ACCESS NUMBER: 85186

STUDY TITLE: Sperm Whale Seismic Study (SWSS)

REPORT TITLE: Sperm Whale Seismic Study in the Gulf of Mexico: Synthesis Report

CONTRACT NUMBER: 1435-01-02-CA-85186

SPONSORING OCS REGION: Gulf of Mexico

APPLICABLE PLANNING AREAS: Western, Central, and Eastern Gulf of Mexico

FISCAL YEARS OF PROJECT FUNDING: 2002, 2003, 2004, 2005, 2006, and 2007

COMPLETION DATE OF REPORT: May 2008

COSTS: FY 2002: $2,069,017; FY 2003: $1,792,477; FY 2004: $2,280,205; FY 2005: $2,516,537; FY 2006: $643,149; FY 2007: $0; CUMULATIVE PROJECT COST: $9,301,385 (Note: $260,972 of this total was contributed to MMS for SWSS by the Industry Research Funders Coalition)

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KEY WORDS: Sperm whale, *Physeter macrocephalus*, Gulf of Mexico

BACKGROUND: The Minerals Management Service (MMS), Gulf of Mexico Outer Continental Shelf Region, recognizes oil and gas and related activities that are moving into the deepwater Gulf of Mexico (Gulf) may occur in regions frequented by deepwater species of cetaceans, particularly the endangered sperm whale (*Physeter macrocephalus*). MMS seeks to expand the existing assessments of Gulf sperm whales and to improve the understanding of effects of seismic exploration on them. In January 2002, the geophysical industry through the International Association of Geophysical Contractors (IAGC) offered to provide a seismic source vessel as a sound source for several weeks of controlled exposure experiments (CEEs) of sperm whales to seismic exploration. With this IAGC contribution, MMS awarded the cooperative agreement for research on sperm whales and their response to seismic sounds to a multi-institutional, interdisciplinary research team with program management provided by Texas A&M University. In the second field year, five major oil companies joined with IAGC to form the Industry Research Funders Coalition (IRFC) to allow the contribution of a seismic source vessel for a second summer of CEEs. In field years 3 and 4, IRFC provided

contributions through MMS for additional sperm whale research under the cooperative agreement. Additional funding sponsors were National Science Foundation for use of the *R/V Maurice Ewing* in year 2, Office of Naval Research for development of tags, and National Fish and Wildlife Foundation for sailboat lease in year 3.

OBJECTIVES: The objectives of this study were to:

- establish the normal behavior of sperm whales in the northern Gulf;
- characterize sperm whale habitat use in the northern Gulf; and
- determine possible changes in behavior of sperm whales when subjected to man-made noise, particularly from seismic airgun arrays used for offshore petroleum exploration and geological monitoring.

DESCRIPTION: Six project components were designed to meet the objectives. These were to study:

1. long-term (months to seasonal) movements and distributions of sperm whales using satellite-tracked radio telemetry tags (S-tags);
2. short-term (hours) behavior of sperm whales using digital-recording acoustic tags (D-tags) and potential changes in behavior of the whales when subjected to seismic airgun sounds during controlled exposure experiments (CEEs);
3. social behaviors of sperm whale groups using visual and passive acoustic observations over periods of days;
4. biopsy samples to determine the sex of the tagged animals and their relatedness to sperm whales from the North Atlantic Ocean and Mediterranean and North Seas;
5. diving depths and movements using 3-D passive acoustic tracking techniques, as well as D-tag data; and
6. the characteristics of the Gulf habitats in which the sperm whales are found.

Nine field cruises were conducted in the summers of 2002-2005. Eight SWSS cruises were focused along the 1000-m isobath in the region off the Mississippi River Delta between 91°W and 86°W in water depths of 800-1200 m. The 2005 S-tag cruise was conducted in the northwest Gulf. One cruise aboard the R/V *Gyre* each summer was in support of S-tag deployments. A cruise in summer 2002 on *Gyre* and another in summer 2003 on R/V *Maurice Ewing* were in support of D-tag/CEE work. The offshore industry work boat M/V *Rylan T*, with the shallow-water airgun boat M/V *Speculator* attached to the rear work deck, provided the seismic airgun array that was used as the sound source for the 2002 CEEs. The seismic survey vessel M/V *Kondor Explorer* provided the airgun sound source for the 2003 CEEs. A third cruise in 2003, Whale Survey and Habitat Characterization cruise, was conducted from *Gyre* concurrently with the D-tag/CEE cruise to collect the supporting suite of environmental, habitat data. In 2004 and 2005, the acoustically quiet, 46' Hunter sailboat *Summer Breeze* was used to study the social behavior of sperm whale groups. Visual and passive acoustic observations of sperm whales were collected on all cruises, as were biopsy samples for

genetic observations. Fluke photographs were taken for photo-identification. Data from hydrophone arrays were used to study codas and 3-D passive acoustic tracking of sperm whales. Habitat characterization included currents from 153-kHz and 38-kHz acoustic Doppler current profilers; temperature and salinity profiles; continuous, near-surface temperature, salinity, and fluorescence/chlorophyll observations; and sea surface height and ocean color from remote sensing. In 2005, 70- and 38-kHz fishery echosounders were used to observe locations of the deep layers of biota.

SIGNIFICANT CONCLUSIONS: Genetic analyses, coda vocalizations, and population structure support the conclusion that sperm whales in the Gulf of Mexico are different from other populations-a discrete stock. Sperm whales are present year-round in the Gulf, with females generally having significant site fidelity and males and females exhibiting significant differences in habitat usage. Gulf sperm whales seem to be smaller in individual size than sperm whales in some other oceans, but the cause is not apparent. Some groups of sperm whales in the Gulf are mixed-sex groups of females/immatures and others are groups of bachelor males. Typical size for mixed groups is 10 individuals, which is smaller than group sizes in some other oceans. The typical diving and underwater behaviors of the Gulf's sperm whales are similar to those of animals in other oceans. The typical feeding and foraging behaviors of the Gulf's sperm whales are similar to those of animals in other oceans, although differences in defecation rates suggest possible differences in feeding success. In the otherwise oligotrophic Gulf of Mexico, the eddy field contributes to development of regions of locally high surface productivity that in turn may create conditions favorable for the trophic cascade of surface production to the depths where Gulf sperm whales dive to forage. Knowledge of the prey field itself is lacking. There appears to be no horizontal avoidance to controlled exposure of seismic airgun sounds by sperm whales in the SWSS study area. Data analysis suggests it is more likely than not that some decrease in foraging effort may occur during exposure to full-array airgun firing as compared to the post-exposure condition, at least for some individuals. However, additional CEE studies are required to increase the sample size for improved statistical power. Knowledge of the acoustic propagation and airgun sound characteristics is critical to developing the capability for accurate predictions of exposures and the modeling of potential resulting effects.

STUDY RESULTS: Comparisons of mitochondrial DNA and other molecular markers of tissue samples from sperm whales in the northern Gulf of Mexico, Mediterranean Sea, North Sea, and North Atlantic Ocean reveal a significant genetic differentiation between the Gulf population and populations of the other three regions. Analyses of coda vocalizations also suggest there are significant differences in repertoires between the Gulf population and the populations of the rest of the Atlantic. The available recorded coda vocalizations indicate that the mixed groups in the Gulf belong to an acoustic clan that is rarely encountered in other areas and, from this, it is inferred that groups from other clans rarely enter the northern Gulf. The population structure also is different. The mean group size in the study area is 10 individuals, which is about one-half the size of groups elsewhere. The observed sexually mature females averaged 9-m in length, and bachelor males of unknown sexual maturity averaged 11-m. These individual whales seem to be significantly smaller in length than what would be expected on the basis of

whaling data from the Gulf or lengths in the Sea of Cortez. It is not known why this size difference exists, as individual size could be mediated by age, population-level genetic differences, food/nutrition, energetic differences, environmental stressors, or a combination of these. It is also not known if this size difference exists in animals in other regions of the Gulf. Mature males seem to have either a different behavior or a different seasonality to those in other regions as no large breeding males were observed in 2004 or 2005 from the sailboat. Groups of females/immatures have a high site fidelity. There is no evidence of long-distance movements as no matches were found between the 185 individuals identified in the northern Gulf and ~2500 individuals identified in the North Atlantic and Mediterranean Sperm Whale Catalogue. These results indicate a degree of segregation between sperm whales in the Gulf and the Atlantic, likely spanning temporal scales of years (absence of matches) to decades (differences in coda repertoire).

The eddy field in the Gulf of Mexico generates off-shelf conditions that transport relatively nutrient-rich, high-productivity shelf waters to the slope or upwell nutrient-rich waters from depth into the photic zone where they can fuel phytoplankton growth. SWSS results support the findings of GulfCet and SWAMP that lead to the hypothesis that locally high chlorophyll features, particularly cyclonic eddies or eddy-induced off-margin flows, that persist for 3-4 months, provide primary production that cascades to support prey assemblages for sperm whales along the continental slope. Consistent with this hypothesis, in summers 2002 and 2003, most sperm whales were encountered in regions of negative sea surface height anomaly and/or higher-than-average surface chlorophyll. In contrast, however, only a few of the whale encounters in summer 2004 were in regions of negative sea surface height anomaly and/or higher-than-average surface chlorophyll. Comparisons of the locations of sperm whales observed during the 2005 S-tag cruise with the acoustic backscatter from a fishery echosounder support the hypothesis, as significantly higher midwater backscatter was measured when whales were locally abundant. The eddy field during SWSS varied both from year to year and within individual summers. Both sources of variability appeared to influence the encounter rates with whales. The interannual variability of the Mississippi River discharge itself may also have significant impact on sperm whale distributions in the area along the 1000-m isobath between Mississippi Canyon and De Soto Canyon. This discharge provides nutrients that result in relatively high biological productivity, which then can be transported off-shelf into the habitat of the sperm whale by the eddy field. In 2005, sperm whales were not found in similar abundance or in the usual groupings in the main SWSS study area that were found in the GulfCet and 2002-2004 SWSS study years. The change in distribution may have been related to the lower discharge from the Mississippi River in 2005. A real gap in habitat knowledge, however, is the understanding of the complex pathway by which surface productivity translates into mid- or deepwater productivity that sustains the prey field for the apex predator, the sperm whale. The actual prey species of the northern Gulf sperm whales are not known. The prey field itself requires dedicated study: what species are used by the sperm whale? what are their distribution patterns in space and time? what factors affect their populations?

The two D-tag/CEE cruises directly examined the behavior of sperm whales when exposed to airgun sounds. The movement and sound-recording D-tag was used to record acoustic exposure and foraging behaviors of 8 sperm whales before, during, and after 1-2 hr controlled sound exposures of industry-provided airgun arrays in the Gulf in 2002 and 2003. In 2002, two CEEs were conducted involving 4 subjects. In 2003, three CEEs were completed also with 4 subjects. The 8 whales for which these CEEs were conducted were exposed to maximum sound levels between 111 to 147 dB re 1 µPa (rms) (131 to 164 dBp-p re 1 µPa) at ranges of approximately 1.4-12.6 km from the sound source. The direction of movement did not change for any of the eight exposed whales at either the onset of gradual ramp-up at ranges of 7.3-12.5 km or during full power exposures at ranges of 1.4-12.6 km. The CEE results, together with results from two other independent approaches, do not indicate any horizontal avoidance of sperm whales in the Gulf to seismic survey activities. These data do not support the assumption that whales swim away from an airgun array as it ramps up or approaches the whale at full power. However, there was only limited exposure above 160 dBp-p re 1 µPa. Further research is required to test for avoidance at higher received levels. Gulf sperm whales, at least in the area studied, may have some level of acclimation to seismic airgun sounds. Moreover, whales were tagged in a region with substantial human activity, so they are not naïve to human-generated sounds. Follow-on studies in regions not as affected by human activities are needed to address the issue of habituation.

The effects of airguns on the foraging behavior of sperm whales were assessed. The whale that was approached most closely prolonged a surface resting bout hours longer than typical, but resumed foraging immediately after the airguns ceased. While this whale showed no horizontal avoidance, the alteration of diving behavior might be a vertical avoidance response. Foraging response measures between exposure and post-exposure control periods in the remaining 7 exposed whales (which made foraging dives during both conditions) were assessed. Results of an ANOVA statistical test of the D-tag/CEE data to determine whether there were changes in foraging behavior indicated a statistically significant decrease in swimming movements during full-array exposure as compared to post-exposure periods. Likewise an ANOVA of data on the buzzes produced when whales attempt to capture prey indicated the buzz rate was lower during the exposure condition, but this effect was not statistically significant. The sample size of 7 animals that conducted foraging dives during exposure was too small to provide definitive results. To examine the odds-ratio of whether the limited CEE data support the conclusion of a change in behavior, Bayesian analyses were conducted. These analyses indicated that the odds favor that, during full-array exposure, there was a decrease in foraging activity of approximately 20% rather than that there was no change in foraging activity. A statistical analysis of the odds that each individual whale changed its foraging behavior during exposure demonstrated that one whale showed a statistically significant ($p<0.002$) decrease of 60%. However, the power of the test to detect small changes in foraging success was low, and no conclusions on the biological significance of these effects for an individual animal or for the population can be made from the data sets available.

STUDY PRODUCTS: Jochens, A., D. Biggs, K. Benoit-Bird, D. Engelhaupt, J. Gordon, C. Hu, N. Jaquet, M. Johnson, R. Leben, B. Mate, P. Miller, J. Ortega-Ortiz, A. Thode, P. Tyack, and B. Würsig. 2008. Sperm whale seismic study in the Gulf of Mexico: Synthesis report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2008-006. 341 pp.

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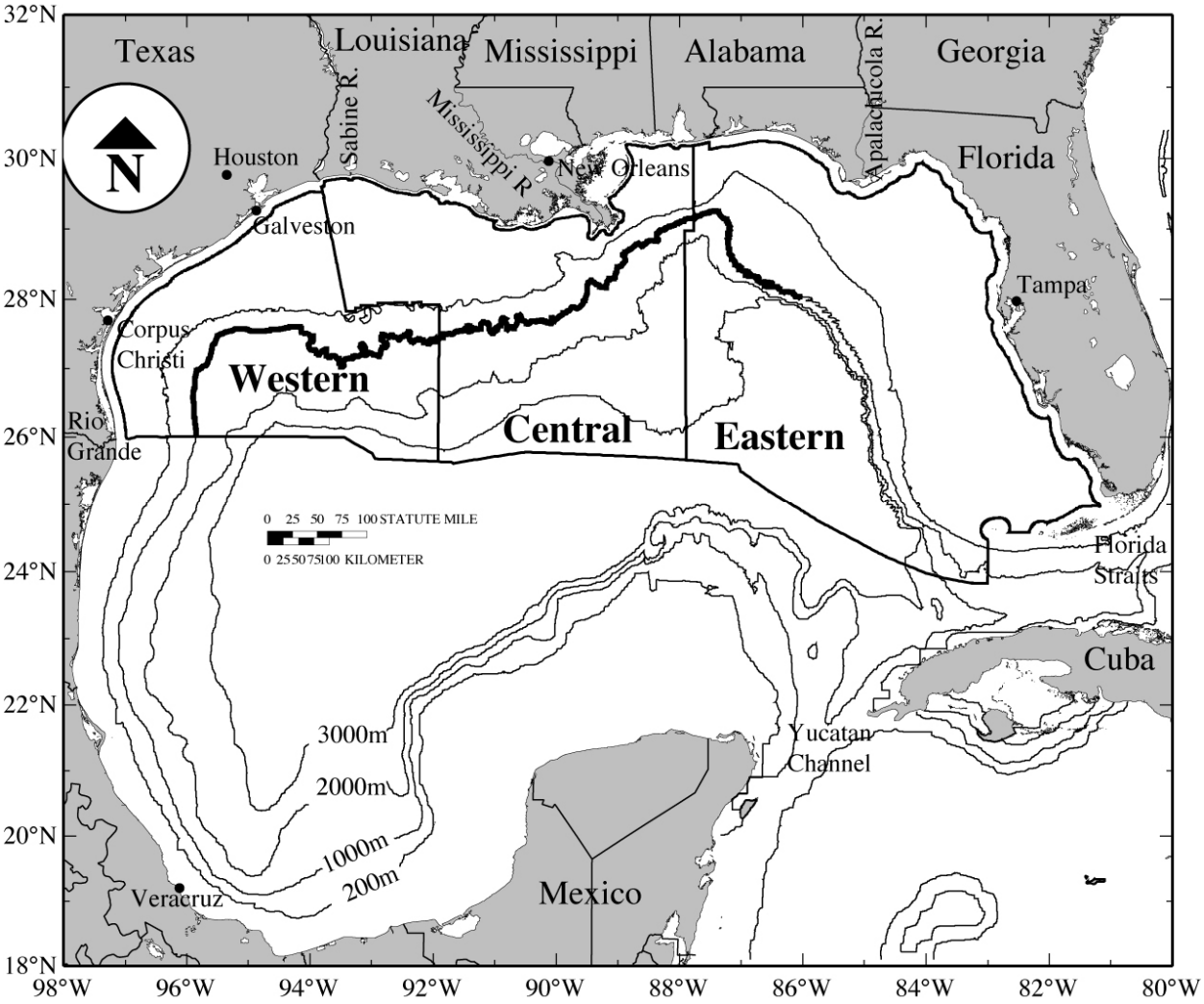

Study area of the Sperm Whale Seismic Study (SWSS), which focused along the 1000-m isobath of the northern Gulf of Mexico. Bathymetry contours shown are 200, 1000, 2000, and 3000 m.

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