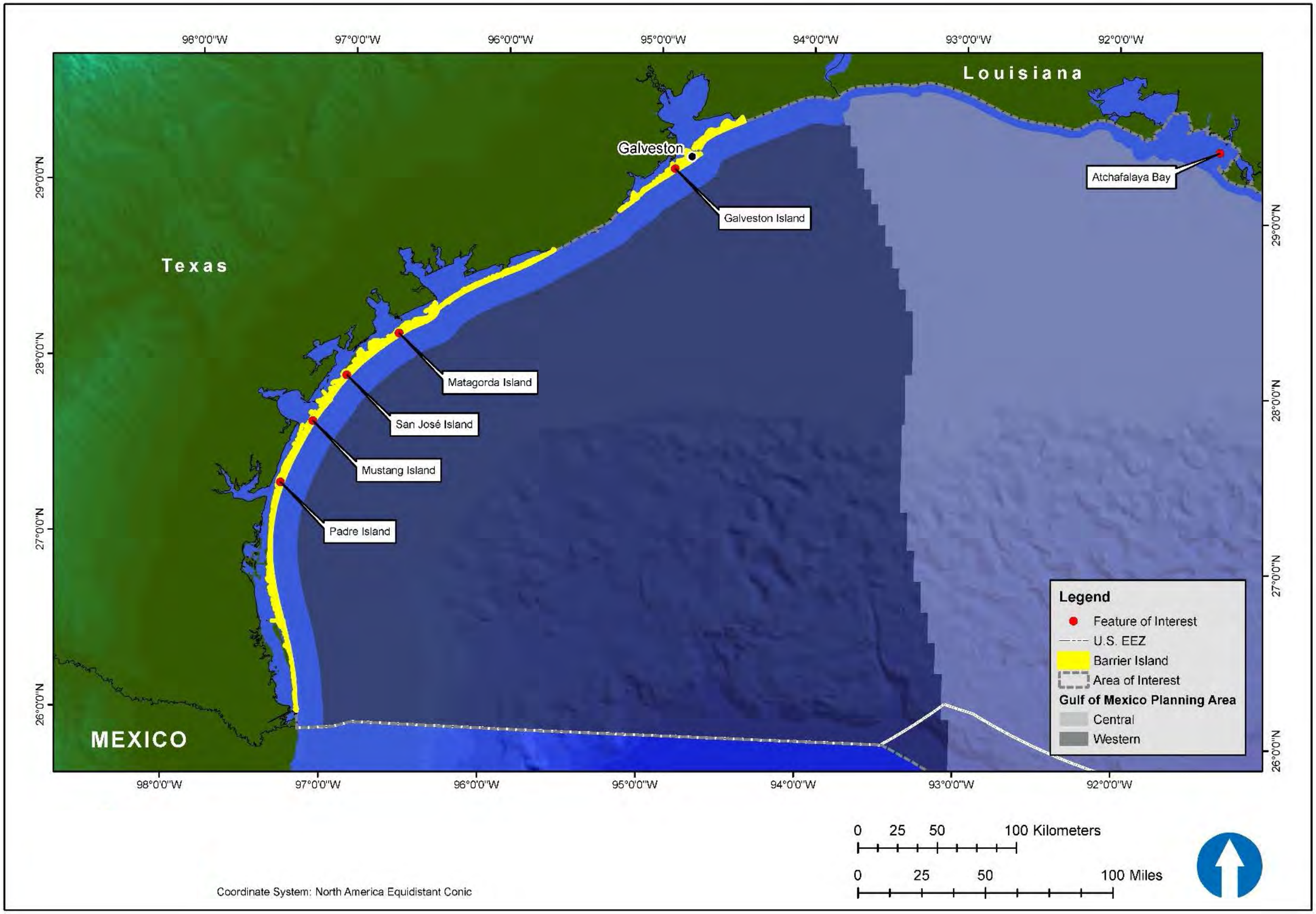

Figure E-10. Texas Coastal Barrier Island Beaches.

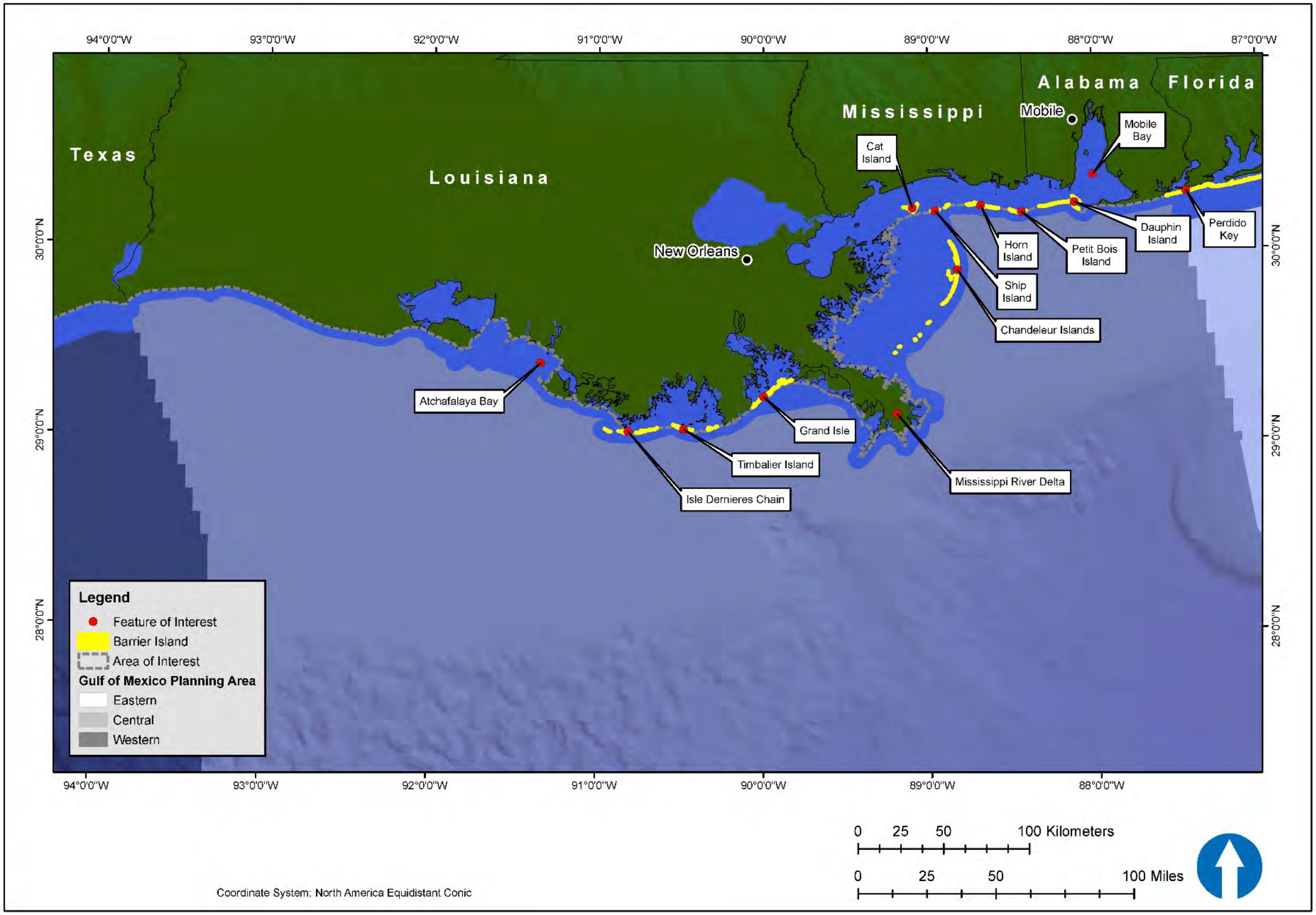

Figure E-11. Louisiana to Alabama Coastal Barrier Island Beaches.

The Gulf Coast of Florida has two prominent areas with barrier island beaches (**Figure E-12**). A semicontinuous chain of barrier islands from Perdido Key on the Alabama-Florida State line to Panacea, Florida, dominates the coastline of most of the Florida Panhandle. A long stretch of coastline without barrier island protection is present from Apalachee Bay near the Big Bend region of Florida to Anclote Key just north of Tampa. The Big Bend region of Florida is dramatically different than the rest of Florida's sandy coasts, instead dominated by a marshland made up of black needle rush (*Juncus roemerianus*) and shelly sand beaches (State of Florida, Dept. of Environmental Protection, 2010; USDOI, BOEM, 2013a). The barrier island chain continues south along the southwest edge of Florida until it ends at Ten Thousand Islands on the edge of the Everglades. The barrier island beaches of Florida are low to moderate energy beaches with low relief and small dunes composed mostly of quartz sand (Godfrey, 1976). Most of barrier island beaches in the region are wider and more stable than the eroding barrier islands of Mississippi, Alabama, and Texas (Otvos and Carter, 2008) and include wind dominated and mixed energy islands that reflect the diversity of the energy availability on Florida's coasts (Hine et al., 2001).

Deepwater Horizon Explosion, Oil Spill, and Response

The *Deepwater Horizon* explosion, oil spill, and response influenced barrier islands in the GOM. On May 11, 2010, the State of Louisiana requested emergency authorization to build a berm barrier seaward of the existing barrier islands to enhance protection of mainland habitats from the *Deepwater Horizon* oil spill (Lavoie et al., 2010). Oil was observed on 50.8 percent of beaches and 1,773 km (1,102 mi) of shoreline in the GOM (Michel et al., 2013). Oiling was heaviest on the islands and marshes of eastern Louisiana near Barataria Bay (USDOI, BOEM, 2012a; Michel et al., 2013), but the beaches of Mississippi, Alabama, and the Florida Panhandle were also oiled to varying degrees (OSAT-2, 2011; Michel et al., 2013; Parham and Gundlach, 2015). On May 23, 2010, approximately 1 month after the spill began, the Louisiana Department of Environmental Quality indicated that oil had been confirmed on the Chandeleur Islands, Whiskey Island, Raccoon Island, South Pass, East Fourchon/Elmers Island, Grand Isle, Trinity Island, Brush Island, Pass a Loutre, and Marsh Island (USDOI, BOEM, 2012a). Oil was first seen on Dauphin Island and Petit Bois Island, Alabama, on June 1, 2010 (Cleveland, 2010); by June 4, 2010, oil was washing ashore on the barrier island beaches of the Florida Panhandle as far east as Panama City (Cleveland, 2010).

In August 2012, Hurricane Isaac occurred in the GOM, causing storm surge, strong winds, and rough waves (USDOI, BOEM, 2015a). The extreme weather conditions caused oil buried deep in beach sediments to surface and re-mobilize (Michel et al., 2013; USDOI, BOEM, 2015a). After Hurricane Isaac, oil was observed on Elmer's Island and Grand Isle that matched oil from the *Deepwater Horizon* oil spill (USDOI, BOEM, 2013a). Oil and sand mixtures were observed forming oil residue mats that were repeatedly buried and exposed along the shoreface and foreshore of barrier islands off the coast of Louisiana, Mississippi, Alabama, and Florida (Michel et al., 2013; Parham and Gundlach, 2015).

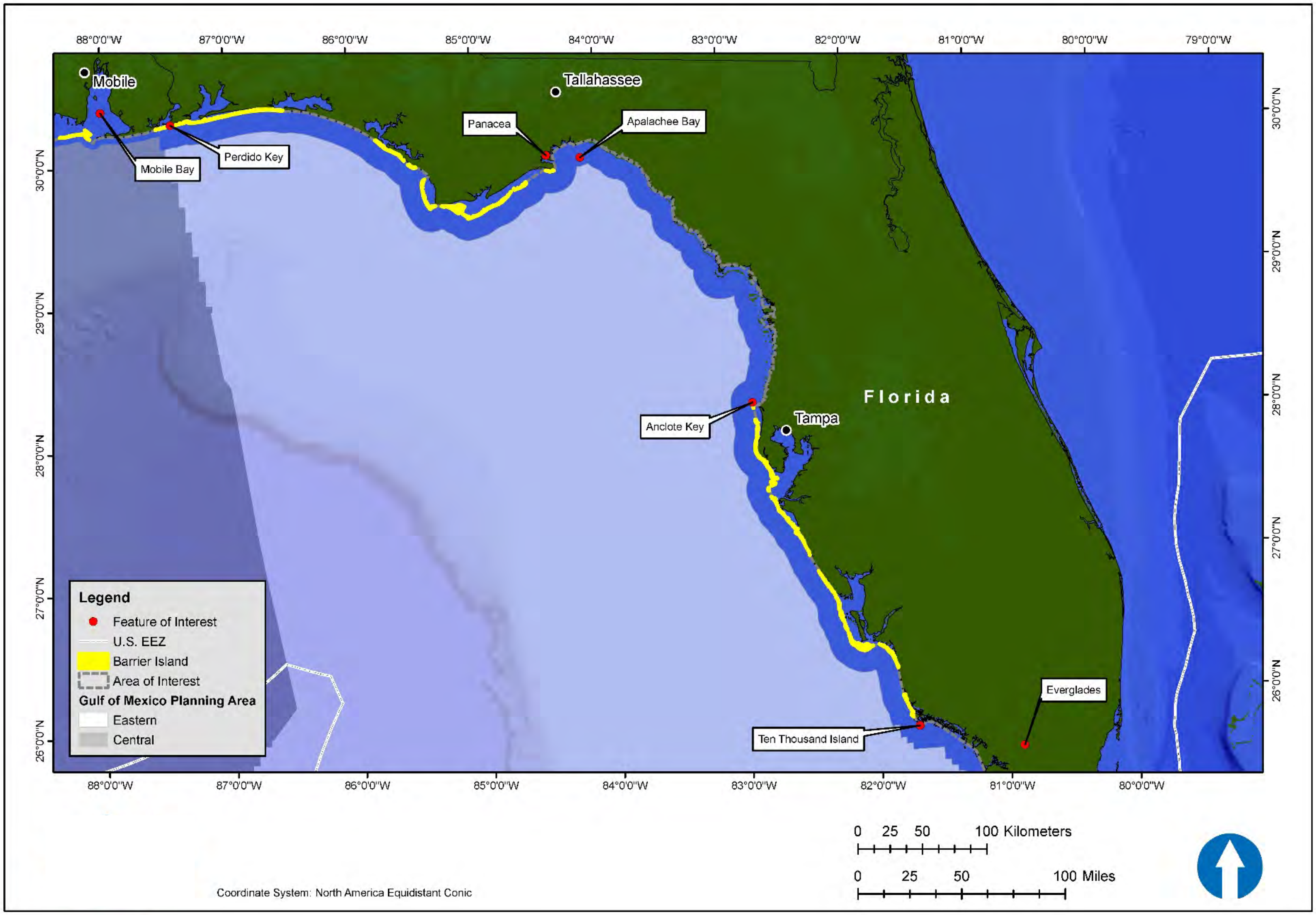

Figure E-12. Florida Coastal Barrier Island Beaches.

On October 2, 2014, a plan was finalized for funding early restoration projects in the GOM as mentioned in the Final Phase III Early Restoration Plan and Programmatic Environmental Impact Statement (USDOI, 2014). More than half of the money was allocated to the restoration of barrier islands by restoring beach sediments, dunes, marsh habitats, and bird populations (USDOI, 2014).

20 SEAGRASS

Seagrasses are a vital component of the GOM's coastal ecology and economy (Dawes et al., 2004). Seagrasses provide a variety of ecological services, including sustenance through food webs and habitat for marine life (fisheries in particular); critical habitat to other animals; maintenance and improvement of water quality; stabilization of sediments; and dampening of wave activity, which in turn prevents coastal erosion (Short et al., 2000; Dawes et al., 2004). Seagrasses are also economically important. On the Gulf Coast of Florida, seagrass beds are utilized by recreational boaters and fishers as well as commercial fishers, directly bringing in millions of dollars to the State (Bell, 1993; Dawes et al., 2004).

The seagrass environment of the AOI includes waters of the GOM that lie adjacent to the five Gulf Coast States, an area called the Northern Gulf Region (**Figure E-13**). The region consists of 2,414 km (1,500 mi) of coastline. Significant additional shoreline is located behind barrier islands or in estuarine embayments along the coast (USEPA, 2004); however, these regions of seagrass are not included as part of the AOI. The southwestern boundary of the Northern Gulf Region begins near Brownsville, Texas (within the WPA), and terminates at the easternmost reaches of Florida Bay, including the northern boundary of the Florida Keys and Dry Tortugas (within the southeast section of the EPA) (Dawes et al., 2004; USEPA, 2004). Of the Gulf Coast States, the vast majority of seagrasses (88%) are found around Florida (Yarbro and Carlson, 2011).

Deepwater Horizon Explosion, Oil Spill, and Response

The U.S. Government has estimated that 4.9 million bbl of oil were released into the GOM during the *Deepwater Horizon* oil spill. Studies in peer-reviewed literature related to direct impacts to seagrasses from the spill are scarce. The majority of aquatic vegetation that has been directly affected appears to be emergent vegetation associated with wetlands, and this subject is addressed in **Section 21**. Aerial photography was collected on seagrass beds around Breton Island, the Chandeleur Islands, and Mississippi Sound (Wells et al., 2012) to assess the condition of seagrass beds as part of damage assessment. The results of this effort have not yet been published in a peer-reviewed journal.

Indirect impacts to seagrasses occurred from spill response activities and included injuries from propeller scarring by response vessels used to deploy and anchor spill boom curtains in shallow waters, blowholes from response vessels, and scouring from boom curtains and anchor tethers. The USDOC, NOAA (2011) authorized some preliminary restoration work for these indirect impacts. Indirect impacts were documented and subsequent restoration efforts were carried out in specific regions along the Florida Panhandle.

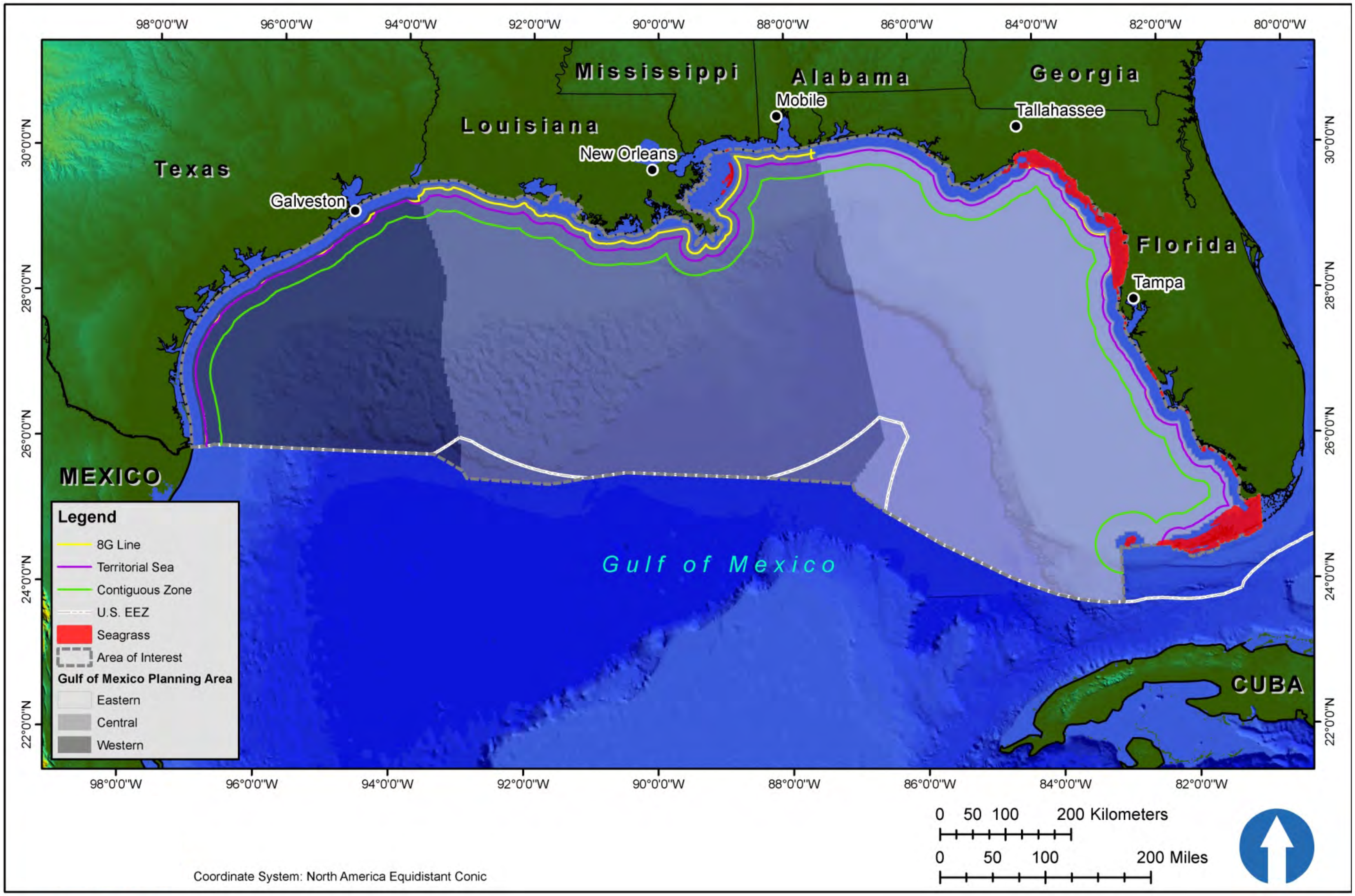

Figure E-13. Seagrass Locations Along the Gulf Coast Within the Area of Interest.

The following discussion provides an overview of regions with seagrass communities located within the AOI.

20.1 WESTERN PLANNING AREA

Seagrasses in the WPA are widely scattered beds in shallow, high-salinity coastal lagoons and bays. Texas coastal waters have the second greatest amount of seagrasses of the Gulf Coast States (11%, 92,854 ha [140,066 ac]), the majority of which (74%) are located in the broad shallows of the Laguna Madre (USDOI, BOEM, 2012b); however, like other coastal bays, the Laguna Madre is outside of the AOI.

20.2 CENTRAL PLANNING AREA

Seagrasses are limited off of coastal Louisiana and within its estuaries as a result of turbid waters and the soft, highly organic sediments. One offshore area with an established seagrass community is located along the Chandeleur Islands. The northern end of the Chandeleur Islands is 35 km (22 mi) south of Biloxi, Mississippi; the southern end, Breton Island, is 25 km (16 mi) northeast of Venice, Louisiana (Poirrier and Handley, 1940). Turtle grass, manatee grass, shoal grass (*Halodule wrightii*), star grass (*Halophila engelmannii*), and widgeon grass (*Ruppia maritima*) have been documented in this region, with seagrasses mapped on the western side of the Chandeleur Island chain. Seagrass beds in Louisiana are often affected by storm events of difference severities, with recovery times varying as a function of the size of the disturbance (Franze, 2002; Fourqurean and Rutten, 2004, as cited in USDOI, BOEM, 2012a). Over a period of 5 years, three tropical cyclones made landfall near or on the Louisiana coast: Hurricane Humberto (2007), Tropical Storm Edouard (2008), and Hurricane Gustav (2008) (USDOC, NOAA, 2010). The storms hit areas that had a small amount of submerged vegetation present. Hurricane Ida (2009) made landfall as a weakened tropical mass in Alabama and did not have any documented long-term effect on local seagrass communities (USDOC, NOAA, 2010). Some strong storm events resulting in significant removal of seagrass beds caused changes to the nekton community structure. Results of a study done in Biloxi Marsh following Hurricanes Cindy (2005) and Katrina (2005), which removed essentially all of the widgeon grass present, indicated that the post-storm nekton community resembled communities that had no vegetation prior to the hurricanes (Maiaro, 2007, as cited in USDOI, BOEM, 2012a).

In Mississippi and Alabama, seagrasses are present within Mississippi Sound (USDOI, BOEM, 2012b). A study by Byron and Heck (2006), which took place following the passage of Hurricane Ivan (2004) through the area, resurveyed a series of stations that were surveyed previously by Vittor and Associates (2003) while ground-truthing seagrass areas for aerial imagery collected over three zones of interest: Grand Bay, Mobile Bay (including Mississippi Sound east of Grand Bay), and Perdido Bay. Byron and Heck (2006) reconfirmed that shoal grass was the most common seagrass found at the study sites and additionally noted that widgeon grass was also prevalent. Additionally, in 2003, Vittor and Associates reported turtle grass for the first time in Little Lagoon, Alabama; Byron and Heck (2006) reconfirmed its presence.

20.3 EASTERN PLANNING AREA

As noted previously, Florida's coastal waters contain the vast majority of seagrass habitat (88%) seen in the Gulf Coast States (Yarbro and Carlson, 2011). Significant seagrass areas with portions falling within the AOI are summarized in the following subsections.

20.3.1 Big Bend – Overview

The Big Bend region extends from Anclote Key northwestward to Ochlockonee Point in the Panhandle region and includes the coastal waters of Pasco, Hernando, Citrus, Levy, Dixie, Taylor, Jefferson, and Wakulla Counties (Dawes et al., 2004). This portion of Florida's coast is an extensive area devoid of offshore barrier islands, with several rivers, creeks, and marshes that discharge directly into the GOM (Zieman and Zieman, 1989, as cited in Dawes et al., 2004). The inshore and offshore seagrass beds of the region are among the largest in the eastern GOM (Iverson and Bittaker, 1986). With regard to ongoing seagrass mapping and monitoring as reported in Yarbro and Carlson (2011), the Big Bend region is divided into four monitoring areas described in the following sections: (1) the northern region; (2) the southern region; (3) the Suwannee Sound, Cedar Keys, and Waccasassa Bay region; and (4) the Springs Coast region, which extends from the mouth of the Crystal River south to Anclote Key.

20.3.1.1 Northern Big Bend

The northern region extends from the mouth of the Ochlockonee River in the west to the mouth of the Steinhatchee River in the southeast. The northern Big Bend region contained at least 60,355 ha (149,140 ac) of seagrass in 2006 based on aerial imagery. Seagrass cover in the northern Big Bend region is stable, but the recent monitoring assessment noted slight declines between the St. Marks and Ochlockonee Rivers (Yarbro and Carlson, 2011). Seagrass species composition also appears to be stable; the most recently reported annual monitoring efforts by FWC in 2009 saw an upward trend of manatee grass, which occurred >50 percent of the time in almost all of sampling locations (Yarbro and Carlson, 2011). Turtle grass, which also showed an increase, was seen frequently mixed with manatee grass and was the second most abundant seagrass present, occurring at nearly 40 percent of the sites. Shoal grass appears to have declined from 2004 to 2009. Star grass occurred in 7.5 to 15 percent of all sampling locations in that same period. The occurrence of widgeon grass decreased from an already low level (<5 percent). Sampled areas with no seagrass present account for 23.5 percent (Yarbro and Carlson, 2011).

The 2001 and 2006, mapping efforts did not extend far enough offshore to capture the deep edge of seagrass beds in the northern Big Bend region. The beds probably serve as a corridor for grouper and other important fish and shellfish species as they migrate inshore and offshore. Deep seagrass beds are present in all Big Bend monitoring areas.

20.3.1.2 Southern Big Bend

The southern Big Bend region extends from the mouth of the Suwannee River north to the mouth of the Steinhatchee River. The southern Big Bend region contained 22,721 ha (56,146 ac) of seagrass cover during its latest assessment in 2006 (Carlson et al., 2010), an almost 6 percent decrease since the previous assessment in 2001, when coverage was 24,149 ha (59,674 ac) (Yarbro and Carlson, 2011). Considerable bed fragmentation also occurred during the same time period, with a 14 percent decrease of continuous seagrass coverage, which measured 20,730 ha (51,224 ac) in 2001 and 17,850 ha (44,109 ac) in 2006; it is possible that some of this reduction was a result of recent hurricanes (Yarbro and Carlson, 2011). The majority of seagrasses within the southern Big Bend region occur south of the Steinhatchee River mouth and the subregion known as Horseshoe West, while the areas of least extensive seagrass beds are located near the mouth of the Suwannee River (Yarbro and Carlson, 2011).

As of 2009, the FWC noted that approximately 50 percent of the sample locations had no seagrass present, which has been a slowly growing trend over the last 5 years, and this could be amplified by the storms of 2004 and 2005 (Carlson et al., 2010). Turtle grass is currently the most abundant seagrass species at 35 percent occurrence, followed by manatee grass at 28 percent. Both of these species had exhibited a 21 to 24 percent decrease as a result of the storms of 2004 and 2005 (Carlson et al., 2010; Yarbro and Carlson, 2011).

Like its northern counterpart, the southern Big Bend region had extensive but sparse beds of paddle grass (*Halophila decipiens*) located farther offshore that cannot be mapped with conventional aerial photography. These likely serve as a corridor for economically important fish and shellfish as they migrate inshore and offshore (Yarbo and Carlson, 2011).

20.3.1.3 Suwannee Sound, Cedar Keys, and Waccasassa Bay

The Suwannee Sound, Cedar Keys, and Waccasassa Bay region extends south from the mouth of the Suwannee River to just south of the mouth of the Waccasassa River. The latest aerial assessment that was analyzed for this region was performed in 2001. Based on that effort, the majority (approximately 72%) of the seagrass beds in this region are located in Waccasassa Bay, with 9,787 ha (24,184 ac) of seagrass. Of that total, 6,979 ha (17,245 ac; approximately 71%) were continuous beds and 2,808 ha (6,939 ac; 29%) were composed of patchy beds.

Suwannee Sound had the least amount of seagrasses (669 ha [1,652 ac]), but approximately 55 percent of the beds (366 ha [905 ac]) are continuous. Seagrasses in the Cedar Keys (3,152 ha [7,789 ac]) are also predominantly found in continuous beds (79%) (Yarbro and Carlson, 2011).

20.3.1.4 Springs Coast

The Springs Coast region contained at least 153,380 ha (379,010 ac) of seagrass in 2007. Seagrass cover in the Springs Coast region appears to be stable or increasing slightly, based on a rough comparison of data collected in 1999 and 2007 (Yarbro and Carlson, 2011). It should be noted that a recent pilot study (Baumstark et al., 2013), using satellite imagery versus conventional aerial imagery, mapped and verified baseline information for the western extent of seagrass along the Springs Coast, which reaches nearly 20 mi (32 km) offshore.

20.4 OFFSHORE *HALOPHILA* BEDS

The vast acreage of offshore and deepwater *Halophila decipiens* and *Halophila engelmanni* beds stretching from the Tortugas Bank to the Florida Panhandle (essentially the entire west coast of Florida) is consistently overlooked in seagrass censuses for the eastern GOM. The majority of the resource is located in waters 10 m (33 ft) and deeper, mostly beyond the detection limits of standard remote-sensing techniques based on reflected light. Most of this habitat lies outside of State waters, which is why it is not included in Florida's totals. Nonetheless, early work supported by the MMS (BOEM's predecessor) (Continental Shelf Associates, Inc., 1986 and 1987) found that more than 1.2 million ac (485,623 ha) of offshore *Halophila* existed in the area north of Tarpon Springs, extending to the eastern end of St. George Bay; approximately 3 million ac (1.2 million ha) existed up to 40 to 60 km (25 to 37 mi) offshore and to lesser distances south of Sanibel Island to the Dry Tortugas. These surveys did not cover the entire breadth of the *Halophila* habitat, which in the latter area extends out to depths of 30 m (98 ft) (Fonseca et al., 2008). Beyond what was not completely covered by these surveys, between the two study areas there exists an approximately 209-km (130-mi) alongshore region from offshore of Tampa Bay that apparently has never been surveyed. Therefore, the partially documented extent of this habitat exceeds 4 million ac (1.6 million ha) and probably exceeds at least 7 million ac (2.8 million ha) (Yarbro and Carlson, 2011). Thus, this poorly documented seagrass community, lying as it does mostly in Dederal waters, greatly exceeds the entire inshore seagrass acreage of the conterminous U.S. combined (Fonseca, unpublished; Fonseca et al., 2001). An issue with documenting these *Halophila* communities is that they are seasonally ephemeral and more variable farther from shore. Depending on the survey, patches of *Halophila* may not be present in the same place or in the same cover.

21 WETLANDS

Wetlands are essentially low-lying habitats where water accumulates long enough to affect the condition of the soil or substrate and promotes the growth of water-tolerant plants (LaSalle, 1998). Because of their importance, wetlands are protected by Federal, State, and occasionally local laws. From a regulatory standpoint, a wetland is defined as: "Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions" (40 CFR § 230.3; 33 CFR § 328.3).

Wetlands are important as they provide several ecological benefits. Wetlands protect water quality by filtering out pollutants and excess nutrients (Gosselink et al., 1974). They stabilize shorelines from erosion, thereby decreasing the amount of sediments and pollutants entering downstream waterbodies (Barbier et al., 2011). Wetlands provide natural storage of water, helping prevent downstream flooding from heavy rainfall or storm surges associated with tropical storms and hurricanes, which are prevalent occurrences in the GOM. Wetlands can also attenuate associated wave and wind energy and protect coastal regions by lessening the damage from these storms (Stedman and Dahl, 2008). In terms of wildlife, wetlands provide habitat for a variety of floral and faunal species, including some endangered species. Additionally, wetlands are essential to the health of commercially and recreationally important fisheries resources. Many economically important gamefish spend a portion of their life history in or near coastal wetland habitat. From an economic standpoint, wetlands provide large-scale opportunities for commercial and recreational activities, particularly in the GOM.

There are two broad classifications of wetlands found within the GOM: inland and coastal. Inland wetlands typically are found within the floodplains along rivers and streams, in isolated depressions surrounded by dry land, and in other low-lying areas. Inland wetlands generally include freshwater ecosystems, such as bottomland hardwood forests, swamps, freshwater mangrove swamps, and freshwater marshes (Gulf Restoration Network, 2004). Coastal wetlands are primarily intertidal habitats, located at the interface between terrestrial and coastal water environments and are influenced bidirectionally from forces at their seaward and landward sides (Battaglia et al., 2012; USDOI, BOEM, 2012b) (**Figure E-14**). Across this boundary, plants that characterize this transition are positioned based primarily on their tolerances to salinity and inundation gradients as well as to sulfide concentrations and substrate stability (Baldwin and Mendelssohn, 1998, as cited in Battaglia et al., 2012). The most common coastal wetlands include saltwater mangrove swamps, saltwater marshes, and non-vegetated areas such as sand bars, mud flats, and shoals (Gulf Restoration Network, 2004). The vegetated coastal wetlands are primarily emergent wetlands, which Cowardin et al. (1979) described as "characterized by erect, rooted, herbaceous hydrophytes, excluding mosses and lichens, present for most of the growing season in most years". Coastal emergent wetlands along the Gulf Coast include smooth cordgrass (*Spartina alterniflora*), Gulf cordgrass (*Spartina spartinae*), salt meadow cordgrass (*Spartina patens*), and saltgrass (*Distichlis spicata*) (Handley et al., 2012). Mangrove swamps are also a common emergent wetland, particularly around Florida, which includes one or more additional members of the three mangrove species found in the GOM region: red mangroves (*Rhizophora mangle*), black mangroves (*Avicennia germinans*), and white mangroves (*Laguncularia racemosa*). Black mangroves have expanded their range and become established along the shorelines of the CPA.

Seagrasses are part of the submerged coastal wetland habitat that can, in some cases, significantly extend into marine waters of the GOM (Fonseca et al., 2008). Seagrasses are addressed in **Section 20**.

The emergent coastal wetlands around the GOM vary topographically and ecologically, and have been categorized as different ecoregions: the Western Gulf Coastal Plain; the Mississippi Alluvial Plain; and the Southern Coastal Plain (USEPA, 2013b). The Western Gulf Coastal Plain comprises the coast of Texas (including Corpus Christi, Nueces Bay, Aransas Bay, and Galveston Bay) and the western half of Louisiana's coast. This region is characterized by flat topography, plains, and grasslands, and contains several barrier islands, bays, peninsulas, marshes, lagoons, and estuaries (Handley et al., 2012).

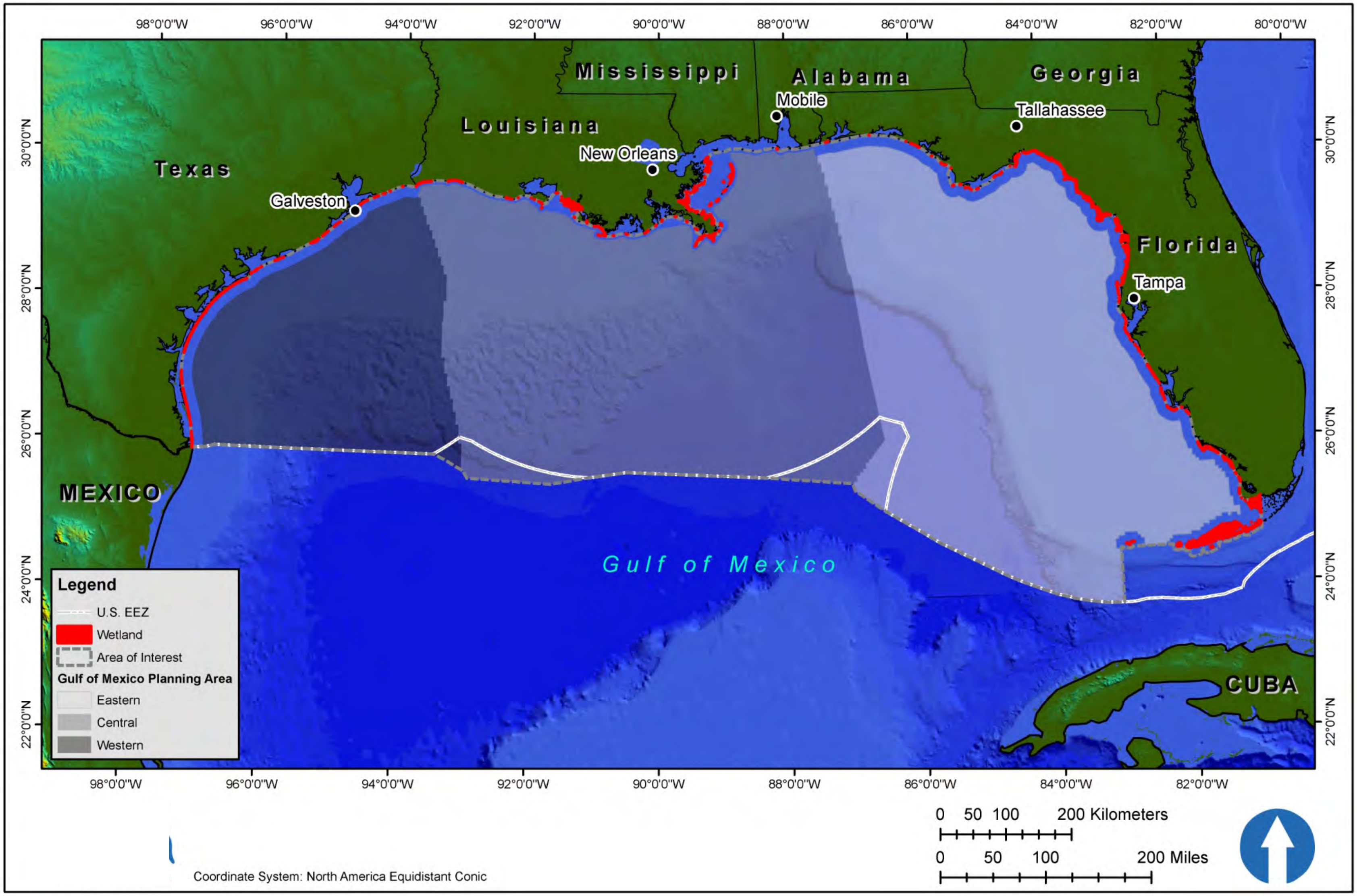

Figure E-14. Wetland Locations Along the Gulf Coast Within the Area of Interest.

The Mississippi Alluvial Plain encompasses the eastern half of Louisiana's coasts, including Barataria Bay, Terrebonne Bay, and the Mississippi River Delta (USDOI, BOEM, 2012b; USEPA, 2013b). Extensive salt and brackish marshes occur throughout this coastal region, with intermediate and freshwater marsh systems occurring farther inland (Handley et al., 2012; USDOI, BOEM, 2012b). Stands of expanding black mangrove are established in some high-salinity areas within this region (Perry and Mendelssohn, 2009; Roth, 2009).

The Southern Coastal Plain extends from the Mississippi coast across Alabama, the Florida Panhandle, and along the Gulf Coast of Florida to just south of the Caloosahatchee River, where the ecoregion transitions to the Southern Florida Coastal Plain (USEPA, 2013b). The Southern Coastal Plain includes Mississippi Sound in Mississippi; Mobile Bay in Alabama; and the Florida Panhandle, Tampa Bay, Sarasota Bay, and Charlotte Harbor in Florida. Coastal wetlands in this region are composed of salt and brackish marshes as well as extensive mangrove forests (particularly alongside the Florida peninsula) located along the many barrier islands and estuaries and lagoons positioned along this section of the Gulf Coast (Handley et al., 2012; USEPA, 2013b). The Southern Florida Coastal Plain, which consists of the southern quarter of the Florida peninsula, is nearly level and subtropical to tropical in its climate, with coastal wetlands comprising freshwater marshes, wet prairies, sloughs, swamps, and coastal wetlands (USEPA, 2000).

These various ecoregions of the Gulf Coast share certain defining characteristics, including emergent wetland habitats as part of the broader-scale GOM ecosystem. All of these wetlands have experienced alteration to varying degrees. Losses of coastal wetlands have been occurring along the Gulf Coast for decades, resulting in the conversion of wetland habitats to open water; Louisiana has been particularly affected (USDOI, BOEM, 2012b). These changes will likely continue as a result of ongoing land development, sea-level rise, induced subsidence, canal construction, and tropical storms and hurricanes.

Ongoing and recently initiated coastal habitat protection and restoration efforts are underway along the Gulf Coast to address the issue of erosion and land loss. The USDOI, BOEM (2012b), in cooperation with State and local agencies as well other Federal entities, has been involved in developing habitat restoration projects using OCS sand resources. Other government entities, as well as nongovernmental organizations and private partnerships, have assisted and continue to assist in a variety of projects to restore coastal wetlands and other important GOM habitats.

***Deepwater Horizon* Explosion, Oil Spill, and Response**

The U.S. Government has estimated that 4.9 million bbl of oil were released in the GOM during the *Deepwater Horizon* oil spill. In spite of that volume, it appears that environmental damage to wetlands was limited to marsh shorelines and generally not the marsh interior (Mendelssohn et al., 2012). There was an estimated total of 430 mi (692 km) of marsh shoreline that were oiled, and a summary by Zengel and Michel (2011) reported that of those marsh shorelines, 41 percent (176 mi [283 km]) were heavily or moderately oiled. Silliman et al. (2012) observed that, in some heavily oiled Louisiana marshes, shoreline fringes helped contain oil from the interior, but these areas underwent extensive mortality to marsh plants from the marsh to 5 to 10 m (16 to 33 ft) inland and had sublethal impacts on plants 10 to 20 m (33 to 66 ft) from the shoreline, where oiling was less severe.

The primary marsh types affected included salt marshes dominated by smooth cordgrass and black needle rush; mangroves, dominated by the black mangrove, which were present on small islands and shorelines and as scattered stands within slat marshes; and low- to intermediate-salinity marshes, dominated by the common reed (*Phragmites aurtalis*) along the margin of the Mississippi River Birdfoot Delta. Studies following the spill showed variable impacts, depending on oiling severity (DeLaune and Wright, 2011; Mendelssohn et al., 2012; Silliman et al., 2012). Near-complete mortality of the two dominant species (i.e., smooth cordgrass and black needle rush), occurred along heavily oiled shorelines, whereas moderate oiling had no significant effect on *Spartina* despite lowering live aboveground biomass and stem density (Mendelssohn et al., 2012). DeLaune and Wright (2011), following extensive review of oil spills literature and related studies in the GOM, noted that marsh vegetation under most conditions will recover naturally from oil exposure without remediation. The rate of recovery will depend on the degree of oiling, the amount of oil penetrating the soil profile, and the plant species' sensitivity to oil.

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APPENDIX F

G&G SURVEY DESCRIPTIONS

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ABBREVIATIONS AND ACRONYMS

°	degrees
2D	two-dimensional
3D	three-dimensional
4C	four-component
4D	four-dimensional
AOI	area of interest
AUV	autonomous underwater vehicle
BOEM	Bureau of Ocean Energy Management
CCS	carbon capture and storage
CHIRP	compressed high-intensity radar pulse
cm	centimeter
COST	continental offshore strategic test
CPT	cone penetrometer test
CSEM	controlled source electromagnetic
EIS	Environmental Impact Statement
FAZ	full azimuth
ft	feet
G&G	geological and geophysical
GOM	Gulf of Mexico
GPS	global positioning system
HRG	high-resolution geophysical
HSSE	health, safety, security, and environment
Hz	hertz
in.	inch
in^3	cubic inch
IVI	Industrial Vehicles International, Inc.
kg	kilogram
kHz	kilohertz
km	kilometer
km^2	square kilometer
kn	knot
lb	pound
m	meter
MAZ	multi-azimuth
MBES	multibeam echosounder
mi	mile
mi^2	square mile
mm	millimeter
ms	millisecond
MT	magnetotelluric

NAZ	narrow azimuth
NTL	Notice to Lessees and Operators
OBC	ocean bottom cable
OBN	ocean bottom node
OBS	ocean bottom seismic
OCS	Outer Continental Shelf
psi	pounds per square inch
RAZ	rich azimuth
ROV	remotely operated vehicle
SBES	single-beam echosounder
TMS	tether management system
UHR3D	ultra-high-resolution 3D
USBL	ultra-short baseline
USDOI	U.S. Department of the Interior
VSP	vertical seismic profile
WAZ	wide azimuth

1 GEOPHYSICAL SURVEYS

A variety of geological and geophysical (G&G) techniques are used to characterize the shallow and deep structure of the shelf, slope, and deepwater ocean environments. The G&G surveys are conducted to (1) obtain data for hydrocarbon and mineral exploration and production; (2) aid in siting of oil and gas structures and facilities, renewable energy structures and facilities, and pipelines; (3) locate and monitor use of potential sand and gravel resources for development; (4) identify possible seafloor or shallow depth geologic hazards; and (5) locate potential archaeological resources and benthic habitats that should be avoided. The selection of a specific technique or suite of techniques is driven by data needs and the target of interest. These activities include the following:

- various types of deep-penetration seismic surveys used almost exclusively for oil and gas exploration and development;
- other types of surveys and sampling activities used only in support of oil and gas exploration and development, including electromagnetic surveys, deep stratigraphic and shallow test drilling, and various remote-sensing methods;
- high-resolution geophysical (HRG) surveys used to detect shallow geohazards and marine minerals, archaeological resources, and certain types of benthic communities; and
- geological and geotechnical bottom sampling used to assess the suitability of seafloor sediments for supporting structures (e.g., platforms, pipelines, cables, renewable energy facilities such as wind turbines) or to evaluate the quantity and quality of marine minerals and sand for beach nourishment or other potential marine mineral extraction projects.

Refer to **Table F-1** for an overview of G&G activity types that are included in this Programmatic Environmental Impact Statement (EIS), the applicable program areas in which the different types of surveys are used, and their purpose for use in G&G activities.

Table F-1. Types of G&G Activities Included in This Programmatic EIS.

Survey Type	Applicable Program Areas			Purpose(s)
	O&G	REN	MMP	
Deep-Penetration Airgun Seismic Surveys				Seismic surveys evaluate subsurface geological formations to assess potential hydrocarbon reservoirs and optimally site exploration and development wells. The 2D surveys provide a cross-sectional image of the Earth's structure while 3D surveys provide a volumetric image of underlying geological structures. Repeated 3D surveys result in time-lapse, or 4D, surveys that assess the depletion of a reservoir. The VSP surveys provide information about geologic structure, lithology, and fluids.
2D Seismic – Towed Streamer	X	X[1]	--	
3D Seismic – Towed Streamer	X	--	--	
2D Seismic – Seafloor Cable or Nodes	X	X[1]	--	
3D Seismic – Seafloor Cable or Nodes	X	--	--	
Wide Azimuth and Related Multi-Vessel	X	--	--	
Borehole Seismic	X	--	--	
Vertical Cable	X	--	--	
4D (Time-Lapse)	X	--	--	
Airgun HRG Surveys				A single airgun used to assess shallow hazards, archaeological resources, and benthic habitats.
High-Resolution Seismic	X	X	-	
Non-Airgun HRG Surveys				Assess shallow hazards, potential sand and gravel resources for coastal restoration, archaeological resources, and benthic habitats. Devices used in subbottom profiling surveys include • sparkers; • boomers; • pingers; and • CHIRP subbottom profilers.
Subbottom Profiling	X	X	X	
Side-Scan Sonar	X	X	X	
Single Beam and Multibeam Echosounders	X	X	X	
Non-Acoustic Marine Geophysical Surveys				Electromagnetic signals are used to develop a conductivity/ resistivity profile of the seafloor, helping to identify economic hydrocarbon accumulations and aid with archaeological surveys.
Marine Gravity	X	--	--	
Marine Magnetic	X	--	--	
Marine Magnetotelluric	X	--	--	
Marine Controlled Source Electromagnetic	X	--	--	
Airborne Remote Surveys				Gravity and magnetic surveys are used to assess structure and sedimentary properties of subsurface horizons. Airborne magnetic surveys evaluate deep crustal structure, salt-related structure, and intra-sedimentary anomalies.
Airborne Gravity	X	--	--	
Airborne Magnetic	X	--	--	

Table F-1. Types of G&G Activities Included in This Programmatic EIS (continued).

Survey Type	Applicable Program Areas			Purpose(s)
	O&G	REN	MMP	
Geological and Geotechnical Surveys				Collect surface and near-surface sediment samples to assess seafloor properties for siting structures such as platforms, pipelines, or cables. Different types of geologic cores include • gravity corers; • multicorers; • piston corers; • rotary corers; • ROV push cores; and • vibracorers. Geologic coring is also used to assess sediment characteristics for use in coastal restoration projects. Shallow test drilling is conducted to place test equipment into a borehole to evaluate gas hydrates or other properties. The COST wells evaluate stratigraphy and hydrocarbon potential without drilling directly into oil and gas bearing strata.
Grab and Box Sampling	X	X	X	
Geologic Coring	X	X	--	
Shallow Test Drilling	X	X	--	
COST Wells	X	X	--	
Cone Penetrometer Tests	X	X	--	
Other Surveys and Equipment				The devices in this category assist in the execution of surveys, either by providing location or facilitating underwater service tasks. Additionally, water guns are no longer used as a seismic source except in extremely rare instances.
Acoustic Pingers	X	X	--	
Transponders, Transceivers, Responders	X	X	--	
ROVs and AUVs	X	X	--	

2D = two-dimensional; 3D = three-dimensional; 4D = four-dimensional; AUV = autonomous underwater vehicle; CHIRP = compressed high-intensity radar pulse; COST = continental offshore stratigraphic test; HRG = high-resolution geophysical; MMP = Marine Minerals Program; O&G = Oil and Gas Program; REN = Renewable Energy Program; ROV = remotely operated vehicle; VSP = vertical seismic profile.

[1]The renewable energy scenario includes the possibility that a (2D or 3D) deep-penetration seismic survey would be conducted to evaluate formation suitability for carbon sequestration. However, given the much greater number and extent of seismic surveys included in the oil and gas scenario, a single seismic survey for carbon sequestration is not analyzed separately in this Programmatic EIS.

1.1 DEEP-PENETRATION SEISMIC AIRGUN SURVEYS

Marine seismic surveys using airgun sources are capable of imaging geological structures to several kilometers depth and have become an essential tool for geoscientists studying the Earth's uppermost crust. Deep-penetration seismic surveys are conducted to obtain data on geological formations several thousand meters beneath the seafloor. A survey vessel tows an airgun array that emits acoustic energy pulses that propagate through water then pass into the seafloor. The acoustic signals reflect (or refract) off subsurface layers having acoustic impedance contrasts; upon return through the earth, the signals are detected by sensors (i.e., hydrophones, geophones) that may be towed in streamer cables behind the vessel (hydrophones) (**Figure F-1**) or incorporated into cables or autonomous nodes and placed on the seafloor (geophones). Receivers may also be placed in boreholes or, in rare instances, spaced at various depths in vertically positioned cables in the water column.

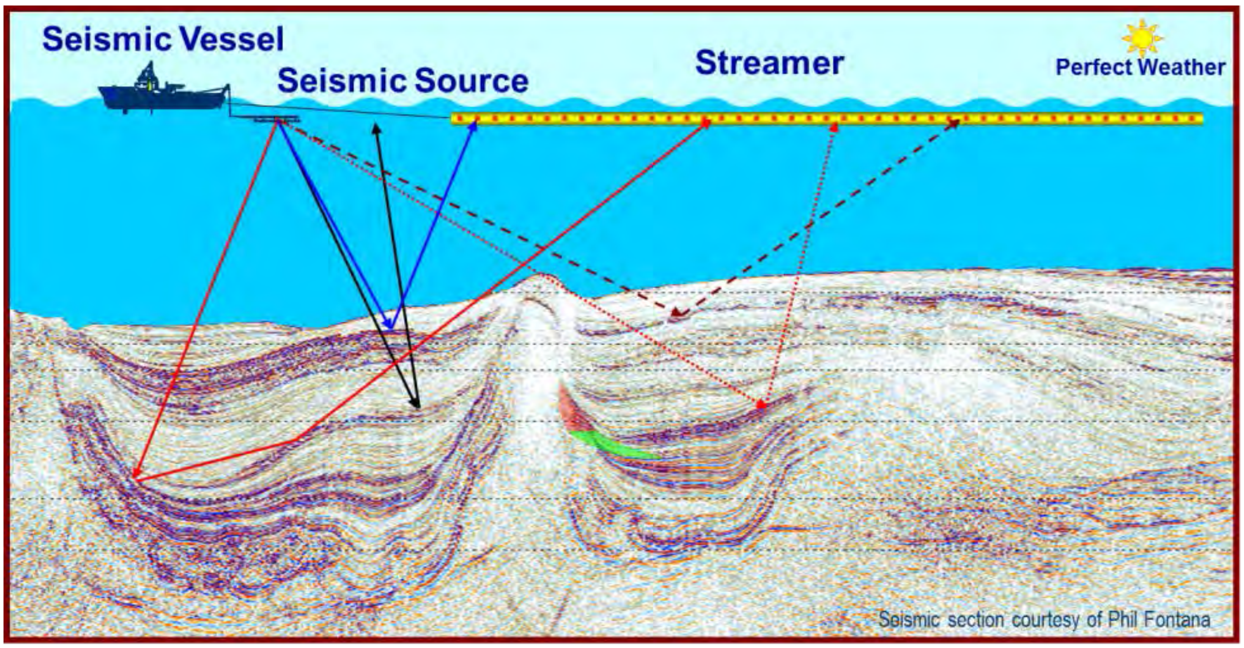

Figure F-1. A Marine Seismic Survey Vessel Towing an Airgun Array and a Streamer Containing Hydrophones (From: Caldwell, 2015).

Data from these surveys can be used to assess potential hydrocarbon structural and stratigraphic traps and reservoirs, and also to help locate exploration, development, and production wells to optimize extraction and production from a reservoir. Seismic airgun surveys are the only commercially proven technology currently available to accurately image the subsurface. Deep penetration seismic airgun surveys are also used for scientific and academic research and to detect geological fault lines. State-of-the-art computer systems are used to process and analyze seismic datasets and to display the subsurface geology in two or three dimensions. Seismic data acquisition, processing, and analysis technologies are continuously evolving to provide more information about the subsurface. Consequently, regions already surveyed may be resurveyed using a new technology to obtain an improved description of subsurface geology, which may lead to increased success in the discovery and production of oil and gas resources.

The types of deep-penetration seismic surveys discussed in this section primarily use airguns or airgun arrays as sound sources (**Figure F-2**). The survey types differ in where the receivers that detect the reflected sound source energy are located. The locations for receivers are as follows:

- in the water column, integrated into horizontally towed streamers or stationary vertical cables;
- in autonomous nodes placed on the seafloor;
- in cables laid on the seafloor; or
- in sensor packages located in wellbores (vertical seismic profiles [VSPs] and checkshot surveys).

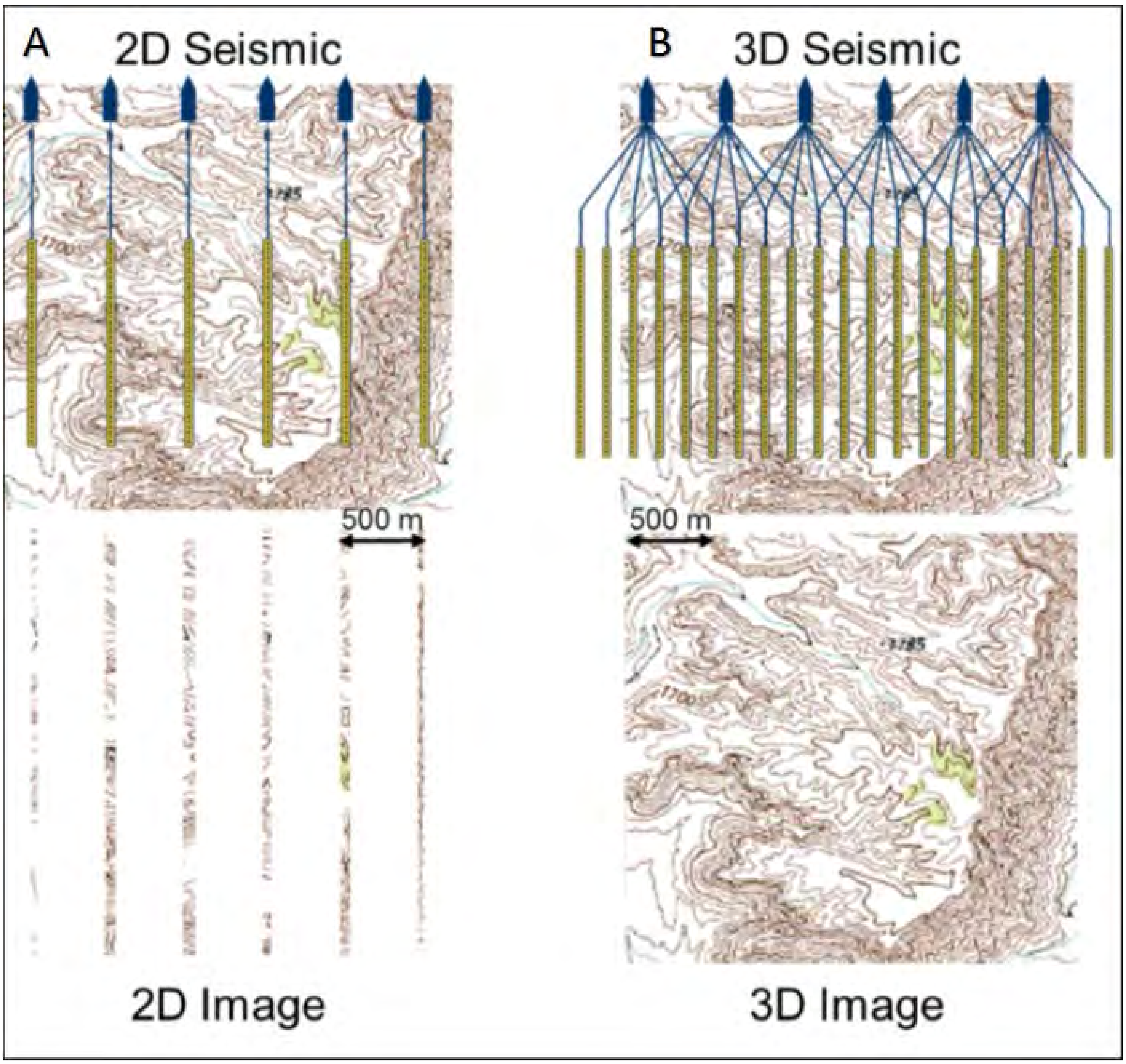

Figure F-2. The Basic Difference Between 2D and 3D Survey Geometries (From: Caldwell, 2015).

The different types of deep-penetration seismic surveys have three elements in common: (1) a sound source; (2) the means to detect, process, and analyze sound reflected and refracted from subsurface geology; and (3) vessels or equipment to deploy the sound source.

The impacts of all survey sound sources are addressed in **Chapter 4** of this Programmatic EIS. A typical marine seismic source is a sleeve-type airgun array that releases compressed air into the water, creating a bubble that generates a pulse of sound sufficiently energetic to penetrate deep beneath the seafloor (refer to **Chapter 3.4** of this Programmatic EIS for more information about airguns, including their source levels). Airguns are broadband acoustic sources that generate energy over a wide range of frequencies, from less than 10 hertz (Hz) to more than 5 kilohertz (kHz), with industry usable frequencies ranging between 5 and 100 Hz. Most of the energy is concentrated at frequencies less than 500 Hz. The acoustic energy produced by an airgun or airgun array depends on the following three factors:

(1) firing pressure (2,000 pounds per square inch [psi] for most airguns currently in use);

(2) the number of airguns in an array (generally between 20 and 80); and

(3) the total volume of all the airguns in the array (generally between 1,500 and 8,460 cubic inches [in^3]).

The output of an airgun array is directly proportional to airgun firing pressure, the number of airguns, and the cube root of the total volume of airguns in the array. The geometry of an airgun array is designed to project the maximum amount of seismic energy generated by the array vertically into the seafloor. However, the acoustic directivity of an airgun array is complex and not uniform in all directions. Some energy is emitted in directions that are more horizontal than vertical with the directivity of emitted sound, in terms of frequency as well as intensity, being a function of the geometry of the airgun array and other factors.

Guard (or chase) vessels are similar to crew boats and range in size from approximately 40 to 50 meters (m) (130 to 160 feet [ft]) and are responsible for maintaining clearance of the streamers, and typically follow within 1 to 2 kilometers (km) (0.6 to 1 mile [mi]) of the array. This ensures no interaction with other vessels and minimizes interaction with other marine users in line with the survey and maintain the appropriate stand-off distance. These vessels are critical to maintain array safety. Depending on the size of the survey, one to three guard vessels typically are used.

1.1.1 2D (Towed-Streamer) Seismic Surveys

Two-dimensional (2D) surveys provide a cross-sectional image of subsurface geology. A single vessel towing an airgun array and a single streamer cable usually conduct 2D seismic surveys. The streamer is a polyurethane-jacketed cable containing several hundred to several thousand sensors (mostly hydrophones). An integrated navigational system is used to georeference the locations where the airgun array is fired as well as the location and depth of streamer cables. Tail buoys at the ends of streamer cables also contain global positioning system (GPS) receivers. Radar reflectors usually are placed on the tail buoys so other vessels can detect the ends of streamers.

The 2D surveys are primarily used to describe structural and stratigraphic geology, to perform reconnaissance surveys in frontier exploration areas, to link known productive areas over large geographic areas, and to determine if a three-dimensional (3D) survey is warranted in an area of interest (AOI). The 2D towed streamer seismic exploration surveys are conducted on a proprietary or a non-exclusive (multi-client) basis. Proprietary surveys usually cover only a few Outer Continental Shelf (OCS) lease blocks for an individual client who owns the data and has exclusive use of it. In contrast, non-exclusive (multi-client) survey data are owned by the seismic surveyor, typically are collected over large multi block areas, and are licensed for use to as many clients as possible. Because the survey data are not for the exclusive use of any one client, the surveyor's goal is to license the data multiple times.

Vessels conducting 2D surveys typically are 60 to 90 m (197 to 295 ft) long and tow an airgun array 200 to 300 m (656 to 984 ft) behind the ship at a depth of approximately 5 to 10 m (16 to 33 ft). The airgun array often consists of 3 subarrays, of 6 to 12 airguns each, and is approximately 12.5 to 18 m (41 to 59 ft) long and 16 to 36 m (52 to 118 ft) wide. Following behind the airgun array by 100 to 200 m (328 to 656 ft) is a single streamer approximately 5 to 12 km (3.1 to 7.5 mi) long. The airgun array and streamers are towed at a speed of approximately 4.5 to 5 knots (kn) 5.2 to 5.8 miles per hour (mph). Approximately every 10 to 15 seconds, at a separation distance of 23 to 35 m (75 to 115 ft) for a vessel traveling at 4.5 kn (5.2 mph), the airgun array is fired; the actual time between firings depends on ship speed and data requirements. The airguns used for analysis of the proposed action include a small single airgun (90 in^3) and a large airgun array (8,000 in^3) as described in **Chapter 3.4** of this Programmatic EIS.

In **Figure F-2A** (left panel), a typical marine 2D seismic survey geometry is shown; in **Figure F-2B** (right panel), a typical marine 3D seismic survey geometry is shown. Both survey geometries are presented over contour maps that indicate the structure of a particular horizon (strata) in the subsurface. The number of airgun array firings is exactly the same for both surveys. The subsurface images of the target strata that are generated by the two survey types are shown in the bottom half of **Figure F-2**. The figure illustrates the difference in the level of detail of the subsurface produced by a 3D survey compared to a 2D survey. The ship track spacing shown in the figure is 500 m (1,640 ft) for both survey types. Typically, spacing between adjacent ship tracks during 2D surveys will be 1 km (3,280 ft) or more. For 3D surveys, track spacing depends on several factors, such as the number of airgun arrays being used (often two) and the number of streamers being towed (commonly 8 to 10). In **Figure F-2B**, the spacing between streamers is 133 m (436 ft). The result is that, in the case of this example, data density will be 15 to 50 times greater in the cross-track dimension for the 3D survey. The data density in the along-track dimension of the figure will be approximately the same for both survey types.

Following ramp-up of the airgun array to full operational output, the 2D survey vessel moves along a preset track line until a full line of data is acquired. At the end of a track, the vessel typically takes approximately 2 to 6 hours to turn around, realign the airgun array and streamer, and begin another survey track. Sometimes it can take much longer to turn between tracks. The spacing between track lines and the length of track lines can vary greatly, depending on the objectives of a survey. The time required to turn a survey vessel between tracks can vary based on location and associated navigational constraints, environmental conditions, and proximity to other vessels. Some 2D surveys might include only a single long track. Others may have numerous tracks, with track spacings as short as 2 to 10 km (1.2 to 6.2 mi). When the survey vessel is operational, data acquisition usually is continuous (24 hours per day) and, depending on the size of the survey area, may continue for days, weeks, or months. However, data acquisition may be interrupted. A typical seismic survey experiences approximately 20 to 30 percent of non-operational downtime due to a variety of factors, including technical or mechanical problems, standby for weather or other interferences, and performance of mitigation measures (e.g., ramp-up, pre survey visual observation periods, and shutdowns) (Caldwell, official communication).

Fewer 2D surveys are conducted than 3D surveys. The 2D surveys usually cover a larger area in the same time as 3D surveys do but with lower spatial resolution and also much lower cost. Typical spacing between track lines for 2D surveys, which is also the spacing between adjacent streamer line positions, is on the order of 1 km (0.6 mi) or more. Geophysical surveyors often have proprietary methods for data acquisition depending on the survey target and their data-processing capabilities. Such differences can make each surveyor's dataset for the same area somewhat unique, and may prevent a client from combining one surveyor's dataset for an area with that of another surveyor for the same area.

1.1.2 3D (Towed-Streamer) Seismic Surveys

As with 2D towed-streamer seismic surveys, 3D towed-streamer seismic surveys are conducted by geophysical surveyors on a proprietary or a non-exclusive multi-client basis. Proprietary surveys usually cover only a few OCS lease blocks for an individual client who owns the data and therefore will have exclusive use of it. In contrast, for non-exclusive surveys the data are owned by the geophysical surveyor, are often collected over large multi block areas, and are licensed to as many clients as possible to recover costs, make a profit, and keep the cost to clients lower than would be the case for a proprietary survey.

3D seismic surveys provide data that image the subsurface geology with much greater clarity and higher resolution than is possible with 2D surveys (**Figure F-2**). Compared with 2D seismic surveys where track spacing is usually 1 km (3,280 ft) or more, the separation between tracks for 3D surveys depends on several factors such as the number of airgun arrays being used and the number of streamers being towed (commonly eight). A common survey design parameter for 3D surveys is to have the distance between streamer tracks be on the order of 75 to 150 m (246 to 492 ft). The result is that the data density for any subsurface point will be 15 to 30 times greater in the cross-track direction for 3D surveys than for 2D surveys. The data density in the along-track direction will be approximately the same for 2D and 3D towed-streamer surveys.

The 3D survey data can be used to distinguish hydrocarbon-bearing zones from water-bearing zones below the seafloor. The 3D seismic surveys techniques have improved since first used in the 1970s, and areas surveyed by older 3D methods may be resurveyed using updated methods to provide better characterization of subsurface geology. The 3D surveys also are used in areas previously surveyed using 2D techniques that show potential for development. Repeated 3D surveys in a single area are used to monitor changes in the structure of producing reservoirs. Such surveys, which typically are conducted at 6-month intervals, are called four-dimensional (4D) or time-lapse 3D surveys. There are several types of 3D surveys that differ in the number of vessels, sound sources, and the location of hydrophones. Conventional, single-vessel 3D surveys are referred to as narrow azimuth (NAZ) 3D surveys. Other 3D seismic surveys include wide azimuth (WAZ), multi azimuth (MAZ), and rich azimuth (RAZ) surveys, which are discussed in the following sections.

The current state-of-the-art ships used for 3D surveys are purpose-built vessels with much greater towing capability than vessels used for 2D surveys. The 3D seismic survey vessels generally are 60 to 120 m (197 to 394 ft) long, with the largest vessels more than 120 m (394 ft) in length and more than 65 m (213 ft) wide at the stern. The seismic ships typically tow two parallel airgun arrays 200 to 300 m (656 to 984 ft) behind them. The arrays contain various numbers and sizes of airguns. Streamers containing hydrophones and other sensor are towed 100 to 200 m (328 to 656 ft) behind the dual airgun arrays.

Most 3D ships can tow eight or more streamers, with the total length of streamers (number of streamers multiplied by the length of each streamer) exceeding 80 km (49.7 mi). The theoretical maximum number of streamers that can be towed by a modern vessel is 24, each of which can be up to 12 km (7.5 mi) long, for a total of 288 km (179 mi) of streamers. A 3D seismic vessel usually will tow 8 to 14 streamers, each 3 to 8 km (1.9 to 5 mi). The width of the streamer array towed by a 3D seismic vessel can be quite large. For example, an array of 10 streamers where the streamers are 75 to 150 m (246 to 492 ft) apart will have a width of 675 to 1,350 m (2,215 to 4,429 ft), which is the swath of ocean surface covered by the survey vessel during each track line. Other streamer configurations may result in narrower or wider swaths.

Seismic survey vessels tow their airgun and streamer arrays at a speed of 4 to 5.5 kn (4.6 to 6.3 mph) during data acquisition. During a 3D seismic survey, one of the two airgun arrays being towed is fired approximately every 11 to 15 seconds (i.e., a distance of 25 m [82 ft] for a vessel traveling at 4.5 kn [5.2 mph]). The other array is fired 11 to 15 seconds later. To achieve a desired distance between airgun firings, the time between firings is a function of survey vessel speed. At the end of each track line, which can be 100 to 167 km (62 to 104 mi) long and may take 12 to 20 hours to complete, the survey ship turns to begin the next planned track line, an operation that may require up to 10 hours to complete, depending on the length of streamers. This procedure runs continuously day and night, and may continue for days, weeks, or months depending on the size of the survey area. There are survey designs such as coil surveys where turning is continuous, as is data acquisition. Regardless of survey type, data acquisition is almost never continuous. A typical seismic survey experiences approximately 20 to 30 percent non-operational downtime due to technical or mechanical problems, standby for weather or other interferences, and performance of mitigation measures (e.g., ramp up, pre-survey visual observation periods, and shutdowns). The airguns used for analysis of the proposed action include a small single airgun (90 in^3) and a large airgun array (8,000 in^3) as described in **Chapter 3.4** of this Programmatic EIS.

1.1.3 Ocean-Bottom Seismic (Cables and Nodes)

2D Surveys

Ocean-bottom seismic (OBS) surveys can be conducted using ocean-bottom cables (OBCs) and/or ocean-bottom nodes (OBNs). The OBC surveys originally were designed to enable seismic surveys in shallow water and congested areas such as producing fields with many platforms and subsea production structures. The cables contain pairs of hydrophones and geophones to measure pressure and very small movements (linear accelerations) of the seafloor. Some seafloor cables are used in a retrievable mode of operation, some are used in a permanent installation, and some can be used in both modes. Recent innovations in OBS surveys include development of autonomous nodes that can be tethered to coated lines and deployed from ships or remotely operated vehicles (ROVs), depending on water depth (**Figures F-3 and F-4**). Current technology can be used in water depths to 3,000 m (9,842 ft) or slightly greater. The OBS surveys are most useful to acquire data in shallow water and obstructed areas as well as four-component (4C) survey data, which consists of pressure and 3D linear acceleration. The 4C data can provide more information than 2D data about subsurface fluids and rock characteristics.

The OBC and autonomous node seismic airgun surveys require the use of several ships. One or two ships usually are needed to lay out and pick up cables, one ship is needed to record seismic data, one ship tows an airgun array, and two smaller utility boats support survey operations. Seismic airgun surveys conducted using recording buoys do not need a recording vessel but still need other vessels.

Most 2D OBS surveys use OBCs, with OBNs being a lesser-used alternative. The length of a 2D survey line varies from a few to tens of kilometers (miles), depending on the objectives of the survey. Because most 2D survey lines are longer than the length of available cables, lines are completed in segments that require cables to be picked up and re-laid several times. The distance between adjacent 2D lines usually is several hundred meters (a few thousand feet) to a few kilometers (a couple of miles). Within survey lines, when autonomous nodes are used, they are placed a few hundred meters (several hundred feet) apart; when cables are used, the sensors in the cables are usually 50 to 100 m (164 to 328 ft) apart.

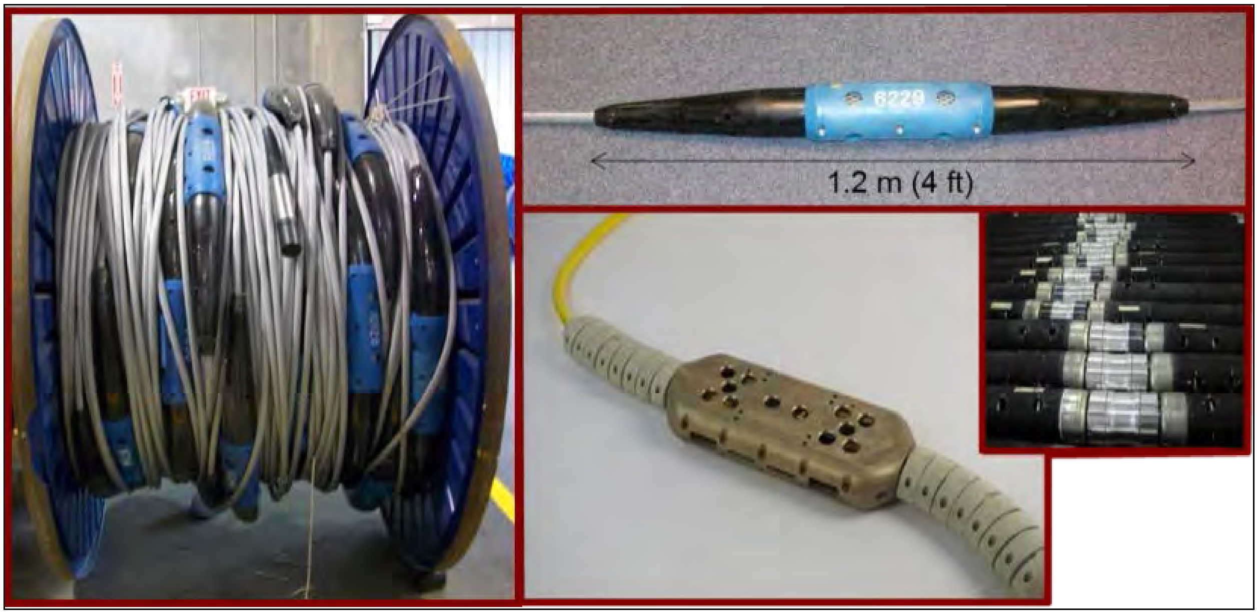

Figure F-3. Three Examples of OBCs (From: Caldwell, 2015).

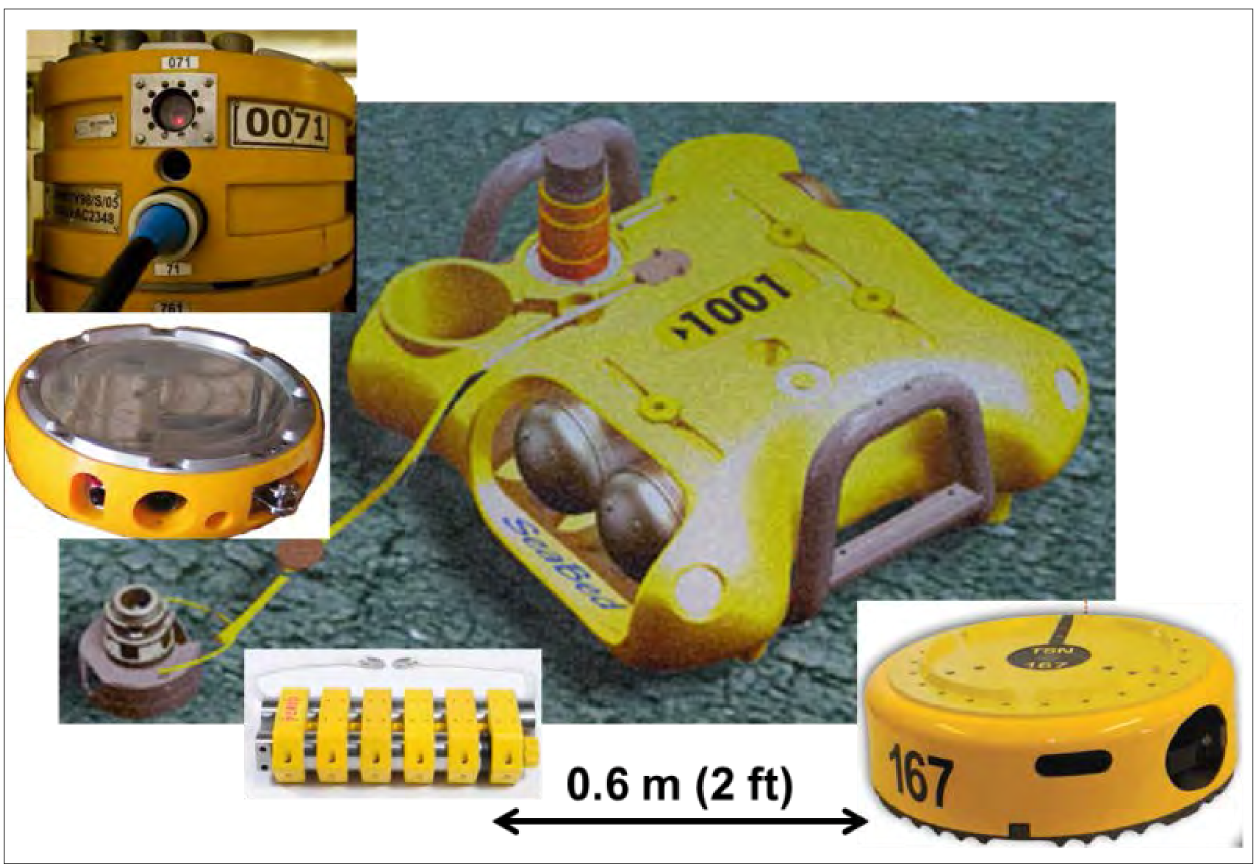

Figure F-4. Five Types of OBNs (From: Caldwell, 2015).

After OBNs or OBCs are deployed, a vessel towing an airgun array (source vessel) passes along the line of sensors (**Figure F-5**). The spacing between discharges of the airgun array (shots) depends on survey objectives. Typical spacing between airgun array shots are 25 m (82 ft), 50 m (164 ft), 75 m (246 ft), and 100 m (328 ft). When shot spacing is 25 m (82 ft), a shot is fired every 11 seconds when the source vessel's speed is 4.4 kn (5.1 mph). After a survey line is completed, the source vessel takes approximately 10 to 15 minutes to turn around then passes along the next segment of bottom-deployed sensors. During a survey, OBNs or OBC may remain deployed for a couple of days to several weeks, depending on operating conditions and the survey's design. Usually more than one cable, or more than one set of nodes, will be used so that the next receiver line segment can be deployed while the previous line segment is being shot.

Figure F-5A shows the layout for a 2D ocean bottom receiver seismic survey with a source vessel towing an airgun array and a recording vessel connected to a seismic cable. **Figure F-5B** shows the location of OBCs or autonomous nodes relative to a recording vessel and the track line of the seismic source vessel. Nodes, while autonomous, may be tethered to a line that is connected to a deployment vessel; alternatively, the nodes could be kept autonomous from a surface vessel and deployed on the seafloor using an ROV.

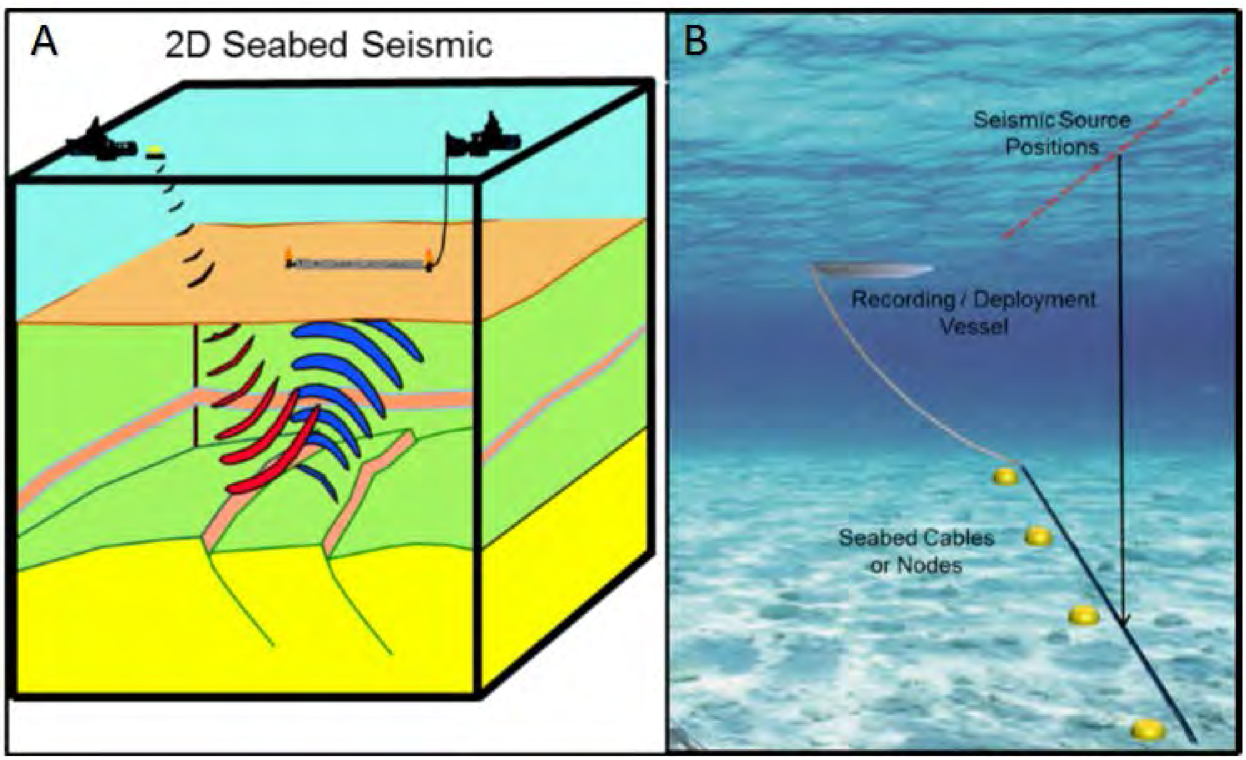

Figure F-5. Layout for a 2D Ocean-Bottom Receiver Seismic Survey (From: Caldwell, 2015).

3D Surveys

Newer technology 4C receiving sensors, rather than older 2D sensors (refer to **Section 1.1.2**), are used for most ocean bottom receiver 3D surveys. The new 4C technology was developed for new types of OBC and autonomous receiving units (nodes) that can be attached to coated lines or as autonomous nodes using ROVs. Most 3D ocean-bottom receiver surveys are RAZ or in areas where there are structural obstructions on the sea surface or seafloor (**Figure F-6**). Some seafloor surveys are conducted because the receivers are in the quieter environment of the seafloor rather than the noisier environment of the sea surface, thereby generally producing better, more easily interpreted data than would a streamer survey. Finally, seafloor surveys methods are used for some 4D seismic surveys.

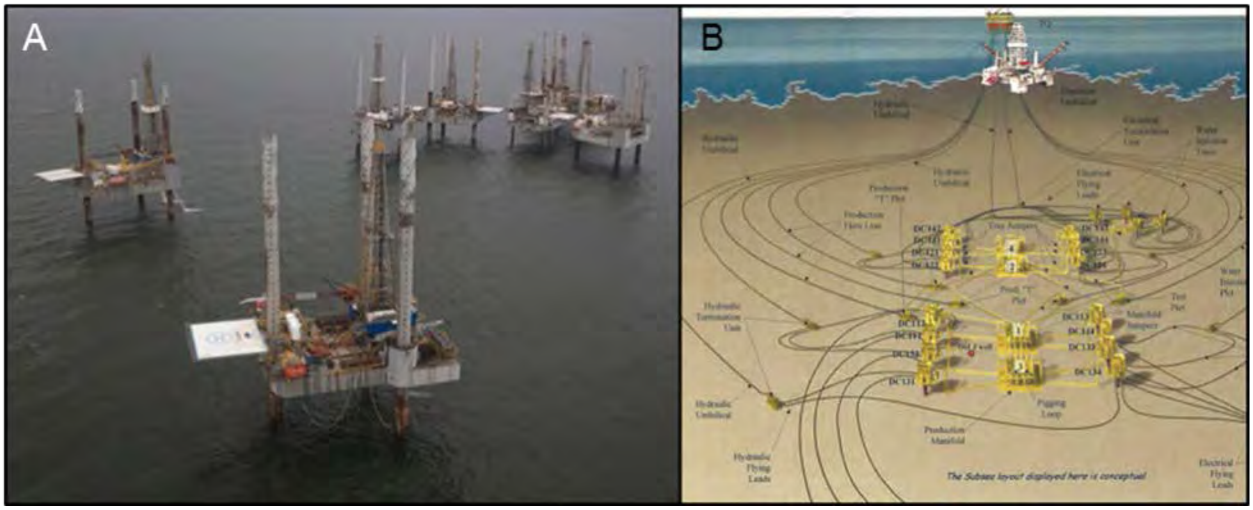

Figure F-6. (A) Drill Rigs and Platforms in the Gulf of Mexico in a Configuration that Makes a Towed-Streamer Seismic Survey Impossible to Conduct; OBCs or OBNs Would be Required to Acquire 3D Seismic Data in Such an Obstructed Area. (B) Schematic of One Possible Deployment of Subsea Structures at the Atlantis Field in the Gulf of Mexico; the Acquisition of 3D Seismic Data in Such a Situation Might Best be Handled Using an OBN System (From: Caldwell, 2015).

Electrical power, command and control signals, and seismic data are transmitted via cable to/from a ship, platform, or buoy in seismic surveys that use seafloor cables. In contrast, autonomous nodes are equipped with a power source, seismic sensors, and computer processor based hardware and software to acquire, pre-process, and store seismic data. Seismic cables are laid on the seafloor using special equipment off the back of a vessel that may be designed for that purpose. Autonomous nodes generally are deployed from a specially equipped vessel able to lay nodes on the seafloor attached to a line or cable, or to individually place nodes on the seafloor using a ROV. The deployment method used depends primarily on water depth, but other factors such as safety in obstructed areas may be a factor in deployment method selection. The maximum deployment depth for new recording systems is approximately 3,000 m (9,842 ft).

Ocean-bottom seismic recording systems may be kept deployed for extended periods of time when attached to a buoy or platform at the surface. The power supply of autonomous nodes requires periodic replacement or recharging. The service schedule for current autonomous nodes for power supply maintenance and data recovery is 120 to 140 days, which is sufficient time to complete most surveys.

A nominally rectangular grid of sensors is laid on the seafloor for 3D OBC or OBN surveys (**Figure F-7**). The spacing between sensor modules on a cable usually is 50 to 200 m (164 to 328 ft), and the spacing between adjacent cables usually is 200 to 400 m (656 to 1,312 ft). When autonomous nodes are used, spacing between nodes often is 300 to 400 m (984 to 1,312 ft) measured both parallel and perpendicular to the seismic source vessel's track lines. The size of the receiver grid is usually limited by the amount of equipment the seismic survey contractor has available. For example, 961 receiving nodes would be required for a 12- × 12-km (7.5- × 7.5-mi) survey area with 400-m (1,312-ft) spacing between nodes, if it was desired to lay out the total grid of nodes at the initiation of a survey. The survey could be broken into smaller segments requiring fewer nodes; however, to efficiently conduct a survey, approximately 500 nodes or 100 km (62 mi) of cable are needed.

Figure F-7A illustrates the layout pattern of an OBN or OBC system (cables and nodes are shown side-by-side only for illustrative purposes; generally, only one of the system types would be used for a survey) for a 3D survey. The OBC system is connected to a recording vessel or buoy. The OBN system would not need a connection to the surface if deployed as individual autonomous nodes. A surface connection would be needed if the otherwise autonomous nodes were deployed attached to a line or cable. **Figure F-7B** shows cable systems attached to recording vessels and indicates that the track lines of the seismic source vessel may be aligned perpendicular (orthogonal or patch geometry) or parallel (parallel or swath geometry) to the receiving array; most surveys are shot using orthogonal geometry.

3D ocean-bottom surveys are conducted using the same type of seismic source (airgun arrays) used for 2D ocean-bottom and towed-streamer surveys. Once the grid of receiving sensors is in place, a seismic source vessel, typically much smaller than a high-end, towed-streamer, 3D seismic vessel, traverses the area of the grid. A dual-airgun array usually is used, and the distance between discharges of the airgun array is 25 to 50 m (82 to 164 ft). The time between airgun array discharges corresponding to these distances is 10 to 25 seconds when the source vessel's speed is 4.5 kn (5.2 mph). After a track line is acquired, the seismic source vessel takes approximately 10 to 15 minutes to turn around and begin the next survey track line. When data acquisition using sets of recording nodes or cable is complete, the nodes or cable are retrieved and moved to their next position. A particular set of nodes or cable may remain in place for a couple of days to several weeks, depending on operating conditions, survey size, and the logistics of the survey. In some cases, nodes or cables may be left on the seafloor for future 4D surveys (**Figure F-8**).

The seafloor topography of the Atlantis Field in the Green Canyon Area of the Gulf of Mexico (GOM) is shown in **Figure F-8**. The inset map shows the BP Atlantis platform and its location. Water depth ranges from approximately 1,300 to 2,200 m (4,265 to 7,218 ft). The dots in the figure indicate OBN locations for the first of multiple 3D surveys (part of a 4D seismic program) conducted in the field. The first survey required two patches of nodes (the pink area and the gray area), each patch consisted of approximately 800 nodes and nodes were 426 m (1,398 ft) apart. The total area covered by the nodes was 247 square kilometers (km^2) (95 square miles [mi^2]), and the area transected by the sound source vessel was 757 km^2 (292 mi^2).

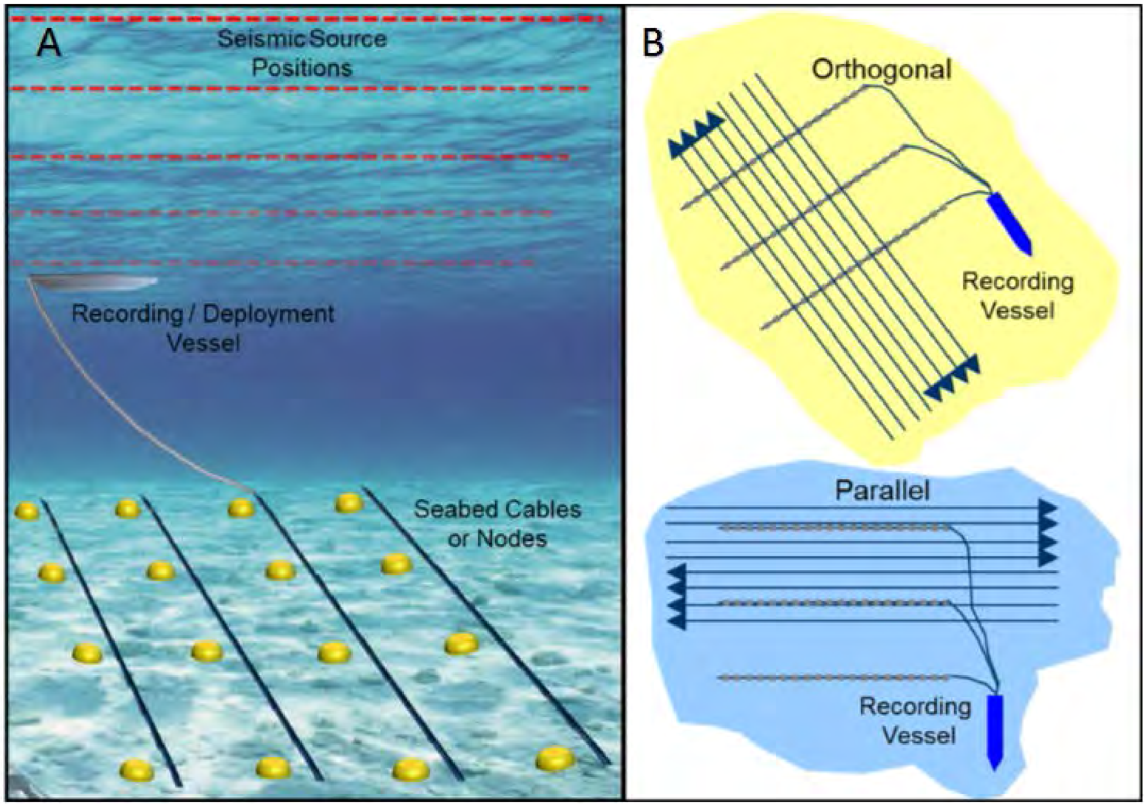

Figure F-7. Placement of an OBN or OBC System in a 3D Seismic Survey (From: Caldwell, 2015).

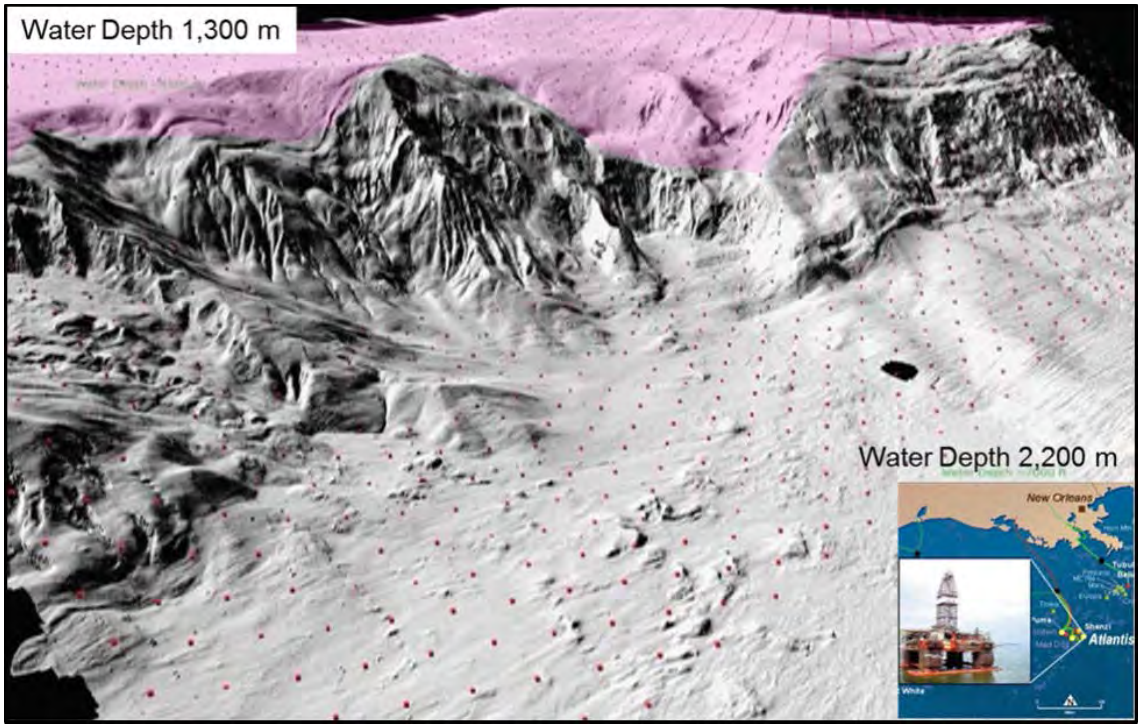

Figure F-8. OBNs Left on the Seafloor for Use in 4D Surveys (Modified from: Beaudoin and Ross, 2007).

1.1.4 Wide Azimuth and Related Multi-Vessel Surveys

In conventional 3D seismic surveys involving a single source vessel, only a subset of the reflected wave field can be obtained because of the narrow range of source-receiver azimuths, and thus are called NAZ surveys (**Figure F-9**). New techniques such as WAZ, MAZ, RAZ, and full azimuth (FAZ) towed streamer acquisition as well as associated data processing have emerged to provide better data quality than that achievable using traditional NAZ seismic surveys (**Figure F-10**). The new methods provide seismic data with better illumination, higher signal-to-noise ratios, and higher resolution. The various azimuth surveys have been particularly helpful in deepwater locations of the GOM and other areas, where breakthroughs have been achieved in imaging subsurface areas containing complex geologic structures, particularly those beneath salt bodies with very irregular geometries.

Figure F-9 shows offset (the distance between a source and a particular receiver) and azimuth (the angles covered by the various directions between a seismic source and individual receiving sensors). The two thin green arrows in **Figure F-9** show the range of azimuths to the farthest offset receivers. The pink rectangle indicates the nominal area imaged by the reflection points produced in the subsurface by the recording of energy at all of the receivers in the streamer array when the seismic source is fired one time. "Inline" means in the same direction as the vessel track, and "crossline" means in the direction perpendicular to the vessel track. With NAZ surveys, the width (crossline dimension) of the pink area will be less than half the length (inline dimension). The aspect ratio (crossline divided by inline) of the pink area is much less than 0.5 (the inline dimension in **Figures F-9 and F-10** is shown much less than it is in actuality compared to the crossline dimension so as to fit the page). At least one company performs coil surveys that do not require any turns, therefore allowing shorter survey durations.

To achieve wider azimuthal coverage, the crossline dimension of the pink areas should be greater than that shown in **Figure F-9** and should approach the length of the streamers indicated in the figure. The thin green arrows in **Figure F-10** indicate the azimuthal coverage between the source and the farthest receiver, and the heavy short green arrows (**Figure F-10D**) indicate the various azimuths produced by the various passes in the illustrated geometry. **Figure F-10A** illustrates one method to acquire WAZ data. This method requires three seismic source vessels, only one of which tows receiver streamers, and produces more azimuthal coverage than the NAZ geometry but does not generate data for all azimuths. **Figure F-10B** illustrates another configuration used to acquire WAZ data, using the same three vessels shown in **Figure F-10A,** but in a different spatial arrangement. **Figure F-10C** shows another WAZ data acquisition strategy; it uses two source-and-streamer vessels and two source-only vessels. The red arc illustrates that this method obtains more than 90° of azimuth. **Figure F-10D** shows the most basic method used to acquire MAZ data. Using this method, a single seismic source and streamer vessel, using conventional 3D survey methodology, transects the same area multiple times along different azimuthal directions. **Figure F-10E** illustrates acquisition of RAZ data using multiple passes of one source-and-streamer vessel and two source-only vessels, the same vessel configuration shown in **Figure F-10B**. Making two passes at right angles to each other with the vessel configuration shown in **Figure F-10C** would produce FAZ (180° azimuth) coverage. **Figure F-10E** demonstrates that a combination of WAZ and MAZ geometries will produce a RAZ or FAZ geometry. **Figure F-10** does not show all of the tested survey designs, and new designs will be tested as the seismic industry continues to work to make WAZ, MAZ, RAZ, and FAZ shooting more efficient and less costly.

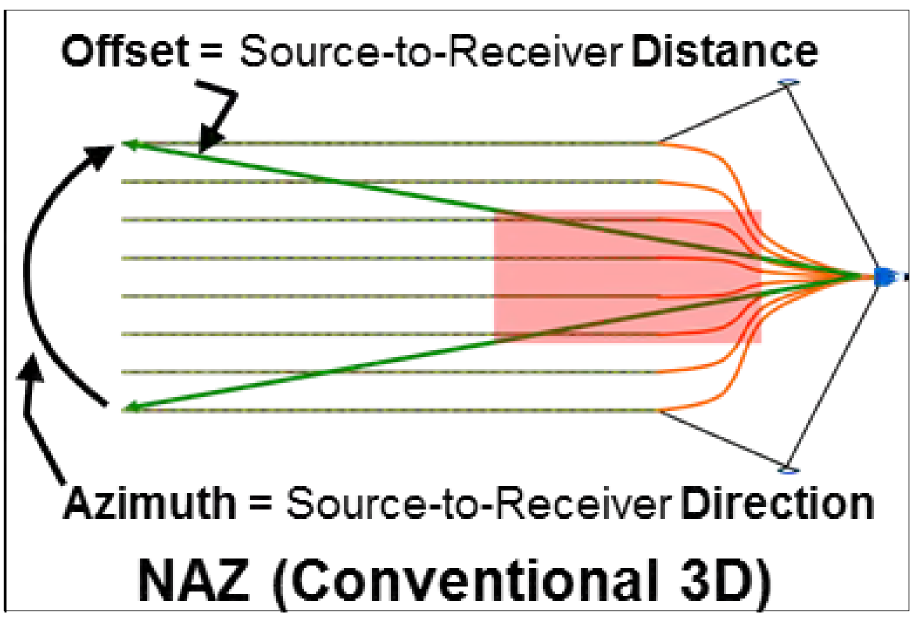

Figure F-9. The Narrow Range of Source-Receiver Azimuths in Single-Vessel 3D Surveys (From: Caldwell, 2015).

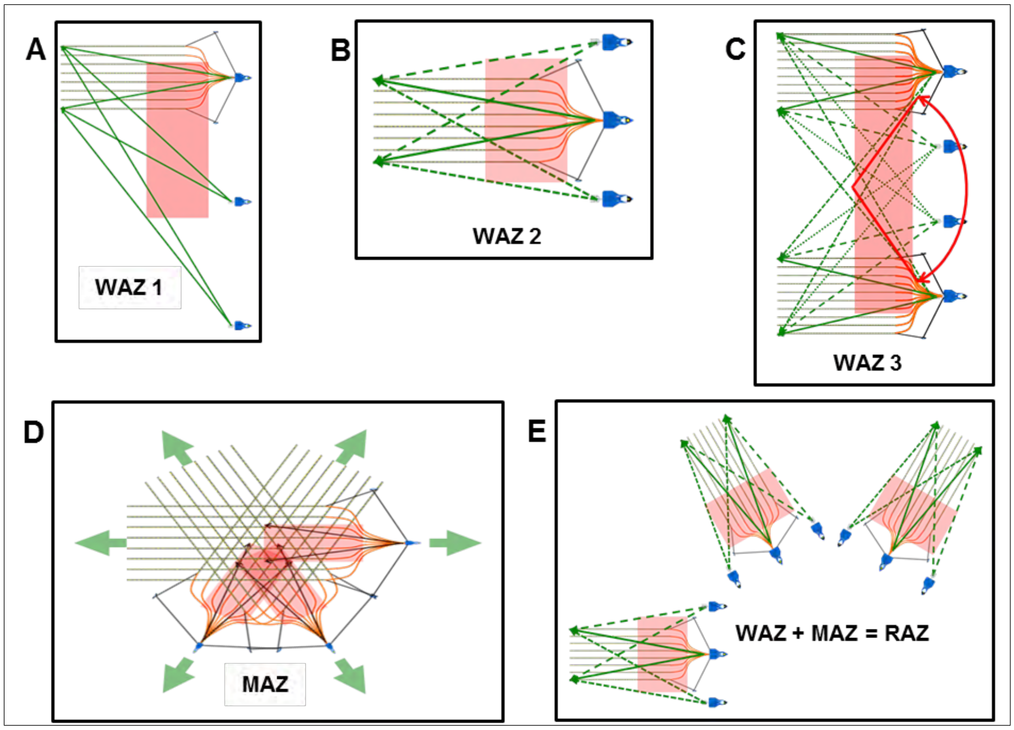

Figure F-10. New 3D Acoustic Survey Techniques that Provide Improved Data Quality (From: Caldwell, 2015).

The WAZ, MAZ, RAZ, and FAZ seismic survey strategies generally require multiple vessels using a variety of vessel operation geometries. **Figure F-10** illustrates only some of the survey configurations that have been tested or are feasible. The geophysical objectives of a survey, the need for high-quality data, data acquisition efficiency, safety, and cost are factors that influence survey design. Whatever the design, better azimuthal coverage costs more because some combination of more vessels or more vessel passes over the survey area will be required. Seismic survey designers continue to create new survey strategies to acquire data more efficiently and at less cost. Synchronized discharge of airgun arrays being towed by different vessels is being used in some cases because data processing techniques can separate the energy from synchronized seismic sources using differences in source-to-receiver offset distances. While this increases the level of sound in the ensonified water volume, it also reduces the length of time that the water volume is ensonified because the discharge of all the seismic airgun arrays being used for the survey occurs at one time. The seismic industry continues to study, design, and refine seismic survey designs to increase data quality while reducing survey time, survey costs, and environmental impact. Some survey designs have been patented, such as coil survey design where one or more seismic source-receiver array vessels follow an overlapping circular path, and there are other proprietary and unique designs as well.

The specifications and other elements of the design of MAZ survey airgun arrays are developed to obtain the best information possible given the characteristics and depth of geologic targets of interest. The energy levels of the airguns used for WAZ, NAZ, and RAZ surveys are the same as those discussed in **Section 1.1**.

The time required to complete one pass of a transit line for a single NAZ vessel and the time required for one pass by multi-vessel conducting a WAZ survey will be essentially the same. Turn times will be somewhat longer during multi-vessel surveys to ensure that all vessels are properly aligned prior to beginning the next transit line. Turn times depend mostly on the vessels and the equipment they are towing (as in conventional 3D surveys); however, the number of vessels towing streamers in the entire entourage is the main determinant of the increased time to turn. The MAZ technique, where multiple passes are made, increases the time needed for a survey in proportion to the number of passes that will be made within an area. The reduction in the number of passes is one of the most significant driving factors in continued efforts to design more efficient seismic surveys.

1.1.5 Borehole Seismic Surveys

2D VSP Surveys

The placement of seismic sensors in a well or borehole is another way seismic data can be acquired. The VSP surveying is conducted by placing seismic receivers, usually three-component geophones, at many depths in a wellbore, and recording both direct-arriving and reflection energy from an acoustic source (**Figure F-11**). Thirty years ago, VSP surveys were conducted using a single receive sensor. More modern VSP surveys are conducted using strings of 12 to 120 seismic sensors. The use of multiple sensor strings shortens acquisition time and helps ensure that the airgun source level referenced during data processing is the same for all sensors in a string for each airgun discharge. The typical spacing between sensors in strings (tools) is 15 m (49 ft), but it can be any distance needed to meet survey requirements. The receiver sensors must be coupled to the borehole casing during borehole surveys to obtain high-quality data. There are a variety of methods used to couple receive sensors to a borehole casing, including electrically operated locking arms, bow springs, magnets, or even just gravity (in deviated wells). Borehole seismic surveys include (1) 2D VSPs, (2) 3D VSPs, (3) checkshot surveys, and (4) seismic while drilling. Sensors usually are placed at 50 to 200 depths, but this number depends on several factors. The seismic sensors usually are spaced equally apart at 15 m (49 ft) so that the total depth covered is a few thousand meters (several thousand feet). The seismic source usually is a single airgun or small airgun array hung from a platform or deployed from a source vessel. The airguns used for VSPs may be the same or similar to those used for 2D and 3D towed-streamer surveys. Normally, the number of airguns and the total volume of airguns used are less than those used for towed-streamer surveys (**Sections 1.1.1 and 1.1.2**). Less sound energy is required for VSP surveys because the seismic sensors are in a borehole, which is a much quieter environment than that for sensors in a towed streamer, and because the VSP sensors are located nearer to the targeted reflecting horizons. The total round-trip path for sound from the seismic source to reflector and back to a sensor in a VSP is one-half to two-thirds as long as those for seismic surveys where the source and seismic sensor are located near the sea surface. VSP survey duration mostly depends on the equipment used for the survey, but it also depends partially on survey type and objectives. Some VSP surveys take less than a day, and most are completed in a few days. The 2D VSP survey type is defined by seismic source location (**Figure F-11**), and less by the number and depth of sensors.

There are four commonly used types of 2D VSP surveys (refer to **Figure F-11**):

- zero-offset;
- offset (and multiple-offset);
- walkaway; and
- deviated-well (or walk above).

A zero-offset VSP uses a single position for the seismic source that is close to the well compared to the depths of the receiving sensors so the sensors mostly receive vertically propagating energy. The seismic source usually is an airgun or a small array of airguns hung from a platform. In an offset VSP survey, the seismic source is deployed from a small, stationary vessel far enough away from the well so that the received seismic waveforms have a significant amount of horizontally propagating energy and image some lateral distance away from the borehole. The seismic source for a multiple-offset VSP is deployed using a small vessel at multiple locations, typically less than 10, where it is held stationary during data acquisition. In some situations, the seismic source locations are in a line radiating away from or through the well location. In a walkaway VSP survey, a relatively small number of receiving sensors are deployed within the well and the seismic source is moving during data acquisition. The walkaway VSP requires a small source vessel capable of accurately positioning the seismic source at many positions along a line passing over or near the well. During a deviated-well VSP survey, the seismic source, which may be stationary or moving depending on the source output level and survey objectives, is fired from a small vessel that is positioned at various points above the path of the well. If the number of depth levels at which data are needed to meet survey requirements exceeds the number of seismic sensors in a string, then the string is repositioned as many times as necessary to obtain data at all desired depths.

The subsurface image obtained from a VSP survey will be a 2D plane defined by the source location and the borehole (**Figure F-12**). In **Figure F-11**, the black arrows indicate ray paths for energy that propagates from the seismic source directly to each sensor in a borehole. The red arrows indicate ray paths for energy that is reflected from some point in the subsurface to sensors in the borehole. For the deviated-well VSP, the red ray paths show the directly arriving energy paths as well as the reflected energy paths. In general, the zero-offset and offset VSPs will have several depth levels (typically 50 to 150) in the borehole where sensors are placed, while the walkaway and deviated-well VSPs will have fewer depth levels where sensors are placed.

VSP surveys are useful for several reasons: they (1) provide an accurate depth to a seismic reflector at the wellbore; (2) provide good rock-velocity information near the well; (3) aid in the identification of seismic multiples, such identification being useful in the processing of surface seismic data; (4) produce high resolution images of the subsurface near the well; and (5) may be used in a time-lapse mode. The VSP surveys provide information about geologic structure, lithology, and fluids that is intermediate between that obtained from sea surface seismic surveys and the well-log scale of information. The VSP surveys may be conducted during all stages of oil and gas industry activity (i.e., exploration, development, and production), but most are conducted during the exploration and development stages.

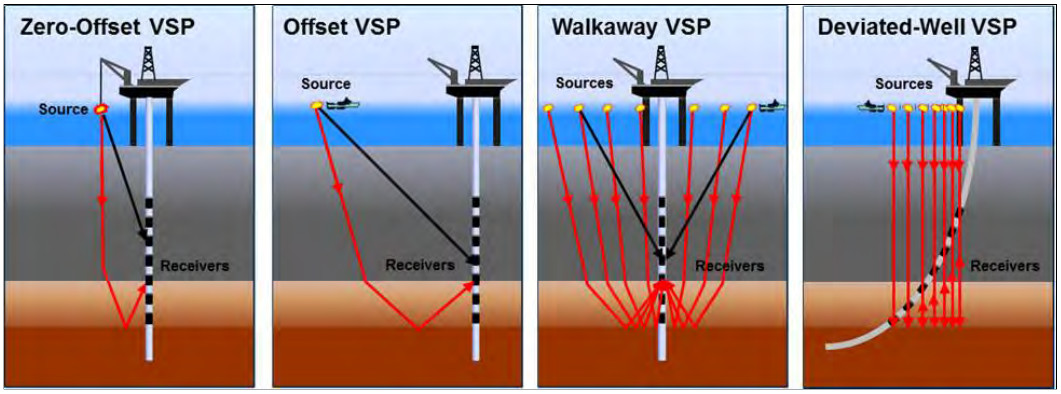

Figure F-11. The Geometries of the Four Basic Types of 2D VSPs (From: Caldwell, 2015).

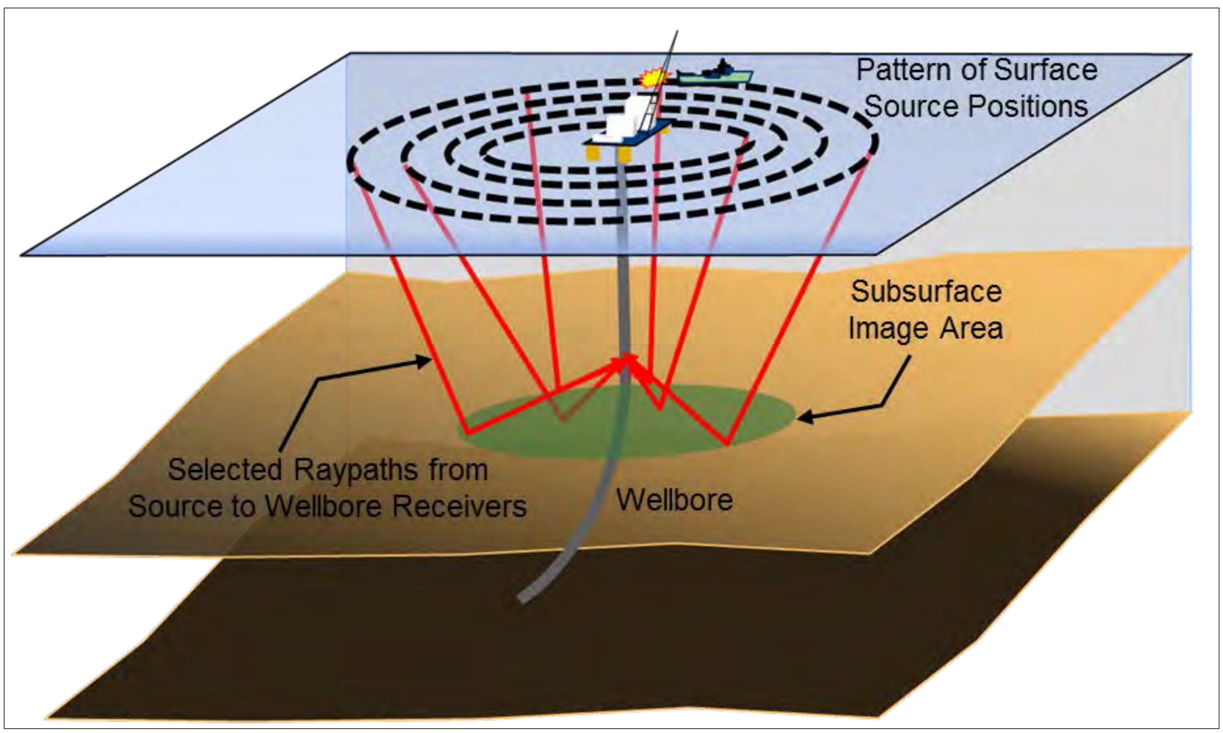

Figure F-12. The Geometry of a 3D VSP Survey (From: Caldwell, 2015).

3D VSP Surveys

The 3D VSPs are relatively new technology made possible by development of multi-level sensor strings, with 50 to more than 150 sensors positioned in a well at one time. The distance between sensors in a string usually is 15 m (49 ft), but other spacing distances are possible. An interval between 1,500 and 3,000 m (4,921 and 9,842 ft) within a well can be instrumented in one or two placements of such sensor strings. The time required to conduct a 3D VSP survey depends on the number of seismic source positions required to meet data needs and how quickly a seismic source vessel can cover the survey area. The 3D VSP surveys involve many more source positions covering some area around a well compared to the relatively few source positions needed for a 2D VSP survey.

The airguns used for 3D VSP surveys are the same as those used for 3D towed-streamer surveys, and the design of the airgun arrays can be quite similar. The data acquisition design (the track line of the survey vessel and the schedule for discharge of the airgun arrays) depends on the objectives of the survey and can dramatically affect the time required to conduct a survey. Both rectangular survey vessel track patterns, as used for 3D towed-streamer surveys, and spiral track patterns where the spiral dimensions get larger as the seismic source vessel moves away from the well, have been used for 3D VSP surveys (**Figure F-12**). A rough rule-of-thumb for the design of 3D VSP surveys is that the distance from the well covered by the seismic source vessel will about equal the depth of the well (i.e., for a 3,000-m [9,842-ft] well, the area around the well covered during the survey will have a radius of 3,000 m [9,842 ft]).

By completing several seismic source discharge locations around a well, 3D VSP survey data will include a substantial number of reflection points around the well. The number of times the seismic source is discharged will depend on the objectives of the VSP survey and the number of sensors deployed in the borehole at one time. As many as 160 sensors have been deployed in a wellbore at one time, which dramatically reduces the number of times the seismic source must be discharged to complete a 3D VSP survey. Deployment of several (>50) sensors in a well at one time is making the 3D VSP technique economically attractive. Permanent fiber optic, single-fiber sensors and a small number of multi-fiber sensors were initially used in 2015 for 3D VSP surveys (Caldwell, official communication). Few of these types of sensors are currently employed but their use is likely to increase in the future. They are attractive because they are small, easy to install, relatively low cost, and can be used to place an unlimited number of sensors in a single well.

Checkshot Surveys

Checkshot surveys are similar to a zero-offset VSP surveys but (1) are less complex and require less time to conduct, (2) produce less information, (3) are cheaper, (4) use a less sophisticated borehole seismic sensor, and (5) acquire shorter data records at fewer depths. During a checkshot survey, a seismic sensor is sequentially placed at a few depths (<20) in a well, and a seismic source (almost always an airgun) is hung from the side of the well platform (**Figure F-13**). Only the first energy arriving at the sensor from the seismic source is permanently recorded by the sensor and recording unit combination (the black arrow in **Figure F-13** indicates a ray path for energy propagating from the source directly to a sensor positioned in the borehole). No reflection events are recorded, and no sophisticated data processing like that for VSP surveys is required. The purpose of a checkshot survey is to estimate the velocity of sound in rocks penetrated by the well. Typically, the depths at which the sensors are placed are at, or near, the boundaries of prominent lithologic features. Checkshot surveys can be conducted quite quickly, much quicker than VSP surveys, but they produce much less information. Because checkshot surveys are much less expensive and do not use the wellbore and the drilling rig as long, they are much more common than VSP surveys.

In most checkshot surveys, the seismic source is hung from the platform in a fixed location within the water column, so a surface vessel is not needed. Because reflection energy does not need to be acquired, the seismic source usually is smaller than those used for VSP surveys. On occasion, the availability of seismic sources and logistics sometimes makes it operationally and financially advantageous to use a VSP type of seismic source array.

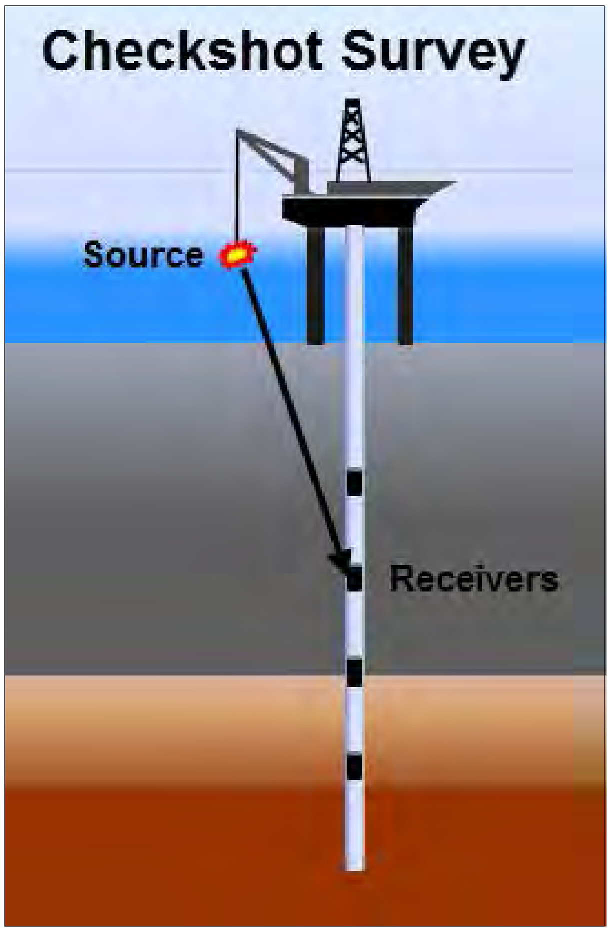

Figure F-13. The Geometry of a Checkshot Survey (From: Caldwell, 2015).

Seismic While Drilling

The acquisition of seismic while drilling refers to the acquisition of borehole data while there is downtime from the actual drilling. There are two different modes of acquisition. One mode collects data when a stand of pipe (90 or 135 ft; 27 or 41 m) is being connected to the drill stem. These surveys can take days to a month to complete, but they are done intermittently during that time period. Airgun arrays are 1,200 to 1,560 in^3. The other mode collects borehole data during the time while round tripping all drill pipe out of the borehole to change the bit. This survey is run intermittently for weeks and sometimes up to a month to the well completion depth.

1.1.6 Vertical Cable Surveys

Vertical cable surveys use hydrophones positioned along a cable held vertically in the water column between a seafloor anchor and a buoy at the sea surface. The hydrophones record the energy produced by an acoustic seismic source, typically an airgun array. The primary energy of interest is reflections from subbottom geological features. This technique produces a VSP without using a well, but it requires two vessels: one to manage the hydrophone cables and one to manage the seismic sources.

The objectives of the survey determine the number and positions of hydrophone cables and seismic sources. The hydrophone cables may be left in place for hours or days, depending on the size of the survey area and operating conditions. The airgun array is the same as that used for 3D towed-streamer surveys. These types of surveys are not common because of the better data acquisition techniques available using other types of surveys.

1.1.7 4D Time-Lapse Surveys

The 4D surveys are repeated one or more times after the original baseline survey has been completed. The purpose of 4D surveys is to monitor reservoir changes in a producing field. For approximately 25 years, the purpose of 4D surveys in the hydrocarbon industry has been to monitor changes in oil and gas reservoirs to better manage them. However, in addition to that purpose, 4D surveys now are being used to monitor changes for environmental and safety reasons. Examples of this include monitoring for oil leaks in the seafloor above reservoirs not only for health, safety, security, and environment (HSSE) purposes but also for carbon capture and storage (CCS). Some of the survey types described in this section can be used in time-lapse mode, including VSP, 3D towed-streamer, and multibeam bathymetry.

The usefulness and value of 4D surveys is well-established, and such surveys have become common. The particular acquisition technique chosen (towed-streamer, temporary OBC or OBNs, or permanently emplaced systems on the seafloor) depends on the objectives of the survey, the particular geology being addressed, the physical facilities in a given field, and the nature of the geophysical response to changes such as reservoir saturation and pressure. The seismic sensors used for 4D surveys have been almost exclusively nodal. The seismic survey equipment and procedures used for 4D surveys are the same as those described in previous sections. However, because these surveys are conducted over producing fields, the survey area is smaller and the survey time shorter than needed for most other 3D towed-streamer and 3D OBC or OBN surveys. The time lapse between a baseline survey and 4D survey has been as short as 3 months and as long as 10 years. Many 4D surveys are repeated every 1 to 2 years. When permanently emplaced receiver systems are used, the repeat time generally is on the order of several months because a relatively small and inexpensive seismic source vessel is all that is required to conduct additional monitoring surveys. A key requirement of 4D surveys is acquisitional repeatability, with emphasis on controlling factors that could confound results. This means the monitoring surveys use the same seismic source size and depth as well as the same receiver systems, and attempt to duplicate as much as possible all other details of the original survey.

1.2 AIRGUN HIGH-RESOLUTION GEOPHYSICAL SURVEYS

The HRG surveys are conducted using several techniques involving airguns and electromechanical sources such as side-scan sonars, shallow- and medium-penetration subbottom profilers, and single-beam echosounders (SBESs) or multibeam echosounders (MBESs). This section discusses shallow-penetration airgun seismic surveys used for HRG surveys. Non-airgun acoustic HRG surveys are discussed in **Section 1.3**.

The HRG surveys are conducted to investigate the shallow subsurface for geohazards and soil conditions over specific locations in one or more OCS lease blocks. Identification of geohazards are necessary to avoid drilling and facilities emplacement problems. Geohazards include shallow gas, over-pressured zones, shallow water flows, shallow buried channels, gas hydrates, incompetent sediments, and mass transport complexes. These surveys also are used to identify potential benthic biological communities (or habitats) and archaeological resources. Survey data are used for initial site evaluation, drilling rig emplacement, and platform or pipeline design and emplacement. HRG surveys and reporting requirements are outlined by Notice to Lessees and Operators (NTL) 2008-G05 (“Shallow Hazards Program,” extended with NTL 2014 G03) and NTL 2005-G07 (“Archaeological Resource Surveys and Reports”).

Because the intent of high-resolution, shallow-penetration airgun seismic surveys is to image shallow depths (typically 1,000 m [3,280 ft] or less below the seafloor) and to produce high-resolution images, the airgun sources used (typically one or two airguns) are smaller (typically 40 to 400 in^3), the streamers are shorter and towed shallower, the streamer-separation distances are smaller (150 to 300 m [492 to 984 ft]), and the firing times between airgun shotpoints are shorter than for conventional 2D and 3D airgun seismic surveys. Typical surveys cover one OCS lease block, which is usually 4.8 km (3 mi) on a side. The presence of historic archaeological resources (e.g., shipwrecks), shallow hazards, or live bottom features can require surveys using a maximum line spacing of 300 m (984 ft). Including vessel turns at the end of lines, the time required to survey (transect all lines) one OCS lease block is approximately 36 hours. Other activities before and after the time spent actively acquiring seismic data, such as streamer and airgun deployment and other operations, add to the total survey time. In addition, weather can create conditions that degrade the performance of streamer arrays and prevent acquisition of useful data, especially in shallow water where streamers are towed close to the sea surface. Sea state conditions caused by weather in the GOM can result in operational downtime. Also, in some instances, the time required to conduct a survey is affected by needs for tighter line spacing to accomplish survey objectives and data quality (USDOI, BOEM, 2012b).

The 3D high-resolution airgun seismic surveys using ships towing multiple streamer cables have become more common. These surveys include (1) dual-source acquisition that incorporates better source and streamer positioning accuracies (derived from GPS) that allow for advanced processing techniques (pre stack time migration), (2) single-source multi-streamer (up to 6 streamers maximum in most cases), (3) dual-source multi-streamer, and (4) P-Cable acquisition. All of these 3D survey types except P-Cable acquisition have the same surveying practices as high-resolution 2D surveying, including shorter streamers (typically 100 to 1,200 m [328 to 3,937 ft]); shallower streamer tow depths; more closely spaced shots, often as close as 12.5 m (41 ft); smaller airgun arrays (typically 40 to 400 in3); and more closely spaced track lines (generally 25 to 100 m [82 to 328 ft]).

The P-Cable acquisition survey technique was first tested in 2007 and utilized in 2014 for the first multi-client geohazards ultra-high-resolution 3D (UHR3D) survey in the GOM (Caldwell, official communication). In a UHR3D survey, a cable is towed oriented perpendicular to the ship track (**Figure F-14**). Attached to the cable are a series (10 to 20) of short (25 to 300 m [82 to 984 ft]), closely spaced (12.5 m [41 ft]) streamers. UHR3D surveying requires accurate geological positioning. **Figure F-15** shows the level of detail of the seafloor morphology and of the subsurface below the seafloor provided by UHR3D technology for five examples of geohazards. It should be noted that the subsurface velocities required to process the P Cable (and similar technologies) cannot be obtained from this acquisition technique; instead, it must be obtained from borehole checkshot surveys (refer to **Section 1.1.5**) or other methods that measure the appropriate velocities (Hill et al., 2015).

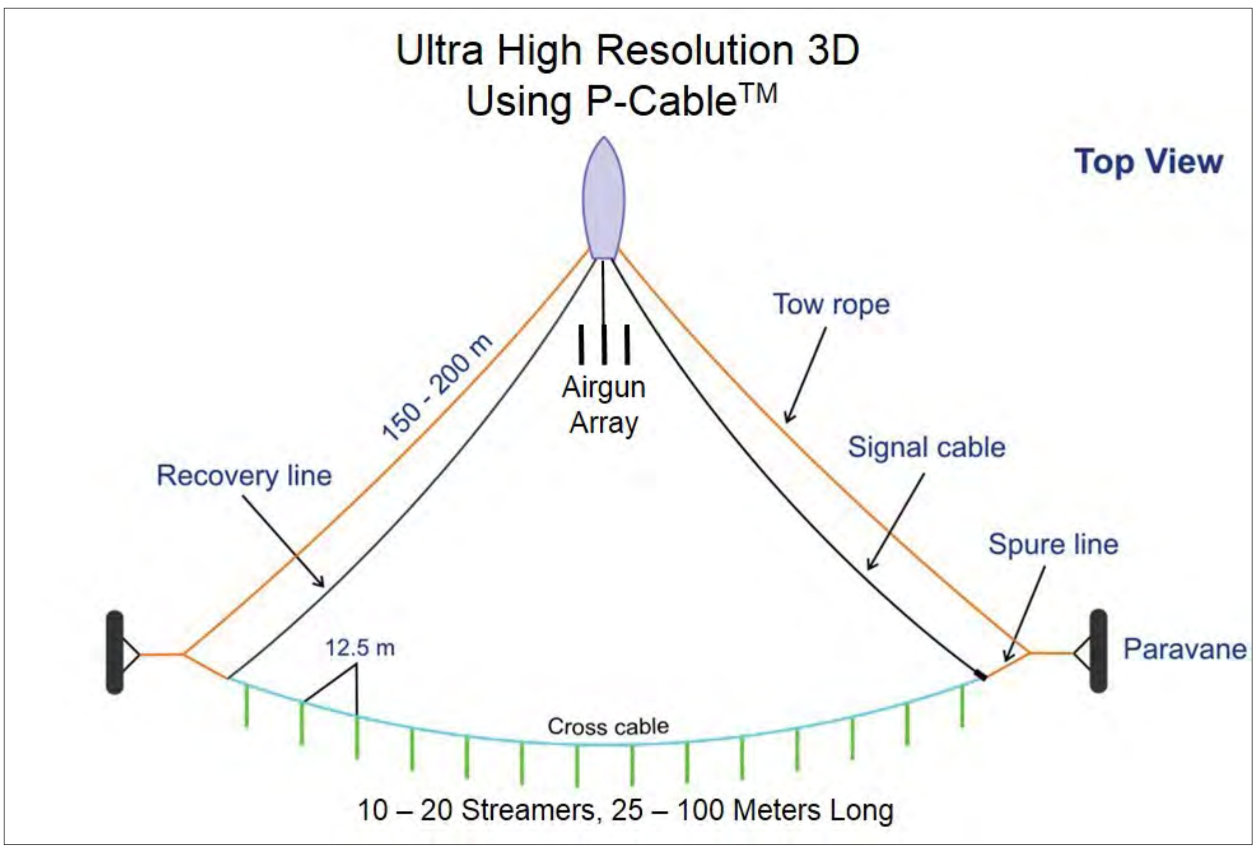

Figure F-14. The Equipment Layout for a P-Cable Acquisition Survey (From: Caldwell, 2015).

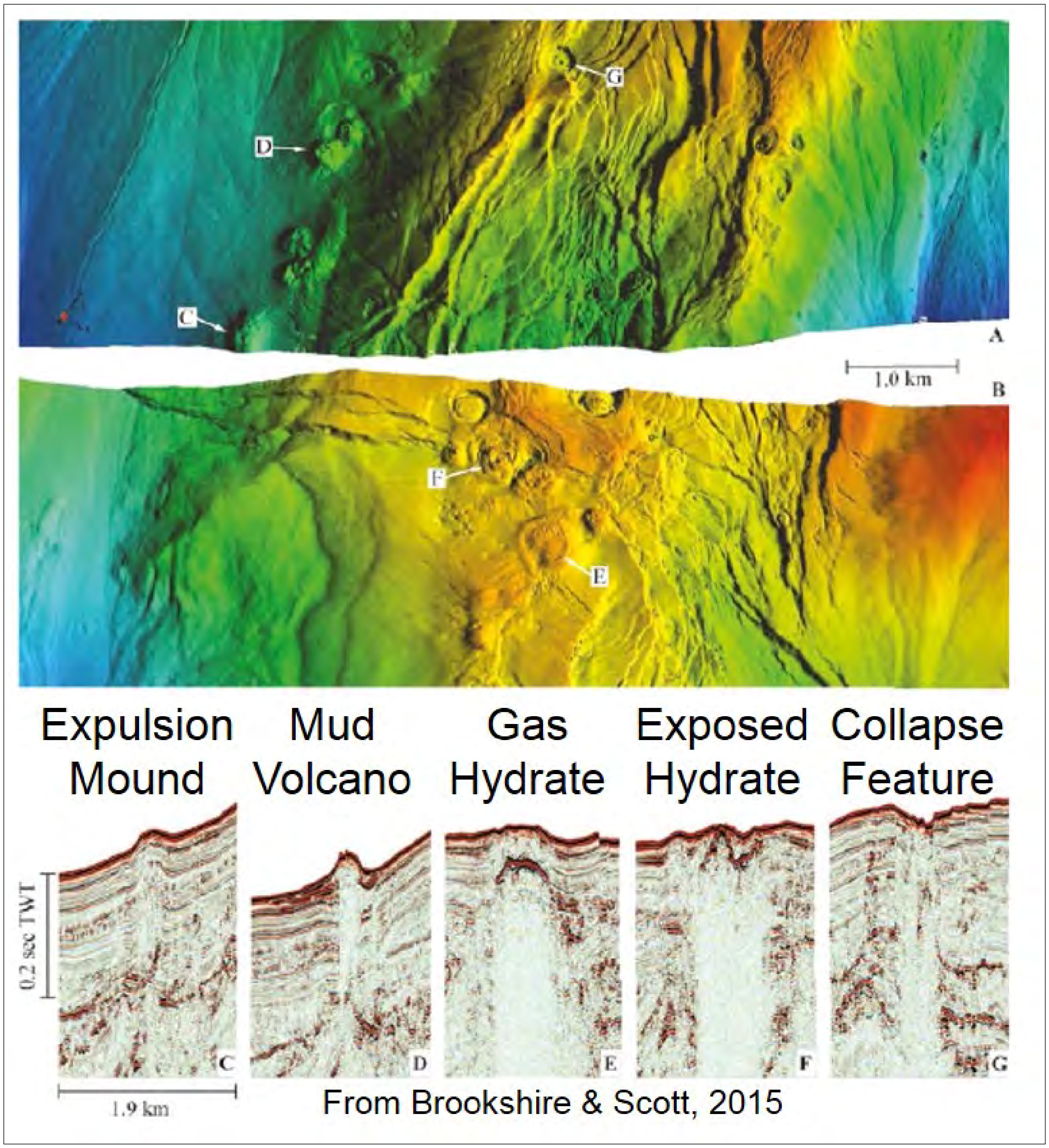

Figure F-15. Examples of the Data that the P-Cable Technology can Deliver. Diagrams (A) and (B) Show the Seafloor Morphology in Two Areas of the Gulf of Mexico and the Locations of Features (C) Through (G) Whose Vertical Structures are Shown at the Bottom (From: Brookshire and Scott, 2015).

1.3 NON-AIRGUN ACOUSTIC HIGH-RESOLUTION GEOPHYSICAL SURVEYS

As mentioned in **Section 1.2**, before any operation takes place on the seafloor, there is an operational and legal regulatory need to characterize the nature of the seafloor and the geologic layers immediately beneath it. In most cases, conventional 2D and 3D deep-penetration seismic surveys do not have the resolution to provide the required information. Consequently, in addition to high-resolution, shallow-penetration airgun 2D or 3D seismic surveys, non-airgun acoustic surveys are conducted (often from the seismic vessel, but sometimes from a vessel dedicated to such surveys). Typical non-airgun HRG surveys may involve one or more types of high-frequency acoustic sources such as the following:

- subbottom/sediment profilers (2.5 to 7 kHz);
- pingers (2,000 Hz);
- sparkers (50 to 4,000 Hz);
- boomers (300 to 3,000 Hz);
- compressed high-intensity radar pulse (CHIRP) subbottom profilers (4 to 24 kHz);
- side-scan sonar (usually 16 to 1,500 kHz);
- single-beam echosounders (12 to 240 kHz); and
- multibeam echosounders (50 to 400 kHz).

In general, any combination of these techniques, which are employed for both hazard and archaeological surveys, may be conducted during a single deployment from the same vessel. However, conventional 3D seismic data generally cannot be substituted for HRG survey data for pipeline pre-installation surveys. The vessel tow speed during non-airgun HRG surveys may be up to 4 to 5 kn (4.6 to 5.8 mph). If a high-resolution airgun survey is required to meet the survey objective, it makes operational/economic sense to do everything in a single deployment. For post-lease engineering studies used to guide the placement of production facilities and pipelines in deep water and to meet archaeological requirements, HRG surveys often are conducted with autonomous underwater vehicles (AUVs) equipped with side-scan sonar, an MBES, and a subbottom profiler. Geophysical contractors have been using AUVs since 2000 to make detailed maps of the seafloor before installing subsea infrastructure.

1.3.1 Subbottom Profiling Surveys

Sparker

A sparker is an acoustic source that uses electricity to vaporize water, creating collapsing bubbles that produces a broadband (50 Hz to 4 kHz) omnidirectional pulse of sound that can penetrate a few hundred meters (several hundred feet) into the subsurface. Because of the sparker’s relatively high frequency compared to deep-penetration seismic, it is used for high-resolution shallow imaging. Short hydrophone arrays towed near the sparker receive sound reflected from subsurface features. Normally, the sparker is towed on one side of a ship’s wake and the hydrophone array is towed on the other side. Some of the operational characteristics of sparker surveys are as follows:

- sparker and hydrophone array tow depths are 1 to 1.5 m (3 to 5 ft);
- vessel speed is 3 to 6 kn (3.5 to 6.9 mph) (similar to seismic), but can be faster;

- acquired reflection return length typically is 500 millisecond (ms) (shorter than seismic);
- operating rate of two discharges per second (faster than seismic);
- analog-to-digital sampling interval of 0.1 to 0.25 ms (higher than seismic); and
- dominant sound frequency band is 300 to 800 Hz (higher than seismic).

Boomer

A boomer is an acoustic sound source that uses electricity to cause two spring-loaded plates to rapidly repel each other, generating an acoustic pulse. The acoustic pulse has a bandwidth of 300 Hz to 3 kHz. A boomer is commonly mounted on a sled and towed behind a vessel. Short hydrophone arrays towed nearby receive sound reflected off subbottom features. Depending on subsurface geology, the resolution of the boomer system typically is 0.5 to 1 m (1.6 to 3 ft) and penetration is 25 to 50 m (82 to 164 ft). Boomers generate a sound pulse with very repeatable characteristics, although wave motion can distort the signal. A boomer often is deployed with other higher frequency systems to increase the depth range achieved by the survey.

Pingers and CHIRP Subbottom Profilers

The acoustic pinger is the oldest technology used for bathymetric and subbottom profiling surveys. A pinger operates at a single frequency (usually 2 kHz) and is a relatively weak sound source, penetrating to a maximum depth of approximately 5 m (16 ft), depending on the composition of seafloor sediments.

The CHIRP systems are used for high-resolution subbottom profiling. Instead of operating at a single frequency, CHIRP subbottom profilers transmit a pulse consisting of a continuous sweep of frequencies ranging from low to high. The CHIRP subbottom profiling technology then processes echo returns to achieve high spatial resolution and subbottom penetration equal to or greater than equipment previously used for this purpose.

1.3.2 Side-Scan Sonars

Sonar uses reflections of sound pulses to locate, image, and aid in the identification of objects in the water and on the seafloor, and to determine water depth. Side-scan sonars transmit sound pulses in a beam that is narrow in the direction along the tow vessel's track and wide vertically. The fan-shaped transmit beam sweeps the seafloor from directly under the sound source to either side, typically to a distance of 50 to 200 m (164 to 656 ft). The sound pulses do not penetrate the subbottom but are reflected off the seafloor and objects lying on the seafloor. As the vessel moves forward, an image of the seafloor and the relative size and location of objects on the seafloor to either side of the vessel is created. Side-scan sonar typically consists of three components: a towfish that contains the sound source and receiving transducers; a transmission cable; and a topside echo signal processing and display unit. Side-scan sonars often are used in conjunction with a SBES or MBES system that covers the part of the seafloor directly under the survey vessel that is not covered by the side-scan sonar. Because these types of sonars are used to detect relatively small objects, they operate at higher frequencies (1 to 1,500 kHz), and because of the high attenuation of high-frequency sound in the ocean, these sonars have useful ranges of a few hundred meters or less. There are hull-mounted and towed side-scan sonars, but because they operate at higher frequencies and their range is limited, imaging the seafloor in water depths greater than 10 m (33 ft) requires the use of a towed body or an AUV to position the side-scan sound source and receiving transducers closer to the seafloor.

1.3.3 Echosounders

Echosounders, also called depth sounders and fathometers, are used to estimate water depth. Most seismic and HRG survey vessels have an echosounder, which works by emitting a short, usually single frequency, pulse of sound and receives, processes, and displays echo returns from the seafloor. If the speed of sound in sea water is known, the device can estimate water depth by multiplying the speed of sound by half the time from transmit of a pulse to receipt of an echo. Many echosounders also have sensors that detect salinity, temperature, and conductivity, measurements that are used to estimate the speed of sound in water.

Single-Beam Echosounders

An SBES transmits a sound pulse aimed vertically below the vessel to estimate the distance to the seafloor directly beneath the ship. Typically, higher operating frequencies are used for shallow depths and lower frequencies are used for greater depths. For example, an echosounder operating at 200 kHz would be used in shallow (<100 m [328 ft]) water, and an echosounder operating at 3 kHz would be used in very deep water (3,000 m [9,842 ft]). If a high level of detail about seafloor depths is needed, a survey vessel must complete many closely spaced track lines because depth is only estimated directly beneath the ship.

Multibeam Echosounders

The MBESs emit multiple sound beams in a fan shape, covering a range of angles beneath the ship orthogonal to the ship's track. Therefore, in one pass of the survey vessel over an area, the bathymetry of a swath of the seafloor is estimated, so a larger area can be covered in a shorter time and with fewer track lines than is possible using an SBES. The width of the swath depends on the number of sound beams, the multibeam operating frequency, and water depth. The MBESs that operate at low frequencies (e.g., 12 kHz) are used to survey at depths up to 10,000 m (32,808 ft) while others operating at high frequencies (e.g., >300 kHz) are used to survey at depths as shallow as 20 m (66 ft) or less.

1.4 NON-ACOUSTIC MARINE GEOPHYSICAL SURVEYS

1.4.1 Marine Gravity Surveys

Measurements of Earth's gravity field are useful in helping investigate the geologic structure of the subsurface. Marine gravity surveys are used in frontier exploration areas and as a complement to seismic surveys in well explored areas. There are two basic types of gravity surveys: more common conventional gravity surveys and newer gravity gradiometry surveys. While conventional gravity surveys measure acceleration due to gravity at each survey point, gravity gradiometry measures the spatial rate of change of acceleration due to gravity. Because it is a measure of the derivative of Earth's gravity, gravity gradiometry has a higher signal-to-noise ratio at higher frequencies, and therefore higher resolution, than conventional gravity survey data. However, conventional gravity survey data have greater sensitivity for deeper geological features.

Both types of marine gravity data can be collected using instruments located on the seafloor, in boreholes, on board fixed-wing aircraft, or on helicopters, but most gravity surveys are conducted using ships. Conventional shipboard gravity meters are fairly small devices, on the order of 0.7 × 0.6 × 0.6 m (2.3 × 2 × 2 ft), and weigh approximately 100 kilograms (kg) (220 pounds [lb]). Gravity surveys are conducted from dedicated vessels that can operate at speeds of 8 to 10 kn (9.2 to 11.5 mph) and can make rapid line changes. Survey transect line spacing typically is 0.5 to 3 km (0.3 to 1.9 mi), and surveys that cover 500 km^2 (193 mi^2) can be completed in a few days. Gravity data are now routinely collected by seismic vessels during seismic surveys, but at slower seismic vessel speeds. Gravity gradiometry surveys are less common than conventional gravity surveys, and the instrumentation for commercial gravity gradiometry is still evolving.

1.4.2 Marine Magnetic Surveys

Marine magnetic surveys measure the Earth's magnetic field. Magnetic data are used to (1) estimate the structure and sedimentary properties of rocks bearing magnetic material; (2) locate pipelines, undersea cables, and other offshore structures; and (3) identify archeological sites. BOEM requires marine magnetometers for hazard and archaeological surveys in water depths less than 200 m (656 ft) (USDOI, BOEM, 2012b). These surveys often are run with acoustic HRG surveys. A marine magnetometer sensor is housed in a cylindrical package approximately 1 to 2 m (3 to 7 ft) long and 15 to 20 centimeters (cm) (5.9 to 7.9 inches [in]) in diameter, weighing approximately 14 kg (31 lb).

Magnetic surveys can be conducted from a ship, where the magnetometer is towed at least two and a half ship-lengths behind the ship, so that the ship's magnetic field does not affect measurement of Earth's magnetic field. Magnetic surveys may be conducted using an AUV as well. Magnetic surveys may be conducted in combination with other survey methodologies; if used with an airgun survey, the magnetometer package is towed approximately 100 m (328 ft) behind the seismic airgun array. The magnetometer typically is towed at a depth of approximately 3 m (10 ft) and depth-indicating devices mounted on the tow cable are used to maintain a constant depth. In high-resolution magnetic surveys for archaeological resources, the magnetometer must be towed within 6 m (20 ft) of the seafloor.

1.4.3 Marine Magnetotelluric Surveys

Magnetotelluric (MT) surveys are used to image Earth's subsurface by measuring natural variations in electrical and magnetic fields. Investigation depth ranges from 300 m (984 ft) below the seafloor, by recording higher electromagnetic frequencies, to 10,000 m (32,808 ft) below the seafloor, by recording lower electromagnetic frequencies. Natural variations in Earth's magnetic field induce electric currents in the subsurface. By measuring the components of the electrical and magnetic fields, a model of the electrical resistivity of the subsurface can be obtained and is often combined with seismic data to produce a more complete picture of subsurface structures and stratigraphy. This section primarily applies to shallow MT surveys, mostly used for geohydrologic or gas hydrate surveys rather than for oil and gas industry activities. **Section 1.4.4** describes the technique generally used for oil- and gas-related surveys.

2D and 3D MT surveys are common. For marine work, a deployment vessel is required. The survey instruments are "V" shaped devices, with the arms of the "V" 5 to 15 m (16 to 49 ft) in length; the arms approximately 25 cm (9.8 in.) in diameter; and the weight of the entire unit, including the data logger and the sensors, approximately 145 kg (320 lb). The recording unit usually will be anchored to the seafloor using one or two anchors and connected to a buoy at the sea surface (**Figure F-16**). The instruments are retrieved using an acoustic release that disconnects the anchors from the instrument unit when sent an acoustic command signal, and the instruments are then pulled to the surface by recovering the buoy.

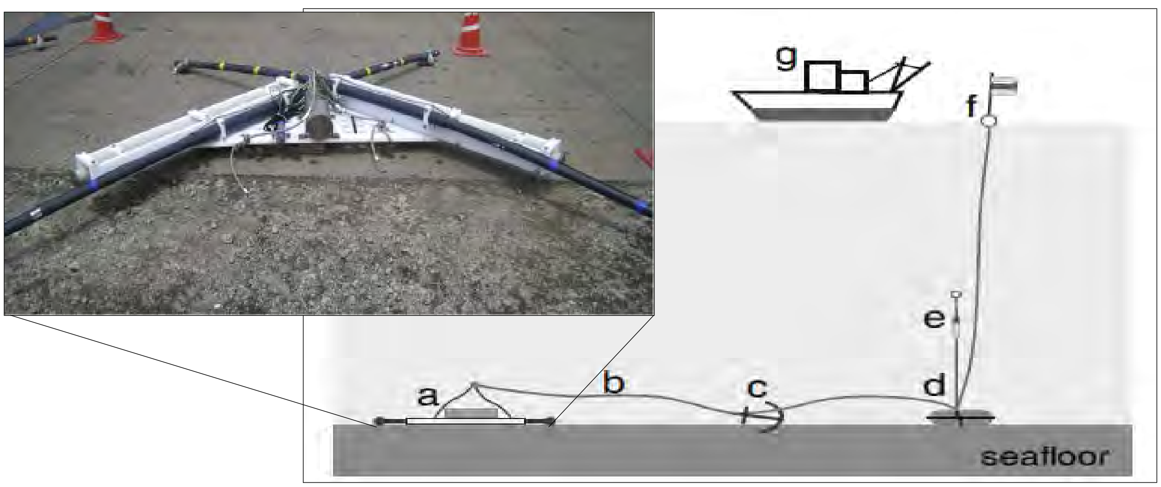

Figure F-16. The Marine MT Measurement System: (a) Electric and Magnetic Field Receiver, (b) Rope, (c) and (d) Anchors, (e) Water Flow Meter, (f) Buoy with a Flag, and (g) Survey Vessel (Modified from: Ueda et al., 2014).

1.4.4 Marine Controlled Source Electromagnetic Surveys

The controlled source electromagnetic (CSEM) method is an offshore geophysical technique employed by the commercial offshore oil and gas industry that uses electromagnetic remote-sensing technology to estimate the presence and extent of subbottom hydrocarbon accumulations. Electric and magnetic field sensors are placed on the seafloor, in a line for a 2D survey or in a grid for a 3D survey, commonly 500 to 4,000 m (1,600 to 13,000 ft) apart. The sensors typically record for several days to several weeks before being moved to a new line or grid. The complete surveys, therefore, can take weeks to months to complete. The sensors are situated in a deployment package that weighs approximately 100 kg (220 lb) and is approximately 2.5 × 2.5 × 1 m (8 × 8 × 3 ft) (**Figure**

F-17A). The electric dipoles of each receiver station are approximately 10 m (33 ft) long and 1.5 m (5 ft) high. The receiver packages use biodegradable anchors for deployment and flotation devices for retrieval. The CSEM transmitter employs an active dipole source, typically 50 to 100 m (164 to 328 ft) long, that is towed approximately 25 to 100 m (82 to 328 ft) above the seafloor (**Figure F-17B**) to transmit a time-varying electromagnetic field into the subsurface. The output of the transmitter commonly is 200 to 500 amps, with a maximum for some surveys of 1,000 amps. To achieve the penetration needed to detect small hydrocarbon deposits several miles below the seafloor, relatively low-base frequencies (0.05 to 50 Hz) are used. This field emitted by the transmitter is modified by the presence of subsurface resistive layers, and changes are detected and logged by the array of receivers. Because hydrocarbon-bearing formations are highly resistive compared to surrounding formations, a CSEM survey can indicate the presence of oil and gas in offshore situations. When source transmissions are complete, an acoustic signal commands releases to separate the instruments from biodegradable anchors, permitting the sensor packages to rise to the surface.

Recent developments have improved the methods and equipment used in towed CSEM surveys. The CSEM surveys utilize a source and receivers within towed streamers that can be used simultaneously with seismic equipment. While this survey technique has been in development since the early 1940s (Srnka, 1986), only recently have receivers been successfully deployed during a survey that was using seismic airguns. Similar systems have been used to study subsea geologic activity at thermally or magmatically active locations (Sinha et al., 1990). An electromagnetic streamer can be deployed and operated in a similar manner to a seismic streamer, but it typically is towed at depths up to 100 m (328 ft). An electromagnetic streamer can be up to 10 km (6.2 mi) in length and can be towed at the same speed as airgun arrays and seismic streamers (4 to 5 kn [4.6 to 5.8 mph]). It is likely that this technology will become more widespread and may be conducted concurrently with 3D seismic surveys within the next 5 to 10 years.

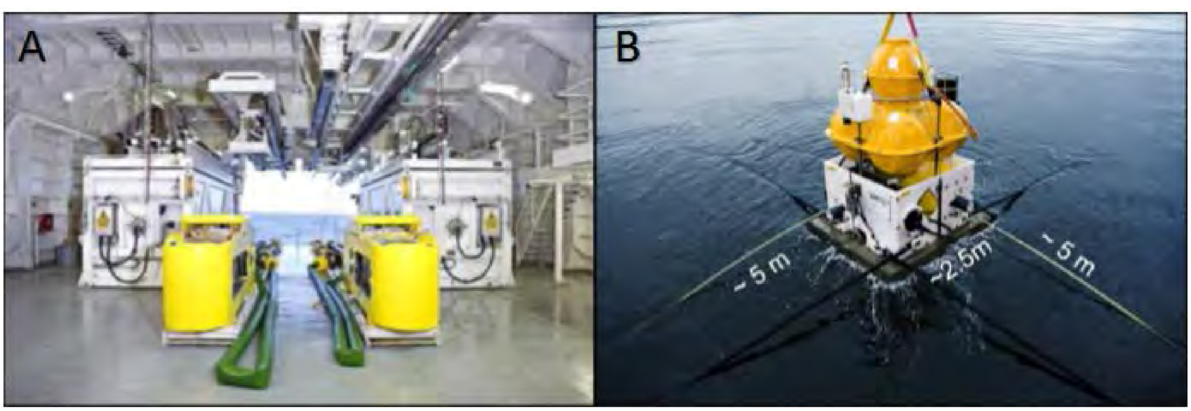

Figure F-17. (A) CSEM Receiver (From: Electromagnetic Geoservices ASA, 2015a); (B) CSEM Source (Modified From: Electromagnetic Geoservices ASA, 2015b).

1.5 AIRBORNE REMOTE SURVEYS

1.5.1 Airborne Gravity Surveys

In addition to ship-based marine gravity surveys, conventional airborne gravity surveys and airborne gravity gradiometry surveys can be conducted using fixed-wing aircraft, though helicopters may be used. However, offshore surveys using aircraft are uncommon because of the logistics required to keep them in the air for extended periods of time far from shore. The dimensions of the gravity instruments and mount are approximately 1 × 1 × 1.5 m (3 × 3 × 5 ft) high and the total weight is approximately 150 kg (330 lb). The survey acquisition grid is similar to ship-based surveys, generally with flight-line spacing of 0.5 to 3 km (0.3 to 1.9 mi). Surveys of 500 km^2 (193 mi^2) can be completed in a few hours, with the aircraft flying at an altitude of 70 to 300 m (230 to 984 ft). The objectives of the survey will determine the distance between flight lines and the altitude at which the survey will be conducted.

1.5.2 Airborne Magnetic Surveys

Measurements of Earth's magnetic field are useful in helping investigate the geologic structures and stratigraphy of the subsurface. Such data are useful in frontier exploration areas and as a complement to seismic surveys in well explored areas. There currently are at least five types of magnetometers, three of which are commonly used in airborne magnetic surveying. In addition to these three different airborne type magnetometers (i.e., proton precession, optically pumped vapor, and fluxgate), there are several different configurations that can be used on aircraft, including the following:

- a single sensor, typically a tail installation;
- two horizontally separated magnetometers, usually wingtip pod sensors;
- two vertically separated sensors, usually tail-mounted; and
- a total magnetic intensity configuration, typically involving three but potentially four magnetic sensors, towed a short distance behind the aircraft.

The sensor pods are cylindrical in shape, usually 1 to 2 m (3 to 7 ft) long and several centimeters (several inches) in diameter.

The objectives of a survey (e.g., the size of area to be covered and the desired detail to be obtained), the cost, the altitude at which the survey will be conducted, the flight line (transect) separation distances, and the flight line orientation are the most important factors to be specified for a survey. Recent surveys done in the GOM have been flown at altitudes of 60 to 300 m (197 to 984 ft), at speeds of 110 kn (126.6 mph), and with flight line spacing of 0.5 to 2 km (0.3 to 1.2 mi) (Caldwell, official communication).

2 GEOLOGICAL AND GEOTECHNICAL SURVEYS

Geotechnical surveys are conducted to obtain information about surface and subsurface geological and geotechnical features. This information is used to aid siting, design, construction, and operation of energy facilities and for the assessment of sediment resources and minerals. Geotechnical surveys measure conductivity, pressure, and temperature and also collect geologic cores and grab samples. Sediment sampling and testing locations for geotechnical surveys are identified using geophysical data and maps developed from HRG survey data.

The principal objectives of geotechnical surveys are (1) to assess the suitability of shallow foundation soils to support energy structures and associated infrastructure (i.e., transmission cables, pipelines, etc.) under any extreme operational and environmental conditions that might be encountered; and (2) to obtain information about soil characteristics needed for design and installation of energy structures, support infrastructure, and assessment of sediment resources and minerals for non-energy projects. Geotechnical survey data describe the stratigraphic and geoengineering properties of sediment that may affect the design of foundations and anchoring systems. Geotechnical surveys typically are conducted using a barge or ship approximately 20 to 100 m (65 to 328 ft) in length.

2.1 GRAB AND BOX SAMPLING

Coring and grab sampling are used to obtain sediment samples for geological and geotechnical analyses. Geotechnical sampling and testing are used in engineering studies for placement of structures such as platforms and pipelines. Usually, bottom sampling and shallow coring are conducted concurrently, using a small marine drilling vessel.

Grab sampling is done using a device with opposing jaws that is dropped onto the seafloor and then closed, capturing a small amount of bottom material that is brought to the surface. Grab sampling is not ideally suited for collection of coarse sediments because larger pieces of rock tend to get caught between the sampler's jaws, holding them open and causing the contents of the sampler to be lost as it is brought to the surface.

A box corer is a large mechanical coring device that takes a large, relatively undisturbed sample when lowered to the seafloor by a wire from the vessel. The box corer pushes into the sediment by its own weight. As soon as retrieval of the corer is initiated, a rotating spade closes and seals the bottom of the box, and the box and materials are brought to the surface with a lower chance of loss of contents than with grab samplers. Both techniques are used to obtain samples to depths up to 900 m (2,953 ft).

2.2 GEOLOGIC CORING

Gravity Corers, Multicorers, Piston Corers, and Rotary Corers

A gravity corer is a weighted tube mounted within a frame that is lowered from a vessel to the seafloor using a cable spooled from a winch. When the corer penetrates the seafloor, the tube fills with sediment. A hydraulically damped gravity corer has a slow rate of penetration into the seafloor that is controlled by a water-filled piston. Disturbance of the water-sediment interface is minimal, and maximum penetration in mud is approximately 1 m (3 ft). A core-catcher (sliding gate) on the bottom of the tube moves into place when retrieval begins, trapping the sediment sample in the corer. Operation of a gravity corer requires a ship with a winch powerful enough to lower and raise the corer, which can have hundreds to thousands of pounds of weight attached. In addition, the winch must have enough wire to reach desired depths. Multicorers are gravity corers with up to 16 tubes attached to a frame that are used to obtain core samples in shallow water.

A stationary piston corer is a gravity corer that is dropped freefall using a trigger system after it has been lowered to a predetermined height above the seafloor. It contains a piston that remains stationary at the surface of the seafloor sediment as the core barrel penetrates into the sediment. The movement of the coring tube relative to the piston creates a negative pressure in the tube that holds the bottom material within the core during retrieval. The operation of a fixed piston gravity corer results in better recovery rates and higher quality cores compared to those obtained with a standard gravity corer, particularly in soft sediments, because the piston keeps the sediments from being disturbed as the corer cuts through them. The piston assembly uses different core barrel lengths to obtain cores up to 30 m (98 ft) long and is able to obtain continuous core samples in water depths up to several thousand meters (several thousand feet).

Deep geologic cores (cores longer than 30 m [98 ft]) are obtained by standard rotary coring. Rotary corers are designed as two- or three-tube devices where the innermost tube acts as a core liner; the middle tube, if present, acts as a holder; and the rotating outer tube carries the hollow drill bit. As the drill bit cuts through the sediment and rock, the core created passes into the liner in a relatively undisturbed state. The cores obtained by this method vary in diameter (3 to 20 cm [1.2 to 7.9 in.]) and can penetrate several hundred meters beneath the seafloor.

ROV Push Corers

ROV push cores are used to obtain sediment cores in deepwater environments. Traditionally, sediment coring is done remotely from surface vessels; however, use of an ROV facilitates the ability to take multiple high-quality cores from locations with specific seafloor types or habitats for biological, physical, geological, or chemical analysis. Depending on conditions, ROV push samplers can acquire cores up to 1.5 m (5 ft) long. The manipulator arms of a ROV operate a push corer. Generally, ROV push corers are used to obtain fairly short small-diameter cores in water depths greater than 6,000 m (19,685 ft).

Vibracorers

Vibracorers use a vibratory motor and gravity to cut through seafloor sediments. They have a metal frame construction and generally are not used in water depths greater than a few hundred meters (several hundred feet). The diameter of the core barrel usually is 8 to 10 cm (3.1 to 3.9 in.), and cores up to 15 m (49 ft) long can be obtained using vibracorers. For better penetration and recovery rates, the vibratory motor can be run at various frequencies for different types of materials.

Jet Probes

A jet probe is composed of a rigid stainless steel tube with trigger function connected by a pressure-rated hose to a high-pressure cylinder. The rod will be marked with graduated increments to note the depth of penetration. The jet probe kit is completely self-contained and does not require any surface supply lines. Jet probe surveys acquire indirect physical information on subsurface lithology by surveying the thickness and stratigraphic layering of sedimentary covers by penetrating the sand cover with a jet of water.

2.3 COST AND SHALLOW TEXT WELLS

A continental offshore strategic test (COST) well can be drilled without acquiring a lease on the OCS, but it can be drilled in a leased block if it does not interfere with the leaseholder's activities. COST wells are funded by industry consortia; drilled off structure so as not to encounter hydrocarbons; and intended to provide information about regional stratigraphy, the existence and potential quality of reservoir beds, and the existence of potential hydrocarbon source rocks. The data are used to (1) evaluate the interpretation of other data to identify geological structures; (2) ground truth interpretation of geophysical survey data by providing samples of subsurface rock and geological strata; (3) estimate the age of sediments encounter during drilling; (4) evaluate the potential for hydrocarbon accumulations; and (5) determine the presence, absence, or quality of gas hydrate deposits. Drilling is done by conventional rotary drilling equipment from a drilling rig. It is possible but uncommon that a COST well would be drilled in the GOM during the period of interest for this Programmatic EIS.

Shallow test wells can be drilled to allow operators to place wireline testing equipment into a borehole to evaluate subsurface properties for the presence of gas hydrates, hazards to drilling, or physical structures. Drilling is done by conventional rotary drilling equipment from a vessel such as a drilling barge or semisubmersible.

2.4 CONE PENETROMETER TESTS

A cone penetrometer is an instrument consisting of a pointed steel pipe that is forced into the seafloor to determine the near-seafloor stratigraphic profile. Penetration is achieved through a hydraulic jacking mechanism that pushes the cone into the seafloor, with the depth of penetration on the order of 100 m (328 ft). Sensors at the tip take two measurements: the pressure against the cone tip (resistance) and the drag on the pipe just behind the cone (friction). The ratio of these two numbers is used to map sediment types. A tiny hole near the cone allows pore water pressure to be measured, and other sensors can be added to the cone to make additional measurements such as gravimetric, electromagnetic, and shear-wave velocities.

In water less than 30 m (98 ft) deep, floating or jack-up barges commonly are used to support pushing equipment. In water deeper than 30 m (98 ft), it is common to place cone penetrometer test (CPT) equipment on the seafloor. It also is possible to push a cone penetrometer from the bottom of a borehole using down-hole equipment. Recently, remotely controlled seafloor drill rigs have been developed that can drill, sample, and push a cone penetrometer into the seafloor in water depths up to 3,000 m (9,842 ft).

3 EMERGING TECHNOLOGIES

Marine vibroseis is considered the most promising alternative to airguns in select settings and applications (i.e., shallow water, sensitive habitat, near biological resources). However, marine vibroseis may not be a complete replacement for airguns, and there currently is not a vibroseis design viable for commercial applications. The attractiveness of marine vibroseis is that it could provide the same energy as airguns at lower power levels and in a more contained frequency band that would include the fully useable seismic bandwidth.

The oil and gas industry has been developing and testing marine vibroseis technologies since the early 1980s, and development is continuing today at an accelerated pace. Limited tests have been conducted that show reasonably good technical results. Issues of operational effectiveness, reliability, and durability are the key elements confronting the commercial viability of marine vibroseis technology at this time, and development work is ongoing to address these areas.

ExxonMobil, Shell, and Total teamed up with the Texas Experimental Engineering Station (part of Texas A&M University) to create the Marine Vibroseis Joint Industry Program in order to develop and build a full vibrator source array for commercialization. The Marine Vibroseis Joint Industry Program used a four-phased approach that began with scoping and development. Phase III, which is underway, is pursuing three different technologies and expects that the first prototype will be tested and evaluated in 18 months. Phase IV began in late 2014 and was intended to build and field test commercial systems from the technologies tested and evaluated in Phase III. Phase IV is anticipated to be completed in 2016 (Schostak and Jenkerson, 2015).

Two fundamentally different designs for a marine vibrator currently are under development; one vibrator design would use hydraulic activation and the other electrical activation. Both designs have passed initial feasibility tests, but both still have technical and operational issues that need to be addressed before they are commercially viable.

3.1 MARINE VIBROSEIS (VIBRATORS)

3.1.1 Hydraulic Marine Vibrator

In 1985, Industrial Vehicles International, Inc. (IVI) offered the first commercial marine vibrator. The IVI system consists of a marine vibrator, vibrator controller, and power unit. The IVI marine vibrator contains a piston within a housing with power supplied to the electrical, pneumatic, and hydraulic subsystems by a power unit. An alternator, air compressor, and two pressure driven hydraulic pumps are powered by an air cooled diesel engine. The source is capable of generating modulated frequencies between 10 and 250 Hz and can be used in water depths as shallow as 1 m (3 ft). The source output is controlled using conventional land vibrator controllers (Industrial Vehicles International, Inc., 2010).

The system has been tested in various environments from transition zones to deep water. Acoustic performance tests conducted at the Seneca Lake Facility of the Naval Underwater Systems Center in 1988 evaluated the system and determined that the marine vibrator was deficient in production of low frequencies (Johnston, 1989; Walker et al., 1996). A comparison of the IVI marine vibrator, dynamite, and airgun sources in southern Louisiana concluded that the marine vibrator was a viable seismic source for environmentally sensitive areas (Potter et al., 1997; Smith and Jenkerson, 1998). In transition zones, when coupled with the seafloor, marine vibrators operate like a land vibrator (Christensen, 1989). The best performance is on the seafloor, which couple the vibrator with the subbottom.

Initial deepwater tests were conducted in the GOM by Geco-Prakla, a subsidiary of Schlumberger, using a vibrator with an energy output approximately equivalent to a 1,000-in^3 airgun. Despite limitations in generation of low-frequency energy, good definition of reflectors down to 3 seconds indicated that the system was viable (Haldorsen et al., 1985). In 1996, Geco-Prakla performed a commercial field test in the North Sea comparing an array of six marine vibrators with a single 4,258-in^3 airgun; the objectives were to evaluate cost, reliability, production rate, and quality of geophysical data. After 2 weeks of data collection, a comparison between marine vibrator and airgun data indicated that the marine vibrator generated more sound above 30 Hz and less sound below 10 Hz than the airgun, but the seismic data obtained were comparable overall. Marine vibrator production rates were slightly lower than those of the airgun, but by the end of the survey, the technical downtime of the marine vibrator was similar to that for the airgun (Johnson et al., 1997).

Geco-Prakla participated in IVI's marine vibrator program, conducting surveys and tests until 2000 when the exclusive-use agreement between IVI and Schlumberger expired (Bird, 2003). IVI continued to develop the system into the early 2000s. IVI is no longer actively marketing the product because there currently is no client base for the system. The significant expense to retrofit marine exploration companies' ships to support marine vibrators is not offset by reduced operation costs or better data quality. IVI presently has marine vibrator systems that could be used for seismic data collection, but they would require renovation prior to deployment, which could take 3 months to 1 year (Christensen, official communication, 2010).

Stephen Chelminski, the inventor of the airgun and primary founder of Bolt Technology Corporation, also designed a marine vibrator prototype: "seavibe" (Weilgart, 2012). Seavibe is a modular, fully functional marine vibratory sound source that is 20 ft long with a 20- to 22-in diameter and can be towed at speeds up to 12 kn (13.8 mph) at any depth. The signal can be pulse-coded, a frequency swept signal, or a combination of the two without any high frequencies (5 to 100 Hz, although the vibrators operating frequency range is 2 to 200 Hz). The signal duration can be changed in real time. According to Weilgart (2012), the prototype system is reliable, more efficient than airguns, and requires less horsepower to tow than airgun arrays. A significant amount of the engineering and design for the Chelminski Research Marine Vibratory Sound Source has been completed on the marine vibrator prototype and patents have been applied for, but assembly and testing have not begun. Once financing has been secured, prototypes can be built and testing can occur within 1 year (CSA Ocean Sciences Inc., 2014).

3.1.2 Electric Marine Vibrator

The Geokinetics marine vibrator is a collaborative project with Petroleum Geo-Services and is a significant design departure from previous marine vibrators. The proof of concept of the Geokinetics marine vibrator was demonstrated in water offshore Texas in 1999. The Geokinetics marine vibrator design specifications are a frequency range of 6 to 100 Hz and an output level of approximately 2 bar meters peak-to-peak. The potential advantages of the marine vibrator include lower environmental impacts because of lower source signal amplitude levels, the capability to generate specialized frequency sweeps using pseudo-noise technology, and no in-water hydraulics with electromechanical drivers and controls. Reduction in overall sound level, specifically at frequencies above 100 Hz, which are higher than the useful seismic range, is a major advantage of the system. Another advantage is the reduction of peak acoustic power compared to conventional seismic sources, which occurs because the source energy is spread over a longer transmission time (Tenghamn, 2005 and 2006).

The Geokinetics flextensional shell design minimizes water flow and maximizes pressure wave generation that generates low frequencies efficiently. Another design feature of the Geokinetics marine vibrator is the two intentional resonances within the seismic bandwidth that help the vibrator generate the desired seismic frequency band. The resonant frequencies show up as peaks in the generated signal amplitude spectrum. Subtones present have resonant frequencies of 8 and 24 Hz. The tritons have resonant frequencies of 28 and 80 Hz. If the two spectrums are combined, there is an overall high amplitude spectrum completely inside the useable bandwidth for seismic surveys.

Currently, the Geokinetics marine vibrator is the electric marine vibrator closest to commercialization. Information collected to date suggests that marine vibroseis is less environmentally damaging than airguns, but this evaluation needs to be expanded to a full environmental assessment to identify and evaluate potential impacts and tradeoffs for the different technologies (CSA Ocean Sciences Inc., 2014).

3.2 Low-Frequency Acoustic Source (Patented)

Originally designed as a ship sound simulator for the Norwegian navy, the low-frequency acoustic source (LACS) is being promoted as an alternative source for seismic acquisition (Weilgart, 2010). The LACS system is a combustion engine with a cylinder, spark plug, two pistons, two lids, and a shock absorber. It creates an acoustic pulse when two pistons push lids vertically in opposite directions; one wave reflects from the sea surface and combines with the downward moving wave. There is no bubble noise from this system as all air is vented and released at the surface, not into the underwater environment. The absence of bubble noise allows the system to produce long sequences of acoustic pulses at a rate of 11 shots per second; this allows the signal energy to be built up in time with a lower amount of energy put into the water (Askeland et al., 2007 and 2009).

The system design also controls the output signal waveform, which can reduce the amount of non-seismic (>100 Hz) frequencies produced (Spence et al., 2007). The transmitted pulses are recorded by a near-field hydrophone and seafloor, and sediment reflections are recorded by a far-field streamer (Askeland et al., 2007 and 2009).

Two LACS systems are being offered commercially. The LACS 4A has a diameter of 400 millimeters (mm) (15.7 in), a height of 600 mm (24 in), and a weight of approximately 100 kg (220 lb) in air. Pulse peak peak pressure is 218 dB re 1 μPa at 1 m. Field test results of the LACS 4A system demonstrate that the system is capable of accurately imaging shallow sediments (~230 m [755 ft]) within a fjord environment (Askeland et al., 2008 and 2009). This system is suitable for shallow penetration towed streamer seismic surveys or VSPs (Askeland et al., 2008).

The second system, the LACS 8A, theoretically has the potential to compete with a conventional deep-penetration airgun seismic array. The LACS 8A system has pulse peak-peak pressure of 3 bar meter or 230 dB re 1 μPa at 1 m. The weight is 400 kg (880 lb), and the diameter is 800 mm (31.5 in). Several LACS units may be operated together to provide an increased pulse pressure (Bjørge Naxys AS, 2010). This system currently does not exist, and the project is presently on hold. It would take at least 18 months to build and field test one of these systems if money came available to do so (Abrahamsen, official communication, 2010).

The LACS system may be suitable but currently exists only as a design, and there is no known interest in further development of this system.

3.3 Deep-Towed Acoustics/Geophysics System

The U.S. Department of the Navy developed a deep-towed acoustics/geophysics system (DTAGS) to better characterize the geoacoustic properties of abyssal plain and other deepwater sediments. The system was tested and modified in the early 1990s and was used in various locations around the world until it was lost at sea in 1997 (Gettrust et al., 1991; Wood et al., 2003).

The second generation DTAGS is based on the original design but with more modern electronics. It uses the same Helmholtz resonator source consisting of five concentric piezoelectric ceramic rings sealed in an oil-filled rubber sleeve to generate a broadband signal greater than 2 octaves. The optimum frequency performance range is between 220 and 1,000 Hz with a source level of 200 dB re 1 μPa @ 1 m, which is a major improvement over the original DTAGS. The source is extremely flexible, allowing for changes in waveform and a decrease in sound level to produce a source amplitude, waveform, and frequency to suit specific requirements (Wood et al., 2003; Wood, 2010).

The DTAGS is towed behind a survey vessel usually at a level of 100 m (328 ft) above the seafloor and a vessel speed of 2 kn (2.3 mph; 3.7 km/hr); it can operate at full ocean depths (6,000 m [19,685 ft]). A 450-m (1,476-ft), 48-channel streamer array is towed behind the source to record the reflected signals. The DTAGS can also be configured with an aluminum landing plate, which transmits the acoustic energy directly into the seafloor. With this configuration, vertical bottom-founded hydrophone arrays are used to receive reflections (Breland, 2010).

Proximity of the acoustic source to the seafloor is an advantage of the DTAGS. The system has a limit of 1 km (0.6 mi) penetration in most marine sediments (Wood et al., 2003). It has been used successfully to map gas hydrates in the GOM (Wood et al., 2008), Canadian Pacific (Wood and Gettrust, 2000; Wood et al., 2002), and Blake Ridge (Wood and Gettrust, 2000).

There is only one DTAGS in existence at this time. While it has imaged shallow sediments and gas hydrate environments extremely well, the current tool design could not replace a deep-penetration airgun array for oil and gas exploration at this time; DTAGS was not designed for this purpose. However, there is no physical limitation to designing a resonant cavity source to simulate the frequency band of airguns.

According to Weilgart (2012), DTAGS was tested in the GOM in the summer of 2011 and was scheduled to undergo another trial off the coast of Oregon in September 2012. Though the frequency range of DTAGS is currently 200 to 4,000 Hz, it may be extended down to about 100 Hz (Wood, official communication, as cited in Weilgart, 2012).

3.4 Low-Frequency Passive Seismic Methods for Exploration

Low-frequency passive seismic methods utilize microseisms, which are faint tremors caused by the natural sounds of the earth, to image the subsurface. A typical survey consists of highly sensitive receivers (usually broadband seismometers) placed in the AOI to collect data over a period of time. Upon completion of the survey, the data are analyzed and filtered to remove all non-natural sounds, which is most efficiently completed using an automated process (Hanssen and Bussat, 2008).

All of the current methods use one of following three sources of natural sounds: natural seismicity; ocean waves; or microseism surface waves.

Natural seismicity uses the earth's own movements as a source of energy. Two techniques have been developed to use this energy source. Daylight imaging (DLI) uses the local seismicity of an area to produce reflection seismic profiles, similar to those recorded in active seismic surveys (Claerbout, 1968). As in active reflection seismic operations, geophones are deployed; the target can be imaged using a regularly spaced 2D line geometry (Hohl and Mateeva, 2006; Draganov et al., 2009). The seismicity of the area, geologic complexity, and receiver sensitivity control the record length. Daylight imaging can augment active seismic data, where it is difficult to collect data. Local earthquake tomography also uses local seismicity of a region to map on the reservoir scale (Kapotas et al., 2003). However, it is used to calculate the velocity structure of the subsurface in 3D by analyzing each earthquake on multiple receivers and generating ray paths instead of cross-correlating the recorded signals. This method requires a longer period of data collection than the other methods to produce results.

Ocean waves are used as a sound source for the seafloor compliance technique. The method requires that ocean-bottom seismometer stations with highly sensitive, broadband seismometers and differential or absolute pressure gauges be installed in water several hundred meters deep. In the right setting, a coarse one-dimensional (1D) S-wave velocity model of the subsurface down to the Moho can be generated using the measured water pressure and vertical movement of the seafloor caused by large passing ocean waves (Crawford and Singh, 2008).

Ambient-noise (surface-wave) tomography [AN(SW)T] uses low-frequency (between 0.1 and 1 Hz) ambient noise records to estimate shear wave velocities and structural information about the earth. The ambient noise used consists mainly of microseism surface waves (Rayleigh and Love waves) (Bussat and Kugler, 2009). This technique requires the use of broadband seismometers to record the low-frequency surface waves, which can penetrate to depths of several kilometers (Bensen et al., 2007 and 2008). Because the marine environment produces abundant, high-energy surface waves, a few hours or days of acquisition can produce good quality data. The AN(SW)T can be used in areas where seismic data are difficult to collect or in environmentally sensitive areas. While this technology is new and still in need of further testing, the lateral resolution at several kilometer depths may reach a few hundred meters, and the resolution may be better than gravimetric or magnetic data, which is promising for oil and gas exploration (Bussat and Kugler, 2009).

Surface-wave amplitudes is a method that images the geological structure of the subsurface by analyzing passive acoustic data that have not been geophysically processed. The transformation of incoming micro-seismic surface waves, scattered at vertical discontinuities, into body waves may produce these data, but the process is not well understood (Gorbatikov et al., 2008).

Low-frequency spectroscopy, also known as LFPS or hydrocarbon microtremor analysis (HyMAS), tests for an indication of subsurface hydrocarbon accumulation using spectral signatures gathered from the ambient seismic wave field recorded by broadband seismometers. The cause of the spectral anomalies, often called direct hydrocarbon indicators (DHI), is presently unknown, but the following reasons have been proposed: standing wave resonance; selective attenuation; resonant amplification (Graf et al., 2007); and pore fluid oscillations (Frehner et al., 2006; Holzner et al., 2009). Energy anomalies in the frequency range between 1 and 6 Hz have been observed in known hydrocarbon areas including Mexico (Saenger et al., 2009), Abu Dhabi (Birkelo et al., 2010), Brazil and Austria (Graf et al., 2007), and southern Asia (West et al., 2010). However, this methodology is highly dependent on the ability to process out all anthropogenic noise and topography (Hanssen and Bussat, 2008). This method is still in the early stage of development and has not been confirmed in the field during all studies (Ali et al., 2007; Al-Faraj, 2007).

The most successful use of low-frequency passive micro-seismic data has been on land, where it is easier to isolate the extraneous noise from the natural signal. The technique is also promising in the marine environment. To ensure success of a marine survey, (1) it is imperative that the recording instruments are in proper contact with the substrate (the natural signal may not be accurately recorded in unconsolidated material) and (2) the increase in both anthropogenic and naturally produced noise in the marine environment is correctly filtered so that it does not mask the signal of interest.

Passive seismic surveys cannot replace active seismic acquisition. However, passive acoustic data have the potential to enhance oil recovery at a better resolution than magnetic or gravimetric methods (Bussat and Kugler, 2009), especially in areas that are environmentally sensitive or where active seismic operations are difficult.

3.5 Low-Impact Seismic Array

Nedwell (2010) describes the concept of a low-impact seismic array (LISA) based on the use of inexpensive but powerful and rugged electromagnetic projectors to replace airgun arrays. The prospective benefit was that since the signal could be well controlled, both in frequency content and in the direction in which the sound propagated, the possibility existed of undertaking seismic surveys in environmentally sensitive areas with little or no collateral environmental impact.

The LISA project embodies the idea of using a large array of small but powerful electromagnetic projectors to replace airgun arrays. Initial measurements were made on a small (n = 4) array of existing electromagnetic transducers. It was found that a source level of about 142 dB re 1 μPa per volt @ 1 m was achieved, at a peak frequency of 25 Hz. The operating frequency could be reduced to below 10 Hz with reasonable modifications, allowing use of an array for seismic exploration. The results indicate that it would be possible to achieve an array source level of about 223 dB re 1 μPa @ 1 m, which is adequate for seismic surveying.

3.6 Fiber Optic Receivers

Short of replacing seismic airguns, improvements in fiber optic sensing and telemetering could allow use of smaller airguns and airgun arrays in the future (Nash and Strudley, 2010). Fiber optic receivers are receivers that incorporate optical fibers to transmit the received acoustic signal as light. They are most frequently used in the petroleum industry for seismic permanent reservoir monitoring, a 4D reservoir evaluation application. The optical receivers are permanently placed on the seafloor, ensuring consistency and repeatability of the 4D surveys, better signal-to-noise ratios, and quality of subsequently collected data. Fiber optic systems are not new. Fiber optical components have been used by the military for years in similar applications for antisubmarine warfare and area surveillance and have proven to be highly reliable.

Fiber optic receivers are more sensitive than standard receivers, which allows for smaller airgun arrays to be used. While these receivers offer a benefit to the environment through a decrease in airgun noise, this technology is not presently available for towed-streamer surveys.

Fiber optic receivers typically are used in areas with large-scale oil and gas production requiring 4D monitoring. They would not be expected to be used in the Gulf of Mexico OCS during the time period of this Programmatic EIS.

3.7 AIRGUN MODIFICATIONS TO LESSEN IMPACTS

In addition to alternative methods for seismic data collection, industry and the public sector have actively investigated the use of technology-based mitigation measures to lessen the impacts of airguns in the water.

3.7.1 Airgun Silencers

One such measure, an airgun silencer, which has acoustically absorptive foam rubber on metal plates mounted radially around the airgun, has demonstrated 0- to 6-decibel (dB) reductions at frequencies above and 0- to 3-dB reductions below 700 Hz. This system has been tested only on low pressure airguns and is not a viable mitigation tool because it needs to be replaced after 100 shots (Spence et al., 2007).

Spence et al. (2007) characterized the airgun silencer as a "proof-of-concept" that would require further development to become a commercial product. During a workshop conducted for the Spence et al. (2007) report, participants suggested that placing the absorbent material farther from the airgun may increase the life of the silencer and allow it to be used for larger airguns and arrays. However, a later review by Spence (2009) characterized the airgun silencer treatment as "impractical" for the same reasons noted above.

3.7.2 Bubble Curtains

Bubble curtains generally consist of a rubber hose or metal pipe with holes to allow air passage and a connector hose attached to an air compressor. They have successfully been tested and used in conjunction with pile driving and at construction sites to frighten away fishes and decrease the noise level emitted into the surrounding water (Würsig et al., 2000; Sexton, 2007; Reyff, 2009). They have also been used as stand-alone units or with light and sound to deflect fishes away from dams or keep them out of specific areas (Pegg, 2005; Weiser, 2010).

The use of bubbles as a mitigation for seismic noise has also been pursued. During an initial test of the concept, the sound source was flanked by two bubble screens; it demonstrated that bubble curtains were capable of attenuating seismic energy up to 28 dB at 80 Hz while stationary in a lake. This two bubble curtain configuration was field tested from a moving vessel in Venezuela and Aruba where a 12-dB suppression of low-frequency sound and a decrease in the sound level of laterally projecting sound was documented (Sixma, 1996; Sixma and Stubbs, 1998). A different study in the GOM tested an "acoustic blanket" of bubbles as a method to suppress multiple reflections in the seismic data. The results of the acoustic blanket study determined that suppression of multiples was not practical using the current technology. However, the acoustic blanket measurably suppressed tube waves in boreholes and has the capability of blocking out thruster noises from a laying vessel during an ocean bottom cable survey, which would allow closer proximity of the shooting vessel and increase productivity (Ross et al., 2004 and 2005).

A recent study, “Methods to Reduce Lateral Noise Propagation from Seismic Exploration Vessels,” was conducted by Stress Engineering Services Inc. under BOEM’s Technology Assessment & Research Program (Ayers et al., 2009 and 2010). The first phase of the project was spent researching, developing concepts for noise reduction, and evaluating the following three concepts: (1) an air bubble curtain; (2) focusing arrays to create a narrower footprint; and (3) decreasing noise by redesigning airguns. The air bubble curtain was selected as the most promising alternative, which led to more refined studies the second year (Ayers et al., 2009). A rigorous 3D acoustic analysis of the preferred bubble curtain design, including shallow-water seafloor effects and sound attenuation within the bubble curtain, was conducted during the second phase of the study. Results of the model indicated that the bubble curtains performed poorly at reducing sound levels and are not a viable option for mitigation of lateral noise propagation during seismic operations from a moving vessel (Ayers et al., 2010).

3.7.3 eSource Airgun

Bolt Technology Corporation has engineered a new type of airgun (the eSource airgun) designed to abridge the potential impact of seismic survey operations on marine life while also conveying optimal bandwidth for subsurface imaging. The eSource airgun optimizes output in the seismic band, suppressing the high-frequency components that contribute to acoustic impact, while retaining the low-frequency components that are critical to seismic exploration. This new technology could be widely available for commercial applications, as only the airguns would have to be changed on vessels and all of the handling systems would remain the same. Weilgart (2012) notes that “This approach may be too piecemeal and not comprehensive enough, however, as other potentially damaging characteristics of airgun pulses remain.”

4 OTHER SURVEYS AND EQUIPMENT

4.1 ACOUSTIC PINGERS

Acoustic positioning systems (i.e., acoustic pingers/transponders/transceivers/responders) can yield position estimation accuracy of a few centimeters to tens of meters and can be used over operating distances from tens of meters to tens of kilometers. Performance at any particular place or time depends on the design of the positioning system, its installed configuration, and the characteristics of the underwater acoustic environment. In general, acoustic pingers and transponders/transceivers/responders are components used to create underwater positioning systems. The operating frequencies of these devices usually is between 8 and 300 kHz. The operating frequency selected for a particular system is a function of the design of the system. The range over which various devices can be used varies from less than 100 m (328 ft) to more than 10 km (6.2 mi). The effective range of individual devices depends on the operating environment and the characteristics of the device, including its operating frequency.

Acoustic positioning systems are used to keep track of the locations of various components of seismic survey systems, including the locations of airgun arrays, streamer positions, OBN and

OBC locations, and to track ROVs as they operate. Valuable equipment often has a pinger attached to facilitate its recovery should it break away from a mooring or otherwise be lost.

4.2 TRANSPONDERS/TRANSCEIVERS

Transponders, like pingers, are a component used in acoustic positioning systems and are attached to a mooring, anchor, or other underwater item to be retrieved or located in the future. Unlike a pinger, a transponder may remain idle until it is "interrogated" by a transceiver. When the transponder is interrogated, it transmits a signal that may include location information. A transceiver is used to receive signals from pingers and to transmit signals to interrogate transponders, and in both cases aid in locating marine equipment for recovery. Transceivers usually are located on a vessel.

4.3 REMOTELY OPERATED VEHICLES AND AUTONOMOUS UNDERWATER VEHICLES

An AUV is a robot that travels underwater without requiring input from an operator after it is released. The AUVs constitute part of a larger group of undersea systems known as autonomous underwater vehicles, a classification that includes non-autonomous ROVs that are controlled and powered from the surface by an operator/pilot via an umbilical or using a remote control. The ROVs are unoccupied, highly maneuverable, and operated by crew on board a vessel. They are linked to the ship by a neutrally buoyant tether or, often when working in rough conditions or in deeper water, a load-carrying umbilical cable that is used along with a tether management system (TMS). The TMS is a garage-like device that contains the ROV during lowering through the splash zone; on larger work-class ROVs, the TMS is a separate assembly that sits on top of the ROV. The purpose of the TMS is to lengthen and shorten the tether to minimize the effect of cable drag where there are underwater currents. The armored umbilical cable contains electrical conductors and fiber optic cables that carry electrical power, video, and data signals between the operator and the TMS. The TMS then relays the signals and power for the ROV down the tether cable. Once at the ROV, electrical power is distributed to the ROV's components. In high-power applications, most of the electrical power drives a high-power electrical motor, which drives a hydraulic pump. The hydraulic pump is used for propulsion and to power equipment such as torque tools and manipulator arms where electrical motors would be unsuitable for use. Most ROVs are equipped with at least a video camera and lights. Additional equipment is commonly added to expand the ROV's capabilities. These may include sonars; magnetometers; a still camera; a manipulator or cutting arm; water and sediment samplers; and instruments that measure water clarity, temperature, salinity, sound velocity, light penetration, and pressure. The ROVs are classified based on their size, weight, ability, or power. The ROVs typically are positioned via acoustic link from the topside vessel, usually in the form of an ultra-short baseline (USBL) tracking system. Acoustic transponders also can be placed on the seafloor to improve position accuracy for an ROV and other objects.

The ROVs are used to support some G&G surveys, including deploying and retrieving some types of seismic sensors, particularly seismic nodes, on the seafloor. Other G&G surveys (such as CSEM) use ROVs to do the same with their sensor packages. While AUVs are not as commonly used as ROVs, they are used to make detailed maps of the seafloor before construction of subsea infrastructure begins; pipelines and subsea completions can be installed in a cost-effective manner with minimum disruption to the environment by using an AUV. An AUV allows survey companies to conduct precise surveys of areas where traditional bathymetric surveys would be less effective or too costly. Post-lay pipe surveys are possible now as well.

The AUVs now are the preferred method to meet archaeological survey requirements or hazard assessment requirements for pipelines in water depths exceeding 200 m (656 ft). Because use of magnetometers is waived at these water depths and airguns are not required for pipeline surveys, AUVs are used to deploy some of the same sensors as are used during a towed HRG survey (**Section 1.3**), including sonars, subbottom profilers, and MBESs. Although AUVs are autonomous, most AUVs are acoustically monitored using a USBL transponder and tracked from a mothership in order to ensure accurate positioning.

4.4 Water Guns

Water guns are very similar to the airguns used as seismic sound sources for a variety of G&G surveys. Water guns use compressed water to produce sound instead of compressed air used by airguns. Similar to airguns, water guns produce impulsive signals containing frequencies between 20 and 1,500 Hz depending on the size of the water chamber (USDOI, GS, Woods Hole Coastal and Marine Science Center, 2015). Water guns are not analyzed separately in this Programmatic EIS because the sound they generate is so similar to the sound produced by airguns that the analysis would be almost identical. Additionally, the oil and gas industry no longer uses water guns as a seismic source except in extremely rare instances.

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APPENDIX G

SCREENING OUT TEAM REPORT

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ABBREVIATIONS AND ACRONYMS

°	degree
2D	two-dimensional
AUV	autonomous underwater vehicle
BOEM	Bureau of Ocean Energy Management
CATEX	categorical exclusion
dB	decibel
dB re 1 μPa	decibel relative to 1 micropascal
EIS	Environmental Impact Statement
ft	foot
G&G	geological and geophysical
GOM	Gulf of Mexico
HRG	high-resolution geophysical
in^3	cubic inch
kHz	kilohertz
Mm	meter
Mms	millisecond
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OCS	Outer Continental Shelf
PRR	pulse repetition rate
rms	root mean square
ScOT	Screening Out Team
SEL	sound exposure level
SL	source level
SME	subject matter expert
SPL	sound pressure level
U.S.	United States
USDOC	U.S. Department of Commerce
USDOI	U.S. Department of the Interior
VSP	vertical seismic profile
WAZ	wide azimuth

1 INTRODUCTION AND PURPOSE

As part of the planning and drafting of the Programmatic Environmental Impact Statement (Programmatic EIS) for geological and geophysical (G&G) activities on the Outer Continental Shelf (OCS) of the United States (U.S.) in the Gulf of Mexico (GOM), it was recognized by senior staff of Bureau of Ocean Energy Management (BOEM) that there was a need to identify, quantify, and analyze all active acoustic source operations that might occur during G&G activities. Ultimately, it was desired that this process indicate which sources and activities, based on their potential to affect the environment, required a thorough analysis in the Programmatic EIS and which sources and activities did not. During the initial meeting on this subject, senior BOEM staff decided to create a Screening Out Team (ScOT), which first convened in April 2014, to examine the issue and make recommendations. The team consisted of subject-matter experts (SMEs) from BOEM's Gulf of Mexico OCS Region, BOEM's Headquarters, and CSA Ocean Sciences Inc.

Specifically, the ScOT was assigned the following tasks:

- include for consideration the entire U.S. GOM (e.g., all depth regimes);
- identify all active acoustic G&G sources for the Oil and Gas, Marine Minerals, and Renewables Energy Programs currently or in the near future within BOEM's jurisdiction;
- identify all sources regardless of whether they are hull-mounted, towed, or fixed;
- examine all frequency regimes for identified acoustic G&G sources;
- characterize all relevant source operating parameters (e.g., source levels [SLs], pulse length, beam patterns, pulse repetition rates);
- identify acoustic G&G sources that may be used simultaneously; and
- consider potential new technology.

The ScOT did not examine non-G&G or non-G&G-related sound sources, including the following:

- explosive removal operations;
- construction noises such as pile driving, dredging, etc.;
- production and drilling noise;
- machinery or propulsion noise from vessels or oil platforms;
- local navigation transponders or systems, acoustic communication systems, or acoustic releases;

- active acoustic sources from geotechnical/geological testing and vessels; and
- vessel traffic.

It should be noted that, even though the charter of the ScOT was very specific (i.e., to identify which active acoustic sources/operations that might be or could be screened out from extensive and unnecessary analysis), the broad range of the details needed to complete the analysis would provide information to the Alternatives' discussion for the Programmatic EIS. Furthermore, the historic and operational data collected to complete the analysis would provide many of the technical and operational details for current and future activities that would directly feed into the Programmatic EIS acoustic impact modeling. Additionally, the ScOT needed to understand and be consistent with ongoing internal BOEM discussions concerning possible future category exclusions (CATEXs) for these acoustic systems.

2 APPROACH USED

The ScOT began examination of the task using a "top-down" approach in order to ensure that all BOEM programs, survey types, acoustic systems, and overall operations to be addressed in the Gulf of Mexico G&G Programmatic EIS were identified and included in the analysis. However, it quickly became evident that this approach had a severe disadvantage in identifying and analyzing the specific details (e.g., operational frequencies, modes, depths, repetition rates, etc.) of the numerous systems and operations that might be used in the GOM. Recognizing this problem and having gained a general understanding of the breadth of potential systems and operations that needed examination from that first attempt, the ScOT decided to shift to a "bottom-up" approach to ensure access to all of the details needed to examine and evaluate those systems. Unfortunately, this approach became bogged down in the examination and quantification of the numerous systems potentially used; in addition, it was recognized that a large number of permutations and variations were possible in how these systems could be deployed together or separately.

After several discussions, the ScOT decided to try a "middle-out" approach. This method used the issues encountered in the first two approaches to guide a process that attempted to avoid the same pitfalls while maintaining the fidelity needed to complete the desired analyses. In this way, the ScOT would be able to group the sources such that those with negligible potential to cause impacts could be identified for possible removal from further consideration. At the same time, the systems that did not have negligible impact potential could be better characterized and understood for subsequent analyses in the Programmatic EIS (e.g., in discussions of alternatives, mitigation, etc.). Examples of the steps used in this approach include the following:

- using data from the top-down approach to completely identify all of the surveys and active acoustic source system types that needed to be examined;
- using data from the top-down approach to begin grouping and categorizing the surveys by characteristics that are operationally significant but not directly related

to the systems employed (e.g., operating water depths, durations of operations, etc.);

- using historic data and practical experience of the SMEs to identify which systems are operated together for which survey types;
- using data from the bottom-up approach to examine each active acoustics system type (i.e., single airgun, airgun arrays, boomers, multibeam sonar, side scan sonar, subbottom profilers, and echosounder systems) and identify the range of the important system parameters present (e.g., frequencies, pulse lengths, etc.); and
- utilizing the knowledge of the SMEs to group systems together that have similar operating parameters and divide the ranges of the system parameters into "natural" divisions based on operational requirements (e.g., what is needed to make that system perform well in a given situation) or known biological parameters (e.g., frequencies believed to be beyond the hearing range of various species).

The ScOT recognized that within the scenarios proposed for the Programmatic EIS, this assessment would need to address the projected active acoustic sources activities in the GOM for the next 10 years, including changes to the types or specifications for the sources. Furthermore, this effort needed to consider currently known technical issues that could affect how the ScOT parses the sources. Specifically, the ScOT

- searched for and identified the current trends for source operations in the GOM, including the following:
  - the trends to increased size and SLs for the numerous variations of wide azimuth (WAZ) surveys to better examine areas under subsurface salt structures,
  - the relatively new approach in speculation ("spec") surveys that use a single airgun,
  - the reduction/absence of vertical cable surveys in recent years,
  - a decrease in the number of geophysical surveys conducted on the OCS (i.e., water depths less than 200 meters [m]; 656 feet [ft]) and the current trend of exploration and production activities moving to deeper water areas farther offshore,
  - the common use of frequencies above 180 kilohertz (kHz) during marine mineral high-resolution geophysical (HRG) surveys to ensure the resolution needed for these surveys on the shelf,
  - the combinations of HRG survey sources typically used together, and

- boomer use in shallow water is rare for the Marine Minerals Program because it provides a 0.5- to 1-m (1.6- to 3.3-ft) resolution and typically is replaced with subbottom profile systems that have sufficient depth penetration and higher resolution (note that it was kept in the analysis because it may be used to examine ancient, sediment-filled river channels in the future), and that in Renewable Energy Program surveys, it is more commonly used;

- recognized the need to be flexible in this discussion to accommodate minor variations in source parameters and operational techniques;
- recognized the need to consider new or developmental systems, such as marine vibrators or parametric subbottom profilers;
- recognized the potential for changes to the acoustic thresholds or calculation techniques that could influence how these sources are perceived; and
- recognized the recent developments or papers that discuss these sources (i.e., LGL Ltd., 2010; Martin et al., 2012; Zykov, 2013; Zykov and MacDonnell, 2013; Applied Acoustic Engineering, Ltd., 2014a, 2014b, and 2014c; Deng et al., 2014; EdgeTech, 2014).

In order to complete the screening process, several specific technical details needed to be discussed and resolved by the ScOT. Some of the most important details included the following:

- Using an acoustic metric or suite of metrics that are consistent with existing and proposed acoustic thresholds but that also allow appropriate source characterization. Typically, root mean square (rms) sound pressure levels (SPLs), or SPLrms, and sound exposure levels (SELs) are used. Broadband sources like airguns and boomers can use standard metric. However, to capture the character of most HRG sources, the SPLrms needs to consider the duration of the individual pulses used because they are much shorter than 1 second (e.g., microseconds [μs] to milliseconds [ms]). For this analysis, SPLrms has been corrected for pulse duration. Thus, if a 200 decibel relative to 1 micropascal (dB re 1 μPa) at 1-m source has a 10-ms pulse, it is shown as a 180 dB re 1 μPa at 1-m source (e.g., 200 + 10log(0.010 sec) = 200 - 20 = 180 dB).
- Water depths were divided into three categories: shallow or shelf (0 to 20 m; 0 to 66 ft), slope (20 to 1,100 m; 66 to 3,609 ft), and deep (>1,100 m; 3,609 ft). This is consistent with depth zones presented in the Atlantic G&G Programmatic EIS (U.S. Department of the Interior [USDOI], BOEM, 2014) and is consistent with bathymetric features in the GOM.
- Possible operating frequency bands for multibeam, side-scan, and echosounder systems were divided into three groups: <30 kHz, 30 to 180 kHz, and >180 kHz. This was done to accommodate the understandings that (1) most mysticetes are

believed to have reduced sensitivity above 30 kHz (U.S. Department of Commerce [USDOC], National Oceanic and Atmospheric Administration [NOAA], 2013); (2) odontocetes and pinnipeds have some hearing capability below 30 kHz but their best sensitivity is between 10 and 120 kHz (estimated by a reduced sensitivity of greater than 20 dB from the audiograms in Figure 8.1 of Richardson et al. [1995]); and (3) most marine mammals (even high-frequency species) are not believed to hear above approximately 180 kHz, but even if they do, it is with a very reduced sensitivity level (e.g., more than 40 dB less sensitive than for their best frequencies) (Richardson et al., 1995; USDOC, NOAA, 2013).

- SLs for airguns were identified for single airguns and airgun arrays (i.e., multiple airguns operated together in an array). These sources were then divided into groups using the volume (in cubic inches) of the airgun or array and the respective SLrms bands. A simple assessment for the airguns or arrays as small, medium, or large resulted in the following bands:
  - for single airguns, SLs of <210, 210 to 230, and >230 dB rms (with corresponding volumes of <200, 200 to 350, and >350 cubic inches [in^3]); and
  - for the airgun arrays, SLs <240, 240 to 250, and >250 dB rms, (with corresponding volumes of: 2,000 to 3,000; 3,000 to 4,000; and 4,000 to 8,600 in^3).
- The SMEs identified these as representative of the sources that have been used in the GOM since 2010.
- The ScOT understood and was cognizant of the potential influence of pulse duration and signal or pulse repetition rates (PRRs) for the various sources. All of the sources listed in **Table G-1** employ signals with durations of less than 1 second, and many have signal lengths in the microsecond range. This characteristic, when combined with how often that signal is transmitted, directly leads to how long an animal could be exposed to the sound source. Neither the signal duration nor the PRR were directly used to recommend removal of a system from further consideration, but they were considered for sources that require further examination.
- Similarly, beam patterns and transmission sequencing by sources (e.g., sequential ensonification of different sectors or portions of a full beam with different frequencies, such as is often used by multibeam sonar) were not directly used in the screening out process, but they may be useful for further analysis. However, it should be noted that most of the HRG systems have relatively narrow beams which only ensonify small narrow or “pencil-like” volumes of the water column (Zykov and MacDonnell, 2013; USDOI, BOEM, 2014). For example, most subbottom profilers have a beam that is 15° to 25° wide (depending on the frequencies used), while multibeam and side-scan sonar

produce beams or beam fans that are 1° to 2° wide. Various models of the HRG systems can be hull-mounted or deployed on a tow body or possibly an autonomous underwater vehicle (AUV). When the tow body or AUV is employed, these platforms try to maintain a constant height above the seafloor. For subbottom profilers, this height may be 3 to 6 m (10 to 20 ft); for side-scan and multibeam sonars (in deep tows), it may be 50 to 100 m (164 to 328 ft). For hull-mounted systems, with the exception of the more powerful multibeam sonars and boomers, there are water depth limitations for optimal use of these systems, which limits their operation to shelf waters (i.e., approximately <200 m; 656 ft) or reduces their transmission repetition rates. The operation of many of these systems in shallow waters or near the seafloor causes the main acoustic beam to quickly interact with the bottom and accelerate energy loss. This significantly reduces the possibility of adverse effects to nearby marine mammals. For example, it would be highly unlikely that a marine mammal would pass through the main beam of a subbottom profiler that is being towed 3 m (10 ft) above the seafloor. In addition, the acoustic energy that reflects from the seafloor is greatly reduced (e.g., 15 to 35 dB) when it interacts with the seafloor, further reducing the possibility of impacts.

At the time of the ScOT analysis, the report on the 2008 Madagascar mass stranding of melon-headed whales (Southall et al., 2013) was available and one source of concern was multibeam sonar systems (or other similar high-frequency HRG system) and their potential for adversely affecting marine mammals. Additionally, at the time of the ScOT analysis, the National Marine Fisheries Service (NMFS) was in the process of preparing a final version of their Level A acoustic threshold criteria for airguns (USDOC, NOAA, 2013). The ScOT was aware of these documents and attempted to consider them in their analysis.

Furthermore, results from Deng et al. (2014) had been released and were considered in this analysis. Deng et al. (2014) discussed how active acoustic systems such as multibeam and side-scan sonars are designed to produce a signal with a specific frequency content (i.e., in the desired frequency band, but also produce a broader range of frequencies. Included in this broader frequency band are harmonic and subharmonic signals that nominally display only 40 to 60 dB below that produced in the desired band. As an example, while a 240-kHz multibeam sonar has a primary (and most powerful) signal above the frequency of an animal’s hearing range, the animal may be aware of its presence because it can hear the subharmonics at 120, 80, or 60 kHz frequencies, which are within its hearing range. These signals will be present at a reduced SLs and are, therefore, significantly less likely to affect an animal; nevertheless, operation of the active acoustic systems is not undetectable to that animal.

Table G-1. Consolidated Acoustic Source and Survey Table.

Notes:	Program	Survey Type	Name	Variation of Survey Methodology	Water Depth	Duration (days)	Typical # Block /Survey	Single Airguns Vol. [in^3] Src Lvl[dB rms]			Airgun Arrays Vol. [in^3] Src Lvl[dB rms]			Boomer	Multibeam [kHz] (8,9)			Sidescan [kHz] (10,11)			Subbottom Profiler (12,13)	Echosounder [kHz] (14)		
					S = shallow (<200m)			S	M	L	S	M	L											
					M = slope (200-1100m)			< 200	200 -350	> 350	2-3 k	3-4 k	8 k	dB	< 30	30-180	> 180	< 30	30-180	> 180		< 30	30-180	> 180
					D = deep (>1100m)			< 210	210-230	>230	< 240	240-250	>250	rms	kHz	kHz	kHz	kHz	kHz	kHz	dB rms	kHz	kHz	kHz
1	Oil & Gas	Deep, Penetrating Seismic	2D		S	various	various				Similar to Slope & Deep maybe slight (5-15 dB?) reduction in SL													
1	Oil & Gas	Deep, Penetrating Seismic	3D / 4D		S	various	various																	
1	Oil & Gas	Deep, Penetrating Seismic	3D WAZ		S	various	various																	
1	Oil & Gas	Deep, Penetrating Seismic	2D Hi Res		S	various	various																	
1	Oil & Gas	Deep, Penetrating Seismic	3D Hi Res		S	various	various																	
1	Oil & Gas	Deep, Penetrating Seismic	2D		M, D	various	various					240-250												
1	Oil & Gas	Deep, Penetrating Seismic	3D / 4D		M, D	various	various					240-250												
1	Oil & Gas	Deep, Penetrating Seismic	3D WAZ		M, D	various	various						>250											
1	Oil & Gas	Deep, Penetrating Seismic	2D Hi Res		M, D	various	various					240-250												
1	Oil & Gas	Deep, Penetrating Seismic	3D Hi Res		M, D	various	various					240-250												
1	Oil & Gas	Deep, Penetrating Seismic	VSP	0 Offset, Walk Away, 3D VSP	S, M, D	1-2	1-1.5				< 240													
2	Oil & Gas	Deep, Penetrating Seismic	Vertical Cable		S, M, D	?	?	?	?	?	?	?	?											
3	Oil & Gas	Deep, Penetrating Seismic	New	Single Gun Spec Survey	S, M, D	various	50-100		215-225															
	Oil & Gas	HRG		multi-source	S, M, D	1-2, up to 7	< 1								10-15	120 & 410	200 or 400		120 & 410	300 & 600	<200		24 & 200	> 180
	Oil & Gas	HRG		multi-source w/ airgun	S, M, D	1-2, up to 7	< 1	186											105 & 410		<200		24 & 200	
5	Oil & Gas	HRG		multi-source w/ boomer	S, M, D	1-2, up to 7	< 1							215					105 & 410		<195		24 & 200	
	Oil & Gas	HRG		multi-beam only	S, M, D	1-2, up to 7	< 1										207							
6	Marine Minerals	HRG		multi-source	S	1-2, up to 7	< 1										> 180			300 & 600	<200			> 180
4,5,6	Marine Minerals	HRG		multi-source w/ boomer	S	1-2, up to 7	< 1							215			> 180			300 & 600	<195			> 180
6	Marine Minerals	HRG		sub-bottom profiler only	S	1-2, up to 7	< 1														<195			> 180
6	Marine Minerals	HRG		multi-beam or sidescan only	S	1-2, up to 7	< 1										> 180			300 & 600				> 180
6	Renewable	HRG		multi-source	S	1-2, up to 7	< 1									100 & 500	> 180		100 & 500	300 & 600	<200			> 180
4,5,6	Renewable	HRG		multi-source w/ boomer	S	1-2, up to 7	< 1							215		100 & 500	> 180		100 & 500	300 & 600	<195			> 180
6	Renewable	HRG		sub-bottom profiler only	S	1-2, up to 7	< 1														<195			> 180
6	Renewable	HRG		multi-beam or sidescan only	S	1-2, up to 7	< 1									100 & 500	> 180		100 & 500	300 & 600				> 180
7	Renewable	CO2 Sequestration	2d, 3D		S, M, D	1-30 est.	< 1					240-250												

Key:

(dark green)	> = 180 kHz, therefore above MM hearing and not an issue - **Strong candidate to be scoped out.**
(light green)	In MM freq. band, but relatively low Src Lvl - **Possible candidate to be scoped out.**
(yellow)	Mixed frequencies, **some can be scoped out, others need more analysis.**
(orange)	Med.-High Src Lvl and in MM Freq. band, needs further analysis - Potential issue, but pulse length is very short and it may help.
(red)	High Scr Lvl, and in MM hearing range, can **NOT** be scoped out
(white)	In MM freq. band, and Src Lvl relatively low, but pulse length and beam pattern may help, needs further analysis
(grey)	Not Applicable - i.e., a source using these parameters is not present in this survey

Notes:	
1	These are the standard or typical seismic survey currently in use
2	There surveys are extremely rare. Only one company has done them in recent memory. It is old technology and not expected to be used, but it should be included in EIS for completeness.
3	This is a new technology and approach. It is speculative and just beginning to be used.
4	These Boomer surveys are very rare. None has been performed in approximately the last 7 years. Keep in EIS for completeness and in case they are needed.
5	Boomer typically 20-800 Hz, with peak-to-peak SL <220 dB
6	All sources used for Marine Minerals are > 180 kHz, as are many for Renewables. But, some renewable sources may be < 180 kHz.
7	For CO2 Sequestration, area surveyed is < 1 OCS Block, expect 2D or 3D surveys to be < 1 week in duration.
8	Max. SPL SL for multibeams is approx. 242 dB for hull mounted and <210 for towed or AUV systems. In shallow water, expct Scr Lvl to be reduced to reduce reverb, and freq to increase (maybe to > 180 kHz) to improve resolution.
9	Marine Mineral surveys may replace multibeam systems with swath interfermetric systems with similar frequency and SL characteristics.
10	Nominal SPL SL for sidescan sonars is typically < 220 dB rms, but many are 210 dB or less.
11	Distance off bottom for towes in normally 10-20 % of depth in slope and deep water, or ~ 4 m below the surface in shallow water.
12	Typical freq. bands for sub-bottom profilers are: 2-6, 2-16, or 4-24 kHz.
13	Typical SPL SL for sub-bottom profilers is < 210 dB rms.
14	Typical SPL SL for echosounders is < 200 dB rms. Also, often used for safety/navigation purposes replacing or substituting for simple fathometers.

3 RESULTS AND RECOMMENDATIONS

Based on the ScOT discussions outlined previously, the team constructed and refined **Table G-1**. This table is designed to capture the overall nature of the possible surveys that may occur during G&G activities. The first major division in this table is the separation of the deep penetrating seismic surveys from the HRG-like surveys. This was done to indicate that these two categories of surveys typically do not occur together in any coordinated way for any given project because the vessels they utilize would physically interfere with the other survey. Furthermore, it is highly unlikely that they would occur together for different projects due to the exclusive nature of the leasing procedures. Each row or line in the table represents a different type of survey, with the columns to the right side of the table identifying which sources would be used for each survey type. The two main factors that drive the number of rows in the table are (1) the sources or combinations of sources used for each survey type and (2) the depths at which the sources with those critical characteristics are employed. Examples of the consequence of these factors can be seen in the comparison of the rows for the two-dimensional (2D) and vertical seismic profile (VSP) surveys. Because of the differences in the size and power of the sources used (i.e., reduced SL for 2D surveys in shallow or shelf waters ["S" in the sixth column]), there are two 2D survey rows, one for shallow depths (S) and one for slope or deep depths (M or D), while there is only one for the VSP surveys. All of the sources for VSP surveys fall into the SL range for a small airgun array, which is used for all VSP surveys regardless of the depth in which the survey occurs. A much larger table was reduced or concentrated down to this table, while still maintaining the ability to differentiate the critical source or operational characteristics of each survey type.

The selection and grouping of the critical characteristics of a source allowed it to be represented by a reduced number of cells in **Table F-1**. For example, the operating frequencies for the multibeam sonars commonly used in marine mineral, HRG, and multiple source surveys may include 200, 234, 300, and 600 kHz systems. For brevity and tabular clarity, these various systems have been contained in the ">180 kHz" cell for this survey type.

Additionally, the cells in the various source columns have been color coded by the ScOT to indicate its recommendations concerning whether or not a system can be screened out. The color code system is as follows:

- Dark Green identifies sources with operating frequencies above 180 kHz, which have been highly recommended to be screened out. Systems that operate at these design frequencies are above the hearing range of marine mammals, and the portion of their signals that are with the hearing range of marine mammals (i.e., the subharmonics and off-design incidental noise components) is significantly reduced in level.
- Light Green identifies sources that operate within the marine mammal frequency hearing bands but have relatively low SLs (less than 200 dB re 1 μPa at 1 m for a single pulse); have a short pulse length (i.e., much less than one second and typically 5 to 40 ms); and operate where their main beams quickly interact with

the seafloor (i.e., within 20 to 40 m), which significantly reduces their strength. Therefore, these sources are recommended to be screened out. There may be a very small and narrow volume of the ocean where harassment impacts might occur, but it is very unlikely that marine animals would be in these volumes while the source is ensonifying them.

- Yellow identifies sources that use dual frequencies (one of which is greater than 180 kHz) or that use a range of frequencies (part of which is above 180 kHz), and are conditionally recommended be screened out for the operations above 180 kHz and should be further examined for the remaining frequencies. After the high frequency systems have been screened out, the remaining systems will need to be examined using the approach described in the previous bullet. Alternatively, these systems could be directed to only use frequencies above 180 kHz, which have been highly recommended for screening out.

- Orange identifies sources with medium or high SLs that operate within the marine mammal frequency hearing range, and are not recommended for screening out. They probably require additional analysis even though many of these systems are rarely employed.

- Red identifies most single airgun or airgun array systems that are strongly not recommended for screening out and definitely require full analysis.

- White identifies a small single airgun system that has relatively low power and less than frequent use that may be able to be screened out due to the low SL, but, for consistency, perhaps all airgun systems should be treated the same. Based on the historic acoustic threshold of 160 dB for Level B impacts, the range around this source that might impact a marine mammal is approximately 20 m, without any weightings applied.

A review of **Table G-1** leads to a few overall conclusions about the operation of these sources, including the following:

- Due to their strong signal, frequency content, and persistence of operations, deep penetrating seismic surveys will require a full analysis of their potential acoustic impacts in the Programmatic EIS. Additionally, the use of airgun arrays for possible carbon dioxide sequestration surveys will require complete analysis, as will use of medium and large single airgun surveys. The small single airguns may be eligible for screening out due to their low SL, but it may be simpler to treat them the same as other airgun systems.

- The HRG surveys associated with the Oil and Gas Program often need to operate off of the OCS. This changes the selected operating systems parameters (i.e., lower frequencies, higher SLs, longer signals, higher heights above the seafloor, etc.) from those typically used for the Renewable Energy and

Marine Minerals Programs. Therefore, even though **Table G-1** seems to indicate that these systems may be operated in a fashion similar, they typically are operated at the opposite end of the range for that parameter. For example, for a dual frequency 120- or 400-kHz multibeam, the 410-kHz system setting may be suitable for shallow water, but the 120-kHz setting is used in deeper water to reduce signal attenuation in the water column so that it is not above the 180-kHz requiring analysis. It is recommended that the HRG operations associated with the Oil and Gas Program receive a full analysis in the Programmatic EIS.

- With the exception of the rarely used boomer and the relatively low powered subbottom profilers, all systems used for Marine Minerals Program surveys should be screened out because they operate above 180 kHz. Discussions with the SMEs for those operations identified that this operational selection was driven partially by the need for higher resolution in the surveys due to their operation in shallow water and by the need to quantify the sediments being examined; however, it was a deliberate choice based on potential marine mammal impacts.

With the exception of the carbon dioxide sequestration survey, the Renewable Energy HRG surveys currently are conducted in a manner similar to the Marine Minerals surveys, but they also include some sources that operate below 180 kHz. It is possible that these surveys could use higher frequency systems and minimize potential impacts and the need for additional analysis.

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APPENDIX H

MARINE MAMMAL HEARING
AND
SENSITIVITY TO ACOUSTIC IMPACTS

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ABBREVIATIONS AND ACRONYMS

dB	decibel
dB re 1 μPa	decibels relative to 1 micropascal
EIS	Environmental Impact Statement
FR	Federal Register
G&G	geological and geophysical
GOM	Gulf of Mexico
HESS	High Energy Seismic Survey (team)
Hz	hertz
kHz	kilohertz
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
PTS	permanent threshold shift
rms	root mean square
SEL	sound exposure level
TTS	temporary threshold shift
USDOC	U.S. Department of Commerce

1 INTRODUCTION/OVERVIEW

Marine mammals rely on sound to live, producing and receiving it to perform various life functions. The ocean is naturally noisy, but humans add a myriad of sounds that are increasingly impinging on the underwater soundscape. There is clear evidence that certain sounds can negatively affect marine life under certain conditions, but the type and magnitude of these impacts for different species and sound types remain poorly understood. Recently, there have been significant advances in scientific knowledge, at least in some conditions, on hearing systems, the effects of noise on hearing, and behavioral responses to various sounds. The scientific community is discovering group (e.g., species, taxonomic) and species-specific differences in hearing and how it may be affected as well as the overarching relevance of sound exposure context in driving the probability, severity, and consequences of behavioral response. New ways of assessing and mitigating potential impacts emerged from this evolution in understanding.

The initial focus on how anthropogenic noise might affect marine mammals centered on potential injurious types of sound impacts. This was driven largely by concerns over direct hearing or tissue damage and isolated marine mammal mass stranding events; these have primarily involved beaked whales exposed to military sonar but recently have included melon-headed whales (*Peponocephala electra*) exposed to military and commercial sonar systems. Largely due to various research (discussed in **Section 4.2**) indicating that direct physical injury from noise is limited for some species except when quite close to sound sources, there is increasing interest in biologically significant behavioral changes from noise within a broader ecological context. While the zones around sounds in which species from different marine mammal groups may be physically harmed appear to be small, the areas over which animals may be disturbed in significant ways that may impact vital life functions (e.g., foraging, reproduction, or even survival if reactions increase risk of predation or stranding) may be significantly larger. These considerations and the underlying complexity of understanding and assessing their probability of occurrence have become more central in developing noise exposure criteria and other means of assessing the probability of negative effects from noise exposure. A key challenge in establishing and updating exposure criteria and conducting environmental assessments given the rapidly evolving science revealing these complexities is establishing an appropriately precautionary yet tractable approach. Many of these issues and the underlying science are considered in detail in a major comprehensive review and application of science in the context of noise exposure criteria (Southall et al., 2007). Selected recent studies that have provided additional important findings are also summarized here, and subsequent efforts to synthesize and apply more recent scientific findings and evolve exposure criteria for various sound sources by Finneran and Jenkins (2012); the U.S. Department of Commerce, National Marine Fisheries Service (*Federal Register*, 2013); and Tougaard et al. (2014) are discussed also.

This appendix summarizes the current state of scientific knowledge about the importance of sound and the effects of noise on marine mammals. Most attention is given to species typically present in the Gulf of Mexico (GOM), primarily odontocetes (toothed whales and dolphins), with some discussion of mysticetes (baleen whales), and sirenians (manatees). The potential effects of noise exposure on marine mammal physiology, hearing, communication, and behavior from continuous and pulsed (impulsive) sound source types (e.g., longer continuous signals versus brief transient impulsive signals) are discussed. Additionally, evolving noise exposure criteria and operational mitigation measures are building on historical approaches, with attention to the types of acoustic sources present in the proposed geological and geophysical (G&G) operations proposed within the Area of Interest.

2 ROLE OF ACOUSTICS IN MARINE MAMMAL ECOLOGY

The underwater acoustic environment can be noisy, with sounds from a host of natural and anthropogenic sources. Some natural sounds are biological (e.g., fishes, marine mammals, some invertebrates) and others are environmental (e.g., waves, earthquakes, rain). Among the anthropogenic sources, many produce noise as an unwanted by-product of normal operations (e.g., shipping, drilling, tidal turbines), whereas others (e.g., sonars, airguns, underwater communications systems) are produced for a specific remote-sensing or data transfer purpose (Hildebrand, 2009). Detailed measurements have been made for many of these sources, but how they interact and cause or contribute to adverse effects on acoustically oriented marine life remains poorly understood.

For most marine vertebrates, the production and reception of sound serves critical biological functions, including communication, foraging, navigation, and predator avoidance (Schusterman, 1981; Watkins and Wartzok, 1985; Richardson et al., 1995; Tyack, 1998; Wartzok and Ketten, 1999; National Research Council [NRC], 2003, 2005; Clark and Ellison, 2004; Southall et al., 2007). All marine mammals that have been observed and studied at even a very basic level are known to produce sounds in a variety of inter- and intra-individual contexts, most associated with the vital life functions of foraging, reproduction, and survival (NRC, 2005). As described in detail in previous summaries of marine mammal vocalizations (Wartzok and Ketten, 1999), it is evident that different species groups use different frequency ranges in the sounds they typically produce, including social communication and (for odontocetes) echolocation sounds. These broad relationships reveal some general conclusions regarding the potential interference, which is driven largely by frequency overlap, of human noise with marine mammal vocal signals. While the frequencies of vocalizations do not always completely overlap with the best frequencies of species-typical hearing, these comparisons reveal a greater potential for interference between low-frequency shipping and seismic survey noise and low-frequency calls of mysticetes than with the moderate to very high frequencies (ultrasonic) produced by odontocetes (dolphins and porpoises).

Odontocetes have developed sophisticated biosonar capabilities involving high-frequency (ultrasonic) impulsive clicks to feed and navigate (Au, 1993) and use a variety of whistles and other calls to communicate in social interactions. These animals make sounds across some of the widest frequency bands that have been measured in any animal group. Communicative sounds generally range from a few hundreds of hertz to several tens of kilohertz, but echolocation clicks can extend above 100 kilohertz (kHz).

Mysticetes have developed moderate to long-range communication capabilities for reproductive and social interactions and to orient themselves in the underwater world (Clark, 1990; Popper and Edds-Walton, 1997). These whales generally produce low-frequency sounds in the tens of hertz to several kilohertz band, with a few signals extending above 10 kHz, most notably in humpback whales (*Megaptera novaeangliae*) (Au et al., 2006).

Other non-cetacean marine mammals, including manatees (sirenians) and pinnipeds, make and listen to sounds for a variety of communicative and spatial orientation functions, but like the large whales, they appear to lack specialized echolocation capabilities (Schusterman, 1981; Wartzok and Ketten, 1999; Schusterman et al., 2000; Nowacek et al., 2003). These sounds can extend above those used by mysticetes but occur over a narrower frequency band than those used by odontocetes and are from approximately 100 hertz (Hz) to several tens of kilohertz.

3 HEARING IN MARINE MAMMALS

Hearing has been measured using behavioral and electrophysiological methods in approximately 25 percent of the known marine mammal species, although with a disproportional representation of species commonly found in captivity, and some entire groups (e.g., mysticetes) remain untested. For detailed reviews, refer to Southall et al. (2007), Mooney et al. (2012), and Reichmuth et al. (2013); key subsequent findings are discussed here. The focus of this appendix is on marine mammal hearing, but other marine vertebrates can be affected by human sounds as well. For a discussion of hearing and the effects of noise on sea turtle hearing, refer to **Appendix I**. For a discussion of hearing and the effects of noise on fish hearing, refer to **Appendix J**.

In terms of the physical morphology of hearing structures for the primary taxa of concern in the GOM (cetaceans), a detailed review is given in Mooney et al. (2012). Broadly speaking, cetacean ears include many of the same features present in terrestrial mammals, including an external opening (outer ear); a tympanic membrane, Eustacian tube, and ossicles (middle ear elements); and a cochlea and semicircular canals (inner ear). There are clear differences, however, including the fact that the outer ear does not include an external ear appendage (pinna) and the auditory meatus (ear canal) is an elongated and mostly collapsed structure winding through the tissues of the head. The bony portions of the ear are extremely dense and are not as directly integrated into the skull as in terrestrial mammals. The exact pathways of sound into the cochlea are not completely understand and may differ among species and sound frequencies. However, for some species (and especially odontocetes that are the primary focus here), there are specialized fats present in the lower jaw and modifications of the bony structures that appear to provide a sound transduction path via a fundamentally different route that the conventional external to middle to inner ear path common in terrestrial mammals (refer to Mooney et al. [2012] for a review). These auditory conduction pathways (first proposed by Norris [1964] for dolphins) have been fairly well studied recently in other odontocetes and appear to be important if not the primary sound transmission pathways for these species; the extent to which these specializations extend to mysticetes is an area of current research, although there are some similarities known. Most of the structures of the inner ear (within the cochlea) for transducing sound into neural signals are common to terrestrial mammals; the cochlea is in fact one of the most conserved structures across all mammals. However, there are known differences across taxa, including relatively large and limber basilar membranes supporting the sensory cells in low-frequency cetaceans (mysticetes) and narrower and stiffer basilar membranes in the mid- and high-frequency cetaceans (odontocetes).

In terms of measuring hearing capabilities directly, auditory sensitivity generally is quantified by determining the quietest possible sound that is detectable by an animal (via a behavioral response or by quantifying an electrical response) on some signal presentations. By testing such responses across a range of frequencies, a measure of the animal's overall hearing capability (typically called an "audiogram") may be obtained; an example is given in **Figure H-1**.

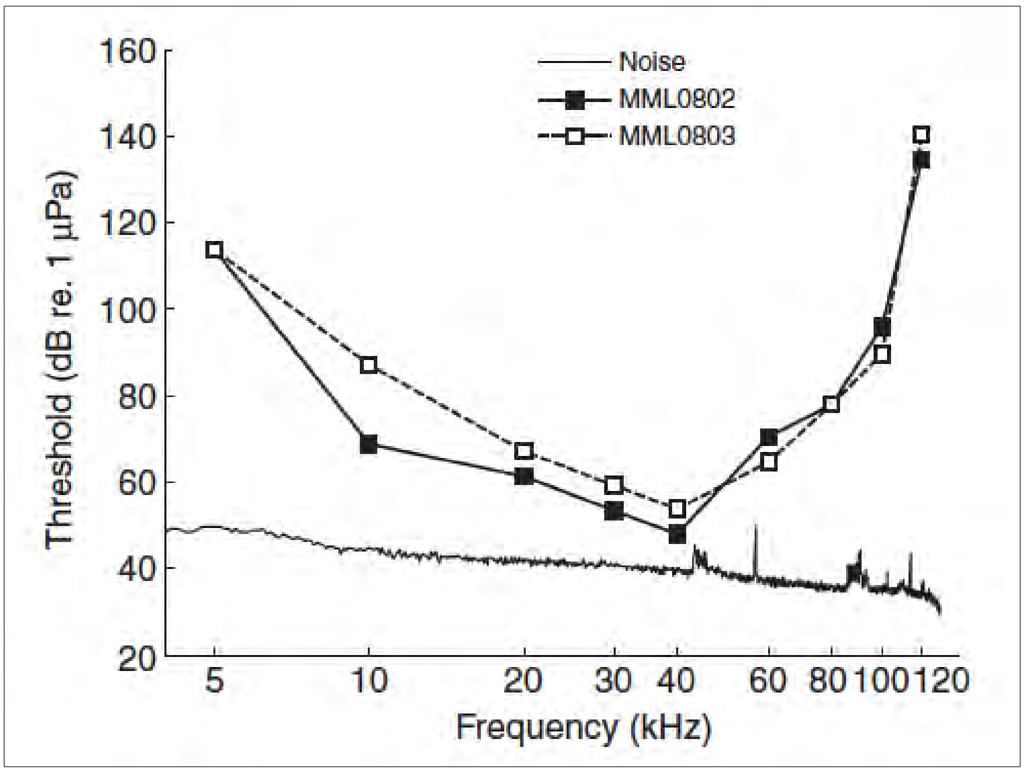

*Figure H-1. Example of a Hearing Profile, or Audiogram, for Two Pygmy Killer Whales (*Feresa attenuata*) Using an Electrophysiological Measurement Technique (including measurements of background noise) (From: Montie et al., 2011).*

Where detection threshold levels are lower, hearing sensitivity is greater (i.e., the animal can hear better at frequencies where detection thresholds are lower), and vice versa. This sensitivity usually follows a U-shaped curve with regions of relatively good sensitivity at the bottom of the curve, and sensitivity is greatly reduced in regions above and below. The region of lowest overall average hearing is called the range of best hearing sensitivity. Similarly, the region where hearing thresholds are within some range from the lowest overall threshold (e.g., 80 decibels [dB] in Southall et al. [2007]) is often referred to as the overall range of functional hearing.

Given the available direct measurements of hearing (such as those used to create audiograms, as shown in **Figure H-1**), the extrapolations based on taxonomy, and the predictions based on auditory morphology, vocalizations, or behavior, it is clear that not all marine mammals have equal hearing frequency ranges or best hearing sensitivity (Richardson et al., 1995; Wartzok and Ketten, 1999; Southall et al., 2007). This is particularly true within the odontocetes, which are the primary focus here given their relatively common occurrence in the GOM (refer to Mooney et al., 2012).

Most marine mammals have measured or estimated (in the case of mysticetes) functional hearing capabilities in frequency ranges that are similar to where their vocalizations occur (**Figure H-2**). However, for some species, there can be substantial differences in auditory capabilities relative to vocal parameters (Ladich and Yan, 1998); specifically, hearing may occur over broader ranges than those associated with species-typical vocalizations (Luther and Wiley, 2009). This can be important as vocal frequency ranges may be particularly important with regard to potential interference of communication from noise (masking), whereas hearing sensitivity is an important consideration with regard to direct auditory impacts such as temporary or permanent threshold shift (TTS or PTS, respectively).

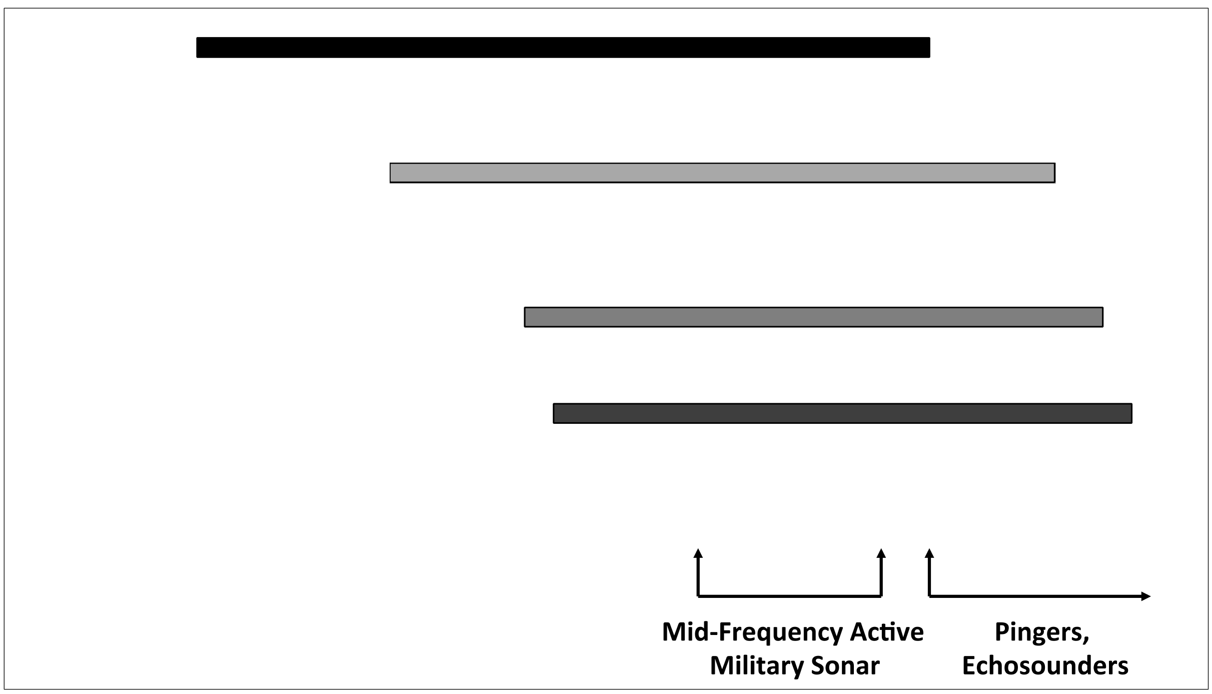

Figure H-2. Measured or Estimated Functional Hearing Ranges for Different Marine Mammal Groups Shown Relative to Various Human Noise Sources.

While vocalizations and functional hearing for marine mammals as a whole cover a wide frequency band (refer to Southall et al., 2007; Mooney et al., 2012; Reichmuth et al., 2013), mysticetes likely hear into very low frequencies, while odontocetes hear over a very broad range, extending well into the ultrasonic (for humans) range. Specific hearing characteristics for different marine mammal groups are described in the following sections.

3.1 HEARING IN MYSTICETES

Because of the lack of captive subjects and logistical challenges of bringing experimental subjects into the laboratory, direct measurements of hearing in mysticetes are unavailable, although there was an unsuccessful attempt to directly measure hearing in a stranded gray whale (*Eschrichtius robustus*) calf by Ridgway and Carder (2001). Consequently, hearing in mysticetes is estimated based on other means such as vocalizations (Wartzok and Ketten, 1999), anatomy (Houser et al., 2001; Parks et al., 2007; Tubelli et al., 2012a), behavioral responses to sound (Frankel, 2005; Reichmuth, 2007), and nominal natural background noise conditions in the likely frequency ranges of hearing (Clark and Ellison, 2004).

The combined information from these and other sources strongly suggests that mysticetes are likely most sensitive to sound from tens of hertz to approximately 10 kHz. However, humpback whales produce sounds with harmonics extending above 24 kHz (Au et al., 2006). Additionally, Ketten et al. (2007), Ketten and Mountain (2009), and Tubelli et al. (2012a,b) suggested, based on anatomical data, that some mysticetes could hear frequencies up to 30 kHz. Southall et al. (2007) estimated the lower and upper frequencies for functional hearing in mysticetes, collectively, to be 7 Hz and 22 kHz, respectively; however, based on the previous information, this may be a slight underestimate on the high-frequency cutoff. Nevertheless, the cited studies support the conclusion that mysticetes operate primarily in the very low- and low-frequency ranges.

3.2 HEARING IN ODONTOCETES

Because of the presence of specialized high-frequency biosonar and lower frequency communication systems in odontocetes (including dolphins and porpoises), it is almost certain that they hear over an extremely wide frequency range, spanning 12 octaves in some species. Hearing has been directly measured in controlled conditions with behavioral or electrophysiological techniques for more than a dozen odontocete species (refer to Mooney et al., 2012). Southall et al. (2007) reviewed the available literature and (like Wartzok and Ketten [1999]) identified two functional hearing groups within the odontocetes, which they referred to as mid-frequency cetaceans (with functional hearing between 150 Hz and 160 kHz) and high-frequency cetaceans (functional hearing estimated between 200 Hz and 180 kHz).

Subsequent to the Southall et al. (2007) publication, additional data have been obtained on a number of species that had been tested previously, including bottlenose dolphin (*Tursiops truncatus*) (Popov et al., 2007; Houser et al., 2008) and harbor porpoise (*Phocoena phocoena*) (Kastelein et al., 2012a). Additionally, direct behavioral measurements, electrophysiological measurements, or anatomical modeling results have been obtained for a number of new species, including white-beaked dolphin (*Lagenorhynchus albirostris*) (Nachtigall et al., 2008), Cuvier's beaked whale (*Ziphius cavirostris*) (Cranford et al., 2008a,b), Gervais' beaked whale (*Mesolodon europaeus*) (Finneran et al., 2009), long-finned pilot whale (*Globicephala melas*) (Pacini et al., 2010), short-finned pilot whale (*Globicephala macroorhynchus*) (Schlundt et al., 2011), Blainville's beaked whale (*Mesoplodon densirostris*) (Pacini et al., 2011), false killer whale (*Pseudorca crassidens*) (Montie et al., 2011), and Indo-Pacific humpback dolphin (*Sousa chinensis*) (Li et al., 2011). While there are slight species-specific differences, the combined results expand the overall understanding of cetacean hearing and suggest that these additional species have basic hearing ranges and functional capabilities similar to those of other cetaceans. These and other studies have contributed to an increased understanding of hearing in odontocetes, but they are fundamentally consistent with the Southall et al. (2007) assessment for these species in terms of the broad range and high-frequency extension of functional hearing in odontocetes.

3.3 HEARING IN SIRENIANS (MANATEES)

Hearing has been tested in terms of absolute and masked hearing capabilities in the sirenians that occur in the GOM, which are West Indian manatees (*Trichechus manatus*) (Gerstein et al., 1999; Mann et al., 2005; Gaspard et al., 2012). The combined data suggest that they have hearing capabilities similar to phocid seals except perhaps at the lowest frequencies, with functional hearing between approximately 250 Hz and 80 kHz. Based on these data, the extrapolation of data from some pinnipeds (phocid seals) to manatees, where information is lacking, would seem reasonable. This is particularly important in terms of the assessment of potential noise effects on hearing because there is little direct data for manatees but a comparatively larger amount of data for seals. Thus, pinnipeds are discussed here in the context of extrapolating results to manatees despite almost exclusively not occurring in the GOM.

Pinnipeds are amphibious mammals and have functional hearing above and below water, although they have broader functional hearing ranges in water (refer to Kastak and Schusterman [1998] for a more detailed discussion). Direct measurements of hearing using behavioral and electrophysiological methods have been obtained in nearly 10 different species of seals and sea lions (Southall et al., 2007; Mulsow and Reichmuth, 2010; Mulsow et al., 2011; Reichmuth et al., 2013). Southall et al. (2007) estimated functional hearing across all pinnipeds as extending between 75 Hz and 75 kHz underwater and between 75 Hz and 30 kHz in air. However, they also noted that there appears to be a segregation in functional hearing within pinniped taxa, as there is with odontocetes, with phocids (seals lacking external ear pinnae that are less mobile on land, such as harbor seals [*Phoca vitulina*]) extending to much higher frequencies, especially in water, than otariids (sea lions and fur seals that have distinct external ear pinnae and are more agile on land). This would be a logical additional segregation in terms of functional hearing within marine mammals, as proposed by the National Oceanic and Atmospheric Administration (USDOC, NOAA, 2013) in expanding on the Southall et al. (2007) functional hearing groups. As described previously, manatees appear most similar to phocid seals, and the effects of noise on their hearing is considered based on this extrapolation.

3.4 MARINE MAMMAL HEARING WEIGHTING FUNCTIONS

Because marine mammals, like most animals, do not hear equally well at all frequencies, frequency-weighting functions are often used as a means of quantitatively assessing and accounting for differential frequency responses for different species. The functions are commonly applied in calculating the potential for the detection of a sound at a specific frequency and for assessing potential noise impacts. The frequency-weighting functions derived by Southall et al. (2007), as well as subsequent proposed variants, are described briefly here (Finneran and Jenkins, 2012; USDOC, NOAA, 2013); newer versions of frequency-weighting functions' (Finneran, 2015) and NOAA's proposed acoustic guidelines (USDOC, NOAA, 2015) were released and are in review, but they were not available for analysis in this Programmatic Environmental Impact Statement (EIS). Several recent iterations of noise exposure criteria are discussed in greater detail in **Section 4**. As noted previously, subsequent results largely support the segregation of marine mammals into these general functional hearing categories with some minor modifications, including the extrapolation of results from seals to manatees.

Table H-1 shows the five functional hearing groups and estimated functional hearing ranges for marine mammals proposed in the Southall et al. (2007) noise exposure criteria. Using the estimated lower and upper frequency cut-off limits as 6-dB down points on an exponential roll-off for the frequency-weighting functions (as is done in human C-weighting), Southall et al. (2007) developed frequency-weighting filters for each of the five functional hearing groups as shown in **Figure H-3**.

Table H-1. Marine Mammal Functional Hearing Groups and Estimated Functional Hearing Ranges Proposed by Southall et al. (2007).

Functional Hearing Group	Estimated Auditory Bandwidth	Genera Represented	Number of Species/ Subspecies	Frequency-Weighting Network
Low-frequency (lf) cetaceans	7 Hz to 22 kHz*	*Balaena, Caperea, Eschrichtius, Megaptera, Balaenoptera*	13	Mlf
Mid-frequency (mf) cetaceans	150 Hz to 160 kHz	*Steno, Sousa, Sotalia, Tursiops, Stenella, Delphinus, Lagenodelphis, Lagenorhynchus, Lissodelphis, Grampus, Peponocephala, Feresa, Pseudorca, Orcinus, Globicephala, Orcacella, Physeter, Delphinapterus, Monodon, Ziphius, Berardius, Tasmacetus, Hyperoodon, Mesoplodon*	57	Mmf
High-frequency (hf) cetaceans	200 Hz to 180 kHz	*Phocoena, Neophocaena, Phocoenoides, Platanista, Inia, Kogia, Lipotes, Pontoporia, Cephalorhynchus*	19	Mhf
Pinnipeds in water (pw)**	75 Hz to 75 kHz	*Trichecus manatus*	1	Mpw

* As described in the text, more recent modeling work would suggest that the upper frequency end of the estimated auditory bandwidth may be slightly higher (approximately 30 kHz), at least for some species.

** Pinniped functional hearing values are given here for the purposes of applicability to manatees, given the limited data on noise impacts on manatees and general similarities in at least the functional hearing bandwidth between manatees and phocid seals (for which the Southall et al. [2007] functional hearing group for pinnipeds was based).

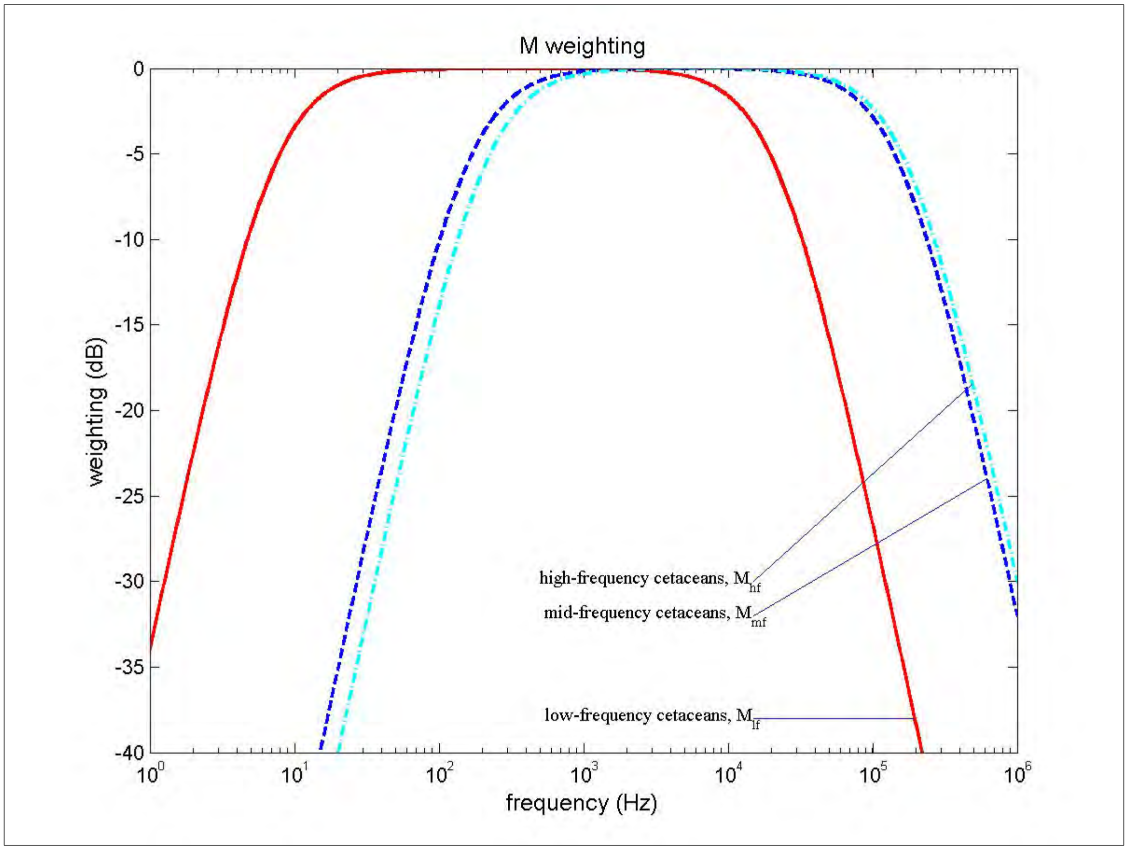

Figure H-3. Frequency-Weighting Functions for Cetaceans Proposed by Southall et al. (2007).

Considerable subsequent research supporting modifications to these initial frequency-weighting functions has been conducted. Finneran and Schlundt (2011) conducted subjective equal loudness measurements with a bottlenose dolphin from which frequency-weighting functions were derived. Finneran and Schlundt (2010, 2013) conducted frequency-specific TTS measurements that demonstrated a high degree of frequency-specificity in the susceptibility of dolphins to TTS. Based on these results, Finneran and Jenkins (2012) proposed a modification of the Southall et al. (2007) auditory weighting functions that represents relatively increased susceptibility to noise-induced threshold shifts at intermediate sound frequencies of greater hearing sensitivity. These hybrid functions (called Type 2 filters) were extrapolated to frequencies where data currently exist (Finneran and Jenkins, 2012) (**Figure H-4**). Tougaard et al. (2014) noted the importance of sound frequency in the potential effects of noise, with specific reference to relatively recent data on harbor porpoises. They built on earlier arguments related to the use of narrower frequency-weighting functions than the original M-weighting functions pioneered by Southall et al. (2007). The considerable recent experimental hearing data clearly supports the use of narrower frequency-weighting filters and potentially additional functional hearing groups, although considerable scientific debate about the nature of these modifications remains.

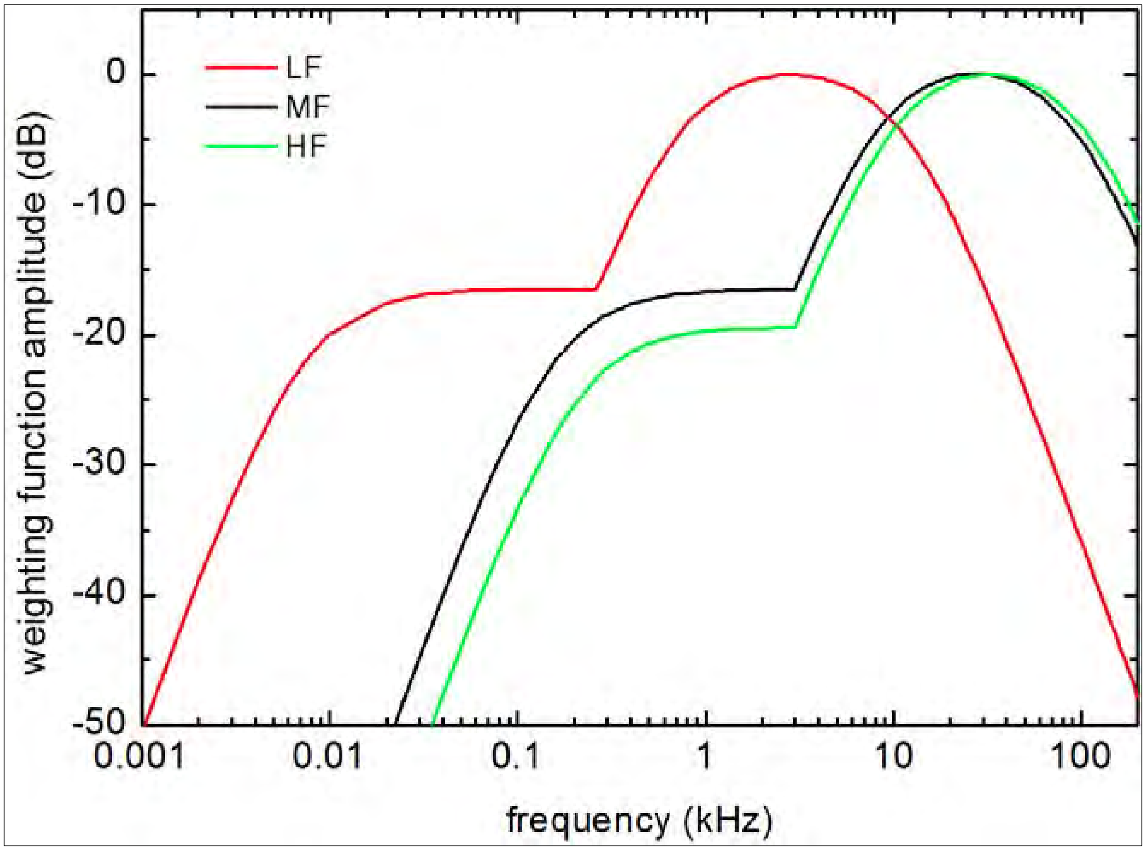

Figure H-4. Frequency Weighting Filters ("Type 2") for Low-Frequency (LF), Mid-Frequency (MF), and High-Frequency (HF) Cetaceans Derived by Finneran and Jenkins (2012).

Within their draft acoustic guidelines, NOAA (USDOC, NOAA, 2013) proposed the use of the mid- and high-frequency cetacean weighting functions in regulatory contexts, given the supporting data from odontocetes described previously. These proposed functions were available at the time of this Programmatic EIS preparation; NOAA's (USDOC, NOAA, 2015) modified proposed guidelines have further modifications that are not explicitly discussed in this appendix. **Figure H-5** shows these frequency-weighting functions and the components derived from the Southall et al. (2007) M-weighting and subsequent hearing data.

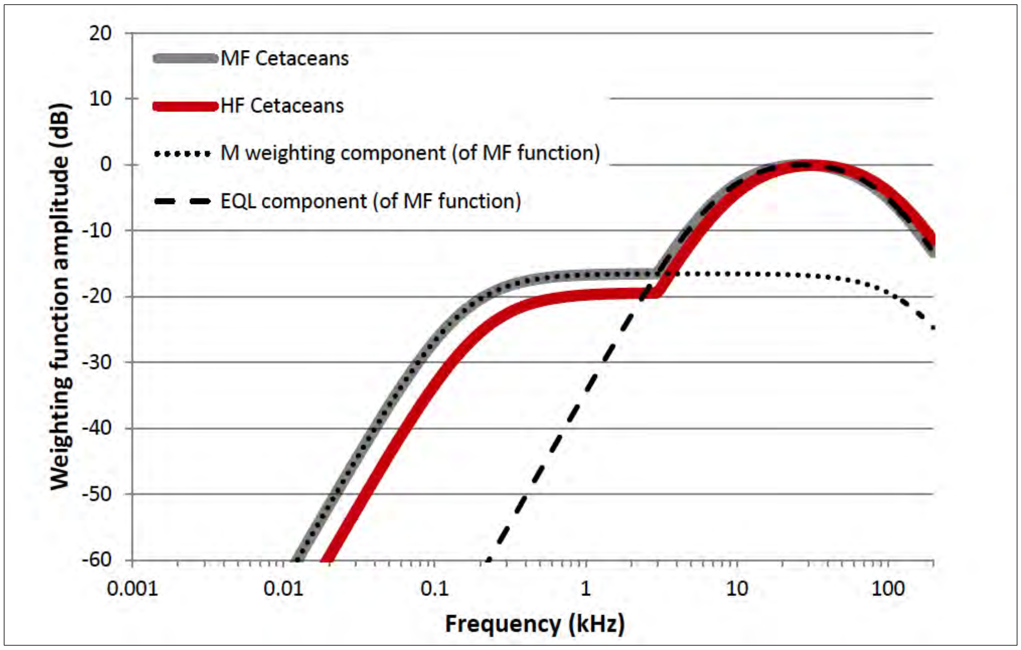

Figure H-5. "Merged" Auditory Filters for Mid-Frequency (MF) and High-Frequency (HF) Cetaceans Proposed by the National Oceanic and Atmospheric Administration (From: USDOC, NOAA, 2013).

However, NOAA (USDOC, NOAA, 2013) took a different approach regarding low-frequency cetacean weighting functions, given the considerable uncertainty regarding all aspects of hearing in these taxa. Because there are no direct measurements of hearing in mysticetes, this function was based on auditory anatomy and characteristics of vocalization parameters for different mysticete species (**Figure H-6**).

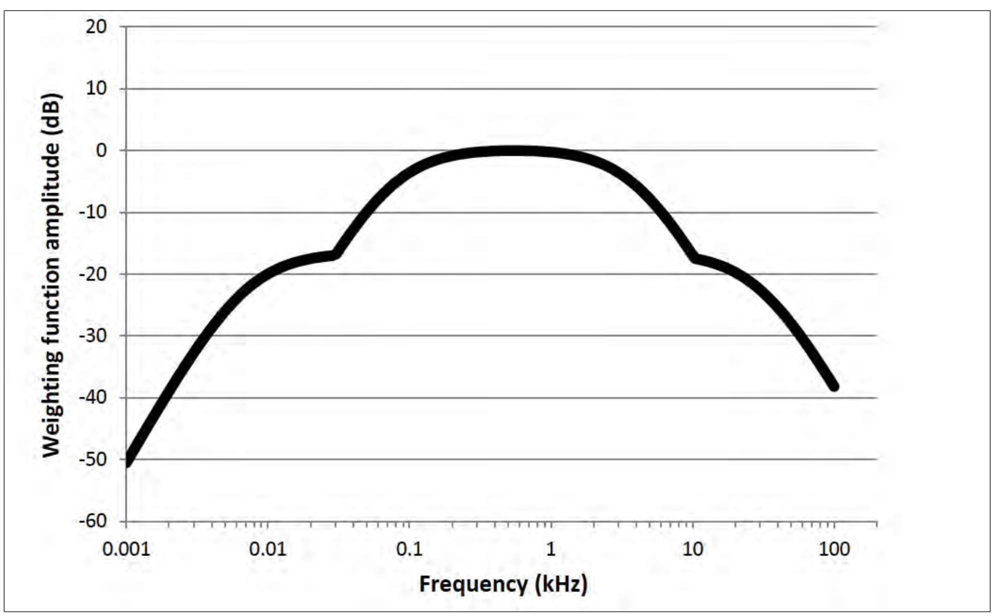

Figure H-6. Modified Auditory Filters for Low-Frequency (LF) Cetaceans Proposed by the National Oceanic and Atmospheric Administration (From: USDOC, NOAA, 2013).

Additionally, NOAA (USDOC, NOAA, 2013) proposed a segregation of the Southall et al. (2007) functional hearing groups within pinnipeds, separating phocids (seals) from otariids (sea lions and fur seals) (**Figure H-7**). While there are more limited equal loudness and frequency-specific TTS data for pinnipeds than those now available for dolphins, NOAA (USDOC, NOAA, 2013) proposed retaining the M-weighting concept from Southall et al. (2007) and also segregating the two groups based on what is known about frequency ranges of hearing. Given the extrapolation suggested from seals to manatees, the phocid weighting function would be the more appropriate based on information currently available.

The scientific understanding of hearing and perceptual processes relevant to deriving sound frequency-weighting functions are areas of active research and deliberation. There are clear functional differences in hearing sensitivity across broad groups of marine mammals, but there is incomplete information with which to unequivocally derive some of these functions. More data are available for odontocetes than for mysticetes or sirenians. The series of quantitative methods derived to express these differences in terms of the relative perception and sensitivity of different marine mammal groups to noise exposure reflects some of the progress made in this challenging area, including approaches proposed by NOAA (USDOC, NOAA, 2013).

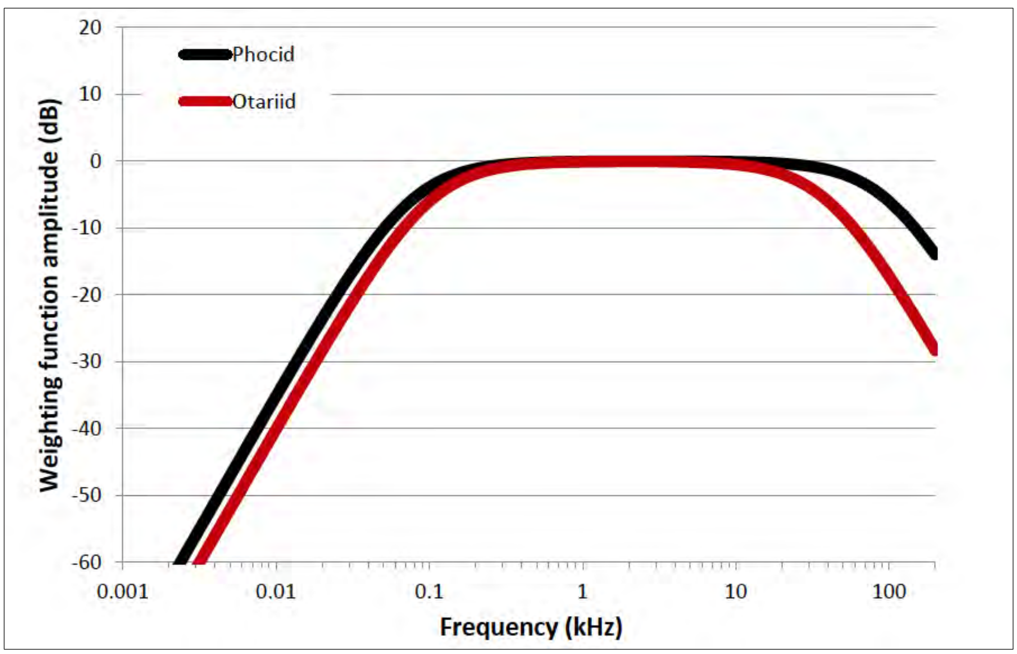

Figure H-7. Auditory Filters for Seals (Phocids) and Sea Lions (Otariids) Proposed by the National Oceanic and Atmospheric Administration (From: USDOC, NOAA, 2013).

4 EFFECTS OF NOISE ON MARINE MAMMAL HEARING AND BEHAVIOR

Around loud noise sources or where there is an overlap between more distant sources and the frequencies of sound used by marine mammals, noise may interfere with important biological functions. Although there may be no effect of exposure, noise (natural or anthropogenic) can affect marine life in various ways, inducing alteration of behavior, reduction of acoustic communication, reduced navigation or orientation capability, temporary or permanent damage to the auditory or other systems, and in extreme cases, habitat avoidance or even death (Richardson et al., 1995; NRC, 2003, 2005; Nowacek et al., 2007; Southall et al., 2007). Noise impacts may be synergistic with those of other human stressors. While determining the biological significance of noise exposure impacts remains challenging (refer to NRC [2005] and Southall et al. [2007, 2009]), significant strides have been made in quantifying the effects of noise on marine mammals. The potential and measured effects of noise on physiology, hearing, and behavior are reviewed here, with attention to findings subsequent to the Southall et al. (2007) review and assessment of noise impacts on marine mammals.

4.1 EFFECTS OF NOISE ON MARINE MAMMAL PHYSIOLOGY

Noise can result in direct physiological impacts on marine mammals, even in cases where hearing impacts or behavioral responses may be lacking. These may include stress responses and direct physical injury (e.g., tissue damage). Stress responses can range from an acute startle response to more chronic effects and can vary widely across individuals in type and magnitude according to a host of factors (refer to Busch and Hayward [2009] for a recent review). Stress reactions in humans and other vertebrates include various physiological changes to pulmonary, respiratory, cardiac, metabolic, neuro-endocrine, immune, and reproductive functions; these can vary from relatively benign to very detrimental or fatal in some conditions.

Direct measurements of physical stress responses in marine mammals from sound exposure are relatively limited but increasing (Thomas et al., 1990; Miksis et al., 2001; Romano et al., 2004; Rolland et al., 2012). A greater amount of data is available for terrestrial mammals and other animals and, in some cases, may be useful where direct information is lacking (Wright et al., 2007a,b). The available literature for marine mammals indicates endocrine secretions of glucocorticoids and altered cardiovascular function following relatively intense noise exposure in some cases.

Direct physical injury can occur from exposure to high levels of sound or, more commonly, to shock wave pulses associated with high-intensity events such as explosions. These pulses are typically short peak pressures that may damage internal organs or air-filled body cavities such as lungs (Yelverton et al., 1973; Goertner, 1982; Young, 1991). Data on direct physical injury are limited to anecdotal or forensic investigations after accidental events because ethical considerations typically have limited direct empirical methods to measure such impacts in marine mammals. However, such observations (e.g., Todd et al., 1996) and modeling based on impact data for the human vestibular system, as well as other organs (e.g., lungs), for underwater sound exposures (Cudahy and Ellison, 2002) suggest that marine mammals could be susceptible to direct physical injury to particular organ systems and tissues following intense exposure, particularly where high particle motion events occur.

Other forms of physiological damage that have been investigated and in some cases seen in marine mammals include the formation of gas bubble lesions and fat emboli similar to those associated with human decompression sickness; these have been observed in beaked whale species that stranded near naval mid-frequency sonar training exercises (Jepson et al., 2003; Fernández et al., 2005). Currently, these tissue impacts are thought to result from a behavioral response that changes diving patterns in some way and subsequently causes lesion/emboli formation, rather than as a direct physical effect of sound exposure (Cox et al., 2006; Zimmer and Tyack, 2007). These kinds of emboli have not been definitively shown in other marine mammals exposed to natural or anthropogenic sound to date.

4.2 Effects of Noise on Marine Mammal Hearing

Much of the scientific and regulatory attention on the impacts of noise on marine life has centered on the issue of how sound affects hearing in marine mammals. While the available literature on the underlying issues remains quite limited compared to that available for terrestrial species, considerable progress has been made in these areas, particularly in the last decade, for marine mammals. There have been numerous reviews of the available data on these issues (Richardson et al., 1995; Wartzok and Ketten, 1999; NRC, 2003, 2005), the most recent comprehensive assessment being the Southall et al. (2007) review and application of the available science in the context of proposing noise exposure criteria. A summary description of temporary and permanent hearing losses and auditory masking is provided here, with reference to these reviews and some discussion of more recent literature on each issue (refer also to Finneran and Jenkins, 2012; USDOC, NOAA, 2013).

4.2.1 Temporary and Permanent Threshold Shift in Marine Mammals

Noise-induced threshold shifts are increases in hearing thresholds within a certain frequency range (Yost, 2000). Following exposure, the magnitude of the threshold shift normally decreases over time after cessation of noise exposure. Threshold shifts can be temporary (TTS) or permanent (PTS) and can consist of a variety of physiological, chemical, and neural phenomena that may or may not recover following noise exposure. Several important factors relate to the type and magnitude of hearing loss, including exposure level, frequency content, duration, and temporal pattern of exposure. A range of mechanical stress or damage (e.g., supporting cell structure fatigue) and metabolic (e.g., inner ear hair cell metabolism, such as energy production, protein synthesis, and ion transport) processes within the auditory system underlie TTS and PTS (Kryter, 1994; Ward, 1997; Yost, 2000). Intense sound exposure often results in changes in mechanical processes, whereas prolonged exposure typically results in metabolic changes (e.g., Saunders et al., 1985).

The TTS is a relatively short-term reversible loss of hearing, often resulting from cellular fatigue and metabolic changes. For marine mammal TTS studies, a threshold shift of 6 dB is commonly considered the minimum threshold shift that is statistically larger than typical day-to-day or session-to-session variation in a subject's baseline threshold at a particular frequency (Kastak et al., 2005; as in Southall et al., 2007). Conversely, PTS is an irreversible loss of hearing (permanent damage) that commonly results from inner ear hair cell loss or severe damage to auditory tissues (e.g., Saunders et al., 1985; Henderson et al., 2008). Southall et al. (2007) reviewed the available terrestrial literature and concluded that 40 dB of TTS was a reasonable and conservative approximation of PTS onset for marine mammals (refer to Henderson et al. [2008] for a consideration of the human literature in this regard). The PTS data typically are not collected in marine mammals owing to ethical and permitting considerations, but an earlier TTS experiment was found to unintentionally induce PTS in a harbor seal (Kastak et al., 2008). In this experiment, which involved exposure to tonal fatiguing noise of increasing exposure level, initial experiments failed to induce measurable TTS on multiple trials, but following subsequent exposure at similar levels, an initially large TTS of at least 30 dB was measured and decreased over a period of months but remained a measurable PTS at the exposure frequency of approximately 5 dB for years following the experiment.

The TTS data on different exposures with impulsive and continuous noise have been obtained in four odontocetes, including two mid-frequency cetaceans (bottlenose dolphin and beluga whale [*Delphinapterus leucas*]) and two high-frequency cetaceans (harbor porpoise and Yangtze finless porpoise [*Neophocaena asiaeorientalis*]). Similar measurements have been obtained for three pinniped species (two phocids: harbor seal and elephant seal [*Mirounga lionina*]; one otariid: California sea lion); these are considered here relative to potential noise effects on manatees in the GOM. Much of the data was reviewed in detail by Southall et al. (2007), but there are some notable new data that change some of the conclusions reached in that assessment (Finneran, 2013; USDOC, NOAA, 2013). In general, it appears that marine mammal auditory systems for most species are relatively resilient to noise exposure and that relatively intense sounds are required to cause TTS (Finneran and Schlundt, 2010, 2013) and, given some simplifying assumptions to extrapolate to 40 dB TTS, PTS as well. However, there are clear differences in the sound exposure types and noise exposure frequency as well as between species. As in terrestrial mammals, marine mammals experience TTS at relatively lower onset levels for impulsive noise than for non-impulsive noise. The relative TTS onset levels for different marine mammal groups from the Southall et al. (2007) criteria are discussed in the following section regarding exposure criteria. However, some modifications to these criteria are now appropriate based on subsequent information.

New data are available demonstrating much lower (>20 dB) TTS onset exposure levels for harbor porpoises exposed to impulse noise (airguns) than has been measured in other odontocetes (Lucke et al., 2009). These data are significant because they are the only TTS measurements available for any individual in the high-frequency cetacean functional hearing group for the kinds of impulse noise involved in seismic surveys. Additional measurements with harbor porpoise using pile-driving noise (Kastelein et al., 2012b) and non-impulse bands of noise for harbor porpoises (Kastelein et al., 2013a) and finless porpoises (Popov et al., 2011a,b, 2013) similarly indicate much lower TTS onset in high-frequency cetaceans. This argues for use of direct measurements for TTS onset in these animals rather than using the extrapolated (though much more expansive) data for mid-frequency cetaceans in predicting auditory fatigue (refer also to Tougaard et al., 2014).

Several studies have contributed to an expanded understanding of TTS onset and growth at a range of sound frequencies in odontocetes and pinnipeds. Mooney et al. (2009a,b) demonstrated conditions where equal energy assumptions about exposure of different durations and levels fail to accurately predict TTS onset and growth. Finneran and Schlundt (2013) provided additional measurements across a wide range of frequencies (3 to 80 kHz) for examining relationships between frequency and growth rates. Kastelein et al. (2012b,c, 2013b) provide TTS onset data for several sound types, including impulse noise for harbor seals; these are generally consistent with the conclusions derived by Southall et al. (2007) from the earlier pinniped data from Kastak et al. (1998, 2001, 2005). Finneran and Schlundt (2010; 2013) and Finneran et al. (2010a,b) provided additional TTS data for bottlenose dolphins, demonstrating a greater sensitivity (10 to 20 dB) to noise exposure (lower absolute TTS onset levels) and a more rapid growth of TTS with increasing noise exposure level at higher frequencies within their range of best sensitivity than had been tested when the Southall et al. (2007) criteria were published. These data suggest that the exposure level relative to the subject's absolute hearing sensitivity (referred to as the sensation level) is particularly important in determining TTS onset. They also suggest that exposure levels in the region of best hearing sensitivity should be used as generic TTS onset values against which frequency-weighting functions could be applied to account for frequency-specific hearing. The importance of frequency relationships between noise sources and potential high-level auditory effects such as TTS-onset has been demonstrated in odontocetes; the recent demonstration of very high absolute received levels with little or no TTS measured low-frequency noise from a seismic airgun in odontocetes that hear poorly at these frequencies (Finneran et al., 2015). These overall findings for odontocetes provide some insight into potential effects for mysticetes because no mysticete TTS values are or, for the foreseeable future, will be available). However, caution should be taken in directly applying absolute exposure levels for TTS onset from one group to another where large differences in frequency-specific hearing likely exist.

4.2.2 Auditory Masking

In addition to potential effects on hearing from relatively high levels of sound exposure that would occur relatively close to anthropogenic sound sources in the field, noise interference ("masking") effects can, and likely do, occur over much greater distances from real sound sources. Noise can affect hearing and partially or completely reduce an individual's ability to effectively communicate; detect important predator, prey, and conspecific signals; and detect important environmental features associated with spatial orientation (refer to Clark et al. [2009] for a review). Spectral, temporal, and spatial overlap between the masking noise and the sender/receiver determines the extent of interference; the greater the spectral and temporal overlap, the greater the potential for masking.

Southall et al. (2007) considered auditory masking issues and realized the much greater relative areas over which this phenomena could occur relative to TTS and PTS, but they did not propose explicit exposure criteria for marine mammals, owing in part to the very divergent conditions in which masking can occur and a lack of clear understanding about defining an "onset" for masking that would be statistically definable and biologically meaningful. Largely for the same reasons, masking effects generally have been considered only qualitatively in planning of activities and regulatory decisions related to noise impacts. Subsequent data have demonstrated vocal modifications in marine mammals exposed to noise that are presumably the result of anthropogenic masking noise (Holt et al., 2009). Additionally, Clark et al. (2009) provided a quantitative means of determining the relative loss of acoustic communication range for marine mammals using specific calls in conditions where they are exposed to specific anthropogenic noise sources. While Clark et al. (2009) included a metric for individual processing gain that accounts for the individual ability to segregate signals from masking noise based on spatial differences between signals and noise as well as other cues, more recent measurements of masked hearing in various kinds of masking noise, including co-modulated noise, suggest that this processing gain may be considerably greater than previously considered (Branstetter and Finneran, 2008; Branstetter et al., 2013).

There is particular concern that low-frequency anthropogenic noise may mask communication in mysticetes, which can communicate over long distances and within the same frequency band (Payne and Webb, 1971; Clark et al., 2009). An example of mysticete calling behavior that may be increasingly masked by nearby ship noise is shown in **Figure H-8**.

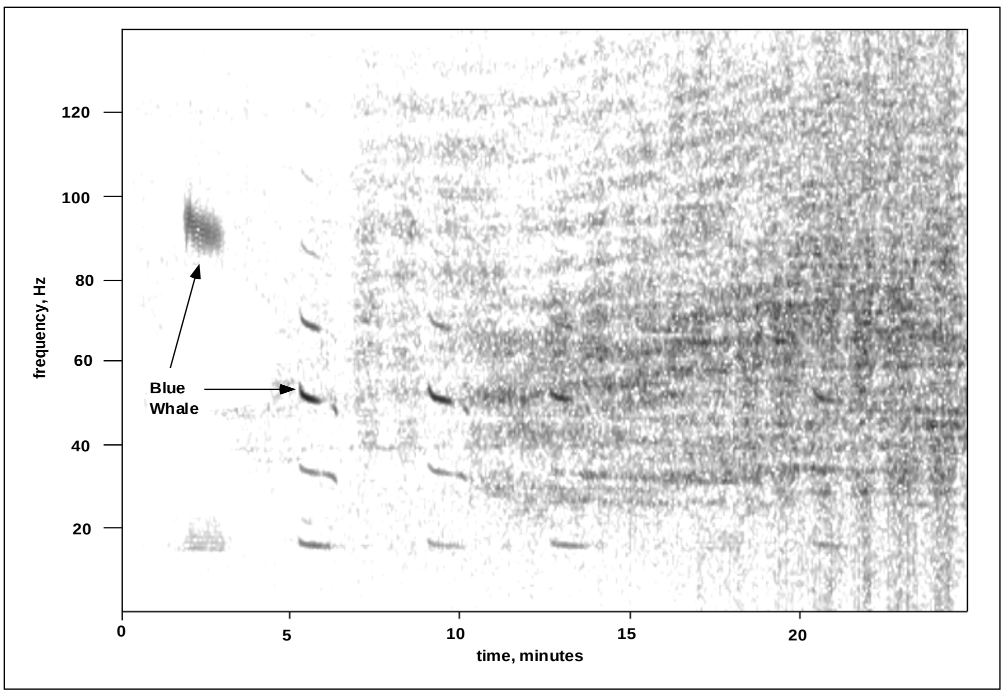

*Figure H-8. Time Series Plot Showing a Calling Blue Whale (*Balaenoptera musculus*) and the Increasing Noise (and masking) in the Same Low-Frequency Band from an Approaching Vessel (Image courtesy of C. Clark).*

4.3 EFFECTS OF NOISE ON MARINE MAMMAL BEHAVIOR

Behavioral responses to sound are highly variable and critically depend on the context of sound exposure, as much or more than the level-duration-frequency characteristics that determine the probability of auditory effects (Wartzok et al., 2004; Southall et al., 2007). There is a wide range of possible behavioral responses to sound exposure, given that the sound is audible to the particular animal, including the following, in approximate order of increasing severity but decreasing likelihood:

- none observable – animals can become less sensitive over repeated exposures (habituation) and this does not preclude the occurrence of physiological stress responses;
- looking or increased alertness;
- minor behavioral responses such as vocal modifications associated with masking;
- cessation of feeding or social interactions;
- temporary avoidance behavior (emerging as one of the more common responses);
- modification of group structure or activity state;
- habitat abandonment; and
- injury or death via direct response or possibly exacerbated by physiological factors.

These effects clearly have differing probabilities to affect marine mammal vital rates (NRC, 2005), but it has proven (and remains) exceedingly difficult to establish a generally accepted definition and criterion for biologically meaningful behavioral disturbance. Assessing the severity of behavioral effects of anthropogenic sound exposure on marine mammals presents unique challenges associated with the inherent complexity of behavioral responses and the contextual factors affecting them, within and between individuals and species. Severity of responses depends on characteristics of the sound source (e.g., moving or stationary, number and spatial distribution of sound source[s], similarity to predator sounds, and other relevant factors) (Richardson et al., 1995; NRC, 2005; Southall et al., 2007; Wirsing et al., 2008; Bejder et al., 2009; Barber et al., 2010). Ellison et al. (2012) reviewed these and other studies demonstrating the context-specificity of marine mammal behavioral responses and proposed a new context-based approach to the assessment of behavioral responses in marine mammals.

Southall et al. (2007) reviewed the considerable amount of available literature on the effects of noise on marine mammal hearing but (other than for single impulse exposures where TTS onset was used as a threshold value for behavioral disturbance) did not find a single metric or identifiable exposure level that was broadly applicable as a benchmark for behavioral effects. Several general observations were made, including that many of the responses observed across taxa were temporary avoidance behavior. Additionally, certain species (e.g., harbor porpoises, beaked whales) appear to be categorically more sensitive to noise than other species observed, and certain behavioral states (e.g., migrating) can make species such as bowhead whales (*Balaena mysticetus*) more sensitive to exposure. Subsequent data have demonstrated and quantified behavioral responses of various species, including some of the Endangered Species Act-listed marine mammals being considered in this Programmatic EIS, to seismic exploration using airguns (Weir, 2008a,b; Miller et al., 2009). Additional data have demonstrated behavioral responses of cetaceans to vessels associated with whale-watching activities (e.g., Bejder and Lusseau, 2008; Visser et al., 2010), seismic surveys (Thompson et al., 2013), mid-frequency military sonar with blue whales (Goldbogen et al., 2013), and to the construction of offshore energy installations (Tougaard et al., 2009, 2013; Thompson et al., 2010; Dähne et al., 2013). Additionally, a recent report (Southall et al., 2013) concluded that multibeam echosounders used in offshore energy development projects may have played a role in a mass stranding of melon-headed whales, most likely by affecting their behavior. Finally, there has been considerable new information, using both controlled exposure experiments and opportunistic observations of anthropogenic noise source operations, on the behavioral responses of particularly sensitive marine mammals, including harbor porpoises (Kastelein et al., 2008a,b, 2012b; Gilles et al., 2009) and beaked whales (Caretta et al., 2008; McCarthy et al., 2011; Southall et al., 2011; Tyack et al., 2011; DeRuiter et al., 2013). The findings of these studies support and amplify the conclusions of Southall et al. (2007) that these are particularly sensitive species, although it remains unclear whether any additional species should be added to this general category.

5 MARINE MAMMAL NOISE EXPOSURE CRITERIA

Beginning in the 1980s with regulations on oil and gas exploration, sound-producing entities and regulatory agencies have been grappling with how to quantitatively predict and operationally mitigate the effects of human noise from industrial activities on marine life. While the marine noise issue is an increasingly global one, many of the developments on exposure criteria for marine mammals have involved U.S. regulatory processes.

In June 1997, the High Energy Seismic Survey (HESS, 1999) team convened a panel of experts to assess existing data on marine mammals exposed to seismic pulses and to predict exposures at which physical injury could occur. With the limited available data at that time, exposure to airgun pulses with received levels above 180 dB re 1 μPa (decibels relative to 1 micropascal) (root mean square [rms] – averaged over the pulse duration) was determined to have a high potential for "serious behavioral, physiological, and hearing effects."

Based on the HESS (1999) panel conclusions, the National Marine Fisheries Service (NMFS) established a 180-dBrms (received level) threshold criterion for injury from impulse sound and continuous (non-impulsive) sound exposure for cetaceans and a 190-dBrms threshold criterion for pinnipeds (*Federal Register*, 2003). Additionally, behavioral response criteria were developed as step-function (all-or-none) thresholds based solely on the rms value of received levels and have been used by NMFS, although not entirely consistently. Thresholds for behavioral response from impulse sounds are 160 dBrms (received level) for all marine mammals based on behavioral response data for marine mammals exposed to seismic airgun operations (Malme et al., 1983, 1984; Richardson et al., 1986). The threshold for behavioral response for continuous sounds has been 120 dBrms (for some but not all sound sources) based on the results of Malme et al. (1984) and Richardson et al. (1990).

These acoustic thresholds for seismic sounds and sounds other than those associated with U.S. Navy activities are based exclusively on dB rms measurements and the 1980s estimates of such levels associated with hearing impact as opposed to the direct measurements that have been made subsequent to establishment of the thresholds. The duration over which the rms is calculated can vary significantly for impulsive sounds, and the use of this metric for characterizing impulse noise has been questioned (Madsen et al., 2006). In addition, the duration and impulsive nature of the sound also determine the potential level of PTS. Therefore, thresholds based on rms values alone are not very predictive of the likelihood of PTS onset.

Recognizing that the available data on hearing and noise impacts were rapidly evolving and that a more comprehensive and scientifically robust method of assessment would be required than these simplistic threshold estimates, NMFS supported an expert working group to develop more comprehensive and current marine mammal noise exposure criteria. This process ultimately resulted in the Southall et al. (2007) marine mammal noise exposure criteria. Within this process, several important segregations were made. First, the marine mammals were segregated into functional hearing groups (not entirely taxonomy-based), as described previously. All cetacean criteria are discussed here, but the relatively low probability of occurrence of both low- and high-frequency cetacean species in the GOM is noted. Additionally, criteria for seals are discussed given the relevance of extrapolation to manatees given the lack of such supporting data. Second, sound sources were categorized into functional categories based on their acoustic and repetitive properties (**Table H-2**).

Table H-2. Sound Source Categories, Acoustic Characteristics, and Examples Proposed by Southall et al. (2007).

Sound Type	Acoustic Characteristics (at source)	Examples
Single Pulse	Single acoustic event; >3 dB difference between received level using impulse versus equivalent continuous time constant	Single explosion; sonic boom; single airgun, watergun, pile strike, or sparker pulse; single ping of certain sonars, depth sounders, and pingers
Multiple Pulse	Multiple discrete acoustic events within 24 hours; >3 dB difference between received level using impulse versus equivalent continuous time constant	Serial explosions; sequential airgun, watergun, pile strikes, or sparker pulses; certain active sonar (IMAPS); some depth sounder signals
Non-Pulse	Single or multiple discrete acoustic events within 24 hours; <3 dB difference between received level using impulse versus equivalent continuous time constant	Vessel/aircraft passes; drilling; many construction or other industrial operations; certain sonar systems (LFA; tactical mid-frequency); acoustic harassment/deterrent devises; acoustic tomography sources (ATOC); some depth sounder signals

ATOC = acoustic thermometry of ocean climate; IMAPS = Integrated Marine Mammal Monitoring and Protection System; LFA = low-frequency active.

The potential for hearing and behavioral effects for noise exposures of these different categories was assessed for each of the different functional hearing groups according to a wider and more applicable set of acoustic exposure metrics. Using an alternate threshold such as sound energy (sound exposure level [SEL]) that incorporates amplitude level and duration as well as peak sound pressure into the noise metric is considered to be more biologically realistic. Consequently, Southall et al. (2007) suggested SEL thresholds for TTS onset and the predicted PTS onset levels they estimated. As has been observed for humans (Kryter et al., 1966), recent work in marine mammals demonstrates that TTS onset is not perfectly correlated with received SELs either; rather, duration appears to have a larger impact on TTS onset than predicted by SELs, and recovery time between noise exposure also has an impact on the levels of TTS (Mooney et al., 2009b; Finneran and Schlundt, 2010). At this point, SEL remains a better metric for the prediction of injury onset than rms, but with some demonstrated limitations similar to those observed in predicting TTS dependence on sounds of different exposure level and duration in terrestrial mammals; these threshold metrics will need to be reevaluated regularly as new data are reported. For behavioral effects, the conventional rms levels for sound exposure were considered, in part because this typically is all of the information available regarding available studies.

5.1 Derivation of TTS and PTS Criteria

Southall et al. (2007) estimated PTS onset as noise exposures estimated to result in 40 dB of TTS for different sound types, using both a peak pressure and an SEL criterion; the SEL threshold is ultimately the functional criteria for most realistic exposure scenarios. For all cetacean functional hearing groups, estimated TTS onset levels for impulse and non-impulse noise were based on data obtained from a few individuals of two mid-frequency species (bottlenose dolphins and beluga whales). For pinnipeds, some data were available on non-impulsive noise but extrapolations to PTS onset for impulsive noise (such as that associated with seismic airguns) also included extrapolations involving data from bottlenose dolphins.

Based on data available at the time, Southall et al. (2007) proposed explicit numerical exposure level values for injury from sound exposure for each of the marine mammal functional hearing groups. Received level threshold values were determined using measured TTS onset levels where possible (or extrapolating them from related species where not), a series of extrapolation procedures to estimate the growth of TTS, and a reasonably conservative estimate of physical injury (40 dB TTS). For SEL values, the frequency-weighting functions described previously would be applied to the received sound to account for differential frequency sensitivity among the different marine mammal groups. The resulting thresholds for injury from sound exposure for different marine mammal groups, obtained via these general methods and using all available relevant data as proposed by Southall et al. (2007), are summarized in **Table H-3**.

While the Southall et al. (2007) exposure criteria represented a major step forward in the assessment of potential noise effects on marine mammals, subsequent data have resulted in modification and re-evaluation of exposure criteria. A variety of modifications to exposure criteria have been proposed.

Notably, for high-frequency cetaceans (e.g., harbor porpoises), subsequent data are available from Lucke et al. (2009). The data indicate a lower TTS onset value in terms of SEL and peak pressure. In this analysis, these directly relevant data form the basis for estimating TTS onset and potential for injury in harbor porpoises and other high-frequency cetaceans, rather than the extrapolated predictions of Southall et al. (2007); refer to also Tougaard et al. (2014). Consequently, a PTS onset threshold for impulse noise of 179 dB re 1 $\mu Pa^2 \cdot s$ is used for this functional hearing group, based on Lucke et al. (2009) TTS onset levels and the Southall et al. (2007) extrapolation procedure to PTS as proposed by Wood et al. (2012).

Table H-3. Marine Mammal Noise Exposure Criteria for Injury for Different Marine Mammal Functional Hearing Groups Proposed by Southall et al. (2007).

Marine Mammal Group	Sound Type		
	Single Pulses	Multiple Pulses	Non-Pulses
Low-Frequency Cetaceans	Cell 1	Cell 2	Cell 3
Sound Pressure Level (flat*)	230	230	230
Sound Exposure Level (Mlf)	198	198	215
Mid-Frequency Cetaceans	Cell 4	Cell 5	Cell 6
Sound Pressure Level (flat)	230	230	230
Sound Exposure Level (Mmf)	198	198	215
High-Frequency Cetaceans	Cell 7	Cell 8	Cell 9
Sound Pressure Level (flat)	230	230	230
Sound Exposure Level (Mhf)	198	198	215
Pinnipeds (in water)	Cell 10	Cell 11	Cell 12
Sound Pressure Level (flat)	218	218	218
Sound Exposure Level (Mpw)	186	186	203

* "Flat" for peak sound pressure level indicates no frequency-weighting is applied.

Sound pressure levels are expressed in units of dBpeak re µPa. Sound exposure levels are expressed in units of dB re 1 $\mu Pa^2 \cdot s$.

An additional consideration regards the assessment of potential auditory effects of impulse noise on low-frequency cetaceans (mysticetes). There are no direct measurements of TTS/PTS in low-frequency mysticetes because of the inability to test their hearing in the wild. Some TTS data for mid-frequency cetaceans in regions of best sensitivity (Finneran and Schlundt, 2010) may be applicable when considering the appropriate TTS onset value to extrapolate to mysticetes, which are highly unlikely to be tested in a controlled hearing study to measure auditory fatigure. Gedamke et al. (2011) modeled the potential for TTS onset for mysticetes. Their model does suggest that TTS (and possibly PTS) onset from seismic surveys is plausible over ranges of several kilometers; however, the uncertainty of the inputs to the model (i.e., the extrapolations of noise impacts and hearing in other species), as well as individual variation, can have a large impact on the estimates, which must at this point be considered speculative (as the authors themselves state). In addition, much of the cumulative SEL is due to the loudest airgun pulses when the animal is closest to the airgun array. In the absence of direct measurements of hearing or noise impacts in any mysticete species, subsequent data on TTS in other cetaceans calls into question the hearing group extrapolation proposed by Southall et al. (2007). Specifically, Finneran and Schlundt (2010, 2013) recently demonstrated greater sensitivity to non-impulse noise exposure for mid-frequency cetaceans at higher frequencies (within their region of best sensitivity) than had been tested when the Southall et al. (2007) criteria were published. Given the measurements of lower TTS onset values in the region of best hearing sensitivity for mid-frequency cetaceans and the low-frequency nature of seismic airgun impulses, a more conservative extrapolation of results to low-frequency cetaceans was considered justified (refer to Southall et al., 2007). For reasons relating to the much higher natural ambient background levels at low frequencies and presumed adaptations in basic hearing capabilities of these species than for other cetacean species (Wartzok and Ketten, 1999), rather than a direct application of the high-frequency cetacean TTS onset values, a more conservative extrapolation of the mid-frequency TTS onset data for impulse noise than that proposed by Southall et al. (2007) was suggested by Wood et al. (2012). In this assessment, given the results from odontocetes and a reasonable interpretation that such frequency-specific effects would likely occur at low frequencies for mysticetes, a modification of the PTS onset level was derived by subtracting 6 dB (half the magnitude in terms of sound pressure) from the original Southall et al. (2007) level, for a resulting PTS onset threshold for mysticetes of 192 dB re 1 $\mu Pa^2 \bullet s$.

Newer TTS measurements in mid- and high-frequency cetaceans (Finneran and Schlundt, 2010; Finneran et al., 2010a,b) will require reanalysis of the appropriate TTS onset (and thus injury onset) point for this category as well. For example, onset of TTS from pulsed watergun/airgun noise has been tested in three species of cetaceans. Finneran et al. (2002) exposed a beluga whale and bottlenose dolphin to watergun noise. The beluga whale showed TTS onset at 186 dB re 1 $\mu Pa^2 \bullet s$ (equivalent to 183 dB M-weighted), but the bottlenose dolphin did not show indication of TTS at the levels this experiment was able to produce. The level for the beluga whale was therefore used in the initial Southall et al. (2007) threshold for all cetaceans (198 = 183 + 15). However, Lucke et al. (2009) found a TTS onset in a harbor porpoise exposed to airgun noise at 164 dB re 1 $\mu Pa^2 \bullet s$, considerably lower than reported by Finneran et al. (2002) for beluga whales. Whether this difference is due to species or individual difference or a combination of the two is difficult to say. Onset of TTS in pinnipeds in water has been tested for several species (e.g., Kastak et al., 2005), but only with non-pulsed sounds (Southall et al., 2007). As a result, Southall et al. (2007) used the relationship between TTS onset from non-pulsed sounds in beluga whales and harbor seals (approximately 12 dB) to estimate TTS onset levels for pinnipeds in water exposed to pulsed sounds.

Improvements based on additional data were envisioned, and in most cases specifically called for in terms of experimental approaches and priorities, and the conclusions and threshold values will continue to evolve over time. Despite the expected requisite re-thinking based on new data, the Southall et al. (2007) approach to marine mammal noise exposure represented a major evolution in the complexity and scientific basis for predicting the effects of noise on hearing in marine mammals over the simplistic historical NMFS thresholds for injury. Within their recently proposed acoustic guidelines, NOAA (USDOC, NOAA, 2013) considered the earlier Southall et al. (2007) criteria, modifications based on Finneran and Jenkins (2012), and the subsequent scientific data described previously and summarized modified onset thresholds for TTS and PTS. These values are summarized in **Table H-4**, and there is an extensive discussion of derivation of these criteria in USDOC, NOAA (2013).

Table H-4. Revised Marine Mammal Noise Exposure Criteria for TTS and PTS Onset Proposed by the National Oceanic and Atmospheric Administration (From: USDOC, NOAA, 2013).

Hearing Group	PTS Onset (Received Level)		TTS Onset (Received Level)	
	Impulsive	Non-Impulsive	Impulsive	Non-Impulsive
Low-Frequency Cetaceans	Cell 1 230 dBpeak; 187 dB SELcum	Cell 2 230 dBpeak; 198 dB SELcum	Cell 11 224 dBpeak; 172 dB SELcum	Cell 12 224 dBpeak; 178 dB SELcum
Mid-Frequency Cetaceans	Cell 3 230 dBpeak; 187 dB SELcum	Cell 4 230 dBpeak; 198 dB SELcum	Cell 13 224 dBpeak; 172 dB SELcum	Cell 14 224 dBpeak; 178 dB SELcum
High-Frequency Cetaceans	Cell 5 201 dBpeak; 161 dB SELcum	Cell 6 201 dBpeak; 180 dB SELcum	Cell 15 195 dBpeak; 146 dB SELcum	Cell 16 195 dBpeak; 160 dB SELcum
Phocid Pinnipeds (Underwater)	Cell 7 235 dBpeak; 192 dB SELcum	Cell 8 235 dBpeak; 197 dB SELcum	Cell 17 229 dBpeak; 177 dB SELcum	Cell 18 229 dBpeak; 183 dB SELcum
Otariid Pinnipeds (Underwater)	Cell 9 235 dBpeak; 215 dB SELcum	Cell 10 235 dBpeak; 220 dB SELcum	Cell 19 229 dBpeak; 200 dB SELcum	Cell 20 229 dBpeak; 206 dB SELcum

dB = decibel; PTS = permanent threshold shift; SEL = sound exposure level; and TTS = temporary threshold shift.

5.2 DERIVATION OF BEHAVIORAL EFFECTS CRITERIA

In terms of behavioral impacts, the Southall et al. (2007) noise exposure criteria took a dual approach that was dependent on the sound type. For exposure to single impulses (e.g., explosions), the acoustic component of the event was considered sufficiently intense to constitute behavioral harassment at levels consistent with TTS onset (**Table H-5**). The logic for this was that these events are so brief and transient that any responses other than those affecting hearing would likely be similarly transient in nature and thus not affect the long-term health or fitness of animals. It was noted, however, that startle responses can trigger stress and other physiological responses, the biological significance of which remains poorly understood.

For all other sound types (which are the majority), Southall et al. (2007) did not propose explicit threshold criteria for the reasons of context-dependence and other complexities in the nature of behavioral responses and available literature described previously. It was concluded that significant behavioral effects would likely occur at exposure levels below those required for TTS and PTS but that simple step-function thresholds for behavior (such as the historical NMFS values) were inconsistent with the best available science. While an overarching exposure level approach for behavior, as seems reasonable for injury, is perhaps more convenient from an assessment standpoint, the underlying reasons behind the type and magnitude of behavioral response involve a multitude of factors and require a multivariate assessment method to adequately describe.

Table H-5. Marine Mammal Noise Exposure Criteria for Behavior for Different Marine Mammal Functional Hearing Groups Proposed by Southall et al. (2007).

Marine Mammal Group	Sound Type		
	Single Pulses	Multiple Pulses	Non-Pulses
Low-Frequency Cetaceans	Cell 1	Cell 2	Cell 3
Sound Pressure Level	224 dBpeak re 1 μPa (flat*)	See Tables 6 and 7 in Southall et al. (2007)	See Tables 14 and 15 in Southall et al. (2007)
Sound Exposure Level	183 dB re 1 μPa^2•s (Mlf)	N/A	N/A
Mid-Frequency Cetaceans	Cell 4	Cell 5	Cell 6
Sound Pressure Level	224 dBpeak re 1 μPa (flat)	See Tables 8 and 9 in Southall et al. (2007)	See Tables 16 and 17 in Southall et al. (2007)
Sound Exposure Level	183 dB re 1 μPa^2•s (Mmf)	N/A	N/A
High-Frequency Cetaceans	Cell 7	Cell 8	Cell 9
Sound Pressure Level	224 dBpeak re 1 μPa (flat) Southall et al. (2007)	See Tables 18 and 19 in Southall et al. (2007)	See Tables 18 and 19 in Southall et al. (2007)
Sound Exposure Level	183 dB re 1 μPa2•s (Mhf)	N/A	N/A
Pinnipeds (in water)	Cell 10	Cell 11	Cell 12
Sound Pressure Level	212 dBpeak re 1 μPa (flat)	See Tables 10 and 11 in Southall et al. (2007)	See Tables 20 and 21 in Southall et al. (2007)
Sound Exposure Level	171 dB re 1 μPa^2•s (Mpw)	N/A	N/A

* "Flat" for peak sound pressure level indicates no frequency-weighting is applied. N/A = not applicable.

Southall et al. (2007) reviewed the available marine mammal literature and proposed a severity scaling for behavioral response applied to the available data but did not present explicit step-function thresholds for behavioral response. This was because of the lack of convergence in the data on broadly applicable exposure levels resulting in significant behavioral responses.

The Southall et al. (2007) severity scaling attempted for the first time to put some reasonable bounds on the likely significance of observed responses, highlighting the importance of responses with the potential to affect vital rates and survivorship (as in NRC, 2005). An ordinal ranking of behavioral response severity (refer to Table 4 in Southall et al. [2007]) was developed to delineate behaviors that are relatively minor or brief from those considered more likely to affect vital rates. The observed behavioral responses in all 10 conditions for multiple pulses and continuous noise for each of the five functional hearing groups were reviewed in detail, and individual responses were assessed according to this severity scaling and measured or reasonably estimated exposure levels. An example of this severity scaling of the observed behavioral literature in one of these conditions (low-frequency cetaceans exposed to impulse noise, predominantly airguns) that may be particularly relevant to this assessment is shown in **Table H-6**. Blank cells in this table indicate the lack of data regarding a measured response rather than a known lack of response for these received sound levels and response categories; an overarching conclusion of Southall et al. (2007) was the striking lack of data in most exposure conditions for marine mammals.

Table H-6. Southall et al. (2007) Assessment of Individual Behavioral Responses of Low-Frequency Cetaceans to Multiple-Pulse Exposure for Various Received Levels. (Individual observations are weighted to account for statistical considerations.)

Response Score	Received Exposure Level (dBrms re 1 µPa)											
	80 to <90	90 to <100	100 to <110	110 to <120	120 to <130	130 to <140	140 to <150	150 to <160	160 to <170	170 to <180	180 to <190	190 to <200
9												
8												
7										1 (6)		
6				9.5 (3,7)	47.4 (3,7)	2.2 (3,7)	1.4 (4)	2 (1,2)	5.5 (1,2,4,6)	9.3 (1,2,4,6,8)		
5					1 (3,7)		1 (4)	1 (1,2)				
4												
3									1 (1,2)	1 (1,2)		
2												
1				5 (3,7)	6 (3,7)	1 (3,7)	2 (1,2)	3 (5)				
0				59.8 (3,7)	17.7 (3,7)	1.1 (3,7,8)	0.1 (8)	0.1 (8)	6.8 (1,2,8)	6.3 (1,2,8)		

[1]Malme et al. (1983); [2]Malme et al. (1984); [3]Richardson et al. (1986); [4]Ljungblad et al. (1988); [5]Todd et al. (1996); [6]McCauley et al. (1998); [7]Richardson et al. (1999); and [8]Miller et al. (2005).

This severity scaling, as evident in **Table H-6**, did not reveal broadly applicable patterns of response in most cases, i.e., where no response occurs below some specific received level and a high probability of response occurs above some point (as step-functions would presume). Certain observations were made, including the behavioral context-dependence of response for different received levels in migrating bowhead whales and the particular sensitivity of harbor porpoises both in field and laboratory experiments. But the primary advances made in the Southall et al. (2007) criteria in terms of behavioral response were to very clearly demonstrate that step-function thresholds for response using a single received level and no other considerations related to behavioral context are overly simplistic and outdated, and to develop at least a qualitative means of addressing behavioral response severity issues.

The Southall et al. (2007) review found that contextual factors of sound exposure relating to different animal groups, sound types, and exposure conditions as well as differing activity states complicate efforts to derive simple step-function thresholds for all species (refer also to Ellison et al., 2011). A recent modified approach proposed by Wood et al. (2012) sought to account for both species and contextual differences and is discussed here as an example of the derivation and broad application of the Southall et al. (2007) severity scaling to behavioral response criteria. Within this process, for the majority of marine mammal species, a method similar to the NMFS step-function threshold (160 dB re 1 μPa [rms]) for impulse noise was used. As reviewed in detail in Appendix II ("Studies Involving Marine Mammal Behavioral Responses to Multiple Pulses") of Southall et al. (2007), most marine mammals exposed to impulse noise demonstrate responses of varying magnitude in the 140 to 180 dB re 1 μPa (rms) exposure range, including the mysticetes in the Malme et al. (1983, 1984) studies on which the NMFS threshold is based. Potential disturbance levels at SPLs above 140 dB re 1 μPa (rms) were also highlighted in HESS (1999). Within the Wood et al. (2012) analysis of a proposed seismic survey off California, based on the integrated conclusions of Southall et al. (2007) using the severity scaling approach across different marine mammal groups, a probabilistic approach was applied at which 10 percent, 50 percent, and 90 percent of individuals exposed are assumed to produce a behavioral response at exposures of 140, 160, and 180 dB re 1 μPa (rms), respectively. Finally, in this analysis, the M-weighting functions of Southall et al. (2007) were applied to these exposure estimates.

As noted by Southall et al. (2007) and supported by subsequent data, certain marine mammal species and (within some species) individuals in specific behavioral modes appear to be significantly more sensitive to noise exposure. For instance, migrating bowhead whales are much more likely than other mysticetes (including feeding bowhead whales) to respond clearly to seismic airgun noise at much lower (120 to 140 dB re 1 μPa [rms]) received sound levels (Richardson et al., 1999).

Finally, certain species including harbor porpoises and beaked whales, appear to have a categorically different level of response than other marine mammals to much lower received levels. As reviewed in Southall et al. (2007), for harbor porpoises this appears to be consistent across sound types and laboratory and field settings. As demonstrated by Tyack et al. (2011) and DeRuiter et al. (2013), beaked whales appear to share this particular sensitivity, which may in part explain their disproportionate representation in marine mammal stranding events associated with sound exposure. Based on the initial assessment of Southall et al. (2007) and considering the more recent supporting evidence for beaked whales specifically, a particularly sensitive behavioral response category for these species and porpoises is assessed here. NMFS also recognizes species and contextual factors in setting behavioral response thresholds, the most obvious being the use of a 120 dB re 1 μPa threshold for behavioral response of harbor porpoise to Navy acoustic sources with a wide range of activities (U.S. Dept. of the Navy, 2008). Thus, for these species, independent of behavioral state, Wood et al. (2012) applied the conclusions of Southall et al. (2007) severity scaling assessments for these species to derive 50 percent and 90 percent behavioral response probabilities calculated for M-weighted exposure levels of 120 and 140 dB re 1 μPa (rms), respectively; the 10 percent probability was not modeled in this case, but the 50 percent criterion is used as a step-function. **Table H-7** provides a synopsis of the thresholds and the probability of a Level B behavioral response. Probabilities provided here from Wood et al. (2012) are not additive; that is, they reflect the probability of disturbance for a range of received sound levels along a theoretical response curve.

Table H-7. Probabilistic Disturbance (rms) Sound Pressure Level Thresholds (M-weighted) Proposed by Wood et al. (2012) based on Southall et al. (2007) Severity Scaling to Predict a Level B Behavioral Response. (For comparison, the National Marine Fisheries Commission threshold for behavioral response for all marine mammals is 160 dB re 1 μPa (rms, unweighted. Probabilities are not additive and reflect the probability of disturbance for a range of received sound levels along a theoretical response curve.)

Marine Mammal Group	Probabilistic Disturbance rms Thresholds (M-weighted dB re 1 μPa [rms])			
	120	140	160	180
	Behavioral Response Probability (percent)			
Porpoises/beaked whales	50	90	--	--
Migrating mysticetes	10	50	90	--
All other species/behaviors	--	10	50	90

Note: Behavior Response Probability is based on low (10%), moderate (50%), and high (90%) categories of probability for different response levels in different contexts. Cells with dashes indicate probabilities less than 10% or more than 90%.

The Southall et al. (2007) criteria for behavior are a starting point to develop a rudimentary framework in moving toward a more multivariate and biologically meaningful way of assessing the type and magnitude of behavioral responses of marine mammals to noise than historical thresholds (refer to Ellison et al., 2012; Wood et al., 2012). As evidenced by the absence of data in many exposure level and response types, significant data gaps exist in almost all areas, and many of the available studies lack key information about the nature of exposure in which behavioral responses were observed (which is why many studies were excluded from the Southall et al. [2007] analysis). This is an active area of research, and subsequent studies (some described previously) have begun to report additional information on background noise, various exposure metrics, and behavioral contexts.

Broad application of the Southall et al. (2007) criteria for injury and behavior has been relatively slow in evolving, in part due to the increased complexity of the recommendations over previous simplistic approaches, such as step-functions used by NMFS. However, NMFS has used exposure criteria consistent with the Southall et al. (2007) thresholds for injury from sound exposure for assessing potential impacts of U.S. Navy active sonar operations (*Federal Register*, 2009a and 2009b) for a host of species, including large whales and pinnipeds; subsequent derivations of the Southall et al. (2007) criteria based on some of the subsequent data described previously are given in Finneran and Jenkins (2012). In fact, these regulations actually include higher exposure values for certain species for which higher TTS onset values were directly measured than the more conservative values used in Southall et al. (2007). Additionally, recent NMFS regulations (*Federal Register*, 2009a,b) have begun to use a more graduated dose-function based approach to behavioral response rather than the historical step-function thresholds. NMFS is preparing acoustic exposure guidelines that are expected to increasingly consider the complexity and context-dependence of responses of marine mammals to sound.

6 ASSESSMENT OF HEARING INFORMATION FOR SPECIES/ GROUPS IN THE AREA OF INTEREST

Specific sound sources that will be used in G&G exploration activities in the GOM, as discussed in **Chapter 3** of this Programmatic EIS, include impulsive (e.g., two- and three-dimensional seismic exploration surveys using conventional airguns) and continuous noise sources such as, vessel propulsion systems, drilling, dredging, sediment sampling, and electromagnetic surveys.

Most of the marine mammals likely to be present in the Area of Interest, as discussed in **Chapter 4.2.2** of this Programmatic EIS, are mid-frequency cetaceans and manatees with some mysticetes (Bryde's whales) and high-frequency cetaceans (dwarf and pygmy sperm whales). For some of these species (e.g., bottlenose dolphins), relatively good information exists about hearing and behavioral responses to some types of sounds (e.g., Nowacek et al., 2001), though not for seismic exploration specifically. For most of the mid-frequency cetacean species, including the endangered sperm whale, the injury criteria proposed by Southall et al. (2007) and general conclusions on behavioral response would be expected to be applicable; direct recent information on behavioral responses in sperm whales to seismic airguns are available as well (e.g., Miller et al., 2009).

For West Indian manatees, direct measurements of hearing are available (Gerstein et al., 1999; Mann et al., 2005) as well as responses to vessel presence and noise (Nowacek et al., 2004). From the perspective of hearing injury, the use of pinniped exposure criteria from the Southall et al. (2007) criteria would seem reasonable, as described previously. These animals generally are very coastal-oriented, meaning they likely would encounter G&G activities only in nearshore waters.

For the mysticetes that could occur in the area (limited to Bryde's whales), as for all low-frequency cetaceans, no direct information regarding hearing is available. As described previously, the Southall et al. (2007) exposure criteria for injury are based on assumptions and extrapolations from mid-frequency cetacean data that may need to be reassessed to some degree based on the subsequent measurements of lower onset TTS levels in bottlenose dolphins within their range of best hearing sensitivity (Finneran and Schlundt, 2010), although there is limited direct available data with which to support such extrapolation.

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APPENDIX I

SEA TURTLE HEARING
AND
SENSITIVITY TO ACOUSTIC IMPACTS

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ABBREVIATIONS AND ACRONYMS

ABR	auditory brainstem response
AEP	auditory evoked potential
cm^3	cubic centimeter
CT	computed tomography
dB re 1 μPa	decibels relative to 1 micropascal
Hz	hertz
in^3	cubic inch
MRI	magnetic resonance imaging
ms	millisecond
PTS	permanent threshold shift
TTS	temporary threshold shift

1 INTRODUCTION

There is growing concern over anthropogenic sound in the world's oceans and its potentially harmful effects on protected marine organisms, including sea turtles. There are seven extant species of sea turtle: green (*Chelonia mydas*); hawksbill (*Eretmochelys imbricata*); loggerhead (*Caretta caretta*); olive ridley (*Lepidochelys olivacea*); Kemp's ridley (*Lepidochelys kempii*); flatback sea turtle (*Natator depressus*); and leatherback (*Dermochelys coriacea*). All sea turtles share a similar body form, although shell morphology is different in leatherback turtles compared to the hard-shelled species. Similar to other migratory marine species, sea turtles occupy different ecological niches throughout ontogeny (refer to the review by Bolton, 2003), each characterized by unique acoustic conditions. Sea turtles spend the majority of their lives in the ocean; their only land-linked behaviors are egg deposition and hatching. Once hatchlings reach the sea, they are pelagic, moving primarily with ocean currents. After a period of years, the number of which varies among species and populations, a critical ontogenetic habitat shift occurs whereby most sea turtles actively recruit to a demersal, neritic habitat and are considered juveniles. Upon reaching maturity, sea turtles maintain a discrete foraging area (this region frequently overlaps with the juveniles' habitat), migrating only to return to their natal nesting beach. The exception to this life history model is in the North Atlantic leatherback turtle populations, which remain pelagic as juveniles and adults and return to the neritic zone only for reproduction (Bolton, 2003).

Few studies have examined the role acoustic cues play in the ecology of sea turtles (Mrosovsky, 1972; Cook and Forrest, 2005; Samuel et al., 2005). There is evidence that sea turtles may use sound to communicate; the few vocalizations described for sea turtles are restricted to the grunts and gular pumps of nesting females (Mrosovsky, 1972; Cook and Forrest, 2005) and four types of sounds within the nest environment of leatherback turtles (Ferrara et al., 2014). These noises are low-frequency sounds and have been described as relatively loud compared to ambient noise, leading to speculation that the sounds are not just a result of nesting and hatching activity but that nesting females and hatchlings may use sound to communicate with conspecifics (Mrosovsky, 1972; Cook and Forrest, 2005; Ferrara et al., 2014). Very little is known about the extent to which sea turtles use their auditory environment ("soundscape") for navigation, environmental assessment, or identification of predators and prey. However, the passive acoustic environment for sea turtles changes with each ontogenetic habitat shift. In the inshore environment where juvenile and adult sea turtles generally reside, the ambient biotic environment is noisier than the open ocean environment of the hatchlings and is dominated by low-frequency sound (Hawkins and Myrberg, 1983). In highly trafficked inshore areas, nearly constant low-frequency noises from shipping, recreational boating, and seismic surveys compound the potential for acoustic impact (Hildebrand, 2005) and might prevent an animal from hearing signals from biologically important stimuli (Fay, 2009).

The focus of this appendix is on sea turtle hearing, but other marine vertebrates can be affected by human sounds as well. For a discussion of hearing and the effects of noise on marine mammal hearing, refer to **Appendix H**. For a discussion of hearing and the effects of noise on fish hearing, refer to **Appendix J**.

2 MORPHOLOGY

Much of the early research on the hearing capacity of sea turtles is limited to gross morphological dissections (Wever, 1978; Lenhardt et al., 1985). More recently, researchers have been describing the middle ear cavity using x-ray computed tomography (CT) and magnetic resonance imaging (MRI) (Ketten et al., 1999; Willis et al., 2013). The tympanum is a continuation of the facial tissue and is distinguishable only by palpation of the area. Beneath the tympanum is a thick layer of subtympanal fat (**Figure I-1**), a feature that distinguishes sea turtles from terrestrial and semi-aquatic turtles. The fats appear to differ bilaterally within an animal and vary considerably between animals. With the difference in fat levels, a variation in middle ear air space is observed also (Willis et al., 2013). Recent imaging data suggest that this layer of fat is similar to the fats found in the jaws of odontocetes and may function as a low-impedance channel for sounds to the ear (Ketten et al., 1999). The middle ear cavity lies posterior to the tympanum, and the Eustachian tube connects the middle ear with the throat (Wever, 1978; Lenhardt et al., 1985). As with most turtles, the middle ear is small and encased by bone. The ossicular mechanism consists of two elements: the extracolumella and the columella (stapes). The extracolumella is a cartilaginous disk under the tympanic membrane attached to the columella by ligaments. The columella, a long rod with the majority of its mass concentrated at each end, extends medially from the middle ear cavity through a narrow bony channel and expands within the oval window to form a funnel-shaped end. The columella is free to move only longitudinally within this channel so that when the tympanum is depressed directly above the middle of the extracolumella, the columella moves readily in and out of the oval window without any flexion of the columella. The stapes and oval window are connected to the saccular wall by fibrous strands. It is thought that these stapedo-saccular strands relay vibrational energy from the stapes to the saccule (Wever and Vernon, 1956; Wever, 1978; Lenhardt et al., 1985). For semi-aquatic turtles, the columella is the main pathway for sound input to the inner ear; when the columella is clipped but the tympanum is intact, a test animal displayed an extreme decrease in hearing sensitivity (Wever and Vernon, 1956).

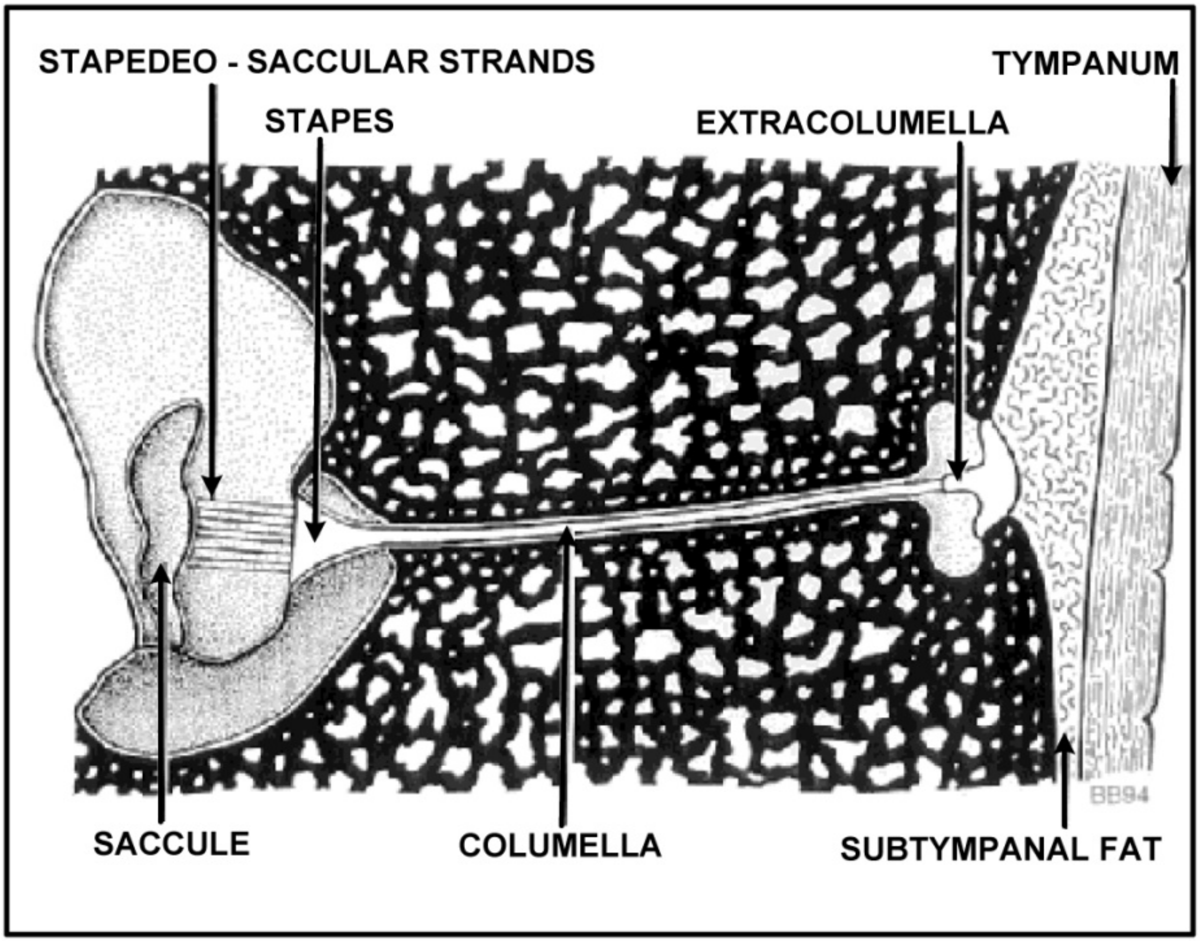

Figure I-1. Middle Ear Anatomy of a Juvenile Loggerhead Sea Turtle (From: Moein, 1994).

The auditory sense organ within the inner ear of the sea turtle cochlea is the basilar papilla (basilar membrane). This membrane is large and composed of dense connective tissue in sea turtles (compared to the thin basilar membrane found in terrestrial turtles) (Wever, 1978; Hetherington, 2008). The basilar papilla is positioned opposite the round window and lies within the pathway of fluid displacement due to columella motion. In most reptiles, and presumably in sea turtles as well, the tectorial membrane lays over the hair cells of the basilar papilla. For sea turtles, the innervations of the hair cells may be accomplished through the movement of the overlying tectorial membrane rather than the movement of the papillae (Hetherington, 2008).

Based on the functional morphology of the ear, it appears that sea turtles receive sound through the standard vertebrate tympanic middle ear path. The sea turtle ear morphology, however, is adapted to underwater sound not aerial sound. For the terrestrial vertebrate, the middle ear is an impedance transformer between sound in air (environment) and sound in fluid (inner ear). This impedance mismatch can be overcome by having a high convergence ratio between the tympanic membrane and the oval window (thus amplifying the force acting on the inner ear) or by having a multiple bone ossicular mechanism that acts as a lever system to amplify force. The convergence ratio of the tympanic membrane to the oval window in sea turtles is reported to be lower than semi-aquatic turtles (Lenhardt et al., 1985), and sea turtles lack an ossicular mechanism that acts as an effective lever (having only a single straight columella). Thus, the sea turtle ear appears to be poorly adapted to receive aerial sounds. However, the ear is well adapted to sound conducted in water. The dense layer of fat under the tympanum may act as a low-impedance channel for underwater sound (similar to the pathway found in odontocetes [Ketten et al., 1999]). Furthermore, the retention of air in the middle ear of sea turtles suggests that they are able to detect sound pressures (Hetherington, 2008).

3 ELECTROPHYSIOLOGICAL RESPONSE TO SOUND

Electrophysiological studies on hearing have been conducted on juvenile and subadult green turtles (Ridgway et al., 1969; Bartol and Ketten, 2006; Dow Piniak et al., 2012a); juvenile Kemp's ridley turtles (Bartol and Ketten, 2006); post-hatchling, juvenile, and adult loggerhead turtles (Bartol et al., 1999; Lavender et al., 2012, 2014; Martin et al., 2012); and hatchling leatherback turtles (Dow Piniak et al., 2012b). Electrophysiological responses, specifically auditory evoked potentials (AEPs), are the most widely accepted technique for measuring hearing when normal behavioral testing is impractical. AEPs reflect the synchronous discharge of large populations of neurons within the auditory pathway and thus are useful for monitoring the functionality of the auditory system. Some AEP research has concentrated the responses occurring within the first 10 milliseconds (ms) following presentation of click or brief tone burst stimuli. This response has been termed the auditory brainstem response (ABR) and consists of a series of five to seven patterned and identifiable waves. These techniques are noninvasive and often performed on conscious subject animals (Bullock, 1981; Corwin et al., 1982; Bartol et al., 1999).

Green Sea Turtle

Ridgway et al. (1969) measured auditory cochlear potentials of green turtles using aerial and vibrational stimuli. Thresholds were not measured; instead, cochlear response curves of 0.1 microvolt potential were plotted for frequencies ranging from 50 to 2,000 hertz (Hz). Green turtles' best sensitivity fell within a limited frequency range for aerial stimuli (200 to 700 Hz) and vibrational stimuli (300 to 500 Hz). Though this investigation examined two separate modes of sound reception (i.e., air and bone conduction), sensitivity curves were relatively similar, suggesting that the inner ear is the main structure for determining frequency sensitivity. More recently, Bartol and Ketten (2006) collected underwater ABRs from juvenile and subadult green turtles. For these experiments, a speaker was suspended in air while the sea turtle's tympanum remained submerged underwater. All sea turtles tested responded to sounds in the low-frequency range, from at least 100 Hz (lowest frequency tested) to no greater than 800 Hz. Interestingly, hearing sensitivity of green turtles varied with size; smaller green turtles had a broader range of hearing (100 to 800 Hz; greatest sensitivity at 600 to 700 Hz at 95 decibels relative to 1 micropascal (dB re 1 μPa) than that detected in larger subadult subjects (100 to 500 Hz, greatest sensitivity 200 to 400 Hz at 93 to 97 dB re 1 μPa). Dow Piniak et al. (2012a) recorded both in-air and in-water AEP responses from juvenile green turtles. The AEP signature recorded from green turtles was similar to that seen in studies of fish evoked potentials, with a frequency-doubling response (i.e., where response waves oscillate at twice the stimulus frequency). Juvenile green turtles responded to stimuli between

50 and 1,600 Hz in water and 50 and 800 Hz in air. Ranges of maximum sensitivity were between 50 and 400 Hz in water and 300 and 400 Hz in air. Although these animals responded to an expanded range of frequencies, sensitivity decreased sharply for frequencies above 400 Hz in both media.

Loggerhead Sea Turtle

Hearing has been studied on multiple size classes of loggerhead sea turtles. Bartol et al. (1999) collected ABRs from juvenile loggerhead turtles by delivering vibratory stimuli directly to the dermal plates over the tympanum. Thresholds were recorded for both tonal and click stimuli. Best sensitivity was found in the low-frequency region of 250 to 1,000 Hz. The decline in sensitivity was rapid above 1,000 Hz, and the most sensitive threshold tested was at 250 Hz. Lavender et al. (2012, 2014) recorded underwater AEPs from post-hatchling to juvenile loggerhead turtles. These experiments involved submerging a restrained, fully conscious sea turtle just below the water surface and presenting sound using an underwater speaker. Under these conditions, post-hatchling and juvenile loggerhead turtles were found to respond to frequencies between 50 and 1,100 Hz. Post-hatchlings responded with the greatest sensitivity at 200 Hz (116 dB re 1 μPa) while juveniles were most sensitive at 50, 100, and 400 Hz (117 to 118 dB re 1 μPa). Martin et al. (2012) acquired AEPs from a single submerged adult loggerhead turtle using an underwater pool speaker and reported thresholds between 100 and 1,131 Hz, with highest sensitivity occurring at 100 to 400 Hz (threshold levels were approximately 109 dB re 1 μPa).

Leatherback Sea Turtle

Only one study has addressed the hearing of leatherback sea turtles (Dow Piniak et al., 2012b). This study measured the hearing of hatchlings (immediately after emergence from the nest) in water and in air. For these recordings, the animals were sedated then fully submerged and presented with stimuli from an underwater speaker or placed on a foam pad and stimulated with an aerial speaker. The animals reacted to low-frequency sounds, responding to stimuli between 50 and 1,600 Hz in air and 50 and 1,200 Hz in water (lowest sensitivity recorded was 93 dB re 1 μPa at 300 Hz).

Kemp's Ridley Sea Turtle

Bartol and Ketten (2006) recorded hearing from Kemp's ridley turtles using the same methods described for juvenile and subadult green sea turtles. The two juveniles tested had a restricted hearing range (100 to 500 Hz) with their most sensitive hearing falling between 100 and 200 Hz (110 dB re 1 μPa) (Bartol and Ketten, 2006).

4 BEHAVIORAL RESPONSES TO SOUND

Multiple studies have attempted to examine the behavioral responses of juvenile loggerhead turtles to sound in their natural environment, both in controlled settings (O'Hara and Wilcox, 1990; Moein et al., 1995; McCauley et al., 2000; Lavender et al., 2012; 2014; Martin et al., 2012) and as observed in situ (Holst et al., 2007; Weir, 2007; DeRuiter and Doukara, 2012).

Behavioral Audiograms

Behavioral audiograms have been collected from post-hatchling, juvenile, and adult loggerhead turtles (Lavender et al., 2012, 2014; Martin et al., 2012) and required the animal to perform a task in the presence of auditory stimuli. Though time consuming (it can take months to train a sea turtle to sound), behavioral audiograms are a more sensitive measure of hearing threshold than electrophysiological responses (Kastak and Schusterman, 1998; Szymanski et al., 1999; Nachtigall et al., 2000; Casper et al., 2003; Wolski et al., 2003) and ascribe a critical behavioral component to hearing trials. Lavender et al. (2012, 2014) recorded audiograms using a two-response, forced-choice approach, whereby the sea turtles were required to vary behavior according to the presence or absence of sound. Post-hatchling and juvenile loggerhead turtles responded to similar frequencies as found in their previous AEP studies (50 to 1,000 Hz); however, their threshold levels were more sensitive than reported using the electrophysiological approach. Post-hatchling turtles responded with the greatest sensitivity at 200 Hz (85 dB re 1 μPa) while juveniles were most sensitive at 800 Hz (76 dB re 1 μPa). This study reported no difference in threshold levels between the two ontogenetic stages. Martin et al. (2012) recorded a behavioral audiogram from one adult loggerhead turtle using a go/no-go paradigm and found the animal responded to sounds between 50 and 800 Hz with best sensitivity at 100 Hz (98 dB re 1 μPa).

Behavioral Responses in Controlled Settings

Several sea turtle behavioral studies have been initiated to assist in the development of an acoustic repelling device for sea turtles. O'Hara and Wilcox (1990) attempted to create a sound barrier for loggerhead turtles at the end of a canal using seismic airguns (Bolt Technology Model 600B, 165 cubic centimeters [cm^3] and Model 542, 13 cm^3). The test results indicated that airguns were effective as a deterrent for a distance of approximately 30 meters (98 feet) when the sound output of the system was approximately 220 dB re 1 μPa at 1 m in the 25- to 1,000-Hz range. However, this study did not account for the reflection of sound by the canal walls, and the stimulus frequency and intensity levels are ambiguous. Moein et al. (1995) investigated the use of airguns (Bolt Technology Par 2800, 20-cubic inch [in^3] chamber) to repel juvenile loggerhead turtles from hopper dredges. A net enclosure was erected in the York River, Virginia to contain the sea turtles, and an airgun was stationed at each end of the net. Sound frequencies of the airguns ranged from 100 to 1,000 Hz at three decibel levels (175, 177, and 179 dB re 1 μPa at 1 m). Avoidance of the airguns was observed upon first exposure. However, after three separate exposures to the airguns, the sea turtles habituated to the stimuli. This termination of response to stimuli could indicate damage to the sea turtles' ears and a temporary or permanent shift in their threshold levels. McCauley et al. (2000) examined the response of sea turtles (one green turtle and one loggerhead turtle) to an airgun signal (Bolt Technology Model 600B, 20-in^3 chamber). For these trials, the sea turtles were placed in cages and behavior was monitored as a single airgun approached and departed. The sea turtles showed a noticeable increase in swimming behavior when the received airgun level was higher than 166 dB re 1 μPa at 1 m, and they became erratic and increasingly agitated when the received level was higher than 175 dB re 1 μPa at 1 m. Because these animals were caged, avoidance behavior could not be monitored. However, the researchers speculated that avoidance would occur at 175 dB re 1 μPa at 1 m, the point at which the animals were acutely agitated (McCauley et al., 2000).

Behavioral Responses In Situ

Researchers have attempted to monitor sea turtle avoidance to sound during active seismic surveys (Holst et al., 2007; Weir, 2007; DeRuiter and Doukara, 2012). Weir (2007) observed 240 animals during a 10-month seismic survey off the coast of Angola (source levels of 220 to 248 dB re 1 μPa, peak energy between 10 and 200 Hz). Behaviors were recorded at the first sighting and as the vessel and towed equipment moved in relation to the sea turtle. Fewer sea turtles were observed near the airguns as they were firing (compared to the shutdown state). However, the source of agitation for the sea turtle could not be identified; the sea turtle could have reacted to the ship and towed equipment rather than specifically to the airgun (Weir, 2007). DeRuiter and Doukara (2012) observed sea turtles (mainly loggerhead turtles) during active operation of an airgun array (252 dB re 1 μPa [peak]) and found a startle response (rapid dive) to the airgun as it approached. Though the researchers did not perform a control with the airguns off and thus could not rule out if these responses were due to visual cues, the timing of the sea turtles' responses to the firing of the sounds indicates a reaction to the airgun (DeRuiter and Doukara, 2012). Holst et al. (2007) looked at sea turtle monitoring data during seismic surveys. This report included data from visual observations and passive acoustic monitoring. Displacement of the sea turtles during the surveys was apparent for large- and small-source surveys.

5 EFFECTS OF ANTHROPOGENIC NOISE

Anthropogenic noise levels are increasing in the oceans (Hildebrand, 2009); however, very little is known about the effects anthropogenic noise may have on marine species, especially sea turtles. Anthropogenic noises can originate from several sources, including shipping traffic, seismic surveys for petroleum exploration, military sonar operations, and pile driving. These sounds have the potential to impact an animal in several ways, including trauma to hearing (temporary or permanent), trauma to non-hearing tissue (barotraumas), alteration of behavior, and masking of biologically significant sounds (McCarthy, 2004).

Hearing damage usually is categorized as a temporary or permanent injury. Temporary threshold shifts (TTSs) are recoverable injuries to the hearing structure and can vary in intensity and duration. Normal hearing abilities return over time; however, animals often lack the ability to detect prey and predators or assess their environment effectively during the recovery period. In contrast, permanent threshold shifts (PTSs) are the permanent loss of hearing through loss of sensory hair cells (Clark, 1991). Few studies have looked at hair cell damage in reptiles, and it is unknown if sea turtles are able to regenerate hair cells (Warchol, 2011). There are almost no data on the effects of intense sounds on sea turtles; thus, it is difficult to predict the level of damage to hearing structures. Clear avoidance reactions to seismic signals at levels between 166 and 179 dB re 1 μPa have been observed (Moein et al., 1995; McCauley et al., 2000); however, both studies were done in a caged environment, so the extent of avoidance could not be monitored. Moein et al. (1995) observed a habituation effect to airguns; the animals stopped responding to the signal after three presentations.

This lack of behavioral response could be an indication of TTS or PTS brought on by exposure to airguns.

Currently, data gaps prevent the development of science-based quantitative exposure criteria and guidelines. Based on the available literature, qualitative sound exposure guidelines for sea turtles have been developed for five classes of sounds: (1) explosions; (2) seismic airguns; (3) pile driving; (4) active sonar; and (5) continuous sound sources (Popper et al., 2014). In the guidelines, sea turtles are placed in moderate-to-high levels of risk for physical impairment when near the source for all G&G source categories except mid-frequency sonar that operates at frequencies outside of the hearing range of sea turtles (**Table I-1**) (Popper et al., 2014). For example, there is an overlap in the frequency range of output from seismic airguns sounds and hearing ranges of sea turtles (**Figure I-2**). The frequency overlap can be seen when the sound energy of an acoustic signal (i.e., seismic) is distributed across the frequency domain. In **Figure I-2**, only the frequencies with the maximum (highest) sound energy for airguns are illustrated and range from 20 to 200 Hz (Popper et al., 2014). Furthermore, while physiological data on the adverse effects of seismic airguns on sea turtles are not available, it can be inferred that if the received levels are high enough, exposure could cause injury (TTS or PTS).

Table I-1. Relative Risk of Injury to Sea Turtles Exposed to Seismic Airgun Sounds at Three Distances from the Sound Source (From: Popper et al., 2014).

Type of Animal	Impairment			Behavior
	Recoverable Injury	TTS	Masking	
Sea Turtles	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low

F = far (thousands of meters from source); I = intermediate (hundreds of meters from source); N = near (tens of meters from source); TTS = temporary threshold shift.

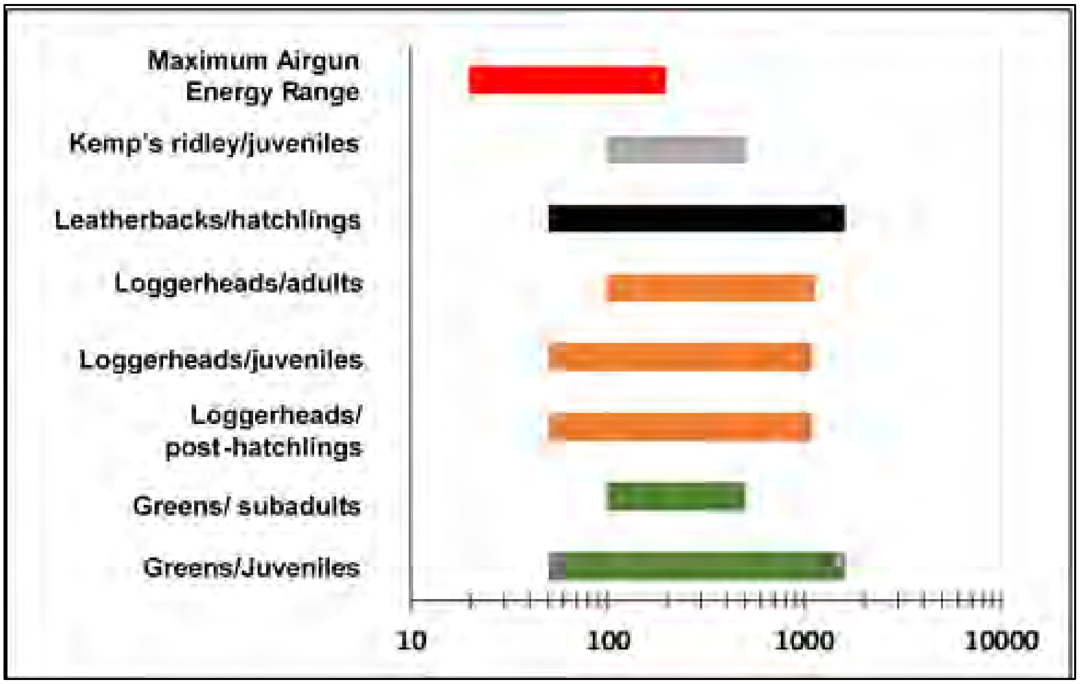

Figure I-2. Typical Range of Frequencies that Contain Maximum Acoustic Energy from Seismic Airgun Signals Compared to Frequency Ranges of Hearing in Sea Turtles. (Hearing data have not been collected from sea turtles to frequencies lower than 50 Hz [Data from: Bartol et al., 1999; Bartol and Ketten, 2006; Dow Piniak et al., 2012a,b; Martin et al., 2012; Lavender et al., 2014]).

Anthropogenic noises below injury levels could provoke annoyance responses and mask relevant sounds in an animal's environment. Ideally, when studying the behavioral responses of wild animals, multiple individuals should be observed in situ and under natural conditions. These data are difficult to collect and even more difficult to interpret. Avoidance and startle responses to seismic airguns have been demonstrated for sea turtles in a few studies (O'Hara and Wilcox, 1990; Moein et al., 1995; Holst et al., 2007; Weir, 2007; DeRuiter and Doukara, 2012) and these behavioral avoidance reactions could interfere with sea turtles' normal behaviors. For example, DeRuiter and Doukara (2012) speculated that the observed startle response prevented sea turtles from basking and could result in decline in their metabolic activity. Furthermore, masking sounds (i.e., signals that can reduce the detectability of another sound) can interfere with a sea turtle's ability to acquire prey, to find a mate, to avoid predators, and to identify an appropriate nesting site (Nunny et al., 2008). Sea turtles appear to be low-frequency specialists; thus, potential masking noises would fall within at least 50 to 1,000 Hz. However, there are no quantitative data demonstrating masking effects for sea turtles.

More research on the behavioral and physiological responses to sounds needs to be conducted on sea turtles before appropriate noise exposure criteria can be developed for reduced fitness, injury, and death. While the research community is making progress in determining the frequency range of hearing for sea turtles, there are few data on hearing loss/damage, hair cell regeneration, masking, and behavioral responses. Inner ear research on hair cell population needs to be conducted on multiple species and age classes by using histology/imaging techniques to analyze variations in auditory anatomy among stages and species. The critical point at which noise disrupts scene analysis and masks signals should be explored, and quantitative data on masking need to be collected for sea turtles. When looking at behavioral responses, research beyond the startle response must be conducted. Controlled experiments in the natural environment need to be conducted to document and classify reactions to sound as either nuisance (i.e., causing the animal to move away, changing the animals' behavior to another acceptable consequence) or injurious (i.e., preventing the animal from completing essential behavior). The results of these research studies could provide new data on the hearing ability and response to sound for sea turtles, and serve as a quantitative base for assessing potential impacts of man-made sound sources on multiple species of sea turtles across habitats and developmental stages.

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APPENDIX J

FISH HEARING AND THE SENSITIVITY OF FISH TO HEARING LOSS AND INJURY FROM EXPOSURE TO ANTHROPOGENIC SOUND

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ABBREVIATIONS AND ACRONYMS

dB re 1 μPa	decibels relative to 1 micropascal
dB re 1 $\mu Pa^2 \cdot s$	decibels relative to 1 micropascal squared second
EIS	Environmental Impact Statement
g	gram
G&G	geological and geophysical
GOM	Gulf of Mexico
Hz	hertz
kHz	kilohertz
m/s	meters per second
nm/s	nanometers per second
PTS	permanent threshold shift
rms	root mean square
SEL	sound exposure level
SPD	sound pressure difference
SPL	sound pressure level
TTS	temporary threshold shift

1 INTRODUCTION

One of the objectives of the Gulf of Mexico (GOM) Programmatic Environmental Impact Statement (EIS) is to determine or estimate the potential impacts of sound generated by geological and geophysical (G&G) survey activities on fish populations in the northern part of the GOM. Over millions of years, fishes have evolved hearing systems that utilize sound to perform a wide range of important life functions, including finding food and mates, communicating with conspecifics, and avoiding predators (Clack and Allin, 2004). Evolutionary processes that have resulted in the adaptations exhibited by the more than 32,000 species of fish (Helfman et al., 2009) have only had to contend with high levels of anthropogenic sound within the last few decades (Hildebrand, 2009).

The basics of hearing in fishes are known even though the hearing of only a very small number of species (approximately 50) has been studied (Fay, 1988; Popper et al., 2003; Lovell et al., 2005; Wysocki et al., 2009; Meyer et al., 2012). The study of fish hearing has, from necessity, involved studying the physics of underwater sound.

This appendix reviews the physics of underwater sound, mechanics of fish hearing, sources of anthropogenic sound and sound metrics, mechanisms of injury to fish from exposure to anthropogenic sound, and criteria for the protection of fish from exposure to injurious levels of G&G survey sounds. References cited in the appendix include technical reports as well as peer-reviewed literature. This appendix is not intended to be a comprehensive review of fish hearing, fish physiology, and the physics of sound but an overview of the elements of these subject areas that relate directly to the assessment of risk of hearing loss and injury to fish from exposure to anthropogenic sound. For a discussion of hearing and the effects of noise on marine mammal hearing, refer to **Appendix H**. For a discussion of hearing and the effects of noise on sea turtle hearing, refer to **Appendix I**.

2 THE PHYSICS OF UNDERWATER SOUND

Sound is a mechanical disturbance that propagates as a longitudinal wave through compressible media. The acoustic energy propagated in a sound wave consists of very small molecular vibrations that travel at a rate dependent upon the density of the medium. In water, the speed of sound is approximately 1,500 meters per second (m/s) (4,921 feet per second) and is slightly faster in saltwater than in freshwater. The speed of sound increases with temperature, salinity, and depth (hydrostatic pressure). The propagated mechanical energy in a sound wave is in the kinetic energy of water particle motion and the potential energy of the pressure (stress) component of a sound wave. When water molecules are closer together, the fluid is compressed and pressure is higher; when water molecules are farther apart, the fluid is rarefied and pressure is lower. In this appendix, cited works will be those that consider these topics within the context of bioacoustics.

Because of the relative ease of measuring pressure (a scalar quantity), it is the most commonly measured component of sound. Water particle velocity (a vector quantity with both magnitude and direction) is more difficult to measure under field conditions and therefore is infrequently measured. The difficulty in measuring water particle velocity in the field poses a considerable challenge in the study of fish hearing impacts. While all fish can detect the water particle velocity component of a sound wave, only those with swim bladders, which may be associated with specialized structures connected to or in close proximity to their ears, can utilize the pressure component of a sound wave in order to hear. This is a particular problem when studying fish hearing within the near field of a sound source.

The definition of "near" for a sound source is complicated by many factors. Near a sound source, the particle motion component of the acoustic field has the characteristics of incompressible hydrodynamic flow. This means that the ratio of particle velocity and acoustic pressure amplitudes is much higher than when farther from the source. The rate of change in particle motion in the region near the source is a function of the characteristics of the source. The rate of decrease with range of acoustic particle motion near a source is on the order of 1/r2 to 1/r3, where r is the range from the source. This decreases to 1/r in the propagation of a far field sound wave where the ratio of the amplitudes of particle velocity and acoustic pressure equals the specific acoustic impedance (Clay and Medwin, 1977; Kalmijn, 1988; Uric, 1983; Au and Hastings, 2008). As the distance from an acoustic source increases, the ratio of pressure to particle velocity approaches the value expected for a plane wave, where the majority of energy in the propagating sound wave is in the form of pressure, and far field conditions are satisfied (Kalmijn, 1988; Au and Hastings, 2008).

In the far field, as sound propagates away from its source, a number of factors, including geometric spreading, attenuation, reflection, scattering, and refraction, interact to affect the level of sound and other characteristics of the sound wave. For the low frequencies at which the vast majority of fish species hear (frequencies <1 kilohertz [kHz]), attenuation is not a major factor (Rogers and Cox, 1988). More important are other propagation effects that reduce the intensity (energy per unit time) of the sound wave and modify features of the signal that may change its information content. In general, from the perspective of the receiver, as distance from a source increases, the various factors affecting propagation make the sound harder to detect and significantly affect the quality of information it carries (Rogers and Cox, 1988).

Because of the various factors that influence sound as it travels from its source, the resulting sound field has considerable complexity in space and time. As a rule, single measurements made at a point in the volume cannot be used to describe conditions in the sound field at other locations (nearer or farther from the source). Consequently, when an estimate of sound field characteristics for a large volume are needed, sound propagation models are used to estimate the intensity in the sound wave at points distant from the source. Such models may be used to estimate amplitude and frequency features of the propagating sound wave. There are several sound propagation models in use at any time, each designed to satisfy a particular sound propagation simulation need (Etter, 2012).

Sound propagation is complex as it needs to consider propagation through the water column as well as through the seafloor. Sound introduced into the seafloor through activities such as pile driving, some types of geophysical sound sources, and explosions from buried explosive material or in structures connected to the seafloor can result in sound being transmitted long distances through the earth and reintroduced into the water column some distance from the source (Jackson et al., 1994).

3 THE MECHANICS OF FISH HEARING

Fish use light and sound to sense their environment. Because of the rapid attenuation of light, particularly in the portion of the electromagnetic spectrum visible to humans and most fish, sound is very important to fish to obtain information about their environment as it attenuates much more slowly than light. Fish are believed to use sound to sense their environment (acoustic scene assessment), communicate with conspecifics, detect prey, navigate, and perform other life-sustaining functions (Bregman, 1990; Fay and Popper, 2000; Lewis and Fay, 2004; Bass and Ladich, 2008).

There is considerable literature covering the morphology and physiology of fish ears as well as fish hearing. Popper et al. (2014) reviewed literature addressing the elements of fish hearing related to sensitivity to man-made sound. This appendix addresses the basic mechanics of the fish ear, swim bladder, and specialized structures that enhance hearing and may contribute to the susceptibility of fish to hearing loss or injury when exposed to anthropogenic sound.

The basic elements of a fish's inner ear are three orthogonal, semicircular canals and their associated otolith organs. More detailed descriptions of the morphology of fishes' ears and their function can be found in Popper et al. (1988, 2003). In addition to hearing, the vestibular system of the inner ears of fish enable them to sense gravity and function as six degrees of freedom sensors; this permits fish to sense tri axial linear (x, y, and z or forward-backward, side-to-side, and up-and-down) and angular (pitch, roll, and yaw) accelerations of their bodies (Fay and Popper, 2000; Platt, 1988).

The inner ear of fish is stimulated by the water particle motion component of a sound wave. The fish, which is nearly neutrally buoyant, moves with the oscillatory motion of the water particles in the sound wave whereas the otolithic masses, because they are approximately three times the density of the fish, lag behind the motion of the sensory epithelia of the fish's ear. The resulting differential motion between the otolithic masses and the otolithic sensory epithelia bends hair cell stereocilia, which causes the fish to hear the sound wave. Fish without swim bladders, which includes many teleost species and all elasmobranchs, only hear sounds when the level of particle motion in the sound is high enough to cause the sequence of events described above. Consequently, these fish are considered to have poor hearing and can only hear (detect a source) when they are close to a sound source with sufficient energy to cause particle motion above their hearing thresholds (Kalmijn, 1988; Rogers and Cox, 1988; Fay and Popper, 2000).

Fish with swim bladders have the potential to extend the frequency range and sensitivity of their hearing. The extent to which this happens depends on the location of the swim bladder relative to the ear or structures that would pair the swim bladder to the ear. However, the mere presence of a swim bladder without further specialization appears to offer minimal hearing enhancement over that of fish without swim bladders (Braun and Grande, 2008). Braun and Grande (2008) described the known specializations that have evolved in fishes to enhance hearing. The hearing specializations include swim bladder rostral extensions, auditory bullae, suprabranchial chambers (does not involve the swim bladder), and Weberian apparatus (Braun and Grande, 2008).

The hypothesis that the presence of a swim bladder or other hearing specialization is the basis for the observed differences in hearing sensitivity between fish species and that hearing function at the level of hair cells (particle motion) is similar among vertebrates continues to gain scientific support (Popper and Fay, 1997; Radford et al., 2012).

There are three listed fish species in the portion of the GOM covered by this Programmatic EIS: Gulf sturgeon (*Acipenser oxyrichus desotoi*); smalltooth sawfish (*Pristis pectinata*); and largetooth sawfish (*Pristis perotteti*). The Gulf sturgeon has a swim bladder but no hearing specializations. The sawfish are elasmobranchs and do not have swim bladders. The species of fish taken by commercial and recreational fishers within the GOM are identified by the Gulf of Mexico Fishery Management Council (2012). The majority of the managed fish species within the GOM have swim bladders such as snappers (Lutjanus, Etelis, Ocyurus, Pristipomoides, Rhomboplites), groupers (Epinephelus, Mycteroperca), tilefishes (Caulolatilus, Lopholatilus), jacks (Seriola), triggerfishes (Balistes), wrasses (Lachnolaimus), cobia (*Rachycentron canadum*) (a migratory pelagic fish), and bluefish (*Pomatomus saltatrix*) (a species that is not managed but is taken by fishers). Managed fish species without swim bladders include mackerel (Scomberomorus spp.), cero (*Scomberomorus regalis*), and little tunny (*Euthynnus alletteratus*). Dolphinfish (*Coryphaena hippurus*), which also do not have a swim bladder, are not managed but are taken in commercial and recreational fisheries. The relationship between the morphology of the swim bladder and inner ears and the hearing of some species of fish within the families listed above have been investigated and found to vary between species (Barun and Grande, 2008; Horodysky et al., 2008; Wright et al., 2011).

4 SOURCES OF ANTHROPOGENIC SOUND AND SOUND METRICS

There is considerable interest in anthropogenic (human made) underwater sound driven by a better understanding of the importance of sound to aquatic animals and the potential impacts of sound on the health of aquatic animals. Anthropogenic sound can be assigned to one of two general categories: continuous and pulsed (or impulsive). Pulsed sounds can be single (e.g., an underwater explosion) or multiple (e.g., a seismic sound source or pile driving).

Continuous sounds include ship noise or noises from drilling or operation of pumps. At locations far from a seismic survey or in cases where more than one seismic survey is underway in a part of an ocean, seismic sounds that are pulsed sounds near the source may appear continuous depending on several factors that affect the propagation of sound over long distances (Greene and Richardson, 1988). Continuous sound may vary in amplitude with time, and the sound sources may be narrow band with dominant discrete frequencies (tonal) or have a continuous distribution of sound over a broad frequency range (broadband). Continuous sound sources such as ship engines can have signatures that permit individual vessels to be identified (Hildebrand, 2009; Ogden et al., 2011). Shipping noise has spectra that are lower in frequency with highest levels in the 20 to 50 hertz (Hz) range, which overlaps the range of best hearing for most species of fish (Rogers and Cox, 1988). The same is true of seismic sources. Many sources of continuous anthropogenic sound have not been measured so information about their characteristics is not available.

Pulsed sounds typically are short in duration and generated by a large number of sources (e.g., seismic sound sources, pile driving, explosions, commercial and recreational sonars and echosounders, and subbottom profilers). Such sounds are impulsive in nature in that they are short (typically less than 100 milliseconds [ms] in duration), have a relatively rapid onset, a relatively high peak amplitude, and a gradual decline to ambient sound levels at which time they may appear almost continuous in nature. Because of the shorter rise times and other features, transient sounds tend to have a relatively broad frequency range. A complete characterization of transient sounds that are repeated, as is the case for pile driving and seismic exploration, need to include the time period over which the sounds are generated and the time between sounds. Explosions are an example of an impulsive sound source. If an explosion occurs in the water column, it will likely have a very rapid rise time and high amplitude typical of a shock wave. Impulsive sound from single charge explosions tend to have durations similar to that of seismic and pile driving sounds but much higher peak pressures and much shorter rise times. However, if the explosion results from several time-delayed charges, the resulting sound may have considerable duration and will not have the distinctive features of the impulsive sound generated by a single explosive charge (Continental Shelf Associates, Inc., 2004). Impulsive sounds generated by seismic sources, pile driving, and explosions have part of their energy at low frequencies that can be heard by fish and can create overpressures capable of physically injuring fish.

A wide range of navigation, military, commercial, and recreational sonars generate impulsive sounds. Such sound-producing instruments are very common and are used by almost every vessel on the water. Military sonars are designed to detect submarines; surface vessels and other military targets typically operate at frequencies less than 20 kHz and may generate complex transmissions that can be up to 100 seconds in duration. The military uses other sonars with characteristics similar to that of commercial sonars for other detection tasks. Commercial sonars are used to locate targets (fish) in the water column, map the seafloor, and perform some subbottom characterization objectives. Except for a small number of clupeid species that can hear at ultrasonic frequencies (Mann et al., 1997, 2001, 2005; Popper et al., 2004; Wilson et al., 2009), the impulsive sounds generated by high-frequency sound sources cannot be heard by fish and will not pose a threat of physical injury or affect behavior.

Hildebrand (2009) grouped anthropogenic and natural sources of sound into three frequency bands. According to Hildebrand (2009), the lowest band (10 to 500 Hz) is dominated by shipping sound with additions from seismic exploration being conducted in deeper water. Because of low attenuation, low-frequency sound may propagate very long distances affecting entire ocean basins. The middle band (0.5 to 25 kHz) is produced primarily by natural sources with contributions from some commercial and military sonars and small vessels. Because of higher attenuation, mid-frequency band sound affects more local areas, on the order of tens of kilometers, around sound sources. The highest frequency band (>25 kHz) contains anthropogenic sound produced by various commercial and recreational sources. However, at high frequencies, sound attenuation is very high and the characteristics of some sources, such as high directivity, limit their effect to small areas very near the source. Most types of G&G sound sources other than vessels and airguns produce sound within the mid- and high-frequency bands described by Hildebrand (2009).

Sound may be described by several metrics depending on the needs of the target analysis (Hastings, 2008). In the case of this appendix, the focus is on metrics that are used to evaluate the potential for a sound to affect fish hearing or to cause injury to fish. Fish differ from marine mammals in that their hearing is sensitive to both the particle motion and pressure components of a sound. The hearing of marine mammals is discussed in Appendix H. Some impacts to fish hearing are thought to be related to the energy in an exposure. The energy related metric currently used is a measure proportional to the energy of an exposure in the far field of a sound source. For transient impulsive sound, this metric is sound exposure level (SEL). SEL is expressed in decibels relative to 1 micropascal squared second (dB re 1 μPa^2•s) and is computed from observed pressures in a transient sound signal as shown in **Equation 1**. SEL can be expressed as an index of the energy in an exposure from a single impulsive sound or of the cumulative energy in an exposure from multiple impulsive sounds. If cumulative SEL is used to index the energy in a multiple event sound exposure, then information about the number of events and their distribution in time should be part of the metric. SEL for a single impulsive sound event is expressed as SELss, where "ss" stands for "single strike" (**Equation 1**). SEL for the cumulative energy in multiple impulsive sound events is SELcum (**Equation 2**), where "cum" stands for cumulative.

$$SEL_{ss} = 10log_{10}(\int p(t)^2\, dt) \tag{1}$$

$$SEL_{cum} = 10\ log_{10} \sum_{i=1}^{n} 10^{(SEL_{ss,i}/10)} \tag{2}$$

The SEL metrics for impulsive sounds with durations less than 1 second are derived from a more general measure of sound energy than those for sounds longer in duration; this is the equivalent continuous sound pressure level (SPL). **Equation 3** shows the computation for the commonly used equivalent continuous SPL using standard terminology and units. In **Equation 3**, T is in seconds and po is the reference sound pressure in μPa.

$$L_{eq}SPL_{eq} = 10\ log_{10}\left(\frac{1}{T}\int_0^T \frac{p(t)^2}{p_0^2}\, dt\right) \tag{3}$$

Current practice is to characterize continuous sound using the SPL, which is the level of the root mean square (rms) pressure in all or segments of an exposure. This metric is computed as shown in **Equation 4**, where T is in seconds. It is presented as SPLrms referenced to 1 μPa.

$$SPL_{rms} = 20\ log_{10}\left(\sqrt{\frac{1}{T}\int p(t)^2\,dt}\right) \qquad (4)$$

The SPLrms also is used as a measure of the rms pressure in transient sounds. When used for this purpose, it is computed differently than for continuous sounds. Because of the very short duration of most transient sound signals, inclusion of background noise in the computation can bias the metric. To avoid this bias, the current convention is to only include the central 90 percent of the signal in the computation, excluding the first and last 5 percent of the signal. In this case, the metric is computed as shown in **Equation 5** and is referenced to 1 μPa.

$$SPL_{rms,90} = 20\ log_{10}\left(\sqrt{\frac{1}{T_{90}}\int p(t)^2\,dt}\right) \qquad (5)$$

A third commonly used metric to report SPLs is SPLpeak, which can take several forms. Common forms include the levels of the peak positive and negative pressure (zero to peak; or peak) or the level of the absolute peak pressure (p-p). In all cases, the reference for the levels is 1 μPa. Because of the increasing importance of peak negative pressure as an explanatory variable for evaluation of potential decompressive injury to fish and the historical use of peak positive pressure in regulatory practice, it is suggested that both peak positive and peak negative pressure levels be reported for impulsive sounds. **Equation 6** shows how these metrics are computed.

$$SPL_{peak} = \ 20\ log_{10}(\max(\pm p(t))) \qquad (6)$$

It has been known for some time that all fish "hear" the particle motion component of sound (Ladich and Popper, 2004). As in the case of pressure, particle motion measurements are reported as levels relative to a reference value. The ANSI S1.1 1992(R2004) standard is a sound particle velocity reference, with the units nanometers per second (nm/s). In ISO/DIS 1683, the International Organization for Standardization recommends the use of 1 nm/s as the reference for sound particle velocity. Because particle velocity is a vector, both magnitude and direction need to be considered. **Equation 7** shows the computation to reduce tri-axial particle velocity measurements over the duration of a sound event to a single particle velocity magnitude time history.

$$v(t) = \ \lceil v(t) \rceil = \ \sqrt{v_x(t)^2 + v_y(t)^2 + v_y(t)^2} \qquad (7)$$

The result of the operation described in **Equation 7** is a series of particle velocity vector magnitude values at the digital sampling frequency of the particle velocity measurement system over the duration of the sound event. This set of particle velocity amplitudes can be summarized in several ways. **Equation 8** is used to compute the level (L), referenced to 1 nm/s, of the peak particle velocity in the sound event. **Equation 9** is the particle velocity analog of SPLrms for pressure. This computation returns the decibel level for the rms of particle velocity amplitude over the central 90 percent of the duration of an impulsive sound event.

$$L_{VPk} = \ 20\ log_{10}(v_{peak}) \qquad (8)$$

$$L_{v90} = 20\,log_{10}\left(\sqrt{\frac{1}{T_{90}}\int v(t)^2 dt}\right) \qquad (9)$$

To date, regulatory authorities have not used particle velocity as an element of exposure criteria for fish.

5 MECHANISMS OF HEARING LOSS AND INJURY

High levels of anthropogenic sound can affect hearing in or cause injury to fishes. The mechanisms of hearing loss and injury differ, and the susceptibility across species and age groups, at least for the species tested to date, is quite variable.

5.1 HEARING LOSS

Hearing loss in animals, in general, is a function of the intensity, frequency content, and duration of exposure. Hearing loss is the result of overstimulation of hair cells. For fish, the overstimulation may result in loss of hair cells and temporary hearing loss (i.e., temporary threshold shift [TTS]). Permanent hearing loss (i.e., permanent threshold shift [PTS]) has not been demonstrated in fish because fish are known to regenerate hair cells and increase the number of hair cells in their ears over their life (Popper and Fay, 1999). The TTS has been observed in fish exposed to continuous and transient sound (Popper and Schilt, 2008). The occurrence of hair cell loss and TTS is a function of the species of fish as well as the characteristics of the sound exposure (Popper and Schilt, 2008; Au and Hastings, 2008). The recovery time from TTS varies with the magnitude of TTS, species, and likely other factors not identified in studies performed to date (Popper and Hastings, 2009). For example, Popper et al. (2005) found that northern pike (*Esox lucius*) and lake chub (*Couesius plumbeus*) experienced TTS following exposure to seismic sound but recovered within 24 hours. Broad whitefish (*Coregonus nasus*) exposed to the same levels of seismic sound did not experience TTS. No damage was found to the structure of the ears of these fish (Song et al., 2008).

The question when evaluating the likely effect of exposure to G&G sound sources on hearing in fish is the SEL (the level of sound the fish receive) at which TTS is likely to occur. It has been shown for mammals that asymptotic TTS is a linear function of the difference between the SPL of an exposure noise and a baseline-hearing threshold (Carder and Miller, 1972). Based on an analysis of data, Hastings et al. (1996) suggested that sound levels 90 to 140 decibels (dB) above the baseline-hearing threshold of fish could injure their inner ears. Smith et al. (2004) tested the hypothesis of linear threshold shift (LINTS) where the TTS in fish is a linear function of the difference (in dB) between the level of noise exposure and baseline hearing threshold. The linear function fit to data indicated that a TTS of 6 dB would be experienced at a sound pressure difference (SPD) of 40 dB and a TTS of 20 dB would be experienced at an SPD of 100 dB. The data also suggested that fish are more susceptible to TTS at lower sound frequencies where hearing tends to be most sensitive. Even though limited in the number of species tested, the studies completed to date provide initial estimates of the level of noise that may lead to TTS in fish.

5.2 Injury

Injury to fish from exposure to anthropogenic sound is from barotrauma. Barotraumas are tissue injuries resulting from rapid changes in pressure. Depending on the sound source and the receiving distance from a source, barotrauma may be caused by concussion or decompression.

5.3 Concussion

Concussion injuries are caused by high amplitude positive overpressures typified by an initial positive pressure pulse with a very rapid rise time and high peak pressure. Well-known examples of a high-energy concussive overpressure pulse are the shock waves produced by in-water detonation of explosives with the chemical dynamics (rapid burn rate) of dynamite (Cole, 1948).

Concussion is most likely not a significant source of mortality for fish exposed to sound generated by G&G sources such as airguns in open field conditions. Falk and Lawrence (1973) found that while linear and point source explosions killed fish, exposure to a seismic airgun did not. Recent studies of exposure of fish to seismic airguns did not observe barotrauma injuries (Hastings et al., 2008; Popper et al., 2005; McCauley and Kent, 2012). McCauley et al. (2003) observed hair cell damage in pink snapper (*Pagrus auratus*) and erratic behavior of exposed fish that may have indicated vestibular disruption; however, immediate or delayed mortality of exposed fish resulting from injuries to tissues other than ear tissue was not reported.

5.4 Decompression

Decompression injuries are caused by negative overpressures such as the negative pressure resulting from pulsations of a gas bubble created by an explosion or airgun discharge. The high positive overpressures generated by sources that can cause concussion injuries at short distances from the source become a negative overpressure and a cause of decompression injuries when they are inverted, by reflection from the water surface (Cole, 1948). The negative overpressures that result from airguns may be sufficiently large at shorter ranges from a source pose the risk of decompressive injuries to fish with swim bladders. Decompressive injuries have been observed in fish exposed to sounds generated by pile driving, which are very similar to the sounds generated by airguns (Halvorsen et al., 2011) and similar enough to serve as a primary data source for guidelines on the exposure of fish to seismic survey sounds (Popper et al., 2014). Seismic exploration devices such as water guns produce, by implosion rather than a bubble, a negative overpressure pulse (Hutchinson and Detrick, 1984).

Injuries caused by decompression were first noticed and described during investigations of injuries to fish caused by explosions. Investigators expecting to find primarily concussive injuries found instead evidence that the swim bladder seemed to explode in fish immediately killed by explosions and that mortally injured fish had injuries to swim bladders and other internal organs suggestive of decompression rather than concussion. Decompression has become the focus of injury to fish from exposure to sound and other events where the pressure that fish are exposed to changes quickly.

There are two primary sources of decompression injuries to fish, one involving fishes' swim bladders and the other involving gases dissolved in the blood and tissues of fish. Boyles' and Henry's Laws describe the basic mechanics of these decompression injury mechanisms (Chang, 2005).

Boyles' Law describes the response of gas-filled bodies, such as a fish's swim bladder and bubbles that may exist in the digestive track or elsewhere, to changes in pressure. It can be expressed as shown in **Equation 9**, where P stands for pressure and V for volume.

$$P_1 \bullet V_1 = P_2 \bullet V_2 \tag{9}$$

In **Equation 9**, P1 is the pressure acting on a fish prior to exposure and, for swim bladder fish, this is assumed to be their acclimation pressure. Here, acclimation refers to buoyancy and it is assumed that when acclimated, a fish's swim bladder is filled to volume V1 and that the fish is neutrally buoyant. Pressure is absolute pressure and, after allowing for atmospheric pressure, is proportional to the depth of the fish. The P2 is the pressure of exposure and it is the instantaneous pressure that exists during passage of a sound wave. The V2 is the volume of the fish's swim bladder in response to the change in pressure acting on the fish. When the compressive portion of the sound wave is at the fish, then V2 < V1; antithetically, when the decompressive (rarefaction) portion of the sound wave is at the fish, V2 > V1.

Scientists investigating the effect of explosions on fish estimated that a 60 percent reduction in pressure was sufficient to rupture the swim bladder (Simenstad, 1974). Development of criteria for the design of hydroturbines included the specification that the pressure drop (which is essentially instantaneous) through the turbine runner should not exceed 60 percent of the pressure at the acclimation depth of the fish passing through the turbines (Cada et al., 1997). The susceptibility of fish to injury when decompressed is determined by the ratio of the acclimation pressure and exposure pressure (Yelverton et al., 1975; Goertner, 1978a; Brown et al., 2009, 2012), meaning the risk of decompression injury from sound is depth dependent. Rogers and Zeddies (2008) extended consideration of the effect of depth on the ability of a fish's swim bladder to enhance hearing. They noted that due to an increase in the density of air in the swim bladder with depth, the swim bladder volume fluctuations from an incident sound wave would become increasing smaller with depth. This effect would, while resulting in decreased hearing sensitivity, reduce the risk of hearing loss due to overstimulation of ear hair cells.

Fish acclimate to the concentration of dissolved gas in the water they occupy. Gas exchange through gills maintains gas tensions in the blood at the levels that exist in the water fish occupy, provides oxygen for bodily functions, and removes carbon dioxide (Perry and McDonald, 1993). Henry's Law defines the relationship between the concentration of gas in solution in a fish's blood and the pressure acting on the fish. Henry's Law states that there is a constant of proportionality between the pressure acting on a fluid and the concentration of gas in the fluid. This relationship is shown in **Equations 10 and 11**, where P stands for pressure, C for concentration, and kg is a gas-specific solubility coefficient (Chang, 2005).

$$P = k_g C \tag{10}$$

Or for a particular gas,

$$P_1 C_1 = P_2 C_2 \tag{11}$$

The primary causes of death, both immediate and delayed, in decompressed swim bladder fish are various combination injuries resulting from bubbles in the gills, hemorrhaging in internal organs, and frothy blood in the heart (Gaspin, 1975; Yelverton et al., 1975; Christian, 1973; Goertner, 1978b; Brown et al., 2009, 2012; Rummer and Bennett, 2005). It appears that the combination of swim bladder expansion and change in the gaseous state from dissolved to free, at decompression (**Equation 11**) has effects that injure and kill fish. Two examples are as follows: (1) the release of gas from the blood and formation of bubbles in the gills blocks oxygen exchange; and (2) increased internal pressure in the caudal vein causes increases in intra-vein pressure, a rupture of the vein, and hemorrhaging in the kidney (Brown et al., 2009). The change in relative pressure drives changes in the state of gas carried by a fish's blood, and fish at depth (higher pressure) are relatively less at risk of injury from decompressive pressure exposure. Unlike the case for swim bladder rupture and related decompressive injuries, no thresholds for injury or response functions have been derived for the risk of injury from changes in the state of gas at decompression.

6 EXPOSURE CRITERIA AND GUIDELINES

At present, there are no standardized or widely accepted criteria to gauge the exposure of fish to anthropogenic sound. Interim criteria for the onset of injury have been proposed for pile driving (Woodbury and Stadler, 2008; Stadler and Woodbury, 2009). These are dual criteria that also consider the size of fish. The criteria are expressed as levels for the allowable peak pressure (SPLpeak = 206 dB re 1 μPa) and an index for the total energy of exposure over the time required to drive a pile (SELcum = 187 dB re 1 $\mu Pa^2 \bullet s$ for fish weighing ≥2 grams [g] and 183 dB re 1 $\mu Pa^2 \bullet s$ for fish weighing <2 g). Additional information about these interim criteria can be found in Popper et al. (2006) and Carlson et al. (2007).

Popper et al. (2014) presented guidelines for the exposure of fish to seismic sound. The guidelines resulted from consideration of data available through mid-2013 for impacts to hearing and physiological injury to fish from exposure to anthropogenic sound by a working group initially convened in 2004 by the U.S. Department of Commerce's National Oceanic and Atmospheric Administration. In 2006, the working group was reorganized under the ANSI-Accredited Standards Committee S3/SC 1, Animal Bioacoustics, sponsored by the Acoustical Society of America. The guidelines for exposure of fish to sound produced by seismic airguns are presented in Table 7.4 of Popper et al. (2014).

Exposure guidelines are presented for mortality and potential mortal injury, recoverable injury, TTS, masking, and behavior in Popper et al. (2014). The guidelines for injury and TTS are presented as sound levels and those for masking and behavior as a relative risk of effect (high, moderate, or low) in zones near (tens of meters), intermediate to (hundreds of meters), and far from (thousands of meters) a seismic source. Exposure guidelines for injury include an index of the total sound energy of exposure (SELcum) as well as the peak pressure (SPLpeak) of exposure. In the case of TTS, the exposure guideline is limited to an index of total energy of exposure. Numerical values are not given for masking and behavior guidelines. In all cases where numerical values are given the values are for the level of sound received by a fish.

For fish without swim bladders, exposure guidelines for mortality and potential mortal injury, recoverable injury, and TTS are >219 dB SELcum or >213 dB SPLpeak, >216 dB SELcum or 213 dB SPLpeak, and >186 dB SELcum, respectively. The guidelines for relative risk of masking are low for all distances from an airgun source, while for behavior the relative risks are high, medium, and low for zones near, intermediate, and far from a seismic source.

Exposure guidelines for fish with swim bladders not involved in hearing are 210 dB SELcum or >207 dB SPLpeak for mortality and mortal injury, 203 dB SELcum or >207 dB SPLpeak for recoverable injury, and >186 dB SELcum for TTS. For this class of fishes, the relative risks for masking are low at all distances from a seismic source and are high, moderate, and low for risk of effect on behavior at near, intermediate, and far zones respectively from a seismic source.

Exposure guidelines for fish with swim bladders involved in hearing are 207 dB SELcum or >207 dB SPLpeak for mortality and mortal injury, 203 dB SELcum or >207 dB SPLpeak for recoverable injury, and >186 dB SELcum for TTS. For this class of fishes, the relative risks for masking are low for near and intermediate zones from a seismic source and moderate for the far zone from a source. The risk for effects on behavior are high in near and intermediate zones from a seismic source and are moderate in the far zone from a source.

No exposure criteria or guidelines are available for G&G sources other than airguns.

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APPENDIX K

CUMULATIVE AND CHRONIC EFFECTS IN THE GULF OF MEXICO

Cumulative and Chronic Effects in the Gulf of Mexico

Estimating Reduction of Listening Area and Communication Space due to Seismic Activities in Support of the BOEM Geological and Geophysical Activities Draft Programmatic Environmental Impact Statement

Submitted to:

Jolie Harrison
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Executive Summary

This report presents a chronic and cumulative effects assessment of noise exposures caused by oil and gas exploration activities in the United States (U.S.)–managed areas of the Gulf of Mexico by assessing changes in listening area, applicable to all marine mammal species, and communication space for Bryde's whale (*Balaenoptera edeni*). This assessment considers four levels of activity, which correspond to the alternatives defined in Chapter 2 of the Gulf of Mexico Geological and Geophysical Activities Draft Programmatic Environmental Impact Statement (G&G EIS) (NOAA 2016).

The two relatively new methods of assessing changes in listening area and communication space are explained in detail in Sections 2.5 and 2.6 of this report. The change in listening area method follows an approach applied to an effects assessment for in-air sounds to birds (Barber et al. 2009), but it had not previously been applied to underwater noise and marine fauna. To our knowledge, this study, and a related assessment of chronic and cumulative effects of noise in arctic waters, are the first applications of the listening area method to underwater sounds. The communication space assessment implemented the methods previously used for assessing anthropogenic noise effects on blue (*Balaenoptera musculus*) and fin (*Balaenoptera physalus*) whales by Clark et al. (2009).

The term "listening area" refers to the region of ocean over which sources of sound can be detected by an animal at the center of a space. Sound sources considered by this method can be the same species (such as calls from conspecifics), a different species (such as a predator or prey species), natural sounds (such as breaking surface waves), and anthropogenic sounds. The change in listening area method applied by Barber et al. (2009) calculates a fractional reduction in listening area due to an addition of anthropogenic noise to the environment. It does not provide absolute areas or volumes as does the communication space method; however, a benefit of the change in listening area method is that it does not require the signal source levels. The method only depends on the rate of sound transmission loss. Changes in listening space can be related to the effects of anthropogenic noise on marine fauna.

This communication space assessment considers the region within the ocean surrounding a calling Bryde's whale, in which other Bryde's whales can detect its calls. The relationship between communication space and the well-being of Bryde's whales is presently unknown, but it is reasonable to assume that Bryde's communications serve an important purpose, as it does in other marine mammals, (e.g., attracting mates, identifying and tracking offspring, and maintaining group structure) that could affect an individual's and possibly a population's health. Bryde's whale communication space is limited by the masking of their calls due to natural ambient sounds and/or anthropogenic noise. Communication space is larger for louder calls. Adding ambient and especially anthropogenic noise to the environment surrounding the Bryde's whales leads to a decrease in communication space. Hence, the possible effects of anthropogenic noise on Bryde's whales can be inferred by examining the reduction in communication space.

1. Introduction

This study evaluates potential chronic and cumulative effects to marine mammals from noise exposures caused by oil and gas exploration activities in the Gulf of Mexico in support of the Bureau of Ocean Energy Management (BOEM) Geological and Geophysical Activities Draft Programmatic Environmental Impact Statement (G&G EIS). In this assessment, the methods for calculating a change in listening area by Barber et al. (2009) and communication space by Clark et al. (2009) were applied. Both of these methods require knowledge of ambient and anthropogenic noise levels at receiver positions. JASCO developed a framework to calculate cumulative sound exposure levels (SEL) produced by large numbers of geographically distributed acoustic sources, such as the seismic pulses from multiple seismic surveys using airgun arrays. SELs were calculated for several scenarios for one full year of exploration activities in the Gulf at ten receiver sites (Table 1 and Figure 1). The framework was implemented using scripted Excel spreadsheets, which incorporated acoustic transmission loss tables from sound propagation modeling of an 8000 in^3 airgun array and single 90 in^3 airgun. The same source types (Table 2) were considered in a previous modeling assessment of marine mammal exposures (G&G EIS, Appendix D; NOAA 2016).

BOEM divided the study area into three project management zones (Western, Central, and Eastern Gulf–grey areas, Figure 1). For the purpose of this assessment, we subdivided these zones into six activity zones based on the water depth. The 200 m isobaths was chosen as the divider of coastal and offshore areas.

Table 1. Modeled receiver site locations and water depths.

Site	Receiver Site	Latitude	Longitude	Water Depth (m)
1	Western Gulf	27.01606	−95.7405	842
2	Florida Escarpment	25.95807	−84.6956	693
3	Midwestern Gulf	27.43300	−92.1200	830
4	Sperm Whale Site	24.34771	−83.7727	1053
5	Deep Offshore	27.64026	−87.0285	3050
6	Mississippi Canyon	28.15455	−89.3971	1106
7	Bryde’s Whale Site	28.74043	−85.7302	212
8	De Soto Canyon	29.14145	−87.1762	919
9	Flower Garden Banks National Marine Sanctuary	27.86713	−93.8259	88
10	Bottlenose Dolphin Site	29.40526	−93.3247	12

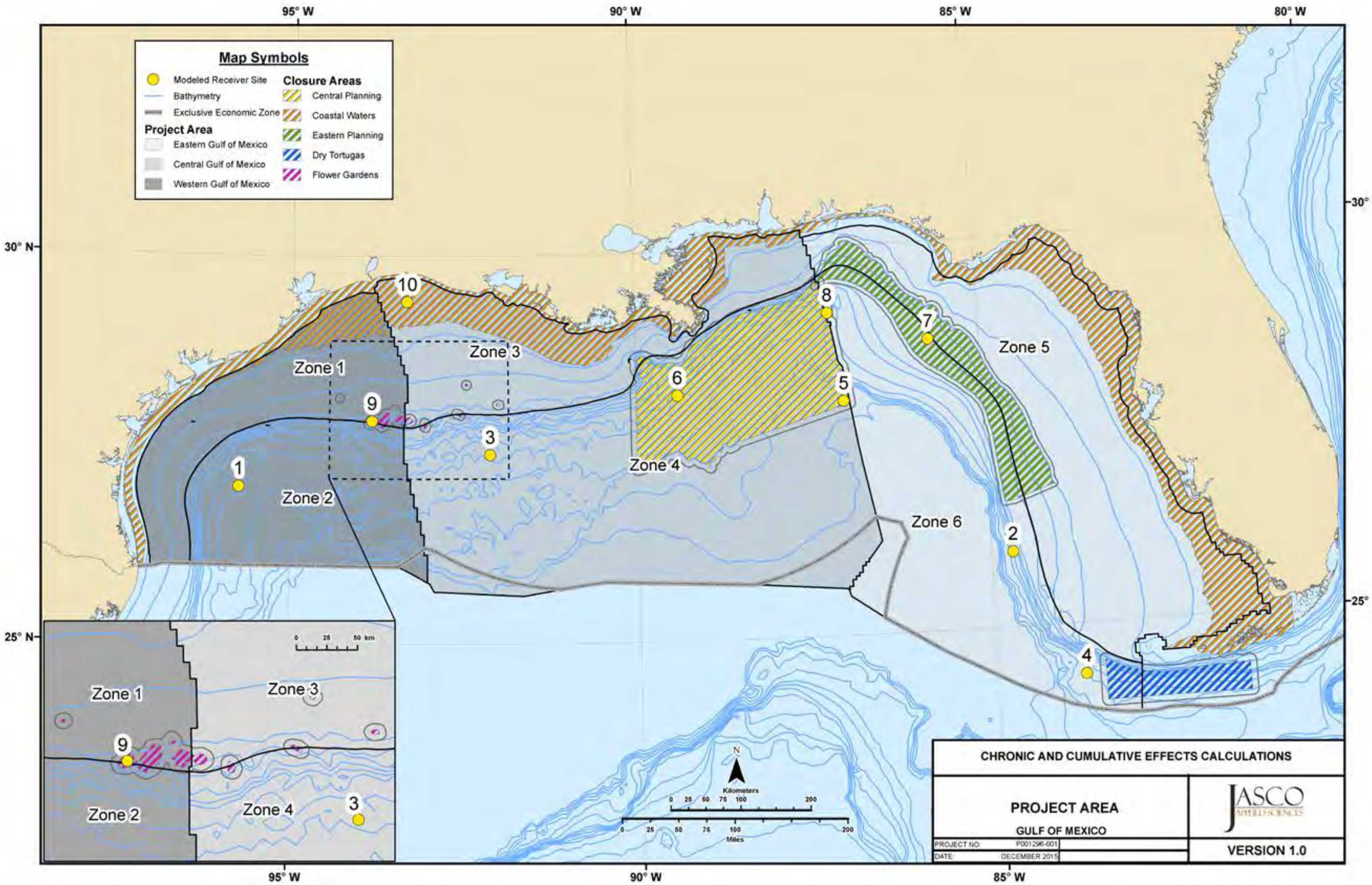

Figure 1. G&G EIS project area with ten modeled receiver sites (yellow dots), project management zones (grey shaded areas), activity zones (1–6), and closure areas (hashed arears). The inset shows a zoom into the Flower Gardens closure area.

Table 2. Survey types and sources used to represent the modeled activities.

Survey Type	Representative Airgun Array	Pulse Spacing (m)
2-D seismic	1 × 8000 in³	50
3-D NAZ seismic	2 × 8000 in³	37.5
3-D WAZ seismic	4 × 8000 in³	37.5
3-D Coil seismic	4 × 8000 in³	50
Geotechnical	1 × 90 in³ (single airgun)	0.7*

* Assumes 3 pulses per second and a tow speed of 4 knots, which is a surrogate for boomer-type sources.

Chapter 2 of G&G EIS (NOAA 2016) describes a number of alternatives that represent different survey activity levels in the Gulf of Mexico. For this analysis, Alternatives, C, E, and F were chosen to represent a range of activity levels; the content of each of these alternatives is summarized in Table 3. For the purpose of this assessment Alternative F was split into two sub-alternatives, F1 and F2. The later reflects the addition of closure areas (as for F1) and a 25% reduction of the activity level in all activity zones (as for E). Additionally, calculations of change in listening area and communication space require baseline noise levels for reference. We refer to this condition as Alternative A. It is defined by commercial shipping noise and noise from natural sounds produced mainly by wind and breaking waves. It therefore does not include seismic survey activity.

Table 3. Description of survey activity levels for G&G EIS Alternatives.

G&G EIS Alternatives	Description
A	No seismic survey activities. Noise consists of natural sounds and commercial vessel noise.
C	All activities uniformly distributed throughout the project area, over 12 months, except for coastal water closures (Figure 1) beginning of February to end of May.
E	Same as Alternative C, with a 25% reduction of the activity level in all activity zones.
F1	Same as Alternative C, with the addition of closure areas (Flower Gardens, Central Planning, De Soto, and Dry Tortugas closure areas; Figure 1) and 25% of the activity that would have occurred in the closure areas redistributed in non-closure areas of the same activity zone.
F2	Same as Alternative F1, with a 25% reduction of the activity levels in all activity zones.

In addition to the survey and source types (Table 2), BOEM provided the anticipated annual (2017–2026) survey lengths (km) for each type of activity and project management zone. The survey lengths were annually averaged for each type of activity, in each activity zone, and for all alternatives (Table 4). These lengths were used to calculate the survey distributions across the study area.

Table 4. Survey lengths (km) associated with each alternative for each activity zone. A dash means no survey of this type is expected within the activity zone.

Activity Zone	Alternative C					Alternative E				
	2-D	3-D NAZ	3-D WAZ	3-D Coil	Geotechnical	2-D	3-D NAZ	3-D WAZ	3-D Coil	Geotechnical
1	-	5,391	-	-	154	-	4,043	-	-	116
2	-	25,698	9,995	4,284	237	-	19,274	7,496	3,213	178
3	-	53,921	7,695	3,297	3,176	-	40,441	5,771	2,473	2,382
4	12,038	112,190	-	28,031	12,149	9,029	84,143	-	21,023	9,112
5	-	-	-	-	505	-	-	-	-	379
6	10,001	23,706	7,260	3,111	2,528	7,501	17,780	5,445	2,333	1,896
Activity Zone	Alternative F1					Alternative F2				
	2-D	3-D NAZ	3-D WAZ	3-D Coil	Geotechnical	2-D	3-D NAZ	3-D WAZ	3-D Coil	Geotechnical
1	-	5,344	-	-	150	-	4,008	-	-	113
2	-	25,663	9,981	4,278	236	-	19,247	7,486	3,209	177
3	-	53,719	7,666	3,285	3,134	-	40,289	5,750	2,463	2,351
4	9,191	85,659	-	21,402	9,256	6,893	64,244	-	16,052	6,942
5	-	-	-	-	444	-	-	-	-	333
6	8,982	21,290	6,520	2,794	2,186	6,736	15,968	4,890	2,095	1,639

1.1. Acoustic Metrics

Underwater sound pressure amplitude is commonly measured in decibels (dB) relative to a fixed reference pressure of p_o = 1 μPa. Because the loudness and other exposure effects of impulsive (pulsed) noise, e.g., shots from seismic airguns, are not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate impulsive sound effects on marine life.

1.1.1. Root-Mean-Square Sound Pressure Level

The root-mean square (rms) SPL (L_p, dB re 1 μPa) is the rms pressure level in a stated frequency band over a time window (T, s) containing the pulse:

$$L_p = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)dt \Big/ p_o^2\right) \quad (1)$$

The rms SPL can be thought of as a measure related to the average sound intensity or as the effective pressure intensity over the duration of an acoustic event, such as the emission of one acoustic pulse. Because the time window length, T, is a divisor, pulses having the same total acoustic energy, but more spread out in time, will have a lower rms SPL. The value of T for the purpose of the rms SPL calculation can be selected using different approaches. According to one, T is defined as the 90% energy pulse duration, containing the central 90% (from 5% to 95% of the total) of the cumulative square pressure (or sound exposure level) of the pulse, rather than over a fixed time window (Malme et al. 1986, Greene 1997, McCauley et al. 1998). The 90% rms SPL (L_{p90}, dB re 1 μPa) in a stated frequency band is calculated over this 90% energy time window, T_{90}:

$$L_{p90} = 10\log_{10}\left(\frac{1}{T_{90}}\int_{T_{90}} p^2(t)dt \Big/ p_o^2\right) \quad (2)$$

The other approach for rms SPL calculation of a pulse is to use fixed time window. In this study, a sliding window was used to calculate rms SPL values for a series of fixed window lengths within the pulse. The maximum value of rms SPL over all time window positions is taken to represent the rms SPL of the pulse.

1.1.2. Sound Exposure Level

The sound exposure level (SEL) (L_E, dB re 1 μPa^2·s) is the time integral of the squared pressure in a stated frequency band over a stated time interval or event. The per-pulse SEL is calculated over the time window containing the entire pulse (i.e., 100% of the acoustic energy), T_{100}:

$$L_E = 10\log_{10}\left(\int_{T_{100}} p^2(t)dt \Big/ T_o p_o^2\right) \quad (3)$$

where T_o is a reference time interval of 1 s by convention. The per-pulse SEL, with units of dB re 1 μPa·√s, or equivalently dB re 1 μPa^2·s, is related, at least numerically, to the total acoustic energy flux density delivered over the duration of the acoustic event at a receiver location. SEL, unlike energy flux density, neglects the acoustic impedance of the medium (here water), which depends on density,sound speed, and on proximity to reflective surfaces and position within refractive environments. SEL is a measure of sound exposure through time rather than just sound pressure.

SEL is a cumulative metric; it can be accumulated over a single pulse, or calculated over periods containing multiple pulses. To accumulate multiple pulse cumulative SEL (L_{Ec}), the single pulse SELs are summed. If there are N such pulses having individual SELs of (L_{Ei}), then:

$$L_{Ec} = 10\log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{Ei}}{10}}\right) \quad (4)$$

The SEL is related to the total acoustic energy flux density delivered over the duration of the set period of time, i.e., 24 h. It is a representation of the accumulated SEL delivered by multiple acoustic events, e.g., multiple pulses of a single acoustic source.

Because the rms SPL and SEL of a single pulse are computed from the same time integral of square pressure, these metrics are related numerically by a simple expression, which depends only on the duration of the 90% energy time window T_{90}:

$$L_E = L_{p90} + 10\log_{10}(T_{90}) + 0.458 \quad (5)$$

where the factor of 0.458 dB accounts for the missing 10% of SEL due to consideration of just 90% of the cumulative square pressure in the L_{p90} calculation. It is important to note that the decibel reference units of L_E and L_{p90} are not the same, so this expression must be interpreted only in a numerical sense. No similar relationship exists when SPL is calculated using fixed time windows shorter than the full pulse duration, T_{100}; however, if the window length T is equal to or greater than T_{100} then the relationship is simply:

$$L_E = L_p + 10\log_{10}(T) \quad (6)$$

1.1.3. Energy Equivalent Sound Pressure Level

Energy equivalent SPL (dB re 1 µPa, denoted L_{eq}) is the measure of the average amount of energy carried by a time-dependent pressure wave, $p(t)$, over a period of time T. It is defined as the rms SPL over a fixed duration time window:

$$L_{eq} = 10\log_{10}\left(\frac{1}{T}\int_{T} p^2(t)dt \bigg/ p_o^2\right) \tag{7}$$

The L_{eq} is numerically equal to the rms SPL of a steady sound that has the same total energy as the sound measured over the given time window. The expressions for L_p and L_{eq} are numerically identical; conceptually, the difference between the two metrics is that the former is computed over short time periods, usually one second or less, and tracks the fluctuations of a non-steady acoustic signal, whereas the latter reflects the average SPL of an acoustic signal over tens of seconds or longer. The integration time should be specified for both L_p and L_{eq}.

1.2. Marine Species and Auditory Bands

Within this assessment, a number of species were considered, with a variety of hearing acuities and frequency-dependent sensitivities. Twenty-one cetacean species are listed in Appendix D in the G&G EIS (NOAA 2016). These include low-, mid-, and high-frequency cetaceans. Hence, the corresponding M-weighting filters defined by Southall et al. (2007) were applied in the assessment of change in listening area. Because Bryde's whales are the only low-frequency cetacean, the most common mysticete in the Gulf, and appear to be present year-round (G&G EIS, Appendix E; NOAA 2016), this species was selected for the communication space assessment.

1.3. Chronic and Cumulative Effects

Historically, studies focused on short-term effects from high-intensity sounds (e.g., the near-field sounds from seismic airguns, sonars, and pile driving) when researching the effects of anthropogenic noise on marine mammals. More recently, focus has shifted to effects of long-term exposure that affect marine mammals over larger spatial and temporal extents (Clark et al. 2009, Hatch et al. 2012). These long-term exposures, or chronic effects, may in some cases be more relevant to marine animals than short-term acute effects, especially for communication between conspecifics (e.g. Hatch et al. 2012).

2. Methodology

2.1. Acoustic Source Models

The source levels and directivity of the airgun array were predicted with JASCO's Airgun Array Source Model (AASM; MacGillivray 2006). This model is based on the physics of oscillation and radiation of airgun bubbles described by Ziolkowski (1970). The model solves the set of parallel differential equations that govern bubble oscillations. AASM also accounts for nonlinear pressure interactions between airguns, port throttling, bubble damping, and generator-injector (GI) gun behavior that are discussed by Dragoset (1984), Laws et al. (1990), and Landro (1992). AASM includes four empirical parameters that were tuned so model output matches observed airgun behavior. The model parameters fit to a large library of empirical airgun data using a "simulated annealing" global optimization algorithm. These airgun data are measurements of the signatures of Bolt 600/B guns ranging in volume from 5 to 185 in^3 (Racca and Scrimger 1986).

AASM produces a set of "notional" signatures for each array element based on:

- Array layout
- Volume, tow depth, and firing pressure of each airgun
- Interactions between different airguns in the array

These notional signatures are the pressure waveforms of the individual airguns at a standard reference distance of 1 m; they account for the interactions with the other airguns in the array. The signatures are summed with the appropriate phase delays to obtain the far-field source signature of the entire array in all directions. This far-field array signature is filtered into 1/3-octave-bands to compute the source levels of the array as a function of frequency band and azimuthal angle in the horizontal plane (at the source depth), after which it is considered a directional point source in the far field.

A seismic array consists of many sources and the point-source assumption is invalid in the near field where the array elements add incoherently. The maximum extent of the near field of an array (R_{nf}) is:

$$R_{\mathrm{nf}} < \frac{l^2}{4\lambda} \tag{8}$$

where λ is the sound wavelength and l is the longest dimension of the array (Lurton 2002, §5.2.4). For example, an airgun array length of l = 16 m yields a near-field range of 85 m at 2 kHz and 17 m at 100 Hz. Beyond this R_{nf} range, the array is assumed to radiate like a directional point source and is treated as such for propagation modeling.

The interactions between individual elements of the array create directionality in the overall acoustic emission. Generally, this directionality is prominent mainly at frequencies in the mid-range between tens of hertz to several hundred hertz. At lower frequencies, with acoustic wavelengths much larger than the inter-airgun separation distances, the directionality is small. At higher frequencies, the pattern of lobes is too finely spaced to be resolved and the effective directivity is less.

2.2. Transmission Loss Models

The acoustic fields at the receiver sites were modeled at frequencies from 10 Hz to 5 kHz, for sources up to 500 km away, using JASCO's Marine Operations Noise Model (MOMN; Racca et al. 2015). MONM computes received per-pulse SEL for directional impulsive sources at a specified source depth.

MONM computes acoustic propagation from 10 Hz to 1 kHz via a wide-angle parabolic equation solution to the acoustic wave equation (Collins 1993) based on a version of the U.S. Naval Research Laboratory's

Range-dependent Acoustic Model (RAM), which has been modified to account for a solid seabed (Zhang and Tindle 1995). It computes acoustic propagation above 1 kHz via the BELLHOP Gaussian beam acoustic ray-trace model (Porter and Liu 1994).

The parabolic equation method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins et al. 1996). MONM accounts for the additional reflection loss at the seabed due to partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces, and it includes wave attenuations in all layers. At frequencies above 1 kHz, MONM also accounts for sound attenuation due to energy absorption through ion relaxation and viscosity of water in addition to acoustic attenuation due to reflection at the medium boundaries and internal layers (Fisher and Simmons 1977). The version of MONM used in this assessment was validated with real data from marine seismic survey projects near Sakhalin Island (Racca et al. 2015) that used large airgun arrays similar to the ones considered in this report.

MONM incorporates the following site-specific environmental properties: a bathymetric grid of the modeled area, underwater sound speed as a function of depth, and a geoacoustic profile based on the overall stratified composition of the seafloor.

MONM computes acoustic fields in three dimensions by modeling transmission loss within two-dimensional (2-D) vertical planes aligned along radials covering a 360° swath from the source, an approach commonly referred to as N×2-D. These vertical radial planes are separated by an angular step size of $\Delta\theta$, yielding N = 360°/$\Delta\theta$ number of planes (Figure 2).

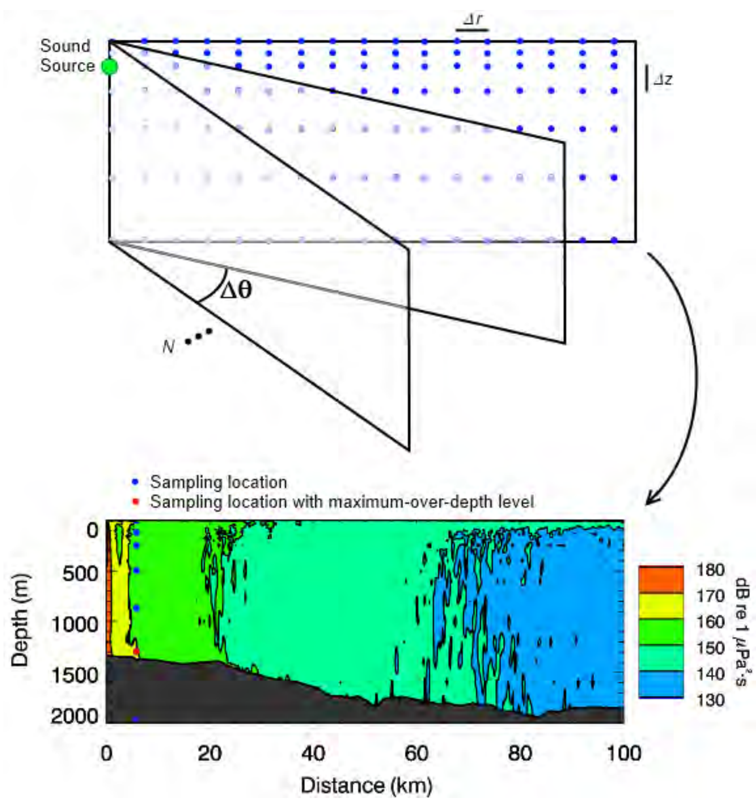

Figure 2. The N×2-D and maximum-over-depth modeling approach used by MONM.

MONM treats frequency dependence by computing acoustic transmission loss at the center frequencies of 1/3-octave-bands. Sufficiently many 1/3-octave-bands, starting at 10 Hz, are modeled to include the majority of acoustic energy emitted by the source. At each center frequency, the transmission loss is modeled within each of the N vertical planes as a function of depth and range from the source. The 1/3-octave-band received per-pulse SELs are computed by subtracting the band transmission loss values from the directional source level in that frequency band. Composite broadband received SELs are then computed by summing the received 1/3-octave-band levels.

The received per-pulse SEL sound field within each vertical radial plane is sampled at various ranges from the source, generally with a fixed radial step size. At each sampling range along the surface, the sound field is sampled at various depths, with the step size between samples increasing with depth below the surface.

2.3. Chronic and Cumulative Exposure (CCE) Calculator

A Chronic and Cumulative Exposure (CCE) calculator was developed to assist with assessing chronic seismic exploration noise received by marine mammals at the 10 receiver sites. This calculator is implemented as Microsoft Excel spreadsheets with scripting to provide a flexible tool for evaluating cumulative SELs generated by scenarios of seismic activity distributed over wide areas. The modeling geometry implemented in the CCE calculator makes use of acoustic reciprocity, whereby the model was run with the source and receiver positions interchanged—an efficient approach when there are more potential source sites than receiver sites.

The acoustic transmission loss results and the modeled source levels for each activity type are stored in the spreadsheets of the CCE calculator. The CCE calculator contains sets of marine mammal hearing frequency weighting filter coefficients that can be applied to the received levels. For change in listening space calculations, we applied filters for low-, mid-, and high-frequency cetaceans as defined by Southall et al. (2007). The CCE calculator also contains baseline (ambient) level spectrum for all receiver sites and depths (Section 2.4).

The CCE calculator computes three values: cumulative SELs, L_{eq}, and L_{eq} above ambient at the selected receiver site resulting from all pulses from the seismic surveys specified for each alternative.

2.3.1. Survey Distribution

Since the activity locations were unknown, the survey source pulses were uniformly distributed throughout each activity zone according to the respective survey line lengths within the activity zones (Table 4) and pulse intervals. Rather than modeling every pulse position throughout each activity zone, the seismic surveys were divided into several survey cells, each representing a portion of the overall project area. The number of pulses contained within each cell was based on the average pulse density in each activity zone (Table 5) and the cell areas. The cumulative levels estimated using this approach are accurate when the cell dimensions are small, relative to the source-receiver separation.

Table 5. Maximum average pulse density (annual number of pulses per km^2; Alternative C) per airgun array in each activity zone.

Representative Airgun Array	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
8000 in³	5.5	43.9	57.5	42.2	0	20.0
90 in³	14.1	58.2	67.3	88.4	1.6	2.9

The coordinates of the center of each cell were entered in the CCE calculator with the number of pulses represented by the corresponding cell. The calculator assumed this number of pulses occurred at the cell's geometric center. The error in cumulative SEL due to approximating all shot locations within the cell by the cell's center location is expected to be negligible.

To minimize the number of cells throughout the project area and to minimize the error in the cumulative level estimates, the cell dimensions were defined so that the distances of the closest side to the most distant side of a cell from any receiver had a ratio of less than 1.5. This approach limited the difference in transmission loss between any point in the cell and its center to less than ~ 2 dB assuming 20×log(R) transmission loss. Thus, cells closest to a receiver represented smaller areas than more distant cells. The entire project area was divided into 1706 cells (Figure 3). The coordinates of the center of each cell were entered in the CCE calculator with the number of pulses contained within the cell.

The number of pulses in each cell in activity zones along the coast accounted for a 4-month coastal-water closure area (orange hashed; Figure 3). Alternatives F1 and F2 include additional closure areas also shown in Figure 3. For these alternatives, we removed activity from areas consisting of the actual closure areas and from a surrounding spatial buffer designed to maintain sound pressure levels (SPL) below 160 dB re 1 μPa (90% rms) at the closure area boundaries. The effect on activities due to closures might be the redistribution of a fraction of the excluded surveying activity. To account for this possibility, 25% of the survey pulses excluded from a closure area were redistributed outside the closure area, but within the same activity zone. The spatial buffer widths varied from 4.8 to 8.4 km for the 8000 in^3 airgun array, depending on the closure area (grey line around closure areas in Figures 1 and 3). No buffers were applied for the 90 in^3 airgun source since its 160 dB re 1 μPa (rms) distance was estimated at less than 100 m for the modeled receiver depths.

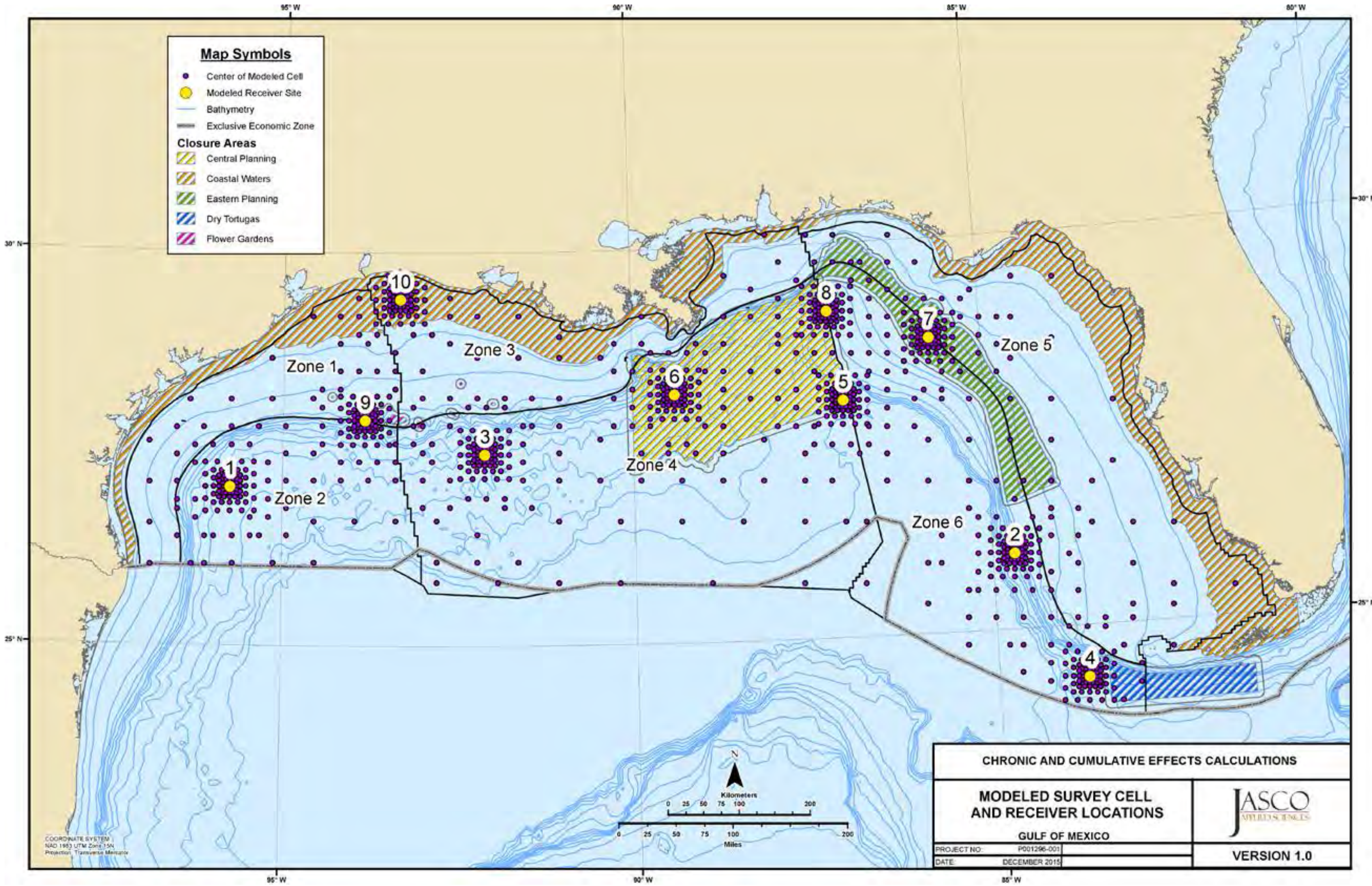

Figure 3. Location of the modeled survey cells (purple dots) and receiver (yellow dots). Survey source pulses were uniformly distributed throughout each activity zone according to the respective survey line lengths within the activity zones. Each modeled survey cell location is associated with a number of pulses proportional to the cell area (not shown here).

2.3.2. Removal of Top 10% of Pulse Exposures

A feature of underwater sound propagation is that nearby sources generally contribute substantially more SEL than more distant sources of the same type, since the exposure levels decay approximately with the square of distance from the source. This causes cumulative SEL received from spatially distributed and moving seismic sources to be dominated by the source pulses generated closest to a receiver. However, the time period of exposures from nearby sources is typically quite short. While exposures from nearby sources are important for assessing acute effects, their inclusion in a chronic effects assessment can be unrepresentative. To avoid this problem, this analysis neglected the highest seismic pulse exposures received during a fraction (10%) of the year-long analysis period.

The specific method for removing the highest pulse contributions first involved sorting cells based on their received per-pulse SEL. Since the pulses were uniformly distributed through each activity zone, the time required to survey each cell was assumed proportional to the number of pulses in the cell. The SEL-ordered cells corresponding to 10% of the 1-year study duration (36.5 days) were neglected prior to calculating cumulative SEL, L_{eq} and L_{eq} above ambient.

2.4. Baseline Levels

To estimate changes in listening area and communication space for various levels of seismic activities, we calculated a baseline noise level containing mainly commercial shipping noise and noise from natural sounds produced mainly by wind and breaking waves. The commercial shipping noise levels were obtained from the SoundMap mapping tool (SoundMap Working Group 2015). SoundMap produces commercial shipping noise levels over the Gulf of Mexico region in 1/3-octave frequency bands between 50 and 800 Hz. Natural ambient noise levels were calculated from the formulas of Wenz (1962) and Cato (2008) for a wind speed of 8.5 knots. The natural noise levels were added to all available vessel noise levels to generate composite 1/3-octave-band baseline levels between 10 Hz and 5000 Hz. Since no data for commercial shipping noise were available outside the frequency range of the SoundMap results, shipping noise outside the 50-800 Hz bands was excluded (Figures 4–6).

Broadband baseline levels varied between 94.3 and 102.3 dB re 1 µPa, depending on the receiver location and depth. Third-octave band baseline levels were entered in the CCE calculator. L_{eq} and L_{eq} above ambient were then calculated in 1/3-octave bands using low-, mid-, and high-frequency cetacean filters and without frequency weighting. Baseline levels in the 100 Hz 1/3-octave band, which varied between 76.1 and 86.7 dB re 1 µPa, were used to calculate Bryde's whale communication space under Alternative A.

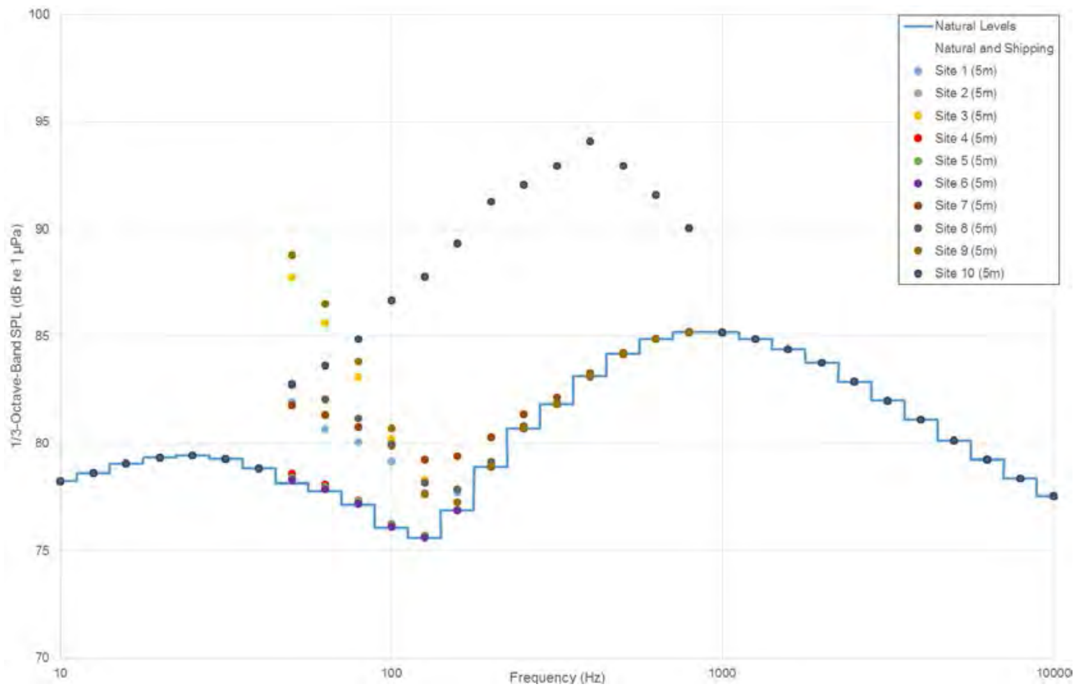

Figure 4. Summed levels for frequency bands of 10 Hz to 10 kHz for all sites at 5 m receiver depth. The natural interpolated sound levels (blue line; Wenz (1962), Cato (2008)) and SoundMap data were summed for frequency bands between 50 and 800 Hz. Beyond these limits the interpolated natural levels were used.

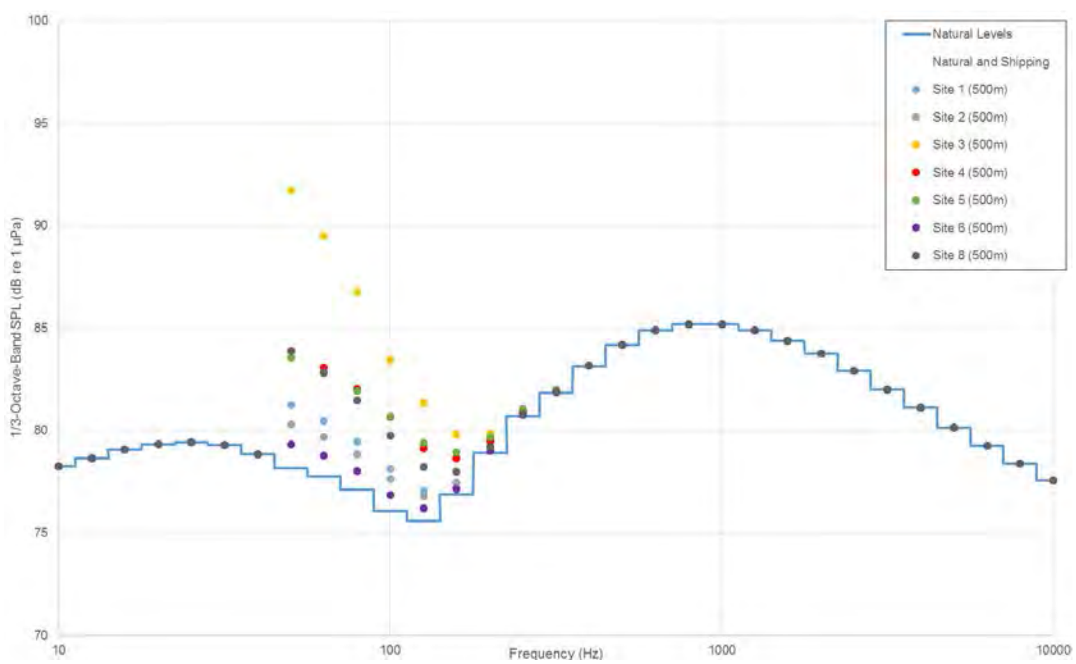

Figure 5. Summed levels for frequency bands of 10 Hz to 10 kHz for nine sites at 30 m receiver. The natural interpolated sound levels (blue line; Wenz (1962), Cato (2008)) and SoundMap data were summed for frequency bands between 50 and 800 Hz. Beyond these limits the interpolated natural levels were used. Note that not all sites have water depth reaching this receiver depth.

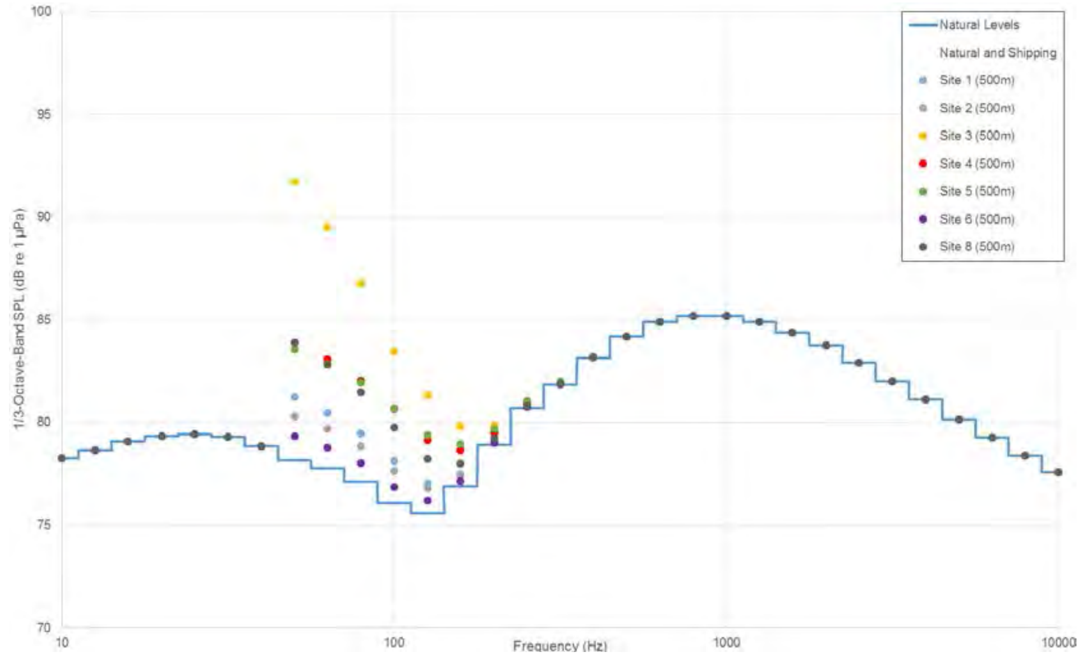

Figure 6. Summed levels for frequency bands of 10 Hz to 10 kHz for seven sites at 500 m receiver depth. The natural interpolated sound levels (blue line; Wenz (1962), Cato (2008)) and SoundMap data were summed for frequency bands between 50 and 800 Hz. Beyond these limits the interpolated natural levels were used. Note that not all sites have water depth reaching this receiver depth.

2.5. Listening Area

The term listening area refers to the area associated with the maximum detection distance of a signal by an animal. A listening area assessment considers the region of ocean where marine fauna can detect sound from conspecifics, as well as from predators and prey (Figure 7). The introduction of noise in the same frequency band as the signal may reduce an animal's ability to detect the signal, and therefore decreases the maximum detection distance and reduces the listening area.

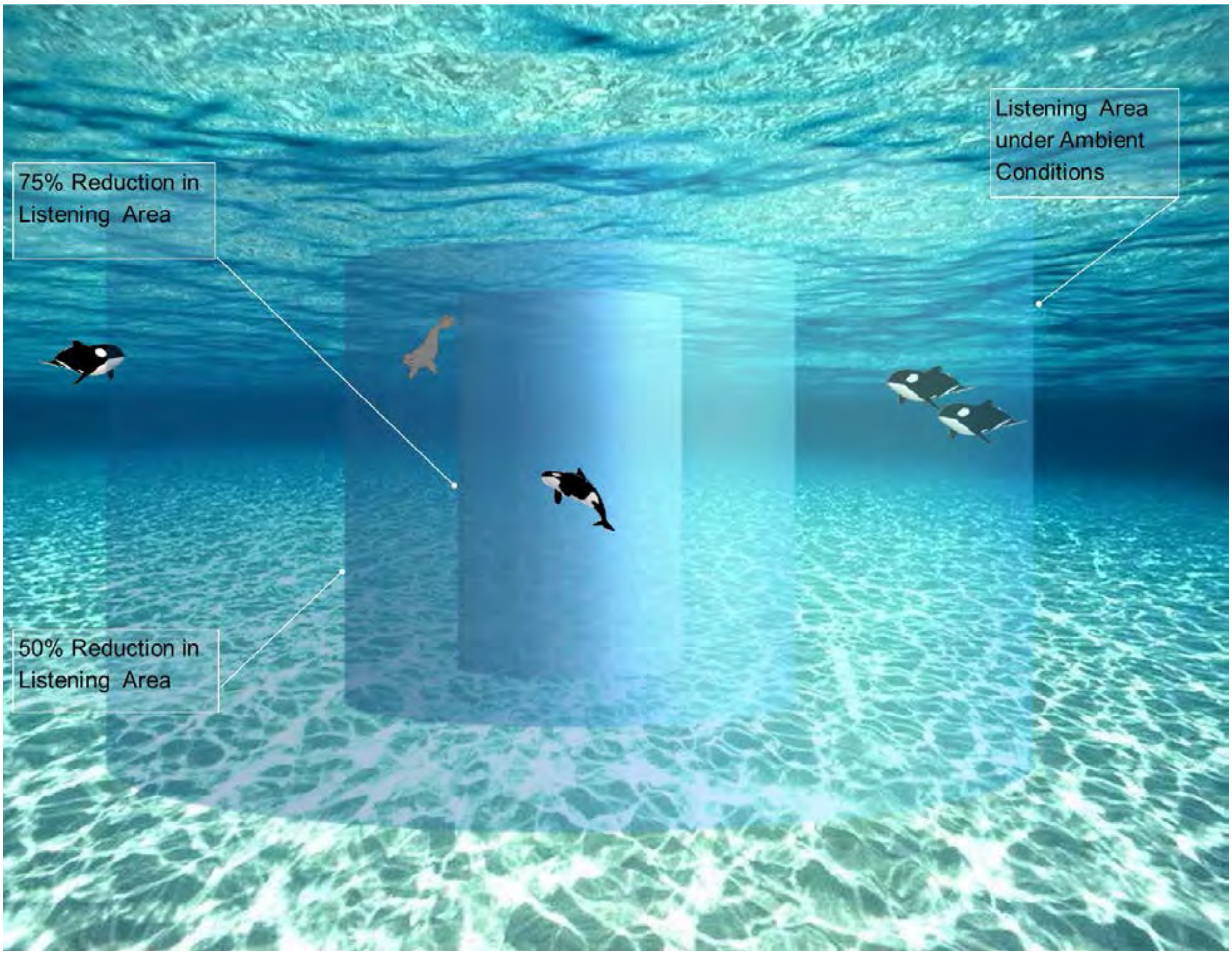

Figure 7. Schematic representation of changes in listening area around a marine mammal. Under ambient conditions, an animal may be able to listen to conspecifics, as well as predators and prey. When the noise level increases, the listening area is reduced. (Figure adapted from NPS 2010.)

The remaining fraction of the listening area after an increase in noise level can be calculated without prior knowledge of the signal source level and detection distance by approximating the transmission loss (*TL*) as:

$$TL = N\log_{10}(R). \quad (9)$$

The maximum detection distance of the signal (R_o), associated with a source level *SL*, will result in a received level RL_o:

$$RL_o = SL - N\log_{10}(R_o). \quad (10)$$

The maximum detection distance (*R*) associated with an increase in noise level will result in a received level (*RL*):

$$RL = SL - N\log_{10}(R). \quad (11)$$

The remaining fraction of listening area after an increase in noise level is therefore:

$$\frac{\pi R^2}{\pi R_o^2} = \frac{10^{2(RL-SL)/N}}{10^{2(RL_o-SL)/N}} = 10^{-2\Delta/N} \quad (12)$$

Where Δ is equal to the increase in noise level, in dB. Results are presented in fractions (percentage) of the listening area that is left, relative to the original, after an increase in noise level.

This concept was applied by Barber et al. (2009) to terrestrial organisms. To our knowledge, this concept has not previously been applied to marine animals. Unlike the assessment of communication space (Section 2.6), the assessment of change in listening area does not require prior knowledge parameters such as the signal source levels, detection thresholds based on the receiver perception capabilities, signal directivity, noise and signal duration, and band-specific (spectral) noise levels. This assessment can be done for specific frequency bands, or by taking into consideration the animal's auditory system and applying a relevant filter to the noise level.

This equation is expected to overestimate the reduction in listening area at most sites, where the *TL* is better estimated by an equation of the form:

$$TL = N\log_{10}(R) - \alpha R \,. \quad (13)$$

In this study, we estimated *N* at each of the receiver sites by curve fitting the modeled *TL* from the receiver at ranges ≤ 75 km. The noise level increase, Δ, is the difference between the estimated ambient level and L_{eq} or between two alternatives being compared. The approach considers the additive nature of ambient noise to L_{eq} in decibel space (for example, if L_{eq} and ambient level were equal, then Δ would be 3 dB). While that may seem counterintuitive, recall that the decibel sum of two equal sound levels is their individual value plus 3 dB. Changes in listening area were calculated for unfiltered broadband (10–5000 Hz) noise levels, as well as by applying low-, mid-, and high-frequency cetaceans weighting to the noise levels.

2.6. Bryde's Whale Communication Space

A communication space assessment considers the region of ocean within marine fauna can detect calls from conspecifics. Masking can be defined as a reduction in communication space (active acoustic space) that an individual experiences due to an increase in background noise (ambient and anthropogenic) in the frequency bands relevant for communicating. Reduction in communication space due to anthropogenic sounds cannot be determined based on the broadband cumulated sound exposure level, because the effect depends on the spectral noise level within the frequency band of the sounds in question and therefore varies dynamically with receiver distance from the sound (noise) source. To estimate the communication space quantitatively, it is necessary to account for parameters such as call source levels, detection thresholds based on the receiver perception capabilities, signal directivity, band-specific (spectral) noise levels, and noise and signal duration.

The communication space for Bryde's whales was estimated using a similar approach to that employed by Clark et al. (2009). This approach calculates the horizontal area in square kilometers over which a call can be detected, recognizing that the true call could originate within a 3-D volume of ocean. The primary difference between our approach and Clark et al.'s is that we a applied the analysis in a single representative 1/3-octave-band rather than to broadband levels. This approach is based on a form of the sonar equation that considers the maximum distance an animal can detect a signal in the presence of masking noise. The form of the sonar equation employed here was:

$$SE = SL - TL - NL - DT + DI + SG \,. \quad (14)$$

The signal excess (*SE*) is the signal excess above detectability. The source level (*SL*) is the animal call source level. *TL* is the acoustic transmission loss between the calling and listening Bryde's whales (a function of the distance of their separation). *NL* is the noise level in the same frequency band as the source level. *DT* is the detection threshold of the animal, representing the amount above ambient level the sound must be in order for it to be detected. The directivity index (*DI*) represents the animal's ability to discriminate sounds coming from a specific direction, in the presence of masking noise arriving uniformly from all directions. *SG* is the signal gain that indicates the ability of the animal to use its knowledge of the time-frequency structure of the call to differentiate it from background noise.

3. Modeled Parameters

3.1. Acoustic Environment

The environmental parameters used by the transmission loss model (MONM; Section 2.2) were the same ones used in the 2016–2025 Annual Acoustic Exposure Estimates for Marine Mammals (Appendix D of the G&G EIS; NOAA 2016). Water depths throughout the modeled area were obtained from the National Geophysical Data Center's U.S. Coastal Relief Model I (NGDC 2014). Sound speed profiles for February for each receiver site were used to estimate the transmission loss for the entire year. This adds a level of conservativeness since the winter profiles include an isovelocity layer and, at some sites, a surface sound channel; both can enhance sound propagation for the near-surface sources considered here. Three of the four sets of geoacoustic parameters (Center-West Shelf, Slope, and Deep) from the G&G EIS, Appendix D (NOAA 2016) were used in this assessment. A fourth set of parameters (Table 6) was developed to model transmission loss at receiver sites on the eastern slope (offshore Florida), based on the information previously acquired (G&G EIS, Appendix D; NOAA 2016).

Table 6. Eastern Slope: Geoacoustic properties of the sub-bottom sediments as a function of depth, in meters below the seafloor (mbsf). Within each depth range, each parameter varies linearly within the stated range.

Depth below seafloor (m)	Material	Density (g/cm^3)	P-wave speed (m/s)	P-wave attenuation (dB/λ)	S-wave speed (m/s)	S-wave attenuation (dB/λ)
0–20	Silt $\varphi=6$	1.44	1532	0.41	200	0.22
20–50		1.7	1725	1.00		
50–200		1.7	1826	1.30		
200–600		1.87	2105	1.75		
> 600		2.04	2466	2.11		

3.2. Acoustic Sources

The source levels and directivity of the two types of airgun arrays were predicted with AASM (Section 2.1). Source levels in 1/3-octave frequency bands for each source were determined and input in the acoustic propagation model. Directivity was purposely removed by averaging the direction-dependent levels modeled with AASM because here we assumed randomly oriented surveys. The averaging preserved total acoustic energy emitted.

The acoustic source levels used in the CCE calculator (Section 2.3) were derived from the Appendix D of the G&G EIS (NOAA 2016).

3.3. Transmission Loss and CCE Calculator

Sixteen vertical planes were modeled around each receiver site, providing an angular spacing of 22.5 degrees. The modeled radial lengths were limited to 500 km. Seismic pulses originating more than 500 km from a specified receiver were estimated to have little influence on the cumulative sound field and were excluded. Receiver depths were modeled at 5, 30, and 500 m. The surrogate sources (90 in^3 and 8000 in^3 arrays) were modeled at 4 and 8 m depths.

The L_{eq} was based on the accumulation period of 1 year, and T was 31.45×10^6 seconds.

3.4. Bryde's Whale Communication Space

A representative source level was estimated from the median Bryde's whale source level reported by Širović et al. (2014). Under the assumption that the call bandwidth spanned two 1/3-octave-bands, a source level of 152 dB re 1 µPa at 1 m was specified for the 100 Hz band based on the broadband source level for Bryde's moans of 155 dB re 1 µPa at 1 m. All communication space calculations were performed in the single 1/3-octave frequency band centered at 100 Hz.

A 1/3-octave-band analysis is relevant for assessing audibility of a signal, as it is often used to approximate the critical bandwidth of the mammalian ear. We used a signal excess of $SE = 0$, to represent the onset of detectability. Transmission loss was obtained at each receiver site from the transmission loss model results. The noise levels were calculated with the CCE calculator as described in Section 2.3. The detection threshold was assumed to be 10 dB and the detection index was assumed to be zero (Clark et al. 2009). The signal processing gain ($SG = 10\log(TW)$), which accounts for the animal's ability to detect and recognize a signal from conspecifics, was estimated as 12.36 dB, based on a median frequency bandwidth (W) of 43 Hz and call length (T) of 0.4 seconds (Širović et al. 2014).

4. Results

This section presents the modeled results of cumulative sound exposure levels (Tables 8–11) and time-averaged equivalent sound pressure levels (Tables 12–19) for all modeled scenarios. Scenario estimates are then compared to each other, as well as to baseline noise level. Relative differences are calculated and ranked. Results are then presented as changes in listening area (Tables 20–27) and changes in communication space for Bryde's whales (Tables 28–36). Communication space and listening area calculations use baseline noise levels (Alternative A) for reference (Table 7). Alternative A is comprised of commercial shipping noise and natural sounds produced mainly by wind and breaking waves.

Table 7. Broadband (10–5000 Hz) baseline (Alternative A; no activity) SPL (dB re 1 µPa) for each receiver site and depth.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	96.1	95.9	96.9	95.9	95.9	95.9	96.3	96.3	97.2	102.2
	30	96.1	95.9	96.3	95.9	96.0	95.9	96.6	96.3	97.2	
	500	96.1	96.0	98.3	96.5	96.5	95.9		96.4		
Mid-Frequency Cetaceans	5	94.6	94.6	94.7	94.6	94.6	94.6	94.7	94.7	94.7	100.3
	30	94.6	94.6	94.7	94.6	94.6	94.6	94.7	94.6	94.7	
	500	94.6	94.6	94.8	94.7	94.7	94.6		94.7		
High-Frequency Cetaceans	5	94.3	94.3	94.4	94.3	94.3	94.3	94.4	94.3	94.3	99.6
	30	94.3	94.3	94.4	94.3	94.3	94.3	94.4	94.3	94.4	
	500	94.3	94.3	94.4	94.4	94.4	94.3		94.3		
Unweighted	5	96.3	96.1	97.1	96.1	96.1	96.1	96.5	96.5	97.3	102.3
	30	96.3	96.1	96.5	96.1	96.2	96.1	96.8	96.5	97.4	
	500	96.3	96.2	98.5	96.7	96.7	96.1		96.6		

* Cells without values correspond to receiver depths that do not exist at shallow sites.

4.1. Cumulative Sound Exposure Levels

Tables 8–11 present the results for cumulative SELs (dB re 1 μPa^{2}s) for each receiver site and depth for all modeled alternatives. These levels were filtered for low-, mid-, and high-frequency cetaceans. These results are based on the total number of pulses (shots) for a one-year duration.

Table 8. Alternative C: Cumulative SEL (dB re 1 μPa^{2}s) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	173.8	170.8	169.1	164.8	189.6	165.1	123.7	164.8	175.8	157.0
	30	176.8	179.4	174.8	174.6	193.8	168.6	138.8	167.9	174.3	
	500	180.9	179.8	178.2	173.8	191.9	174.8		170.9		
Mid-Frequency Cetaceans	5	173.2	160.3	167.1	158.3	186.5	163.6	102.3	161.5	175.7	156.9
	30	172.3	162.4	159.6	161.0	185.1	149.7	113.5	149.3	174.2	
	500	164.7	164.4	163.4	160.2	180.9	155.3		152.0		
High-Frequency Cetaceans	5	172.7	158.1	166.7	156.6	185.9	163.5	99.1	160.9	175.5	156.8
	30	172.0	160.3	157.2	158.2	184.3	146.7	109.6	146.3	174.0	
	500	162.4	162.6	161.0	157.9	179.1	152.7		149.3		
Unweighted	5	173.8	171.2	169.3	165.0	189.6	165.2	125.1	165.1	175.9	157.0
	30	177.6	180.4	175.3	175.2	194.1	169.5	140.0	168.9	174.4	
	500	182.0	181.0	179.2	174.7	193.1	176.2		172.1		

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 9. Alternative E (25% reduction): Cumulative SEL (dB re 1 μPa^{2}s) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	172.5	169.5	167.9	163.5	188.3	163.9	122.5	163.6	174.6	155.7
	30	175.6	178.2	173.5	173.4	192.5	167.3	137.6	166.6	173.1	
	500	179.6	178.6	177.0	172.6	190.7	173.6		169.7		
Mid-Frequency Cetaceans	5	171.9	159.0	165.8	157.1	185.3	162.3	101.1	160.2	174.4	155.7
	30	171.1	161.2	158.4	159.8	183.9	148.5	112.2	148.1	172.9	
	500	163.5	163.1	162.1	159.0	179.6	154.0		150.7		
High-Frequency Cetaceans	5	171.5	156.8	165.5	155.4	184.7	162.2	97.8	159.6	174.3	155.6
	30	170.8	159.1	156.0	157.0	183.1	145.5	108.4	145.1	172.8	
	500	161.2	161.3	159.8	156.6	177.8	151.4		148.0		
Unweighted	5	172.6	169.9	168.1	163.8	188.4	164.0	123.8	163.9	174.6	155.8
	30	176.4	179.1	174.1	174.0	192.8	168.3	138.8	167.7	173.2	
	500	180.8	179.7	177.9	173.5	191.9	174.9		170.9		

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 10. Alternative F1 (area closures): Cumulative SEL (dB re 1 μPa^{2}s) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	174.8	171.4	171.3	165.0	193.4	163.2	123.1	160.3	176.5	158.3
	30	178.9	179.4	177.4	174.9	197.1	166.2	138.1	164.2	175.2	
	500	182.2	179.9	180.9	174.1	195.0	173.3		166.7		
Mid-Frequency Cetaceans	5	174.2	160.8	169.1	158.5	188.9	161.8	101.1	157.5	176.3	158.2
	30	173.3	162.7	162.4	161.2	188.9	142.4	112.1	144.2	174.9	
	500	166.6	165.1	165.5	159.3	184.9	149.1		145.6		
High-Frequency Cetaceans	5	173.8	158.7	168.6	156.8	187.0	161.7	98.3	156.9	176.2	158.2
	30	173.1	160.5	160.0	158.4	187.4	138.9	108.3	140.7	174.8	
	500	164.7	162.9	163.6	157.1	183.4	146.3		142.9		
Unweighted	5	174.9	171.5	171.5	165.2	193.5	163.4	124.5	160.6	176.6	158.4
	30	179.5	180.5	178.2	175.5	197.4	167.0	139.6	165.2	175.2	
	500	183.3	181.0	182.5	175.0	195.6	173.6		168.0		

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 11. Alternative F2 (area closures and 25% reduction): Cumulative SEL (dB re 1 μPa^{2}s) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	173.6	170.2	170.1	163.7	192.2	162.0	121.9	159.1	175.3	157.1
	30	177.7	178.2	176.1	173.6	195.8	165.0	136.9	163.0	173.9	
	500	181.0	178.7	179.6	172.8	193.8	172.0		165.4		
Mid-Frequency Cetaceans	5	172.9	159.5	167.8	157.3	187.7	160.6	99.9	156.2	175.1	157.0
	30	172.0	161.5	161.2	160.0	187.7	141.2	110.8	143.0	173.7	
	500	165.3	163.9	164.3	158.1	183.6	147.8		144.3		
High-Frequency Cetaceans	5	172.5	157.4	167.4	155.6	185.8	160.4	97.1	155.6	174.9	156.9
	30	171.8	159.3	158.8	157.2	186.1	137.6	107.1	139.4	173.5	
	500	163.5	161.6	162.3	155.9	182.1	145.1		141.6		
Unweighted	5	173.6	170.3	170.3	164.0	192.2	162.1	123.3	159.3	175.3	157.1
	30	178.2	179.3	176.9	174.2	196.2	165.7	138.4	164.0	174.0	
	500	182.0	179.7	181.3	173.7	194.3	172.3		166.8		

* Cells without values correspond to receiver depths that do not exist at shallow sites.

4.2. Time-Averaged Equivalent Sound Pressure Levels

Tables 12–19 present the time-averaged equivalent SPLs for each receiver site and depth for all modeled alternatives. The time-averaged equivalent SPLs were calculated by applying the cumulative SELs and the filtered baseline noise levels (Table 7) with a time average of 31.45 × 10^6 seconds. The values in the tables represent time-averaged equivalent SPLs above and below the baseline levels (Alternative A - Table 7).

Table 12. Alternative C: Time-averaged equivalent sound pressure levels (L_{eq}) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	100.7	98.9	98.8	96.8	114.6	96.9	96.3	97.2	102.4	102.3
	30	102.9	105.0	101.4	101.2	118.8	97.9	96.6	98.0	101.4	
	500	106.3	105.4	104.5	100.8	117.0	101.3		99.2		
Mid-Frequency Cetaceans	5	99.8	95.1	96.6	94.9	111.6	95.6	94.7	95.3	101.7	100.4
	30	99.2	95.4	95.1	95.2	110.3	94.7	94.7	94.7	100.5	
	500	95.9	95.8	95.7	95.1	106.2	94.8		94.7		
High-Frequency Cetaceans	5	99.4	94.6	96.3	94.6	111.0	95.3	94.4	94.9	101.5	99.6
	30	98.9	94.8	94.6	94.7	109.5	94.3	94.4	94.4	100.3	
	500	95.1	95.2	95.0	94.7	104.5	94.4		94.4		
Unweighted	5	100.8	99.1	99.0	97.1	114.7	97.1	96.5	97.4	102.5	102.3
	30	103.5	105.9	101.9	101.7	119.1	98.4	96.8	98.4	101.5	
	500	107.4	106.5	105.2	101.5	118.2	102.4		99.9		

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 13. Alternative C: Time-averaged equivalent sound pressure levels (L_{eq}) above ambient at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	4.5	3.0	1.8	1.0	18.7	1.0	0	0.9	5.2	0
	30	6.7	9.1	5.1	5.2	22.9	2.0	0	1.6	4.2	
	500	10.2	9.4	6.1	4.4	20.5	5.4		2.8		
Mid-Frequency Cetaceans	5	5.1	0.5	1.9	0.3	17.0	1.0	0	0.6	7.0	0.1
	30	4.6	0.8	0.4	0.6	15.6	0	0	0	5.8	
	500	1.2	1.1	0.9	0.5	11.5	0.2		0.1		
High-Frequency Cetaceans	5	5.1	0.3	1.9	0.2	16.7	1.0	0	0.6	7.1	0.1
	30	4.6	0.5	0.3	0.3	15.1	0	0	0	6.0	
	500	0.8	0.8	0.6	0.3	10.2	0.1		0		
Unweighted	5	4.4	3.1	1.8	1.0	18.6	1.0	0	0.9	5.1	0
	30	7.2	9.8	5.3	5.5	23.0	2.3	0	1.9	4.2	
	500	11.1	10.2	6.7	4.8	21.5	6.2		3.3		

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 14. Alternative E (25% reduction): Time-averaged equivalent sound pressure levels (*Leq*) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	99.9	98.3	98.4	96.6	113.4	96.7	96.3	97.0	101.6	102.2
	30	101.9	104.0	100.6	100.4	117.6	97.5	96.6	97.6	100.7	
	500	105.2	104.3	103.5	100.1	115.8	100.5		98.6		
Mid-Frequency Cetaceans	5	99.0	95.0	96.2	94.8	110.4	95.4	94.7	95.1	100.7	100.3
	30	98.4	95.2	95.0	95.0	109.0	94.6	94.7	94.7	99.6	
	500	95.6	95.5	95.5	95.0	105.0	94.7		94.7		
High-Frequency Cetaceans	5	98.6	94.6	95.9	94.5	109.8	95.1	94.4	94.8	100.5	99.6
	30	98.1	94.7	94.6	94.6	108.3	94.3	94.4	94.4	99.4	
	500	95.0	95.0	94.9	94.6	103.4	94.4		94.4		
Unweighted	5	100.0	98.6	98.6	96.8	113.5	96.9	96.5	97.2	101.6	102.3
	30	102.6	104.8	101.0	100.8	117.9	97.9	96.8	98.0	100.8	
	500	106.3	105.3	104.3	100.7	116.9	101.5		99.3		

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 15. Alternative E (25% reduction): Time-averaged equivalent sound pressure levels (*Leq*) above ambient at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	3.8	2.4	1.4	0.7	17.5	0.8	0	0.7	4.4	0
	30	5.8	8.1	4.2	4.4	21.6	1.6	0	1.3	3.5	
	500	9.1	8.3	5.2	3.6	19.3	4.5		2.2		
Mid-Frequency Cetaceans	5	4.3	0.4	1.5	0.2	15.8	0.7	0	0.5	6.0	0
	30	3.8	0.6	0.3	0.4	14.4	0	0	0	4.9	
	500	0.9	0.9	0.7	0.4	10.4	0.1		0.1		
High-Frequency Cetaceans	5	4.2	0.2	1.5	0.2	15.5	0.8	0	0.4	6.2	0.1
	30	3.8	0.4	0.2	0.2	13.9	0	0	0	5.1	
	500	0.6	0.6	0.5	0.2	9.1	0.1		0		
Unweighted	5	3.7	2.5	1.4	0.7	17.4	0.8	0	0.7	4.3	0
	30	6.2	8.7	4.5	4.7	21.7	1.8	0	1.5	3.4	
	500	10.0	9.1	5.8	4.0	20.3	5.3		2.7		

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 16. Alternative F1 (area closures): Time-averaged equivalent sound pressure levels (*Leq*) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	101.4	99.2	99.7	96.9	118.4	96.6	96.3	96.6	102.9	102.3
	30	104.6	105.0	103.3	101.3	122.1	97.2	96.6	97.1	102.0	
	500	107.6	105.5	106.6	101.0	120.1	100.3		97.7		
Mid-Frequency Cetaceans	5	100.5	95.1	97.4	94.9	114.0	95.3	94.7	94.9	102.2	100.4
	30	99.9	95.4	95.4	95.2	114.0	94.6	94.7	94.7	101.1	
	500	96.4	96.0	96.2	95.1	110.0	94.7		94.7		
High-Frequency Cetaceans	5	100.1	94.7	97.0	94.6	112.1	95.0	94.4	94.6	102.0	99.6
	30	99.6	94.9	94.8	94.7	112.5	94.3	94.4	94.3	100.9	
	500	95.6	95.2	95.4	94.6	108.6	94.3		94.4		
Unweighted	5	101.5	99.3	99.9	97.1	118.5	96.8	96.5	96.8	103.0	102.3
	30	105.1	106.0	104.0	101.9	122.5	97.5	96.8	97.4	102.1	
	500	108.6	106.4	108.0	101.6	120.6	100.5		98.2		

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 17. Alternative F1 (area closures): Time-averaged equivalent sound pressure levels (*Leq*) above ambient at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	5.2	3.3	2.7	1.0	22.6	0.7	0	0.3	5.7	0.1
	30	8.5	9.1	7.0	5.4	26.1	1.3	0	0.8	4.8	
	500	11.5	9.4	8.2	4.5	23.6	4.3		1.3		
Mid-Frequency Cetaceans	5	5.9	0.5	2.7	0.3	19.4	0.7	0	0.3	7.5	0.1
	30	5.2	0.8	0.8	0.6	19.4	0	0	0	6.4	
	500	1.7	1.3	1.4	0.4	15.3	0		0		
High-Frequency Cetaceans	5	5.8	0.4	2.7	0.2	17.8	0.7	0	0.2	7.7	0.1
	30	5.3	0.5	0.5	0.3	18.1	0	0	0	6.5	
	500	1.3	0.9	1.0	0.3	14.2	0		0		
Unweighted	5	5.2	3.2	2.7	1.0	22.5	0.7	0	0.3	5.6	0.1
	30	8.8	9.9	7.5	5.7	26.3	1.4	0	0.9	4.7	
	500	12.3	10.2	9.5	5.0	24.0	4.4		1.6		

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 18. Alternative F2 (area closures and 25% reduction): Time-averaged equivalent sound pressure levels (*Leq*) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	100.6	98.6	99.1	96.7	117.2	96.4	96.3	96.6	102.0	102.3
	30	103.6	103.9	102.4	100.5	120.9	96.9	96.6	96.9	101.2	
	500	106.4	104.4	105.5	100.2	118.8	99.6		97.4		
Mid-Frequency Cetaceans	5	99.6	95.0	96.9	94.9	112.8	95.1	94.7	94.8	101.2	100.4
	30	99.0	95.2	95.2	95.1	112.8	94.6	94.7	94.7	100.2	
	500	96.0	95.7	95.9	95.0	108.8	94.6		94.7		
High-Frequency Cetaceans	5	99.2	94.6	96.5	94.5	110.9	94.9	94.4	94.5	101.0	99.6
	30	98.8	94.7	94.7	94.6	111.2	94.3	94.4	94.3	100.0	
	500	95.3	95.0	95.2	94.5	107.4	94.3		94.4		
Unweighted	5	100.7	98.7	99.3	96.9	117.3	96.6	96.5	96.8	102.1	102.3
	30	104.0	104.9	103.0	101.0	121.2	97.2	96.8	97.2	101.3	
	500	107.4	105.3	107.0	100.8	119.4	99.8		97.8		

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 19. Alternative F2 (area closures and 25% reduction): Time-averaged equivalent sound pressure levels (*Leq*) above ambient at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	4.4	2.7	2.2	0.8	21.3	0.5	0	0.3	4.9	0
	30	7.4	8.0	6.0	4.6	24.9	1.0	0	0.6	4.0	
	500	10.3	8.4	7.2	3.7	22.3	3.6		1.0		
Mid-Frequency Cetaceans	5	5.0	0.4	2.2	0.2	18.2	0.5	0	0.2	6.5	0.1
	30	4.4	0.6	0.6	0.4	18.1	0	0	0	5.5	
	500	1.4	1.0	1.1	0.3	14.1	0		0		
High-Frequency Cetaceans	5	4.9	0.3	2.1	0.2	16.5	0.5	0	0.2	6.7	0.1
	30	4.4	0.4	0.4	0.3	16.9	0	0	0	5.6	
	500	1.0	0.7	0.8	0.2	13.0	0		0		
Unweighted	5	4.3	2.6	2.2	0.8	21.2	0.5	0	0.3	4.8	0
	30	7.7	8.8	6.5	4.8	25.1	1.1	0	0.7	3.9	
	500	11.1	9.1	8.4	4.2	22.7	3.6		1.2		

* Cells without values correspond to receiver depths that do not exist at shallow sites.

4.3. Listening Area

Tables 20–27 present the calculated change in listening area for each receiver site and depth for all modeled alternatives.

Table 20. Alternative C relative to Alternative A (no activity): Remainder of listening area (%) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	22.1	43.7	55.7	76.0	0.6	72.2	100	75.5	17.7	98.6
	30	13.6	7.7	22.9	21.6	0.2	55.0	100	61.2	29.7	-
	500	6.2	7.1	17.6	29.9	0.3	21.9	-	45.8	-	-
Mid-Frequency Cetaceans	5	18.0	87.5	54.4	91.3	0.9	73.5	100	82.2	9.9	97.9
	30	25.8	80.7	88.7	84.8	1.2	98.7	100	98.8	18.8	-
	500	71.8	72.3	77.4	87.8	4.1	95.7	-	98.0	-	-
High-Frequency Cetaceans	5	18.5	91.6	54.6	93.6	1.0	72.5	100	83.1	9.4	97.6
	30	25.8	86.4	92.7	90.9	1.4	99.3	100	99.4	18.1	-
	500	80.3	78.9	84.5	92.0	5.9	97.4	-	98.8	-	-
Unweighted	5	22.7	42.6	55.8	75.7	0.6	72.6	100	75.0	18.4	98.6
	30	11.9	6.4	21.2	19.7	0.2	50.4	100	56.2	30.3	-
	500	4.9	5.5	14.7	26.3	0.3	17.2	-	39.9	-	-

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 21. Alternative E (25% reduction) relative to Alternative A (no activity): Remainder of listening area (%) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	28.5	51.3	63.1	80.9	0.8	77.8	100	80.6	23.3	99.0
	30	18.1	10.4	29.1	27.5	0.2	62.4	100	68.1	36.7	-
	500	8.4	9.6	22.7	36.7	0.5	27.8	-	53.4	-	-
Mid-Frequency Cetaceans	5	23.7	90.3	61.9	93.4	1.3	78.9	100	86.1	13.7	98.4
	30	32.5	84.9	91.3	88.2	1.7	99.0	100	99.1	24.2	-
	500	77.4	77.8	82.1	90.6	5.6	96.7	-	98.5	-	-
High-Frequency Cetaceans	5	24.4	93.6	62.0	95.1	1.4	78.0	100	86.8	13.1	98.2
	30	32.4	89.5	94.5	93.1	2.0	99.5	100	99.5	23.4	-
	500	84.5	83.3	87.9	93.9	8.1	98.0	-	99.1	-	-
Unweighted	5	29.2	50.1	63.2	80.7	0.8	78.2	100	80.2	24.1	99.0
	30	15.9	8.7	27.1	25.4	0.2	58.0	100	63.5	37.4	-
	500	6.7	7.6	19.3	32.8	0.4	22.3	-	47.4	-	-

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 22. Alternative F1 (area closures) relative to Alternative A (no activity): Remainder of listening area (%) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	17.4	39.9	41.9	75.1	0.2	80.3	100	89.9	15.0	98.1
	30	8.2	7.8	13.0	20.6	0.1	68.2	100	79.1	25.4	-
	500	4.5	6.9	9.6	28.6	0.1	29.2	-	70.1	-	-
Mid-Frequency Cetaceans	5	14.2	86.1	42.0	91.0	0.5	80.8	100	92.1	8.3	97.2
	30	21.3	79.6	80.4	84.2	0.4	99.8	100	99.6	16.0	-
	500	62.3	68.7	67.4	89.8	1.4	98.9	-	99.5	-	-
High-Frequency Cetaceans	5	14.6	90.4	42.7	93.3	0.7	80.3	100	92.7	7.9	96.8
	30	20.9	85.9	86.9	90.5	0.6	99.9	100	99.8	15.4	-
	500	70.5	77.7	75.0	93.2	1.9	99.4	-	99.7	-	-
Unweighted	5	17.9	40.5	41.9	74.8	0.2	80.4	100	89.8	15.6	98.2
	30	7.5	6.2	11.2	18.8	0.1	65.4	100	75.8	26.2	-
	500	3.6	5.6	6.6	25.2	0.1	28.8	-	64.1	-	-

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 23. Alternative F2 (area closures and 25% reduction) relative to Alternative A (no activity): Remainder of listening area (%) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	23.0	47.4	49.7	80.2	0.3	84.6	100	92.3	20.1	98.6
	30	11.2	10.5	17.3	26.4	0.1	74.3	100	83.5	31.9	-
	500	6.1	9.4	12.9	35.4	0.2	36.1	-	75.9	-	-
Mid-Frequency Cetaceans	5	19.1	89.2	49.9	93.1	0.7	85.0	100	94.0	11.6	97.9
	30	27.3	83.9	84.6	87.7	0.6	99.8	100	99.7	20.9	-
	500	69.0	74.7	73.5	92.2	2.0	99.2	-	99.6	-	-
High-Frequency Cetaceans	5	19.6	92.7	50.6	94.9	1.0	84.5	100	94.4	11.1	97.5
	30	26.8	89.1	89.9	92.7	0.8	99.9	100	99.9	20.1	-
	500	76.2	82.3	80.1	94.9	2.7	99.5	-	99.8	-	-
Unweighted	5	23.6	48.0	49.8	80.0	0.3	84.6	100	92.2	20.8	98.6
	30	10.2	8.4	15.0	24.3	0.1	71.8	100	80.8	32.8	-
	500	4.9	7.6	9.1	31.5	0.2	35.7	-	70.6	-	-

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 24. Alternative E (25% reduction) relative to Alternative C: Remainder of listening area (%) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	129.1	117.4	113.3	106.5	140.7	107.7	100	106.7	131.8	100.3
	30	132.5	135.3	127.0	127.7	142.0	113.4	100	111.2	123.5	-
	500	135.2	136.0	129.5	123.1	141.0	127.1	-	116.5	-	-
Mid-Frequency Cetaceans	5	131.8	103.3	113.8	102.2	140.3	107.3	100	104.8	137.7	100.5
	30	125.6	105.1	102.9	104.0	140.7	100.3	100	100.3	129.0	-
	500	107.7	107.6	106.1	103.2	137.6	101.1	-	100.5	-	-
High-Frequency Cetaceans	5	131.4	102.2	113.7	101.6	140.2	107.7	100	104.5	138.2	100.6
	30	125.7	103.5	101.9	102.3	140.5	100.2	100	100.2	129.3	-
	500	105.2	105.7	104.1	102.1	136.2	100.7	-	100.3	-	-
Unweighted	5	128.8	117.8	113.3	106.6	140.6	107.6	100	106.9	131.4	100.3
	30	133.7	136.2	127.9	128.7	142.0	115.1	100	113.0	123.2	-
	500	136.1	137.1	131.1	124.7	141.1	129.6	-	118.9	-	-

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 25. Alternative F1 (area closures) relative to Alternative C: Remainder of listening area (%) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	78.7	91.3	75.2	98.8	34.7	111.2	100	119.1	84.8	99.5
	30	60.0	100.9	57.0	95.4	39.9	124.0	100	129.1	85.6	-
	500	72.1	97.4	54.6	95.9	42.7	133.8	-	153.1	-	-
Mid-Frequency Cetaceans	5	78.9	98.4	77.3	99.6	51.7	110.0	100	112.2	84.1	99.3
	30	82.6	98.6	90.6	99.2	34.9	101.1	100	100.8	85.0	-
	500	86.8	95.0	87.0	102.3	34.5	103.4	-	101.6	-	-
High-Frequency Cetaceans	5	78.6	98.7	78.3	99.7	74.2	110.8	100	111.6	84.0	99.1
	30	81.1	99.4	93.7	99.5	42.8	100.6	100	100.5	84.8	-
	500	87.8	98.5	88.8	101.4	32.8	102.0	-	100.9	-	-
Unweighted	5	78.7	95.1	75.2	98.8	34.4	110.7	100	119.7	84.9	99.5
	30	62.9	96.9	52.9	95.3	38.9	129.7	100	134.9	86.2	-
	500	72.7	100.7	45.0	95.6	50.5	167.6	-	160.9	-	-

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 26. Alternative F2 (area closures and 25% reduction) relative to Alternative E (25% reduction): Remainder of listening area (%) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	80.6	92.4	78.8	99.1	34.8	108.7	100	114.5	86.0	99.6
	30	61.7	100.9	59.5	95.8	39.9	119.2	100	122.6	87.0	-
	500	72.8	97.5	56.6	96.3	42.8	130.0	-	142.2	-	-
Mid-Frequency Cetaceans	5	80.5	98.8	80.6	99.7	51.9	107.8	100	109.2	85.0	99.4
	30	84.1	98.9	92.6	99.4	35.1	100.8	100	100.6	86.0	-
	500	89.2	96.0	89.5	101.8	35.1	102.6	-	101.2	-	-
High-Frequency Cetaceans	5	80.3	99.0	81.5	99.8	74.3	108.4	100	108.8	84.8	99.3
	30	82.8	99.5	95.1	99.6	43.1	100.4	100	100.4	85.9	-
	500	90.2	98.8	91.1	101.0	33.5	101.5	-	100.7	-	-
Unweighted	5	80.6	95.8	78.8	99.1	34.5	108.3	100	115.0	86.2	99.6
	30	64.4	97.0	55.4	95.7	39.0	123.8	100	127.3	87.6	-
	500	73.2	100.7	46.8	96.1	50.5	160.0	-	149.1	-	-

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 27. Alternative F2 (area closures and 25% reduction) relative to Alternative F1 (area closures): Remainder of listening area (%) at each receiver site with M-weighting for low- , mid-, and high-frequency cetaceans and without weighting.

Hearing Group	Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
Low-Frequency Cetaceans	5	132.2	118.9	118.7	106.8	141.1	105.3	100	102.6	133.7	100.5
	30	136.3	135.2	132.6	128.3	142.1	108.9	100	105.6	125.5	-
	500	136.4	136.1	134.3	123.6	141.3	123.5	-	108.3	-	-
Mid-Frequency Cetaceans	5	134.5	103.6	118.7	102.3	140.8	105.2	100	102.0	139.2	100.7
	30	128.0	105.5	105.3	104.2	141.6	100.1	100	100.1	130.6	-
	500	110.7	108.7	109.2	102.6	139.9	100.3	-	100.1	-	-
High-Frequency Cetaceans	5	134.2	102.5	118.4	101.7	140.5	105.3	100	101.9	139.5	100.8
	30	128.2	103.7	103.4	102.4	141.4	100	100	100	130.9	-
	500	108.1	106.0	106.8	101.7	139.4	100.2	-	100.1	-	-
Unweighted	5	131.9	118.6	118.7	106.9	141.1	105.3	100	102.6	133.3	100.5
	30	136.9	136.3	133.8	129.3	142.1	109.8	100	106.6	125.2	-
	500	137.1	137.1	136.4	125.2	141.3	123.7	-	110.2	-	-

* Cells without values indicate that the site was too shallow to place a receiver at the specified depth.

4.4. Bryde's Whale Communication Space

Tables 29–36 present the relative changes in Bryde's whale communication space for all modeled alternatives based on communication in the 1/3-octave band centered at 100 Hz. The baseline levels (SPLs for Alternative A; Table 28) used in these comparisons were calculated for the same frequency band.

Table 28. Baseline (Alternative A; no activity) SPL (dB re 1 μPa) for 100 Hz for each receiver site and depth.

Receiver Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7*	Site 8	Site 9*	Site 10*
5	79.18	76.18	80.21	76.26	76.27	76.13	79.93	79.98	80.70	86.66
30	78.15	76.20	78.95	76.44	76.59	76.19	81.66	79.05	80.59	
500	78.12	77.63	83.46	80.66	80.71	76.86		79.75		

* Cells without values correspond to receiver depths that do not exist at shallow sites.

Table 29. Alternative C relative to Alternative A (no activity): Bryde's whale communication space at all receiver sites.

Site	Receiver Depth (m)	Alternative A area (km^2)	Alternative C area (km^2)	Δ area (km^2)	% of original area
1	5	98.2	49.4	48.8	50
	30	190.9	31.5	159.4	16
	500	182.2	19.2	163.1	11
2	5	186.8	40.9	145.9	22
	30	286.7	51.7	235.0	18
	500	232.1	28.0	204.1	12
3	5	108.4	76.2	32.2	70
	30	186.7	82.7	104.0	44
	500	81.5	26.3	55.1	32
4	5	164.5	77.0	87.6	47
	30	252.3	55.5	196.9	22
	500	135.1	30.9	104.2	23
5	5	0.8	0	0.8	5
	30	4.3	0.2	4.1	4
	500	26.3	0	26.3	0
6	5	186.1	173.1	13.0	93
	30	290.1	244.4	45.6	84
	500	271.3	117.3	154.0	43
7*	5	60.4	60.4	0	100
	30	110.1	110.1	0	100
8	5	81.9	79.4	2.5	97
	30	195.3	167.9	27.4	86
	500	159.3	116.6	42.7	73
9*	5	34.1	34.0	0	100
	30	97.8	97.5	0.3	100
10*	5	3.5	3.5	0	100

* Sites 7, 9, and 10 are located in areas too shallow to place a receiver at the 500 m depth, and Site 10 is located in an area too shallow to place a receiver at the 30 or 500 m depths.

Table 30. Alternative E (25% reduction) relative to Alternative A (no activity): Bryde's whale communication space at all receiver sites.

Site	Receiver Depth (m)	Alternative A	Alternative E	Δ area (km^2)	% of original area
		area (km^2)	area (km^2)		
1	5	98.2	57.9	40.3	59
	30	190.9	43.0	148.0	23
	500	182.2	23.9	158.3	13
2	5	186.8	53.1	133.7	28
	30	286.7	70.6	216.1	25
	500	232.1	37.1	195.0	16
3	5	108.4	83.1	25.3	77
	30	186.7	97.6	89.1	52
	500	81.5	30.8	50.7	38
4	5	164.5	91.3	73.2	55
	30	252.3	77.3	175.0	31
	500	135.1	41.6	93.5	31
5	5	0.8	0	0.8	5
	30	4.3	0.2	4.1	5
	500	26.3	0	26.3	0
6	5	186.1	176.1	10.0	95
	30	290.1	254.9	35.2	88
	500	271.3	141.7	129.6	52
7*	5	60.4	60.4	0	100
	30	110.1	110.1	0	100
8	5	81.9	80.1	1.9	98
	30	195.3	174.3	21.1	89
	500	159.3	125.3	34.0	79
9*	5	34.1	34.1	0	100
	30	97.8	97.6	0.2	100
10*	5	3.5	3.5	0	100

* Sites 7, 9, and 10 are located in areas too shallow to place a receiver at the 500 m depth, and Site 10 is located in an area too shallow to place a receiver at the 30 or 500 m depths.

Table 31. Alternative F1 (area closures) relative to Alternative A (no activity): Bryde's whale communication space at all receiver sites.

Site	Receiver Depth (m)	Alternative A	Alternative F1	Δ area (km²)	% of original area
		area (km²)	area (km²)		
1	5	98.2	34.4	63.7	35
	30	190.9	19.9	171.0	10
	500	182.2	12.9	169.3	7
2	5	186.8	27.3	159.5	15
	30	286.7	57.5	229.2	20
	500	232.1	24.0	208.2	10
3	5	108.4	49.7	58.6	46
	30	186.7	51.8	134.9	28
	500	81.5	19.7	61.8	24
4	5	164.5	74.3	90.3	45
	30	252.3	51.9	200.4	21
	500	135.1	30.3	104.8	22
5	5	0.8	0	0.8	3
	30	4.3	0.1	4.2	3
	500	26.3	0	26.3	0
6	5	186.1	180.2	5.9	97
	30	290.1	276.8	13.2	95
	500	271.3	176.6	94.7	65
7*	5	60.4	60.4	0	100
	30	110.1	110.1	0	100
8	5	81.9	81.2	0.8	99
	30	195.3	188.6	6.7	97
	500	159.3	146.4	12.9	92
9*	5	34.1	34.1	0	100
	30	97.8	97.4	0.4	100
10*	5	3.5	3.5	0	100

* Sites 7, 9, and 10 are located in areas too shallow to place a receiver at the 500 m depth, and Site 10 is located in an area too shallow to place a receiver at the 30 or 500 m depths.

Table 32. Alternative F2 (area closures and 25% reduction) relative to Alternative A (no activity): Bryde's whale communication space at all receiver sites.

Site	Receiver Depth (m)	Alternative A	Alternative F2	Δ area (km^2)	% of original area
		area (km^2)	area (km^2)		
1	5	98.2	41.4	56.8	42
	30	190.9	27.4	163.6	14
	500	182.2	17.5	164.7	10
2	5	186.8	34.9	151.9	19
	30	286.7	77.5	209.2	27
	500	232.1	31.6	200.5	14
3	5	108.4	57.4	50.9	53
	30	186.7	65.8	120.9	35
	500	81.5	22.6	58.9	28
4	5	164.5	88.8	75.8	54
	30	252.3	74.1	178.3	29
	500	135.1	40.8	94.3	30
5	5	0.8	0	0.8	3
	30	4.3	0.2	4.1	4
	500	26.3	0	26.3	0
6	5	186.1	181.6	4.5	98
	30	290.1	280.1	9.9	97
	500	271.3	195.5	75.8	72
7*	5	60.4	60.4	0	100
	30	110.1	110.1	0	100
8	5	81.9	81.4	0.6	99
	30	195.3	190.3	5.1	97
	500	159.3	149.4	9.9	94
9*	5	34.1	34.0	0	100
	30	97.8	97.5	0.3	100
10*	5	3.5	3.5	0	100

* Sites 7, 9, and 10 are located in areas too shallow to place a receiver at the 500 m depth, and Site 10 is located in an area too shallow to place a receiver at the 30 or 500 m depths.

Table 33. Alternative E (25% reduction) relative to Alternative C: Bryde's whale communication space at all receiver sites.

Site	Receiver Depth (m)	Alternative C area (km²)	Alternative E area (km²)	Δ area (km²)	% of original area
1	5	49.4	57.9	−8.5	117
	30	31.5	43.0	−11.5	136
	500	19.2	23.9	−4.7	125
2	5	40.9	53.1	−12.3	130
	30	51.7	70.6	−18.9	137
	500	28.0	37.1	−9.1	132
3	5	76.2	83.1	−6.9	109
	30	82.7	97.6	−14.9	118
	500	26.3	30.8	−4.5	117
4	5	77.0	91.3	−14.3	119
	30	55.5	77.3	−21.8	139
	500	30.9	41.6	−10.7	135
5	5	0.038	0.043	−0.005	113
	30	0.182	0.212	−0.030	116
	500	0	0	0	
6	5	173.1	176.1	−3.0	102
	30	244.4	254.9	−10.4	104
	500	117.3	141.7	−24.4	121
7*	5	60.4	60.4	0	100
	30	110.1	110.1	0	100
8	5	79.4	80.1	−0.6	101
	30	167.9	174.3	−6.4	104
	500	116.6	125.3	−8.7	107
9*	5	34.0	34.1	0	100
	30	97.5	97.6	−0.1	100
10*	5	3.5	3.5	0	100

* Sites 7, 9, and 10 are located in areas too shallow to place a receiver at the 500 m depth, and Site 10 is located in an area too shallow to place a receiver at the 30 or 500 m depths.

Table 34. Alternative F1 (area closures) relative to Alternative C (no activity): Bryde's whale communication space at all receiver sites.

Site	Receiver Depth (m)	Alternative C area (km²)	Alternative F1 area (km²)	∆ area (km²)	% of original area
1	5	49.4	34.4	15.0	70
	30	31.5	19.9	11.6	63
	500	19.2	12.9	6.2	67
2	5	40.9	27.3	13.6	67
	30	51.7	57.5	−5.9	111
	500	28.0	24.0	4.0	86
3	5	76.2	49.7	26.4	65
	30	82.7	51.8	30.9	63
	500	26.3	19.7	6.7	75
4	5	77.0	74.3	2.7	96
	30	55.5	51.9	3.5	94
	500	30.9	30.3	0.6	98
5	5	0.038	0.023	0.015	61
	30	0.182	0.123	0.059	68
	500	0	0	0	
6	5	173.1	180.2	−7.1	104
	30	244.4	276.8	−32.4	113
	500	117.3	176.6	−59.3	151
7*	5	60.4	60.4	0	100
	30	110.1	110.1	0	100
8	5	79.4	81.2	−1.7	102
	30	167.9	188.6	−20.7	112
	500	116.6	146.4	−29.8	126
9*	5	34.0	34.1	0	100
	30	97.5	97.4	0	100
10*	5	3.5	3.5	0	100

* Sites 7, 9, and 10 are located in areas too shallow to place a receiver at the 500 m depth, and Site 10 is located in an area too shallow to place a receiver at the 30 or 500 m depths.

Table 35. Alternative F2 (area closures and 25% reduction) relative to Alternative E (25% reduction): Bryde's whale communication space at all receiver sites.

Site	Receiver Depth (m)	Alternative E area (km^2)	Alternative F2 area (km^2)	Δ area (km^2)	% of original area
1	5	57.9	41.4	16.5	71
	30	43.0	27.4	15.6	64
	500	23.9	17.5	6.4	73
2	5	53.1	34.9	18.2	66
	30	70.6	77.5	−6.9	110
	500	37.1	31.6	5.5	85
3	5	83.1	57.4	25.6	69
	30	97.6	65.8	31.9	67
	500	30.8	22.6	8.2	73
4	5	91.3	88.8	2.5	97
	30	77.3	74.1	3.3	96
	500	41.6	40.8	0.8	98
5	5	0.043	0.028	0.015	65
	30	0.212	0.151	0.061	71
	500	0	0	0	
6	5	176.1	181.6	−5.5	103
	30	254.9	280.1	−25.3	110
	500	141.7	195.5	−53.8	138
7*	5	60.4	60.4	0	100
	30	110.1	110.1	0	100
8	5	80.1	81.4	−1.3	102
	30	174.3	190.3	−16.0	109
	500	125.3	149.4	−24.1	119
9*	5	34.1	34.0	0	100
	30	97.6	97.5	0.1	100
10*	5	3.5	3.5	0	100

* Sites 7, 9, and 10 are located in areas too shallow to place a receiver at the 500 m depth, and Site 10 is located in an area too shallow to place a receiver at the 30 or 500 m depths.

Table 36. Alternative F2 (area closures and 25% reduction) versus Alternative F1 (area closures): Bryde's whale communication space at all receiver sites.

Site	Receiver Depth (m)	Alternative F1	Alternative F2	∆ area (km²)	% of original area
		area (km²)	area (km²)		
1	5	34.4	41.4	−6.9	120
	30	19.9	27.4	−7.4	137
	500	12.9	17.5	−4.6	135
2	5	27.3	34.9	−7.6	128
	30	57.5	77.5	−20.0	135
	500	24.0	31.6	−7.6	132
3	5	49.7	57.4	−7.7	115
	30	51.8	65.8	−14.0	127
	500	19.7	22.6	−2.9	115
4	5	74.3	88.8	−14.5	120
	30	51.9	74.1	−22.1	143
	500	30.3	40.8	−10.6	135
5	5	0.023	0.028	−0.005	122
	30	0.123	0.151	−0.028	123
	500	0	0	0	
6	5	180.2	181.6	−1.5	101
	30	276.8	280.1	−3.3	101
	500	176.6	195.5	−18.9	111
7*	5	60.4	60.4	0	100
	30	110.1	110.1	0	100
8	5	81.2	81.4	−0.2	100
	30	188.6	190.3	−1.7	101
	500	146.4	149.4	−3.0	102
9*	5	34.1	34.1	0	100
	30	97.4	97.5	−0.1	100
10*	5	3.5	3.5	0	100

* Sites 7, 9, and 10 are located in areas too shallow to place a receiver at the 500 m depth, and Site 10 is located in an area too shallow to place a receiver at the 30 or 500 m depths.

5. Discussion and Conclusion

This assessment applied acoustic modeling to determine changes to Bryde's whale communication space and changes in listening area (all species), caused by the introduction of various seismic survey activities in the Gulf of Mexico. Ten receiver sites were modeled (Table 1, Figure 1) for five alternatives of seismic survey activity (Table 3), representing possible levels of annual survey activity across six geographic activity zones comprising the project area (Figure 1). The assessment results for change in listening area are presented in Tables 20–27, and results for Bryde's whale communication space are presented in Tables 28–36.

The key findings of this acoustic effects assessment are:

- Communication space and listening area decreased for all alternatives relative to the no-activity Alternative A, except at Site 7. Change in listening area was generally greater for low-frequency cetaceans than for mid- and high-frequency cetaceans.
- The largest decreases, by up to 99.9% of listening area (low-frequency cetaceans) and up to 100% of Bryde's whale communication space, occurred at Site 5 for reasons outlined below. The decreases in communication space and listening area at other sites were highly variable (between 0.1% and 95%). The amount of change depended on the location, receiver depth, and marine mammal frequency weighting filter used.
- Bryde's whale communication space and low-frequency cetacean listening area reductions were greater at the 500 m receiver depth than at the shallower receiver depths (5 and 30 m). That was attributed to the downward refracting sound speed profile near the surface, caused by the thermocline steering sound to deeper depths. It was also influenced by surface interactions that increase transmission loss (lower anthropogenic levels) at shallow depths for low frequencies.
- Listening area reductions for mid- and high-frequency cetaceans were substantially lower than for low-frequency cetaceans at most sites. Change in listening areas were generally small (> 75% remaining) except at Sites 1, 5, and 9. The listening area reductions were not systematically greater at depth, and in fact in some cases were less.

5.1. Site-Specific Results

- Site 1 (Western Gulf, 842 m water depth) experienced decreased listening area of up to 93.8% (6.2% remaining) for low-frequency cetaceans. Bryde's whale communication space was decreased by up to 89% (11% remaining), for Alternative C. The proposed area closures and reduced activity alternatives did not appreciably change these results.
- Site 2 (Florida Escarpment, 693 m water depth) experienced decreased listening area of up to 92.9% (7.1% remaining) for low-frequency cetaceans. Bryde's whale communication space was decreased up to 88% (12% remaining), for Alternative C. The proposed area closures and reduced activity alternatives did not appreciably change these results.
- Site 3 (Midwestern Gulf, 830 m water depth) experienced decreased listening area of up to 82.4% (17.6% remaining) for low-frequency cetaceans. Bryde's whale communication space was decreased up to 88% (12% remaining) for Alternative C. The proposed area closures Alternative F1 actually lead to increased noise at Site 3 due to the redistribution of 25% of the activity inside the central planning area into the rest of Zone 4. This resulted in a decreased listening area of 90.4%.
- Site 4 (Sperm Whale Site, 1053 m water depth) experienced decreased listening area of up to 70.1% (29.9% remaining) for low-frequency cetaceans. Bryde's whale communication space was decreased by up to 77% (23% remaining) for Alternative C. The proposed area closures Alternative F1 did not appreciably affect this site even though it lies near the Dry Tortugas closure area.

- Site 5 (Deep Offshore, 3050 m water depth) experienced the largest change to communication space and had the greatest relative reduction in listening area for all alternatives. Communication space was decreased by more than 95% (to less than 5% remaining) for all activity alternatives relative to the no-activity alternative (Alternative A). Listening area was reduced to less than 1% for low-frequency cetaceans and to less than 8% for mid-frequency and high-frequency cetaceans for all alternatives relative to Alternative A. This site experienced the highest anthropogenic noise levels because:
    1. Receiver 5 was located in Zone 4, which has the highest density of seismic pulses.
    2. This receiver site lies in deep water that supports longer-range low-frequency sound propagation than shallower sites. As a result, a larger number of seismic pulses contributed to its accumulated acoustic energy.
- Site 6 (Mississippi Canyon, 1106 m water depth) experienced decreased listening area of up to 78.1% (21.9% remaining) for low-frequency cetaceans. Bryde's whale communication space decreased up to 77% (23% remaining) for Alternative C. Site 6 lies inside the central planning closure area and consequently Alternative F1 led to improved noise conditions, with listening area loss at 70.8% (29.2% remaining) for low-frequency cetaceans compared to the no-activity alternative (Alternative A). This is an increase of the listening area by 7.3% compared to that for Alternative C.
- Site 7 (Bryde's Whale Site, 212 m water depth) experienced the lowest anthropogenic sound levels (L_{eq}) for all alternatives. These L_{eq} were in fact below baseline levels (Alternative A) even for the full activity level described in Alternative C. Consequently, no changes to communication space or listening area were experienced for any of the alternatives. There are three primary reasons for low anthropogenic noise levels at this site:
    1. The ocean sound speed profile is downward refracting and steers sound energy from distant sources into the seabed, where it is absorbed by softer, non-reflective sediments.
    2. Only geotechnical surveys are performed in Zone 5 (Florida shelf), adjacent to this receiver site. The geotechnical surveys are represented by a single small airgun source that produces substantially less acoustic energy than the 3-D airgun array used in other activity zones (see Table 5).
    3. The 2-D and 3-D survey activity levels in Zone 6, in which this receiver resides, are low relative to other sites.
- Site 8 (De Soto Canyon, 919 m water depth) experienced decreased listening area of up to 54.2% (45.8% remaining) for low-frequency cetaceans. Bryde's whale communication space decreased up to 27% (73% remaining) for Alternative C. The proposed area closures for Alternative F1 further improved the noise conditions at this site since it lies on the eastern edge of the central planning closure area. This led to a change in listening area of 24.1% (75.9% remaining) compared to the no-activity alternative (Alternative A).This is an increase of listening area by 30.1% compared to Alternative C.
- Site 9 (Flower Garden Banks National Marine Sanctuary, 88 m water depth) experienced decreased listening area of up to 54.2% (17.7% remaining) for low-frequency cetaceans and up to 90.6% (9.4% remaining) for high-frequency cetaceans. Interestingly, the Bryde's whale communication space decreases did not show this loss and indicated no loss in space for Alternative C. This result was likely due to noise outside of the Bryde's whale call band affecting listening area, but not the Bryde's communication space. The proposed area closures for Alternative F1 did not appreciably change these results even though the site lies in the Flower Garden closure area.
- Site 10 (Bottlenose Dolphin Site, 12 m water depth) was inside the coastal closure area and experienced little low-frequency seismic survey noise and only marginal higher-frequency noise. Its decrease in listening area was by up to 2.4% (97.6% remaining) for high-frequency cetaceans with even smaller decreases for low-frequency cetaceans and mid-frequency cetaceans. The Bryde's whale communication space was unaffected.

Acknowledgments

With much appreciation, we thank Erin Dunable for her help on the interpretation and editorial review of this report, and Jolie Harrison and Leila Hatch for their insights and contributions to developing the analysis approaches.

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APPENDIX L

PANEL REPORTS

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ABBREVIATIONS AND ACRONYMS

2D	two dimensional
3D	three dimensional
4D	four dimensional
BOEM	Bureau of Ocean Energy Management
dB	decibel
E&P	exploration and production
EIS	environmental impact statement
e.g.	for example
et al.	and others
FAZ	full azimuth
ft	foot
G&G	geological and geophysical
GOM	Gulf of Mexico
GOMR	Gulf of Mexico OCS Region
i.e.	that is
in^3	cubic inch
m	meter
MMS	Minerals Management Service
NAZ	narrow azimuth
OCB	ocean bottom cable
OCS	Outer Continental Shelf
PGS	Petroleum Geo-Services, Inc.
psi	pounds per square inch
RAZ	rich azimuth
SEL	
S/N	signal-to-noise
SPL_{rms}	
U.S.	United States
USGS	U.S. Department of the Interior, Geological Survey
WAZ	wide azimuth

1 LOWEST PRACTICABLE SOUND SOURCE PANEL REPORT

Submitted by Lowest Practical Sound Source Panel (8/12/2016)

1.1 INTRODUCTION

The Natural Resource Defense Council, Inc. et al., as Plaintiffs in a lawsuit against the U.S. Department of the Interior as Defendant, have expressed concern that marine offshore seismic surveys should use the lowest sound intensity level that would not only illuminate subsurface targets but also minimize horizontal propagation that may have physical and/or behavioral effects on marine mammal populations. As per condition **VII.A., the "Order Granting Joint Motion for Approval of Settlement Agreement and Stay of Proceedings"** (June 24, 2013), the Bureau of Ocean Energy Management (BOEM) agreed to convene an internal expert panel to determine whether it would be feasible to develop standards to determine a lowest practicable source level. The panel has determined that it would not be reasonable or practicable to develop these metrics.

1.2 INTERNAL EXPERT PANEL

The internal BOEM Panel who formulated this document consisted of the following personnel:

Tamara S. Arzt, J.D, M.P.A. is an Environmental Protection Specialist and the Endangered Species Act Lead for BOEM's Headquarters. She has worked for BOEM since 2011. Ms. Arzt received her B.A. from Smith College with a major in Government and her M.P.A from the University of Massachusetts, Amherst with a specific focus on environmental policy and endangered species. Ms. Arzt then worked for an alternative dispute resolution firm in Boulder, Colorado, where she focused on resolving multiple Federal environmental issues. In 2003, Ms. Arzt received her J.D. from Vermont Law School concentrating on environmental law. Upon graduation, she was accepted into the Presidential Management Fellowship program and worked for the Bureau of Land Management with the U.S. Department of the Interior in Washington, DC and Colorado. Ms. Arzt continued her career in public service, working for county and municipal government on the Northfork of Long Island, New York, with a continued emphasis on the environment, in particular coastal and wetlands issues. In addition to being the Endangered Species Act Lead in BOEM's Headquarters' Office, Ms. Arzt works extensively with Marine Mammal Protection Act and National Environmental Policy Act, as well as Coastal Zone Management Act and National Historic Preservation Act, issues associated with both traditional and renewable energy development on the Outer Continental Shelf (OCS).

Ronald (Ron) Brinkman currently serves as BOEM's Senior Staff Geophysicist for the Gulf of Mexico OCS Region's Office of Resource Evaluation. He has worked as a geophysical interpreter, permitting and acquisition specialist, and geophysical subject-matter expert in the preparation of the Atlantic and Gulf of Mexico Geological and Geophysical Programmatic Environmental Statements (EISs), as well as subject-matter advisor to the OKEANOS and CETSOUND working groups. Ron has B.S. degrees in Mathematics and Geology from the Louisiana State University (New Orleans) and has been employed with the U.S. Department of the Interior for over 39 years. He has been an active member of the Society of Exploration Geophysicists since 1992.

Ty Collins is a Geophysicist at in BOEM's Gulf of Mexico OCS Region's Office of Resource Evaluation. Prior to working at BOEM, he worked in commercial geophysical survey acquisition in the United States (U.S.) OCS, including the Gulf of Mexico, Beaufort Sea, and Chukchi Sea. He has experience in commercial survey design, acquisition, processing, and interpretation of geophysical data. At BOEM, Mr. Collins interprets geophysical and geological data to evaluate the "fair market value" of lease blocks related to OCS lease sales. Mr. Collins holds a Professional Geoscientist License from the Louisiana Board of Professional Geoscientists and a B.S. degree in Geophysics from the University of New Orleans. He is a graduate of the Daniel J. Tearpock Geoscience Certification Program and is an active member of the Society of Exploration Geophysicists.

Patrick Hart is a geophysicist with the U.S. Department of the Interior's Geological Survey (USGS), working at the Pacific Coastal and Marine Science Center in Santa Cruz, California. Mr. Hart obtained a B.S. and M.S. in Geophysics from Stanford University in 1980. After working in the exploration industry for 6 years in various seismic data acquisition and processing positions, he joined the USGS Branch of Pacific Marine Geology in Menlo Park, California, as a marine seismic data analyst. Over the last 30 years, he has worked on a wide variety of projects utilizing marine seismic data, including gas hydrate characterization, marine geohazard analysis, and sound source verification. Mr. Hart is an active member of the Society of Exploration Geophysicists and the American Geophysical Union.

John Johnson is a supervisory geologist with the BOEM's Gulf of Mexico OCS Region (GOMR) in New Orleans, Louisiana. He received his B.S. and M.S. degrees in Geology from the University of Florida prior to starting work as a geologist with the USGS' Conservation Division (the predecessor of MMS) in 1981. Mr. Johnson evaluated offshore lease prospects for fair market value determination for over 15 years and served as Staff Geologist. Since 2007, he has been supervisor of BOEM's Gulf of Mexico OCS Region, Office of Resource Evaluation's Data Acquisition and Special Projects Unit. This group is responsible for geological and geophysical (G&G) permitting in the Gulf of Mexico and for the purchasing, loading, and managing (including archiving and public release) of digital seismic data for the GOMR.

Stanley (Stan) Labak works in BOEM's Division of Environmental Science in Sterling, Virginia. Mr. Labak has been with BOEM for about 3 years, where he is a Physical Scientist (Marine Acoustician) in the Physical & Chemical Sciences Branch. His specific areas of experience and expertise include modeling, analysis, and evaluation of underwater acoustic source and propagation, especially with regards to its potential impact to marine species. Stan received his B.S. in Ocean Engineering at the U.S. Naval Academy and his M.S. in Ocean Engineering at the Massachusetts Institute of Technology, where he was a Draper Fellow. He is a retired Naval Reservist.

Dr. Carolyn Ruppel is a geophysicist who obtained all of her degrees at the Massachusetts Institute of Technology. After a stint as a Postdoctoral Scholar at Woods Hole Oceanographic Institution, she spent 12 years as a professor (tenured 2000) at Georgia Tech. From 2003-2006, she was a program manager at the National Science Foundation, Division of Ocean Sciences as a faculty rotator. She moved to a senior position in USGS in 2006 and is now Chief Scientist of the USGS' Gas Hydrates Project and the informal contact for environmental compliance issues within the Coastal and Marine Geology Program at USGS. Dr. Ruppel has served on the U.S. Department of Energy's Federal Advisory Committee for gas hydrates, several editorial boards, and numerous national/international committees in marine science; has been a Distinguished Lecturer for the Ocean Drilling Program; and has testified to several National Research Council panels. She is a Fellow of the Geological Society of America.

1.3 Subject-Matter Experts

The Panel would also like to knowledge and thank the following subject-matter experts who, while not official Panel Members, contributed their individual expertise in the document's development:

Tom Neugebauer is the Director of Project Management and Execution Western Hemisphere for TGS-NOPEC Geophysical Company. He received his B.S. in oceanographic technology from Florida Tech and A.S. in electrical engineering technology from HCC. Over the past 36 years Tom has worked in marine seismic acquisition, marine/land data processing, processing management, seismic sales and project development with GSI, Seismograph Services, Geco-Prakla and TGS. Since 2014, Tom has held the position of Director of marine projects for the Western Hemisphere region at TGS.

Detlef Ross is a Geophysical Advisor at Petroleum Geo-Services, Inc. (PGS), located in Houston, Texas. He received his Pre-Diploma (equal B.S.) in Physical Oceanography and Diploma (M.S.) in Geophysics from the University of Kiel, Germany, prior to starting work for PGS Geophysical AS in Oslo, Norway, in 1998.

Over the last 18 years, Mr. Ross has held various positions as a geophysicist, field engineer, supervisor, and project manager, working onshore and offshore. Since 2013, he has assumed the role of geophysical advisor.

We would also like to acknowledge special technical assistance provided to the panel by

Mr. Steven Fishburn who is the former Vice President GOM Multi-Client, Petroleum Geo-Services, Inc.

1.4 HISTORY OF MARINE SEISMIC SURVEYS

In the summer of 1921, a small team of physicists and geologists performed a historical experiment near the Vines Branch area in south-central Oklahoma. Using a dynamite charge as a seismic source and a special instrument called a seismograph, the team recorded seismic waves that had traveled through the subsurface of the earth. Analysis of the recorded data showed that seismic reflections from a boundary between two underground rock layers had been detected. Further analysis of the data produced an image of the subsurface—called a seismic reflection profile—that agreed with a known geologic feature. That result is widely regarded as the first proof that an accurate image of the earth's subsurface could be made using reflected waves. However, because of the economics of that time, it wasn't until 1929 when improvements in technology and economics converged to make seismic reflections an accepted method of prospecting for oil (Dragoset, 2005).

In the 1950s, marine seismic imaging became the foremost exploration method as companies looked to expand drilling provinces into the marine environment. Marine seismic acquisition faced the same fundamental geological challenges as land surveys did with some additional physical challenges brought about by the water column. Dynamite was still the preferred acoustic source, and charges were detonated in the water column at depths ranging from a few feet to tens of feet. The size of the charges and the depths at which they were exploded were determined by the local geology, the nature of ambient noise in the area, and the desired depth of seismic wave penetration in the earth.

However, explosives were not an ideal seismic source when used underwater. The bubble of gases created by an underwater explosion oscillates in the water and produced a source wavelet that consisted of a long sequence of impulses. Seismic records produced with such a source wavelet were then unsuitable for interpretation. The digital filtering technology used to collapse the train of impulses would not become available until the 1960s; therefore, companies tried to detonate the charges at shallow depths so that the gas bubble would reach the surface before any oscillations would occur.

Explosives became obsolete in the 1970s because of the concern for potential damage to marine life, as well as dangers to the crews deploying it. These concerns lead to the development of the marine airgun by Bolt Technologies and Texas Instruments in the 1970s.

The design of the airgun created a pulsed sound by the sudden electro-mechanical release of highly compressed air through a vented port. The airgun also created source wavelets, but this problem was overcome by the tuned airgun array concept. The tuning of airguns involves the simultaneous deployment of different-sized airguns where the initial pulses sum coherently, thereby increasing the strength of the combined source and also minimizing the bubble pulses that do not sum coherently. This maximizes the signal-to-noise ratio of a source.

1.5 Technology and Parameters

It should be noted that airgun acoustic sources are not exclusively used in commercial oil and gas exploration but are also used for scientific research. Some current scientific uses include, but are not limited to the following: (1) hazard identification, such as earthquake faulting, aquifer exploitation, and submarine slides; (2) historical issues, such as review of large-scale plate tectonics; (3) national security; and (4) the delineation of U.S. territorial waters and delineation of the extended continental shelf.

During recent years, the idea that seismic surveys could be adjusted to “lowest practicable source levels” for a particular site or survey has garnered increasing attention. This is despite the fact that source volumes do not correspond linearly with source output levels (in fact, it is a cube root relationship).

Briefly, the key parameters considered, and their impacts on sound levels generated by source arrays, include the following:

(1) **Number of Elements:** There is a linear relationship between the number of **identical** elements and array loudness expressed as peak pressure (SPL_{peak}), i.e., half as many identical elements would make the array half as loud or 6 decibels (dB) quieter in the direction of the downward looking beam.

(2) **Operating Pressure:** There is a ¾ proportional relationship between operating air pressure and loudness expressed as SPL_{peak}, i.e., an array pressurized at 2,000 pounds per square inch (psi) would be about 4 to 5 dB louder than an array pressurized at 1,000 psi.

(3) **Air Volume:** For both the individual source elements and the total array, loudness is proportional to the cube root of the ratio of **different** volumes; therefore, a 6-dB reduction in loudness from a 240-cubic inch (in^3) element would require replacement by a 30-in^3 element, and a 6-dB reduction in loudness from an 8,000-in^3 array would require reduction of total array air volume to 1,000 in^3. When comparing array output from different sizes and combinations of sources and source pressures, we use the peak pressure as the metric of loudness because that is the primary output parameter of interest for the array’s intended purpose. Measurements that sum the energy from multiple pressure oscillations over time, such as SPL_{rms} or SEL, are more

appropriate for far-field measurements away from the array where multi-path and other effects contribute to the received sound field.

(4) **Array Dimensions:** This is the most complicated aspect of the array. The simplest statement that can be made about array geometry is that it is optimized for geophysical imaging and any changes are likely to reduce array effectiveness.

1.6 KEY POINTS

(1) A reduction in source air volume has a relatively minimal influence on source level.

(2) The modeled or theoretical source levels often quoted for seismic source arrays are not directly predictive of the received levels at distance in the water column because of the effect of the element separation in the array.

1.7 DISCUSSION

Setting aside the use of non-equivalent acoustic terminology, these statements have been generally interpreted to mean a goal of reducing the level of sound exposure to marine life, without losses to data quality that would jeopardize the goals of the survey and that may possibly lead to the need for more or lengthier surveys to compensate for any lost data quality.

“Sound intensity level” is not equivalent to “sound pressure level” averaged over some time period (RMS), nor is it equivalent to the cumulative energy within some time period (e.g., SEL). The metric of greatest interest in discussing the source array is peak pressure of the primary pulse, whereas the measures of biological interest away from the source array are typically measures of averaged pressure across the pulse (dB SPL_{rms}), which is usually referenced to 90 percent of the energy in the pulse or Sound Exposure Level (dB SEL) averaged across the multi-path propagation of a single pulse or multiple pulses.

Factors to be considered in the arrays are described in **Chapters 1.7.1-1.7.4** below.

1.7.1 Number of Elements in an Array

Sound pressure (amplitude) is linearly proportional to the number of elements in the array. This only holds true, however, if all of the elements occupy the same location, which is physically impossible. This property is normally discussed as the near-field or far-field of a source or receiver array. For typical airgun arrays, the far-field is not reached until about 200 to 300 meters (m) (656 to 984 feet [ft]).

The difference between point and distributed sources needs to be clarified. Some sources that are physically smaller (e.g., completely contained within a sphere with a 1-m [3-ft] diameter) can be considered point sources. However, most other sources (e.g., an airgun array, which could be tens of meters in width and length) are distributed sources. For a distributed source, a receiver must be some distance away from the source to perceive it acoustically as a single, or point, source. Closer to the source, a receiver gathers many signals from all separate components of the source. The receiver then is considered in the "near-field." Once a receiver is beyond this range and can interpret the signal as a point source, it is considered in the source's "far-field." This problem is visually analogous to viewing an illuminated 100-story building at night and attempting to characterize the lighting intensity around it. One would need to be miles away from that building to see it as a single light source. Anywhere closer, individual floors could be seen, and how they are perceived would strongly influence the level of light received. If the observer was only 10 m (33 ft) from the ground floor, higher floors would be partially seen and the overall light being produced by such a structure could be greatly underestimated.

This distinction between near-field and far-field is a particularly important one for distributed sources such as airgun arrays. This is because the most severe potential impacts on animals generally occur near the source, and an understanding and assessment of these impacts requires a correct understanding of the sound field in the near-field. If a receiver (i.e., animal) is in the near-field of an airgun array, it will receive energy from all individual sources (e.g., individual airguns) in that array (just as the observer of the building would receive some light from the many floors in the example above). However, the closest individual source (i.e., a floor for the building example) will tend to be the dominant source, with other individual sources in the array making smaller contributions to the overall received sound level. Because these additional contributions will be delayed in time (due to the physical geometry and the time differences required for sound travel from individual sources to the receiver) and might not be in phase (i.e., peak pressures might not arrive simultaneously or "in-phase"), these contributions will seldom sum to the maximum energy of the overall signal and could actually result in diminishing some of the signal. In this way, near-field sound of the real array would always be less than that modeled for a theoretical point source. In effect, estimating the near-field sound field around an assumed point source is conservative because it will always be greater than the actual values in the near-field.

The use of the theoretical point source is useful and valid in the far-field, but extreme care needs to be exercised with using it to approximate an airgun array when not in the far-field. The actual received level in the main beam in the near-field can be expected to be 20 to 30 dB less than that approximated by a point source, which can be further reduced outside of that beam, especially in the horizontal directions.

Additionally, the extent and shape of the far-field and the details of the sound field closer than the far-field are highly dependent on the configuration of the airgun array. Reductions in the size and number of airguns in that array will generally reduce the far-field point source level, but it will have a lesser impact to the near-field, sound-field structure and can actually cause increased levels in some of the volume if the main beam is allowed to widen. The existing models can and do predict these effects, but it is very difficult to generalize these trends into a simple and easily understood result.

1.7.2 Operating Pressure of an Array

Based on supplied BOEM geophysical permit application data, the source arrays used by the seismic industry almost exclusively operate at a pressure of approximately 2,000 psi. There is very little practical opportunity of varying source levels by varying the operating pressure used. Generally, increasing the pressure requires greater compressor capacity on the seismic vessel (which is already significant) and decreasing the pressure can potentially lead to water leakage into the compression chambers, but perhaps more importantly it can lead to unwanted “auto-firing” when insufficient pressure in the chamber results in a premature release of air in one or more array elements and in “polluting” the overall output signal with energy outside the signal of interest.

1.7.3 Volume of an Array, Including Individual Element Volumes

The sound pressure (peak amplitude) is proportional to the cube root of the ratio between two source volumes (Caldwell and Dragoset, 2000). Thus, an 8,000-in^3 array produces only about twice the loudness of a 1,000- in^3 array with all things being equal (such as the number of elements and the spatial dimensions of the array). This volume to loudness ratio holds for the sizes of single elements, e.g., a 240-in^3 element only generates twice the peak pressure level of a 30-in^3 element and not eight times the level as some might assume. It is mainly the frequency components of the source signals that differ with size, i.e., larger elements produce more low-frequency sound. A single 800-in^3 element would be required to double the source output of a 100 cubic inch element. However, if we were to create an array of four 100-in^3 elements, we would produce twice the acoustic output in the array pressure peak compared with a single 800-in^3 element. In other words, we get twice the output from only half the volume because we have enabled the output from the four elements to be synchronized so that their peaks align. That is why we have noted that the output sound pressure level for a seismic array is more closely related to the total number of elements in the array than to the total array volume and that is why source geometry is so important. Achieving greater peak pressure outputs from an array of smaller elements than would be achieved by a single element of the same combined volume is only possible if the pressure pulses line up, and since they cannot line up in all directions, the additive gain cannot be achieved equally in all directions.

1.7.4 Array Dimensions

The dimensions of a source array and the number and different volume of elements it contains are very important in reducing the effect of the “bubble trains” to achieve a seismic signal that is optimum for imaging the geological objectives. Furthermore, the distance between the individual elements in the array have a significant influence on the resultant source level generated by the array since acoustic energy is dissipated as it travels the distance needed to align with pulses from the other elements. The alignment of the pulses from the individual elements adds to the peak amplitude of the primary pulse, but it tends to create destructive interference between the subsequent pressure oscillations of the individual bubbles, reducing the number of “confusing echoes” that can interfere with the quality of the resulting geophysical images.

An array is typically 10 by 15 m (33 by 49 ft) (or more) for the purpose of enabling the timing of air bubble releases from the different elements to produce a downward beam of the lower frequencies most useful to seismic surveys (usually between 2 and 250 hertz). Actual maximum source levels of arrays in the direction of the downward beam are generally 10 to 20 dB lower than the theoretical source levels predicted by the number of elements alone, and even lower in the more horizontal or lateral aspects where the additive effect from the individual elements is even less. The actual source levels will be lower because the contributions of acoustic energy from each individual element attenuate before joining the pressure pulses from other elements in the array. A significant amount of attenuation occurs over very short separation distances between elements. As the distance from the source doubles, the sound pressure level halves (think of the sound from an individual element radiating in all directions and getting thinner and thinner, like the skin of a balloon as it is inflated). The dimensions of the source array can have more influence on the resultant output than the number of elements in the array, with output dependent on the way the elements are laid out in the source array. Increasing the number of elements in the array is done primarily to remove unwanted components such as "bubble trains" that reduce the clarity of the resulting returns from the rock layers below, as well as providing directionality. Significantly reducing the number of elements in an array will, therefore, be undesirable from the perspective of the resultant seismic data quality.

In the horizontal or lateral direction, the interaction between the elements is complex, depending on their alignment in space and time. Since the elements are activated to achieve maximum coherence downward, there will be much less coherence in other directions, typically 15 to 30 dB less peak pressure and less suppression of bubble oscillations.

1.8 Summary

An examination of the aspects of a seismic array that can be adjusted demonstrates the following:

(1) the total volume of an array does not have a major influence on the source level of the array because the source level is proportional to the cube root of the volume;

(2) the design of any specific array has to account for acoustic response to specific subsurface geological variations, survey target depths, and length of receivers (offsets) to illuminate geologic anomalies;

(3) the main influences on the source level of an array are not the volumes but

(a) the operating pressure in which there is not much scope for variation;

(b) the number of elements in an array;

(i) the reason for multiple elements is mainly to attenuate the bubble train that is the characteristic of single elements and to maximize output in the downward looking signal. (Multiple elements boost the nominal source level of the primary pulse but still fall 10 to 30 dB peak short of the theoretical maximum predicted by the number and size of the elements alone, due to the spatial separation of array elements.); and

(c) the dimensions of the array (or separation distances of the elements within the array), which is part of achieving the signal from the multiple elements as described above.

1.9 CONCLUSIONS

- There is minimal scope for reducing the source level of an acoustic array by modifying the operating pressure or the total air volume of the array. Changing the source level by modifying the number of elements or the dimensions of the array would result in an undesirable accentuation of high frequencies and would compromise the quality of seismic data with a loss of low frequencies. A goal of achieving reductions in horizontally propagated sound will need to take into account the contributions of the environment in propagating the array output. The array is designed to optimize a relatively short down and back propagation through water and many layers of rock of varying thickness and density. Alterations of that design to achieve reduced lateral propagation will be difficult and will most certainly reduce image quality. A solution that might produce marginal decreases in laterally propagated energy, at best, in one area would likely not work under different ocean conditions, a different geology below, or different depth profiles across the track lines, to highlight only a few of the environmental variables that can affect propagation of sound through the water column.

- The idea of a simple set of standards for a universal solution to limit or reduce array output without loss of data quality and that would yield any measureable benefit to the marine environment is impracticable and not supported by current best available scientific data. A regulatory attempt to establish standards and/or metrics would not be practical or even feasible.

- The panel has determined that it would not be reasonable or practicable to develop metrics.

2 DUPLICATIVE PANEL REPORT

Submitted by Duplicative Seismic Survey Panel (8/12/2016)

2.1 INTRODUCTION

The Natural Resource Defense Council, Inc. et al., as Plaintiffs in a lawsuit against the U.S. Department of the Interior as Defendant, have expressed concern that certain marine offshore areas have been repeatedly subjected to unnecessary seismic surveys and that these surveys contribute to chronic and unwarranted noise that may have physical and behavioral effects on marine mammal populations. As per condition **VII.A., the "Order Granting Joint Motion for Approval of Settlement Agreement and Stay of Proceedings"** (June 24, 2013), BOEM agreed to convene an internal expert panel to determine whether it would be feasible to develop standards to determine whether a deep-penetration seismic survey, as defined in the Agreement, is unnecessarily duplicative. The panel has determined that it would be feasible to develop these standards prior to development of a Programmatic EIS and that BOEM will include and evaluate these standards in the Programmatic EIS.

2.2 INTERNAL EXPERT PANEL

The internal BOEM Panel who formulated the document consisted of the following personnel:

Tamara S. Arzt, J.D, M.P.A. is an Environmental Protection Specialist and the Endangered Species Act Lead for BOEM's Headquarters. She has worked for BOEM since 2011. Ms. Arzt received her B.A. from Smith College with a major in Government and her M.P.A from the University of Massachusetts, Amherst with a specific focus on environmental policy and endangered species. Ms. Arzt then worked for an alternative dispute resolution firm in Boulder, Colorado, where she focused on resolving multiple Federal environmental issues. In 2003, Ms. Arzt received her J.D. from Vermont Law School concentrating on environmental law. Upon graduation, she was accepted into the Presidential Management Fellowship program and worked for the Bureau of Land Management with the U.S. Department of the Interior in Washington, DC and Colorado. Ms. Arzt continued her career in public service, working for county and municipal government on the Northfork of Long Island, New York, with a continued emphasis on the environment, in particular coastal and wetlands issues. In addition to being the Endangered Species Act Lead in BOEM's Headquarters' Office, Ms. Arzt works extensively with Marine Mammal Protection Act and National Environmental Policy Act, as well as Coastal Zone Management Act and National Historic Preservation Act, issues associated with both traditional and renewable energy development on the OCS.

Ronald (Ron) Brinkman currently serves as BOEM's Senior Staff Geophysicist for the Gulf of Mexico OCS Region's Office of Resource Evaluation. He has worked as a geophysical interpreter, permitting and acquisition specialist, and geophysical subject-matter expert in the preparation of the Atlantic and Gulf of Mexico Geological and Geophysical Programmatic EISs, as well as subject-matter advisor to the OKEANOS and CETSOUND working groups. Ron has B.S. degrees in Mathematics and Geology from the Louisiana State University (New Orleans) and has been employed with the U.S. Department of the Interior for over 39 years. He has been an active member of the Society of Exploration Geophysicists since 1992.

Ty Collins is a Geophysicist at in BOEM's Gulf of Mexico OCS Region's Office of Resource Evaluation. Prior to working at BOEM, he worked in commercial geophysical survey acquisition in the United States' OCS, including the Gulf of Mexico, Beaufort Sea, and Chukchi Sea. He has experience in commercial survey design, acquisition, processing, and interpretation of geophysical data. At BOEM, Mr. Collins interprets geophysical and geological data to evaluate the "fair market value" of lease blocks related to OCS lease sales. Mr. Collins holds a Professional Geoscientist License from the Louisiana Board of Professional Geoscientists and a B.S. degree in Geophysics from the University of New Orleans. He is a graduate of the Daniel J. Tearpock Geoscience Certification Program and is an active member of the Society of Exploration Geophysicists.

John Johnson is a supervisory geologist with the BOEM's Gulf of Mexico OCS Region in New Orleans, Louisiana. He received his B.S. and M.S. degrees in Geology from the University of Florida prior to starting work as a geologist with the USGS' Conservation Division (the predecessor of MMS) in 1981. Mr. Johnson evaluated offshore lease prospects for fair market value determination for over 15 years and served as Staff Geologist. Since 2007, he has been supervisor of BOEM's Gulf of Mexico OCS Region, Office of Resource Evaluation's Data Acquisition and Special Projects Unit. This group is responsible for G&G permitting in the Gulf of Mexico and for the purchasing, loading, and managing (including archiving and public release) of digital seismic data for the GOMR.

Stanley (Stan) Labak works in BOEM's Division of Environmental Science in Sterling, Virginia. Mr. Labak has been with BOEM for about 3 years, where he is a Physical Scientist (Marine Acoustician) in the Physical & Chemical Sciences Branch. His specific areas of experience and expertise include modeling, analysis, and evaluation of underwater acoustic source and propagation, especially with regards to its potential impact to marine species. Stan received his B.S. in Ocean Engineering at the U.S. Naval Academy and his M.S. in Ocean Engineering at the Massachusetts Institute of Technology, where he was a Draper Fellow. He is a retired Naval Reservist.

Gary Watkins is a staff geophysicist for BOEM's Gulf of Mexico OCS Region's Geology and Geophysics Section in New Orleans, Louisiana. He received his

Bachelor of Geophysical Engineering (1971), Masters of Science Geophysics (1982) degrees from Colorado School of Mines. After a 5-year tour as an officer with the U.S. Navy, he worked with the Seismograph Service Company in Denver, Colorado (1977); Energy Reserves Group in Denver, Colorado (1981); Union Oil of California in Midland, Texas (1983) and Lafayette, Louisiana (1987); Kansas Department of Health and Environment Bureau of Remediation in Topeka, Kansas (1993); and MMS (BOEM's predecessor) in New Orleans, Louisiana (1997). With BOEM, Mr. Watkins has evaluated offshore lease prospects for fair market value determination for over 19 years and has served as the Geology and Geophysics Section's staff geophysicist since 2008.

2.3 SUBJECT-MATTER EXPERTS

The Panel would also like to knowledge and thank the following subject-matter experts who, while not official Panel Members, contributed their individual expertise in the document's development:

Victoria Cornish is Energy Policy Analyst for the Marine Mammal Commission, an independent U.S. Government agency located in Bethesda, Maryland. At the Commission, Ms. Cornish is focused on the effects of offshore oil and gas and renewable energy activities on marine mammals and their environment, as well as the enhancement of policies and programs to better understand and minimize those effects. Ms. Cornish holds a B.S. in Biology from the University of California at San Diego and an M.S. in Biological Oceanography from the University of Miami. Prior to joining the Commission, Ms. Cornish worked for the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (1991-2007) and for Ocean Conservancy, a not-for-profit environmental organization (2007-2010).

Detlef Ross is a Geophysical Advisor at Petroleum Geo-Services, Inc., located in Houston, Texas. He received his Pre-Diploma (equal B.S.) in Physical Oceanography and Diploma (M.S.) in Geophysics from the University of Kiel, Germany, prior to starting work for PGS Geophysical AS in Oslo, Norway, in 1998. Over the last 18 years, Mr. Ross has held various positions as a geophysicist, field engineer, supervisor, and project manager, working onshore and offshore. Since 2013, he has assumed the role of geophysical advisor.

We would also like to acknowledge special technical assistance provided to the panel by

Mr. Steven Fishburn who is the former Vice President GOM Multi-Client, Petroleum Geo-Services, Inc.

2.4 ACKNOWLEDGEMENT

BOEM would also like to acknowledge and thank the following geophysical companies that have allowed us to display their data used in construction of the composite lines used in this report: Petroleum Geo-Services, Inc. (PGS), Compagnie Generale de Geophysique (CGG), and TGS Geophysical Company (TGS).

2.5 DEFINITION OF DUPLICATIVE SURVEY

The Panel agreed upon the following definition:

Duplicative Seismic Survey – A duplicative seismic survey is a deep-penetration geophysical survey, as defined in Section I.A. of the initial "Settlement" (Civil Action No. 2:10-cv-01882), whose acquisition parameters, design, technology, and geospatial surface location metrics make it essentially the same as an existing seismic survey. Acquisition parameters that should be considered in any duplicative characterization include, but are not limited to, the following: (1) survey geometry (surface orientation, line, and/or shot point orientation); (2) increase in azimuthal imaging for subsalt illumination; (3) source array composition, sequencing, and architecture; (4) spatial sampling and received frequency content; and (5) record length and sample rate.

Note: This definition excludes any reservoir monitoring, time-lapse (4-dimensional [4D]) surveys whose actual intent is to duplicate existing surveys as closely as possible for comparative purposes, any overlap of individual shot points that may occur as a result of resumption of acquisition after an interruption to any initial acquisition, and other survey types excluded in the initial Settlement Agreement.

2.6 BACKGROUND AND HISTORY OF SEISMIC SURVEYS

The collection of marine seismic exploration data in the U.S. began in the mid-1940s with dynamite used as the acoustic source. Subsequent to complaints from sport and commercial fishing that the use of dynamite killed too many fish, geophysical contractors began to use a slower detonating nitro-carbonitrate in marine shooting beginning in the early 1950s. At sea, seismic data collection required that these sources have the capability to be towed and activated at frequent, regular intervals in a series of high-energy releases, or in the industry vernacular, "shots." By the mid-1970s, the most common, reliable, and more environmentally friendly marine source became an acoustic "air gun." It was, and still is, essentially a steel container charged with high-pressure air from a towing vessel that releases the air rapidly through a portal to form a pressure pulse in the water column. The pressure wave produced by this air bubble is transmitted through the surrounding water before it penetrates the ocean bottom boundary and is subsequently reflected and refracted from geologic interfaces in the earth. The reflected signals from these interfaces then return to the water column where they are then recorded by receivers (hydrophones) positioned and towed by the source vessel or by nodal receivers (geophones) that have been geospatially positioned on the ocean bottom. Simplistically, the recorded velocity responses are then processed to provide the geophysical interpreter with a geological illumination of the subsurface.

This process was initially used in the collection of 2-dimensional (2D) data where data were acquired using a single vessel, single source array and one cable of towed receivers. Single lines of data or linear grids were used to create individual planar views that were then used by interpreters to "map" specific areas. In the early 1980s, the process evolved into 3-dimensional (3D) acquisition where the source vessel would tow multiple parallel cables of narrowly spaced receivers, called streamers, that allow for the acquisition of data volumes instead of lines. Technologically, this is analogous to a (3D) medical ultrasound versus a (2D) x-ray.

Coincident to the technological evolution, the architecture of the leasing program in the Gulf of Mexico changed from a process where specific company-nominated blocks were bid on for lease sales (until 1982) to one where the newly formed Minerals Management Service (MMS) offered for leasing all blocks that were not leased at the time of the lease sale. This transition occurred in 1982 and the new process became known as "areawide leasing," which still exists today. This became a seminal moment in the Gulf of Mexico multi-client, seismic acquisition industry in all U.S waters in that it allowed large areas of acreage to be acquired by single seismic contractors who would then license all or parts of those surveys to potential bidders.

The emphasis on deeper water surveys and the illumination of targets below subsurface salt structures deep in the earth led to further technological advances in the acquisition of 3D data. Multiple vessels with longer cables, coil geometry surveys, and increased computer capacities have contributed to the acquisition of wide-, rich-, and multi-azimuthal datasets to produce more robust subsalt geologic illumination.

In **Attachment 1**, we have included a list of geophysical terms with definitions and common abbreviations to refer to as part of the following discussion.

2.7 Environmental and Regulatory Concerns

The concern of noise in the oceans is a topic of recent discussions among marine scientists. Our Panel was tasked specifically to look at the feasibility to develop standards or metrics to determine whether any future proposed survey is unnecessarily duplicative to previous seismic data acquisition. This could have the effect to minimize or eliminate any unnecessary noise in the marine environment that could be chronically disruptive to marine mammals and other affected species in the marine environment.

There were discussions within the Panel regarding possible scenarios where geophysical contractors may collaborate on survey acquisition to acquire a single survey in specific areas rather than compete against each other in specific areas. It was felt that this is outside of the range of this Panel and that this could have other regulatory implications. While it was pointed out that exploration and production (E&P) companies in other countries have collaborated on acquisition projects, it should be noted that the leasing architecture in those countries do not allow for areawide leasing, as is currently prescribed in the United States' OCS areas, but are restricted to specific predefined areas only. Prior to OCS areawide leasing, these types of collective company acquisitions were conducted in U.S. waters and were called "group shoots." These acquisitions were limited to the specific companies who agreed to pool resources for that acquisition.

2.8 DATA AQUISITION

2.8.1 Differences between Multi-Client and Proprietary Data Acquisition

After the advance of areawide leasing, the prevalent business model of multi-client surveys evolved. It had the premise of multiple companies having access to the same geophysical contractor-acquired dataset,but allows any E&P company to have equal access to that data via a license to any or all data collected in that given survey. The geophysical contractors assume the risk of acquisition but retain the ownership of the data and sell licenses for data usage to multiple E&P companies to recoup their investment and make a profit.

Both 2D and 3D seismic exploration surveys are conducted by geophysical contractors either on a proprietary or non-exclusive (multi-client) basis. Proprietary surveys usually cover only a few blocks for an individual E&P client who would then retain the data and therefore would have exclusive use of it. In contrast, non-exclusive survey data are owned by the geophysical contractor, are generally collected over large multi-block areas, and are licensed to as many E&P clients as possible to recover costs and produce profits for the contractor. Because the survey data are not for the exclusive use of any one E&P client, the contractor's goal is to license the data to multiple E&P clients.

Geophysical contractors use proprietary, patented, trade-secret survey acquisition and data processing methods that make their surveys and data unique. While different surveys for different purposes may cover the same general area, these can be done over several years and represent technological shifts that produce better subsurface illumination in specific areas. Geophysical surveys, whether multi-client or proprietary, are temporary and transitory. Seismic source vessels are constantly in motion. The movement of both the vessel and the animals, coupled with the way sound energy decays with time and distance, results in short durations of exposure to sound from operations for marine animals. A survey is in any one location for about 3 minutes, covering 8 to 9 kilometers (5 to 6 miles) at 3 to 5 knots (4 to 6 miles per hour) in a 60-minute period).

Note: We have tried to highlight the differences between multi-client and proprietary surveys in **Attachment 2**.

2.8.2 Why Multi-Client Seismic Data?

Industry estimates of proven oil reserves have doubled since 1980 as a result of better 3D seismic imaging to pinpoint reservoirs, especially in deep water and below thick salt formations

(Aylor, 1997). As seismic acquisition technology and processing techniques continue to advance, geophysical companies often reacquire data over the same area in order to provide greater illumination of the subsurface for their geological evaluations. The technology and techniques of acquisition have improved over time, ultimately improving the illumination the subsurface structural features and giving E&P companies a clearer understanding of the subsurface geology by delineating reservoir boundaries and reducing risks to the E&P companies. Absent this technological advancement, the latest Gulf of Mexico subsalt deepwater discoveries would not have been possible and U.S. production offshore would have been stymied. The E&P companies want the latest and best seismic data to better evaluate prospective acreage prior to OCS lease sales and to substantiate their bid bonus to BOEM. BOEM also benefits from the latest seismic data, enabling BOEM to provide better resource estimates, better estimates for potential worst-case spill discharges, and to determine fair market value of the resources (i.e., oil and gas) when evaluating lease bids and bonuses.

The business model outlined makes use of collective economics by spreading the costs of data acquisition and processing over time among multiple E&P customers who desire to make use of the data. Under this model, the seismic contractor initiates and conducts projects of general industry interest at its own financial risk. Restricted non-transferable data user licenses are then sold to individual E&P companies for a fraction of the cost of acquiring and processing the entire dataset.

This business model also reduces the potential for multiple E&P companies to individually contract specific proprietary surveys to be collected on their behalf, many of which would be considered duplicative by our definition. However, the possibility still exists that a contractor, or E&P company, could attempt to re-survey a given geographic area using the same acquisition parameters.

2.9 Gulf of Mexico Seismic Acquisition Review – Mississippi Canyon Protraction Area

The Duplicative Survey Panel was asked to address the issue of previous overlapping surveys in the Gulf of Mexico (GOM) and their potential for historical seismic acquisition duplication. Recognizing the impractical nature of examining all datasets in the GOM, the Panel decided to focus on the Mississippi Canyon protraction area. This area was chosen for several reasons. First, there have been numerous major oil and gas discoveries over time in the Mississippi Canyon area, yielding an extensive GOM database where multiple datasets had been acquired over the years. Second, the 2002-2006 Sperm Whale Seismic Study managed by Texas A&M University, was conducted primarily near the 200-m (656-ft) isobath in the Mississippi Canyon area. Third, the well-documented *Deepwater Horizon* explosion at the *Macondo* well was also located within the Mississippi Canyon protraction area (i.e., Mississippi Canyon Block 252).

Panel members were able to discern four discrete "generations" of 3D seismic data. BOEM's geophysical interpreters created a composite 2D line from the 3D volumes for each of the four generations over approximately the same geospatial area to demonstrate the quality changes for each generation. The processing scheme used were Kirchhoff 3D prestack time-migrated versions, except for Generation 4, in which the prestack depth-migrated version was used (Note: No time-migrated versions were available; therefore, the vertical scale is in depth and not time).

In an attempt to further define the generations of surveys, the Panel members then looked at acquisition parameters that were available and captured those metrics in **Table L-1**. These parameters were evaluated for similarities and differences. The significant parameters with significant generational differences were azimuth (narrow or wide), streamer length (total length of towed receivers), record length (time to record seismic return after a shot occurred), shot point interval (spacing between source activation), nominal fold (number of recorded rays at a specific point), group interval (spacing of individual receivers on the towed cable), and processed cell size (the bin size from which traces are summed to create the fold). The differences in these acquisition parameter metrics appeared to correspond with the previously identified four generations of data quality.

The four generations of surveys shown in **Figure L-1** (“Generations 1-4 Composite 2D Seismic Lines Built from Multiple Company 3D Datasets”) are defined below.

- The first generation was acquired from 1992 to 1998. In this time period, seismic data acquired in the Mississippi Canyon area used a single vessel, narrow-azimuth (NAZ) methodology, with streamer lengths between 4,800 and 6,000 m (15,748 and 19,685 ft). These had a nominal fold of 48 to 60, record lengths 9 to 12 seconds in length, and a predominant bin size of 12.5 x 20 m (41 x 66 ft).
- The second generation was acquired from 1998 to 2002. The most noticeable change in acquisition was the increase in streamer length to between 7,200 and 8,000 m (232,622 and 26,246 ft). The increase in streamer length allowed for recovery of complexity in the seismic record lost using shorter streamer length. This allowed for an increase in fold to range from 57.6 to 64, but bin size remained the same.
- The third generation was acquired from 2003 to 2005. The main change was the acquisition of smaller group intervals that resulted in smaller bin sizes of approximately 6.25 x 20 m (20.5 x 66 ft). These smaller bin sizes allowed for better imagery in the processing of the data that was temporally complemented by greater storage capacity due to computer technology. This allowed for the increase of complex data used for the construction of subsalt velocity models.
- The fourth generation was acquired from 2004 to 2012. This acquisition method involved wide-azimuth (WAZ) technology that employed multiple source/receiver vessels using long cable offsets (7,000 to 8,100 m; 22,966 to 26,575 ft) and resulted in greater nominal fold. The end product of processing was portrayed in

depth (as opposed to time) since no time-migrated versions were produced by the contractors. These provided a huge increase in fold of 186 to 216.

Table L-1. Mississippi Canyon Seismic Surveys Acquisition Parameters

Type	Acquisition Date	Airgun Source (cu in)	Shotpoint Interval (m)	Streamer Length (m)	Record Length (s)	Nominal Fold	Group Interval (m)	Processed cell Size (M)
NAZ	1991	5400	40	4800	10	60	NA	26.6 x 26 13.3 x 26.6
NAZ	1993	3000	25	4800	9	48	NA	12.5 x 25
NAZ	1993	3000	25	4800	9	48	NA	26.6 x 26.6
NAZ	1995	4720	31.25	6000	10.5	48	25	12.5 x 20
NAZ	1996	5400	25	5200	9	52	NA	12.5 x 20
NAZ	1996	3000	25	6000	12	48	NA	12.5 x 20
NAZ	1997	3000	25	6000	12	48	NA	12.5 x 20
NAZ	1997	3000	25	6000	9	60	NA	12.5 x 20
NAZ	1998	8100	40	4800	10	60	NA	26.6 x 26 13.3 x 26.6
NAZ	1998	4720	31.25	6000	10.5	48	25	12.5 x 20
NAZ	1998	5580	50	6000	13	60	NA	12.5 x 20
NAZ	1999	5400	62.5	8000	12.288	64	25	12.5 x 20
NAZ	1999	5400	62.5	8000	12.288	64	25	12.5 x 20
NAZ	1999	5400	62.5	8000	12.288	64	25	12.5 x 20
NAZ	1999	4180/5400	31.25m - 62.5m	7200/8000	12.288	57.6/64	25	12.5 x 20 & 12.5 x 40
NAZ	1999	4180	75	7200	12.288	57.6	25	12.5 x 22.5
NAZ	1999	5400	62.5	8000	12.288	64	25	12.5 x 20
NAZ	2002	3960	37.5	8100	13	54	12.5	12.5 x 20
NAZ	2004	3040	62.5	8100	10	64	NA	12.5 x 12.5
NAZ	2002	5085	31.25	8000	12	64	12.5	6.25 x 25
NAZ	2002	5085	31.25	8000	12	64	12.5	6.25 x 25
NAZ	2002	3040	62.5	8100	13	64	12.5	12.5 x 12.5
NAZ	2003	5085	25	8000	12	80	12.5	6.25x20
OBC & NAZ	2003	3040 to 8475	62.5-75	9000	13	60-120 & 71-144	12.5 -50	6.25 x 40 & 25 x 40
WAZ	2009	8475	37.5	7000	14	186	12.5	6.25 x 60
WAZ	2009	10,170	42	7000	14	186	12.5	6.25 x 60
WAZ	2010	8475	37.5	7000	14	186	12.5	6.25 x 60
WAZ	2010	8475	37.5	7000	14	186	12.5	6.25 x 60
WAZ	2012	8475	37.5	8100	14	216	12.5 m	6.25 x 60

NA= Not Available

Generation 1 Generation 2 Generation 3 Generation 4

Source: Brinkman, official communication, 2016.

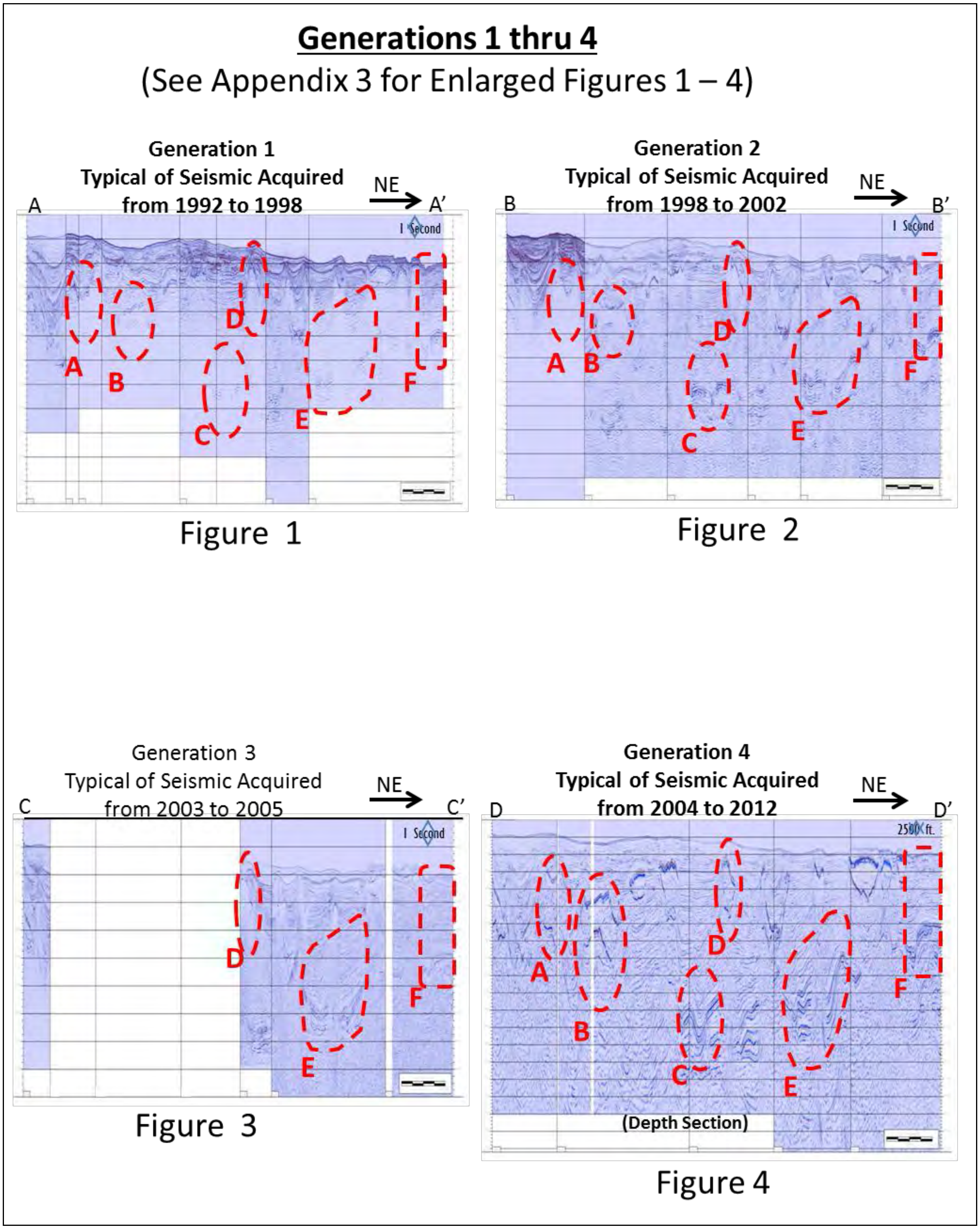

Figure L-1. Generations 1-4 Composite 2D Seismic Lines Built from Multiple Company 3D Datasets.

If these surveys with different acquisition technology would be considered duplicative, then they w ould have identical or no improvement in data quality. Using the four generations of seismic data, multi-survey traverses were constructed for each generation, with the data linearly constructed from the southwest to northeast corners of Mississippi Canyon and the construct matching geographically as close as possible (**Figure L-2**).

We have juxtaposed the four generations of data in **Figures 1-4 of Figure L-1** and have highlighted specific areas identified as Areas A-F to further analyze the improvements in data quality attributed to acquisition improvements. The first three-generational datasets were processed in the time domain (pre-stack time migration), while the fourth generation was in depth (pre-stack depth migration). There were no time datasets available in the construction of Generation 4 since the companies now go directly to depth with no intermediate step for time.

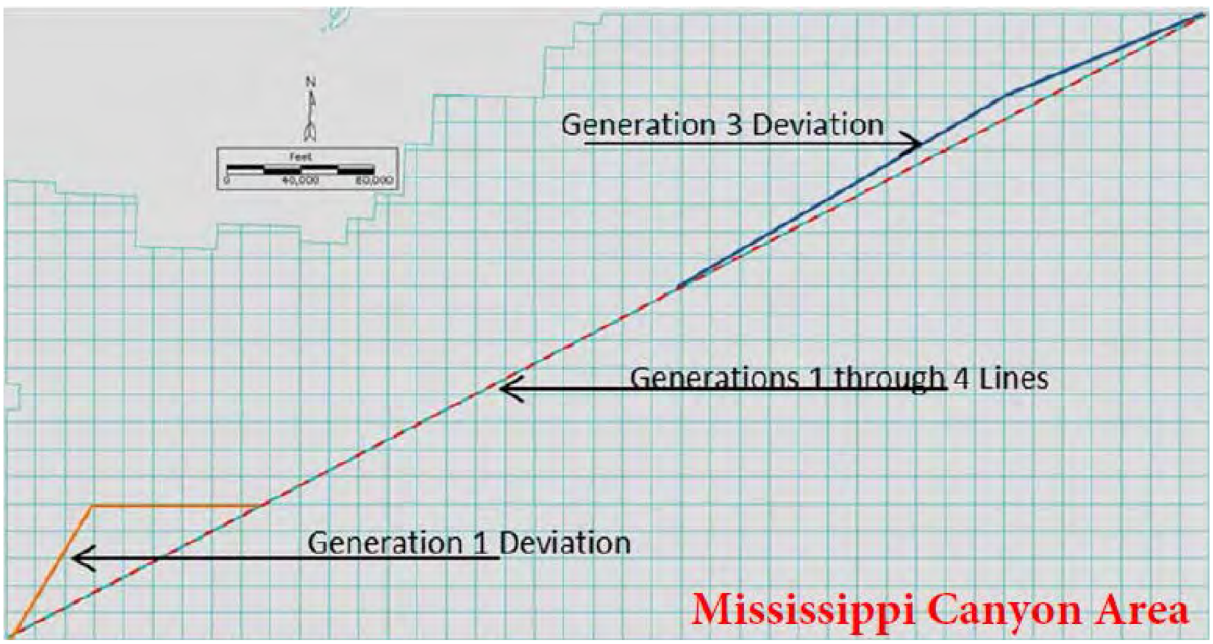

Figure L-2. Orientation of Traverse Lines for Generations 1 through 4 (USDOI, BOEM, 2016).

2.9.1 Comparison of the Generational Events in Highlighted Area A

A comparison of the generational events highlighted in Area A is shown in **Figure L-3**.

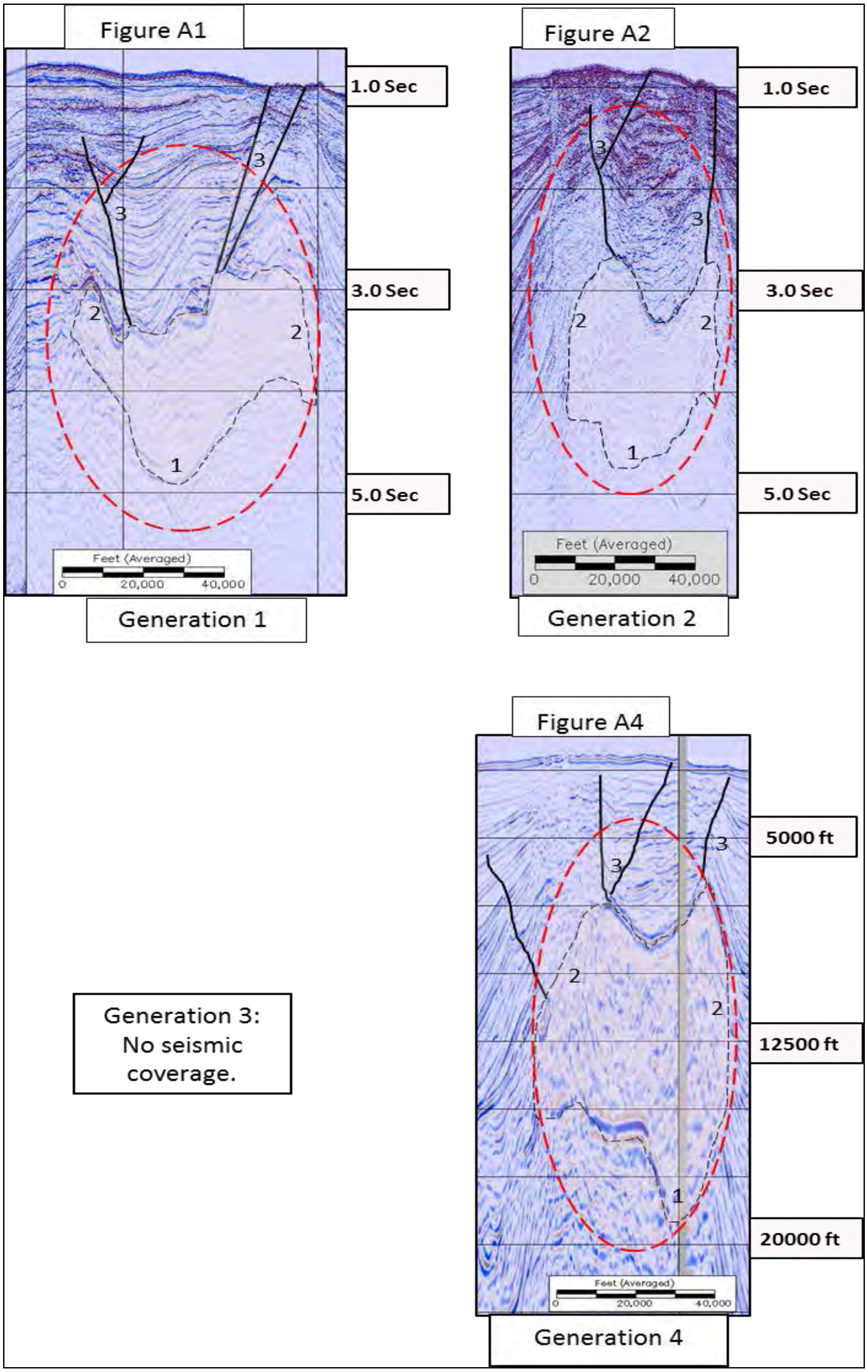

Figure L-3. Generational Comparison of Highlighted Area A.

Analysis of Improvements to Highlighted Area A

The dashed red circle areas of **Figures A1, A2, and A4 of Figure L-3** are an enlargement of the improved seismic data examples of Area A in **Figures 1, 2, and 4 of Figure L-1**. The examples are described below.

- The identification of salt bodies in deep seismic data is important as salt plays an important role in how oil and gas traps develop, especially along the base (1) and sides of salt (2),
- The identification of faults (3) in deep seismic data is critical not only to potentially trap oil and gas but to also identify shallow drilling hazards.

The improvements in the definition of the salt body and faults are attributed to longer offsets or streamer lengths, increased fold, and a change from NAZ to WAZ acquisition methods. Specific changes are described below.

- Streamer length was increased from 4,800 m (15,748 ft) (most commonly used from 1993 to 2000) for Generation 1 to 8,000 m (26,246 ft) (most commonly used from 2000 to 2005) for Generation 2. Generations 3 and 4 also mostly used 8,000-m (26,246-ft) streamer lengths. The reduction of maximum streamer lengths from Generation 3 is attributed to a change in azimuthal methodology.
- Fold was steadily increased from 48 (most common) for Generation 1 to 64 (most common) for Generations 2 and 3, and to 184 (most common) for Generation 4. The increase in fold contributed to more live traces contributing to a stacked trace, which in turn improved the imagery of and around the salt body.

The advancement in survey geometry and azimuthal (NAZ-WAZ) coverage from 1993 to 2014 allowed for more complex seismic ray paths not previously recorded to be captured, contributing to the increase of fold and number of subsurface image points.

2.9.2 Comparison of Generational Events in Highlighted Area B

A comparison of the generational events highlighted in Area B is shown in **Figure L-4**.

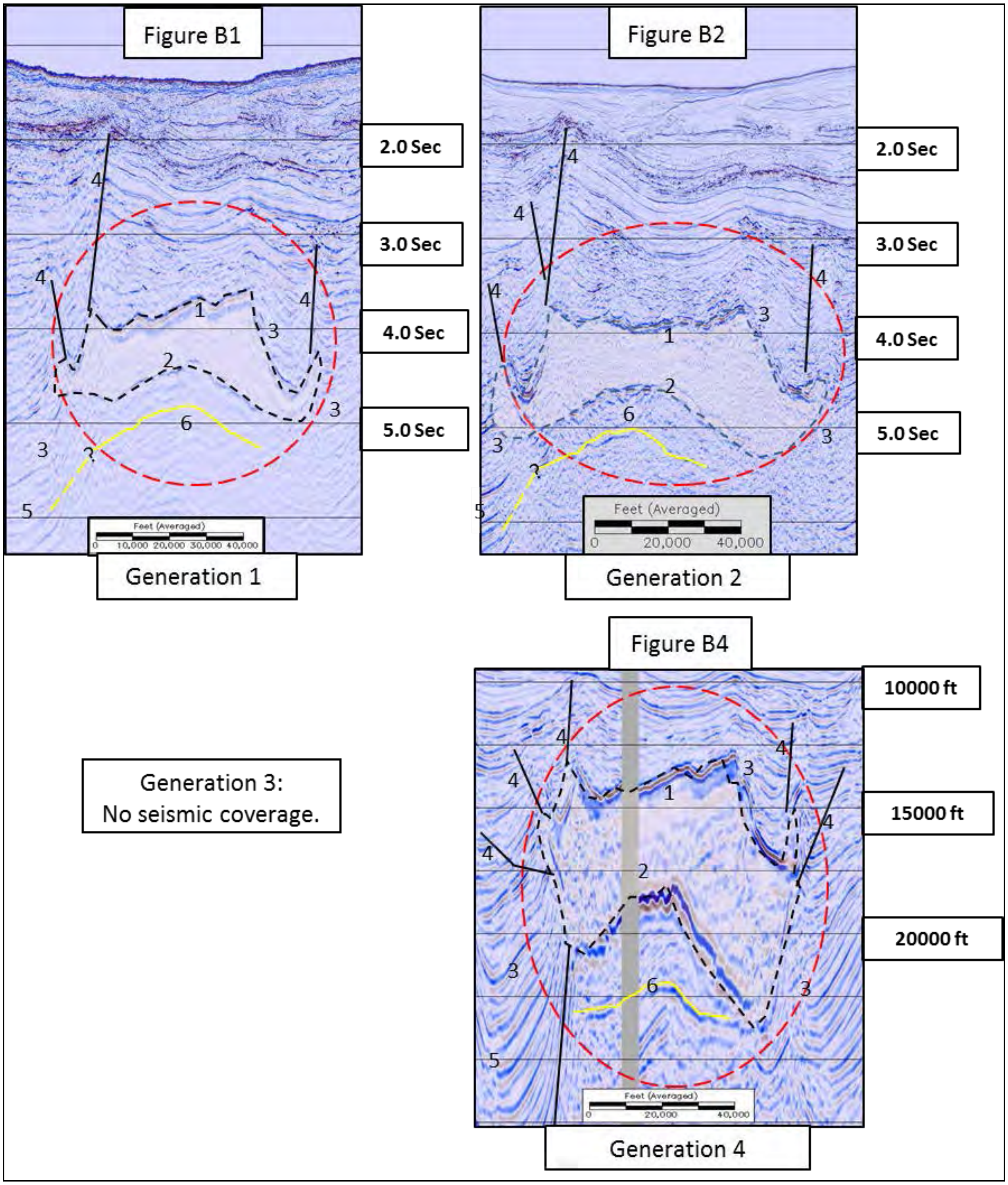

Figure L-4. Generational Comparison of Highlighted Area B.

Analysis of Improvements to Highlighted Area B

The dashed red circle areas of **Figures B1, B2, and B4 of Figure L-4** are an enlargement of the improved seismic data examples of Area B in **Figures 1, 2, and 4 of Figure L-1**. The examples are described below.

- The outlined salt body top (1) and base (2) of salt changed with each generation of seismic data. Reflector continuity on the side of salt (3) also improved with later generations of seismic data.
- Faults (4) are associated with the salt body, which potentially could cause a trap for oil and gas. The faults are similarly positioned in **Figures B1, B2, and B4 of Figure L-4**, but the ability to recognize faults improved with each generation of data.
- Along the left side of the salt body, **Figures B1 and B2 of Figure L-4** have reflectors with a gentle to low angle dip to the left (5); however, in **Figure B4 of Figure L-4**, the dip (5) is much steeper with a low spot developing before they start to rise steeply.
- Below the base of salt (2) is a seismic reflector with a downward arc (i.e., closure) appearance (6, the yellow highlight) and is suggestive of a potential oil trap. In **Figures B1 and B2 of Figure L-4**, this features could be extended farther to the left. In **Figure B4 of Figure L-4**, the arc ends against a salt weld (i.e., a salt weld is caused by the movement of salt, which leaves the sediments on top or sides against the sediments that were below the base of salt). **Figure B4 of Figure L-4** also has reflectors on the left of the salt weld, which dips steeply to the left; while on the right, the reflectors have a significantly less dip.

The improvements in the definition of the salt body, the improved recognition of faults, and clearer seismic reflectors along the side and below the salt body are attributed to longer offsets or streamer lengths, increased fold, a change to WAZ acquisition, and longer record lengths. Specific changes are described below.

- Like at Area A, the increase in streamer length from 4 800 to 8,000 m (15,748 to 26,246 ft) between generations allowed for complex seismic data ray paths from the source to the deep geologic beds and then back to the receiver cable to be captured.
- The steady increase in fold between the generations contributed to more seismic receiver data summed, which improved the imagery of and around the salt body.
- The advancement in survey geometry and azimuthal coverage between generations allowed for more complex seismic ray paths to be captured, which contribute to improved deep-subsurface imaging, especially below salt bodies.

2.9.3 Comparison of Generational Events in Highlighted Area C

A comparison of the generational events highlighted in Area C is shown in **Figure L-5**.

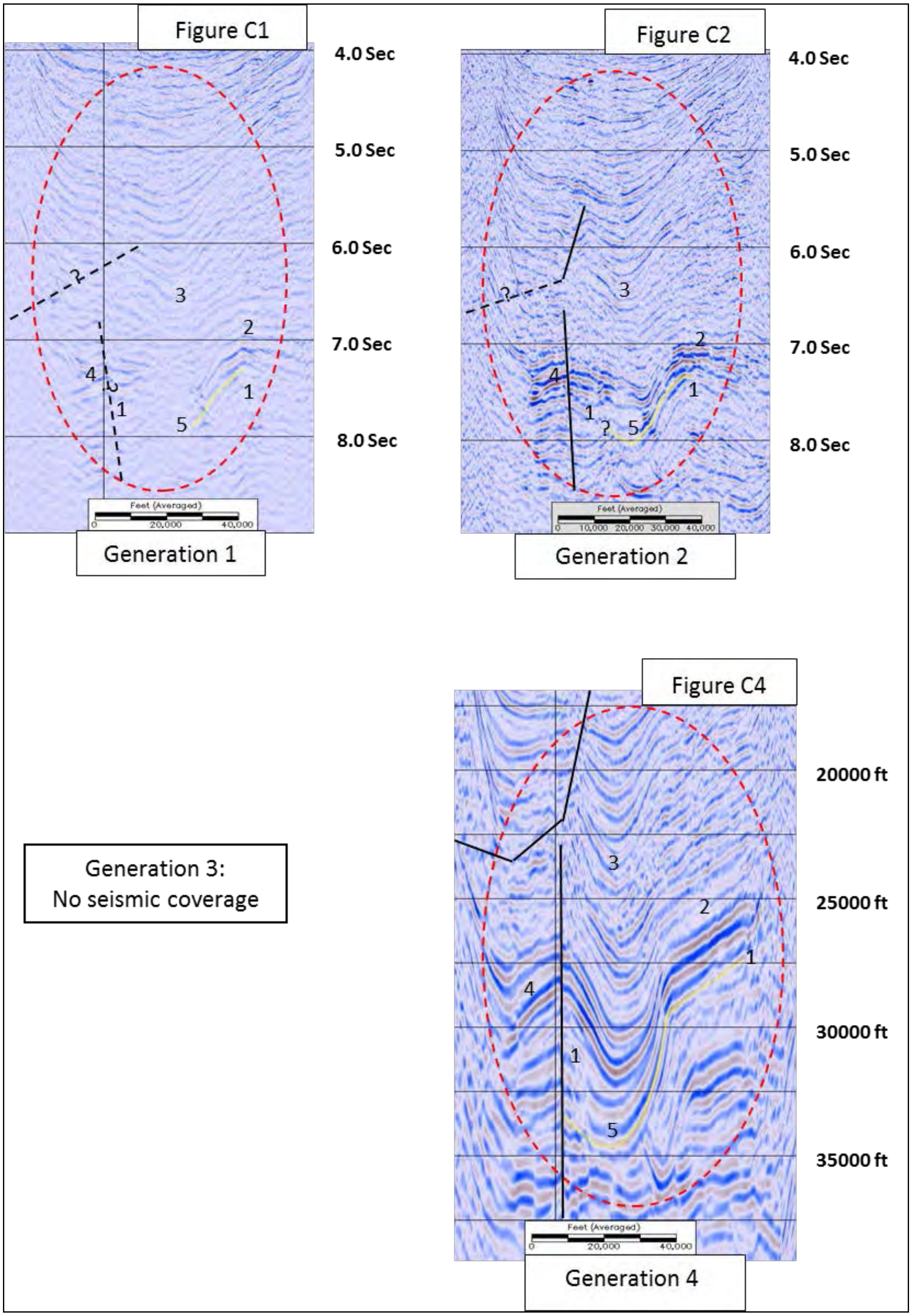

Figure L-5. Generational Comparison of Highlighted Area C.

Analysis of Improvements to Highlighted Area C

The dashed red circle areas of **Figures C1, C2, and C4 of Figure L-5** are an enlargement of the improved seismic data examples of Area C on **Figures 1, 2, and 4 of Figure L-1**. The examples are described below.

- In **Figures C1 and C2 of Figure L-5**, at about the “7.0 Sec” timeline (1) are a series of darker seismic reflectors that are easier to see. In addition, these reflectors are less broken up (i.e., more continuous). In **Figure C4 of Figure L-5**, these reflectors dip (2) from the right side of the figure into the center, but **Figures C1 and C2 of Figure L-5** do not have a similar dip.
- At about the “6.0 Sec” timeline, in the center of **Figures C1, C2, and C4 of Figure L-5**, is a low area (3) with dips by seismic reflectors on the left and right into the low area. The low area is better defined with each generation of seismic data.
- On **Figures C1 and C2 of Figure L-5**, on the left side of the previously noted low area (3) at about the “7.0 Sec” timeline, the seismic reflectors (4) have a predominate, gentle dip into the low area in the center of the figures, with just a slight suggestion of dip to the left; in **Figure C4 of Figure L-5**, the corresponding area (about 27,500 ft [8,382 m]) has reflectors with an obvious dip to the left and right.
- At about the “8.0 Sec” timeline in the center of **Figures C1 and C2 of Figure L-5** (5), the data are broken up within this deep low area (refer to the highlighted line); however, on **Figure C4 of Figure L-5**, the corresponding area no longer has reflectors that are broken up and hard to follow.

The improvements in the definition of the low area and deeper reflectors are attributed mainly to longer offsets or streamer lengths, increased fold, and longer record lengths. Specific changes were:

- As in previous areas, the increase in streamer length between generations has allowed for more complex seismic data ray paths from the source, to the deeper geologic beds, and reflected back to the surface where they are captured. This is especially critical for very deep seismic reflectors to be clearly displayed.
- The steady increase in fold between the generations contributed to more seismic receiver data summed within a specific area into one trace which improved how the data are displayed.
- The use of longer recording time or record length allowed for the deeper data to be captured. The capture of deeper data can enable a better understanding of why and where shallow oil and gas traps occur regionally by changes in the deeper geology.

2.9.4 Comparison of Generational Events in Highlighted Area D

A comparison of the generational events highlighted in Area D is shown in **Figure L-6**.

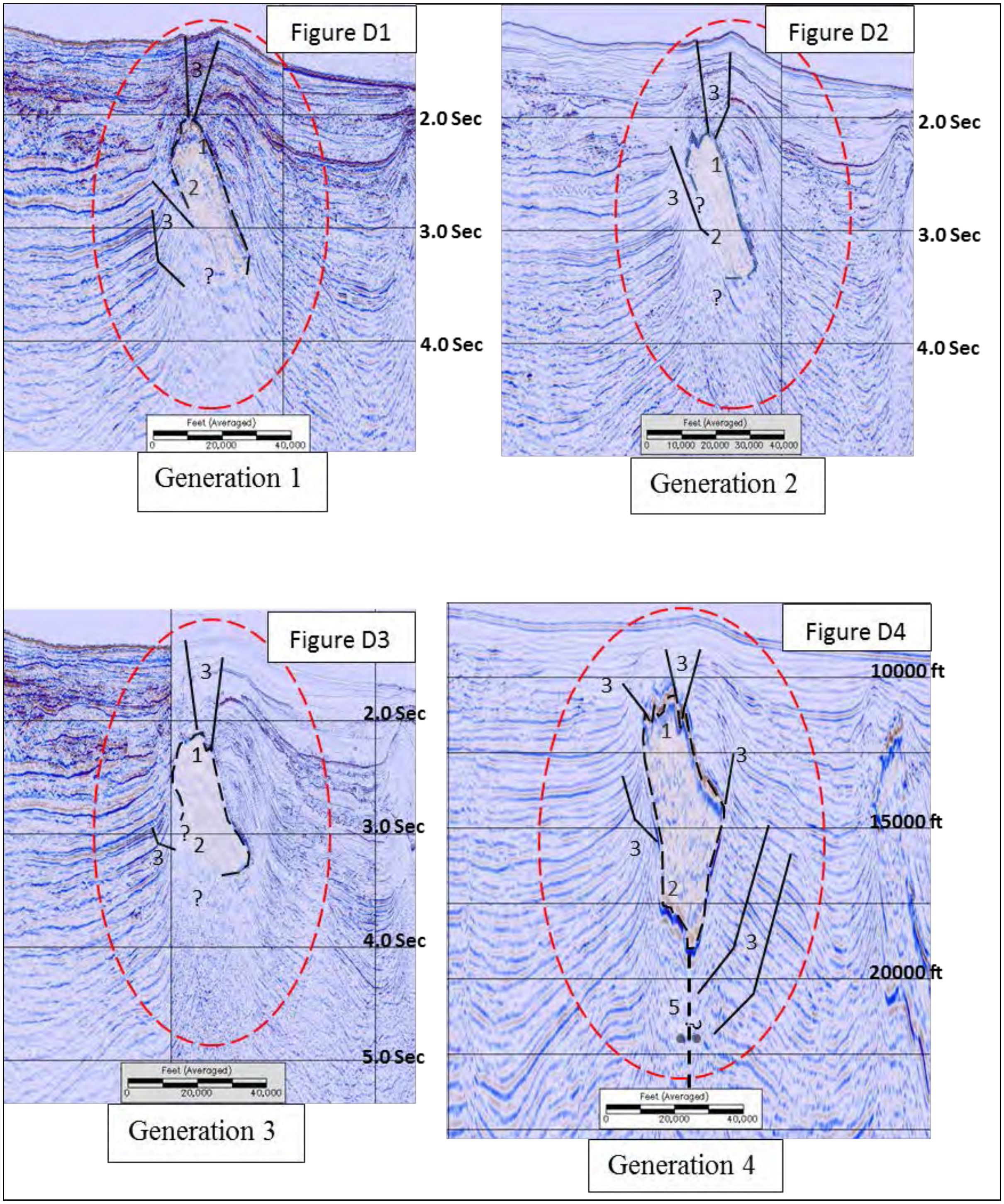

Figure L-6. Generational Comparison of Highlighted Area D.

Analysis of Improvements to Highlighted Area D

The dashed red circle areas of **Figures D1-D4 of Figure L-6** are an enlargement of the improved seismic data examples of Area D on **Figures 1-4 of Figure L-1**. The examples are described below.

- The salt body outlined top (1) and base (2) changed with each generation of seismic data, especially along the left side and base of salt. These two areas changed from no definable edge of salt to a clearer edge of salt. As noted in Area A, the ability to define where salt is located helps to identify the type and location of oil and gas traps. It is also important when designing a drilling program near salt.
- Associated with this salt body are several faults (3); however, the ability to identify the faults improve with each generation.
- The seismic data at the base of salt and below (about the "4.0 Sec" line) has no clear definition in **Figures D1-D3 of Figure L-6**. In these figures, the deeper seismic reflectors all dip away from this undefined area below salt, which imply the salt may extend deeper. In **Figure D4 of Figure L-6**, the area under the well-defined base of salt (5) has improved clarity and suggests the existence of a vertical salt weld (i.e., a vertical salt weld is an area where salt has evacuated upward. As the salt moved up, the sediments on opposite sides collapsed inward against each other to form a vertical weld. It is represented by the vertical dash line with two black circles on either side. Identification of vertical salt welds allow for larger, older fault systems to occur, which have the potential to have deep oil and gas traps away from the salt body. Two such cases are the faults between 15,000 and 20,000 ft (4,572 and 6,096 m) located on the right of the salt weld.

The improvements in the definition of the salt body's left side and base, as well as the deeper seismic data below the base of salt, are attributed mainly to the larger air gun source used in Generation 4, an increase in fold, and longer record lengths. Specific changes are described below.

- The increase in fold was due to a combined reduction in shot point interval, receiver group intervals, and the processed cell size. The smaller shot and receiver intervals allowed for more data to be recorded, which allowed for seismic processing to have more data in which to enhance the clarity of the deeper geology.
- The larger source size employed in Generation 4 allowed for greater energy to be returned from the deeper geologic beds. This in turn enhanced the seismic reflections above the background noise recorded in the acquisition program.

2.9.5 Comparison of Generational Events in Highlighted Area E

A comparison of the generational events highlighted in Area E is shown in **Figure L-7**.

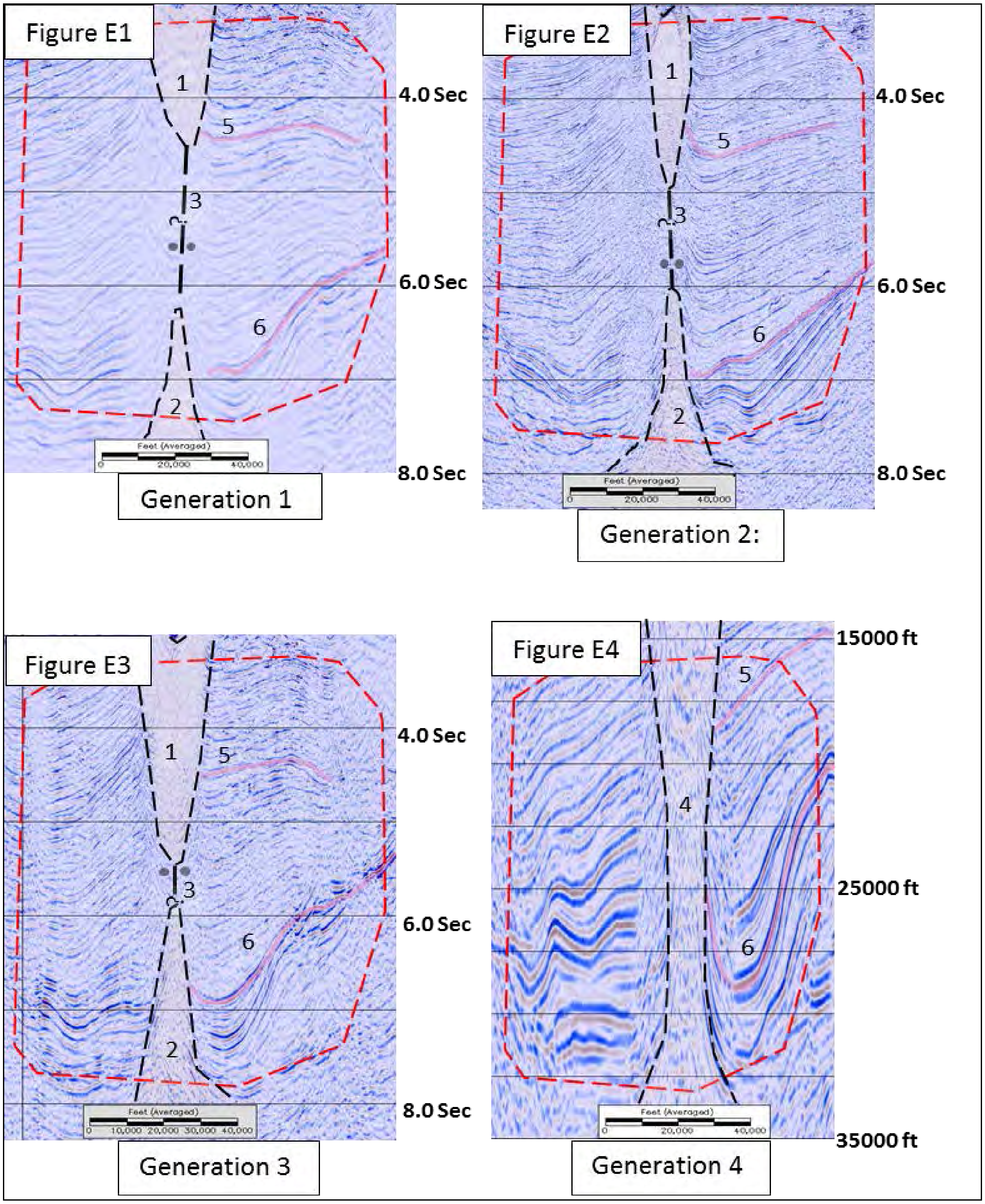

Figure L-7. Generational Comparison of Highlighted Area E.

Analysis of Improvements to Highlighted Area E

The dashed red circle areas of **Figures E1-E4 of Figure L-7** are an enlargement of the improved seismic data examples of Area E on **Figures 1-4 of Figure L-1**. The examples are described below.

- Within Area E is a salt body whose size changes with each generation of seismic data. **Figure E1 of Figure L-7** suggests the salt is divided into a top (1) and bottom (2) segment with a vertical weld (3) in between. **Figures E2 and E3 of Figure L-7** are similar to **Figure E1 of Figure L-7**, but the two salt segments appear to be closer. **Figure E4** suggests a continuous narrow salt column (4) is present to the deeper portion of the data. Knowing if a salt body or a salt weld is present is beneficial because a salt body will always trap oil and gas while a salt weld may not.
- On the right side of **Figures E1-E4 of Figure L-7** are two colored (red) seismic reflectors, one shallow and one deep. The shallow reflector (5) shows a change from a dip to the left (into the salt column) and right in **Figure E1 of Figure L-7**. In **Figure E2 of Figure L-7**, the reflector has mainly left dip into salt. **Figure E3 of Figure L-7** has the shallow reflector with dip to the left and right, but the dips are gentler. However, in **Figure E4 of Figure L-7**, the shallow reflector has just a steep left dip into salt.
- The second, deeper seismic reflector (6) on the right side has a left dip into the deeper portion of the salt column; however, the steepness of the dip changes with each generation. Additionally, the display clarity of the reflector changes between generations, with **Figure E4 of Figure L-7** the easiest display to follow the reflector.

The improvements in the definition of the salt's outline, as well as changes in the dip of seismic reflectors, are attributed mainly to an increase in fold, streamer length, and record. Specific changes are described below.

- The increase in fold was due to a combined reduction in shot point interval, receiver group intervals, and the processed cell size. The smaller shot and receiver intervals allowed for more data to be recorded, which allowed for seismic processing to have more data in which to enhance the clarity of the deeper geology.
- The increase in streamer length, combined with longer records, allows for deeper reflected seismic energies to be captured by the surface receivers. Without the capture of deeper data, the inaccurate interpretation of the critical structures, such as the salt body in **Figures E1-E4 of Figure L-7**, can cause a wrong geologic interpretation that could result in a poorly planned well and/or needless drilled well.

2.9.6 Comparison of Generational Events in Highlighted Area F

A comparison of the generational events highlighted in Area F is shown in **Figure L-8**.

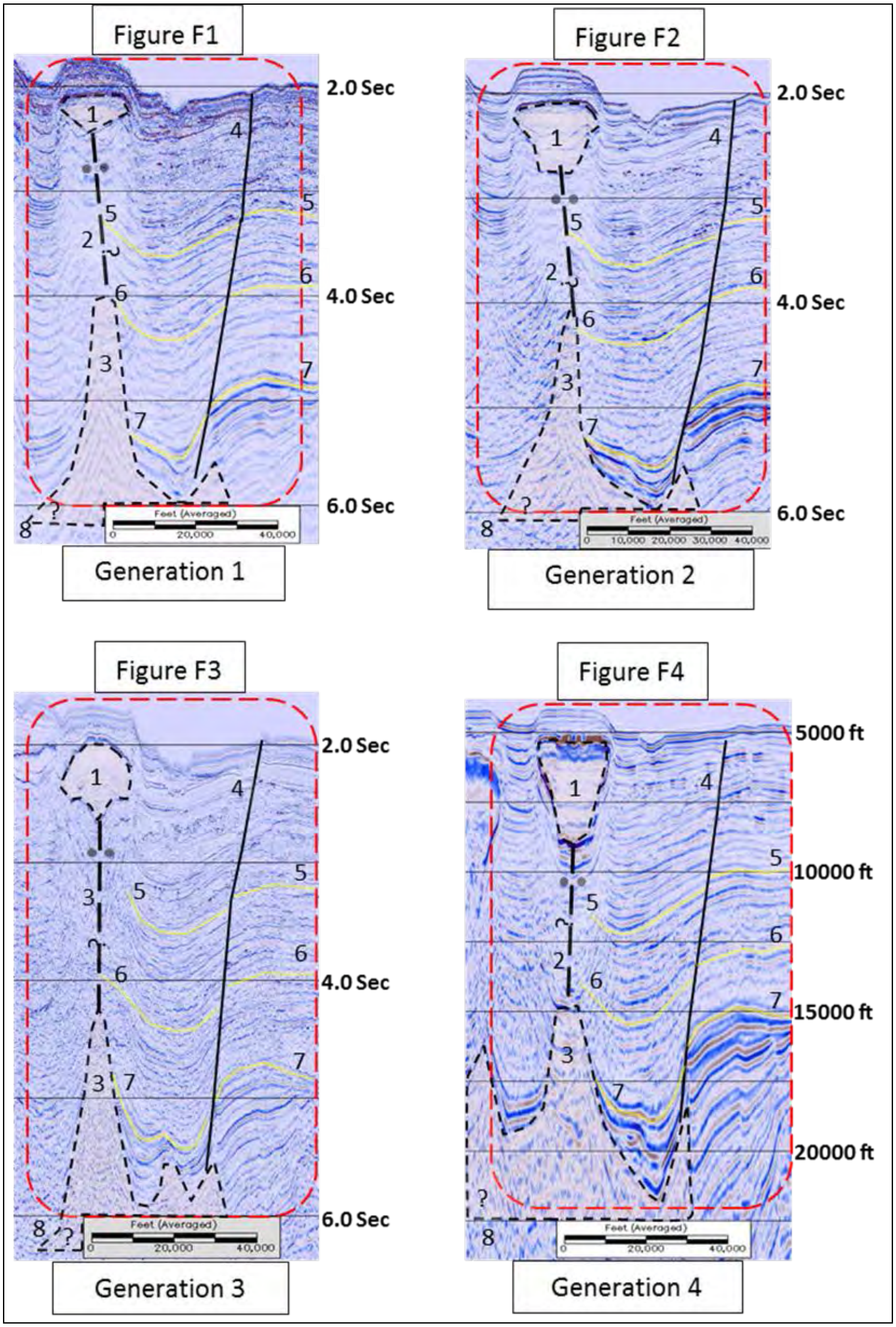

Figure L-8. Generational Comparison of Highlighted Area F.

Analysis of Improvements to Highlighted Area F

The dashed red circle areas of **Figures F1-F4 of Figure L-8** are an enlargement of the improved seismic data examples of Area F on **Figures 1, 2, and 4 of Figure L-1**. The examples are described below.

- At the top left is a shallow salt body (1) on **Figures F1-F4 of Figure L-8** whose base is attached to a salt weld (2), which is attached to the top of a deeper salt body (3). The shape and size of the upper salt (1) and lower salt (3) changed with each generation, but its presence did not change. The clarity of this area did increase somewhat with each generation.
- On the right side of **Figures F1-F4 of Figure L-8** is a fault (4) that extends from the “2.0 Sec/5000 ft” markers to the top of the deeper salt near “6.0 Sec/20,000 ft.” markers. This fault was most likely created by geologic forces as the deeper salt (3) flowed upward. The removal of salt caused a lower area to develop, which allowed more sediment (seismic markers 5, 6, and 7) to be deposited into the low. These types of low areas typically have greater amounts of sand deposited within them. In these figures, the seismic reflectors (5, 6, and 7) all climb up to and end at the salt weld (2), which suggests any deposited sands would do the same and provides for the potential of oil and gas to be trapped. The clarity of these reflectors, as well as the salt weld, improved with each generation.
- In the bottom right (8) of **Figures F1-F4 of Figure L-8**, the lower salt body (3) base is not imaged at all. The full-scale displays of Area F on **Figures 1-4 of Attachment 3** show seismic data below Area F to be poor to the bottom of **Figure 4 of Attachment 3**. Current belief is that this deeper area should be approximately equivalent geologically to oil- and gas-producing intervals onshore in Mississippi and Alabama; however, current seismic data clarity is not good enough to determine if the potential exists for this producing interval to extend into Area F or beyond.

The improvements in the definition of the location of salt are attributed streamer length, airgun source, and fold; however, the lack of clarity of extremely deep seismic reflectors is attributed to insufficient streamer length, array geometry, and fold. Specific acquisition elements that impacted seismic data in Area F are described below.

- The increase of streamer length allowed for greater clarity of the deeper seismic reflectors and top of the lower salt. Generation 4, **Figure F4 of Attachment 3**, has the best display clarity of the deeper portion of the seismic data.
- The decrease in shot point and group intervals, along with a decrease in cell size, cause greater detail clarity in the shallow portion (2.0 to 4 seconds and 5,000 to 10,000 ft [1,524 and 3,048 m). As these elements were decreased in

size, it allowed for thinner geologic beds to be imaged (i.e., an increase in shallow seismic frequency content). Increased shallow geologic detail allows for greater identification of shallow drilling hazards and shallow gas traps.

- The increase in fold was due to greater streamer lengths combined with and increase in airgun energy and a decrease in group intervals. It allowed for seismic processing to improve display clarity of seismic reflectors below and adjacent to the shallow salt and salt weld. The increase in fold also improved the strength and clarity of seismic reflectors away from salt and greater confidence in placement of the fault.
- While the seismic reflectors in Area F improved with each generation of seismic data acquisition, one area did not improve enough that the data can be used for any geologic evaluation. This was the area at the base of the deep salt body (3). The data below the outlined salt is useless and to obtain useable seismic data will require changes to the acquisition parameters used in **Figures F1-F4 of Figure L-8**. Should petroleum companies want to look at the deeper geology, the most likely improvement necessary could be longer streamer lengths, increased fold, and possibly shorter group intervals. It will also probably require new instrumentation, such as hydrophones, as well as new array methods/design for both the source and receivers.

2.10 Overall Analysis

The six areas outlined in **Figures 1-4 of Attachment 3** demonstrated improved subsurface imagery with advances in acquisition methodology and technical advancement. From this observation, it is implied that, at least within the Mississippi Canyon protraction area, spatially duplicative 3D time or depth surveys have occurred, but the surveys cannot be considered as duplicative with the improved subsurface imagery. The improved subsurface images can be contributed to a few acquisition parameters that also allowed for the improved processing of complex seismic ray paths to identify, enhance, and image deep subsurface seismic data of geologic structures.

The earlier acquisition did not provide adequate subsalt imagery to fully define the flanks and base of the shallow salt bodies. The use of NAZ, combined with the shorter streamer lengths (offsets) and record lengths, reduced the fold of the data that hurt imaging of the subsurface. The importance of longer offsets and fold is well documented within geophysical literature. Rekdal and Long (2006) noted, “Longer offsets may benefit imaging quality of very deep targets.”.

The lower fold also contributed to a lower signal-to-noise ratio (S/N), which reduced the continuity of the salt’s surrounding reflectors. A high S/N ratio impacts the seismic imaging. Hegna et al. (2001) commented, “Fold is one of the most important parameter that is evaluated. If the area suffers from low S/N, high fold is desirable in order to improve the data quality.” **Table L-2** shows that the increase in fold from Generation 1 to Generation 4 is manifested in the improved imagery of

Areas A-F in **Figures 1-4 of Attachment 3**. An increase in fold is achieved by a reduction in the shot and/or receiver intervals or by an increase in streamer length, but it is not the only method available to increase the S/N to improve imagery of the subsurface. Other parameters to consider are areal shape/orientation of shot and/or receiver array.

The change in areal shape/orientation of shot or receiver array allows for areas within the subsurface to have more traces to image a specific area that would otherwise be lost to due complex ray paths of the returned energy to the hydrophones. The complex ray paths were caused by abrupt changes in shallow and intermediate salt body thicknesses, combined with complex geologic structures above and below the salt. Brice et al. (2013) commented, "In the presence of complex geology, ray bending can leave portions of the subsurface untouched by seismic waves when only a narrow range of source-receiver azimuths (NAZ) is recorded. Attempts to solve this problem have led to the development of wide-azimuth (WAZ), rich-azimuth (RAZ), full-azimuth (FAZ), and multi-azimuth (MAZ) acquisition configurations." The use of different acquisition methodology of NAZ, WAZ, MAZ, RAZ, and FAZ (refer to **Chapter 2.12**, "Acquisition Geometry Advances," below) provides improved event continuity, higher S/N, and improved imagery of surfaces above and below salt bodies, as well as the salt itself. This is demonstrated in **Figures 1-4 of Attachment 3** by Areas A-F with WAZ acquisition geometry.

The apparent significant acquisition parameters are shown below in **Table L-2**. **Table L-2** also shows that, as the group interval decreased, air gun source increased, and record length increased, the fold increased. As observed in **Figures 1-4 of Attachment 3** and **Figures L-3 through L-8** for Areas A-F, as the fold increased, the imagery quality also increased. Each of the parameters played a part in the improved imagery singly or in tandem with other parameter changes. The Panel also acknowledges that these are currently significant parameters in data acquisition. However, as technology changes, so may the emphasis of other parameters that may contribute to future significant data quality.

Table L-2. Summary of Significant Parameters

Generation	Type	Streamer Length (meter)	Airgun Source (cu in)	Shotpoint Interval (meter)	Record Length (seconds)	Nominal Fold	Group Interval (meter)
1	NAZ	4800-6000	3000-5400	25-40	9 to 12	48 to 60	25
2	NAZ	6000-8100	3960-5580	31.25-75	12.8 to 13	57.6-64	12.5-25
3	NAZ & OBC	8000-9000	3040-8475	25-62.5	10 to 13	64 to 144	12.5-50
4	WAZ	7000-8100	8475-10170	37.5-42	14	186-216	12.5

Source: Brinkman, official communication, 2016.

2.11 Geophysical Hardware Advancements

The geophysical industry continuously undertakes research to develop new hardware in an attempt to improve the sub-surface seismic imagery. These proprietary accomplishments allow for the seismic service companies to hold a competitive advantage over their competitors and foster further research as competitors attempt to gain the competitive edge. Below is a partial list of streamer technology advancements literature dated from 2005 to 2013. The list emphasizes the effort seismic contractors and hardware manufacturers put into research and development.

- Hoogeveen et al. (2005) discuss the use of the solid streamer by PGS to overcome the unwanted low-frequency noise bursts caused by swell noise.
- Tenghamn et al. (2007) discuss dual-sensor streamers by PGS to eliminate spectral notches caused by ghost reflections at the receivers. Dual sensors also allow for increased flexibility in streamer towing depth to permit continued recording in rough seas and increase the potential bandwidth of the data.
- Proprietary hardware advancements have allowed geophysical service companies to collect seismic data that are unique and not replicated by any of their competitors.

2.12 ACQUISITION GEOMETRY ADVANCEMENTS

Figure L-9 shows the progression and differences in 3D marine seismic acquisition in areas of sub-salt illumination. Narrow-azimuth (conventional NAZ) seismic acquisition shows how a single vessel acquires a volume of data by towing multiple streamers. Multi-azimuth (MAZ) consists of several acquisitions of data in an area from different orientations. These distinct datasets are merged into one multi-azimuth dataset. Wide-azimuth (WAZ) data involve multiple sources and acquisitions that provide wider ranges of azimuths. **Figure L-9** is just one of several types of multi-vessel designs for WAZ surveys. Rich azimuth (RAZ, not shown) requires several traverses of WAZ surveys in different orientations.

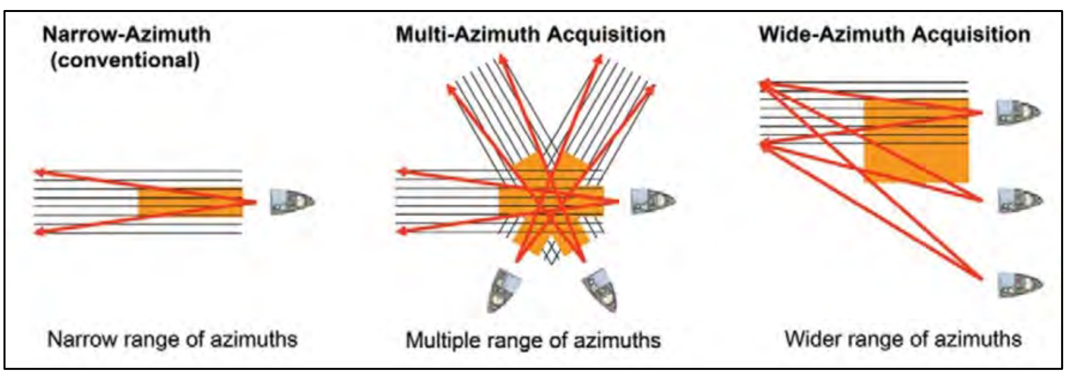

Figure L-9. Schematic Comparison of Narrow-Azimuth vs. Multi-Azimuth vs. Wide-Azimuth Streamer Acquisition (Wide-azimuth presents the most aggressive scenario and necessitates more than one vessel. Multi-azimuth uses two or more shooting directions using one vessel.) (Rekdal and Long, 2006).

2.13 POTENTIAL METRICS TO DETERMINE DUPLICATIVE SURVEYS

BOEM's geoscientists examined historical datasets and looked at all acquisition criteria. The list, while not in any order of importance, have all been determined to be the significant factors in determining whether surveys would be deemed duplicative.

(1) Geospatial Location – This is the first and most obvious metric to review. A potential survey's spatial extent can be viewed as a polygon. This polygon can be compared with existing survey polygons to determine where overlap of the proposed survey and existing survey(s) would occur, and it is the starting point to determining duplication.

- Overlap with Current Datasets and Extent of that Overlap
- Surface Orientation/Geometry

(2) Survey Acquisition Design – A survey's potential for advanced imagery in complex regimes are dependent upon the richness of its azimuthal acquisition. Generally, higher azimuthal richness results in a better quality signal acquired.

- Acquisition Geometry
- Azimuthal Imaging
- Line/Shot Pint Orientation

(3) Receiver Criteria – An increase in receivers tends to lead to an increase in azimuth, fold, and S/N. This is achieved by the lengthening of streamers or from towing more streamers. Individual geophysical contractors use proprietary streamers that enhance the received signal and give them a competitive advantage.

- Streamer Type
- Number of Receiver (Streamer) Boats
- Number of Streamers per Boat
- Location (Ocean Bottom Cable [OBC]/Vessel Towed)
- Length
- In-line/Crossline Offsets
- Streamer Separation
- Number of Channels
- Streamer Depth

(4) Source Criteria – The source is designed to optimize the harmonics of the produced wavelet by taking advantage of constructive and destructive

interference in the wave train. The source is carefully planned for that specific survey with geology, water depth, and other factors in mind to optimize a particular zone or multiple zones of interest. An increase in source size does not always lead to better geologic penetration.

- Source Type
- Array Size
- Array Architecture/Composition
- Source Arrays per Vessel
- Firing Sequence
- Gun Depth
- Number of Source Vessels

(5) Data Sampling – This criteria focuses on the density of the seismic data. Generally, the denser the data, the more signal is generated in acquisition, but it is more labor and cost intensive.

- Spatial
  - Fold of Coverage
  - Shot-Point Interval
  - Group Interval
  - Recorded Bin Size
- Temporal
  - Sample Rate
  - Record Length
- Frequency Content

2.14 SUMMARY

As demonstrated in the Mississippi Canyon case study provided in this report, a comparison of the spatial polygons of seismic survey coverage acquired in the Gulf of Mexico, in and of itself, is not adequate to determine whether duplicative seismic acquisition has occurred in the past or might result from a new survey. The polygons represent only one portion of the potential metrics needed to determine if a survey is unnecessarily duplicative or not. The case study demonstrated additional criteria that could be considered during the permitting process. These criteria could be, but are not limited to, geospatial location, survey acquisition design, receiver and source criteria, and data sampling. All of the previously mentioned metrics, jointly and individually, play a role to determine whether a survey would be deemed unnecessarily duplicative. Any evaluation of a proposed survey will require an in-depth evaluation of how its metrics compare with existing surveys. Sound environmental stewardship is critical to BOEM's mission, and the suggested metrics outlined in this report can help BOEM achieve its mission by the reduction and/or prevention of unnecessary seismic survey acquisition.

2.14.1 Panel Determination

The Panel has determined the following:

(1) It is feasible to determine whether or not a newly proposed seismic survey is unnecessarily duplicative when compared with previous surveys in an area

(2) This determination can be accomplished under the current laws and regulations governing G&G activities on the OCS. However, the additional information required from the companies may necessitate reviewing any additional burden placed upon them to ensure the requirements of the Paperwork Reduction Act of 1995 are met.

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ATTACHMENT 1: GLOSSARY OF GEOPHYSICAL TERMS AND COMMON ABBREVIATIONS

Glossary of Geophysical Terms

Acquisition Density – the density of source emissions or receiver recording density.

Aliasing – frequency uncertainty resulting from having less than two samples per cycle (refer to Spatial Sampling)

Azimuth – the horizontal angle measured from true north.

Bin Size – the theoretical sample interval determined by source and receiver spacing for grouping of traces that sample the same sub-surface point or area

Channels – receiver groups; one or more receivers can compose one channel.

Common Depth Point (CDP) – the CDP with a given bin size as defined above.

Energy Source Type – the type of source or method used to produce a signal directed into the earth to record seismic events such as reflections or refractions, e.g., compressed air used in air guns.

Firing Sequence – pattern in which individual/groups of arrays are fired, i.e., popcorn sequencing or alternate sequencing.

Fold – the number of traces that sample a given location in a survey (referred to as common mid-point) that are stacked together during an imaging sequence.

Frequency Content – refers to the bandwidth of a signal that is produced by the source or the bandwidth that is retrieved by the receivers.

Group Interval – the horizontal distance between streamer components that represents one receiver group (channel); multiple receivers are grouped (summed) into one channel; the distance each of these groups span is referred to as the group interval.

Line Spacing – the spacing between adjacent lines traversed during the acquisition of a survey and can be sail line spacing, surface receiver (cable) spacing, or sub-surface line spacing.

Listening Window – refer to Record Length.

Location (OBC/vessel towed) – describes whether receivers are towed behind a vessel or semi-permanently positioned on the seafloor.

Offset – distance between source/receiver pairs, either in the parallel (in-line) or perpendicular (crossline) direction.

Overlap – the same spatial area over which two or more surveys have acquired data.

Receiver – a sensor designed to record signals, such as reflections or refractions, generated by a seismic energy source.

Receiver Boats (cable) – acquisition vessels that tow streamers.

Receiver Depth – depth below water surface in which streamers are being towed.

Record Length – the amount of time in milliseconds that is recorded for each source excitation during the acquisition of a survey.

Sample Interval – the time between readings recorded during seismic acquisition or the time or depth interval between sequential samples of a seismic trace.

Sample Rate – the inverse of the sample interval, the time in micro or milliseconds between sample points recorded by a recording system during seismic acquisition.

Separation – the distance between receiver locations, source point locations, streamers, or source arrays that dictate the nominal geometry of a survey design.

Sequential Sourcing – the individual source emission pattern in an operation that utilizes multiple energy sources.

Simultaneous Sourcing – the emission of multiple sources at or near the same tie in the recording sequence.

Source – a device that releases energy used to generate a seismic pulse that is directed into the earth, reflected, refracted, and recorded during seismic acquisition.

Source Array – the total arrangement of source elements or sub-arrays that comprises a seismic source.

Source Depth – depth below water surface in which sources are being towed.

Source Point – the location where seismic energy is released and where arrays are used; this usually refers to the geometric center of the arrays.

Source Spacing – the distance between sequential source points along a line of a survey.

Spatial Sampling – measurements taken only at discrete locations.

St Streamer Length – total length of streamers measured from a position on the vessel to the tail buoy; this includes active and inactive sections.

Streamer – towed cable containing receivers.

Streamer Length – total length of streamers measured from a position on the vessel to the tail buoy; this length includes active and inactive sections.

Streamer Separation – distance between streamers towed by the same vessel.

Sub-array (source) – composed of individual airgun elements; multiple sub-arrays compose an air gun array; sub-arrays are designed to optimize harmonics.

Survey Geometry – the relationships of source spacing, line spacing, receiver spacing, and offset ranges that a particular deployment of in-field equipment produces.

Survey Orientation – the primary orientation of survey lines or primary azimuth of source and receiver relationships, typically related to NAZ acquisition, that can affect the imaging quality of a survey due to geological orientations of the subsurface events.

Syncline – a fold in stratified rocks in which the rocks dip toward a central depression, i.e., the attitude of the rocks is concave upward; opposite of anticline.

Trace – a record of data from one seismic channel.

Tow Depth – the depth, below the surface of the water, at which a source or receiver array is towed behind a seismic vessel (typically 5 to 30 m; 16 to 98 ft).

Common Abbreviations

FAZ (Full-Azimuth Acquisition) – a survey that, by design, combines elements of NAZ, WAZ, and RAZ to generate azimuths that sample the sub-surface from all directions.

MAZ (Multi-Azimuth Acquisition) – a survey that, by design, produces multiple narrow ranges of azimuths through acquisition of NAZ in multiple directions (refer to **Figure L-9**, "Acquisition Geometry Advancements," in **Chapter 2.12** for a diagram).

NAZ (Narrow Azimuth Acquisition) – a survey that, by design, produces only a narrow range of azimuths related to the travel paths between source and receiver locations, typically single vessel (refer to **Figure L-9**, "Acquisition Geometry Advancements," in **Chapter 2.12** for a diagram).

OBC (Ocean Bottom Cable) – sources towed behind a source vessel while the receiver arrays (assembled in cables) are placed on the seabed, deployed, and recovered/repositioned for a cable-laying (recording) vessel.

OBN (Ocean Bottom Node) – same as OBC only receivers are deployed as individual units and recovered/repositioned via a remotely operated vehicle from the recording vessel.

RAZ (Rich-Azimuth Acquisition) – a survey that, by design, combines elements of either or both NAZ and WAZ to produce a large range of azimuths, typically multiple vessels and multiple acquisition directions.

TS (Towed Streamer) – receiver and airgun (source) cables (streamers) are towed through the water at a given depth (typically between 5 and 30 m [16 and 98 ft] below the sea surface) behind a seismic source vessel.

TS 2D (Two-Dimensional Towed Streamer) – a TS survey where the seismic vessel only tows one source and one streamer to record a single CDP line of the sub-surface (1 horizontal direction, i.e., in-line and depth, hence 2D).

TS 3D (Three-Dimensional Towed Streamer) – a TS survey where the seismic vessel tows multiple sources and streamers to record multiple CDP lines of the sub-surface in a single pass (in-line and cross-line, i.e., perpendicular to the in-line direction and depth, hence 3D).

TS 4D (Four-Dimensional [or Time Lapse] Towed Streamer) –, TS 3D surveys acquired repeatedly with the same survey geometry over the same survey area; the difference between two of these surveys then represents the changes in the sub-surface (e.g., due to a producing oil or gas field) over a given time period, typically a couple of years.

VC (Vertical Cable) – same as OBC only the cables are positioned vertically in the water column with an anchor at the seabed and buoys at/near the sea surface.

VSP (Vertical Seismic Profiling) – the receiver is placed from a production or drill rig at different depths inside a well while the sources are positioned in a given pattern at the sea surface.

WAZ (Wide-Azimuth Acquisition) – a survey that, by design, produces a wider range of azimuths related to the travel paths between sources and receivers, and uses multiple vessels (refer to **Figure L-9**, "Acquisition Geometry Advancements," in **Chapter 2.12** for a diagram).

ATTACHMENT 2: DIFFERENCES BETWEEN MULTI-CLIENT AND EXCLUSIVE SURVEYS

Multi-Client Surveys	Exclusive Surveys
Multi-client acquisition develops a product – seismic data available for licensing to multiple E&P companies	Proprietary acquisition provides a service – seismic data only available to the E&P company
Seismic contractor designs a survey that E&P companies (the market) have asked for; E&P companies use the information to develop prospects and delineate reservoirs, as well as for use in the preparation of an upcoming lease sale. Covers large areas – in the Gulf of Mexico, a multi-client acquisition project would likely cover hundreds of OCS blocks.	Seismic company and E&P company enter into agreement for acquisition of seismic data over a pre-determined area (e.g., possibly acreage under lease). The proprietary model is used often to "fine tune" an E&P company's exploration and development plan(s) (e.g., where to drill the initial well and subsequent wells) to sufficiently and efficiently identify gas hydrocarbon reservoirs. This includes time-lapse surveys to better understand the reservoir and how well the current wells are recovering oil and/or gas.
Seismic contractor bears the risk – i.e., pays the cost of acquisition (with some pre-commitment money furnished by E&P companies), obtains all necessary permits and approvals, and develops, manages and conducts projects.	Seismic contractor provides the vessel and crew to acquire data; E&P company pays the full cost of acquisition.
Seismic contractor owns the seismic data.	E&P company owns the seismic data.
Contractor license use of the seismic data to E&P companies – either all of the data acquired or some subset. License agreement will determine how E&P company can use the data.	E&P company can use and share the data with other E&P companies without restrictions.
The E&P company can license to use the data at a fraction of the project cost of what an E&P company would pay for acquisition of seismic data on much less acreage (fewer OCS blocks).	On a per acre basis, cost of seismic data acquisition is much higher than if only licensed from the contractor. Cost of acquisition is dependent on supply/demand of vessel and crew.

E&P = exploration and production.
OCS = Outer Continental Shelf.

ATTACHMENT 3: ENLARGED VERSIONS OF COMPOSITE GENERATIONAL LINES

Figure 1

Generation 1 Enlarged Composite Line

Typical of Seismic Acquired from 1992 to 1998

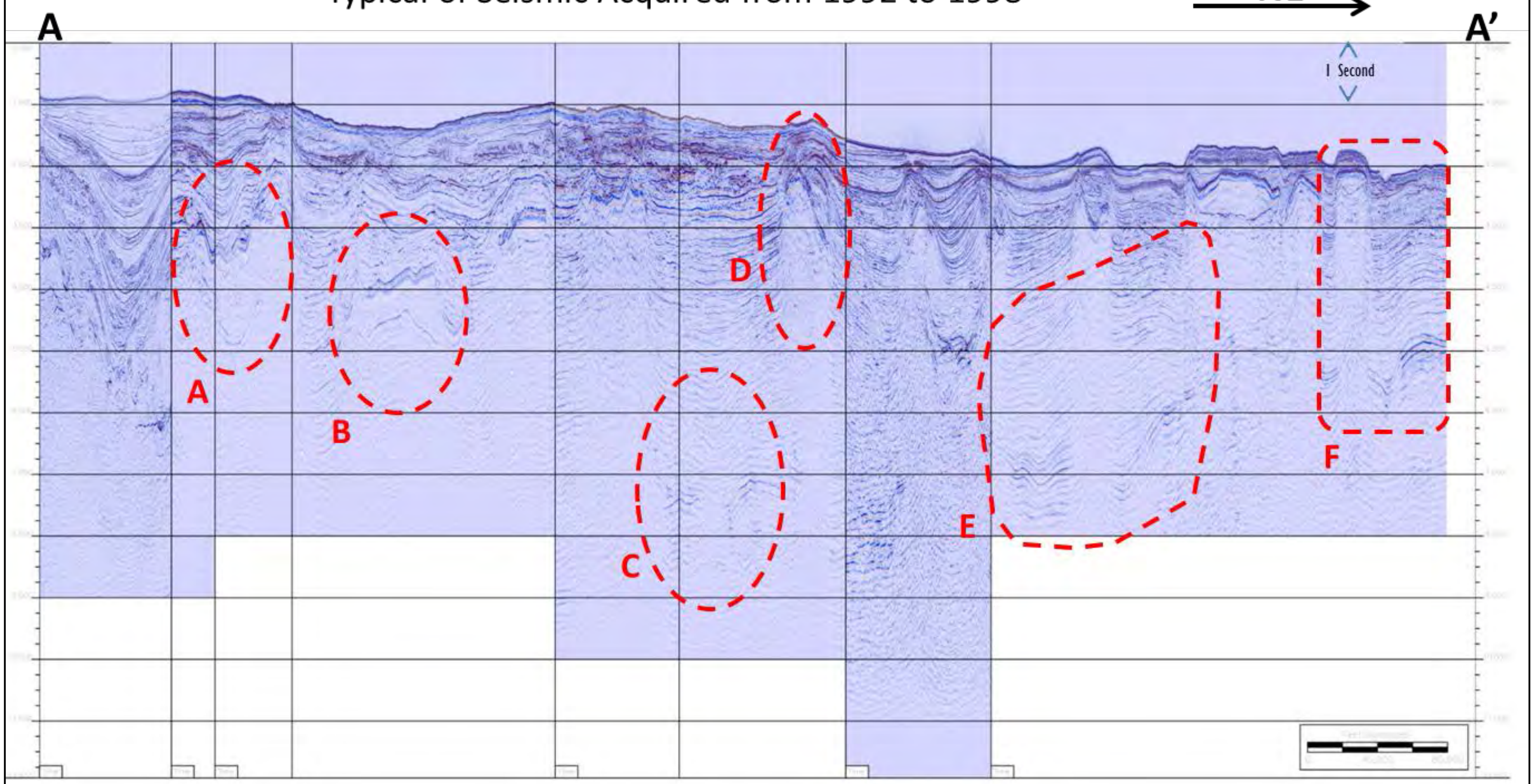

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Figure 2

Generation 2 Enlarged Composite Line

Typical of Seismic Acquired from 1998 to 2002

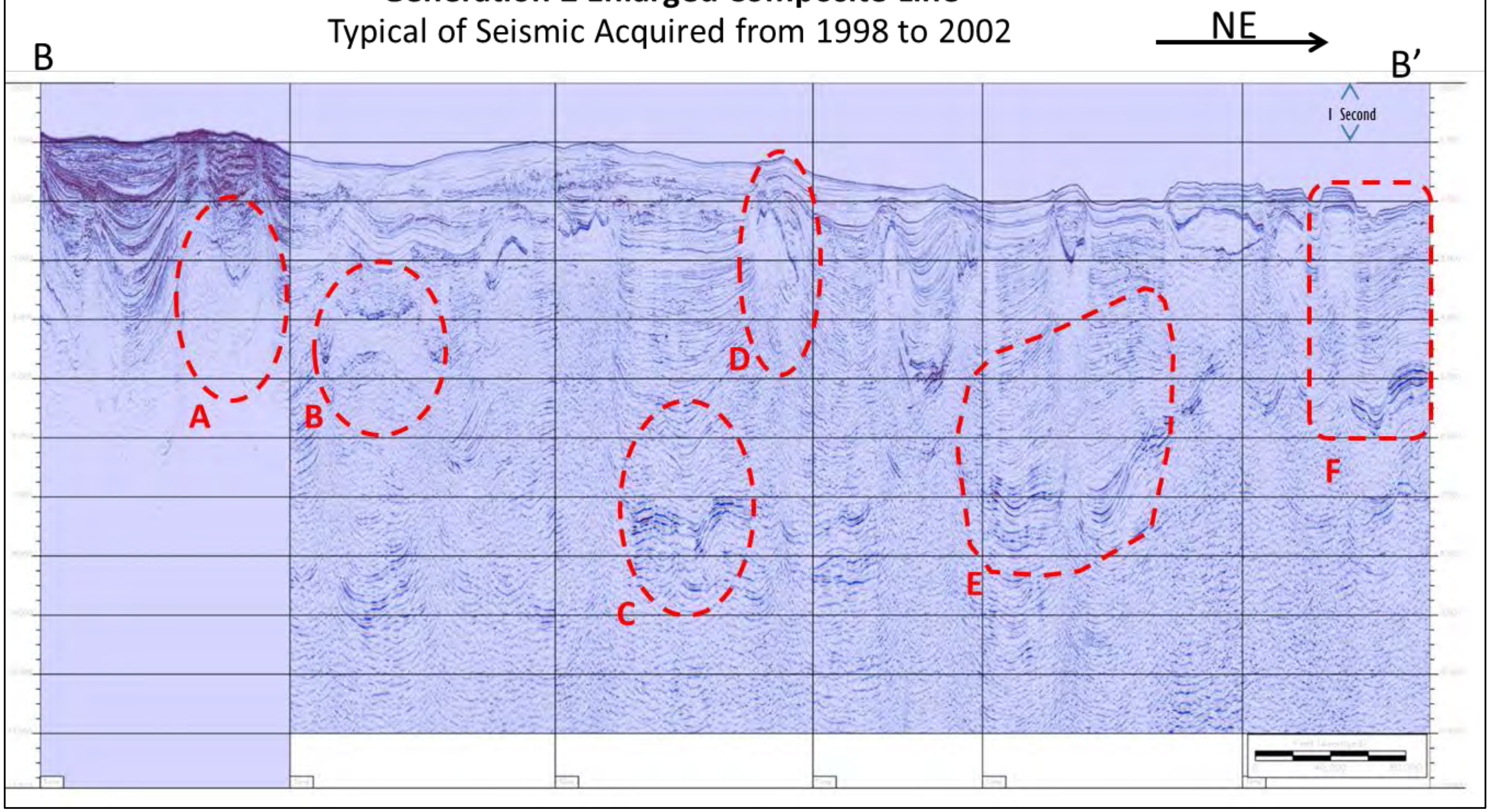


Figure 3

Generation 3 Enlarged Composite Line

Typical of Seismic Acquired from 2004 to 2005

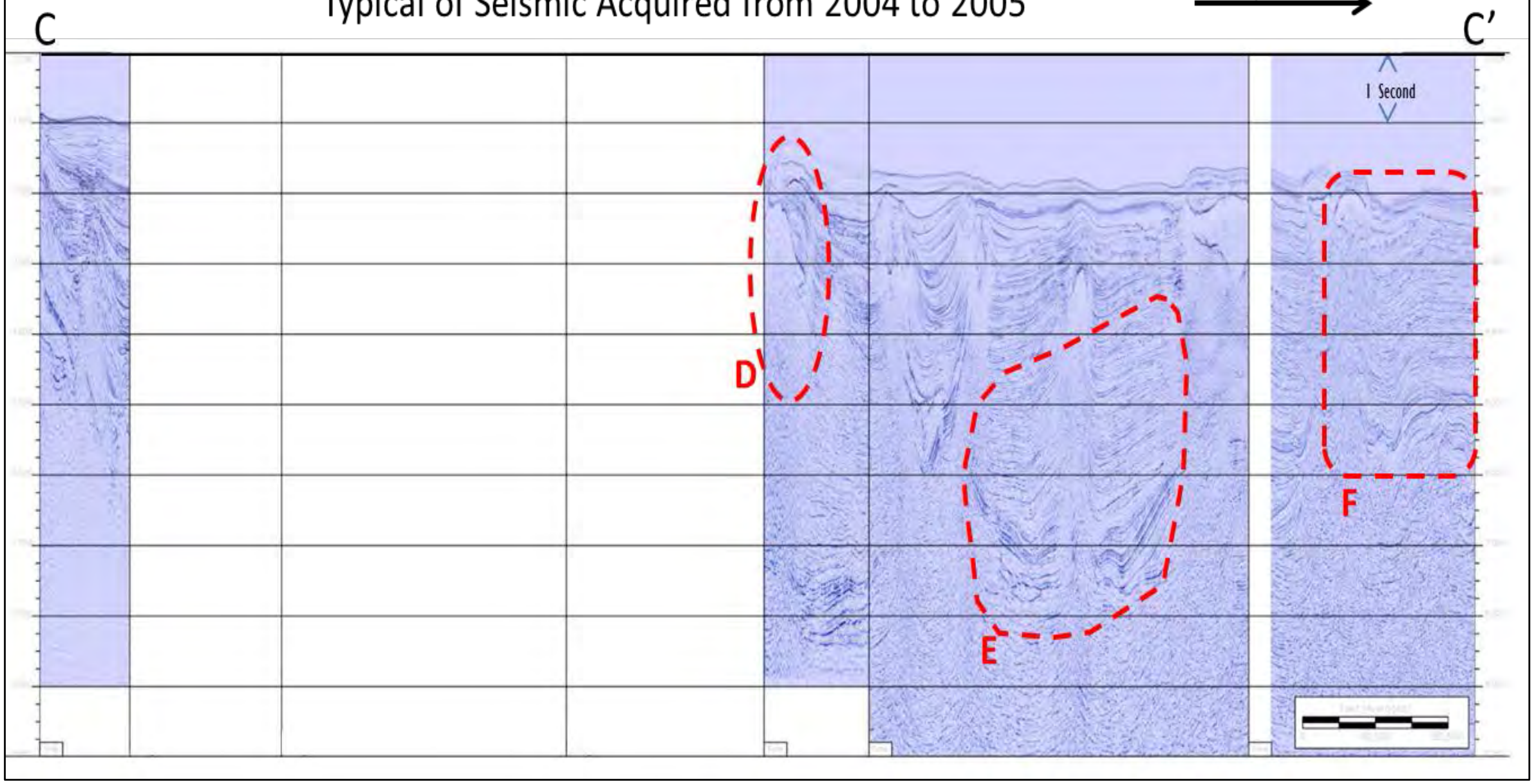
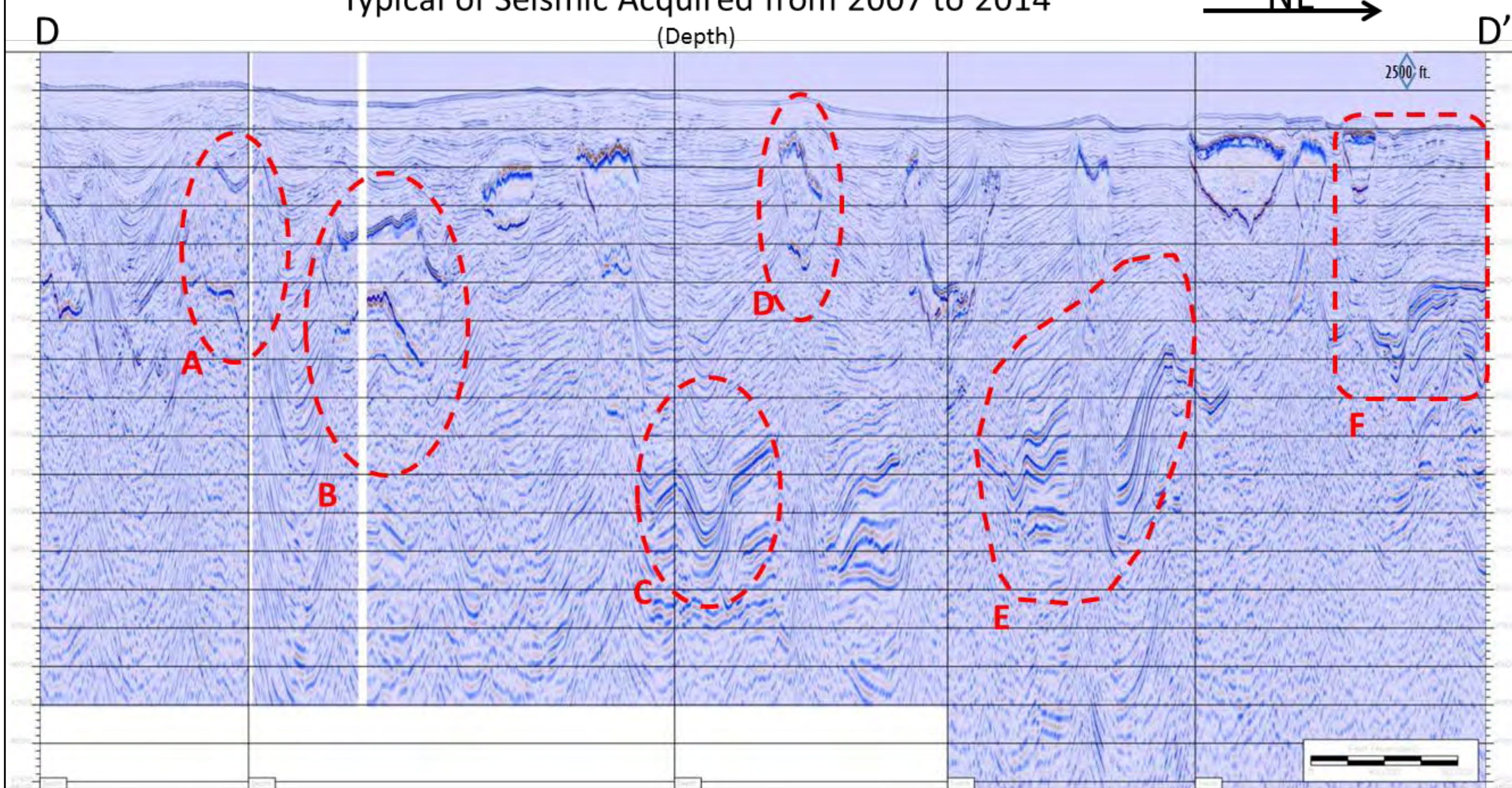


Figure 4

Generation 4 Enlarged Composite Line

Typical of Seismic Acquired from 2007 to 2014

(Depth)



The Department of the Interior Mission

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

The Bureau of Ocean Energy Management Mission

The Bureau of Ocean Energy Management (BOEM) is responsible for managing development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.