OCS Study
MMS 2003-069

Sperm Whale Seismic Study in the Gulf of Mexico

Annual Report: Year 1

MMS U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

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Annual Report: Year 1

Editors

Ann E. Jochens
Douglas C. Biggs

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Texas A&M University
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ABOUT THE COVER

The cover art shows a sperm whale beginning a dive in Mississippi Canyon Block 127 in the northern Gulf of Mexico (photo by Christoph Richter).

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This report would not have been possible without the contributions of a large number of people. Each principal investigator (PI) of the Sperm Whale Seismic Study (SWSS) contributed ideas to and authorship of portions of the text, many participated in the cruises and in data reduction and processing. The principal investigators, their affiliations, and their tasks are:

Ann E. Jochens	TAMU	Program Manager, Co-PI for habitat characterization
Douglas C. Biggs	TAMU	Project Scientist, PI for habitat characterization
Dan Engelhaupt	UDurham	PI for genetic analyses
Jonathan Gordon	Ecologic	PI for Photo I.D. and S-tag acoustics
Matthew K. Howard	TAMU	Data Manager
Nathalie Jaquet	TAMUG	Co-PI for Photo I.D.
Mark Johnson	WHOI	Co-PI for D-tag study
Robert L. Leben	CU	Co-PI for habitat characterization
Bruce Mate	OSU	PI for S-tag whale tagging and tracking
Patrick Miller	WHOI	Co-PI for D-tag study
Peter Tyack	WHOI	PI for D-tag study
Bernd Würsig	TAMUG	Co-PI for Photo I.D.

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The use of a seismic source vessel, which was crucial for conducting the D-tag controlled exposure experiment, would not have been possible without the contribution of the seismic source and vessel, *Rylan T./Speculator* by the International Association of Geophysical Contractors. SWSS scientists extend thanks to Chip Gill, Phil Fontana, and Jack Caldwell, as well as all members of IAGC, for their enthusiastic work in support of SWSS, and to Jim Thompson of Fairfield Industries for making the logistical arrangements for and supplying the seismic source vessel. We thank Tim Pinnigton and Craig Douglas of Seamap, Inc., for contributing both the Seamap hydrographic array for the seismic source vessel and their time as its operators during the D-tag cruise.

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ADCP	Acoustic Doppler current profiler
ASCII	American Standard Code for Information Interchange
AVHRR	Advanced Very High Resolution Radiometer
CCAR	Colorado Center for Astrodynamics Research, University of Colorado
CD	compact disk
CDT	Central Daylight Time
CEE	controlled exposure experiment
CHL	chlorophyll
CORIS	Coastal and Offshore Resource Information System
CTD	conductivity-temperature-depth sensor
CU	University of Colorado
DGPS	differential Global Positioning System
DGoMB	Deepwater Gulf of Mexico Benthic Habitats Program
DMSO	dimethylsulfoxide
DNA	deoxyribose nucleic acid
DoC	Department of Conservation, Wellington, New Zealand
DODS	Distributed Ocean Data System
D-tag	digital acoustic tag
GERG	Geochemical and Environmental Research Group at TAMU
GIS	Geographical information system
GMT	Generic Mapping Tools
GPS	global positioning system
GulfCet	Gulf of Mexico Cetacean Study
IAGC	International Association of Geophysical Contractors
ID	identifier for cruises
IFAW	International Fund for Animal Welfare
ITM	Information Transfer Meeting
LATEX	Louisiana-Texas Shelf Physical Oceanography Program
LC	Loop Current
LCE	Loop Current eddy
MCS	middle continental slope
MMS	Minerals Management Service, U.S. Department of the Interior
mtDNA	mitochondrial DNA
M/V	Marine Vessel
NASA	National Aeronautics and Space Administration
NAMSC	North Atlantic and Mediterranean Sperm Whale Catalogue
NEGOM	Northeastern Gulf of Mexico Physical Oceanography Program
NMEA	National Marine Electronic Association, standard protocol for GPS receivers to transmit data
NMFS	National Marine Fisheries Service (now NOAA Fisheries)
NMNH	National Museum of Natural History
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NOPP	National Oceanographic Partners Program
NVODS	National Virtual Ocean Data System
OCS	outer continental shelf
OSU	Oregon State University
ONR	Office of Naval Research
PC	personal computer
PCR	polymer chain reaction
PDF	portable document format

ACRONYMS
(continued)

Photo-ID	photographic identification
PI	Principal Investigator
PTT	platform terminal transmitter
QA/QC	quality assurance/quality control
RDI	RD Instruments, Inc.
RHIB	rigid-hulled inflatable boat
RL	received level
R/V	research vessel
SAIC	Science Applications International Corporation
SAIL	Serial ASCII Interface Loop
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SIO	Scripps Institution of Oceanography
SSH	sea surface height
SST	sea surface temperature
S-tag	satellite-tracked radio tag
SWAMP	Sperm Whale Acoustic Monitoring Program
SWSS	Sperm Whale Seismic Study
TAMU	Texas A&M University
TAMUG	Texas A&M University-Galveston
TAMRF	Texas A&M Research Foundation
T/E	TAMUG/Ecologic
TIROS	television infrared observational satellite
UD	University of Durham, UK
UHF	Ultra-High Frequency
UK	United Kingdom
UNCW	University of North Carolina, Wilmington
USF	University of South Florida
UTC	Universal Coordinated Time
VHF	Very High Frequency
WHOI	Woods Hole Oceanographic Institution
WSE	warm slope eddy
XBT	expendable bathythermograph probe

1 EXECUTIVE SUMMARY

1.1 Introduction

The Sperm Whale Seismic Study (SWSS) is supported by the Minerals Management Service (MMS) of the U.S. Department of the Interior under Cooperative Agreement 1435-01-02-CA-85186 for *Cooperative Research on Sperm Whales and their Response to Seismic Exploration in the Gulf of Mexico* through the Texas A&M Research Foundation. Under SWSS, scientists from Ecologic, Oregon State University (OSU), Scripps Institution of Oceanography (SIO), Texas A&M University (TAMU), Texas A&M University-Galveston (TAMUG), University of Colorado (CU), University of Durham, and Woods Hole Oceanographic Institution (WHOI) develop and conduct the scientific research plans in coordination with MMS, the Office of Naval Research (ONR), and the International Association of Geophysical Contractors (IAGC).

SWSS is being conducted from April 2002 through April 2005. The study consists of three years of field research with analysis and synthesis. The study area is primarily the northern Gulf of Mexico offshore of the 200-m isobath between DeSoto Canyon in the east and off-shelf of Galveston in the west.

The objectives of SWSS are to

1. establish the "normal" behavior of sperm whales in the northern Gulf of Mexico,
2. characterize habitat use, and
3. determine possible changes in behavior of sperm whales when subjected to man-made noise, particularly from seismic airgun arrays.

In addition to program management, SWSS consists of six components: S-tag, D-tag, genetic analyses, habitat characterization, passive acoustics, and photo identification/surface behavior research. MMS provides fiscal support, project oversight, and cruise participants under this Cooperative Agreement. ONR provides funding for development of both the S-tags and D-tags used in this study. IAGC provided the seismic source vessel and its crew for the controlled exposure experiment in the first field year. Contributions for field year 2 and tentatively for year 3 will expand from the IAGC to a broader industry coalition (including British Petroleum, ChevronTexaco, ConocoPhillips, ExxonMobil, and Shell) and will include the addition of the National Science Foundation as a supporting federal agency through Lamont Dougherty Earth Observatory (LDEO).

The S-tag component is designed to evaluate the seasonal distribution of sperm whales in the Gulf of Mexico. Sperm whales have been sighted in the Gulf of Mexico throughout the year, but little is known about their numbers, site tenacity, and seasonal movements. Under the S-tag component, up to 20 whales per year will be tagged in the northern Gulf of Mexico with a satellite-tracked radio tag (S-tag) that will provide long-term (months) information on surfacing locations of the tagged individuals. Tracking by satellite will be used to help identify behaviors, summer and other seasonal habitats, and, in coordination with the habitat characterization task, associations with oceanographic features.

The D-tag component is designed to quantify diving behavior and vocalizations in Gulf sperm whales and to conduct controlled exposure experiments to measure reactions of these whales to airgun sounds. A digital acoustic tag (D-tag) will be applied to individual whales to provide intensive, short-term (hours) information on whale swimming behavior and to record underwater noise both from the whale and received noise from the environment. The tag records the sounds heard and made by the tagged whale, together with its depth and orientation (pitch, roll, and heading), in a synchronized fashion throughout the dive cycle. Intensive visual and acoustic observations from a nearby research vessel record the social and geographical context of the whales' behavior, before, during, and after tagging. From a baseline understanding of expected sperm whale behavior and preferred habitat, some whales will be tagged with the D-tag and then exposed to sound sources from a seismic vessel provided by IAGC or to other sound sources, such as recorded whale codas.

The genetic analyses component will allow study of groups of sperm whales in terms of relatedness through DNA analyses of skin/tissue samples. Skin and biopsy samples will be taken during the S-tag and D-tag cruises. The genetic analyses will investigate patterns of genetic structure at three hierarchical levels: 1) social structure within and between groups and clusters; 2) phylogeographic structure among putative populations within the Gulf; and 3) phylogeographic structure on a global scale incorporating SWSS results with those of previously published studies with a particular focus on incorporating samples collected in the Caribbean Sea, Atlantic, and Mediterranean Sea regions.

The habitat characterization component will merge biological oceanography, physical oceanography, and remote sensing data to provide an interdisciplinary description of the oceanographic habitat in which sperm whales are encountered.

Visual observations of surface behavior will be coupled with passive acoustic studies of underwater activities of the whales. Passive acoustics will allow the SWSS team to find and follow whales, even at nighttime when visual observations are not made. Photographic techniques will be used to identify individuals and measure their lengths. These techniques will allow improved estimates of the size of the sperm whale population that uses the area south of the Mississippi River Delta and evaluations of their "usual" behavior, their site fidelity, and their population structure.

In addition to its critical support of the tagging and survey efforts by enabling the SWSS team to find and follow sperm whales, passive acoustic experiments will include methods to estimate whale locations underwater from their sound sources (3-D passive acoustics), use of click intervals to estimate whale size, and evaluation of codas for behavioral analyses.

1.2 Field Measurements

The 2002 field work consisted of the SWSS field cruise in two legs aboard the *R/V Gyre* and follow-up cruises from small fishing vessels. The first leg was the S-tag cruise in June/July. This was followed by the D-tag cruise in August/September. The S-tag follow-up cruises were in December 2002 and February 2003. All activities associated with sperm whales are conducted pursuant to approved permits from the National Marine Fisheries Service (now NOAA Fisheries).

The S-tag leg of the SWSS 2002 cruise surveyed for whales along the middle continental slope of the north central Gulf of Mexico between 94.7°W to 86.4°W from 19 June through 9 July 2002. Eighteen sperm whales were tagged with satellite transmitting tags. This will significantly enhance our knowledge of the long term distribution of sperm whales in the Gulf of Mexico as the data reveal information on whale locations over the year. Tagging was done between the western edge of the Mississippi Canyon and DeSoto Canyon, with the majority of the tags applied south and southeast of the Mississippi Delta. Biopsy sampling during the satellite-tagging cruise also exceeded all expectations. Skin and blubber samples from fifteen of the eighteen S-tagged sperm whales were obtained with sterilized darts. In all, a total of twenty-five skin samples were collected. Sixty-five good quality ($Q \geq 3$) identification photographs were taken during the cruise allowing the identification of 43 different individuals. Each day's photos were matched against a set of approximately 2500 photos of sperm whale flukes in the North Atlantic and Mediterranean Sperm Whale Catalogue; but, no matches were found with whales of either the North Atlantic, the Mediterranean, or the Caribbean Sea. Nine matches were found with the existing Gulf of Mexico Catalogue (1994-2001, 58 individuals).

Remote sensing images of sea surface height, ocean color, and sea surface temperature were obtained for the time before and during the S-tag cruise. Five CTD stations were made. Thirty-five expendable bathythermographs were dropped to profile temperature in the upper 760 m, and seven supplemental drops were made to collect additional data from the upper 200 m. Near-surface water was pumped from the ship's hull depth of 3.5 m through SeaBird temperature and conductivity sensors and a Turner Designs Model 10 fluorometer to log sea surface temperature, salinity, and chlorophyll fluorescence approximately once per minute. To provide calibration data for the fluorometer data, 82 water samples from the flow-through stream were collected and filtered. Ocean current velocity in the upper 300 m was monitored continuously with a hull-mounted 153-kHz acoustic Doppler current profiler (ADCP).

The D-tag leg of the SWSS 2002 cruise was conducted from 19 August through 15 September 2002. The study was conducted between the 700-m and 1500-m isobaths, mainly on or near the 1000-m isobath, between 93°W and 88°W in the northern Gulf of Mexico. Two vessels were involved in the D-tag field program. The science vessel was the *R/V Gyre*, which was staged out of Galveston, TX, for the entire period of the cruise. The seismic source vessel was the Atlas Boats vessel, *Rylan T.*, with the Fairfield Industries seismic vessel, *Speculator*, mounted on the back deck of the *Rylan T*. The IAGC provided the funding for the seismic source vessel and its technical support crew for the period 29 August through 13 September 2002 in support of the D-tag controlled exposure experiment. Additionally, Seamap Inc. contributed a prototype passive acoustic system for use on the *Rylan T*.

Despite lost days due to delays and weather, the experiments were an unqualified success. Nineteen sperm whales were tagged. All tags were recovered yielding over 77 hours and 14 Gbytes of digital data. Fourteen animals completed at least one dive before the tag came off. A total of 65 deep dives were recorded. Several notable events occurred including the longest D-tag deployment to date (15 hrs, during which recordings were successfully made for 12.36 hours), a synchronized dive by a pair of tagged whales, and three whales tagged at the same time. Foreign whale codas were played to tagged animals. Two controlled exposure experiments of whales to an operating seismic vessel were achieved, including one with three simultaneously tagged whales. Seventeen fluke photographs were taken of 13 animals for photo-identification and three frame-sets (measured length of animals) were made. Fourteen sperm whale skin samples were collected, eleven from D-tag suction cups, one from biopsy sampling equipment, and two using a dipnet to collect sloughed skin floating in the water. The visual team enjoyed 13 days of good visual working conditions and the acoustics team recorded data on 20 of 25 days from two hydrophone arrays aboard the *Gyre*, as well as numerous days from the array aboard the *Rylan T./Speculator*.

Thirty-eight expendable bathythermograph probes were dropped, eight CTD casts were taken, and chlorophyll concentrations were measured from 75 water samples. Continuous vertical profiles of horizontal currents were collected from 153-kHz and 38-kHz ADCPs whenever whales were not present, and continuous near-surface measurements of temperature, salinity, and fluorescence were recorded whenever the vessel was underway. Remote sensing images of sea surface height, ocean color, and sea surface temperature were obtained for the time before and during the cruise.

1.3 Instruments and Data Methods

Three rigid hulled inflatable boats were launched from the research vessel, *R/V Gyre*, to tag and photograph whales. These were two tag boats, the 24' MMS R2 and the 6.4-m OSU *Puffin*, used for tagging activities on the S-tag and D-tag legs, as well as one supporting boat, the *Gyre*'s 14' Avon, used for S-tag support work and photo-identification.

On both cruises, whales were located and followed by a combination of visual and passive acoustic means. Passive acoustics involved the monitoring of one or two towed hydrophones round the clock for whale vocalizations by a four-person acoustic monitoring team. This enabled the finding and following of sperm whales, as well as being a source of information on the behavior of sperm whales and of responses. A visual observation station was established at the highest, unobstructed point possible on the ship, which on the *Gyre* was on the flying bridge. It consisted of three stand-mounted BigEye binoculars and a data entry station. Visual observers conducted surveys during daylight hours and also supported the tagging efforts by providing information on whale locations to the tag boats.

On locating suitable whales, the tag boat was launched and whales were approached for tagging. The S-tag consists of Telonics transmitters, housed in stainless steel cylinders (19 cm long by 1.9 cm in diameter). They are designed for nearly complete implantation beneath the whale’s skin. They are applied with an air-powered applicator from the tag boat. The tags transmit ultra-high frequency radio signals to the Argos Data Location and Collection System receivers on the National Oceanic and Atmospheric Administration television infra-red observation satellite (TIROS)-N weather satellites. The whale locations are determined and used to study the distribution and large-scale behavior of the whale.

The D-tag is a non-invasive tag that records the sounds heard and made by the tagged whale, together with its depth and orientation (i.e., pitch, roll, and heading), in a synchronized fashion throughout the dive cycle. The tag records data digitally for between 10 and 24 hours, depending on sampling rate, with enough resolution to track individual fluke strokes. The D-tag is cast in epoxy for robustness and is attached to the whale with suction cups. A 40' long cantilevered-pole is used to deliver the tag to the whale, minimizing the impact of tagging. Intensive visual and acoustic observations from a nearby research vessel record the social and geographical context of the whales' behavior, before, during, and after tagging. These data are used to measure the sound exposure levels received by a target animal under baseline conditions and during controlled exposure experiments and to document and study its reaction.

The report contains details on these methods, as well as on methods for genetic typing, photo-identification, and habitat characterization.

1.4 Technical Summary

On 16-17 January 2003, the SWSS scientists, MMS managers, and other interested parties met in New Orleans, LA, to discuss plans for the 2003 SWSS field program. Reviews of SWSS and the Sperm Whale Acoustic Monitoring Program (SWAMP; a pilot study conducted in 2000 and 2001) preliminary results were given as background for that meeting and as part of the MMS Information Transfer Meeting (ITM) on 15 January 2003. Synopses of the reviews presented at the ITM are given. These include discussion of sperm whales in the Gulf of Mexico form photo-identification, photogrammetry, acoustic analyses, and observations of medium-scale movements; identifying the seasonal distribution of sperm whales in the Gulf of Mexico with satellite-monitored radio tags; analysis of sperm whale vocalizations from a towed passive acoustic array; synopsis of diving behavior of D-tagged sperm whales; the molecular ecology of sperm whales in the northern Gulf of Mexico; ship and satellite studies of sperm whale habitat; and tracking responses of sperm whales to experimental exposures of airguns.

2 INTRODUCTION

The Sperm Whale Seismic Study (SWSS) is supported by the Minerals Management Service (MMS) of the U.S. Department of the Interior under Cooperative Agreement 1435-01-02-CA-85186 for *Cooperative Research on Sperm Whales and their Response to Seismic Exploration in the Gulf of Mexico*. This report describes the SWSS program and participants and summarizes the data collection and analysis efforts during year 1 of the study.

2.1 SWSS Background and Objectives

MMS has two core responsibilities in managing the Outer Continental Shelf (OCS) activities: safe offshore operations and environmental protection. As part of its environmental responsibilities, MMS seeks "to ensure that all activities on the OCS are conducted with appropriate environmental protection and impact mitigation" (MMS, 2002). Oil and gas activities in the deepwater Gulf of Mexico have increased over the last decade and are projected to continue to increase in coming years. As these activities move into deep water, potential increases for them to occur in regions frequented by the endangered sperm whale.

In 1999, MMS hosted a Gulf of Mexico Protected Species Workshop (McKay *et al.*, 2001). The purpose was to review past research, evaluate new issues, and recommend research priorities. A panel of experts identified the potential effects of noise from seismic operations on sperm whales as a key research priority. MMS, the Office of Naval Research (ONR), and the National Marine Fisheries Service (NMFS) sponsored the Sperm Whale Acoustic Monitoring Program (SWAMP), which was conducted in fiscal years 2000 and 2001 under the MMS Interagency Agreement No. 15958. SWAMP was a pilot study that developed methods and began documenting a baseline on "usual" behavior of sperm whales in the Gulf of Mexico. This study, as well as earlier survey results, indicated that sperm whales tend to be most likely observed near the 1000-m isobath (MMS, 2002). This Interagency Agreement expired on 30 September 2001.

During the January 2002 MMS Information Transfer Meeting, the International Association of Geophysical Contractors (IAGC) hosted a meeting to discuss future acoustic research relevant to seismic operations, and in particular, as related to understanding the effects of seismic exploration on sperm whales in the Gulf of Mexico. IAGC offered its support for sperm whale research through contribution of a seismic source vessel for controlled exposure experiments. In response, the study entitled *Cooperative Research on Sperm Whales and their Response to Seismic Exploration in the Gulf of Mexico* was proposed, under the auspices of the Texas A&M Research Foundation (TAMRF), to the MMS. It was approved by MMS in April 2002. The Cooperative Agreement was finalized in June 2002.

Under the terms of the June 2002 Cooperative Agreement, SWSS is being conducted from April 2002 through April 2005. The study consists of three years of field research with analysis and synthesis to be completed in the fourth year. The study area is primarily the northern Gulf of Mexico (Figure 2.1), with focus on the region immediately off the Mississippi River Delta. The objectives of SWSS are to

(1) establish the "normal" behavior of sperm whales in the northern Gulf of Mexico,
(2) characterize habitat use, and
(3) determine possible changes in behavior of sperm whales when subjected to man-made noise, particularly from seismic airgun arrays.

The primary noise source being evaluated is from airgun arrays used for offshore petroleum exploration.

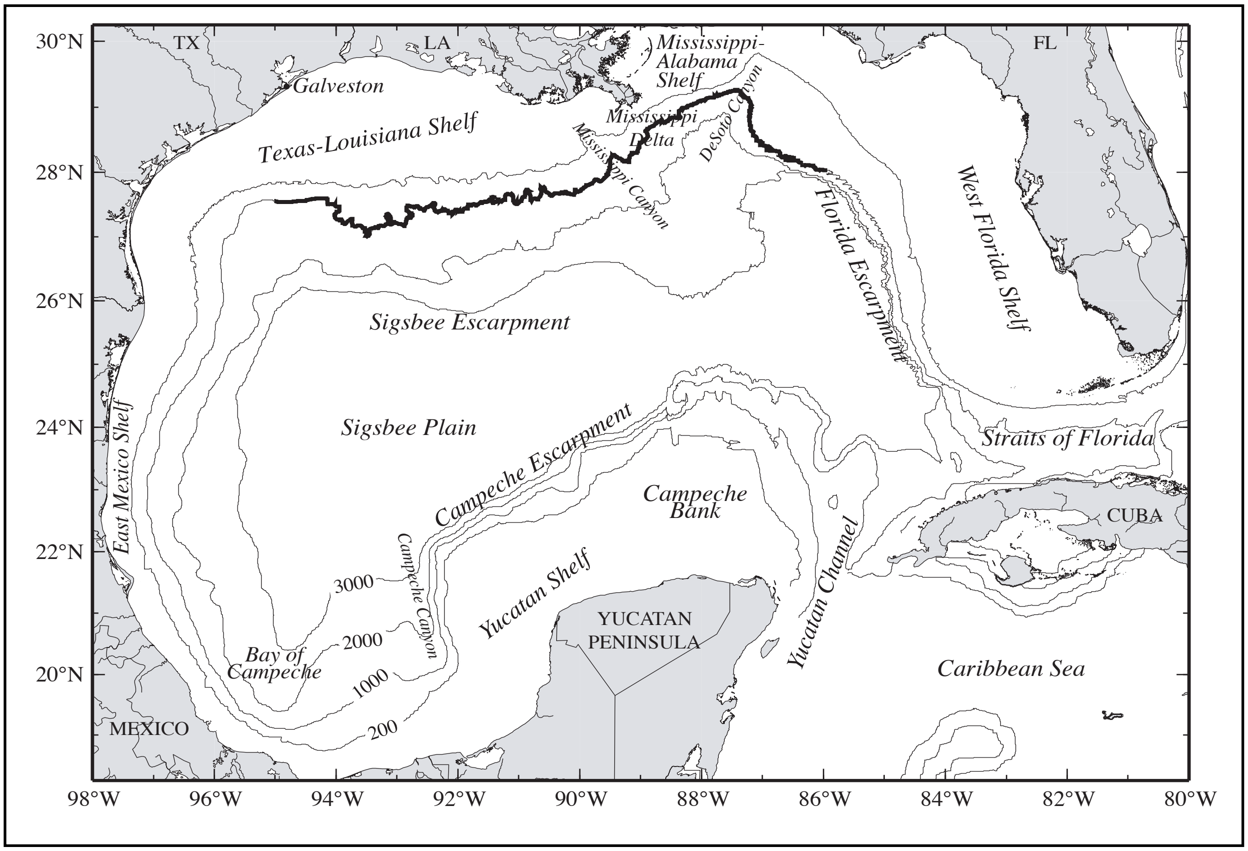


Figure 2.1. Bathymetry and geographical locations in the Gulf of Mexico. The study area was centered about the 1000-m isobath (bold line) approximately between 95°W and 86°W, with a focus between the Mississippi and De Soto canyons.

2.2 Program Participants and Activities

SWSS involves personnel from many groups, including academic and MMS scientists and IAGC engineers. The principal academic scientists are from Ecologic, Oregon State University (OSU), Scripps Institution of Oceanography (SIO), Texas A&M University (TAMU), Texas A&M University-Galveston (TAMUG), University of Colorado (CU), University of Durham (UD), and Woods Hole Oceanographic Institution (WHOI). They develop and conduct the scientific research plans in coordination with MMS, ONR, and IAGC. Table 2.1 identifies these scientists and the tasks for which they are responsible.

In addition to providing funding for SWSS, MMS has substantial direct involvement under this Cooperative Agreement. MMS scientists are actively involved in project oversight and coordination of study activities with academic scientists, ONR, and IAGC, as well as other offshore industry groups. They participate in the cruises on the visual and acoustic teams.

They coordinate the Information Transfer Meeting and internal planning sessions on sperm whales and the SWSS project. Finally they are involved in public outreach related to Gulf of Mexico marine mammals. MMS also is the lead agency for funding and decisions on program activities.

Table 2.1

Major tasks by academic scientists in SWSS

Task	Description	Principal Investigators
Program Management	Management of the program, including scientific, operational, and fiscal; oversight of preparation of deliverables; data management, including data archival	A. Jochens, TAMU, Program Manager D. Biggs, TAMU, Project Scientist M. Howard, TAMU, Data Manager
S-tag Study	S-tag logistics, data collection, data analysis, and reporting for S-tag work	B. Mate, OSU, PI
D-tag Study	D-tag logistics, data collection, data analysis, and reporting for D-tag work	P. Tyack, WHOI, PI M. Johnson, WHOI, co-PI P. Miller, WHOI, co-PI
Genetic Analyses	Skin and biopsy sampling, genetic analyses for group relatedness, and reporting	D. Engelhaupt, UD, PI
Habitat Characterization	Habitat characterization logistics, data collection, data analysis, and reporting for physical and biological habitat characterization	D. Biggs, TAMU, PI A. Jochens, TAMU, co-PI R. Leben, CU, co-PI
Passive Acoustics	Acoustic monitoring, data analysis, and reporting	J. Gordon, Ecologic, PI A. Thode, SIO, PI
Photo Identification/Surface Behavior	Photography and surface observations	J. Gordon, Ecologic, co-PI N. Jaquet, TAMUG, co-PI B. Würsig, TAMUG, co-PI

IAGC provided the seismic source vessel and crew in the first field year. For year 2 and presumably year 3, the IAGC will join a broader industry coalition that will provide similar or greater contributions. The seismic source vessel is a critical contribution to the D-tag effort because it allows controlled exposure experiments with sound from air-guns. IAGC also is working with the industry to develop protocols for reporting operational seismic source vessel locations and related information to SWSS academic scientists for use in the study. SEAMAP, Inc. contributed a hydrophone array for the seismic source vessel in year 1.

ONR provides funding for development of both the S-tags and D-tags used in this study. It also contributed resources, in the form of expendable bathythermographs (XBTs), for the habitat characterization effort to measure the thermal structure that is important for the acoustic and physical investigations in the study area.

In year 2 and anticipated for year 3, the National Science Foundation will provide support through grant support to Lamont Dougherty Earth Observatory (LDEO) for use of the *R/V Maurice Ewing* in D-tag work for SWSS. Coordinated efforts with LDEO to calibrate academic and industry air-gun arrays also are planned.

In addition to program management, SWSS consists of six components: S-tag, D-tag, genetic analyses, habitat characterization, passive acoustics, and photo identification/surface behavior research. These, together with the principal investigators, are listed in Table 2.1. All activities are conducted pursuant to approved permits from NMFS.

The S-tag task is designed to evaluate the seasonal distribution of sperm whales in the Gulf of Mexico. Sperm whales have been sighted in the Gulf of Mexico throughout the year, but little is known about their numbers, site tenacity, and seasonal movements. Under the S-tag task, up to 20 whales per year will be tagged in the northern Gulf of Mexico with a satellite-tracked radio tag (S-tag) that will provide long-term (months) information on surfacing locations of the tagged individuals. Tracking by satellite will be used to help identify behaviors, summer and other seasonal habitats, and, in coordination with the habitat characterization task, associations with oceanographic features.

The D-tag task is designed to quantify diving behavior and vocalizations in Gulf sperm whales and to conduct controlled exposure experiments (CEEs) to measure reactions of these whales to air-gun sounds. A digital acoustic tag (D-tag) will be applied to individual whales to provide intensive, short-term (hours) information on whale swimming behavior and to record underwater noise both from the whale and received noise from the environment. The tag records the sounds heard, and made, by the tagged whale together with its depth and orientation (i.e., pitch, roll, and heading), in a synchronized fashion throughout the dive cycle. Intensive visual and acoustic observations from a nearby research vessel record the social and geographical context of the whales' behavior, before, during, and after tagging. From a baseline understanding of expected sperm whale behavior and preferred habitat, some whales will be tagged with the D-tag and then exposed to sound sources from a seismic vessel provided by IAGC or to other sound sources, such as whale codas, using playback recordings.

The genetic analyses tasks will allow study of groups of sperm whales in terms of relatedness through DNA analyses of skin/tissue samples. Skin and biopsy samples will be taken during the S-tag and D-tag cruises. The genetic analyses will investigate patterns of genetic structure at three hierarchical levels: 1) social structure within and between group and clusters; 2) phylogeographic structure among putative populations within the Gulf; and 3) phylogeographic structure on a global scale incorporating SWSS results with those of previously published studies with a particular focus on incorporating samples collected in the Caribbean Sea, Atlantic, and Mediterranean Sea regions.

The habitat characterization task merges methodologies from biological oceanography, physical oceanography, and remote sensing to provide an interdisciplinary description of the oceanographic habitat in which sperm whales are encountered. As part of the S-tag and D-tag cruises, physical oceanographic and biological data observations are made. At sea measurements include Conductivity-Temperature-Depth (CTD) profiles, expendable bathythermograph (XBT) profiles, current measurements from a 153-kHz acoustic Doppler current profiler (ADCP) and a 38-kHz ADCP, near-surface underway temperature and salinity from a thermosalinograph, and continuous near-surface chlorophyll using a calibrated flow-through fluorometer. Navigation data and station locations are determined using differential Global Positioning System (GPS). Additional Gulf-wide information includes sea surface height fields from satellite altimetry, sea surface temperature fields from satellite AVHRR, and ocean color fields from SeaWiFS.

Visual observations of surface behavior will be coupled with passive acoustic studies of underwater activities of the whales. The passive acoustics will allow the SWSS team to find and follow whales, even at nighttime when visual observations are not made. In addition to visual observations of surface behavior, photographic techniques will be used to identify individuals and measure their lengths. These techniques will allow the improved estimates of the size of the sperm whale population that uses the area south of the Mississippi River Delta and evaluations of their "usual behavior", their site fidelity, and their population structure.

In addition to providing critical support of the tagging and survey efforts, passive acoustic experiments will include methods to estimate whale locations underwater from their sound sources (3-D passive acoustics), use of click intervals to estimate whale size, and evaluation of codas for behavioral analyses.

During the three years of SWSS, field activities will occur mainly during late spring through early fall, with a small component in winter to follow-up on S-tags. The field effort in year 1 consisted of the S-tag cruise (SWSS Leg 1, in June/July 2002), the D-tag cruise (SWSS Leg 2, in August/September 2002), and the follow-up S-tag observations off Louisiana in December 2002 and January 2003 (Table 2.2). The Leg 1 and 2 cruises were aboard the *R/V Gyre*, operated by the TAMU Department of Oceanography. The S-tag follow-up cruises were on fishing vessels out of Venice, LA.

2.3 Report Organization

This is the first annual report of SWSS. It reports on the data-gathering efforts, equipment, measurement and analytical methodologies employed; results of quality control exercises and determinations; status of data archiving and data sharing; and **preliminary** data analysis and results of the various data types collected. **There are no extensive analyses or syntheses of the information**; such will be provided in the final Synthesis Report at the conclusion of SWSS.

Section 1 of this report is the executive summary. Section 3 details the data acquisition of the tag measurements, visual and acoustic observations, genetic samples, and physical and biological oceanographic data. Section 4 discusses instrumentation and data quality and analysis for the observations collected, including data processing efforts and data quality control methods and results. In Section 5 is presented brief technical discussion of the data, with samples of data products for the various data types. All times are reported in Universal Coordinated Time (UTC) unless stated otherwise. References are provided in Section 6.

Table 2.2

Cruise leg identifiers and dates

Leg No.	Start Date	End Date	SWSS ID	Cruise ID
1	19 June 2002	9 July 2002	S-tag	02G08
2	19 August 2002	15 September 2002	D-tag	02G11
	6 December 2002	8 December 2002	S-tag follow-up	*
	18 January 2003	2 February 2003	S-tag follow-up	**

* conducted from the fishing vessels *Delta Dawn* and *Prime Time*, out of Venice, LA
** conducted from the fishing vessel, *Prime Time*, out of Venice, LA

3 DATA COLLECTION CRUISES

Section 3 provides an overview of the SWSS data collection activities from April through December 2002. It describes data gathering efforts on the cruises. Information on the instrumentation and data processing procedures are given in Section 4.

The field cruises conducted in 2002 consisted of the SWSS field cruise in two legs aboard the *R/V Gyre* and follow-up cruises from small fishing vessels. The first leg was the S-tag cruise in June/July. This was followed by the D-tag cruise in August/September. The S-tag follow-up cruises were in December. Additional S-tag follow-up cruises were conducted in January 2003, but these will be reported on in the next annual report. Each cruise is described below.

3.1 S-tag Leg of SWSS 2002

The first leg of the 2002 field cruise was conducted on the *R/V Gyre* from 19 June through 9 July 2002. It was staged out of Galveston, TX, and ended in Gulfport, MS. Dr. Douglas C. Biggs of TAMU was the Field Party Chief. Dr. Bruce R. Mate of OSU was in charge of S-tag activities. Table 3.1.1 lists the cruise participants and their roles.

The S-tag field program was designed to find and tag sperm whales with satellite tags that would enable monitoring of whale locations for up to a year to provide information on the distribution and behavior of sperm whales in the Gulf of Mexico. Additionally, biopsy samples were collected for genetic study, fluke photographs were taken for identification of individual sperm whales and to augment the existing database of fluke photographs from Gulf of Mexico sperm whales, and physical and biological measurements were made for sperm whale habitat characterization.

Operations were conducted generally in accordance with the S-tag cruise plan of 7 June 2002. On leaving Galveston, TX, the *Gyre* headed southward to approximately 94.7°W and the 1000-m isobath. The cruise track is shown in Figure 3.1.1. The S-tag team then surveyed for sperm whales along the middle continental slope to approximately 86.4°W. Although the ship track was centered on the 900-1000-m isobaths, the survey generally followed a zig-zag course between water depths from 575-820 m to 1125-1430 m. Additionally, once the ship reached the region near the mouth of the Mississippi River and east, the course of the track was largely dictated by the locations of sperm whales and tagging activities.

Both passive acoustics and visual observations were used to search for sperm whales. One to two hydrophones were towed continuously and monitored, usually day and night, for sperm whale sounds. Over 400 hours of acoustic observations were made, yielding acoustic contacts with sperm whales as shown in Figure 3.1.2a. Three pairs of BigEye binoculars were used during daylight (generally 06:30 to 19:30 CDT) for spotting sperm whales. These were mounted on the flying deck of the *Gyre* to provide an unobscured view from the highest deck on the ship. Over 200 hours of visual observations were made, resulting in the visual contacts and tracking as shown in Figure 3.1.2b.

When constructed in 1973, the *Gyre* was not specifically designed to be a quiet ship, so when towing Ecologic or WHOI arrays the *Gyre* engine noise and other ship noises limited the ability of observers to hear whales unless animals were within a few kilometers. Nonetheless, most encounters with whales were initiated acoustically. It soon became evident, on days when the weather was favorable but whales had not been located by the *Gyre*, that the search effort could be increased dramatically by dispatching either one, or both, of the rigid-hulled inflatable boats (RHIBs) to monitor acoustically ahead or abeam of the *Gyre*, using directional hydrophones.

Table 3.1.1

The SWSS 2002 cruise, Leg 1, S-tag science team

Description	Person (Institutional affiliation)
Field Party Chief	Doug Biggs (TAMU College Station)
Electronics Technicians	Eddie Webb (TAMU College Station) Paul Clark (TAMU GERG)
Deck Engineers	Bill Green (TAMU Galveston) Mike Fredericks (TAMU GERG)
S-tag Team	Bruce Mate (OSU Newport) * Mary Lou Mate (OSU Newport) Ladd Irvine (OSU Newport) Daniel Palacios (OSU Newport)
Visual Team	Nathalie Jaquet (TAMU Galveston) * Joel Ortega (TAMU Galveston) Christoph Richter (Canada) Will Rayment (New Zealand) Jamie McKee (SAIC) Erin LaBrecque (New Hampshire) Larry Glickman (Oregon)
Acoustic Team	Jonathan Gordon (Ecologic UK) * Sarah Tsoflias (MMS New Orleans) Ricardo Antunes (Madeira, Portugal) Reuben Heule (Netherlands) Dan Lewer (OSU Newport)
Photo ID Team	Jonathan Gordon (Ecologic UK) Nathalie Jaquet (TAMU Galveston)
Biopsy/Genetic Typing	Dan Engelhaupt (Durham Univ UK)
Flow Through Fluorescence/CHL	Alicia Salazar (TAMU College Station)
Videography **	Terry Ketler Productions (San Francisco)

* Team Leader
** Complimentary Program, added at no cost to MMS since bunk space #24 was available
GERG is the Geochemical and Environmental Research Group at TAMU

When operated in this mode, the RHIBs greatly extended the effective acoustical swath. While this RHIBs-as-acoustic-spotter-boats scenario had not been anticipated before this cruise, by the midpoint of the cruise two omni-directional hydrophone systems were constructed using spare equipment that was on hand. Use of these omni-directional hydrophones, along with use of one of the directional hydrophones, allowed reasonably effective away-from-the-mother-ship monitoring from the RHIBs.

In addition to acoustically monitoring for cetacean vocalizations, the presence of anthropogenic noise also was noted. The *Gyre*'s own engine and prop sound masked many sources of anthropogenic noise, but seismic shots were a prominent part of the acoustic scene and were detected at a number of the stations. Opportunistic acoustic monitoring from the RHIBs near platforms and other rigs detected strong tonal sounds that may have resulted from drilling or other anthropogenic operations.

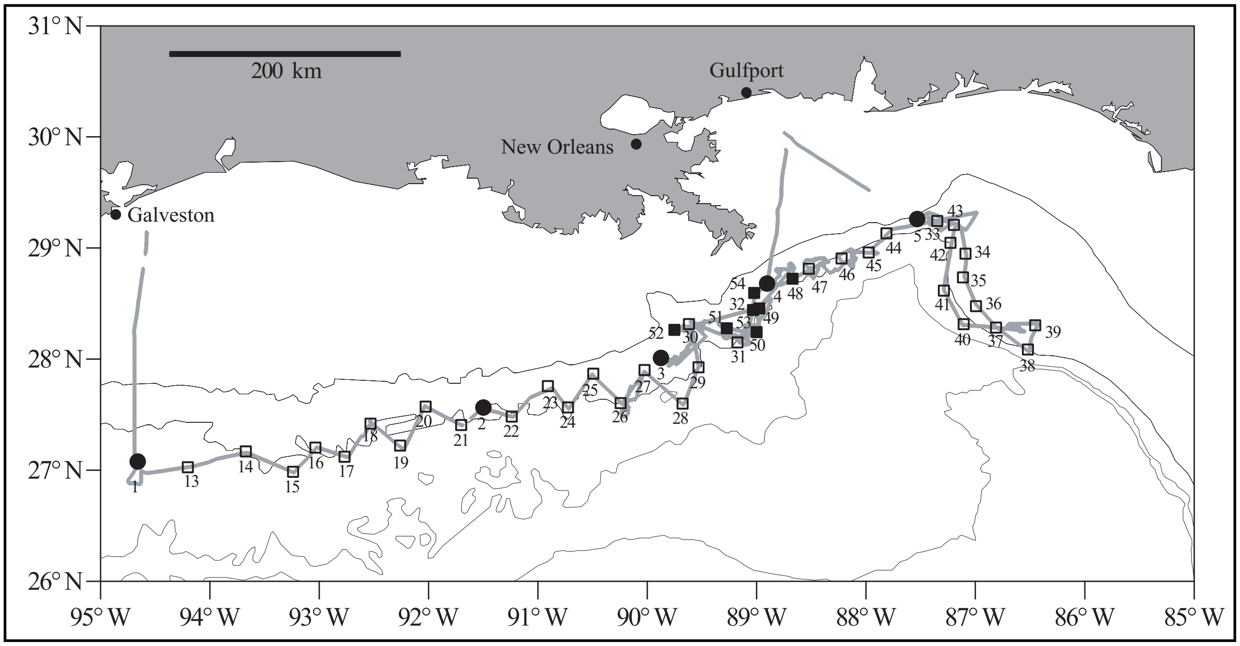


Figure 3.1.1. S-tag cruise track (thick gray line) for June/July 2002. Location of CTD (circles), T7 XBT (open squares), and T10 XBT (filled squares) stations during the cruise. Depth contours are 200, 1000, 2000, and 3000 m.

Eighteen days were spent along the middle continental shelf. During that time, sperm whales were encountered only when the ship was between 89.9°W and 87.1°W. Although there were reports of sperm whales west of 89.9°W, none were encountered. The whales observed were either individuals (two encounters with lone males) or in dispersed groups of 5 to more than 13 animals. Although most of the whales were seen in water depths of 900-1000 m, they also were encountered in water depths both shallower (to 700 m) and deeper (to 1300 m).

Once sperm whales were located, the OSU tag boat, *Puffin* (RHIB-1), was lowered from the *Gyre* into the sea. The tag boat then transited to the whales, keeping always within visual and radio contact with the *Gyre* for safety. Whales were tagged using a compressed air tag delivery system. Eighteen sperm whales were tagged with satellite transmitting tags. Sixteen of the tags were fully deployed and so securely attached; the other two were 40-50% deployed. Figure 3.1.3a shows the locations at which the whales were tagged. Tagging was done between the western edge of the Mississippi Canyon and DeSoto Canyon, with the majority of the tags applied south and southeast of the Mississippi Delta. Table 3.1.2 shows the locations, dates, and times of the tagging.

The air applicator system worked extremely well. In general, tags were placed within 6 inches of the mid-line along the whale's back between the middle of the base of the dorsal fin and 18" forward of the dorsal fin. This is an area that surfaces quite regularly and should provide good numbers of uplink messages during satellite passes when whales are at the surface. High-speed (fast shutter speed) video of each tag application revealed the causes of the two tags deploying incompletely. This enabled appropriate adjustments in hardware and technique to be made in the field. Both of the two incompletely deployed tags were well placed on the whales' backs, and both had good antenna orientation.

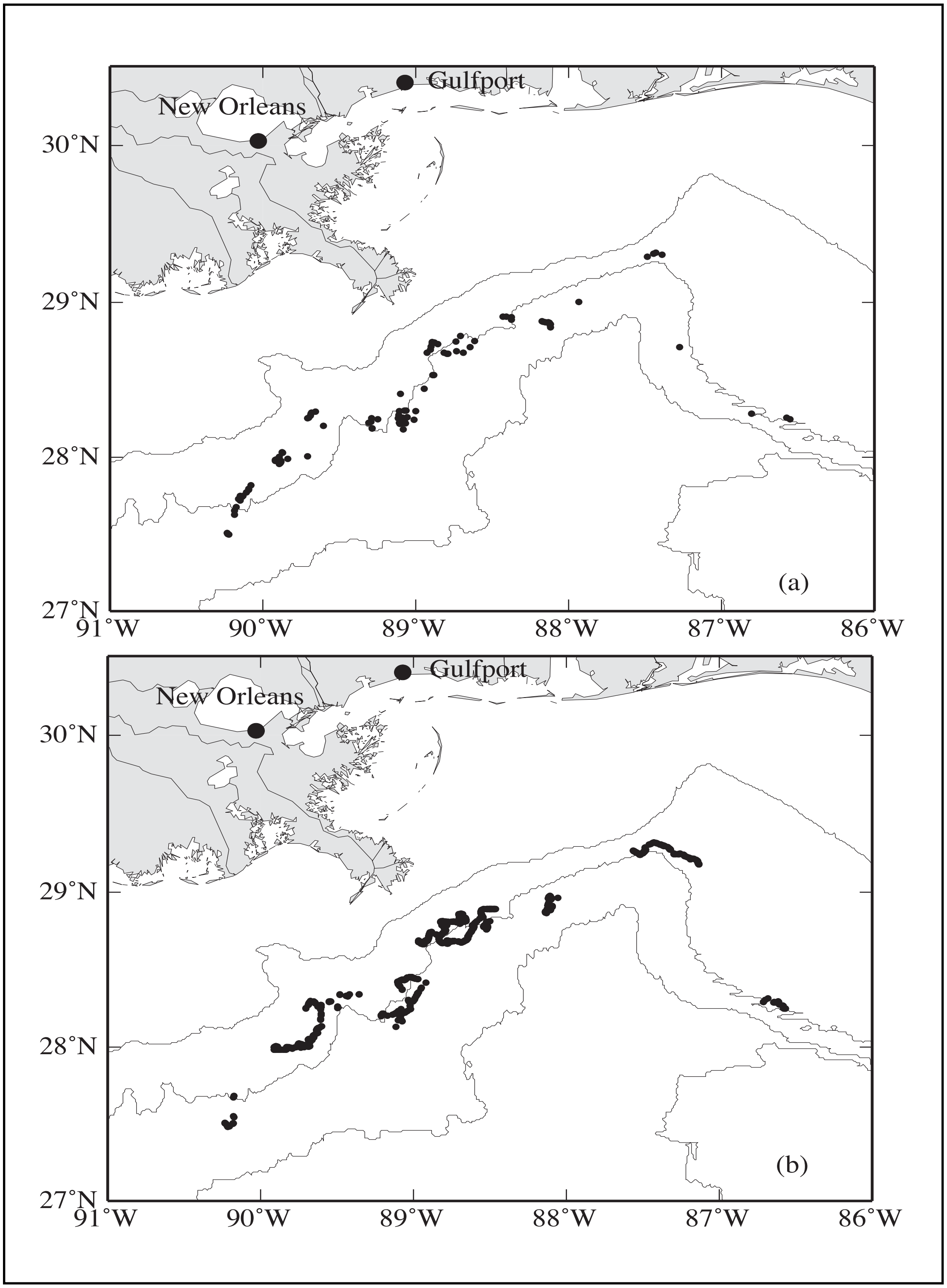


Figure 3.1.2. Locations of (a) acoustic contacts with sperm whales and (b) visual contacts and tracking of sperm whales during SWSS cruise Leg 1, S-tag, June/July 2002. Bathymetry contours are 200, 1000, 2000, and 3000 m.

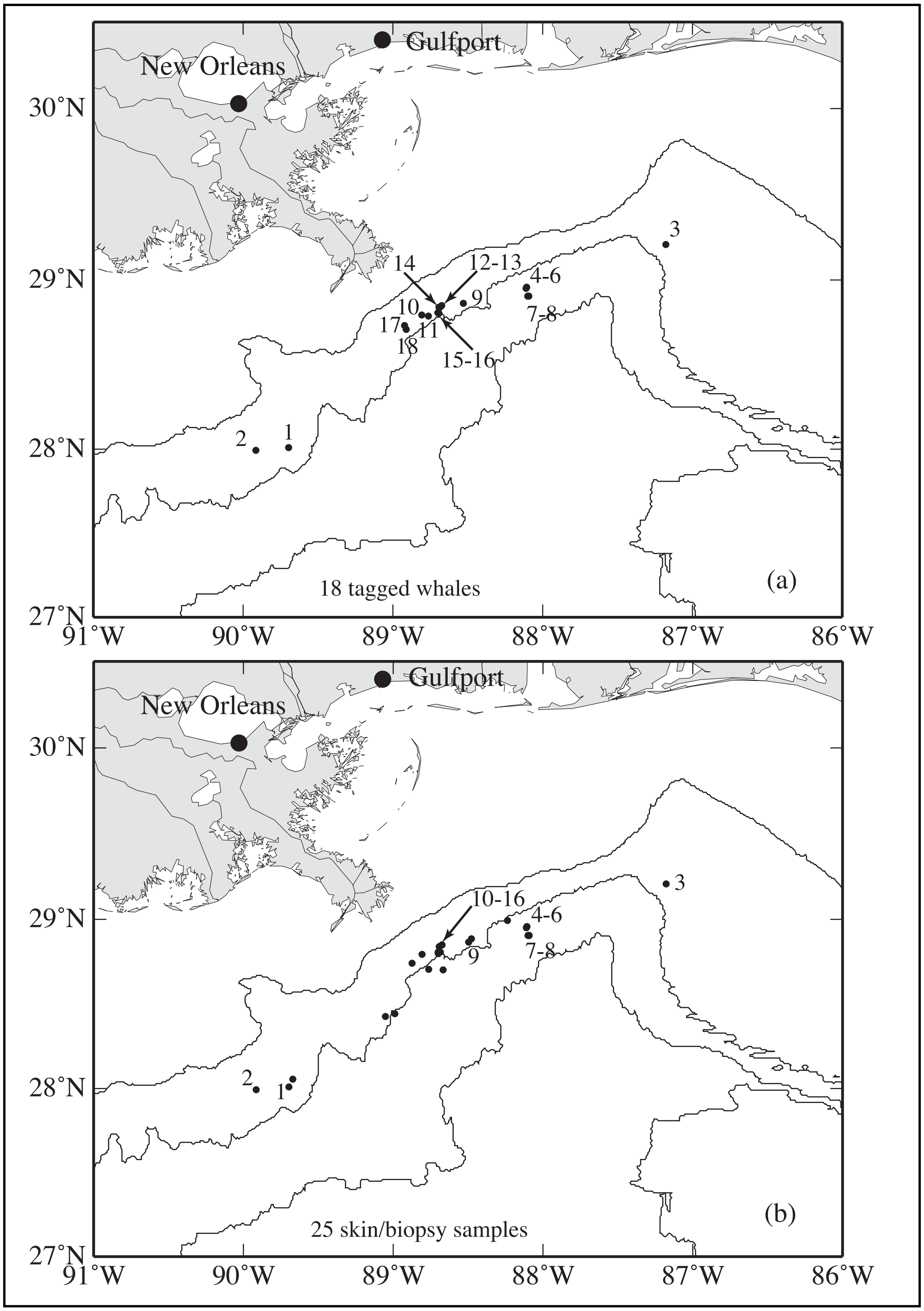


Figure 3.1.3. Locations where (a) sperm whales were tagged with satellite tags and (b) skin samples were taken during S-tag, June/July 2002. The tag number is shown for tagged whales. Bathymetric contours are 200, 1000, 2000, and 3000 m.

Table 3.1.2

Locations, dates, and times of the tagging of sperm whales with S-tags

Latitude (°N)	Longitude (°W)	Date (mm/dd/yyyy)	Time (UTC)	Tag No.	PTT No.
28.0117	-89.6960	06/24/02	18:36	1	5660
27.9937	-89.9135	06/24/02	23:06	2	5654
29.2078	-87.1783	06/26/02	23:03	3	5648
28.9578	-88.1092	07/01/02	19:35	4	5685
28.9562	-88.1088	07/01/02	19:48	5	5650
28.9512	-88.1125	07/01/02	20:16	6	5726
28.9030	-88.0988	07/01/02	21:40	7	5725
28.9028	-88.0923	07/01/02	21:58	8	5647
28.8603	-88.5290	07/02/02	23:10	9	5678
28.7937	-88.8082	07/03/02	15:24	10	5719
28.7883	-88.7640	07/03/02	16:49	11	5709
28.8395	-88.6915	07/03/02	19:48	12	5670
28.8503	-88.6733	07/03/02	20:09	13	5720
28.8385	-88.6865	07/03/02	20:47	14	5655
28.8042	-88.6932	07/03/02	23:07	15	5669
28.8050	-88.6982	07/03/02	23:42	16	5701
28.7323	-88.9230	07/07/02	19:25	17	5710
28.7077	-88.9110	07/07/02	20:20	18	5649

The tags were set for a duty cycle that allowed them to transmit for 4 pre-selected hours every third day for the first 54 days. Starting 5 days before the D-tag cruise, the tags started transmitting 4 hours/day on a daily basis to provide the D-tag group with detailed information on whale locations for cruise planning and operations. Following the D-tag cruise, satellite tags were set to transmit 4 hours/day every fourth day. This duty cycle was selected to extend the operational life of the tags to allow documentation of longer-range seasonal movements.

Argos orbits only last for maximum of 16 minutes overhead (10 minute average), while whales dive for 40 minutes and are at the surface for only about 10 minutes between dives. Thus, on average, whales are only at the surface and available to transmit for 20% of the time. It is not unusual that many fully-functional tags will not be heard during any specific duty cycle.

Whales were encountered only infrequently during the first week of the cruise. During this first week, tagging operations also were hampered with swells large enough to prevent launching RHIB-1 because of risk of damage to its bow pulpit should either RHIB-1 or mother ship surge during the over-the-side deployment of the RHIB-1. During week 2, when the eastern extremity of DeSoto Canyon was being surveyed, calm weather did not coincide with whale sightings. Good concentrations of whales were encountered during the third week of the cruise. On calm weather days, up to 7 whales were tagged in a single day. Tags were applied in sea states up to Beaufort 4, winds up to 15 knots, and swells up to 3 feet. Beyond these conditions, tag application was impossible.

Immediately after tagging, an attempt was made to collect a biopsy sample using crossbow propelled darts. The samples were small plugs of tissue taken from the underside of the flukes or behind the dorsal hump. Samples were collected from both tagged and untagged whales. Twenty-five samples were collected, 16 of which were from whales tagged with S-tags. Figure 3.1.3b shows the locations, and Table 3.1.3 lists the dates, locations, tag number if applicable, group number, and the approximate number of whales in the group.

Biopsy sampling during the satellite-tagging cruise exceeded all expectations. Skin and blubber samples from fifteen of eighteen individual sperm whales outfitted with OSU satellite tags were obtained with sterilized darts. Although biopsy sampling and tagging operations were most successful on sperm whales occupying deepwater areas throughout the Mississippi River Canyon, samples also were collected from whales in the DeSoto Canyon (Table 3.1.3). During tagging approaches, whales' sizes were estimated and a decision was made to either proceed with tagging or switch to a biopsy-only approach for immature whales too small to tag. In all, a total of twenty-five skin samples were collected during the S-tag cruise. Given the amounts collected per biopsy, all tissue samples obtained are expected to provide more than ample material for all genetic applications.

The combination of satellite tagging and genetic techniques will provide an in-depth examination of sperm whales found in the northern Gulf of Mexico. Molecular sexing, microsatellites, and mitochondrial DNA sequencing will provide a rich set of information that can be directly integrated with the movements of satellite tagged whales. A biopsy sample was obtained from multiple members of six groups. Several of these sampled individuals had satellite tags to match. Degrees of relatedness will be tested between whales found within these groups, allowing us to begin to answer questions such as how related and unrelated whales found within groups in the northern Gulf of Mexico maintain long-term close associations over space and time. In an ideal situation, one would attempt to sample all members that comprise a group. Given this year's primary focus on the satellite tagging effort, this was not possible. While our resulting genetic composition of groups may not portray an accurate representation of group structure for free-ranging sperm whales found in the Gulf of Mexico, the benefits of combining biopsy sampling and satellite tagging will supply numerous answers to previously unknown questions.

A second small boat, RHIB-2, was launched to support the RHIB-1 tag boat whenever sperm whales were sighted. RHIB-2 was crewed by two and sometimes three members of the scientific party who were experienced in driving small boats close to whales, tracking whales using a directional hydrophone, and taking identification photographs. A directional hydrophone was used from RHIB-2 to track whales acoustically. This provided fine-scale information on the location of submerged whales, thus allowing the tag boat (RHIB-1) to be close to whales when the animals surfaced. This proved to be very effective, and allowed both RHIBs and the *Gyre* to stay close to groups of whales.

The RHIB-2 crew generally stayed close to RHIB-1 to take identification photographs of whales once they were tagged. Identification photographs were taken using a digital EOS 1D Canon Camera with a Sigma 100-300 mm telephoto lens. In addition, photo-ID images were taken from RHIB-1 using a conventional SLR. Ranges to flukes were measured using Bushnell or Leica laser range finders. This is one of the first times that a digital camera has been used to take sperm whale photo-identification images. The system proved excellent. It offered many advantages over traditional film photography, including the ability to take detailed sequences of each fluke up and to review photographic data and maintain the photo-catalogue at the end of each working day.

Table 3.1.3

Biopsy/genetic typing tissue samples collected during S-tag fieldwork
(The sample number gives the date (yymmdd) followed by the consecutive number for multiple samples taken on any given day (01 to 08). Samples from tagged whales are indicated.)

Sample No.	**Tag No.**	**Group No.**	**Approx. Number of Whales in Area**	**Longitude (°W)**	**Latitude (°N)**
02062401		1	8	-89.6690	28.0557
02062402	5660	1	8	-89.6960	28.0117
02062403	5654	1	8	-89.9135	27.9937
02062801	5648	2	8	-87.1783	29.2078
02070101	5685	3	15-20	-88.1092	28.9578
02070102	5650	3	15-20	-88.1088	28.9562
02070103	5726	3	15-20	-88.1125	28.9512
02070104	5725	3	15-20	-88.0988	28.9030
02070105	5647	3	15-20	-88.0923	28.9028
02070106		3	15-20	-88.0923	28.9028
02070201	5678	4	8	-88.4957	28.8660
02070202		4	8	-88.4777	28.8840
02070301	5719	5	6-11	-88.8082	28.7937
02070302	5709	5	6-11	-88.7640	28.7050
02070303	5670	5	6-11	-88.6915	28.8395
02070304	5720	5	6-11	-88.6733	28.8503
02070305		5	6-11	-88.6733	28.8503
02070306	5670	5	6-11	-88.6990	28.7993
02070307	5701	5	6-11	-88.6982	28.8050
02070308	5669	5	6-11	-88.6837	28.8078
02070601		6	6-8	-89.0502	28.4258
02070602		6	6-8	-88.9907	28.4447
02070701		7	14-16	-88.6653	28.7012
02070702		7	14-16	-88.8750	28.7417
02070801		8	6	-88.2387	28.9920

Each evening the day's photos were matched against a set of 2500 photos of sperm whale flukes in the North Atlantic and Mediterranean Sperm Whale Catalogue (NAMSC) of fluke photos. This was both to find possible matching photographs and also to test performance, ease of use, clarity of the interface, and logic of the data handling procedures. On a dedicated photo-ID project, such immediate information on the identity of individuals could be used to best direct subsequent days' survey effort.

Forty-seven good quality (Q≥3) identification photographs were taken and 32 different individuals were identified. Photo-identification of individual whales was not a priority during the S-tag cruise and could only be conducted opportunistically, which explains the low number of new whales identified. Prior to 2002, the Gulf of Mexico catalogue contained only 58 different individuals, so the 32 new individuals identified by RHIB-2 during the S-tag cruise represents a significant contribution to the catalogue and to our knowledge of the Gulf of Mexico sperm whale population. Furthermore, 18 good quality photographs (Q≥3) were taken by RHIB-1 allowing the identification of another 11 different individuals. Four to five S-tagged sperm whales were photo-identified. The main reason for the low success of the photo-identification work was that sperm whales very rarely fluked after being tagged; additionally, due to the proximity of many other whales, it was not possible to track the tagged whale acoustically during an entire dive cycle.

The images have been contributed to the NAMSC. Table 3.1.4 gives the locations, dates, times, and other pertinent information of the photos taken for photo-identification (51 total by the TAMUG/Ecologic, or T/E, team including 4 resights of Q=2) and for the S-tagging process (20 total by the OSU team including 2 resights of Q=2). A map with locations is given in Figure 3.1.4.

Experience indicated that more tagged whales were successfully photo-identified, including tag attachment photos, when RHIB-2 was used simply to take as many identification photographs of as many whales as possible rather than when RHIB-2 operated exclusively in close proximity to RHIB-1. The S-tag cruise experience also indicated that the use of one or more RHIBs with support from a visual team equipped with BigEye binoculars operating from an elevated platform on a mother vessel could be an effective way of collecting photo-ID material with Gulf of Mexico sperm whales.

The opportunity to test beta versions of two new programs for automated photo-identification of sperm whales was pursued on the S-tag leg. One program, temporarily named "Phlukes", assists the user in extracting the identifying contour of the fluke from the photograph. The other program, temporarily named "Match", finds contours similar to those of the target image from a collection of contours previously extracted from a collection of photos. Both programs are written in Java and are being developed within "Europhlukes", an EU-funded project under the direction of Reuben Huele that will set up a European database of cetacean images.

All S-tag, photo-ID, and biopsy/genetic typing activities were conducted in accordance with federal permits from the U.S. National Marine Fisheries Service to Oregon State University (permit 365-1440-01), to Texas A&M University-Galveston (permit 821-1588-00), and to Dan Engelhaupt/University of Durham (permit 909-1465-01).

In addition to observations of sperm whales, the cruise collected physical and biological observations to allow characterization of the habitat. Sea surface height (SSH) fields were obtained once per week before and during the cruise and used to identify circulation features near the whales. Figure 3.1.5 shows the pre-cruise SSH field for 9 June 2002. It indicated that the circulation over the middle continental slope would be cyclonic (counterclockwise) both west of ~92°W and east of ~89°W. It also indicated that an anticyclonic (clockwise circulation) warm slope eddy was present between 92°W and 89°W, separating the two regions of cyclonic circulation. This cyclonic-anticyclonic-cyclonic triad would tend to advect high salinity, low chlorophyll, "blue" water onto the margin near 92°W and to entrain and transport low salinity, higher chlorophyll, "green" water from the shelf off the margin near 89°W. Subsequent SSH fields showed a similar configuration, although with some weakening of the cyclonic circulation in the east. Data from the *in situ* stations (identified below) generally confirmed the circulation pattern indicated by the SSH fields.

Five CTD stations were made. Thirty-five T7 XBTs were dropped to profile temperature in the upper 760 m, and seven supplemental drops were made with T10 XBTs to collect additional data from the upper 200 m. Figure 3.1.1 shows a map of the locations of the CTD and XBT stations. Table 3.1.5 shows the locations, date, times, total water depth, and depth of the 15°C isotherm for the CTD and XBT stations. Through the passive acoustic monitoring, sperm whales were detected at or near about 25% of the CTD/XBT stations.

Table 3.1.4

Locations and dates of scientific photographs of sperm whales
(The teams taking the photographs were Oregon State University (OSU) for use in assessing S-tag success and Texas A&M University-Galveston and Ecologic (T/E) for use in photo-identification. The ID exposure is the reference number of the photograph. The Q value denotes the quality of the picture following Arnbom 1987, with highernumbers indicating better quality. The preliminary names given in plain text are the best photos for each individual and those in italics are resights. Whale NN2 was identified as a male.)

Longitude (°W)	**Latitude (°N)**	**Date**	**Time of Fluke Up (CDT)**	**Photo Team***	**ID Exposure**	**Q value**	**Prelimi-nary Name**
-89.6520	28.0945	06/24/2002	10:46	T/E	326	4	MTL 1
-89.6615	28.0587	06/24/2002	11:46	T/E	328	3	MTB 1
-89.6700	28.0600	06/24/2002	12:43	OSU	Film 1/Exp 6	3	HR 4
-89.6952	28.0397	06/24/2002	12:46	T/E	333	2	*HL 1*
-89.8188	27.9998	06/24/2002	16:13	T/E	345	3	HL 1
-89.7318	28.0068	06/25/2002	14:41	T/E	356	3	HL 2
-89.7363	28.0022	06/25/2002	14:52	T/E	359	5	HR 1
-89.0993	28.1693	06/26/2002	09:36	T/E	367	5	MTB 2
-87.4507	29.2860	06/28/2002	11:04	T/E	385	3	*SNB 1*
-87.4273	29.2982	06/28/2002	11:40	T/E	392	5	*HL 3*
-87.3800	29.3000	06/28/2002	12:35	OSU	Film 3/exp 13	2	*HL 3*
-87.3560	29.2873	06/28/2002	13:10	T/E	404	3	*SNB 1*
-87.3138	29.2672	06/28/2002	14:13	T/E	413	4	SNB 1
-87.2787	29.2512	06/28/2002	15:18	T/E	441	5	HL 3
-87.2100	29.2200	06/28/2002	17:05	OSU	Film 3/Exp 28	4	SNR 6
-87.1800	29.2100	06/28/2002	18:13	OSU-Video	T292AC~1	3	NN 4
-87.1802	29.1923	06/28/2002	18:14	T/E	477	4	MTL 2
-88.0742	28.9127	07/01/2002	12:16	T/E	618	2	*MTR 1*
-88.0875	28.9022	07/01/2002	17:13	T/E	636	3	MTR 1
-88.5513	28.7707	07/02/2002	14:14	T/E	732	4	SS 1
-88.5300	28.7800	07/02/2002	16:17	OSU	Film 5/ Exp 15	3	*SS 1*
-88.5318	28.8612	07/02/2002	17:54	T/E	752	3	*MTL 3*
-88.5318	28.8612	07/02/2002	17:54	T/E	759	3	*MTB 4*
-88.4803	28.8978	07/02/2002	19:02	T/E	822	5	LNB 1
-88.4760	28.8988	07/02/2002	19:11	T/E	854	5	SNR 1
-88.4800	28.8800	07/02/2002	19:22	OSU	Film 8/Exp 1	3	MTR 4
-88.7903	28.7522	07/03/2002	08:47	T/E	874	3	*MTR 2*
-88.7953	28.7635	07/03/2002	09:22	T/E	883	3	MTB 3
-88.7900	28.7700	07/03/2002	09:29	OSU-Video	T4_7-0~1	3	*HL 4*
-88.7800	28.7800	07/03/2002	09:40	OSU	Film 8/Exp 17	2	*LNB 2*
-88.8052	28.7970	07/03/2002	10:39	T/E	892	4	SNR 2
-88.8047	28.7978	07/03/2002	10:40	T/E	897	3	LNL 1
-88.7900	28.8000	07/03/2002	11:15	OSU	Film 8/Exp 33	4	*MTB 3*
-88.7800	28.7900	07/03/2002	11:33	OSU	Film 6/Exp 1	4	*HL 4*
-88.7675	28.7878	07/03/2002	11:46	T/E	901	4	MTR 2
-88.7643	28.7872	07/03/2002	11:52	T/E	913	4	LNB 2
-88.7705	28.7770	07/03/2002	12:21	T/E	923	2	*MTB 3*
-88.7500	28.7800	07/03/2002	12:18	OSU	Film 6/Exp 8	3	HL 5
-88.7500	28.7800	07/03/2002	12:18	OSU	Film 8/Exp 9	3	NN 3
-88.6600	28.8100	07/03/2002	13:26	OSU-Video	T5_7-0~2	3	*MTB 4*
-88.6647	28.8193	07/03/2002	13:30	T/E	930	3	*LSR 1*
-88.6760	28.8240	07/03/2002	13:44	T/E	934	4	MTL 3

Table 3.1.4

Locations and dates of scientific photographs of sperm whales (continued)

Longitude (°W)	**Latitude (°N)**	**Date**	**Time of Fluke Up (CDT)**	**Photo Team***	**ID Exposure**	**Q value**	**Preliminary Name**
-88.6725	28.8373	07/03/2002	14:38	T/E	945	4	HR 2
-88.6935	28.8325	07/03/2002	15:18	T/E	952	3	*LSR 1*
-88.6700	28.8400	07/03/2002	15:40	OSU	Film 7/Exp 5	3	MTB 5
-88.6708	28.8072	07/03/2002	16:37	T/E	974	5	NN 1
-89.4535	28.3317	07/04/2002	11:36	T/E	1031	4	*NN 2**
-89.5317	28.2955	07/04/2002	14:03	T/E	1036	5	NN 2
-89.5733	28.2907	07/04/2002	15:24	T/E	1043	4	*NN 2*
-89.6632	28.2822	07/04/2002	17:47	T/E	1053	4	*NN 2*
-89.6997	28.2782	07/04/2002	18:49	T/E	1062	4	*NN 2*
-88.9974	28.3293	07/05/2002	10:58	T/E	1071	3	SNR 3
-89.0153	28.2985	07/05/2002	12:06	T/E	1128	2	*SNR 3*
-89.0600	28.2300	07/05/2002	14:43	OSU	Film 9/Exp 25	3	HR 5
-89.0930	28.4185	07/06/2002	15:09	T/E	1283	3	SNR 4
-89.0500	28.4300	07/06/2002	16:20	OSU	Film 9/Exp 28	3	SNL 1
-89.0300	28.4300	07/06/2002	16:47	OSU	Film 10/Exp 3	3	SNL 2
-89.0200	28.4200	07/06/2002	17:09	OSU	Film 10/Exp 9	3	LNL 2
-88.9842	28.4340	07/06/2002	18:11	T/E	1334	3	MTL 4
-88.6400	28.7100	07/07/2002	09:42	OSU	Film 10/Exp 27	3	*HR 2*
-88.6400	28.7000	07/07/2002	10:01	OSU	Film 10/Exp 31	3	*MTB 4*
-88.6677	28.6990	07/07/2002	10:26	T/E	1458	3	*LSR 1*
-88.7645	28.6892	07/07/2002	12:26	T/E	1476	4	HL 4
-88.9398	28.6770	07/07/2002	16:20	T/E	1527	3	*MTL 4*
-88.9293	28.6835	07/07/2002	16:45	T/E	1535	3	SNR 5
-88.9293	28.6835	07/07/2002	16:45	T/E	1546	5	LNR 1
-88.9382	28.6707	07/07/2002	17:26	T/E	1607	3	*HR 2*
*	*	07/07/2002	18:20	T/E	1616	3	MTB 4
*	*	07/07/2002	19:08	T/E	1625	5	LSR 1
-88.2095	28.8948	07/08/2002	10:03	T/E	1631	3	HR 3
-88.2440	28.9387	07/08/2002	13:12	T/E	1660	3	LSB 1

* Computer crash, so locations lost

Near-surface water was pumped from the ship's hull depth of 3.5 m through SeaBird temperature and conductivity sensors and a Turner Designs Model 10 fluorometer to log surface temperature, salinity, and chlorophyll fluorescence approximately once per minute. To provide data with which to calibrate the flow-through fluorometer data, 82 water samples from the flow-through stream were collected and filtered (Figure 3.1.6). The filters then were analyzed for chlorophyll using extraction methods and a Turner Designs Model 10. Sixty-one samples were taken during the S-tag cruise and twenty-one were taken after the cruise when *Gyre* was in transit from Gulfport, MS, to Galveston, TX. Table 3.1.6 gives the locations, dates, times, fluorescence values, and extracted chlorophyll values for these samples.

Ocean current velocity in the upper 300 m was monitored continuously with a hull-mounted 150 kHz ADCP. Figure 3.1.7 (upper) shows the locations with good 153-kHz ADCP data. Figure 3.1.7 (lower) shows processed current velocity vectors at the 13.6-m depth along the cruise track.

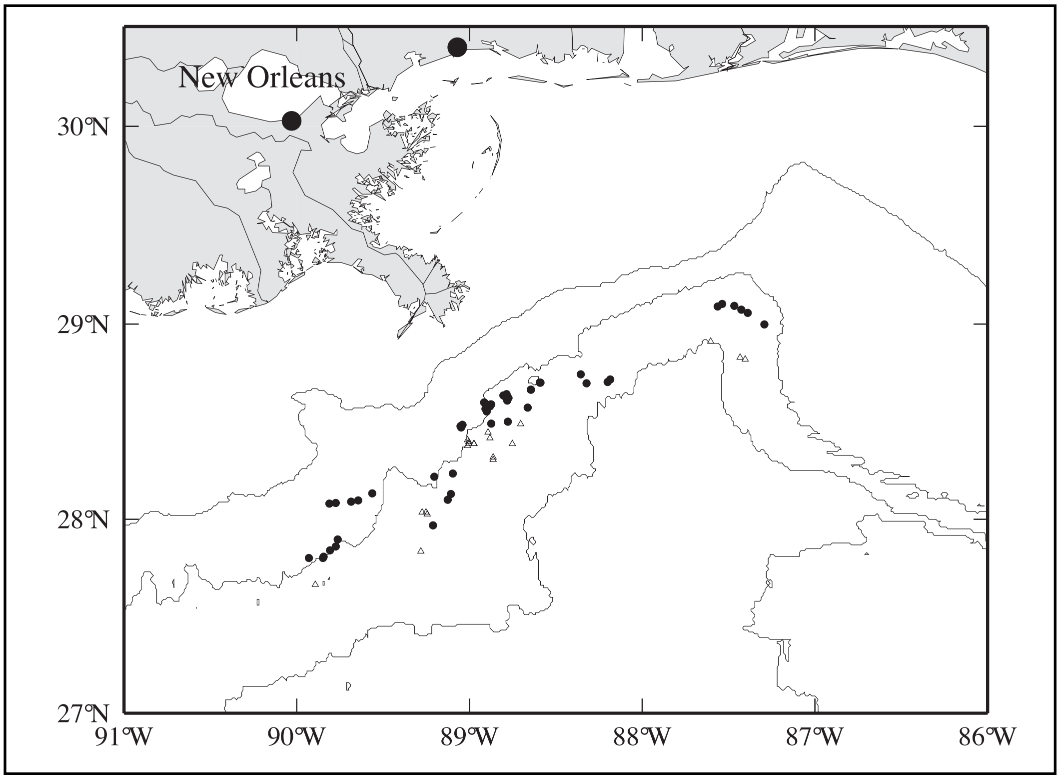


Figure 3.1.4. Locations at which photographs were taken for photo-identification during SWSS cruise Leg 1, S-tag, June/July 2002. Dots denote photo-ID pictures; triangles denote tagging pictures. Bathymetry contours are 200, 1000, 2000, and 3000 m.

A 38-kHz ADCP, which profiles down to approximately 900 m, also was operated continuously. However, data obtained with the 38-kHz ADCP were not usable for several reasons, including problems with instrument mounting, the ship's electrical system, and degraded instrumentation. These problems and their correction for subsequent cruises will be discussed in more detail in Section 4.

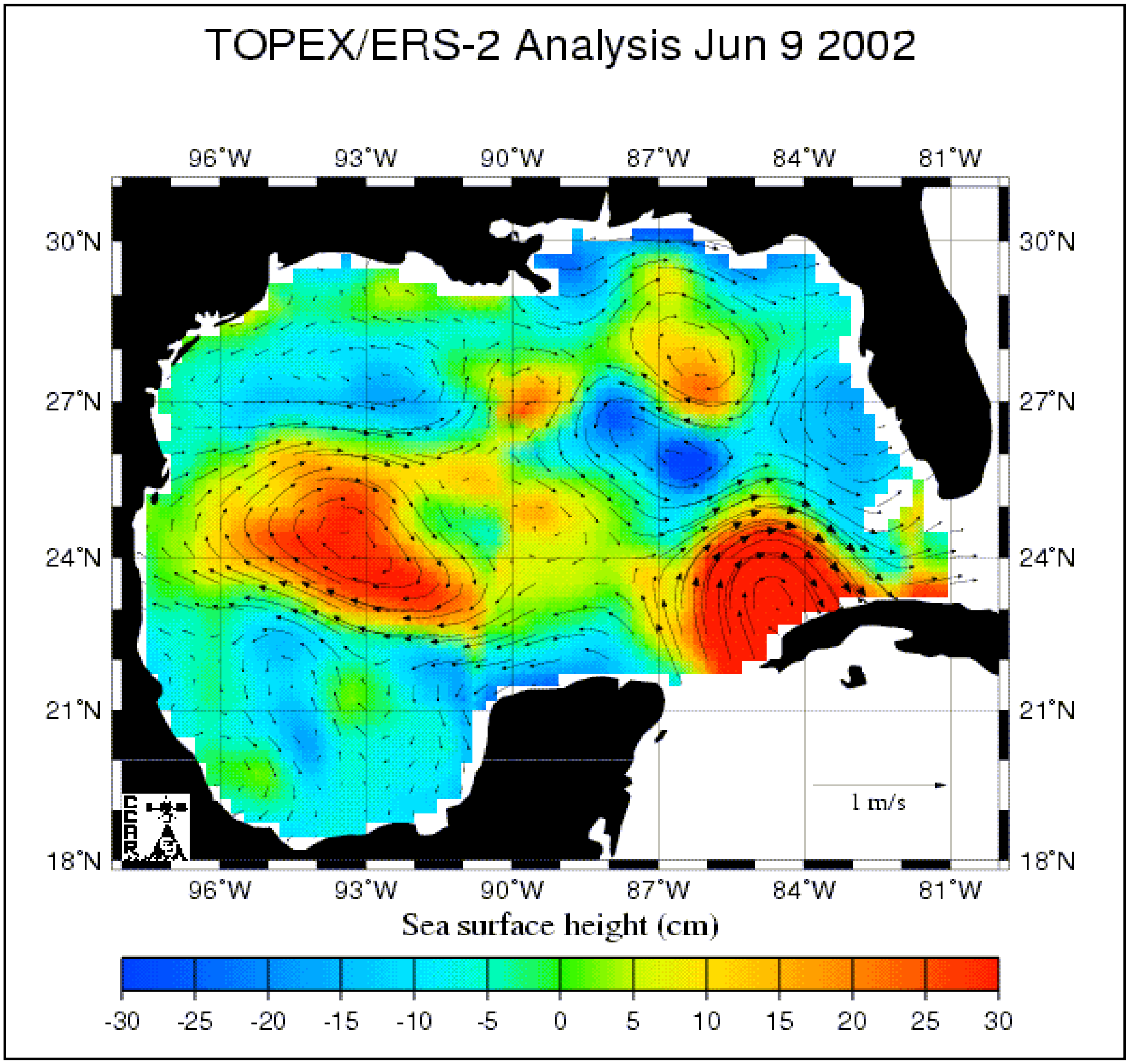


Figure 3.1.5. Sea surface height from TOPEX/ERS-2 altimeters for 9 June 2002. Image is from Robert Leben, Colorado Center for Astrodynamics Research (CCAR), University of Colorado.

Table 3.1.5

Hydrographic stations on S-tag cruise

Station	**Date (mm/dd/yyyy)**	**Time (UTC)**	**Latitude (°N)**	**Longitude (°W)**	**Water depth (m)**	**15°C depth (m)**
CTD-01	06/20/2002	16:05	27.08	-94.68	1030	214
XBT-13 (T7)	06/21/2002	01:52	27.03	-94.16	1780	194
XBT-14 (T7)	06/21/2002	06:10	27.16	-93.67	1020	189
XBT-15 (T7)	06/21/2002	10:10	26.98	-93.24	1325	209
XBT-16 (T7)	06/21/2002	12:49	27.20	-93.03	1160	205
XBT-17 (T7)	06/21/2002	15:32	27.12	-92.75	1360	207
XBT-18 (T7)	06/21/2002	21:29	27.44	-92.53	920	218
XBT-19 (T7)	06/22/2002	01:09	27.20	-92.25	1430	193
XBT-20 (T7)	06/22/2002	06:21	27.57	-92.04	700	190
XBT-21 (T7)	06/22/2002	10:37	27.40	-91.69	1000	194
CTD-02	06/22/2002	13:55	27.55	-91.51	942	189
XBT-22 (T7)	06/22/2002	16:50	27.48	-91.24	1275	223
XBT-23 (T7)	06/22/2002	21:01	27.74	-90.88	925	245
XBT-24 (T7)	06/22/2002	23:20	27.56	-90.72	955	272
XBT-25 (T7)	06/23/2002	02:45	27.85	-90.52	660	258
XBT-26 (T7)	06/23/2002	06:05	27.61	-90.24	1000	300
XBT-27 (T7)	06/24/2002	00:39	27.88	-90.04	700	256
XBT-28 (T7)	06/24/2002	04:42	27.60	-89.69	1125	283
XBT-29 (T7)	06/24/2002	08:08	27.92	-89.53	1010	231
CTD-03	06/25/2002	01:06	28.00	-89.87	680	247
XBT-30 (T7)	06/26/2002	02:47	28.33	-89.60	840	212
XBT-31 (T7)	06/26/2002	07:42	28.15	-89.16	760	208
XBT-32 (T7)	06/27/2002	00:37	28.58	-89.01	575	224
CTD-04	06/27/2002	01:56	28.66	-88.91	990	214
XBT-33 (T7)	06/28/2002	19:40	29.27	-87.32	790	211
XBT-34 (T7)	06/29/2002	02:55	29.01	-87.10	830	228
XBT-35 (T7)	06/29/2002	05:34	28.75	-87.10	820	206
XBT-36 (T7)	06/29/2002	08:08	28.50	-87.00	860	210
XBT-37 (T7)	06/29/2002	10:42	28.29	-86.81	980	230
XBT-38 (T7)	06/29/2002	13:54	28.07	-86.52	1180	231
XBT-39 (T7)	06/29/2002	16:26	28.31	-86.43	715	225
XBT-40 (T7)	06/30/2002	06:09	28.31	-87.11	1330	222
XBT-41 (T7)	06/30/2002	09:32	28.62	-87.29	1150	186
XBT-42 (T7)	06/30/2002	14:05	29.08	-87.21	1000	228
XBT-43 (T7)	06/30/2002	15:24	29.21	-87.17	800	226
CTD-05	06/30/2002	20:52	29.27	-87.44	870	201
XBT-44 (T7)	07/01/2002	13:18	29.17	-87.77	1055	219
XBT-45 (T7)	07/01/2002	16:03	28.99	-87.94	1425	221
XBT-46 (T7)	07/02/2002	12:14	28.89	-88.17	1175	226
XBT-47 (T7)	07/02/2002	21:48	28.80	-88.52	1100	239
XBT-48 (T10)	07/03/2002	12:09	28.68	-88.62	1030	216
XBT-49 (T10)	07/04/2002	05:49	28.48	-88.98	927	217
XBT-50 (T10)	07/04/2002	07:58	28.26	-88.99	1210	216
XBT-51 (T10)	07/04/2002	13:42	28.28	-89.28	813	222
XBT-52 (T10)	07/05/2002	01:45	28.26	-89.70	775	218
XBT-53 (T10)	07/05/2002	10:52	28.46	-88.99	970	215
XBT-54 (T10)	07/08/2002	01:58	28.69	-88.96	790	211

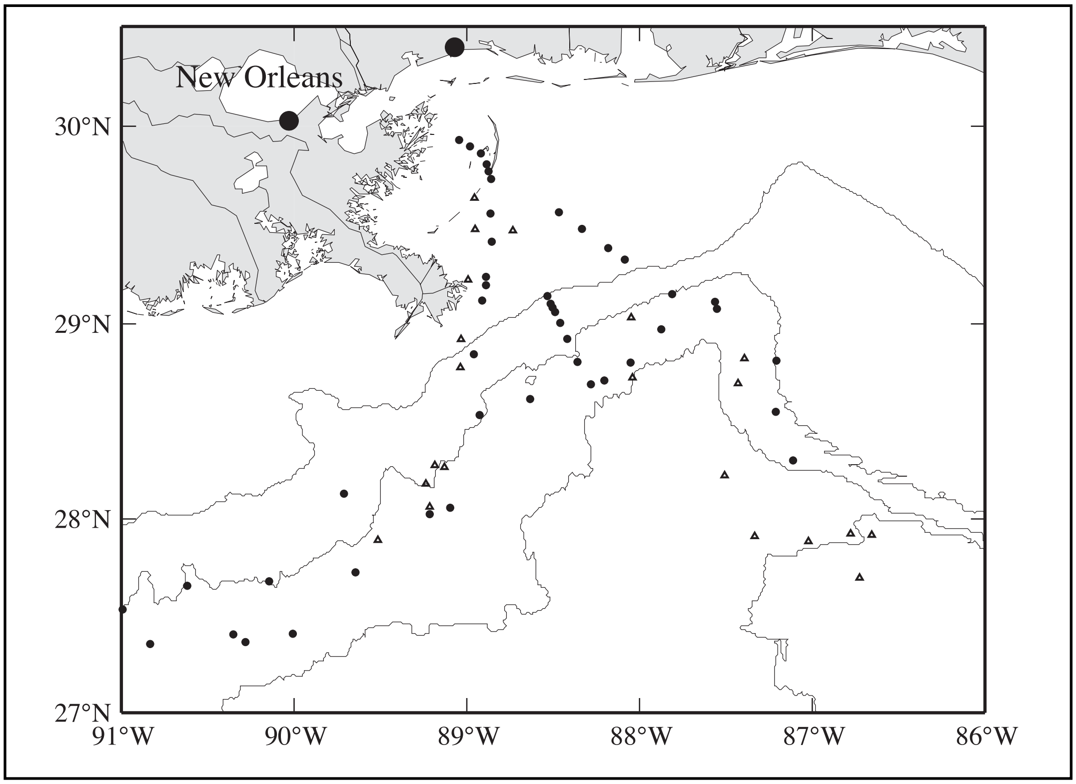


Figure 3.1.6. Locations of water samples filtered and analyzed for chlorophyll during SWSS cruise Leg 1, S-tag, June/July 2002. Dots denote samples used in regression with fluorescence; triangles denote samples not used. Bathymetry contours are 200, 1000, 2000, and 3000 m.

Table 3.1.6

Extracted chlorophyll stations on S-tag cruise

Station	**Date**	**Time (UTC)**	**Longitude (°W)**	**Latitude (°N)**	**Fluor x 31.6 (mvolts)**	**Extracted CHL (ug/L)**	**Notes**
CTD-01	06/20/2002	15:35	-94.683	27.140	171	0.18	
XBT11	06/20/2002	18:03	-94.662	27.056	167	0.14	
XBT12	06/20/2002	18:30	-94.685	27.002	157	0.12	
survey	06/20/2002	19:56	-94.720	26.883	159	0.15	
XBT13	06/21/2002	01:54	-94.160	27.034	147	0.10	
XBT14	06/21/2002	06:14	-93.664	27.158	145	0.12	
XBT15	06/21/2002	10:07	-93.251	26.987	152	0.15	
XBT16	06/21/2002	12:52	-93.025	27.204	151	0.13	
XBT17	06/21/2002	15:32	-92.746	27.119	151	0.13	
XBT18	06/21/2002	21:22	-92.524	27.436	148	0.11	
XBT19	06/22/2002	01:10	-92.245	27.199	145	0.11	1
XBT20	06/22/2002	06:22	-92.037	27.575	148	0.10	
XBT21	06/22/2002	10:37	-91.693	27.403	150	0.14	1
CTD-02	06/22/2002	13:55	-91.514	27.549	145	0.13	
XBT22	06/22/2002	18:08	-91.144	27.572	138	0.12	
XBT23	06/22/2002	21:03	-90.881	27.735	144	0.10	1
XBT24	06/22/2002	23:21	-90.722	27.555	143	0.10	1
XBT25	06/23/2002	02:50	-90.509	27.857	143	0.12	1
XBT26	06/23/2002	06:06	-90.241	27.607	140	0.08	
whales near	06/23/2002	19:30	-90.170	27.565	138	0.08	
XBT27	06/24/2002	00:40	-90.034	27.879	141	0.13	
XBT28	06/24/2002	04:30	-89.897	27.609	139	0.09	
XBT29	06/24/2002	08:07	-89.534	27.924	142	0.13	1
XBT30	06/25/2002	02:45	-89.599	28.329	145	0.14	
XBT31	06/26/2002	12:39	-89.102	28.225	141	0.12	
XBT32	06/27/2002	00:30	-89.014	28.575	1540	6.96	3
CTD-04	06/27/2002	02:28	-88.905	28.660	1480	6.23	3
transit	06/27/2002	06:09	-88.813	29.167	690	3.35	2, 3
transit	06/27/2002	07:09	-88.809	29.311	1280	8.30	2, 3
transit	06/27/2002	09:12	-88.768	29.611	600	2.41	2, 3
transit	06/27/2002	11:01	-88.728	29.867	440	1.31	2, 3
transit	06/28/2002	04:17	-88.731	30.025	901	5.22	2, 3
transit	06/28/2002	05:58	-88.512	29.860	272	1.31	2, 3
transit	06/28/2002	07:05	-88.356	29.762	228	0.29	
transit	06/28/2002	08:05	-88.223	29.677	165	0.18	
transit	06/28/2002	09:16	-88.072	29.581	198	0.24	
transit	06/28/2002	10:00	-87.975	29.522	199	0.29	
transit	06/28/2002	11:07	-87.827	29.421	181	0.08	3, 4
transit	06/28/2002	12:01	-87.701	29.346	180	0.27	
whales near	06/28/2002	16:40	-87.450	29.307	159	0.20	
XBT34	06/29/2002	02:58	-87.097	29.009	164	0.18	
XBT35	06/29/2002	05:37	-87.100	28.746	179	0.20	
XBT36	06/29/2002	08:09	-87.000	28.499	182	0.21	
XBT37	06/29/2002	10:49	-86.800	28.281	138	0.16	3
XBT38	06/29/2002	14:13	-86.503	28.093	139	0.21	3
XBT39	06/29/2002	16:26	-86.431	28.311	139	0.18	3
transit	06/29/2002	17:33	-86.553	28.319	130	0.14	3
XBT40	06/30/2002	06:09	-87.110	28.306	147	0.14	3
XBT41	06/30/2002	09:31	-87.285	28.616	184	0.29	3
XBT42	06/30/2002	14:12	-87.208	29.088	165	0.20	3
XBT43	06/30/2002	15:25	-87.170	29.212	160	0.26	3
CTD 5	06/30/2002	20:54	-87.439	29.273	171	0.21	
XBT44	07/01/2002	13:17	-87.764	29.168	191	0.33	
transit	07/01/2002	14:08	-87.816	29.115	378	1.42	3

Table 3.1.6

Extracted chlorophyll stations on S-tag cruise (continued)

Station	**Date**	**Time (UTC)**	**Longitude (°W)**	**Latitude (°N)**	**Fluor x 31.6 (units?)**	**Extracted CHL (ug/L)**	**Notes**
XBT45	07/01/2002	16:05	-87.940	28.997	235	0.41	
whales near	07/01/2002	22:30	-88.091	28.908	230	0.35	
XBT46	07/02/2002	12:13	-88.170	28.887	135	0.14	
XBT47	07/02/2002	21:58	-88.524	28.812	135	0.15	
XBT48	07/03/2003	13:29	-88.815	28.732	153	0.21	
XBT50	07/04/2002	07:57	-88.987	28.257	133	0.13	
XBT51	07/04/2002	13:49	-89.291	28.286	138	0.19	3
XBT53	07/05/2002	10:52	-88.992	28.457	139	0.19	3
XBT54	07/07/2002	01:02	-88.963	28.670	150	0.17	3
transit	07/08/2002	19:05	-88.250	29.003	173	0.44	
transit	07/08/2002	19:59	-88.308	29.119	180	0.35	
transit	07/08/2002	20:43	-88.350	29.199	202	0.39	
transit	07/08/2002	21:10	-88.379	29.255	215	0.32	
transit	07/08/2002	21:21	-88.392	29.279	232	0.39	
transit	07/08/2002	21:30	-88.402	29.299	249	0.76	
transit	07/08/2002	21:47	-88.421	29.337	284	0.43	
transit	07/10/2002	05:00	-88.935	30.124	908	2.21	5
transit	07/10/2002	05:27	-88.872	30.092	756	1.81	5
transit	07/10/2002	05:55	-88.807	30.059	626	1.27	5
transit	07/10/2002	06:24	-88.773	30.002	424	0.80	5
transit	07/10/2002	06:39	-88.762	29.968	392	0.89	5
transit	07/10/2002	06:56	-88.748	29.929	288	0.39	5
transit	07/10/2002	08:11	-88.753	29.755	266	0.27	5
transit	07/10/2002	09:12	-88.745	29.611	525	1.18	5
transit	07/10/2002	10:27	-88.777	29.435	946	2.61	5
transit	07/10/2002	10:44	-88.778	29.393	1078	3.01	5
transit	07/10/2002	11:17	-88.801	29.313	1391	4.75	5
transit	07/10/2002	13:07	-88.848	29.041	405	1.25	5

Notes:
1 - fluorescence is estimated due to in-line bubbles
2 - only 500 ml was filtered
3 - not used in linear regression
4 - low CHL is an artifact of filtering too dry
5 - sample taken on post SWSS cruise from Gulfport, MS, to Galveston, TX; data used in linear regression

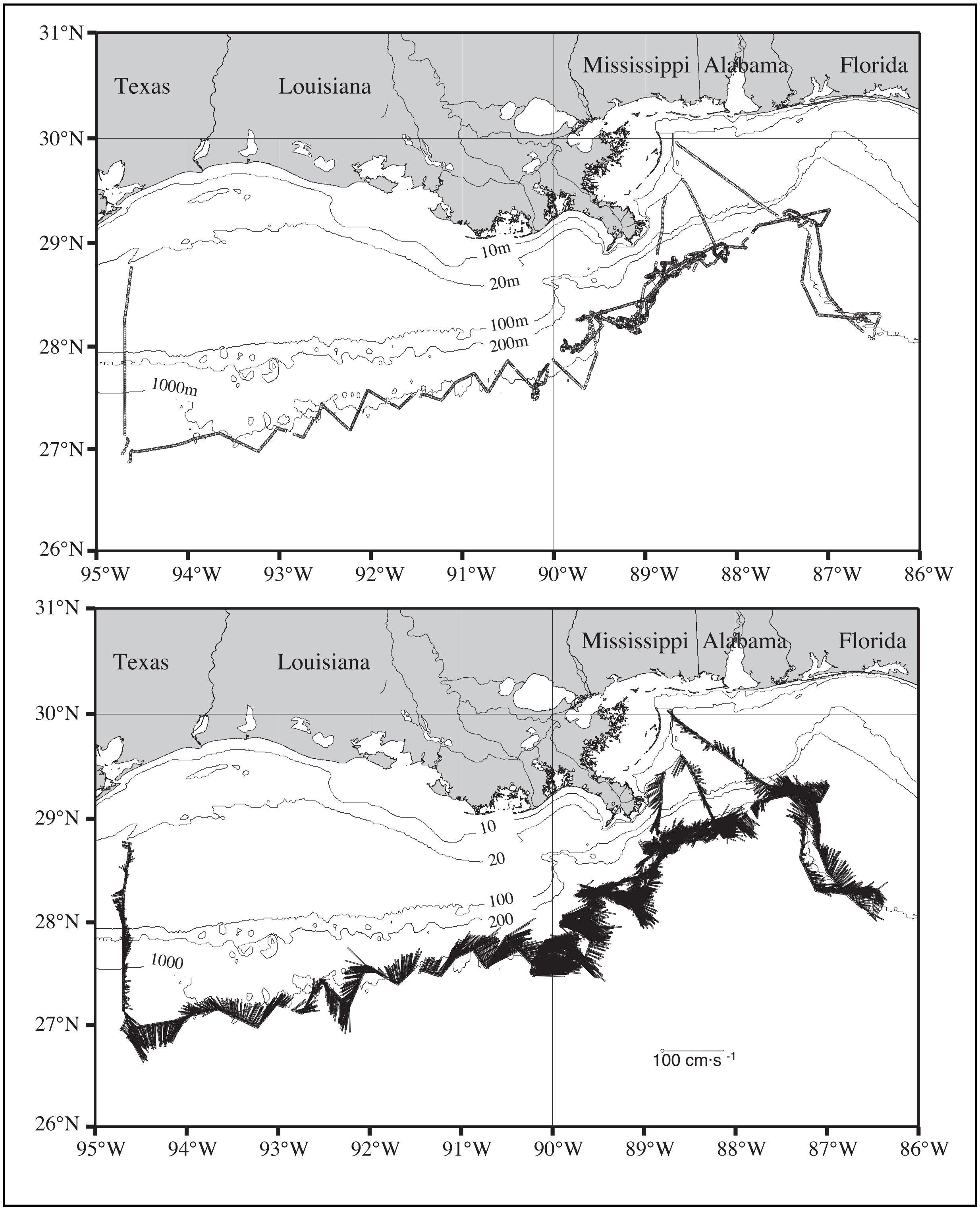


Figure 3.1.7. ADCP data collection on S-tag cruise, 20 June - 8 July 2002. Shown are (upper) the locations of 153-kHz ADCP-measured currents and (lower) the horizontal current velocity at 13.6-m depth.

3.2 D-tag Leg of SWSS 2002

The second leg of the SWSS 2002 field cruise was conducted from 19 August through 15 September 2002. Two vessels were involved in the D-tag field program. The science vessel was the *R/V Gyre*, which was staged out of Galveston, TX, for the entire period of the cruise. Dr. Mark Johnson of WHOI was the Field Party Chief during the basic D-tag operations; Dr. Peter Tyack of WHOI was Field Party Chief during the controlled exposure experiment (CEE). The seismic source vessel was the Atlas Boats vessel, *Rylan T.*, with the Fairfield Industries seismic vessel, *Speculator*, mounted on the back deck of the *Rylan T.* The IAGC provided the funding for the seismic source vessel and technical support crew for the period of the D-tag controlled exposure experiment. Fairfield Industries arranged for the boat modifications and support personnel under contract to the IAGC. Seamap Inc. contributed a prototype passive acoustic system for use on the *Rylan T.*, including hydrophone array, computers and associated software, and technical team. The *Rylan T.* left Texas City, TX, on 29 August and rendezvoused with *Gyre* on 31 August to begin the CEE. It departed the survey area on 11 September to return to port by 13 September 2002. Table 3.2.1 lists the cruise participants for both vessels and their roles.

The major goal of the D-tag experiment was to locate and tag sperm whales both for assessment of normal behavior and then to monitor their behavior in the presence of controlled exposures to specific sounds. Additional important goals were to collect skin and biopsy samples for genetic study, to take photographs of flukes for identification of individuals, and to make oceanographic measurements to characterize the marine habitat. The specific sounds to be presented included foreign and familiar whale codas (called "playbacks") and sounds produced by airguns used in marine seismic surveys. Monitoring included recording the time history of the tagged animal's 3-D location, orientation (roll-pitch-heading), and any sounds produced by or impinging upon the animal.

Mobilization for the D-tag cruise began on 18 August. The *Gyre* left the dock at 0200 CDT on September 21, instead of September 19 as originally planned. This was mainly due to flooding and bad weather in Galveston the week before, which delayed the completion and testing of the custom launch ramp system for the 5000+ pound MMS R2 tag boat until the 19th and 20th. Additionally, the OSU tag boat was outfitted with a back brace and mount for the tagging pole in case this boat would be needed as a back-up; these were constructed and added to the boat just before the cruise departed. Additional time was lost during the cruise due to two unforeseeable events: a crew family emergency and an engine failure. A total of 3 days out of 28 were effectively lost for the above reasons. A further 10 days were lost to poor weather leaving a total of 15 days for the transit to and from Galveston and for the tagging project. Tagging was attempted on 11 out of 13 fair weather days and tags were deployed on 10 days.

Despite lost days due to delays and weather, the experiments were an unqualified success. Nineteen sperm whales were tagged. All tags were recovered yielding over 77 hours and 14 Gbytes of digital data. Several notable events occurred including a 15-hrs tag deployment that is the longest to date, a synchronized dive by a pair of tagged whales, and three whales tagged at the same time. Foreign whale codas were played to tagged animals but, although two attempts were made, uncertainty in the position of the tagged whales precluded the opportunity to playback familiar codas. Most importantly, two controlled exposure experiments of whales to an operating seismic vessel were achieved, including one with three simultaneously tagged whales. Seventeen fluke photographs were taken of 13 animals for photo-identification and three frame-sets (measured length of animals) were made. Fourteen sperm whale skin samples were collected, thirteen from D-tag suction cups and one from biopsy sampling equipment. The visual team enjoyed 13 days of good visual working conditions and the acoustics team recorded data on 20 of 25 days from two hydrophone arrays aboard the *Gyre*, as well as numerous days from the array aboard the *Rylan T./Speculator*.

Table 3.2.1

The SWSS 2002 cruise, Leg 2, D-tag science team

Description	Person (Institutional affiliation)
R/V Gyre 02G11 Science Team	Captain Dana O. Dyer III, *Gyre* captain
Field Party Chiefs	Mark Johnson (WHOI) for basic D-tagging Peter Tyack (WHOI) for CEEs
Electronics Technicians	Eddie Webb (TAMU College Station) Paul Clark (TAMU GERG)
Deck Engineers	Billy Green (TAMU Galveston) Mike Fredericks (TAMU GERG)
Tagging Team	Mark Johnson (WHOI) Patrick Miller (WHOI) Alessandro Bocconcelli (UNCW)
Visual Team	Nicoletta Biassoni (WHOI) Maria Elena Quero (WHOI) Dan Engelhaupt (Durham Univ. UK) Todd Pusser (North Carolina) Amy Beier (New Zealand) Irene Briga (Massachusetts) Mandana Mirhaj (Germany) Simon Childerhouse (DoC, New Zealand) Dee Allen (NMNH Smithsonian)
Acoustics Team	Aaron Thode (SIO) Valeria Teloni (WHOI, Italy) Matt Grund (WHOI) Natacha Aguilar de Soto (Spain) Sarah Tsoflias (MMS New Orleans)
Physical Oceanography	Matthew Howard (TAMU College Station)
Flow through Fluorescence/CHL	Laurie Sindlinger (TAMU College Station)
M/V Rylan T. Science Team	Captain Steve Bennett, *Rylan T* captain
Seismic Team	Cliff Smith (Fairfield Industries) Tony Edwards (Fairfield Industries) Neil Estay (Fairfield Industries)
Acoustic Team	Tim Pinnington (Seamap Inc.) Craig Douglas (Seamap Inc.)
Playback/Permit Team	Natacha Aguilar de Soto (transfer from *Gyre*) Bill Lang (MMS New Orleans) Carol Roden (MMS New Orleans) Sandy Sawyer (Fairfield Industries)

UNCW is University of North Carolina at Wilmington
DoC is the Department of Conservation, Wellington, New Zealand
NMNH is National Museum of Natural History
GERG is the Geochemical and Environmental Research Group at TAMU

Thirty-eight XBT probes were dropped, eight CTD casts were taken, and chlorophyll concentrations were measured from 75 water samples. Continuous vertical profiles of horizontal currents were collected whenever whales were not present, and continuous near-surface measurements of temperature, salinity, and fluorescence were recorded whenever the vessel was underway.

The study was conducted between the 700-m and 1500-m isobaths, mainly on or near the 1000-m isobath, between 93°W and 88°W in the northern Gulf of Mexico. This region includes the continental slope south of the Mississippi River delta between the Mississippi and DeSoto Canyons. This area was where historical sightings and recent reports from satellite-tagged (S-tag) whales indicated there was a high-probability of encountering pods of sperm whales.

Figure 3.2.1 shows the ship track for three periods. The first panel shows the transit from Galveston to Mississippi Canyon where sperm whales were first encountered and where four were tagged (sw235a, b, c, and sw236a; see Table 3.2.2). On 25 August the ship moved northwest to 28.6°N and 89°W, a location that was revisited several times later in the cruise. Nine whales (sw237a-sw240c) were tagged in the vicinity over a 5-day period. On August 29, the ship transited to DeSoto Canyon, but found few whales there. Due to a family emergency, the deck engineer was put ashore in Gulfport, MS, on 30 August.

The second panel of Figure 3.2.1 covers the middle period of the cruise from 30 August to 8 September. During this time the *Gyre* rendezvoused with the *Rylan T.* (31 August) and worked whales between the Main Pass and DeSoto Canyon. Weather and sea-state hampered operations (see under "Tagging" below for additional information). On 5 September, after tagging one whale (sw248a) a group of whales was followed south overnight into the western edge of a cold-core eddy. There one whale (sw249a) was tagged before *Gyre* and *Rylan T.* were chased by bad weather to an area west of the Mississippi. The ships remained anchored there for two and a half days to avoid the remnants of Tropical Storm Edouard to the east and the growing Tropical Storm Fay to the west.

The third panel of Figure 3.2.1 shows the track for the third period covering 9-15 September. During this period, *Gyre* returned to the region near 28.6°N and 89°W with the *Rylan T./Speculator*. Several successes were achieved in this region, including the controlled exposure of one (sw253a) and three tagged whales (sw254a,b,c) to the airgun sounds. These controlled exposures were made possible by a two-day extension of the *Rylan T.* contract by the IAGC. After the departure of the *Rylan T.* on 11 September, *Gyre* steamed westward looking for smoother water. On 14 September the tag team approached a large male, but was not able to get close enough for tagging operations. The biopsy/photography team then went out for a few hours. After they finished, the ship headed for Galveston, TX, arriving at 8:30pm local time on 15 September.

All D-tag and biopsy/genetic typing activities were conducted in accordance with federal permits from the US National Marine Fisheries Service to Peter Tyack/Woods Hole Oceanographic Institution (permits 981-1578-01 and 981-1578-02) and to Dan Engelhaupt/University of Durham (permit 909-1465-01).

General Operations

Operations generally were conducted in accordance with the D-tag cruise plan of 9 August 2002. Upon reaching the study area, a combination of visual and acoustic searches were made to locate whale pods and to follow individuals. The visual search comprised two watches on two-hour rotations using high-power (x25), large-format "BigEye" binoculars. The acoustic search effort comprised two watches, each using one or two hydrophone arrays in conjunction with custom

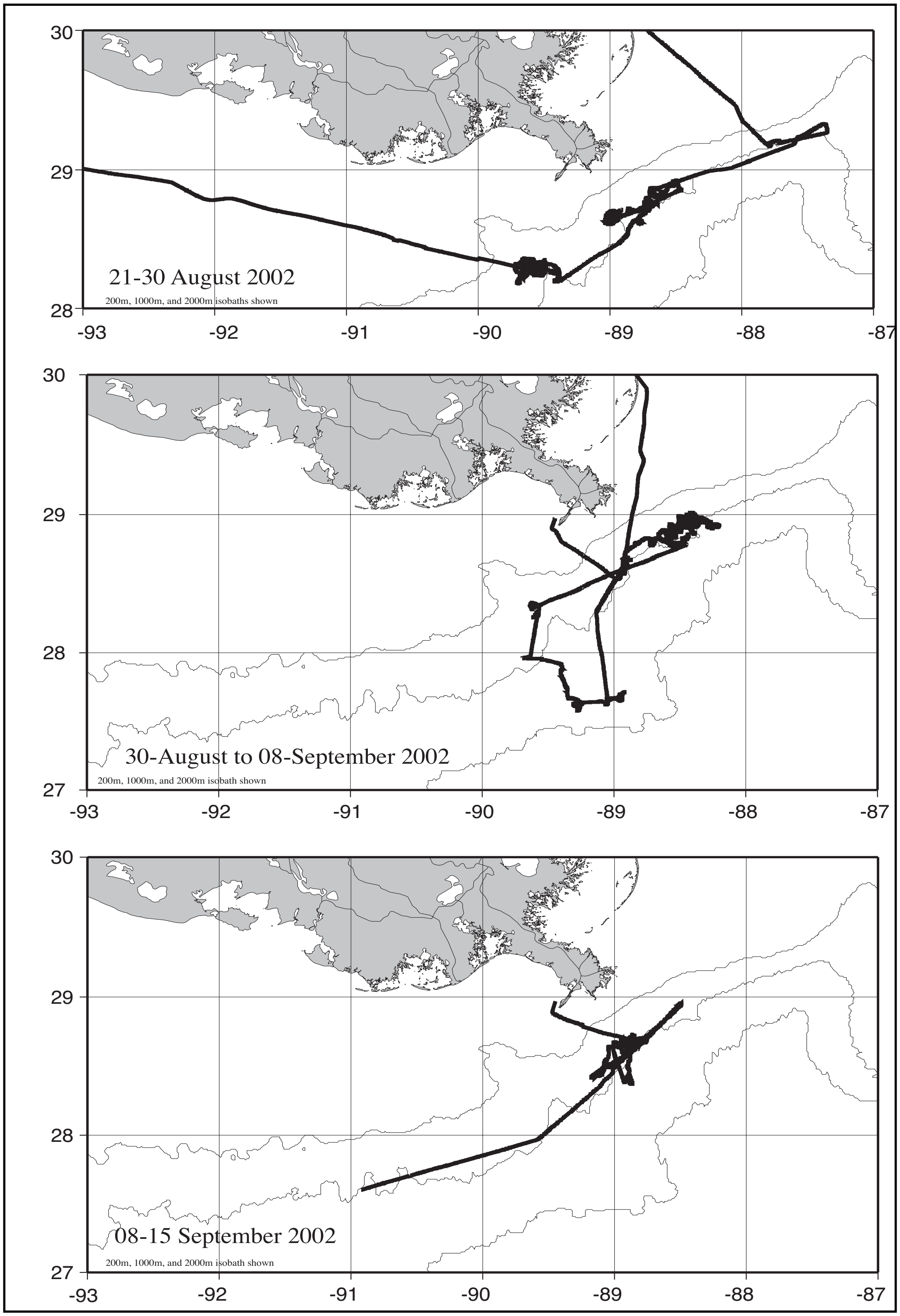


Figure 3.2.1. D-tag cruise track for *R/V Gyre* (02G11) on 21 August to 15 September 2002.

Table 3.2.2

List of 19 D-tag placements on sperm whales
(Shown are date, reference number (Julian day plus letter), the D-tag used (D-tag identification number), the number of complete deep dives made by the animal while tagged, and the number of hours of digital data recorded by the D-tag while on the animal. The total number of hours for all tags is 77.12 hrs.)

Date	Tagging Event Reference Number	D-tag Identification Number	Number of complete deep dives	On-animal data-hours
23 August 2002	235a	10	0	0.18
23 August 2002	235b	12	0	0.46
23 August 2002	235c	10	1	1.32
24 August 2002	236a	10	0	0.49
25 August 2002	237a	10	2	3.51
25 August 2002	237b	12	0	0.56
26 August 2002	238a	10	3	4.44
26 August 2002	238b	12	3	2.11
27 August 2002	239a	10	12	12.36
27 August 2002	239b	12	1	0.89
29 August 2002	240a	12	1	0.73
29 August 2002	240b	12	0	0.37
29 August 2002	240c	10	5	5.22
5 September 2002	248a	10	1	0.89
6 September 2002	249a	12	2	1.92
10 September 2002	253a	12	3	5.41
11 September 2002	254a	10	11	11.54
11 September 2002	254b	12	10	12.36
11 September 2002	254c	11	10	12.36

software to determine relative bearing to individual whales. When whales were located, the visual and acoustics team worked together to track the group and collect pre-exposure observations. During daylight hours, the range and relative bearing to each whale was collected visually using Big-eye binoculars and these data were entered into custom software to resolve and record the whale's locations in geographic coordinates. The acoustics team recorded bearings to whales and the start-times and end-times of dives (as determined by the regular clicking of sperm whales). Digital tape recorders captured continuous records of the sound fields detected by the hydrophone arrays. The acoustics search and tracking effort operated day and night. Similar acoustic operations were conducted onboard the *Rylan T.* The success of the search effort is demonstrated by the fact that whales were located and tracked on 12 out of 13 fair weather days. Additional information on sperm whale locations was available through daily reports provided by Tomas Follett of Oregon State University on S-tagged whales. During the D-tag leg, several of the S-tagged whales were sighted.

During daylight hours, when whales were present and the sea-state acceptable, an attempt was made to place a digital-recording tag (D-tag) on the animals using a 46-ft carbon fiber spar mounted on one of two small boats. The tag contains a 3-axis accelerometer, pressure sensor, compass, hydrophone, VHF beacon, 2.2Gb of solid-state memory and a pair of active suction cups. Playback of recorded whale codas was done by playing a CD through a projector suspended beneath the tagging boat. Airgun sounds were provided by the seismic vessel *Speculator*, mounted on the back deck of the *Rylan T.* These sounds also are called "seismic playbacks", even though they are made directly by the seismic vessel's actual airguns. The *Speculator* hosts a 1680 cubic-inch airgun system, which produces an acoustic signature nearly identical to that of a deepwater 3D airgun array at the distances required to be maintained from the whales on this cruise.

Habitat characterization was achieved by measuring temperature, salinity, fluorescence, chlorophyll, and currents on a not-to-interfere-with-tagging basis. The flow-through systems were run continuously and XBTs were dropped at will. The ADCPs were operated primarily during long straight runs to new locations. CTD casts were taken when the acoustic arrays were onboard and time permitted the ship to stop for sampling.

Biopsy/genetics sampling was dependant on obtaining skin samples. Most of the tags had fragments of skin stuck in the suction cups. One biopsy sample was taken by Dan Engelhaupt, on the last day of operations, using the dart method of sampling.

Both the *Gyre* and the *Rylan T.* passed over EARS acoustic buoys deployed by the Navy near 28.5°N 89.0°W. This will provide some quantification of sound emissions from the two vessels.

Fairfield 1680 in^3 Airgun Array

The IAGC provided a representative airgun source for use in the controlled exposure experiments conducted by the WHOI research group on D-tag. This airgun array consisted of 20 external sleeve type airguns arranged on two separate gun strings (10 guns per string). The array volume totaled 1680 in^3 and had areal dimensions of 8m long by 7m wide. It produced a nearly identical acoustic signature as that of a deepwater 3-D airgun array at the distances required to be maintained from the whales on this cruise. Airguns were towed at a depth of 6m. A schematic of the system is shown in Figure 3.2.2.

The array and required air compressors, air-lines, control electronics, and electrical connections were rigged out on Fairfield Industry's shallow water vessel *Speculator*. In order for the array to be used in the deep water research area, Fairfield arranged for the *Speculator* to be piggybacked on the deep water service vessel *Rylan T.* The array produced a vertical far-field signature with a theoretical point source response of around 252 dB re 1μPa in the 3 to 800 Hz frequency band, as shown in Figures 3.2.3 and 3.2.4.

Because of the areal dimensions of the array, the pressure signal varied as a function of azimuth and emission angle (i.e., angle from the vertical). In order to predict maximum acoustic pressure levels at various distances from tagged whales a set of signatures were modeled for emission angles for various distances corresponding to a tagged whale at a depth of 1,000 m. Table 3.2.3 was then complied to guide the researchers in controlling the source exposure within the limits of the scientific permit allowing these tests.

Visual Survey and Monitoring

During the day, the visual team controlled the direction of the *Gyre*. Two teams of four visual observers kept watch from the flying bridge from dawn to dusk. Their job was to locate sperm whales, keep track of the location and time of "blows" (breathing at the surface) and "fluke-ups" (a behavior indicative of the initiation of a deep dive), to guide the tagging team into proximity of targeted animals, and to keep track of the D-tags after they were deployed. This last item is the notable distinction between operations during the S-tag cruise and the D-tag cruise.

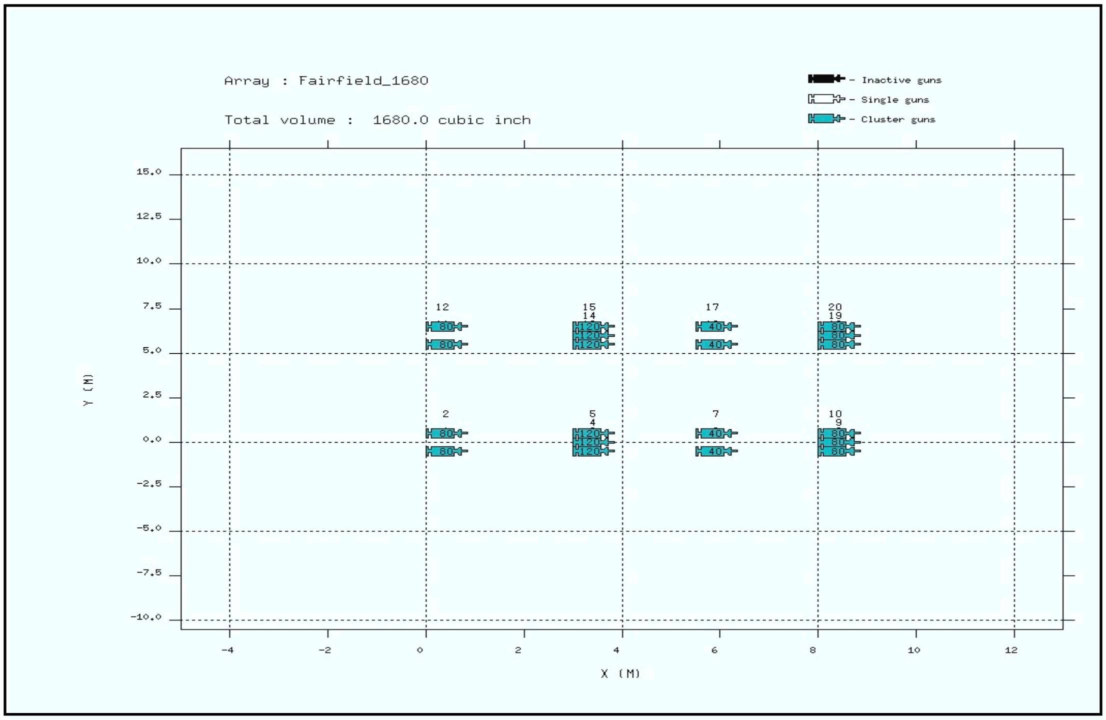


Figure 3.2.2. Schematic of airgun array of Fairfield *Speculator*.

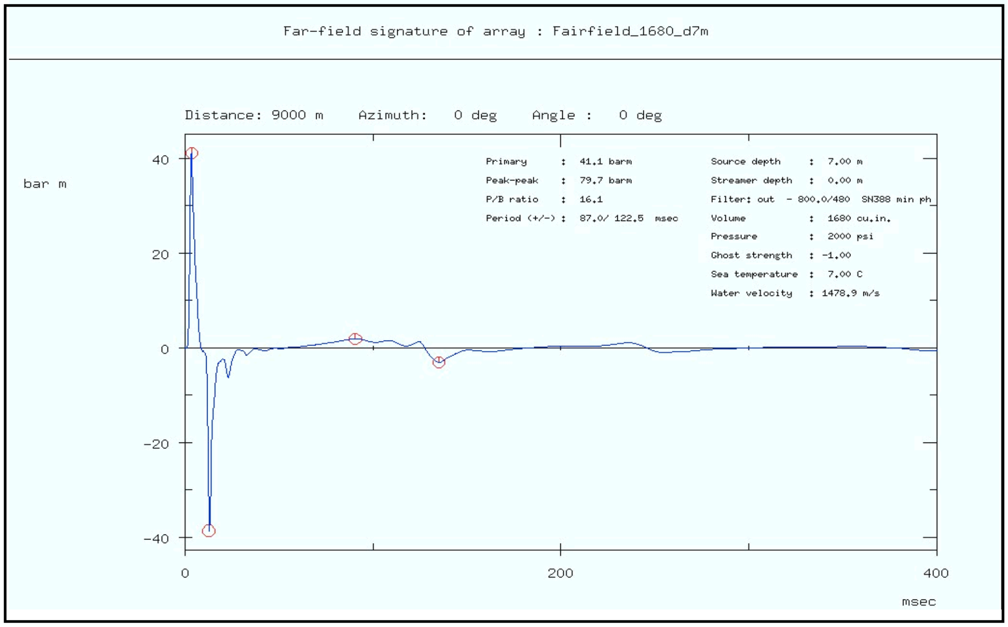


Figure 3.2.3. Far-field signature of airgun array.

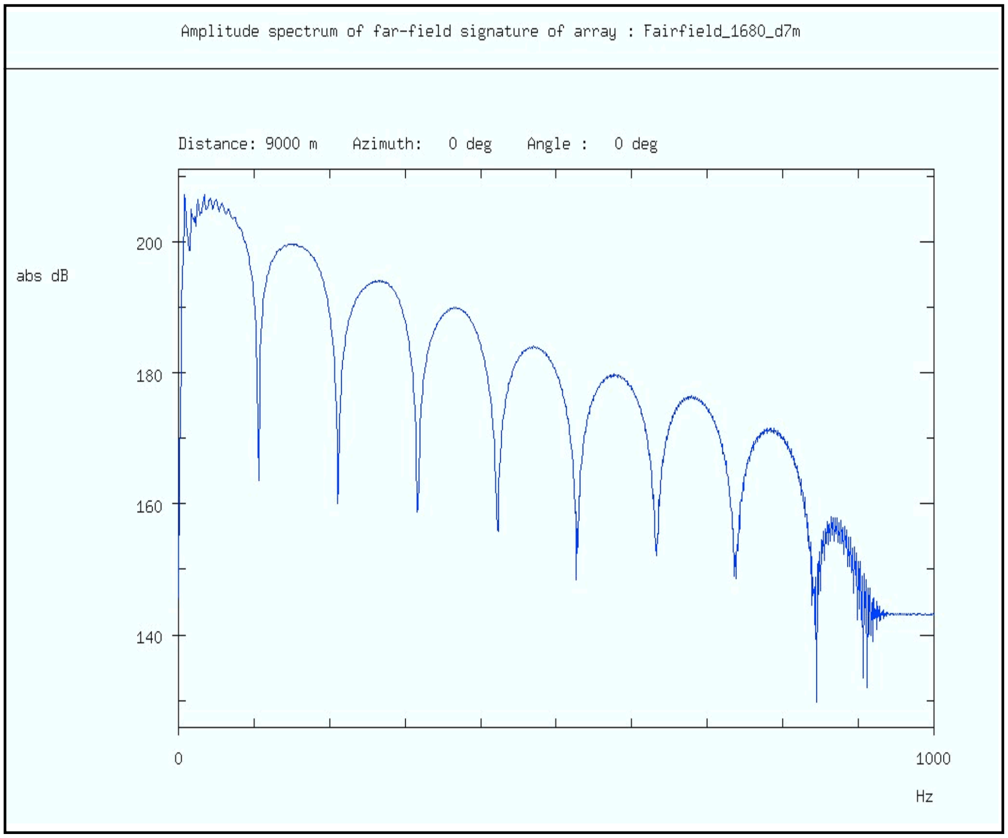


Figure 3.2.4. Amplitude spectrum of far-field signature of airgun array.

Table 3.2.3

Emission angles from the V1680 array for various distances corresponding to a tagged whale at a depth of 1,000 m
(Shaded cells are greater than 180 dB.)

Emission Angle (°)	**Range (km)**						
	500	**1000**	**2000**	**3000**	**4000**	**5000**	**6000**
45	192.6289	186.6083	180.5877	177.0659	174.5671	172.6289	171.0453
63	191.0777	185.0571	179.0365	175.5146	173.0159	171.0777	169.4940
72	188.3660	182.3454	176.3248	172.8030	170.3042	168.3660	166.7824
76	188.1648	182.1442	176.1236	172.6018	170.103	168.1648	166.5812
79	187.8187	181.7981	175.7775	172.2557	169.7569	167.8187	166.2351
82	187.6042	181.5836	175.5630	172.0412	169.5424	167.6042	166.0206

Once an animal was tagged with an S-tag, it received no further special attention by the visual team. On the D-tag cruise, however, when one or more whales were tagged, both visual teams went on watch. One team continued normal operations while the other team focused on following the tag. Although sightings of other marine mammals were noted and logged, the emphasis of the work was on sperm whales.

Three sets of BigEye binoculars were available to measure distance and relative bearing from the ship to animals. Distance was computed via geometry using the known altitude of the binoculars in conjunction with reticule markings in the eye-pieces. From the flying bridge of the *Gyre*, the horizon was approximately 12km away which yields a searchable area of approximately 450 km^2. As each animal was sighted, the observer relayed the reticule and relative bearing information to the data entry person. These data were entered into the "Logger 2000" data collection software along with information such as animal behavior (blow, fluke-up) and heading ("Logger 2000" was developed by the International Fund for Animal Welfare to promote benign and non-invasive research). A custom navigational data string, updated every second, containing ship's heading and location to the Logger software was provided by the TAMU electronics technician, Eddie Webb. This information, when combined with the relative bearing and distance from the binoculars, produced a latitude and longitude fix for each animal. The information is stored in a Microsoft Access database. In practice, about 12 animals at a time can be followed visually using this system. Figure 3.2.5 shows the locations of sperm whale sightings by date.

After one or more animals were tagged, the second watch went up to the flying bridge to follow the tag. They do this visually and by means of radio beacon tracking equipment designed to receive the VHF signal from the tag. The beacon can only be heard when the tag antenna is out of the water. The tagging team tries to place the tag high on the animal near the dorsal fin because this area of the animal is frequently out of the water when the animal is at the surface. The tag is designed to float with the antenna in the air when it is not attached to an animal. Thus, an intermittent signal usually indicates the tag is still on the animal while a continuous signal usually indicates the tag is off the animal and is floating at the surface. Often, the tag will remain on after dark, sometimes almost to dawn. The task of monitoring the radio equipment after dark was primarily borne by the visual team. The beacon frequency is different for each tag. When two or more tags were deployed, two or more VHF units and monitors were needed. At one point, three tagged animals were being worked. This would appear to be the practical limit both for the visual observers and the VHF monitors given the equipment and personnel available.

Tagging

A typical sperm whale dive cycle begins with a 10-15 minute period at the surface followed by a 40-50 minute dive. During the dive the animal may move laterally some 500 to 1000m. Therefore, the tagging team, which normally operates within the large visual survey region, needs timely information to intercept whales at the surface. Often they will arrive in the vicinity just as the whale dives. The tag team then stays in the general area using acoustic tracking equipment on the tag boat so as to be close to the whale at the next surfacing. Some whales were skittish and difficult to approach. At such times the whales either speed up or execute a series of shallow dives changing direction as they do. Other whales were unperturbed by the boat's approach. The triple tagging was accomplished on such a group.

The tag team consisted of scientists Mark Johnson and Patrick Miller, and boat operator Alessandro Bocconcelli. On days when tagging was possible they usually departed between 8 and 9am, returned once between noon and 3pm for a few hours to service a recovered tag, and went out again returning for the day around dusk (~7:15pm). After return, the team scientists worked to recover and download tags. Three D-tags were available for use, but once used, each required several hours to download and refurbish.

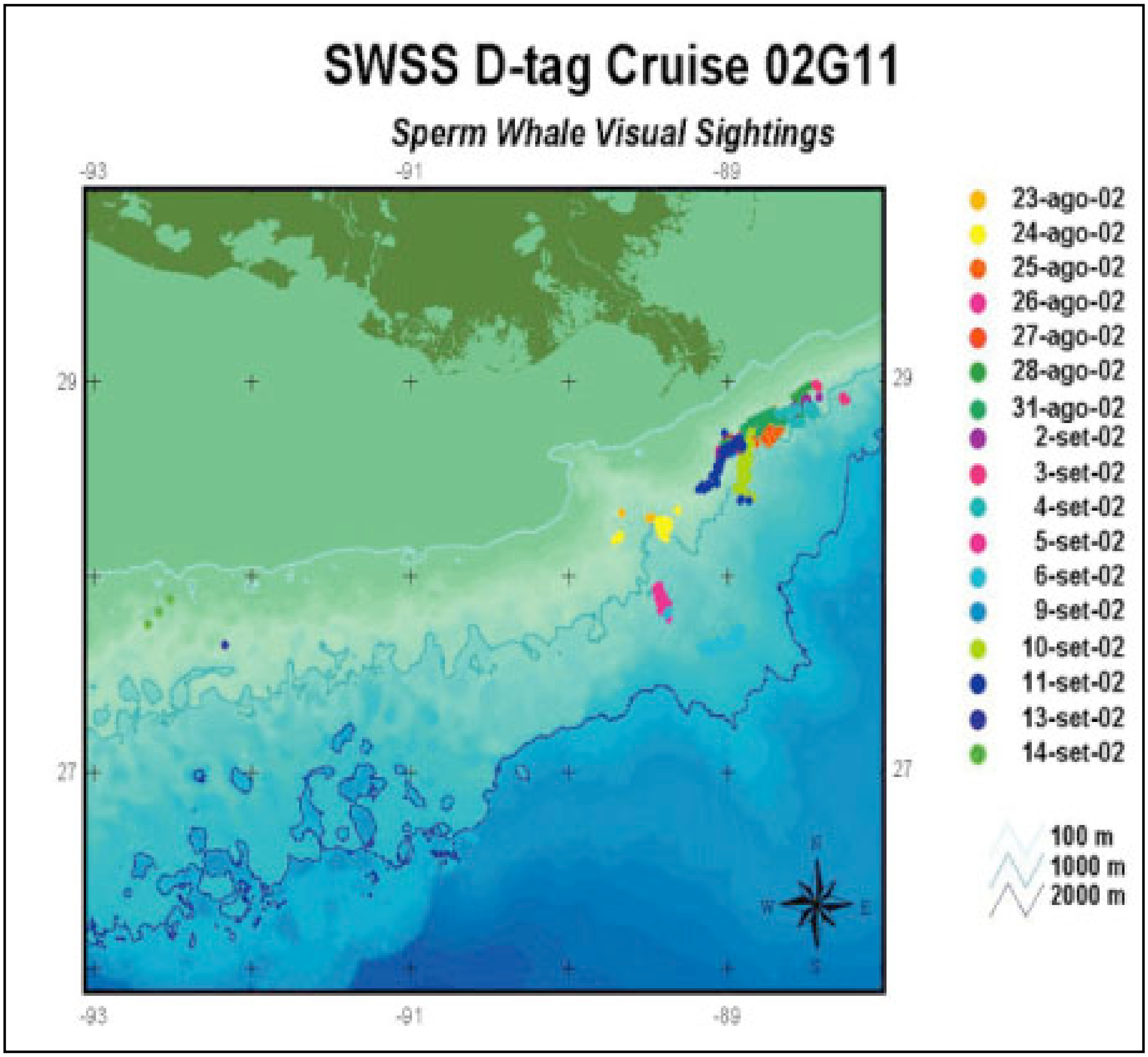


Figure 3.2.5. Locations of visual sightings of sperm whales during the 2002 D-tag cruise.

Nineteen whales were tagged during the D-tag experiment as shown in Table 3.2.2. Fourteen animals completed at least one dive before the tag came off. A total of 65 deep dives were recorded. Figure 3.2.6 shows a map of the locations where whales were tagged. Figure 3.2.7 shows a 2-D representation of the 3-D trajectory of two tagged whales that dove together. The record shows the animals dove to 500-m depth and traveled horizontally some 1500 m before surfacing.

A key goal of this cruise was to conduct controlled exposure experiments (CEEs) using a seismic source. The seismic source vessel, the *Rylan T.* with the *Speculator* on deck, rendezvoused with *Gyre* on 31 August. Whales were in the area, but so was at least one other seismic vessel and efforts were made to move away from that vessel. Weather also became a significant problem as two tropical cyclones, Edouard and Fay, impacted the survey area. During the time the *Rylan T.* was at sea, weather conditions were generally poor to bad, making tagging operations difficult.

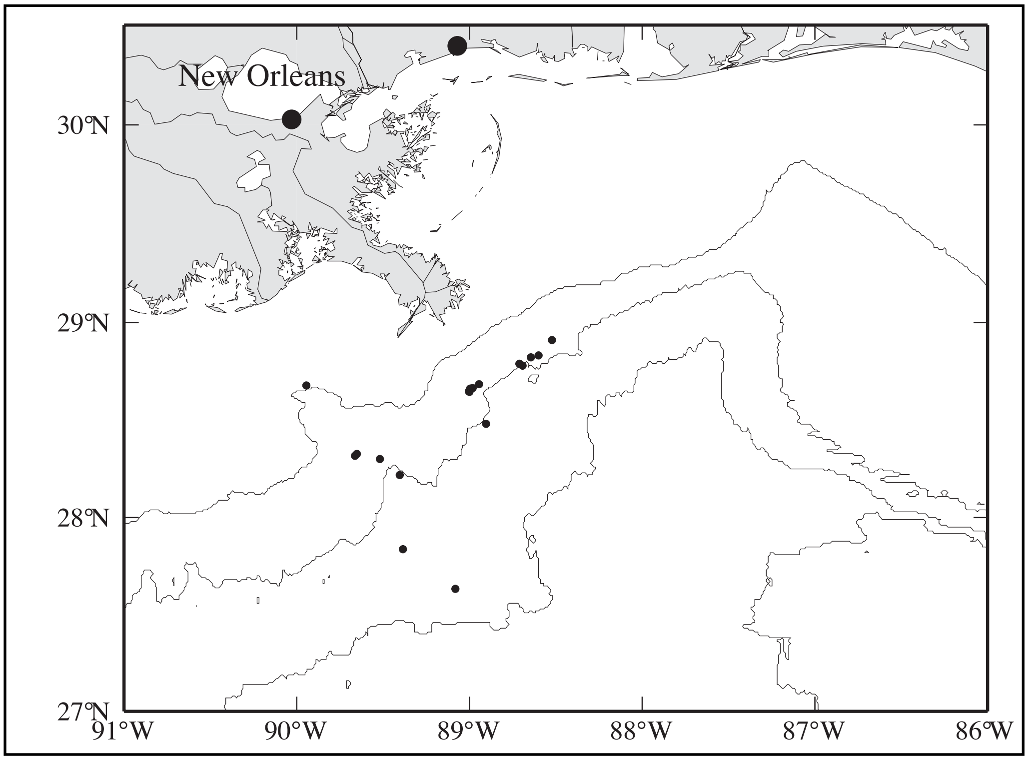


Figure 3.2.6. Locations where sperm whales were tagged with digital tags (D-tags) during SWSS cruise Leg 2, August/September 2002. Bathymetry contours are 200, 1000, 2000, and 3000 m.

Personnel were not transferred between the *Rylan T.* and *Gyre* until the evening of 2 September. Natacha Aguilar de Soto was transferred to the *Rylan T.* and Peter Tyack and Sarah Tsoflias were transferred to *Gyre*. Much of 3 September was spent trying to locate whales acoustically, with the visibility too poor for successful visual operations. The tagging efforts on 4 September were curtailed due to rising seas, after two unsuccessful tagging approaches to whales by the tag boat. On 5 September, no whales were found until late afternoon. One whale was tagged (sw248a), but the tag did not stay on long enough to conduct experiments. A whale was successfully tagged on 6 September (sw249a), but the tag came off just as the *Rylan T.* began to prepare for a seismic test. No additional whales were tagged that day because none could be approached closely enough to tag. Tropical Storm Fay prevented all activities for two days, as both vessels anchored in shelter. On 9 September, the *Gyre* and *Rylan T.* returned to the survey area and located whales acoustically in the afternoon. September 10 provided the first successful controlled exposure experiment using the seismic source; the tagging (sw253a) was done in sea state conditions that were becoming marginal for small boat operations and with rain and squalls in the area. September 11th provided another successful experiment, with three whales tagged (254a-c) for a period extending well beyond the seismic source testing. After the seismic source test on the 11th, the *Rylan T.* headed into port. On Figure 3.2.8 are shown the relative positions of the *Gyre* (coinciding with the black cruise track) and the *Rylan T* during the ramp up of the airguns and the seismic test. The locations and airgun transmission levels for 10 September are in browns and for 11 September are in blues; the scale is shown on the right, with 1680 in^3 being maximum. Table 3.2.4 shows the ramp-up/mitigation timeline for the two controlled exposure experiments using the airguns. During these experiments, there was visual and acoustic monitoring on the *Rylan T.* to ensure no sea turtles or sperm whales were in the immediate area of the vessel during ramp-up and firing operations per permit requirements. The experience between 31 August and 11 September indicates that future cruises should be conducted earlier in the hurricane season to increase the likelihood that the weather conditions will be more amenable to tagging efforts.

Two tag boats were available to use during tagging activities. The MMS tag boat (R2) was intended to be the primary vehicle. During pre-tagging activities (radio range checks and calibration of the acoustic arrays) the check engine light came on first on one and then both of the Mercury 135hp Optimax gasoline engines. The boat was brought on board and an extensively evaluated to diagnose the reason for warning lights. Despite efforts, nothing was resolved, so a decision was made to use the OSU diesel-powered tag boat, *Puffin*. The OSU boat was used until the end of August at which time the starter motor on it failed. Although the cause of the engine light on the MMS boat had not been resolved, the engines started easily and ran acceptably, albeit noisily at high rpm. With MMS concurrence, the MMS boat was put in service and all further tagging operations were conducted from this boat. The OSU boat was deployed from the port side of the *Gyre* using the ship's crane while the R2 was deployed from a custom launch ramp over the fantail. Both deployment/recovery methods were usable in all sea conditions appropriate for tagging.

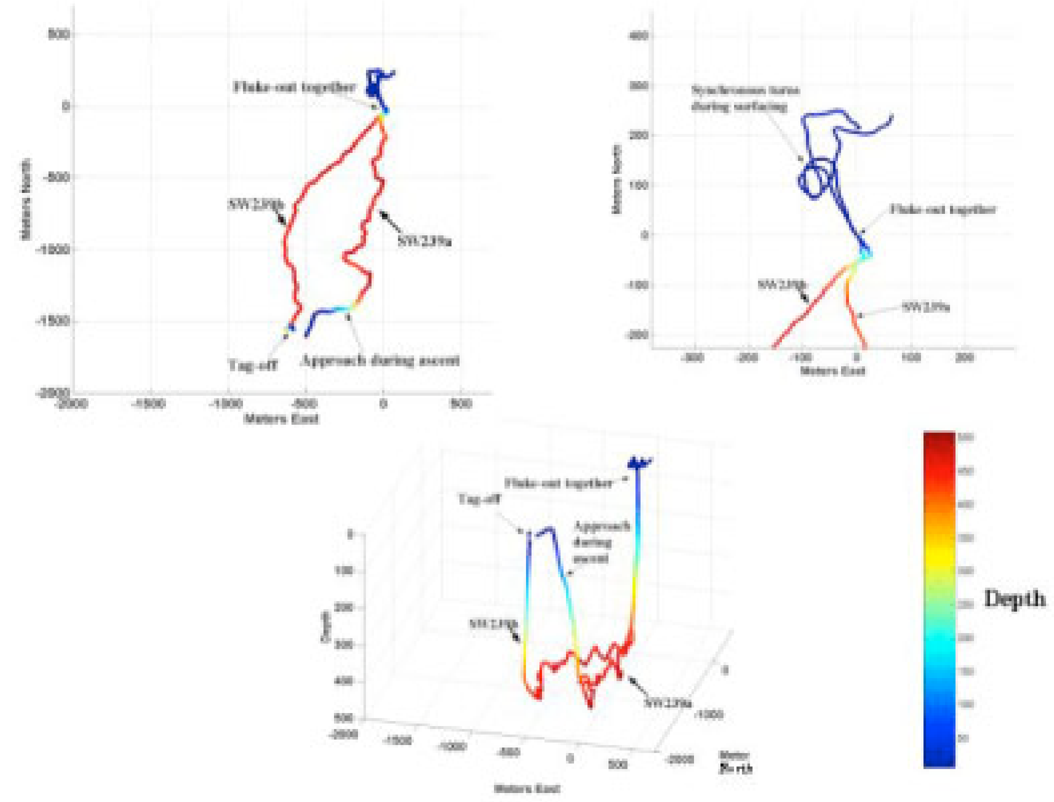


Figure 3.2.7. Dive profiles from two D-tags for sperm whales diving together.

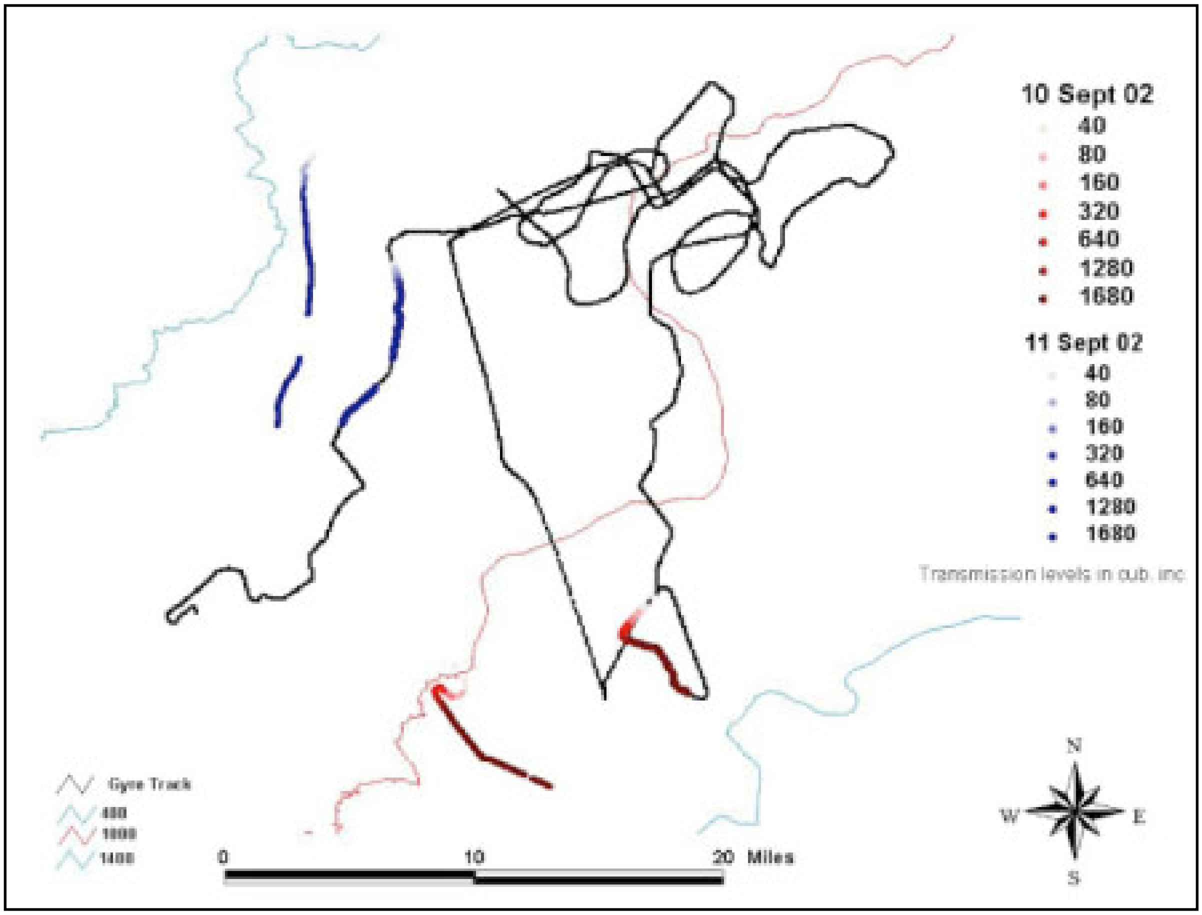


Figure 3.2.8. *R/V Gyre* track (black) and *Rylan T./Speculator* track (color) during controlled-exposure experiments on 10 and 11 September 2002. Color represents the air volume and is proportional to the sound level intensity. Color is repeated on the *Gyre* track to show its position at the same time as the airgun array was operating. Selected isobaths are shown in green and pink.

Acoustics Monitoring

Two watches staffed the acoustics lab aboard the *Gyre* rotating day and night. At night when whales were present, the acoustics team dictated the course of the *Gyre*. Two acoustic arrays were available, each with different acoustic characteristics. The first was the Ecologic acoustic array. The second was the WHOI array, which had a "towfish" sometimes called a "batfish" depressor that pulled the end of the array into a somewhat vertical orientation with the bottom at a depth of 140m or so. In principle, the Ecologic array could be towed faster as it had no depressor and was allowed to stream out a 400-m tow cable horizontally behind the vessel. Both hydrophone arrays were used during the experiment and both fed their signals into the software package called "Rainbow Click," written by Douglas Gillespie of the International Fund for Animal Welfare (to promote benign and non-invasive research), and "Ishmael," written by David Mellinger of Oregon State University. These programs have many features, but primarily allowed the acoustic team to determine the relative bearing to many whales at once. There is a left-right ambiguity in the relative bearing which is resolved by turning the ship to different bearings and following the change in relative bearing. Figure 3.2.9 shows the portion of cruise

Table 3.2.4

Timeline for ramp-up of airguns on *Speculator* for D-tag controlled exposure experiments on 10 and 11 September 2002
(Mitigation observations are noted.)

Time	Latitude (°N)	Longitude (°W)	Comments
9/10/2002			
16:40	28° 27.5	88° 58.46	Tag on
17:10	28° 25.55	89° 00.36	gun deployment started
17:20	28° 25.25	89° 00.89	
17:25	28° 24.92	89° 01.54	guns in water
17:35	28° 24.29	89° 01.28	
17:40	28° 24.08	89° 01.09	
17:50	28° 25.52	89° 00.09	
17:55	28° 23.18	89° 00.38	first shot attempt – boot failure
17:59	28° 22.98	89° 00.26	first shot large grain ship at 4.8 nm
18:04			80ci
18:13			grain ship at 3.4 nm
18:14			340 ci
18:18			turn to cut past grain ship stern
18:19	28° 22.63	89° 01.30	640ci
18:29	28° 21.94	89° 00.92	1680 ci full array power
18:34	28° 21.58	89° 00.69	Gyre radios 145db level
18:54	28° 20.31	89° 59.68	course change to close slightly
19:15–19:19			dolphin shut-down
19:29	28° 19.22	88° 57.17	END
9/11/2002			
10:14	28° 42.80	88° 56.3	TAG ON 28° 39.89 88° 59.2 3.4 nm away
10:28	28° 42.06	88° 57.5	TAG 2 ON
10:33	28° 39.81	88° 59.92	TAG 3 ON
10:57			Gyre estimates about 20 whales around them
11:10	28° 42.54	89° 00.77	observers to flying bridge
11:19	28° 42.89	89° 01.71	Gyre due west at 4.4 nm
11:33			gun deployment begun
11:40	28° 43.11	89° 03.90	guns out
12:10	28° 41.57	89° 05.28	Gyre at 4.5nm platform at 4.0 nm
12:16	28° 44.14	89° 05.58	ramp-up begun
12:26	28° 40.47	89° 05.82	160 ci 4.3 nm to Gyre
12:31	28° 40.08	89° 05.86	320 ci
12:35	28° 39.69	89° 05.86	640 ci
12:41	28° 39.30	89° 05.83	1280 ci platform at 3.25 nm
12:46	28° 38.92	89° 05.79	full power at 4nm to Gyre
12:48	28° 38.72	89° 05.78	approach starts to 2.5 nm
12:51			3.8 nm
12:56			3.6 nm
13:12	28° 36.81	89° 05.61	3.25 nm
13:20	28° 36.17	89° 05.67	3.1 nm
13:22			Tuna off bow
13:26			Bottlenose 2-6 off bow SHUTDOWN
13:43	28° 34.27	89° 05.96	half-ci start-up
13:50	28° 33.74	89° 06.17	full power on guns
13:51			Tuna off bow
13:53	28° 33.44	89° 06.37	order to close mile
13:56			more tuna
14:01	28° 33.05	89° 06.57	2.25nm
14:13	28° 32.21	89° 06.73	2.0nm
14:20	28° 31.73	89° 06.78	END

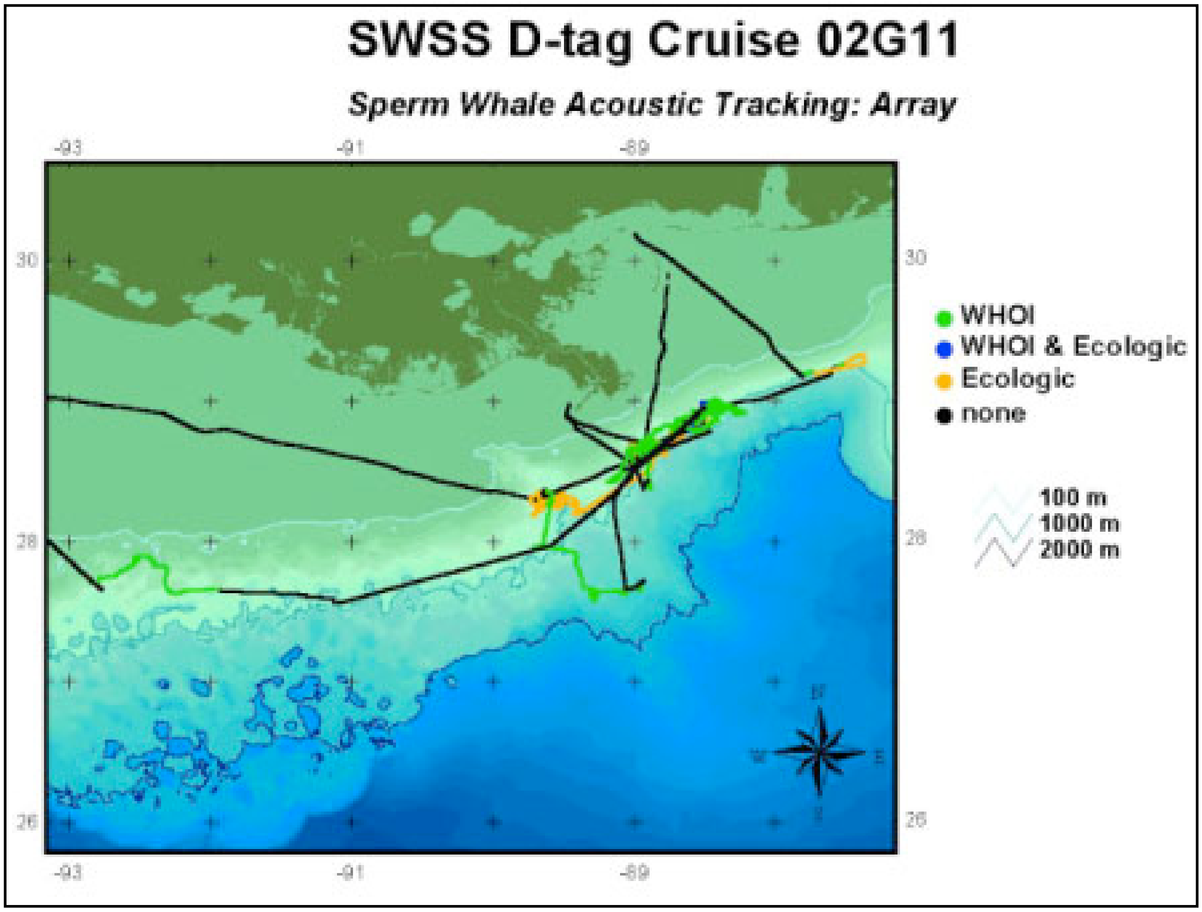


Figure 3.2.9. Ship track color-coded according to which hydrophone array was in use.

track where each array was used. The number of acoustic contacts by geographic location are indicated by Figure 3.2.10.

During the S-tag cruise, the Ecologic array persistently detected noise at a frequency of 19kHz. This noise was observed early on during the D-tag cruise. It was ruled out that this might be due to sub-harmonics of the 38kHz ADCP system because the noise was at 18.45kHz and was a continuous signal, whereas the ADCP has a pulse signal that makes a distinctive discrete signal resembling a vertical array of short horizontal lines when displayed in Rainbow Click. Aaron Thode worked with the ship's engineer to try to locate a shipboard electrical source for the noise but none was found. On the S-tag cruise, the problem had been eliminated by using a different top-end amplifier/conditioner unit. This "quiet" amplifier then was used on the D-tag cruise. However, when the same noise was present on the D-tag cruise, it was eventually cured by replacing one of the hydrophones and preamplifiers in the streamer suggesting that a faulty hydrophone preamplifier was the cause. A further problem developed when the cable was damaged, apparently through being towed with a kink in it. Initially this limited the tow speed to 3 knots but eventually the cable failed completely. The WHOI array proved more reliable but restricted the vessel speed to 4.5 knots. This was useful for monitoring whales already known to be in the area but was too slow to search for whales over large areas.

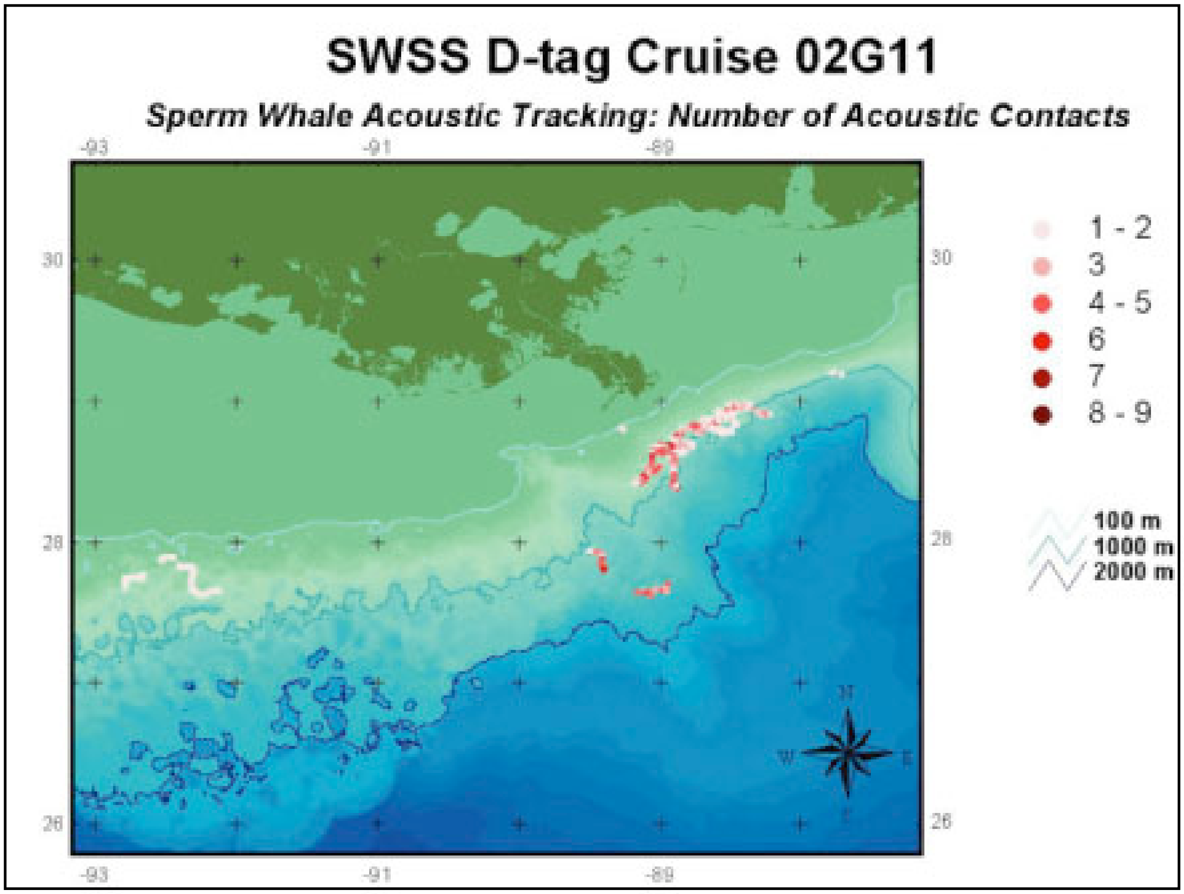


Figure 3.2.10. Numbers of acoustic contacts during the 2002 D-tag cruise.

Twice, during the cruise ranging, experiments were performed to estimate the detection range of the arrays. On 29 August, during a time when no sperm whales were present, a small workboat was deployed from the *Gyre* and driven to points 1.5 and 2.6 nautical miles from the ship. At these two points light bulbs were imploded underwater to generate an impulsive sound roughly like a sperm whale click. The implosions were clearly heard at 1.5 nm on the WHOI array, but barely heard, if at all, at 2.6 nm, suggesting an effective detection range of 4 km, much lower than the 10 nm range or higher reported in the Pacific (Barlow and Taylor 1998).

An additional detection test was performed on a sperm whale group using the Ecologic array on 3 September, when the seismic source vessel *Rylan T.* was present. While the *Rylan T.* remained in the vicinity of the group, the *Gyre* drove directly away from the group until sperm whale sounds could no longer be heard, then turned around and determined when the click sounds became audible again. At a speed of 3.3 knots the Ecologic array had a detection range of about 3.5 km, very close to the WHOI array performance.

One reason behind the limited detection range was ship noise. When the *Gyre* was commissioned in 1973 it was not designed to be acoustically silent. The WHOI array, in particular, suffered from ship noise contamination because the towfish pulled the array not only deeper, but into a noisier region below the ship. It was found that whenever the ship traveled slower than around 2 knots, one of the engines would have to be disengaged, creating a large amount of noise. Even at higher speeds the WHOI array was effectively awash in prop noise.

However, previous acoustic D-tag work in the Gulf on a different ship with different arrays has produced similar detection range results, suggesting that propagation conditions in the Gulf are fundamentally poor for long-range acoustic propagation. XBT and CTD data collected during the cruise show that the effective vertical sound-speed profile in the study region showed a very strong decrease in sound speed with depth, a feature that would be expected to refract acoustic energy into the ocean bottom, away from the surface. Figure 3.2.11 shows an example of an average sound speed profile (thin line), as well as the largest perturbation from the mean profile observed, created after a week of rough weather and storms had mixed the upper 50 m of the ocean (thick line).

The agreement of a numerical simulation with the empirically-measured detection range results suggests that poor propagation conditions are a fundamental fact of life in the Gulf, and simplified acoustic propagation assumptions like cylindrical spreading are inappropriate for the region. Figure 3.2.12 shows the numerical propagation with energy reaching the surface between 3 and 6 km. If a towed array system is well-designed and deployed from a quiet vessel, then the detection range might be extended to about 6 km, a threefold increase in search area. The way to improve detection range further is not by increasing array depth, but by increasing the array gain by incorporating additional hydrophones into an array system. For example, the *R/V Alliance*, a quiet ship using a 128-element hydrophone array, is able to achieve detection ranges in excess of 20 nm in summer-stratified conditions in the Mediterranean Sea.

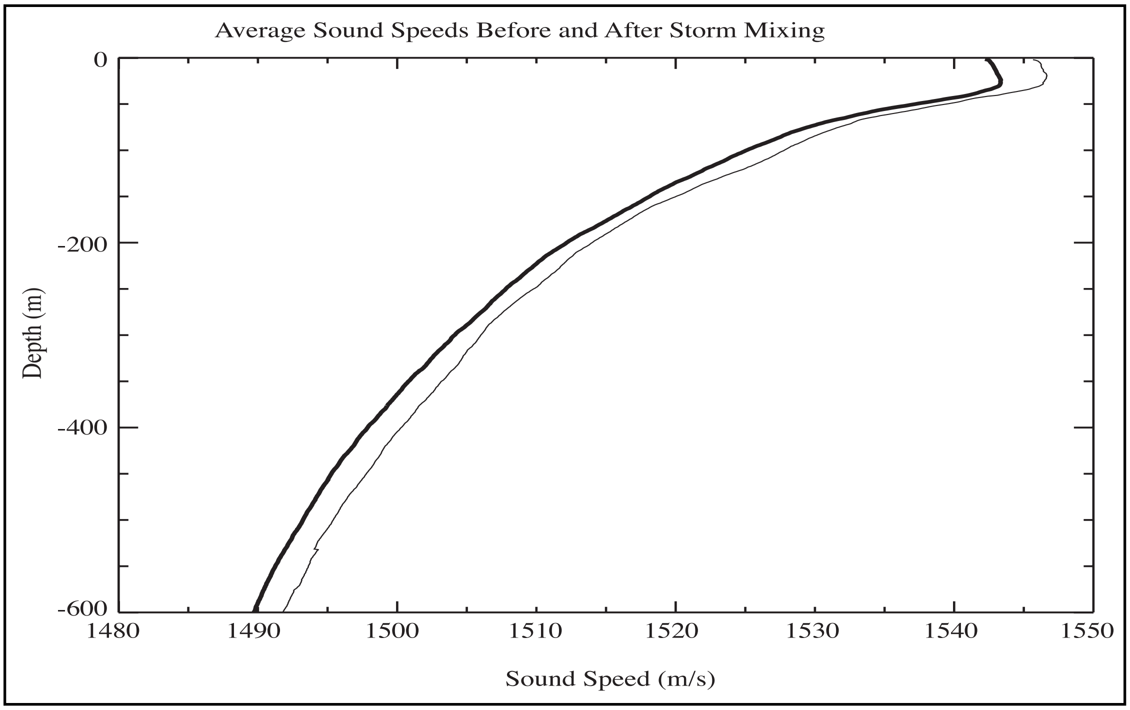


Figure 3.2.11. Average sound speed profile (thin line) and perturbation after a week of rough weather and storms had mixed the upper 50 m (thick line).

Acoustic Monitoring on the *Rylan T.*

Natacha Aguilar de Soto was in charge of permit compliance monitoring for the seismic vessel and worked aboard the *Rylan T* whenever there was a chance that whales would be approached by the *Rylan T* when the *Speculator*'s airguns were operating.

The passive acoustic system onboard the *Rylan T.* was provided by Seamap Inc. It was operated by Craig Douglas and Tim Pinnington from Seamap, and used by Natacha Aguilar de Soto in her role as permit monitor onboard the *Rylan T*. Because of limited detection ranges on board the *Gyre*, the Seamap role expanded from permit monitoring duties to frequent 24-hr acoustic watches to aid in detection and tracking of whales. During the cruise, acoustic team members on the *Gyre* worked extensively with the Seamap team and had the opportunity to view the array, recording hardware, and software. The Seamap array and personnel provided considerable help to the acoustics effort, and the combined search and tracking efforts from both vessels improved detection abilities.

The Seamap system consisted of an oil filled passive acoustic listening array, 56 m long, which was connected to the vessel via a 300-m tow cable. The array was deployed astern of the *Rylan T.* such that the head of the array was 250 m from the stern. The array was ballasted to maintain 40-m depth when towed at 5 knots. At this tow speed, the array was able to detect sperm whale vocalizations out to a range of 5-6 km. During transit between areas, the *Rylan T.* steamed at speeds between 7 and 8 knots. At this higher speed the array maintained depths between 8 and 10 m. During the higher speed steaming, the array was fully functional, but the effective range was reduced from 5-6 km to 3-4 km. Still higher towing speeds could have been supported with the use of supplemental ballasting, which was available on the vessel in the form of hinged weight collars.

The towed array comprised two channels configurable from a selection of any combination of 4 hydrophones. The distance between the outer phones was 50 m with the two center phones between these placed at frequency thirds. The onboard system was configured to two of these groups with a hydrophone spacing of 5.55 m. This separation was chosen as optimal for sperm whale detection.

The system offered a suite of visualization and detection facilities that monitored audio frequencies in real time from 8Hz to 22000Hz and also recorded acoustic data in a proprietary format that subsequently was exported in "wav" file format. The system also was interfaced to GPS to provide positional information that allowed detections to be plotted on the system's mapping software.

During the trial, a TASCAM recorder was attached to the analogue output from the system to provide continuous recording of acoustic data during critical periods. In addition to this recording, the Seamap Cetacean Monitoring System also recorded more than 6 hours of animal vocalizations. The system automatically buffered the last two minutes of digital audio data in the internal memory for recording to hard drive at any time by a single operator mouse click.

The system was deployed on 31 August and was in nearly continuous use until 7 September when it was recovered onboard when the *Rylan T.* and Gyre went to anchor west of the Mississippi Delta sheltering from the weather. The streamer was deployed again on 9 September and remained in use until 11 September when the *Rylan T.* left to demobilize in Texas City. The system performed without any equipment downtime for the entire period of the trial.

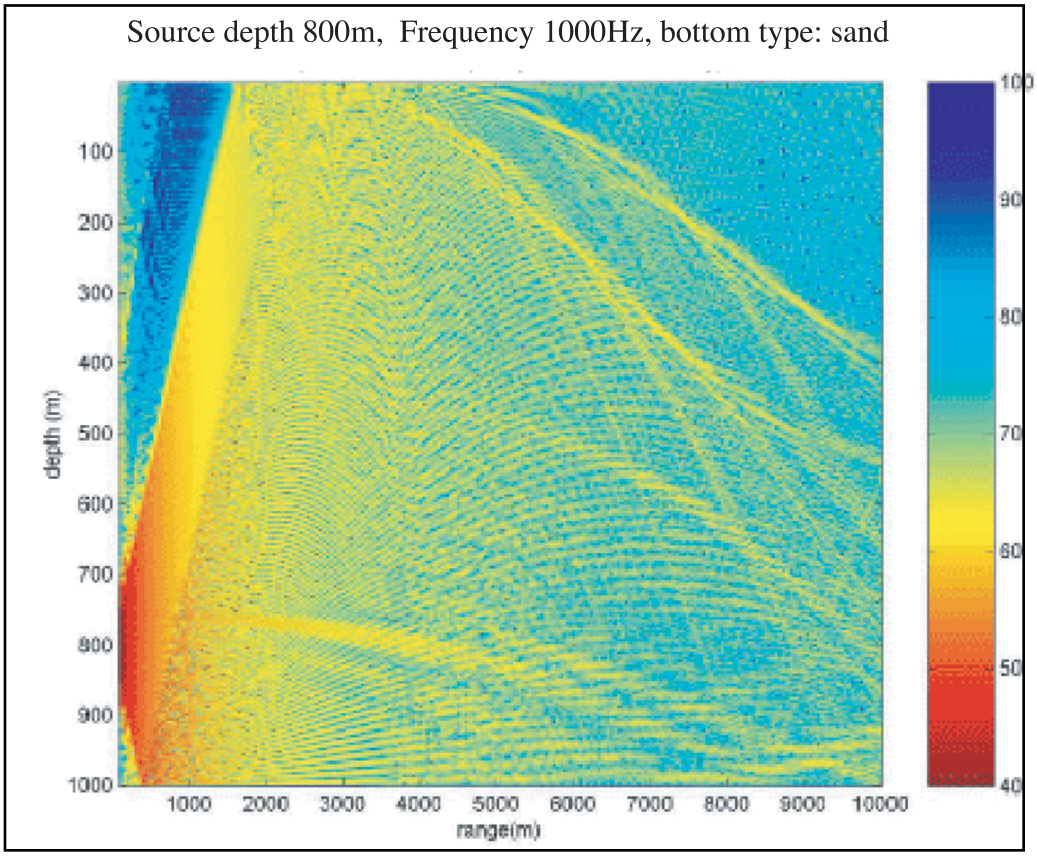


Figure 3.2.12. Acoustic transmission loss, in dB, from a source at 800-m depth in 1000-m deep water over a sandy bottom. The figure was made using a normal mode model, KRAKEN, which is accurate out past a 1-km range.

The Seamap array was able to track sperm whales within 6 km of the operation. For a short interval before the *Rylan T.* became engaged in CEE support, range and bearing estimates for sperm whales that were about to surface were provided by the Seamap team and confirmed by visual observers on board the *Rylan T.* with surprising consistency. This exercise was for tracking and testing equipment for a monitoring role.

Tagging and Playback Coordinators

Coordination of the tagging and seismic playback activities was achieved by Dan Engelhaupt and Peter Tyack, respectively. Their task was to maintain situational awareness of the various operations going on with the tag boat and the seismic vessel, merge the information coming from the acoustic and visual team, and communicate with the ship's bridge crew. This can be quite challenging when all players are active. It would appear that 3 tagged whales and 3 vessels are currently the practical limit for such control.

Tissue Collection/Genetic Typing

Figure 3.2.13 shows the locations at which tissue samples were collected. Tissue sampling during the D-tag cruise was primarily focused on the opportunistic collection of sloughed skin often found attached to the D-tag suction cups placed on sperm whales (Table 3.2.5). Sloughed skin samples from eleven D-tagged sperm whales were collected during the four-week cruise.

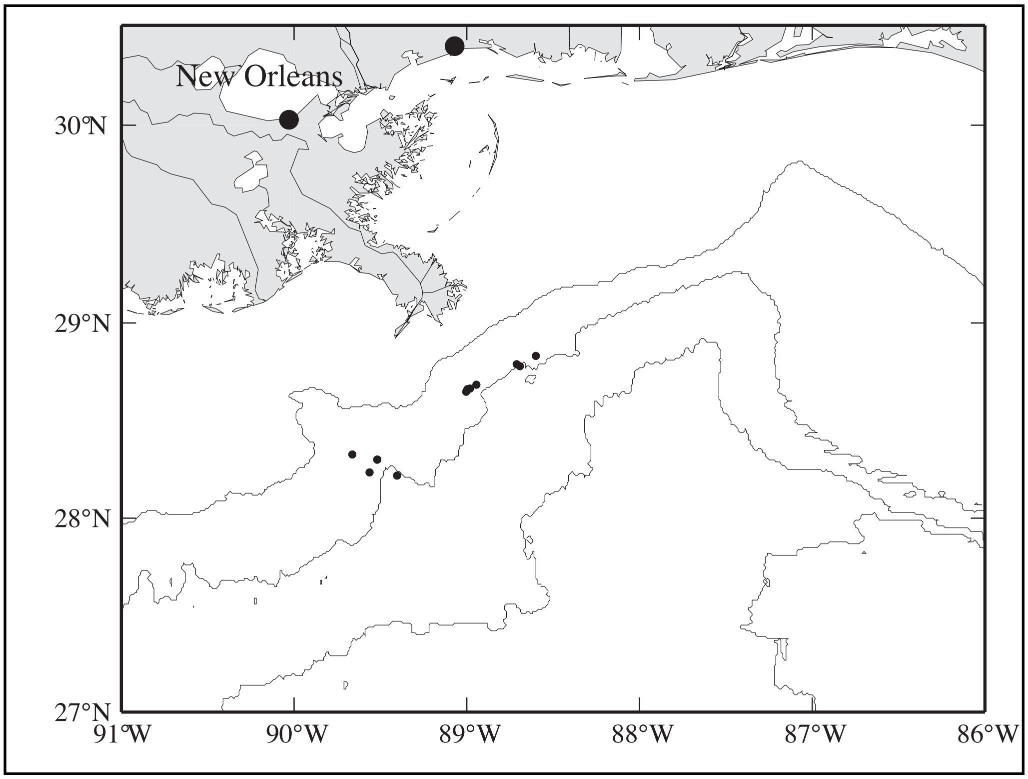


Figure 3.2.13. Locations where skin or biopsy samples were collected during SWSS cruise Leg 2, D-tag, August/September 2002. Bathymetry contours are 200, 1000, 2000, and 3000 m.

Two samples of sloughed skin found free-floating in the water near a group of whales were collected with a dipnet. While sloughed skin obtained from D-tags has proven fairly reliable in the past, sloughed skin in general can be quite difficult to amplify given the DNA's somewhat degraded nature. Due to the extensive weather delays, biopsy sampling was limited to one day with what was thought to be a large sub-adult, or perhaps adult, male based on size estimates from the R2 tag boat. Although this whale proved extremely skittish and evasive to the RHIB, a very minute amount of skin was collected from a biopsy dart that skimmed the whale's back. If this sample provides adequate DNA for analysis, this will mark the largest whale sampled to date throughout the northern Gulf of Mexico and the first free-ranging sperm whale sampled in the western region of the northern Gulf of Mexico. Based on previous and ongoing surveys, large sexually and physically mature males are not common in the northern Gulf of Mexico. Future cruise decisions to biopsy sample, photo-ID, and incorporate photogrammetry techniques on all 'larger' sperm whales will surely aid the overall goals of this research.

The combination of D-tagging and genetic sampling continues to provide an in-depth examination of sperm whales found throughout the northern Gulf of Mexico. Molecular sexing, microsatellites, and mitochondrial DNA sequencing will provide a rich set of information that can be directly integrated with the dive profiles of D-tagged whales. For example, we obtained skin samples from multiple members of three groups (Group #s 1, 3, and 7; see Table 3.2.5). An extremely exciting and interesting result was the collection of skin from all three members (Group 7) of the 'triple-dog' tagging session. Preliminary visual results suggest that the tagged members of Group 7 were surfacing in close proximity to each other. Degrees of relatedness will be tested between whales found within all sampled groups. The combination of genetics and

WHOI D-tag dive profile data may perhaps shed light on how related and unrelated whales found within groups in the northern Gulf of Mexico coordinate both deep foraging and shallow dives.

In an ideal situation, one would attempt to sample all members that comprise a group. Given this year's primary focus on the D-tagging effort and the inclement weather, this was simply not possible. While our resulting genetic composition of groups will not portray an accurate representation of group structure for free-ranging sperm whales found in the Gulf of Mexico, the benefits of combining skin sampling and D-tagging will surely provide numerous answers to previously unknown questions.

Table 3.2.5

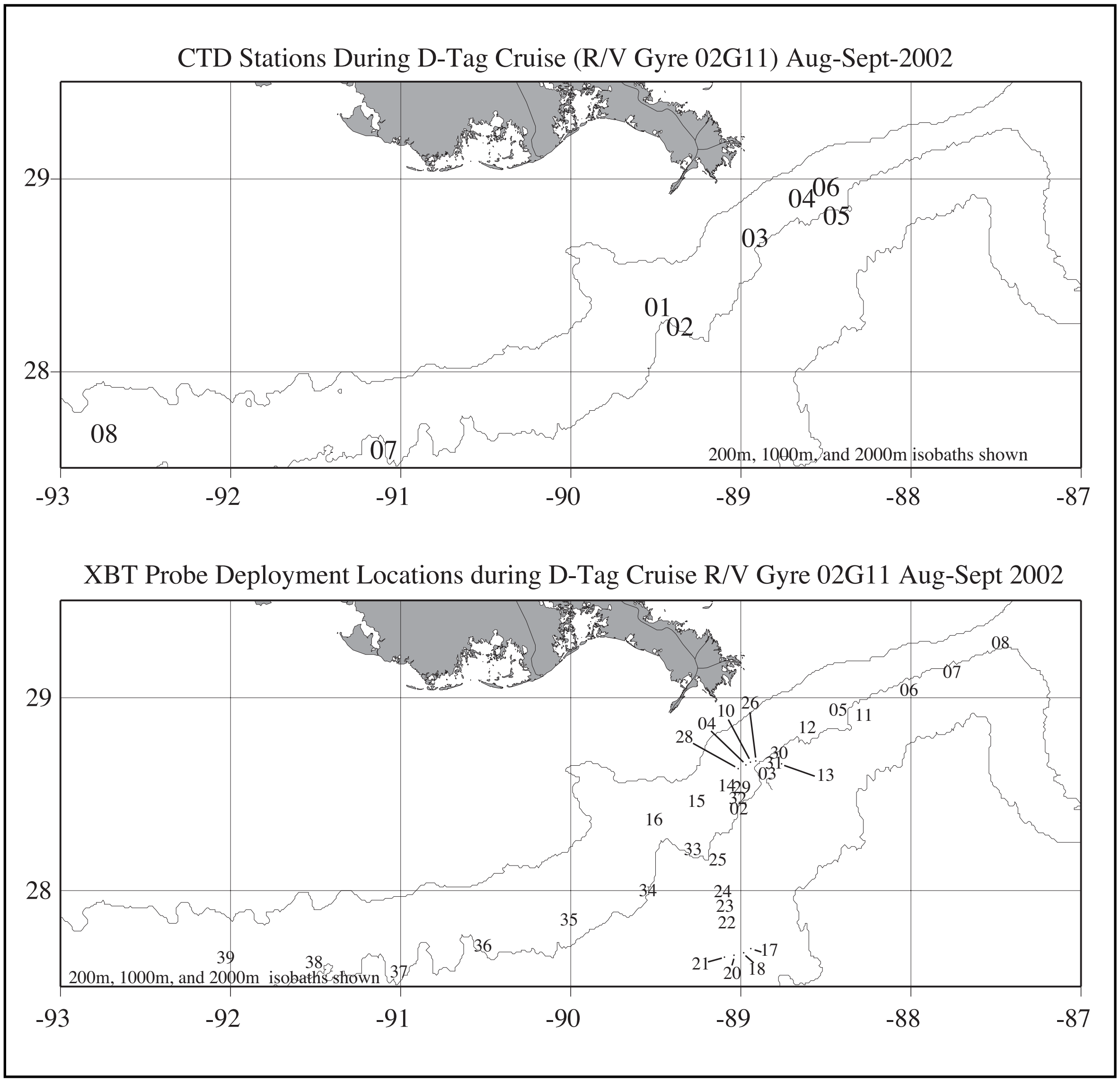
Tissue collection and genetic typing samples collected during SWSS 2002 D-tag fieldwork (The sample number code gives the date (yymmdd) followed by the consecutive number for multiple samples taken on any given day (01 to 04).)

Sample No.	Tag No.	Group No.	Approx. Number of Whales in Area	Longitude (°N)	Latitude (°W)
02082301		1	20	-89.5618	28.2387
02082302		1	20	-89.5189	28.3014
02082303	SW235B	1	20	-89.6640	28.3303
02082304	SW235C	1	20	-89.5189	28.3014
02082401	SW236A	2	7	-89.4053	28.2208
02082501	SW237A	3	15	-88.6930	28.7800
02082502	SW237B	3	15	-88.7102	28.7907
02082601	SW238A	4	5-10	-88.9445	28.6863
02082801	SW239A	5	10	-89.0052	28.6511
02082901	SW240B	6	10	-88.5995	28.8319
02091101	SW254A	7	15-20	-88.9829	28.6645
02091102	SW254B	7	15-20	-88.9924	28.6617
02091103	SW254C	7	15-20	-88.9953	28.6612
02091401		8	2	-92.7571	27.6503

Environmental Characterization

Several types of measurements were collected to characterize the physical-biochemical environment during the cruise. Conductivity-Temperature-Depth (CTD) profiles provided the most complete information about temperature, salinity, density, and sound speed structure of the water column. However, CTD casts were only made when the ship was stopped. When hydrophone arrays were deployed, the ship cannot stop or the arrays will sink. Due to these mutually exclusive requirements, only 8 CTD casts were taken (Figure 3.2.14a). Table 3.2.6 shows the date, time, location, and depth of cast for each CTD cast.

Expendable temperature profiles (XBTs) which can be deployed from a moving ship, are the next best alternative for determining sound speed profiles. Thirty-eight XBTs were deployed, with 35 giving profiles to approximately 760 m. Because we were following whales, it was never


CTD Stations During D-Tag Cruise (R/V Gyre 02G11) Aug-Sept-2002

XBT Probe Deployment Locations during D-Tag Cruise R/V Gyre 02G11 Aug-Sept 2002

Figure 3.2.14. Locations of hydrographic stations on SWSS Leg 2, D-tag, in August/September 2002. Shown are (upper) the locations of the 8 CTD casts and (lower) 35 of the 39 XBT probes deployed.

clear where we would be from hour to hour or day to day. This made it somewhat difficult to plan the deployment of the XBTs to get good spatial coverage, but the coverage turned out well (Figure 3.2.14b). Table 3.2.7 shows for each XBT drop the time, location, and depth of the 15°C isotherm.

Table 3.2.6

Location, time, cast depth and water depth for SeaCat CTD casts taken on the SWSS 2002 D-tag cruise

Station	Date	Time	Latitude	Longitude	Cast	Water
CTD-01	08/22/2	18:20	28.3067	-89.5000	942	945
CTD-02	08/25/2	10:30	28.2057	-89.3728	1007	1016
CTD-03	08/28/2	06:32	28.6651	-88.9305	944	946
CTD-04	08/29/2	05:16	28.8713	-88.6562	664	667
CTD-05	09/04/2	22:48	28.7812	-88.4505	1360	1371
CTD-06	09/12/2	13:09	28.9294	-88.5142	719	735
CTD-07	09/13/2	12:47	27.5648	-91.1142	941	959
CTD-08	09/14/2	22:38	27.6495	-92.7576	719	730

Mean sound speed profiles based on the XBT and limited CTD data were provided to the tag and passive acoustics personnel for use in their acoustic calculations. These were used to obtain estimates of sound speed profiles to assist in extracting precision information from the D-tags. Furthermore, most whales were found along the rather complex frontal boundaries of the Mississippi River plume. Here is where sound speed profiles are likely to differ most from historical averages.

Because of the nature of the controlled exposure experiment, it seemed prudent to reduce extraneous sound sources. The two ADCPs (153 kHz and 38 kHz) were turned off whenever whales were present and were operated only when making long (several hour) high speed runs between locations. Figures 3.2.15 and 3.2.16 show the tracks (upper panels) over which the 153-kHz and 38-kHz ADCP data were collected and the current velocity vectors from the surface-most bin of each instrument (lower panels). Upon reaching a new location, the ADCPs were secured as soon as the first whale was sighted. This action made it clear that the ADCP operations did not interfere with the controlled exposure experiments because they were not operational during the experiments. Data from the long runs should provide an idea of the general circulation patterns over the area between Mississippi and DeSoto Canyons. Additionally, no good data were lost under this method of operating because whale observations generally were made in a 10-km box encompassing the whales that were being studied. Continuous ADCP records within such boxes would have been unwieldy to process and of limited use.

The *Gyre* has two continuously-fed flow-through systems that draw seawater in from ~3m depth. One is located in the bow and measures temperature and salinity, and one is mid-ships and monitors temperature, salinity, and fluorescence. These can be merged with DGPS time and location to produce a continuous record of these parameters during the entire cruise. Water samples were drawn from the mid-ship flow-through system and measured chemically for chlorophyll concentration. Seventy-five such samples (Figure 3.2.17) were collected and analyzed by Laurie Sindlinger (TAMU). The date, time, location, concentration, and subjective ocean color observations for each chlorophyll are listed in Table 3.2.8. The color observations alone show that we were operating in a frontal region between the relatively low-salinity high-chlorophyll regions associated with Mississippi River outflow and the more saline "blue" waters offshore.

Table 3.2.7

XBT probe deployment locations and dates on SWSS 2002 D-tag cruise
(The depth of the 15°C isotherm is given. T7 probes were used. Probes 9, 15, 19, and 27 had good results only in the upper part of the cast; bad data from the lower part were removed.)

Station	Latitude (°N)	Longitude (°W)	Date (mm/dd/yyyy)	Time (UTC)	Cast Depth (m)	Water Depth (m)	15°C Depth (m)
XBT-01	28.3348	-89.6663	08/15/2002	07:30	683	751	218
XBT-02	28.4311	-88.9999	08/25/2002	05:32	760	988	240
XBT-03	28.6146	-88.8329	08/25/2002	09:09	760	1136	260
XBT-04	28.6641	-88.9897	08/27/2002	18:18	662	802	247
XBT-05	28.9413	-88.4148	08/29/2002	07:26	760	873	191
XBT-06	29.0431	-87.9998	08/29/2002	10:02	760	1307	244
XBT-07	29.1349	-87.7478	08/29/2002	11:38	760	1247	220
XBT-08	29.2879	-87.4620	08/29/2002	16:38	760	834	223
XBT-09	28.6679	-88.9275	08/31/2002	14:20	532	953	215
XBT-10	28.6679	-88.9442	08/31/2002	14:36	760	910	208
XBT-11	28.9148	-88.2676	09/03/2002	19:44	760	1173	214
XBT-12	28.8639	-88.5732	09/04/2002	08:41	760	778	222
XBT-13	28.6658	-88.7501	09/05/2002	02:02	760	1233	236
XBT-14	28.5499	-89.0716	09/05/2002	04:38	620	623	250
XBT-15	28.4697	-89.2501	09/05/2002	06:10	531	532	227
XBT-16	28.3748	-89.5001	09/05/2002	08:13	697	728	223
XBT-17	27.7085	-88.9294	09/06/2002	18:56	653	1602	216
XBT-18	27.6789	-88.9638	09/06/2002	20:13	760	1727	206
XBT-19	27.6659	-89.0134	09/06/2002	21:10	760	1641	232
XBT-20	27.6645	-89.0177	09/06/2002	21:16	760	1634	236
XBT-21	27.6676	-89.0520	09/06/2002	22:46	760	1641	237
XBT-22	27.8383	-89.0720	09/07/2002	12:04	760	1393	234
XBT-23	27.9241	-89.0829	09/07/2002	12:44	760	1260	237
XBT-24	28.0000	-89.0959	09/07/2002	01:19	760	1332	235
XBT-25	28.1669	-89.1249	09/07/2002	02:36	760	1135	225
XBT-26	28.6684	-88.9244	09/09/2002	20:05	760	963	221
XBT-27	28.6431	-89.0073	09/11/2002	16:10	456	707	199
XBT-28	28.6425	-89.0184	09/11/2002	16:22	707	708	202
XBT-29	28.5402	-88.9841	09/12/2002	08:26	760	776	222
XBT-30	28.7071	-88.7685	09/12/2002	10:42	760	1140	199
XBT-31	28.6685	-88.7906	09/12/2002	19:11	760	1082	206
XBT-32	28.4855	-89.0074	09/12/2002	21:04	760	885	208
XBT-33	28.2211	-89.2722	09/12/2002	23:41	760	919	252
XBT-34	28.0060	-89.5350	09/13/2002	01:57	760	947	244
XBT-35	27.8531	-90.0006	09/13/2002	05:16	734	745	249
XBT-36	27.7183	-90.5077	09/13/2002	08:46	760	838	273
XBT-37	27.5813	-91.0002	09/13/2002	11:57	760	932	243
XBT-38	27.6307	-91.5000	09/13/2002	16:50	760	793	247
XBT-39	27.6559	-92.0178	09/13/2002	21:21	621	622	227

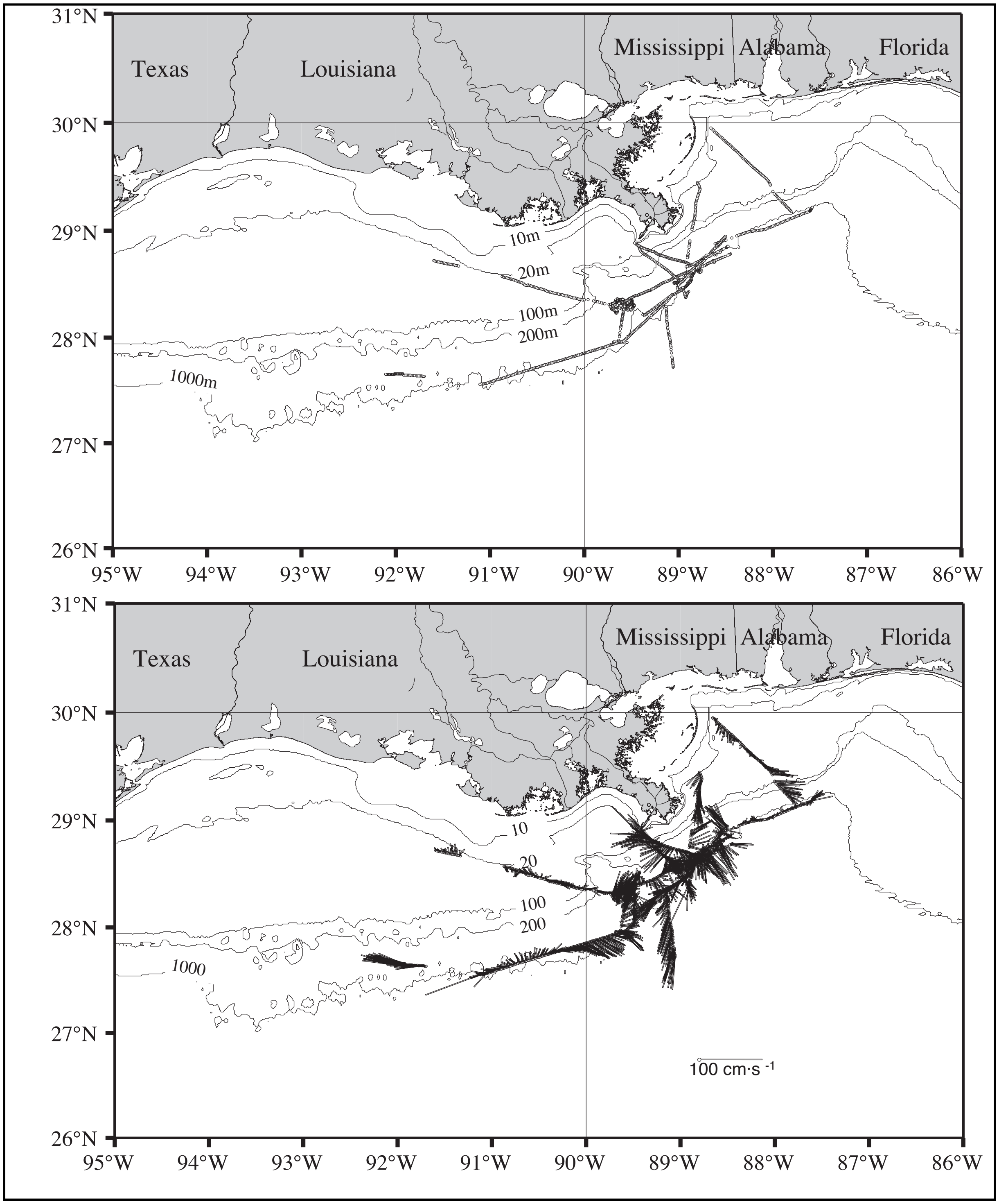


Figure 3.2.15. Data collection from the 153-kHz ADCP on the D-tag cruise from 22 August through 13 September 2002. Shown are (upper) locations of the ADCP-measured currents and (lower) the horizontal current velocity at 13.6-m depth.

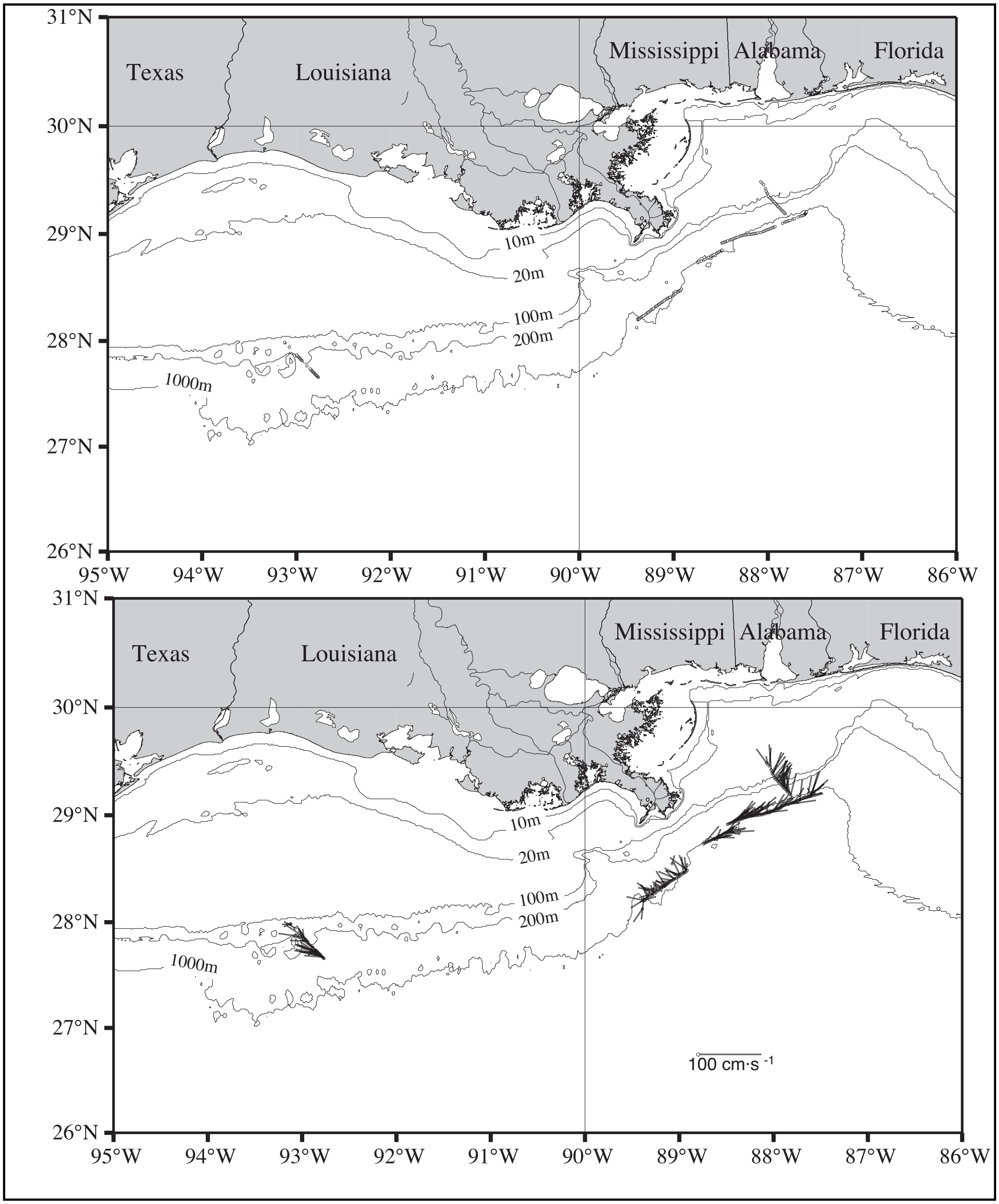


Figure 3.2.16. Data collection from the 38-kHz ADCP on the D-tag cruise from 22 August through 13 September 2002. Shown are (upper) locations of the ADCP-measured currents and (lower) the horizontal current velocity at 13.6-m depth.

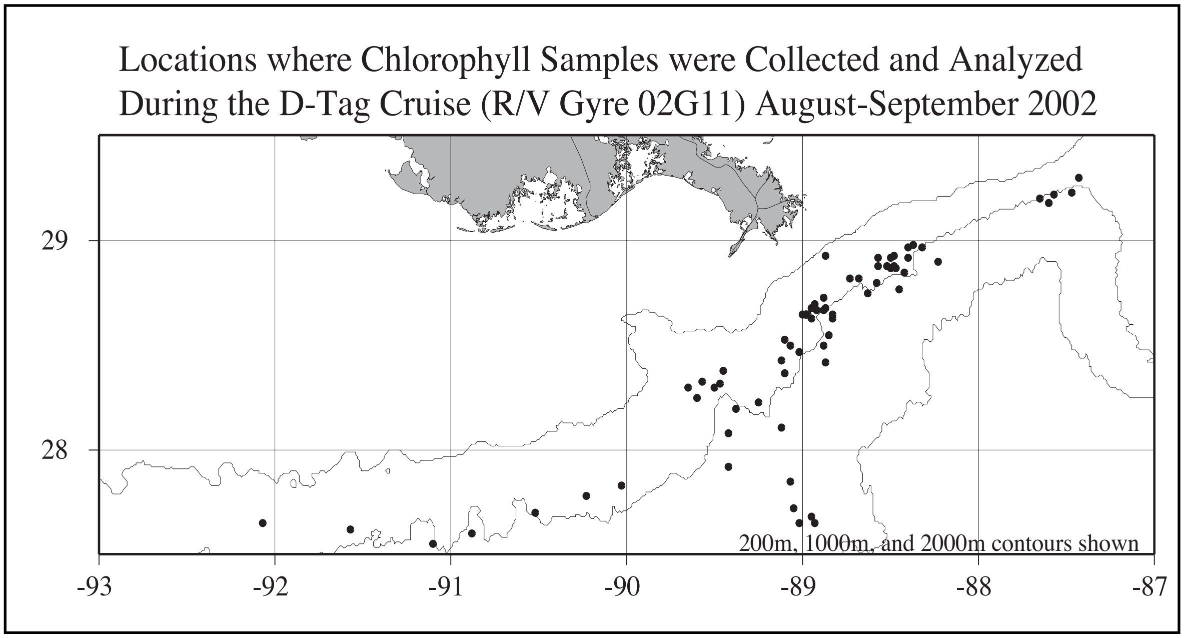


Figure 3.2.17. Locations of near-surface chlorophyll samples during D-tag cruise in August/September 2002. Seventy-five samples were taken.

Table 3.2.8

Extracted chlorophyll stations on the SWSS 2002 D-tag cruise

Sequence	Date (m/d/y)	Time (UTC)	Longitude (°W)	Latitude (°N)	Extracted CHL (μg/L)	Ocean Color
1	8/22/2002	18:01	-89.50	28.30	0.29	blue
2	8/23/2002	15:43	-89.65	28.30	0.36	very blue
3	8/24/2002	16:08	-89.60	28.25	0.28	very blue
4	8/24/2002	17:48	-89.47	28.32	0.27	very blue
5	8/24/2002	19:25	-89.38	28.20	0.25	very blue
6	8/25/2002	00:29	-89.37	28.20	0.32	very blue
7	8/25/2002	01:33	-89.10	28.37	0.23	very blue
8	8/25/2002	04:40	-88.85	28.55	0.18	very blue
9	8/25/2002	15:36	-88.63	28.75	0.37	blue
10	8/25/2002	23:14	-88.87	28.68	0.18	blue
11	8/26/2002	15:06	-88.92	28.67	1.28	green
12	8/26/2002	17:29	-88.98	28.65	0.81	green
13	8/26/2002	21:38	-89.00	28.65	1.66	green
14	8/27/2002	16:09	-88.98	28.65	0.77	green
15	8/27/2002	21:25	-88.97	28.65	0.6	green
16	8/28/2002	00:47	-88.98	28.65	0.46	green
17	8/28/2002	13:03	-88.47	28.87	0.59	green
18	8/28/2002	16:28	-88.48	28.88	0.26	green
19	8/28/2002	18:45	-88.52	28.88	1.28	green
20	8/29/2002	00:56	-88.68	28.82	0.40	green
21	8/29/2002	12:38	-87.60	29.18	0.27	very blue
22	8/29/2002	13:47	-87.57	29.22	0.35	very blue
23	8/29/2002	16:42	-87.43	29.30	0.31	very blue
24	8/29/2002	20:15	-87.47	29.23	0.27	very blue
25	8/29/2002	23:03	-87.65	29.20	0.25	very blue
26	8/30/2002	07:47	-88.25	29.63	0.77	green
27	8/30/2002	11:08	-88.67	29.95	0.47	green
28	8/31/2002	01:00	-88.87	28.93	0.51	green
29	8/31/2002	12:02	-88.88	28.73	0.27	very blue
30	8/31/2002	15:56	-88.73	28.82	0.35	very blue
31	8/31/2002	22:48	-88.73	28.82	0.23	very blue
32	9/01/2002	17:18	-88.40	28.97	0.27	blue
33	9/01/2002	22:42	-88.37	28.98	0.28	blue
34	9/02/2002	13:44	-88.57	28.88	0.85	green
35	9/02/2002	15:42	-88.57	28.92	1.83	green
36	9/02/2002	19:43	-88.50	28.87	0.44	blue
37	9/03/2002	13:12	-88.32	28.97	0.27	green
38	9/03/2002	17:23	-88.23	28.90	0.18	blue
39	9/03/2002	23:20	-88.40	28.92	4.04	very green
40	9/04/2002	13:38	-88.58	28.80	2.42	green
41	9/04/2002	19:33	-88.42	28.85	1.15	blue-green
42	9/04/2002	23:29	-88.45	28.77	1.19	blue-green
43	9/05/2002	02:42	-88.83	28.63	0.68	blue-green
44	9/06/2002	04:45	-89.10	28.53	0.51	blue-green
45	9/05/2002	07:47	-89.45	28.38	0.36	blue-green
46	9/05/2002	12:33	-89.57	28.33	0.33	blue-green
47	9/05/2002	21:43	-89.42	27.92	0.33	blue-green
48	9/06/2002	15:31	-88.93	27.65	0.32	blue
49	9/06/2002	19:42	-88.95	27.68	0.50	blue
50	9/06/2002	21:30	-89.02	27.65	0.28	blue
51	9/06/2002	22:42	-89.05	27.72	0.33	blue
52	9/07/2002	00:07	-89.07	27.85	0.29	blue
53	9/07/2002	02:47	-89.12	28.11	0.37	blue
54	9/07/2002	07:20	-89.02	28.47	0.51	blue

Table 3.2.8

Extracted chlorophyll stations on the SWSS 2002 D-tag cruise (continued)

Sequence	Date	Time (UTC)	Longitude (°W)	Latitude (°N)	Extracted CHL (µg/L)	Ocean Color
55	9/09/2002	17:32	-88.93	28.70	0.89	blue-green
56	9/09/2002	20:46	-88.95	28.68	0.85	blue-green
57	9/10/2002	00:44	-88.95	28.63	0.42	blue-green
58	9/10/2002	14:57	-88.88	28.68	0.64	green
59	9/10/2002	20:52	-88.88	28.50	0.29	green
60	9/11/2002	01:28	-88.87	28.42	0.35	green
61	9/11/2002	13:01	-88.88	28.67	3.77	green/brown
62	9/11/2002	18:28	-89.07	28.50	2.83	green/brown
63	9/11/2002	22:26	-89.12	28.43	0.51	green
64	9/12/2002	10:06	-88.83	28.65	1.19	blue-green
65	9/12/2002	10:40	-88.50	28.92	1.49	blue-green
66	9/12/2002	13:11	-88.48	28.93	0.64	blue-green
67	9/12/2002	23:27	-89.25	28.23	0.15	azure blue
68	9/13/2002	01:01	-89.42	28.08	0.25	azure blue
69	9/13/2002	05:32	-90.03	27.83	0.15	azure blue
70	9/13/2002	06:59	-90.23	27.78	0.14	azure blue
71	9/13/2002	08:53	-90.52	27.70	0.12	azure blue
72	9/13/2002	11:18	-90.88	27.60	0.14	azure blue
73	9/13/2002	12:48	-91.10	27.55	0.16	azure blue
74	9/13/2002	17:19	-91.57	27.62	0.17	azure blue
75	9/13/2002	21:54	-92.07	27.65	0.13	azure blue

While at sea, four SSH fields, produced by Robert Leben of the University of Colorado, were received. These fields represented conditions for 21 August, 28 August, 4 September, and 10 September. All four are similar. The field for 10 September is shown in Figure 3.2.18. The SSH field shows a fairly strong cyclonic flow southeast of the mouth of the Mississippi River separating two moderate regions of anticyclonic flow over the Mississippi and DeSoto Canyons. This configuration should produce offshore flow near 90°W and onshore flow near 88°W. A SeaWiFS image for 24 August also was received, courtesy of Orbimage and NASA and processed by the College of Marine Science of the University of South Florida. Figure 3.2.19 shows the ship track color-coded to reflect near-surface salinity (blue is low salinity, pink is higher) from the flow-through system overlain on this SeaWiFS image, which is indicative of chlorophyll levels in surface waters (red is high, purple is low). The region of blue imbedded in purple south of the delta is a region of apparent cyclonic flow. The image suggests the notion that we were finding whales in the frontal regions. High salinities correlate well with low chlorophyll waters found offshore as do low salinities with high-chlorophyll waters associated with the river plume. Also, the fact that there is some movement of the frontal boundaries is seen in changes with time of salinity from the ship tracks in the same area.

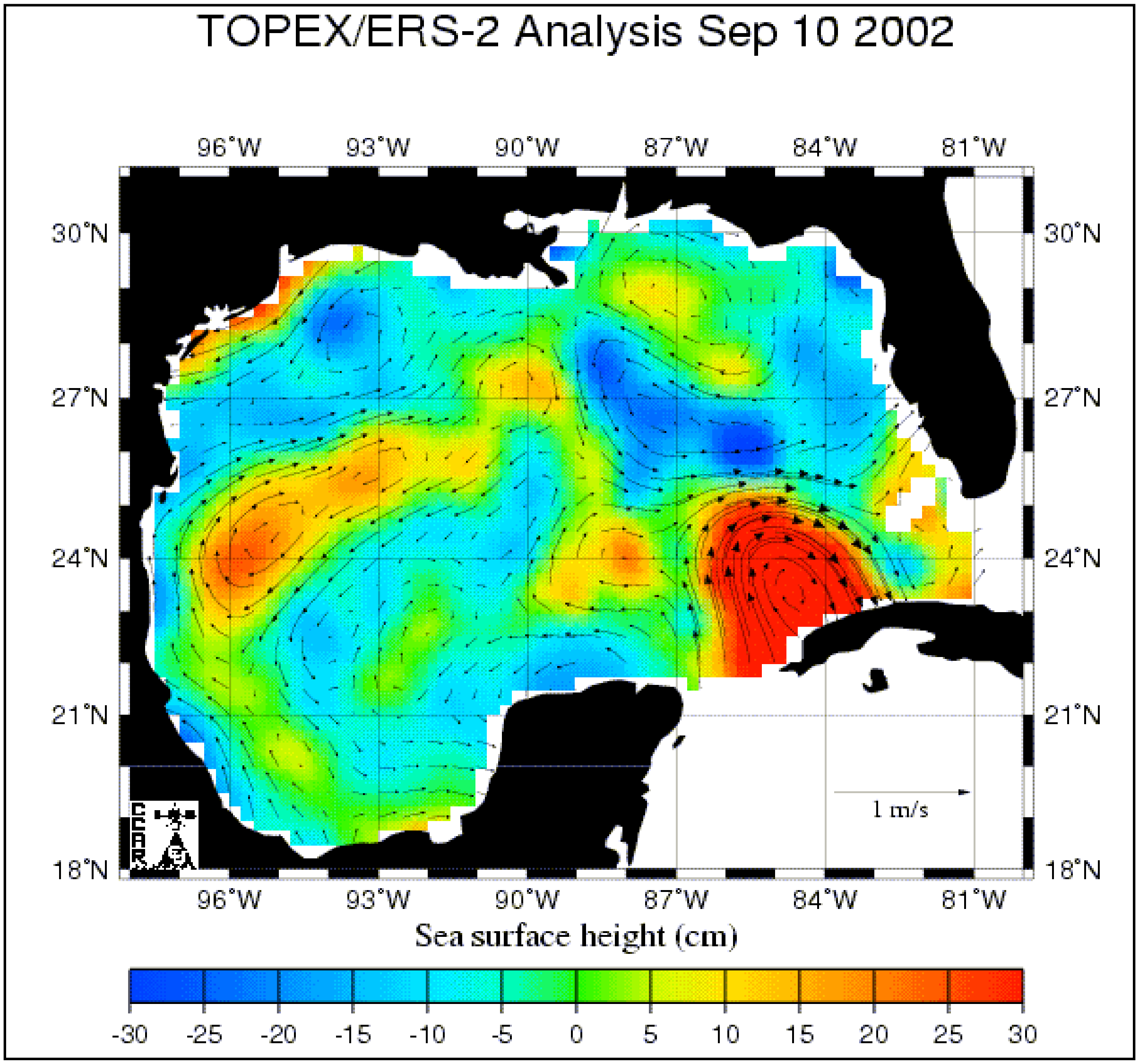


Figure 3.2.18. Sea surface height from TOPEX/ERS-2 altimeters for 10 September 2002. Image is from Robert Leben, Colorado Center for Astrodynamics Research (CCAR), University of Colorado.

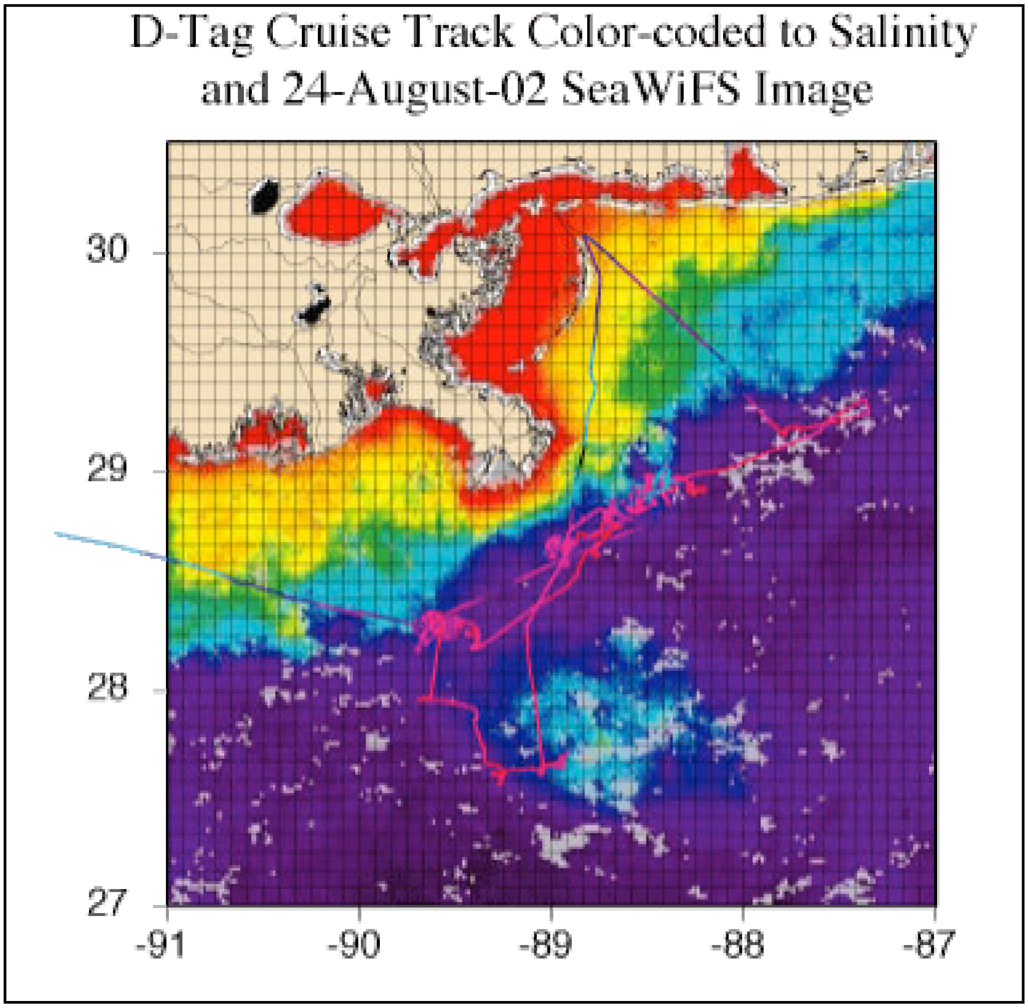


Figure 3.2.19. SeaWiFS image for 24 August 2002 showing chlorophyll concentration and D-tag cruise track color-coded to salinity. For chlorophyll, red is a high concentration and purple is low. For salinity, red is high and blue is low. SeaWiFS image is courtesy of OrbImage and NASA; data were collected and processed at the College of Marine Sciences, University of South Florida.

3.3 S-tag Follow-up Cruises

S-tag follow-up cruises were conducted 6-8 December 2002 and 19 January-2 February 2003 from sport fishing vessels based out of Venice, LA. Sperm whale surveys were conducted in this area with the objectives to relocate tagged sperm whales and to make observations on the tag healing process, possible tag effects, and association between individuals through photo-identification. Surveys were done on board the 36' Delta Dawn and 26' Prime Time fishing vessels. Information on the December cruises is summarized in this report.

The locations of tagged sperm whales were determined from satellite transmissions received from late November through early December 2002 (Figure 3.3.1a). These locations showed many of the whales with operating tags were located off the mouth of the Mississippi River in water depths greater than 200 m. Note the close proximity of the whales to the coast in that region. This proved advantageous because no long transits were needed to make the observations. The track of the survey was based on these locations (Figure 3.3.1b).

The participants in the survey were Joel Ortega and Dan Lewer of OSU. During the survey, the two observers searched for sperm whales by naked eye and with hand held binoculars. Additionally, a hydrophone was deployed at several locations to detect sperm whale vocalizations. Weather conditions were marginal throughout the survey period.

A group of three sperm whales was observed on 7 December 2002 at latitude 28.7288°N and longitude 88.9558° (Figure 3.3.1b). The group consisted of two adults and a juvenile. The whales were approached closely enough to detect the presence of tags; they did not have tags attached. One of the adults had a lump on the dorsum, about 20 cm in front of and 30 cm to the left of the dorsal fin. This protuberance was about 30 cm on the dorsoventral axis and about 15 cm on the sagittal axis. No blood or secretions were observed coming from the lump and the animal did not exhibit any unusual behavior during the time it was observed (about 8 minutes). From its location, it is possible the protuberance could have resulted from a tag previously being attached to the whale. However, the actual cause of the lump is unknown, and no pictures were available to allow positive identification as a tagged whale. Video and pictures were taken of all the observed individuals, including some video footage of the lump. However, due to the environmental conditions, it was not possible to obtain pictures suitable for individual identification.

Additional efforts to relocate tagged sperm whales off the mouth of the Mississippi River began in January 2003. These will be reported on in the next annual report.

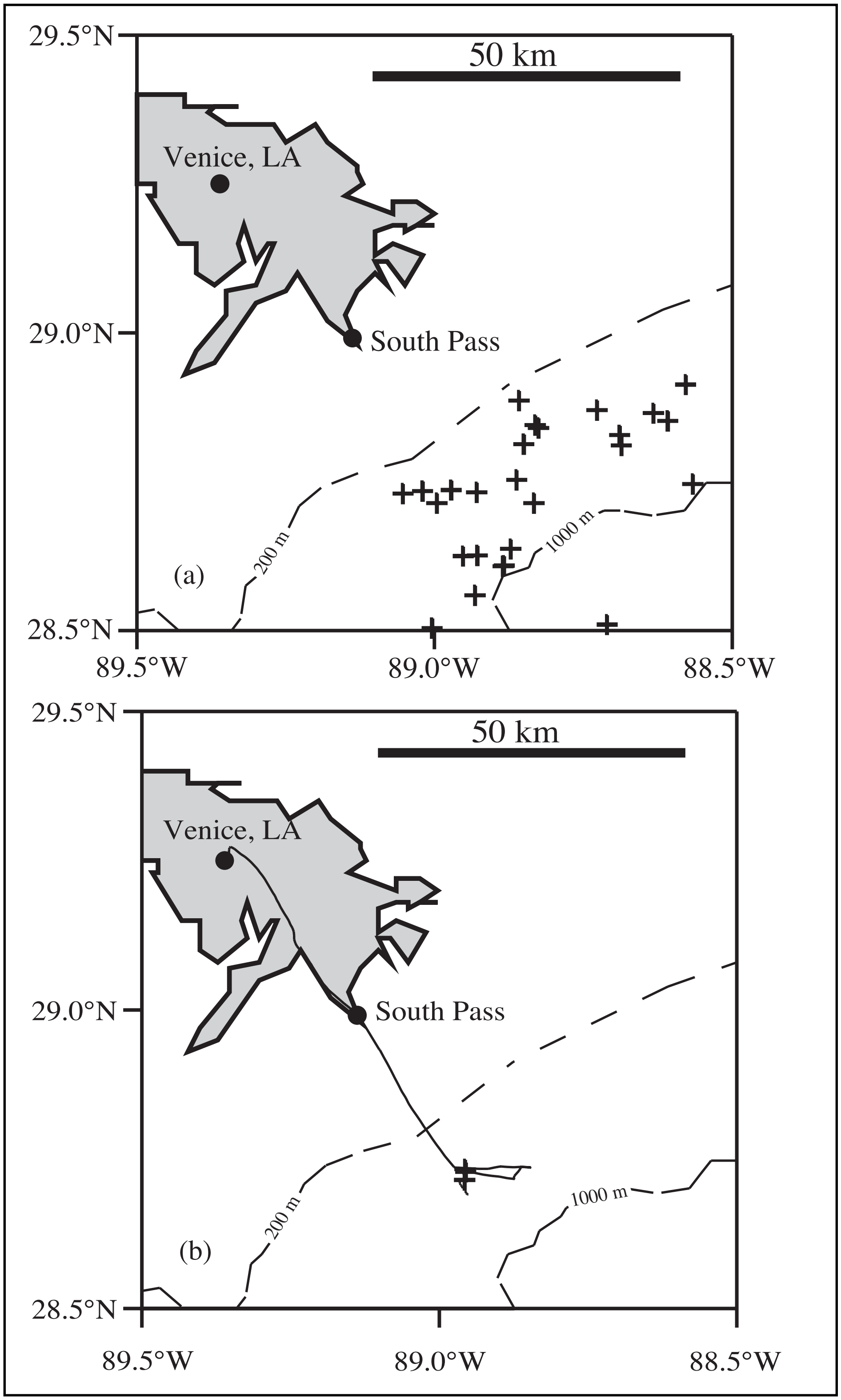


Figure 3.3.1. S-tag follow-up cruises activities. Shown are (a) location of satellite transmissions (crosses) from sperm whales near the mouth of the Mississippi River from 29 November through 4 December 2002. (b) Trackline of the survey effort conducted on 7 December 2002. Crosses indicate the locations of sperm whale sightings.

4 INSTRUMENTATION AND DATA METHODS

4.1 RHIBs

Three small boats were used during the SWSS 2002 cruise. For the S-tag leg, two boats were used: one as the tag boat and one as a support and photo-ID boat. The tag boat was the OSU boat, *Puffin*, which is a 6.4-m, 3400-pound, rigid hulled inflatable boat with diesel powered, engines. To provide a replacement for the MMS R2 tag boat, which was not available for the S-tag cruise, the *Puffin* was refurbished by OSU for use on the S-tag cruise. It also was modified by adding an extended bow pulpit to allow close approaches to tag sperm whales and, from the added height, to allow a better vertical orientation of the antenna. The *Puffin* was launched from the port side of *Gyre* using the ship's crane.

The support/photo-ID boat for the S-tag cruise was the *Gyre's* 14-foot Avon. This boat also is a rigid hulled inflatable. It was crewed by two and sometimes three members of the scientific party and was equipped with a palmtop computer linked to a GPS that allowed the detailed track of the boat as well as the position of diving whales to be recorded accurately. Ranges to whales were measured using Bushnell or Leica laser range finders. A simple, custom-made directional hydrophone, which consisted of a single hydrophone and preamplifier within a reflective dish, was used from the Avon to aid in tracking submerged whales. Considerable attention was given to reducing the amount of noise that could telegraph through the structure and be picked up by the hydrophone. The Avon was launched with the ship's crane.

For the D-tag leg, two boats also were used: one as the main tag boat and one as back up. The primary tag boat was the MMS R2. The back-up boat was the OSU tag boat. The R2 is a 24-foot, 5000+ pound, rigid hulled inflatable boat with two gasoline-powered, 135hp Mercury Optimax engines. It is fitted with electric trolling motors to minimize underwater sound during low speed maneuvering and has a large foredeck for pole-based tagging. Because of the weight of the R2, the *Gyre's* crane was not used to launch the boat; instead a custom launch ramp over the fantail was constructed and used.

4.2 S-tag Instruments and Data Methods

4.2.1 Satellite Tag Data

Data Acquisition

The Argos Data Location and Collection System is used to track whales. This technique is described more fully by Mate *et al.* (1997). Tags transmit ultra-high frequency (UHF) radio signals (401.650 MHz) to Argos receivers on National Oceanic and Atmospheric Administration (NOAA) television infra-red observation satellite (TIROS)-N weather satellites. The satellites are in sun-synchronous polar orbits, with each one passing over the study area at different times of the day three to six times daily, depending on latitude (more passes at higher latitudes). To conserve power, we limited transmissions to select times (four 1-hr periods) when there was a high probability of satellites being overhead. Locations are calculated by Service Argos from Doppler shift of tag transmissions created by the speed of the satellite passing overhead (Fancy *et al.*, 1988).

Tags were applied with an air-powered applicator from a small rigid hulled inflatable boat. The tags consist of Telonics transmitters (ST-15), housed in stainless steel (SS) cylinders (19 cm long by 1.9 cm in diameter), and are designed for nearly complete implantation beneath the whale's skin. Double edged blades are mounted in one end of the tag with a flexible whip antenna and saltwater conductivity switch mounted in the other end. Both endcaps are made of Delrin. A series of thin, outwardly-curved SS strips are wrapped around the housings at the base of the blades to prevent outward migration of the tags. Thin outwardly-curved SS wires are mounted forward of these strips for additional anchorage. The antenna endcap has two perpendicular projections to act as a stop, preventing inward migration of the tag. The tags have a Methacrylate coating of long-dispersant (5–8 month) Gentomycin antibiotic. All tag components are produced in the United States.

In addition to providing transmissions for location calculation, the tags report cumulative number of surfacings, which help to interpret whale behavior. As UHF radio signals rapidly attenuate in seawater, the conductivity switch on the tag determines when whales are at the surface before initiating transmissions. While at the surface, tags are capable of transmitting once every 10 seconds. Anticipated life expectancy is adjustable depending on the transmission duty cycle and the extent of the whale's surface behavior, with a maximum expectancy of one year.

Data from Service Argos are plotted using ArcView® geographic information system (GIS) software. The accuracy of Argos-acquired locations is evaluated with screening criteria to eliminate locations with unacceptable errors.

S-tag Processing Methods

Location Data: Locations of the S-Tags are computed by Service Argos by calculating the Doppler effect on received frequencies. The accuracies of the locations are stated in terms of location "classes" and are assigned by Service Argos. All locations are examined by OSU researchers and initially checked for plausibility by computing the speed between sequential locations. If the speed is below a realistic maximum (for sperm whales a maximum speed of 15k/h is used) the location is retained.

However, if the speed between two locations is greater than the maximum, a radial buffer equal to the accuracy for the location class is applied to each location in order to compensate for errors. The speed is then recalculated after shifting the two locations towards each other by one buffer width. If the speed is still greater than the maximum, one of the two locations is removed. Criteria such as location class, whether one location is on land, and which location results in minimum speed are used to determine which locations to remove and retain.

Locations that map on land (a rare event) have the same radial buffer equal to the accuracy for the location class applied to compensate for error. If there is navigable ocean within the buffer then the location is retained. Locations within 1 hr of each other are also closely examined and only one is retained if the accuracies are low.

Sensor Data: The salt-water switch on the S-Tag is polled every 0.25 seconds. When the switch registers "dry" after having been "wet", a counter is incremented. The counter value is sent in duplicate within the data stream of the transmission. Raw values are received from Service Argos and only those that meet the redundancy check are used.

4.2.2 Acoustic and Visual Observations

Passive Acoustic Observations

Passive acoustic monitoring was the principal means for finding and following sperm whales on all the SWSS legs as well as being a source of information on the behavior of sperm whales and their responses. To this end simple but effective towed hydrophone systems were provided for the Gyre on both legs.

Passive Acoustics Equipment: Figure 4.2.1 outlines the monitoring system. Two systems were used. One, provided by WHOI had a 150-m tow cable and was designed to work in conjunction with a "batfish" depressor to allow the hydrophone to be deployed at greater depths. A second system, assembled by Ecologic, had no depressor, the streamer had a 400-m tow cable and was depressed solely by the weight of the cable. It typically towed at around 9-m depth. The arrays had similar hydrophone streamer sections consisting of 2 (Ecologic) or 3 (WHOI) hydrophone elements mounted about 3 m apart and housed in a polyurethane tube that was about 10 m long. Both streamers were deployed from winches on the *Gyre*. It was found that the depressor on the WHOI system vibrated at speeds of 5 knots and over and this limited its efficacy for everyday use.

Signals from the streamers were brought to an "Acoustic Lab" on the upper science deck of the *Gyre* where they were amplified and filtered using custom electronics before being digitized and further processed on a PC. The Acoustic Lab was established in a dry lab aft of the computer room on the 01 deck of *Gyre*. During days when groups of whales were being tracked for tagging and photo-ID, a second, open-air acoustic monitoring station was established on the flying bridge. This topside station facilitated the coordination of visual and acoustic information on whale locations during these periods.

Typical Monitoring and Data Collection: During the S-tag leg, hydrophones were monitored round the clock by a four-person acoustic monitoring team. Various acoustic analysis and detection programs were also run and monitored continuously. The most useful of these were Ishmael, written by Dave Mellinger of Oregon State University, and Rainbow Click, developed by Douglas Gillespie at the International Fund for Animal Welfare (IFAW). Both of these programs provided a real-time visual representation of the sound being monitored and gave bearings to signals. Every 15 minutes the member of the acoustic team on watch listened critically to the hydrophones and noted down their subjective score of the strength (on a 0-5 scale) of a variety of background noise sources and of various cetacean vocalizations. To achieve scoring consistency monitors used a browser-based training CD before the project began and also compared within the team how they scored different sounds during the course of the fieldwork. These data were entered into an "Acoustic Monitor" database using the Logger program. The ship's location and its research/monitoring activities were also recorded in this database. Of particular importance was to record whether the vessel could be considered to be collecting "survey" data as opposed to actively following whales or, as was often the case, being directed towards known or supposed areas of high whale abundance.

Recordings and Detection Programs: Logger was configured to make regular acoustic recordings, a 20-second sample recording once every 2 minutes. These were made in stereo at a 48kHz sampling rate and were initially stored on the computer's hard disk before being copied to two sets of CDs. Logger maintained a table within the Acoustic Monitor database detailing these sample recordings. As these files were copied to backup CDs, entries identifying the backup CDs were made in the database.

In addition, longer recordings were made at any time when sounds deemed worthy of recording were heard. These included recordings in the presence of socializing groups, which typically contained codas, recordings of other identified cetaceans encountered in the area recordings of anthropogenic sounds.

The automated click detection program "Rainbow Click" was run continuously. Rainbow Click provides information on the number of animals clicking and the relative bearings at which signals arrive at the streamer (with a left-right ambiguity) and was a useful acoustic tracking tool. The Rainbow Click output files were stored and backed up to CD. These files contain a continuous record containing the waveform and bearing information for every transient detected by the program.

Small Boat Acoustic Tracking and Monitoring: Passive acoustic systems on the RHIBs were used for fine scale tracking on whales. Custom-built directional hydrophones were employed for this. The simplicity of the equipment, essentially a shielded hydrophone which was rotated by

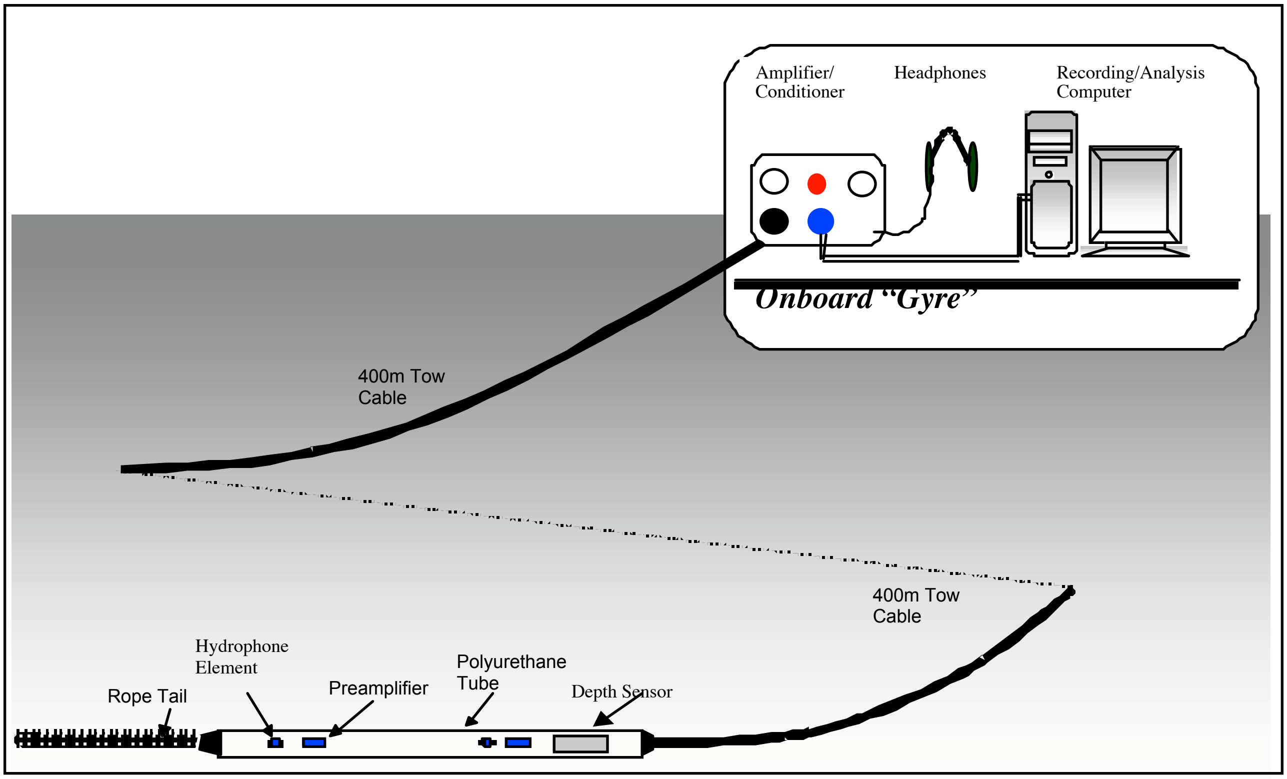


Figure 4.2.1. Diagrammatic representation of underwater and topside components of the acoustic monitoring system.

hand until the whale's clicks sounded loudest, was balanced by the fact that the RHIBs could respond quickly to information, moving on acoustic bearings to reposition and monitor again. The technique was most effective when acoustic information from the small boats was used in conjunction with visual and acoustic data from the *Gyre*.

On some occasions, in particular when the *Gyre* had no acoustic contact with whales on a day of good weather, the RHIBs were launched and used to scout ahead and to the side of the Gyre. Because the RHIBs could be shut down to monitor they were much quieter platforms than the *Gyre* and they could also move more quickly and cover a lot of ground. This use had not been anticipated and the available equipment was not as good as appropriate as it could be, even so use of the RHIBs seemed to significantly increase combined acoustic effectiveness.

Acoustic Data Summary: The acoustic data collected during the project consist of four parts

1. the monitor's summaries of standardized monitoring sessions,
2. regular acoustic samples and more extended recordings as a series of wav files,
3. near continuous summary of transient detection by Rainbow Click, and
4. information on acoustic monitoring effort and vessel acoustic survey activity.

These data were either stored within or referenced by an integrated Access database built upon the database created during the project by the Logger program. All data were backed up on two series of CDs, one of which was archived with the Data Office at TAMU Department of Oceanography.

Visual Observations

A visual observation station was established at the highest, unobstructed point possible on the ship, which on the *Gyre* was on the flying bridge. It consisted of three stand-mounted BigEye binoculars and a data entry station. A team of at least three observers maintained a continuous watch during daylight hours (06:30-19:30 CDT) when the ship transited or surveyed in water depths greater than about 500 m. Two of the observers were on BigEye binoculars while the third person (the data recorder) kept watch closer-in with naked eye and with 7x50 binoculars. This third person also entered data into a laptop computer running Logger software. Logger is a data collection and depiction program written by Douglas Gillespie and made available by the International Fund for Animal Welfare. A digital video camera was mounted on a third pair of BigEyes and was used opportunistically to collect accurate range and bearing for the video recordings and to document detailed animal movements and behavior.

The visual team on the flying bridge worked in different modes depending on the vessel's activity. When searching for whales or surveying, the team searched using BigEye binoculars, 7x50 binoculars, and the naked eye following a line-transect survey protocol. Data on search effort, vessel status, weather condition, and sightings were stored in a Visual Database using the Logger Program. Logger also stored various data from the ship's NMEA line.

Once whales had been detected the task of the visual team was to track the location and movements of whales at the surface, to integrate this information along with acoustic data from the *Gyre*'s acoustic team and data from the small boats, and to guide the small boats on to whales sighted at the surface or into areas in which they were likely to surface.

The surface location and heading of every whale was fixed when it was first seen and when it submerged by measuring its range and relative bearing. Range was determined by measuring the number of reticules in the BigEye's eye-piece "beneath" the horizon for each whale, a visual basic program "gratran" calculated range from reticules and made this available to the Logger program. Relative bearing measurements were made from the Big-Eye's bearing rings. These data were entered into forms within Logger, which also displayed whale locations and the ship's track in real time on a map.

Photo ID

Equipment: The majority of the photo-identification images were collected with a digital SLR camera (Canon EOS1D SLR and Sigma 100-300mm f4 lens). This system gave excellent results. The camera was able to shoot at 8 frames per second and freed from concerns about the cost of film we chose to take extended sequences of every fluke up. This contributed to better quality images than usual. Other advantages of digital included the ability to review images every evening, so that any problems with equipment or technique could be rectified and work could begin immediately to build a local catalogue and make comparisons with existing collections.

Most dedicated photo-ID effort was conducted from the *Gyre*'s smaller RHIB rather than the larger OSU RHIB. This worked well, although its lively motion made protecting camera gear from splashes and taking good images challenging. The *Gyre* RHIB was equipped with a Hewlet Packard palm top PC linked to a GPS running a customized data collection program. This allowed information on group sizes, locations and behavior for the animals being photographed to be noted consistently on a small lively vessel.

Photo-identification was a secondary activity to the cruise's main goal of satellite tagging. Even so, the value for effective photo-ID of having a strong visual and acoustic team on the *Gyre*'s flying bridge to coordinate the movements of the RHIBs, allowing them to sample effectively a larger dispersed group, became apparent.

Photogrammetry: A simple method was employed to measure the size of whales encountered. Photo-ID images were taken from directly behind the whales at a range at which the lens could be used at maximum zoom. The range from the photographer to the whale was measured using Bushnell or Leica range finding binoculars and cases in which the photographer was not directly behind the whale at fluke up were noted and discarded. The focal length of the lens was calibrated using test objects so that when range and fluke size on the image are known fluke span can be determined. Whaling data were used to derive a relationship between fluke span and body length.

Information on the identity and location of appropriate length estimation images are stored in the visual database. Substantial datasets of length images from the same whale will be required to test the reliability of this method.

Data Assurance and Quality Control

All acoustic, visual, and photo-ID data were copied on two duplicate sets of CDs, one of which was archived with the Data Office at TAMU Department of Oceanography.

Any large dataset contains errors and dealing with these is an ongoing process. Mistakes made or problems encountered during data input were noted as comments within the database. These were rectified before the end of the field project. Visual basic routines were written and run on the dataset to detect and fix particular common errors. For example, problems with the GPS interface often resulted in blank or spurious location data being stored. Other errors or problems may be found in the course of analysis. Those involved in analysis fix these errors as they arise and exchange updated datasets with co-workers to ensure that a single "best" visual and acoustic dataset is available. This improved dataset will be archived at TAMU Oceanography from time to time.

Acoustic Data: Regular monitoring sessions made while following sperm whales on which seismic pulses can be detected have been extracted and the bearing to seismic pulses has been measured using Ishmael. These data have been incorporated into the Acoustic Database.

Analysis of sperm whale codas (stereotyped patterns of clicks which are often heard in social contexts) is ongoing. Analysis results in Rainbow Click files in which codas are identified and labeled and, as far as possible, the individual whales making codas is indicated. Data summarizing coda parameters can be readily extracted from these analyzed files using Rainbow Click. The identity and location of coda wav files and analyzed rainbow-click files are stored within the Acoustic Database.

Photo-ID and Photogrammetry: Photogrammerty images have been analyzed. Locations of images and results of analysis are stored within the Visual database. A larger dataset of images are required to test the reliability of this new method.

Image Archiving: All raw digital images are archived at TAMU Oceanography on CD. Selections of the digital images useful for photo-ID and digitized copies of the photo-ID images taken on film stock are maintained within a local photo-ID catalogue. Each image is scored for quality using a well-established method. The "type images" for each individual within this catalogue are shared with other sperm whale researchers through the North Atlantic and Mediterranean Sperm Whale Catalogue.

4.3 D-tag Instruments and Data Methods

4.3.1 Digital Acoustics Tag Data Acquisition

The D-tag was developed by WHOI principal investigators in 1999. Details on its design are in Johnson and Tyack (2003). The D-tag is used to measure the exposure level received by a target animal, and document its reaction. This non-invasive tag records the sounds heard, and made, by the tagged whale together with its depth and orientation (i.e., pitch, roll, and heading), in a synchronized fashion throughout the dive cycle (Caldwell, 2002; Johnson and Tyack, 2003). The tag records data digitally for between 10 and 24 hours, depending on sampling rate, with enough resolution to track individual fluke strokes (Nowacek *et al.*, 2001). The D-tag is cast in epoxy for robustness and is attached to the whale with suction cups. A cantilevered-pole, approximately 40' long, is used to deliver the tag to the whale, minimizing the impact of tagging. Intensive visual and acoustic observations from a nearby research vessel record the social and geographical context of the whales' behavior, before, during, and after tagging. The sensitivity of the D-tag allows a wide range of exposure levels to be tested: D-tags on sperm whales in the northern Gulf have recorded survey sounds at a range of 15 miles with excellent fidelity.

Tagging Method: Once whales are located and the research vessel has moved close to the animals, a RHIB is deployed with a 4-person tagging team to attach D-tags to whales. Once the RHIB is deployed, a directional hydrophone is used to locate and close on sperm whales. Visual and acoustic observers on the research vessel support the tagging effort by providing surfacing positions and acoustic bearings of whales to the RHIB team. Where possible, multiple animals are tagged prior to each CEE to increase data gathering efficiency and to minimize habituation. After attaching a tag, the length of the whale is measured using photogrammetry and photographs of the fluke and other distinguishing features are taken for photo-identification if this has not already been accomplished. The whale’s surfacing location is inspected to search for feces or skin. Once a whale has been tagged and photographed, the RHIB either returns to the research vessel or attempts to tag another whale. The number of whales tagged before each CEE depends on the likely attachment duration, the group composition, and our ability to adequately observe multiple animals. No more than three whales are tagged at one time.

4.3.2 Controlled Exposure Experiments

The primary goal of the controlled exposure experiments is to measure the sensitivity of sperm whales to disturbance from airgun sources. Subsets of animals are exposed to an airgun source and/or to a biologically-relevant sound likely to elicit a response (e.g., a 'coda’, Watkins *et al.*, 1985). This approach ensures detailed and replicated measurements of response suitable for statistical treatment. Sounds from both a closing fully-powered array and from an array in soft-start will be tested with the initial focus on the latter.

One of two sound sources is used: airguns (either a fully-powered array or an array in soft-start), and the playback of a previously recorded sperm whale coda as a biologically-relevant control. As an additional control, a sub-set of tagged animals receives no sound exposure.

The three phases of the CEE are:

1. *Pre-exposure*: Once the desired number of tags are deployed, a pre-exposure period of approximately 2 hours is planned to record baseline behavior of the tagged whales and to move the source vessel into the appropriate position. For deep-diving animals, a 2 hour baseline period amounts to about 2 dives (3 surfacings), sufficient to establish some parameters of foraging activity and to predict swim speed and heading. Visual observers on the research vessel track the tagged whale(s) from a distance and note the positions of other animals in the group. Range from the ship to each surfacing whale is determined by measuring the declination from the horizon

using big-eye binoculars. All visual data are entered in real-time into Logger, a data gathering program, and displayed to aid positioning of the source vessel relative to the whales. Acoustic observers coordinate with the visual team to continue tracking whales while underwater. By combining visual and acoustic observations, a detailed real-time track of each tagged animal will be built up from which the exposure level can be deduced and so the CEE can be controlled.

2. *Exposure*: After the prescribed pre-exposure period, and when the source vessel is in the appropriate position, one of three sounds will be presented to the tagged whale(s): no sound (baseline), coda playbacks (biologically-relevant control), or transmissions from an airgun array as described below. Transmission duration is up to 2 hours, sufficient to document whale reactions during 2 deep-dives. The choice of sound to transmit is determined by the availability of the seismic source vessel and by the need for a statistically significant number of trials of each exposure. Visual and acoustic observations continue during exposure both to qualify the tag data and to ensure mitigation in the event of a strong reaction. In year 1, the primary goal is to measure the behavior of sperm whales during the soft-start onset of an airgun array relative to base-line and biologically-relevant sound exposures.

Following the protocol outlined in WHOI's Federal permit to conduct this research, the target for a received level (RL) at the whale is 120-140 dB re 1μPa in the first year. The target RL may be increased during the course of the study if little response is detected to trials at the initial level. The conditions of the Federal permit under which this research is conducted limit the exposure of whales to an RL <180dB re 1μPa. Transmissions will be halted if any whale is detected visually or acoustically in areas where they may be exposed to levels above those allowed by the permit. To this end visual observers are stationed on the source vessel in cooperation with IAGC. For the biologically-relevant control sound, a broadband underwater source will be deployed off the research vessel or tagging vessel to play coda sounds to tagged whales.

The choice of target RL throughout the program is made as follows. The CEE is started with an RL known to be safe. Preliminary observations of sperm whales exposed to seismic survey show contradictory results, with some animals silencing or avoiding a source and others showing little obvious reaction to RLs in the 120-140 dB range. This suggests an initial target RL of 120-140 dB for airgun sounds, which is the initial target level specified in our Federal permit. The source level for a single airgun is around 215-230 dB implying that, under expected propagation conditions, the source vessel should maintain a range to the tagged whale(s) of some 10s of km. A similar range would be needed for horizontal propagation of a seismic array. Sperm whales will be tagged, if possible, in both Delta and Canyon areas and will include members of family groups and lone males. If whale responses to the first several exposures are consistently weak, we would consider raising the target RL (to say 140-160 dB) in the subsequent days of summer 2002 fieldwork. If we see predictable responses within the target range of RLs, we will continue playbacks at that level until we have enough data to estimate the biological significance of the responses.

3. *Post-exposure*: After the 2-hour sound transmission, visual and acoustic observations will continue. The tagged whale(s) will be tracked and the positions of animals nearby recorded. Post-exposure observations will continue until all D-tags have detached from the subject whales. D-tags will then be recovered using the RHIB, and data will be downloaded from the tags in preparation for the next experiment.

4.3.3 Visual and Acoustic Observations

Detailed visual observations and passive acoustic monitoring complement the D-tag data. Previous research with sperm whales highlights the need to follow tagged whales, and other whales nearby, both visually and with passive acoustics before a controlled exposure is attempted. It is critical to know in real-time where whales are in order to predict the received level at the whales for a sound exposure. In addition, merging data from the tag with visual observations and passive acoustic monitoring, yields much more valuable data than would any single approach (Zimmer *et al.*, 2002). Observations are performed before, during, and immediately after each CEE.

The research vessel is outfitted with high-power ("BigEye") binoculars. The visual/acoustics team interfaces with ship's engineers to assure that visual locations of whales are available real-time using the computer software program "Logger" that has been successfully used both in the Gulf of Mexico and the Mediterranean to track and locate whales in real-time. WHOI personnel manage the visual observation team and train the rest of the observers in the use of BigEye binoculars to track whales. A multi-channel towable hydrophone array with appropriate deck-cabling, sound recording equipment and real-time acoustic data analysis systems is provided. Acoustic signals are recorded on TASCAM digital recorders for detailed analysis after the experiment, and are digitally streamed into PC's for real-time analysis of acoustic bearing during the experiment using Ishmael or Rainbow click software. WHOI personnel install and test array equipment and assure that real-time analysis systems are operating.

During the search phase of operations, sperm whales are located using visual and acoustic techniques. Visual observers scan for whales using BigEye binoculars, and acoustic observers attempt to detect and locate sperm whales by listening for their vocalizations on a towed hydrophone array. Once whales are detected, the research vessel is steered toward the whales, and visual observers record the numbers and distribution of the group of animals. The acoustic observers commence to track submerged whales in preparation for tagging and record array signals to multi-channel digital recorders.

4.3.4 Data Analysis

The following checklist describes the different data streams collected during D-tag operations, how the data are collected, how data are checked and archived in the field, and how data are further archived, checked and analyzed in the lab. It does not report on synthesis-types of data analyses where data from the different data streams are analyzed together. A copy of the Data are provided to SWSS data management after each cruise.

1. *D-tag Data*: These data consist of the animal's depth, sounds heard on tag, temperature, and magnetometer and accelerometer data on the whale. D-tag data are recorded on the tag after attachment to the whale using suction cups. Data are offloaded to a PC using an infra-red link. To check the data quality check in field, raw D-tag data first are converted to raw sensor and acoustic data. The entire sensor record then is checked in MATLAB for quality to assure its completeness and confirm start and end times. The acoustic record is sampled to assure quality. At least 2 copies of the raw D-tag data are archived in the field on CD. In the lab, additional archiving occurs. Four complete D-tag data sets on CD and other copies on hard-drive are held by each of the project principal investigators with a fourth copy held in WHOI's marine mammal center managed by Research Associate Nicoletta Biassoni. Data are checked and analyzed in lab. Sensor data are analyzed as reported in Johnson and Tyack (2003). Acoustic records are completely audited to produce a catalog of sounds produced by the tagged whale as well as other natural and man-made (i.e. seismics) sounds recorded by the tag.

2. *Permit Data/Close Observations from RHIB*: These data include tagging location, reaction of the whale to tagging, tag placement, videogrammetry, and fluke identification. These data are collected using visual observations of the reaction of the whale to tagging, digital video recordings of tagging, fluke-out, and broadside video with laser range-finder. Visual observations are recorded on data sheets. Quality checks in the field begin with double-checking the data on the data sheets to assure completeness and that all whale ID's match those used by visual observers. Data sheets are copied in the field for archival. Video recordings are streamed

into computer using FireWire and back-ups made on CD. Fluke-shots and other images are extracted as high-quality bit-map images. In the lab for archival, videotapes are stored in the marine mammal center at WHOI. At least one additional CD archive is created. Data sheets are scanned into PDF files. In the lab, data are analyzed as needed to support tag-data analysis. Fluke-ID shots are catalogued separately. Video-length analyses are completed in MATLAB. Permit reports of each whale approach are generated for reporting purposes to NMFS.

3. *Skin/Fecal Data*: These data consist of the sex of the whale and diet information. Feces or sloughed skin material is collected during close approached to whales using a dip-net or small plankton tow-net. Skin also is found occasionally on the D-tag suction cups after tag recovery. For quality checks in the field, data sheets are used to record the location and ID from which the material was collected. Tissue is carefully handled with sterilized procedures and placed in prepared DMSO vials or frozen in zip-loc bags. A genetics expert, such as Dan Engelhaupt, collects separate data-sheets with archival information. In the lab, skin tissue is analyzed to determine the sex of the tagged whale. Genetic expert Dan Engelhaupt performs other genetic analyses. Squid beaks are forwarded to an expert for species identification.

4. *Visual Data*: Included are whale locations, locations of the source vessel, and playback condition. Data are recorded on 2 laptops located on the flying bridge running Logger software provided free by IFAW. Locations of whales and of the seismic source vessel are determined using BigEye binoculars to calculate the relative bearing and reticle to the whale. VHF tracking of tagged whales aids in the identification of tagged whales at the surface. Logger integrates this information with the NMEA stream to create a real-time plot of sighting locations. Playback condition is recorded in Logger, and group-id notes and other comments may be recorded on paper data-sheets. For quality checks in the field, Logger data records are checked daily to assure that group ID's are correct, and that focal whales were correctly identified. Data on animal tracks are extracted from Logger records into Excel for export into MATLAB. At least 2 copies of raw Logger data are archived in the field on CD. In the lab, at least one additional CD archive is created. Data sheets are scanned into PDF files. For data checks and analysis in the lab, surfacing locations of whales are plotted in MATLAB or Arcview and integrated with positions of the observation-boat and source-boat.

5. *Acoustic Data*: These are the sounds heard from the observation vessel. Raw acoustic data are recorded on multi-channel TASCAM recorders or direct-to-hard disk recording. Bearings to whales are computed in real time using Rainbow Click software provided by IFAW. Notes on tracking and acoustic activity levels are recorded on a laptop located in the acoustic lab running Logger software provided free by IFAW. Playback condition is recorded in Logger, some notes on tape number and other information are recorded on paper. For a quality check in field, Logger data records are checked daily to assure that group ID's are correct. Samples of data recorded to hard disc are inspected. At least 2 copies of raw Logger data are archived in the field on CD. In the lab, at least one additional CD archive is created. Data sheets are scanned into PDF files. Raw acoustic recordings are copied onto a back-up TASCAM tape or streamed directly to hard-disk. For data checks and analysis in the lab, data that are transferred to hard-disk are used for passive tracking and to link acoustic activity to sounds recorded on the tag.

6. *Source-vessel Data*: These are the source-boat locations, playback condition, and mitigation detections. Mitigation detections are made using a passive towed array running Rainbow click and/or by visual observers using naked eye or hand-held binoculars. Data are recorded on a laptop located in the acoustics lab running Logger software provided free by IFAW with a NMEA stream connection. Locations of the source vessel, playback condition (including number of airguns firing), and detections of marine mammals are recorded in Logger. Data sheets are filled out for permit compliance. In the field, Logger data records are checked daily to assure that group IDs are correct, and for completeness. At least 2 copies of raw Logger data archived in the field on CD. In the lab, at least one additional CD archive is created. Data sheets are copied and

scanned into PDF files. For data checks and analysis in lab, surfacing locations of whales are plotted in MATLAB or Arcview and integrated with positions of the observation-boat and source-boat.

4.4 Genetic Analyses Methods

Biopsy sampling has been done extensively on a variety of cetacean species (Palsboll *et al.*, 1991; Weinrich *et al.*, 1991; Baker *et al.*, 1994; Weller *et al.*, 1997; Hoelzel *et al.*, 1998). Previous work shows that it has minimal immediate effect on the animals and causes no long term disturbance or problems with wound infection (Best and Butterworth, 1980; Brown *et al.*, 1991; Weinricht *et al.*, 1991; Weller *et al.*, 1997). In this study, detailed data sheets and opportunistic digital video are used to record descriptions of the behavioral responses to biopsy sampling. Previous findings show that approximately 70% of whales show no surface reactions to the dart making contact. To account for the bias created by high kinship within a particular group, sampling efforts will include multiple groups from different locations. At the same time, multiple samples are included from some groups to assess kinship patterns within compared to between groups. Differences in group size indicate that there could be differences in the pattern of intergroup kinship to that seen by Richard *et al.* (1996).

4.4.1 Genetic Markers to be Analyzed

Three types of genetic markers will be analyzed in this study: the mtDNA control region, microsatellite DNA loci, and the ZFXY locus for molecular sexing. DNA will be extracted from tissue samples by standard phenol/chloroform extraction (Hoelzel, 1992). The mtDNA control region will be amplified by PCR and include the region studied by Lyrholm *et al.* (1996). MtDNA will be sequenced by automated ABI methods (David and Menotti-Raymond, 1998). Microsatellite DNA will be analyzed using the Genotyper software for the ABI. Molecular sexing is based on a PCR test that reveals different amplification products for males and females on a standard ethidium bromide stained agarose gel. The three types of genetic markers and methods associated with them are described briefly below.

1. *MtDNA Analysis*: We will analyze sequence variability in the mtDNA control region to investigate whether there is differentiation among females occupying various regions of the Gulf of Mexico and in comparison with other oceanic populations. Lyrholm *et al.* (1996) analyzed variation among 37 sperm whale control region sequences and found 12 variable nucleotide sites out of 954, identifying 13 mtDNA haplotypes. In all, a total of 25 lineages have been defined to date (two unique haplotypes occurring in the Gulf of Mexico). We will sequence a 400 base pair (bp) segment of the highly variable control region to provide greater resolution for population discrimination within the Gulf and in surrounding waters.

2. *Microsatellite DNA Analysis*: Fifteen to twenty microsatellite loci will be analyzed, based on published data (Richard *et al.*, 1996; Lyrholm *et al.*, 1999) and ongoing projects all using the same 6-10 microsatellites (Sarah Mesnick, personal communication), which produced clear, polymorphic amplification products. A genetic profile will be constructed for each sample by scoring allele patterns at these loci. Additional loci allows for an increase in resolution required for social structure questions. Information from previous studies suggests that sexually mature males make temporary associations with matrifocal groups, which may mean that population level variation will show less structure at these loci (which reflect the movement of both males and females) than at mtDNA loci (which reflects only the movement of females). By utilizing the same markers as other researchers, we can compare diversity at these loci on a global scale, as well as within the Gulf. This allows us to better address our own questions and that of the species at large.

3. *Molecular Sexing*: While there is significant sexual dimorphism present in this species as whales reach maturity, the younger males and females can be difficult to distinguish in the field. Some mature female sperm whales possess a callus (a whitish patch of thick, hardened tissue) on the upper edge of the dorsal fin that appeared to be a strong indicator of sex (Kasuya and Ohsumi, 1966). However, Chrystal (1998) has discovered that this is not always the case when comparing calluses to genetic results and should therefore not be relied upon. Our determination of sex for individual sperm whales has been performed using techniques described by Berube and Palsboll (1996). This technique uses PCR and three oligonucleotide primers to amplify the ZFX and the ZFY sequence in cetaceans. The resulting ZFX and ZFY amplification products obtained can be distinguished by gel-electrophoresis through a 1.5% Agarose gel (stained with ethidium bromide). After amplification using PCR, males will show two clear bands at approximately 227 base pairs (bp) and 383 bp. Females will only show only one band at approximately 383 bp. The Berube & Palsboll technique provides an internal control to ensure that successful PCR amplification has taken place. Male and female stranded whales of known sex are used as a control.

4.4.2 Genetic Data Analysis

Sequence alignments are generated using the Sequencher 4.1.2 sequence analysis package. The computer software PAUP-star (Sinnaur, 1991) is used to analyze maximum parsimony, neighbor-joining and maximum likelihood phylogenies of mtDNA sequence data both for the Gulf region and for global diversity, incorporating published sequences from other geographic regions. The computer software MEGA (Kumar *et al.*, 1993) and Arlequin 2.0 were used to estimate genetic distance (D_{xy} after Nei, 1987) between putative populations.

Nucleotide and haplotype diversities (π) are estimated as defined by Nei (1987). Tests for heterogeneity are performed using a Markov chain permutation approach (Raymond and Rousset, 1995) using Arlequin 2.0 software (Schneider *et al.*, 2000). F_{ST}, an indication of the amount of differentiation between compared to within populations, and estimates of gene flow (Nm) are computed for both mtDNA and microsatellite DNA markers (e.g., Slatkin, 1995). Population level comparisons include individuals from two datasets ('all' and 'restricted') to avoid biases associated with the inclusion of close kin. Kinship assessment within and between groups are determined using the programs Kinship and Relatedness (Queller and Goodnight, 1989).

4.5 Habitat Characterization Data Methods

4.5.1 Remote Sensing Fields

Remote sensing fields will be obtained from sites that routinely produce satellite sensor data products. These include the sea surface height (SSH) fields produced by the Colorado Center for Astrodynamics Research (CCAR) of the University of Colorado using data from the TOPEX/POSEIDON and ERS-2 satellite altimeters (Leben *et al.*, 2002), the sea surface temperature (SST) fields produced from AVHRR satellite data by the Johns Hopkins University Applied Physics Laboratory, and the ocean color maps made from data from the SeaWiFS satellite by the Institute for Marine Remote Sensing at the College of Marine Science University of South Florida. These fields will be used both as an aid for identification of circulation features that might be of interest for the SWSS cruises and for analysis of such features with the *in situ* data sets collected on the cruises as related to whale observations.

Starting six weeks before and during each cruise, SSH fields are monitored by TAMU and CU scientists for the location of the Loop Current, Loop Current Eddies, and any companion cyclones that are in or near the target field area for each cruise. Participants in the cruises will be kept informed as these features are tracked. The altimeter database will be used to estimate where and when anticyclonic and cyclonic eddies over the continental slope affect the observed physical and biological parameters measured in the study region. Also, the SSH database will be used to monitor the Loop Current as was done for the MMS-supported DeSoto Canyon Eddy Intrusion Study (Hamilton *et al.*, 2000) to identify any possible intrusions into the far northern Gulf.

4.5.2 Flow-through Temperature, Salinity, Fluorescence and Chlorophyll

Near-surface temperature, conductivity, and fluorescence are logged approximately every minute during cruises on the *R/V Gyre* through its Serial ASCII Interface Loop (SAIL) system. Data from the thermosalinograph-fluorometer are binned every 1 minute giving about 0.25 km horizontal resolution of near-surface temperature, salinity, and fluorescence if the ship is underway at cruising speed of 9 knots. The fluorometer is calibrated to give chlorophyll by at sea filtration and analysis for chlorophyll of samples taken from the flow line concurrently with recorded fluorescence. Every second or third day the inflow to the flow-through fluorometer was shut down for 4-6 minutes, during which time the internal cuvette is bleached by the addition of full-strength commercial chlorine bleach as a precaution against growth of algae by biofouling on the quartz sides of the internal cuvette.

Temperature and conductivity are measured by Sea-Bird sensors in a sampling stream that is pumped from a hull depth of about 3.5 m into the main laboratory through a debubbler and mixing chamber of 20-liter volume. Because the pumped flow rate of the sampling stream was 20 $l \cdot min^{-1}$, the water in the mixing chamber has a residence time of about one minute. This pumped flow is reduced from 20 $l \cdot min^{-1}$ to 1 $l \cdot min^{-1}$ using garden hoses connected by adjustable ball valves to a "Y" splitter valve leading off the debubbler. This 1 $l \cdot min^{-1}$ flow is shunted to the temperature and conductivity sensors and to a continuous-flow Turner Designs model 10 fluorometer in the main laboratory.

Raw fluorescence data are calibrated against extracted chlorophyll measured in 1-liter samples drawn several times per day from the pumped sampling stream. Calibration follows standard methods given by Parsons *et al.* (1985). For each cruise, separate algorithms are determined for high and low chlorophyll regimes by regression of fluorescence data with extracted chlorophyll data.

4.5.3 CTD Data

Continuous profiles versus pressure were made of temperature and conductivity using a Sea-Bird SBE-19 SeaCat Profiler. Two CTDs instruments were taken on each cruise, with one serving as back-up. Only the primary CTD was used on both cruises. The primary CTD was calibrated by the manufacturer prior to the first cruise of the summer. The temperature sensor has a measurement range of -5°C to +35°C, an accuracy of 0.01°C, and a resolution of 0.001°C . The conductivity sensor has a measurement range of 0 to 7 $S \cdot m^{-1}$, an accuracy of 0.001 $S \cdot m^{-1}$, and a resolution of 0.0001 $S \cdot m^{-1}$. As converted to depth, the pressure sensor has a range of 0 to 6000 m. The SeaCat was set to record internally. When recovered, the data are downloaded to a PC for processing. Back up copies are made to CD-ROM or other electronic media.

The CTD data are processed through the CTD data acquisition software, SEASOFT Version 5.26 (see Sea-Bird Electronics, Inc., at http://www.seabird.com), to produce a clean set of 0.5-m, bin-averaged data. The configuration files used in this processing contain the instrument calibration values. The processing includes steps to:

1. Convert raw data to engineering units,
2. Separate the upcast from the downcast data,
3. Correct data for pressure reversals due to ship heave,

4. Mark/remove wild data points,
5. Correct conductivity for thermal mass effects,
6. Low-pass filter the data,
7. Average data into 0.5-m depth bins, and
8. Compute potential temperature, salinity, sound speed, and potential density using algorithms in Fofonoff and Millard (1983).

These steps constitute the primary QA/QC of the continuous data sets. After processing with Sea-Bird software, the bin-averaged data for each station are stored electronically in files with the Sea-Bird extension, ".cnv", in the name. Back-up copies are made and stored in the Data Office.

In secondary QA/QC processing of continuous data, the *.cnv files are processed to check for out-of-range data, density inversions, and gaps. The salinity, temperature, and sigma-theta are checked to be sure the values fall within reasonable ranges. Depths are checked to make sure they are monotonically descending. Individual station plots of the continuous sensor data are prepared and inspected to identify spurious data points. Problems identified are corrected in the *.cnv files by linear interpolation across gaps or by replacing bad data with "-999.00" or similar bad data flag; a note on the correction is included in the file header. The latitude, longitude, date and time (in UTC), and total water depth included in the header are checked and corrected as necessary.

4.5.4 XBT Measurements

XBT profiles were obtained using Sippican, Inc., T-7 and T-10 probes. T-7s are nominally rated to 760 m and T-10s to 200 m. However, T-10s recorded to the maximum depths of the wire, so depths sometimes exceeded 200 m. XBTs were deployed from the electronics lab on the *Gyre*'s port side. The probes were released from a hand-held launcher into a tube that extends through the floor and over the port rail, where they fell into the sea a distance of 1.5 m. The raw data files were logged by a Sippican Mark-12 board inserted into one of the PC data loggers on board. A plot of temperature versus depth was displayed in real-time. If the wire broke prematurely before the probe reached its designated maximum depth or if the temperature versus depth signal appeared anomalous for any reason, the operator interrupted data collection and launched another XBT.

At the moment of deployment, the XBT operator produces an event marker in the GERGNAV navigation computer. GERGNAV is a program created by the TAMU Geochemical and Environmental Research Group (GERG) to collect differential GPS data and to interface these data with *Gyre* operations. The event marker records the UTC time and differential GPS location in a disk file at the time of the drop. On the paper copy of the XBT profile, the operator records these values along with a bottom depth reading provided by bridge personnel and the temperature and salinity from the flow-through system. This hand-written information provides a cross-check against the digital data.

The binary format files are converted to ASCII using Sippican software. The ASCII files are plotted and inspected by eye for reasonableness. The first three data points are discarded as they show clear evidence that the probe has not yet either reached the water or come into equilibrium with the sea temperature. Data collected after an active probe reaches the seafloor also are removed. While this depth is frequently obvious from the temperature record, the corrected fathometer depths are used to truncate the records when needed. Traces are examined for outliers. Outliers are replaced by linear interpolation for gaps of a few points or with the flag value -999.00 for larger gaps. Traces which are bad in their entirety are eliminated.

The depth of an XBT is determined by measuring the time elapsed since its release and converting this time to depth using an empirically-determined drop rate equation. Several drop rate equations exist. The older original equation provided by Sippican is useful for comparing profiles from decades ago to recent profiles. For our work, we used the more accurate formulation of Hanawa *et al.* (1995).

4.5.5 Acoustic Doppler Current Profiler Measurements

A 153-kHz narrow-band ADCP (S/N 355) and a 38-kHz ADCP (S/N 8) were used on both S-tag and D-tag cruises on *Gyre*. These ADCPs were manufactured by RD Instruments, Inc. (RDI). When on station, the nominal maximum penetration depth of the 153-kHz ADCP is approximately 250 m (130 m while underway). The maximum depth, however, is a nominal value based on typical oceanic backscatter. The actual range will vary depending on environmental conditions, including sea temperature and ship speed. The 38-kHz ADCP will provide information on currents and backscatter to depths of 500-800 m while underway at cruising speeds of 9 knots. Both units were vessel-mounted directly onto the ship's hull. Mounting and calibration of the 153-kHz ADCP aboard *R/V Gyre* is described in Murphy *et al.* (1992). The 38-kHz ADCP was mounted using divers.

Navigation Data: Accurate ship position data are crucial for useful shipboard ADCP data. Differential global positioning system (DGPS) position fixes are used and usually are available. An AshTech ADU2 3DF positioning antenna array (S/N AD00251), installed on the *R/V Gyre* and capable of providing accurate ship heading by utilizing DGPS fixes, was configured to provide ship heading directly to the ADCPs. It is used to collect high-precision positioning information that is fed to users through GERGNAV. The array provides more accurate attitude (pitch, roll, heading) information than the ship's Sperry gyrocompass. Ship heading determined using the Ashtech was saved in a separate file for post-cruise integration into the ADCP processing. The Ashtech heading allows processing and QA/QC of data collected while on-station, accelerating/decelerating, and turning.

Standard ADCP Processing: ADCP data are recorded using the RDI data acquisition program, VMDAS. VMDAS is an MS-Windows based program that allows for advanced averaging, merging, and visualization schemes. It records binary ADCP data and converts the data to engineering units. The configurations recorded for the ADCP and used by VMDAS for data logging and processing are shown in Table 4.5.1. Configurations are basically identical for each cruise. This enhances continuity among the different cruises and simplifies analysis and interpretation. Ensemble processing was used on VMDAS-recorded data. It merged the ADCP ensembles, consisting of 4-15 seconds of data, with the navigation data from the AshTech antenna to produce current velocities. The velocities then are averaged to produce the five-minute data, which are output in ASCII format. Also output into the ASCII data files are several additional parameters including: date/time/location of observations, vertical and error velocities, the percentage of good ping data, and acoustic echo intensity (in decibels) of each beam.

After collection and converting the averaged files to ASCII format, the QA/QC processing of the resulting data continues on UNIX workstations using a combination of FORTRAN, PV-WAVE, and GMT computer codes. The QA/QC processing of the ADCP data are complex and requires several levels to merge navigation data, determine absolute ship velocity with respect to the DGPS fixes, calculate current velocity, and remove outliers and suspicious data. The QA/QC processing can be separated into four parts: (1) merging of navigation data, (2) rejection of data due to external factors, (3) rejection due to internal factors, and (4) systematic visual examination of vertical and horizontal plots of current velocity. The final step in the processing is the production of ASCII data files containing the processed data and associated metadata and horizontal, vertical, and gridded plots of the quality-controlled data.

Table 4.5.1

ADCP configuration summary

Parameter	153-kHz	38-kHz
Instrument type	narrow-band	phased-array
Frequency (kHz)	153.6	38.4
Transducer pattern	concave	flat
Depth cell length (m)	4	16
Number of depth cells	75	80
Segment time (minutes)	5	5
Time between pings (sec)	1	3
First bin depth (m)	14	36
Transmit pulse length (m)	4	16
Blank after transmit (m)	4	16
Navigation type	DGPS	DGPS
Data recorded	raw, navigation,	raw, navigation,

Current velocity is estimated by subtracting ship speed from the 5-minute averaged ADCP transducer velocities. Poor estimates of ship velocity will seriously degrade data quality. Therefore, good, reliable DGPS data are crucial for a quality shipboard ADCP data set. Ship velocity estimated by the ADCP bottom-tracking mode is used when good bottom track fixes are available, usually in water depths of less than 300 m. Calculated DGPS ship velocity is used when the ship is in deeper water, as was the case during most of the SWSS cruises. The subset of data with both bottom-track and navigation velocities is used to perform a directional calibration of the ADCP after the procedure of Joyce (1989). The errors are of two types: sensitivity and alignment. Sensitivity errors arise because the orientation of the acoustic beam is not correct due to factors such as nonzero trim to the transducer and ship, small errors in the beam geometry, or over-all system bias. The alignment errors are caused by misalignment between the reference frames of the ADCP and the navigation data. Joyce (1989) notes that these two types of errors arise from independent sources and produce errors approximately orthogonal. The misalignment induces an error in the velocity component perpendicular to the ship that is linearly related to the ship speed, while the sensitivity errors occur in the ship-parallel component, again in linear proportion to ship speed. The mean alignment error is typically one to two degrees for the *R/V Gyre*, i.e., viewing the ship from above, the data are rotated clockwise by this angle. The mean sensitivity error is typically 1.00 to 1.04, so the data are scaled up by this value. The complex regression statistics for the bottom-track versus DGPS navigation velocities and the average DGPS ship speed are summarized in Table 4.5.2.

In Table 4.5.2, b_m is the regression modulus and is a measure of the gain or bias between the two vector sets, α is the offset angle between the two data sets, and ρ^2 is the coherence parameter, which measures the amount of variance in the GPS-determined velocities accounted for by the bottom-track-determined velocities ($\rho^2 = 1.0$ for perfect coherence). Table 4.5.2 shows the regression modulus and angle fall within typical values for the sensitivity error and mean alignment error of *Gyre*. Bender and Kelly (1997) also give a more detailed description of the estimation of the regression angle, modulus, and coherence.

Table 4.5.2

Complex regression statistics for GPS velocity versus bottom-track velocity

Description	S-tag 153-kHz	D-tag 153-kHz	D-tag 38-kHz
Number of stations for misalignment angle	4194	1487	890
Sample size actually used	9818	4226	7089
Clockwise regression angle (α)	-0.67	-0.72	0.968
Regression modulus (b_m)	1.00514	1.00989	0.999304
Coherence parameter (ρ^2)	0.996803	0.998949	0.999845
Average GPS ship speed ($cm \cdot s^{-1}$)	251.8	351.4	375.6

Note: There were no usable data from the 38-kHz ADCP during the S-tag cruise.

After the navigation data are merged with the ADCP data, the data are inspected for problems external to the data. These external factors include:

1. No navigation data for a given ensemble,
2. Bottom track depth too shallow for any good data,
3. Slow ship speed (speed < 100 cm/s),
4. Fast ship speed (speed > 650 cm/s), and
5. The percent good pings for the first bin is less than 30%.
6. Insufficient number of beams to produce a velocity estimate.

Data not passing the stipulated requirements for each factor are rejected and removed from the database. Those that pass are corrected as described below and reformatted into a more manageable and efficient format. A summary of the results of this step is given in Table 4.5.3. Further, the bottom 15% of the vertical profile is rejected as unreliable due to improper echo return near bottom. Therefore, the deepest usable bin number is readjusted during this step of processing. If the adjusted bottom depth is less than the first bin depth, the segment is discarded. Processing software for this stage was composed largely in FORTRAN.

After data are removed from the ADCP database due to external reasons, the remaining data are examined for internal problems. Internal data problems are intrinsic and mainly include outliers. Outliers are determined using basic statistics and are identified by estimating the standard deviation and mean of each velocity component for the entire cruise at a given depth level. The entire segment is rejected when any velocity component at any depth is greater than three standard deviations from the average value. This procedure removes many of the grossly anomalous velocity vectors in the ADCP data. Velocity fields also are replaced by a no data flag, "-999.99", if the percent good field falls below 30.

The above-described QA/QC processing steps mainly are objective and based on constraints of the physical system. In the next processing step, vertical profiles showing along- and cross-transect velocities and horizontal maps at a given level are produced, analyzed, and inspected to identify suspect and questionable data. Suspect data are evaluated and then are left as is, flagged as suspect, or rejected entirely and replaced with the no data flag. Viewing such plots allows the data to be examined in context and marks the beginning of the data analysis phase as processes and features become evident. Note that this step is the most subjective and, therefore, the most labor intensive, part of the QA/QC. By its nature, this step is considered to be fine tuning of the dataset since all the gross outliers have been removed previously. Approximately 30-50 segments (out of order 2000) are removed during this step of post-processing. Most of the plots

Table 4.5.3

Results of evaluation of 153 and 38 kHz ADCP data for external factors and number of data segments rejected

Description	S-tag 153-kHz	D-tag 153-kHz	D-tag 38-kHz
Total number of segments	5073	1755	1128
Segments rejected for no navigation	31	24	173
Segments rejected for bottom-track depth too shallow	4	16	28
Segments rejected for slow ship speed (< 100 cm·s^{-1})	470	124	37
Segments rejected for fast ship speed (> 650 cm·s^{-1})	0	0	0
Segments rejected for first bin % good less than 30	0	0	0
Segments rejected for insufficient beams	374	104	0
Total usable segments	4194	1487	890

produced during this stage of processing use the contouring, gridding, and mapping capabilities of the Generic Mapping Tools (GMT) Software System (Wessel and Smith, 1995).

After all quality control steps are performed, the data are formatted into an ASCII data file for distribution to MMS and NODC. The files include metadata with cruise identifiers, instrument type, FORTRAN formatting instructions, and program contacts. In addition, special problems and important processing information unique to the cruise are included in the metadata. This information begins with "$SWSS VERSION" and represents a history of the processing done on that file. The information is crucial to the proper interpretation of the data. It is recommended that the user become familiar with all such information prior to analysis and interpretation. Following the metadata are the data which are listed by ensemble with the date, latitude, and longitude of the beginning and end of each ensemble followed by the GPS ship velocity and bottom-track depth. The current velocity by depth is then reported with vertical and error velocities, the signal intensity of each transducer, and the percent good pings. These latter parameters remain virtually unchanged throughout the estimation of horizontal current velocity and are useful as data quality indicators.

Ensemble Processing Procedure: To improve the overall data quality and to recover segment data eliminated because of bad pings, special in-house processing software was developed during the MMS-sponsored Northeastern Gulf of Mexico Chemical Oceanography and Hydrography Study (Jochens and Nowlin, 1999). The Ashtech data are used for special processing of the individual 8- to 10-second ensembles that are averaged together to make the 5-minute segments. Ensembles are composed of four 2-second pings, of which two are used for bottom tracking, which is good only over the shelf. The remaining two are averaged together to estimate current velocity. In the original processing method, all ensembles are automatically averaged into 5-minute segments for further processing by the VMDAS software. Our experience with shipboard ADCP data, however, has shown that occasionally one or more ensembles in a segment have unrealistic or bad values that result in the removal of an entire 5-minute averaged segment. By quality controlling and discarding bad ensembles prior to averaging into 5-minute bins, the data quality is substantially increased. The ensemble processing is computationally intensive and therefore only used in special circumstances when the standard processing fails. The ensemble processing procedure was not used on any data sets obtained during the summer 2002. However, the procedure is available for use if needed on future cruises.

A by-product of the ensemble processing is the ability to quality control ADCP data when the ship is on station. Previously, these data were discarded because of unreliable ship heading and errors in the 5-minute data due to ship acceleration and deceleration when approaching and leaving a station. The ensemble processing also will lead to removal of slow ship speed criterion for excluding segments.

ADCP Data Quality: Data quality of the 150-kHz ADCP was good for both the S-tag and D-tag cruises. The percent good data quality indicator showed 100 percent data return to about 165 m depth. Data quality then fell to 50 percent good at about 220 m depth. Other data quality indicators (vertical and error velocities and echo intensity) were within expected limits. In general, the narrowband 150 kHz ADCP data were typical of data taken from previous cruises in the northern Gulf of Mexico.

Data quality of the 38 kHz ADCP was poor. Data recorded during the S-tag cruise was unusually noisy. Quality control parameters such as vertical and error velocities were outside acceptable limits. We consider the S-tag 38 kHz data unusable. We believe that mechanical and electrical problems caused the poor data quality during the S-tag cruise. These problems include: poor acoustical insulation from ship engines, unintentional grounding of the ship's electrical system, malfunction of the ADCP deck box, and mechanical deterioration of the transducer frame potting. After the S-tag cruise and prior to the D-tag cruise, many of the problems were identified and corrected. These included: replacement of the deck box, rewiring of the ship's electrical systems, and improvements in acoustically isolating the transducer from ship engine noise. These changes slightly improved the data quality of the 38 kHz ADCP during the D-tag cruise. However, the maximum penetration depth of reliable data from the 38 kHz only reached about 250 m. Below this depth, the data were noisy and unrealistic. Above 250 meters appear reasonable but should be considered suspect and only used with caution. The cause of the suspect quality was attributed to the degeneration of the potting which seals the machine screws between the transducer frame and the ceramic transducer. The instrument has been sent to RD Instruments for refurbishment and will be available for use during the 2003 cruises.

4.6 Data Management

A data management plan was developed for SWSS on 30 July 2002. In brief, the scientists provide their raw data to the Data Office after each cruise. This provides a remote back-up of these data. After completion of QA/QC efforts, the scientists also provide their final data sets to the Data Office for archival and back-up. Much of the final data will be provided to Federal data repositories, MMS, and/or other organizations that hold data sets of the types collected in SWSS. The data management plan is given below.

4.6.1 Introduction

The objectives of data management for the Sperm Whale Seismic Study (SWSS) are four-fold. First is to prevent data loss by duplication and secure storage of data from collection through archival. Second is to assure data quality control. Third is provide for archival of the data sets in a central data repository and, as appropriate, in federal or other data centers. Fourth is to support the scientific mission of the study by facilitating the dissemination and use of the data by the program scientists and the MMS managers.

Three entities participate in the data management. They are:

1. the data originators, who collect the original ("raw") data, perform the quality assurance/quality control (QA/QC) on their data sets, and provide the basic analyses and interpretations of their data,

2. the central data repository, which will be at Texas A&M University, with Dr. Matthew K. Howard as Data Manager, and
3. the data recipients, which include the program scientists, MMS for selected final data sets, the National Oceanographic Data Center (NODC) for final physical oceanographic data sets, and the North Atlantic and Mediterranean Sperm Whale (NAMSW) catalogue for selected sperm whale fluke photographs.

The key program scientists and their respective institutions are:

- Doug Biggs, Matt Howard, Ann Jochens, Texas A&M University (TAMU)
- Dan Engelhaupt, University of Durham
- Jonathan Gordon, Ecologic
- Nathalie Jaquet, Bernd Würsig, Texas A&M University-Galveston (TAMUG)
- Bill Lang, Sarah Tsoflias, Minerals Management Service (MMS)
- Robert Leben, University of Colorado (CU)
- Bruce Mate, Oregon State University (OSU)
- Peter Tyack, Mark Johnson, Patrick Miller, Woods Hole Oceanographic Institution (WHOI)

The International Association of Geophysical Contractors (IAGC) also is a major participant in the SWSS project by virtue of their contribution of a seismic source vessel for the D-tag experiments. IAGC is represented by Chip Gill.

The types of data being collected during the S-tag cruises (S-tag) and D-tag cruises (D-tag) are:

1. locations of tagging or other sampling (all participants collecting data)
2. satellite tracking data (S-tag, OSU as data originator)
3. D-tag data (D-tag, WHOI as data originator)
4. acoustic data (S-tag, Ecologic and OSU as data originators; D-tag, WHOI as data originator)
5. visual observations (S-tag, Ecologic, OSU, and TAMUG as data originators; D-tag, WHOI as data originator)
6. photo-ID data (S-tag, Ecologic, OSU, and TAMUG as data originators; D-tag, WHOI and TAMUG as data originators)
7. genetic analyses (S-tag and D-tag, Engelhaupt as data originator)
8. physical oceanographic data, including CTD, XBT, ADCP, flow-through temperature, salinity, fluorescence, and calibrated chlorophyll (S-tag and D-tag, TAMU as data originator)
9. satellite images of sea surface height (TAMU as image originator with data from CU)
10. structure locations and lease blocks (MMS as data originator)
11. seismic source data for the study and possible information on seismic vessel activity in the Gulf of Mexico during the study period (arranged through IAGC).

4.6.2 Data Manager

Dr. Matthew Howard will be the Data Manager for this study. He holds both B.S. and Ph.D. degrees in Oceanography and has been employed at Texas A&M University in the capacity of data analyst and data manager since 1991. He was the principal Data Manager for the MMS LATEX-A and MMS Deepwater Reanalysis Programs and is currently employed in that capacity for the MMS NEGOM, MMS JETS programs, and for the physical oceanographic data sets collected by the MMS DGoMB program. He is currently the Data Manager for the Texas General Land Office's Coastal Modeling effort in charge of the acquisition, redistribution, and archival of large (~3.2GB/day) continuous streams of weather observations and numerical weather model output for the Gulf of Mexico. He also is involved in the National Ocean Partnership Program (NOPP) Gulf of Mexico Region National Virtual Ocean Data System

(NVODS) with the responsibility of making the archive of Gulf of Mexico Physical Oceanographic data sets available on demand via the Distributed Ocean Data System (DODS). He is a participant in a Sea Grant-sponsored coastal hypoxia study charged with acquisition and usage enhancement of all available dissolved oxygen data for Gulf of Mexico coastal waters.

Howard has extensive experience in the management of large archives of data and model output, quality control and quality assurance of physical oceanographic data sets, acquisition of large and small data sets, data archeology and rescue, production and incorporation of metadata and adherence to Federal guidelines for metadata. He was in charge of the production of the nine CD-ROMs coming out of the MMS LATEX, MMS NEGOM, and MMS Deepwater Programs. He is experienced with data formats, database, 3-D visualization systems, interactive data analysis systems, and is a member of the ESRI Marine GIS user group. He is familiar with the MMS Coastal and Offshore Resource Information System (CORIS). He maintains close and frequent contact with personnel at the User Services group of the National Ocean Data Center and is intimately familiar with their holdings and data information access portals. He has kept abreast of the activities of developing National Coastal Data Development Center and the evolving Gulf of Mexico observing systems.

4.6.3 Data Back-up

The data originator will record pertinent information in data logs during collection of the data sets. High quality copies of these logs will be made as back-ups and provided to the Data Manager. Digital data will be copied to disks or CD-ROMs. Original data sets will be provided to the Data Manager for archival in the central data repository at the SWSS Data Office located at TAMU. This also provides an additional, offsite back-up for the original data. Original data will be provided by the data originator in batches corresponding to reasonable sets of data, such as one season's worth of satellite data or one cruise's worth of acoustic data. All original data will be provided, including satellite tag data, D-tag data, acoustic data, visual observation data, photographic data, and physical oceanographic data. The SWSS Data Office will not release or distribute these data further except as requested by the data originator or MMS or as required by law and then with approval of MMS and the knowledge of the data originator. As the data originators work with their data, routine back-ups will be made.

Routine back-ups will be made by the data originator. Quarterly, the data originator will provide information to the Program Manager on the progress of QA/QC efforts; the Program Manager will summarize such progress in the Quarterly Reports to MMS. The final data sets will be provided by the data originator to the Data Manager for archival at the SWSS Data Office and for submittal as required by the Cooperative Agreement.

4.6.4 Data QA/QC and the Database

Each data originator is responsible for performing QA/QC processing on their data sets to assure high data quality and to prevent loss of data. They will use standard, accepted procedures for each specific data type. Final data sets are those for which all QA/QC processing has been completed. Final data sets will be provided to the Data Manager near the end of the project, in time for preparation for submittal of the data sets to MMS, NODC, and the NAMSW catalogue concurrently with the draft of the final report.

4.6.5 Data Archiving Procedures

The central data repository for Study data sets will be at Texas A&M University. Both original and final data files will be stored on a hard disk connected to the Data Manager's main computer. The ownership and file protection bits of these files will be set so they cannot be deleted inadvertently and no changes can be made to the file contents. The contents of all hard disks attached to this system will be backed-up at regular intervals to 4mm DAT tape, CD-ROMs, or other appropriate storage device. The contents of the back-up media are verified, and the back-up media are stored offsite. As new data are acquired and as value is added to the existing data through the quality-control and quality-assurance steps, new tapes and CD-ROMs will be created and stored   Per the Cooperative Agreement, data will be retained by the SWSS Data Office in the archive for three years after the end of the study.

4.6.6 Data Usage and Sharing

Sharing Among Participants: OSU will provide S-tag data to the participants on the D-tag cruise to guide them to whales. The Data Manager will assist with this effort if requested by OSU. Additional data exchanges between participants will be undertaken by the data originators to facilitate preparation of required reports and/or publications.

Sharing with MMS: Selected final data, discussed in Section G below, will be provided by the Program Manager to MMS concurrently with submittal of the draft synthesis report as required by the Cooperative Agreement. If MMS requests data during the course of the project, the data will be marked provisional prior to transfer.

Sharing with IAGC (Industry): IAGC will work with the SWSS Program Manager to set up a data sharing agreement that will allow the SWSS Data Office to accept and store proprietary data on shot locations, dates, and times in the Gulf of Mexico from cooperating industry parties. It is anticipated that the first and last shot points for each line, together with the date and time, will be provided in a common format. Data will be provided in digital format to the Program Manager or Data Manager. Data will be stored on CD-ROMs or other media and will be held confidential. Data sets will be disseminated by the Data Manager only to academic, IAGC, or MMS persons participating in SWSS and only with the approval or on the request of the IAGC/industry party that originally provided the data set.

IAGC will engage in data exchanges with academic and MMS participants. Such exchanges will be undertaken by the data originators, not the SWSS Data Office. However, the SWSS Data Office will assist with such exchanges if requested by the data originators.

Sharing with Third Parties: The SWSS Data Office will not release or distribute the data provided to the central data repository except as requested by the data originator or MMS or as required by law and then with approval of MMS and the knowledge of the data originator. Data requests received from third parties will be forwarded to the data originator, except as requested by MMS. The data originators are limited in their sharing of data with third parties only by the terms of the Cooperative Agreement in their subcontracts.

For data transfers from the SWSS Data Office, the Data Manager will be responsible for any reformatting needed and the data transfer. Transfers will be made by ftp delivery, website pickup, tape, or CD-ROM.

4.6.7 Data Submission

As required by the Cooperative Agreement, final data will be submitted as follows:

1. Geo-referenced data will be prepared by the Data Manager, using inputs provided by the data originators, in accordance with the specifications of Section V.2.A of the Cooperative Agreement. A draft version will be submitted concurrently with the draft synthesis report. The final version will be submitted concurrently with the final synthesis report. Submittals will be to the MMS persons and in the quantities specified in the schedule given in Section VI.A of the Cooperative Agreement.

2. Physical oceanographic data will be prepared by the Data Manager and submitted to the NODC, in accordance with the negotiated NODC Data Archiving Agreement, concurrently with submission of the draft synthesis report (see Sections V.2 S and T of the Cooperative Agreement). NODC will be provided with a CD-ROM containing the physical oceanographic data in ASCII format.

3. Physical oceanographic data will be prepared by the Data Manager and submitted to MMS concurrently with submission of the draft synthesis report in accordance with the schedule specified in Section VI.T of the Cooperative Agreement. MMS will be provided with CD-ROMs containing the physical oceanographic data in ASCII format.

4. Final versions of the S-tag, D-tag, and acoustic data sets will be prepared by the Data Manager and provided to MMS in ASCII and/or geo-referenced formats. Submittal will be made concurrently with the submittal of the draft synthesis report.

5. A selection of final sperm whale fluke photographs, as determined by TAMUG/Ecologic and WHOI, will be submitted to the North Atlantic and Mediterranean Sperm Whale catalogue. Submittal will be made by TAMUG/Ecologic and WHOI scientists, with copies to the Program Manager. The submittal may be in batches or at the end of the program at the discretion of TAMUG/Ecologic and WHOI. However, the final submittal will be made no later than concurrently with the submittal of the draft synthesis report. Although the full body of photographs submitted to that catalogue are not required to be submitted to MMS, the Program Manager will provide a letter to MMS recording the submittal.

5 TECHNICAL SUMMARY

On 16-17 January 2003, the SWSS scientists, MMS managers, and other interested parties met in New Orleans, LA, to discuss plans for the 2003 SWSS field program. Reviews of SWSS and SWAMP preliminary results were given as background for that meeting and as part of the MMS Information Transfer Meeting (ITM) on 15 January 2003. Given below are synopses of the reviews from the ITM.

5.1 Sperm Whales in the Gulf of Mexico: Photo-identification, Photogrammetry, Acoustic Analysis and Observations of Medium-scale Movements During SWSS 2002

Dr. Jonathan Gordon, Sea Mammal Research Unit, Gatty Marine Laboratory, University of Saint Andrews, Saint Andrews, Fife, Scotland, UK
Dr. Nathalie Jaquet and Dr. Bernd Wursig, Texas A&M University-Galveston, 5007 Ave U, Galveston, TX 77551 USA

Introduction

Our brief for this presentation was to provide a general introduction to the sperm whale and give an overview of research activities carried out as part of the SWSS 2002 project using "standard" non-invasive sperm whale research techniques such as photo-identification and acoustic monitoring and photogrammetry.

Sperm Whales

Sperm whales must rank amongst the most impressive of any animals. Even within cetaceans they are remarkable, differing in many respects from the other great whales. In a nutshell:

- They are the **largest of the toothed whales**. Males reach lengths of 20m while females grow to 12m.
- They are the **most sexually dimorphic** of cetaceans. At 44 tones a mature male is over 3 times the weight of a 13.5 ton mature female.
- They are the **most accomplished of mammalian divers**. Dives of over an hour to depths below 2,000m have been recorded.
- Their massive heads, which can account for up to a third of the body length of the males, is the **largest sound-producing organ** in the animal kingdom. Sperm whales are very vocal, producing loud clicks for most the time they are underwater. Recent research by Bertel Mohl and colleagues indicates that they produce the most powerful of animal-made sounds (>230 dB re 1µ Pa @ 1m) focused in narrow beam (Mohl *et al.*, 2000).
- They have the **lowest rate of reproduction** of any mammal. Females mature at about 9 years of age. Gestation takes about a year and a half and suckling continues for a few years. Average calving intervals in stable populations are around 5 years. Calves may be cared for communally, and the oldest females may contribute to calf care and may have a leadership role when they cease reproducing. Sperm whale populations were decimated by pre-industrial and industrial whaling and have been very slow to recover.
- They have the **most highly developed social organization** of any of the great whales. Females and their young live together in stable family groups of between 12 and 30 individuals.
- They are **extremely wide ranging**. Sperm whales are found in deep waters in all of the oceans of the world. Uniquely, although females and their young are confined to tropical and temperate waters, mature males spend most of their time in cold temperate waters ranging right up to the ice edge.
- They are very **ecologically successful** exploiting populations of deep-living fish and squid about which we still know little. Before whaling, sperm whales were thought to

have been numerous, consuming more biomass than the world's entire modern fishing fleet.
- Perhaps most intriguingly of all, sperm whales have the **largest brains** that have ever existed.

Sperm Whales in the Gulf of Mexico

Sperm whales are the most common species of large whale in the Gulf of Mexico. Extensive surveys conducted during the GulfCet I and GulfCet II Programs (1992-1998) in the offshore waters (100-2,000 m deep) of the northern Gulf showed that most sperm whales were concentrated around the 1000-m depth contour south of the Mississippi River Delta (Davis *et al.,* 2000; Baumgartner *et al.,* 2001). The Texas-Louisiana shelf has been a focus of activity for the offshore oil industry over the past 30 years, with over 15,000 rigs operating in the area. As inshore resources have become fully utilized and deep sea drilling technology has developed, oil exploration beyond the continental shelf has become feasible and is increasingly commonplace. Oil industry activities, including seismic surveys and increased levels of ship traffic, are now impacting offshore areas that are believed to be critical sperm whale habitat.

Underwater noise, including that from seismic exploration, sonar and shipping, has been shown to impact cetacean species. A number of observations have indicated that sperm whales are highly acoustically sensitive and are easily disturbed by unusual sounds. For example, sperm whales showed dramatic responses to military sonar signals in the Caribbean (Watkins *et al.,* 1985), and in New Zealand their vocal behavior changed when whale watching vessels were present (Gordon *et al.,* 1992).

There is little direct information on the effects of oil industry noise on sperm whales. Some researchers have recorded quite dramatic responses: Mate *et al.* (1994) reported that sperm whales moved out of an area after seismic surveys began, while Bowles *et al.* (1994) found that sperm whales stopped clicking in response to weak seismic pulses from a ship perhaps hundreds of miles away. Others, in contrast, have not been able to document such substantial effects (e.g., Swift *et al.,* 1999). A number of unique features of sperm whale biology may make them particularly vulnerable to acoustic disturbance. They are highly acoustically-oriented animals and are vocal for most of the time that they are underwater on their long and deep foraging dives (Gordon *et al.,* 1992; Jaquet *et al.,* 2001). In addition to these vocalizations, which probably serve for short and long range echolocation, they produce complex patterns of clicks, called codas, which are used for communication. Their deep diving, complex social organization and extended period of calf dependence also may contribute to a heightened vulnerability to disturbance.

Research on Free Ranging Sperm Whales

Offshore distribution and deep diving habits of sperm whales made them one of the most difficult of species to study in the field. Bill Watkins was an early pioneer who realized the importance of using passive acoustics as a means of finding and following sperm whales (Watkins and Moore, 1982). A comprehensive research approach, which involved passive acoustics, photo-identification, and photogrammetry, was developed by Whitehead and coworkers (Whitehead and Gordon, 1986; Leaper *et al.*, 1992; Gordon, 1990, 1991; Arnbom, 1987). Crucial to the success of these studies was the use of modest motor-sailors as low cost, non-disruptive, independent research platforms (Whitehead and Gordon, 1986). This approach has been used by a variety of research groups in many parts of the world, including Sri Lanka, Azores, Caribbean, Mediterranean, Canaries, Madeira, Canada, New Zealand, and Gulf of California. Whitehead and his group have been particularly successful working around the Galapagos where they have developed methods for investigating population size, social organization, movements and cultural structure (e.g., Jaquet and Whitehead, 1996; Whitehead, 1990, 1994, 1998, 2001a, b).

SWSS has incorporated many of these techniques into its core program, in particular the use of acoustics to find and follow whales. However, the exciting new telemetry projects that have become its main focus require a very substantial research vessel, which is not appropriate for the "traditional" sperm whale research approach and little time has been available for this sort of study. Nevertheless, during 2002, we were able to conduct photo-id and observational work from a small RHIB as a secondary activity during the satellite tagging project. In addition, the process of finding and tracking whales for tagging provides us with both passive acoustic data and tracking information of sperm whale groups at a medium scale. Analysis of these data is at a preliminary stage but we can provide an overview of data collected and some very preliminary results.

Preliminary Results and Discussion

Photo-identification: Photo-identification images were taken from a small RHIB when opportunities allowed in the course of satellite tagging, and the tagging team also collected some images from the tagging vessel. Good quality images were compared with existing photographs in the North Atlantic and Mediterranean Sperm Whale Catalogue (NAMSC). Most Gulf of Mexico images within this collection come from the GulfCet and SWAMP projects. Forty-four different individuals were identified from images collected during SWSS 2002 bringing the total Gulf of Mexico catalogue to 93 different individuals. This remains a rather small collection for such an important area, a result, no doubt, of the lack of dedicated photo-identification research in the region.

In a situation like this where new images are being compared to a very large existing collection (there are thousands of images in NAMSC), automated matching tools are extremely useful. During SWSS 2002 we used and tested a prototype automated fluke matching program being developed by Dutch Scientists (Eric Pauwels and Adri. Steenbeek) as part of the Europhlukes project. No matches were found between our 44 individuals and the sperm whales identified in the North Atlantic, Mediterranean or Caribbean Sea.

Distribution: Figure 5.1.1 shows the distribution of sperm whales during the S-tag cruise of 2002. For each day, only the first identification of each individual was plotted on the map, avoiding bias due to multiple sightings of the same individual. Most sightings were concentrated just south of the Mississippi River Delta. This is consistent with previous studies in the Gulf of Mexico (for example GulfCet).

Figures 5.1.2 and 5.1.3 show the effort expended, respectively, for visual and acoustic surveys during the 2002 S-tag cruise. Due to unfavorable wind and weather conditions, only very limited efforts were made to conduct visual surveys west of 90°W (Figure 5.1.2). Most of this effort was done in winds of 12 knots or more (≥ Beaufort scale 4), and thus visual detection of sperm whales was impeded by white cups. Compare, however, the acoustic survey effort in the west, which was not impeded by these limitations (Figure 5.1.3). This emphasizes the importance of using passive acoustics to survey for sperm whales. The search effort was very unequal along the survey track (compare Figures 5.1.2 and 5.1.3). Most of the search effort was concentrated between 91°W and 88°W, partly explaining the highest abundance of sperm whales found in this area (Figure 5.1.1).

Mark Recapture Population Estimate: Mark recapture analysis using photo-identification images can provide estimates of population size; indeed, the best current estimates of whale population sizes have been made in this way. Although the existing data are still rather sparse for such an analysis at this stage, we have used them to calculate a simple Peterson estimate for the population. This indicates a population size of 298 with 95% confidence intervals of 137 and 890. Low sample sizes mean that this is very imprecise. It is in general agreement with, though a little lower than, the population sizes indicated by visual surveys.

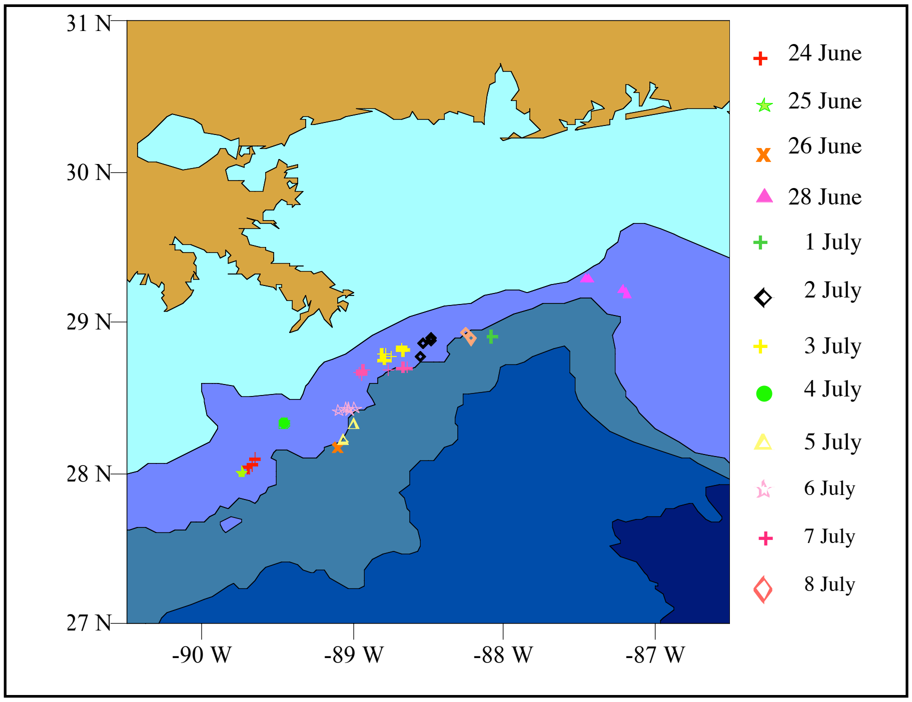


Figure 5.1.1 Distribution of sperm whales during the S-tag cruise in 2002. Each symbol represents the location of the fluke-up of one identified individual. Different colors and symbols were used for each day. For purposes of independence, only the first sighting of an individual was plotted each day.

Defining what is meant by the term "population" is a knotty problem in any cetacean survey. Often populations are determined according to management divisions rather than any biological relevance. It is interesting to note therefore that mark recapture studies conducted within an area of human influence, such as this one, provide an estimate of a "population" which is very relevant to management. In this case photo-id will provide an estimate of the number of animals that pass through the study area (and might thus be subjected to human activities) over the course of the field seasons.

Habitat Use and Site Fidelity: In spite of the low sample size, nine matches were found between the 44 individuals identified during SWSS 2002 and the existing Gulf of Mexico catalogue of 58 individuals from the period 1994-2001. One whale was first identified in August 1994 and was re-identified 8 years later only 6 nautical miles from where it was first observed. Another individual was re-identified after 6 years only 3 nm from where it was first identified. The average *resight*ing distance after two years was 30 nm and after one year 26 nm (Table 5.1.1). In general, the distance between *resight*s was small suggesting a high site fidelity, as has previously been noted by Weller *et al.* (2000). However, the near absence of effort away from the Mississippi River Delta area may also be responsible for the small distances between *resight*s.

Photogrammetry: It has been suggested that sperm whales in the Gulf are smaller than those in other areas. This could be a cause for concern, but no measurements of length have been made.

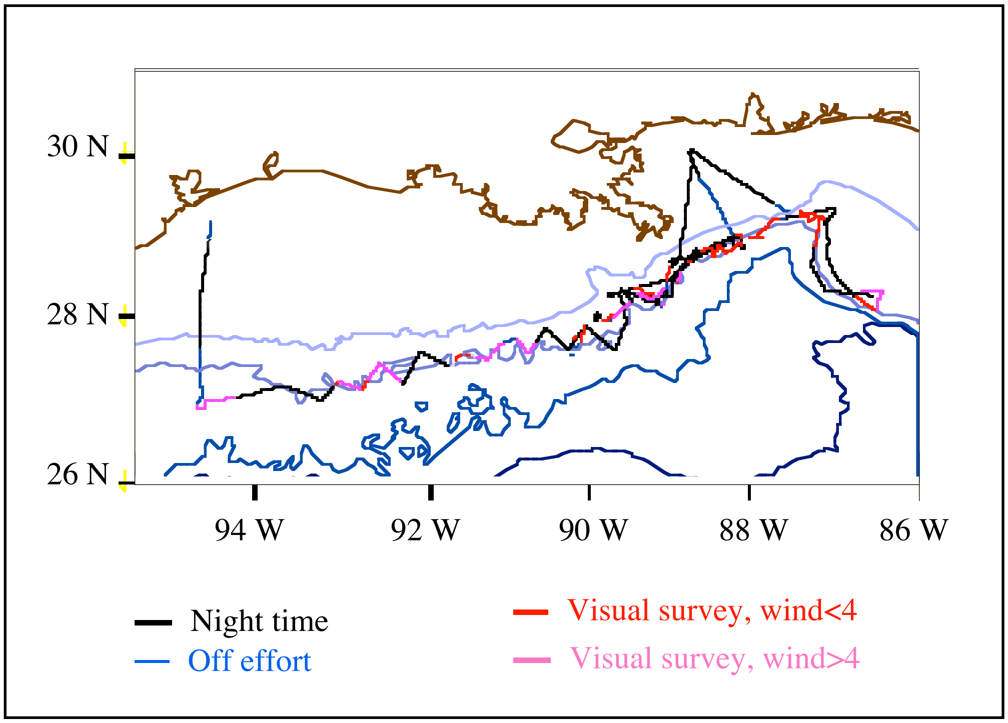


Figure 5.1.2 Visual survey effort during the S-tag cruise in 2002. As white-cups impede the visual detection of sperm whales, the survey effort in conditions with winds less than 12 knots are separated from the survey effort in conditions with winds above 12 knots. This is indicated by the Beaufort 4 scale noted above.

Photogrammetric techniques have been used in previous studies to measure sperm whales but they require a vessel with a mast or specialised stereo-photogrammetry equipment. We have been experimenting with simpler methods, compatible with conducting photo-ID from small RHIBs. Laser range finding binoculars are used to measure the range to fluking whales, allowing the fluke width to be easily calculated. Relationships between fluke widths and total lengths were extracted from whaling data. Only eleven individuals have been measured so far, but these preliminary data tend to support the contention that Gulf sperm whales are small. The accuracy of this technique needs further testing before any conclusions can be drawn.

Population Structure: Most encounters with sperm whales were with groups of at least five individuals, and up to 13 different whales were identified within a group. On two occasions (29 June and 4 July), single males were observed. However, no estimate of size could be made as RHIB-2 did not get the opportunity to approach any of these males. First-year calves were occasionally observed.

Small-scale Movements: It has been shown that patterns of small-scale movements of groups of sperm whales are a good indicator of the amount of food available to them in a particular location. Figure 5.1.4 shows one example of a group that we followed for 9 hours on 3 July 2002. During this time, the group traveled a total distance of 27.4 nm while the straight-line distance was only 6.3 nm. The amount of zig-zag performed by the group suggests high food

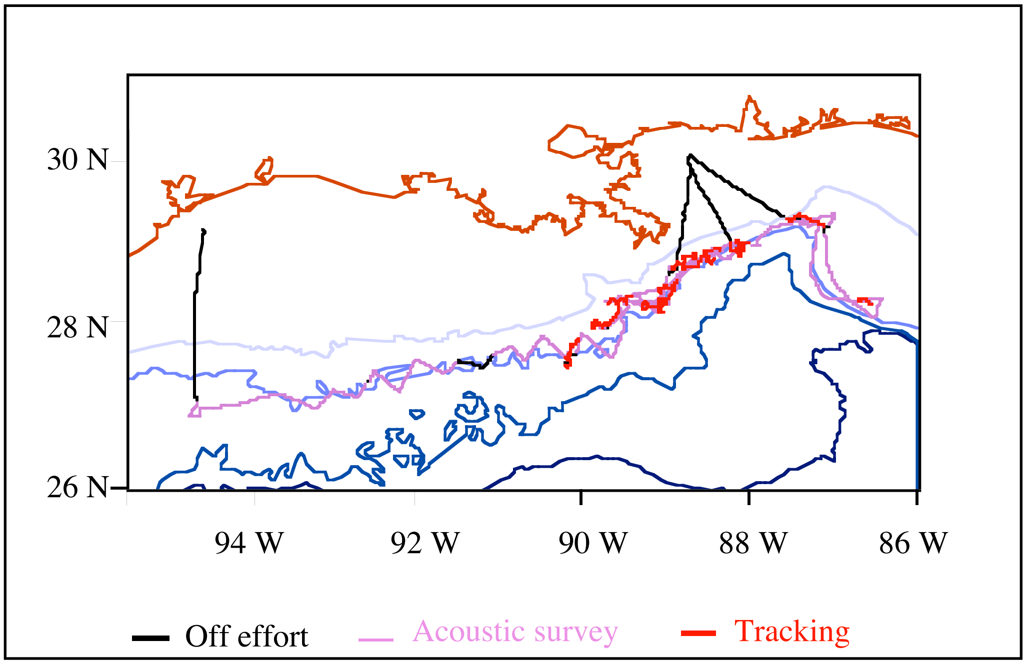


Figure 5.1.3 Acoustic survey effort on SWSS 2002 S-tag cruise. The pink track denotes the acoustic survey following a determined track line while towing at least one hydrophone array at speeds ranging from about 4 to 6 knots. Red denotes tracking of sperm whales by trying to stay in acoustic contact with whales or trying to reencounter a group of whales after losing it.

resources in the area which could explain the high site fidelity found south of the Mississippi River Delta.

The small-scale movements of a lone male that was followed for 7 hours on 4 July 2002 are also shown on Figure 5.1.4. In this case the small-scale movements are completely different and typical of a lone male in tropical waters. This male traveled a total distance of 13.5 nm with an average of 4 nm between fluke-ups. At 1800 hour, the male entered the periphery of a group of females and codas could be heard on the hydrophones.

Tracking of Movements and Headings in Response to Seismic Sounds: During the 2002 field season seismic airguns could be heard clearly at 52% of monitoring stations when the vessel was within what seems to be the whale's preferred area (south of the Mississippi delta, between longitudes 88 and 90°W). Airguns and sperm whales were heard at 16% of monitoring stations.

The visual observers that search for whales, spot animals and then guide the tagging boat to them during tagging sessions, record the range and bearing to all sightings and also estimate the animal's headings. In some cases range is also measured accurately using video techniques (Gordon, 2001). These data could provide medium-scale data on animal's responses to seismic surveys complimenting the very detailed data from D-tags and the longer-term data from S-tags. The bearing to seismic pulses was measured using the Ishmael analysis program to compare arrival time at the hydrophones in the main towed stereo array, and these were compared with the net movements of the whale groups. At this stage there are no indications that whales move

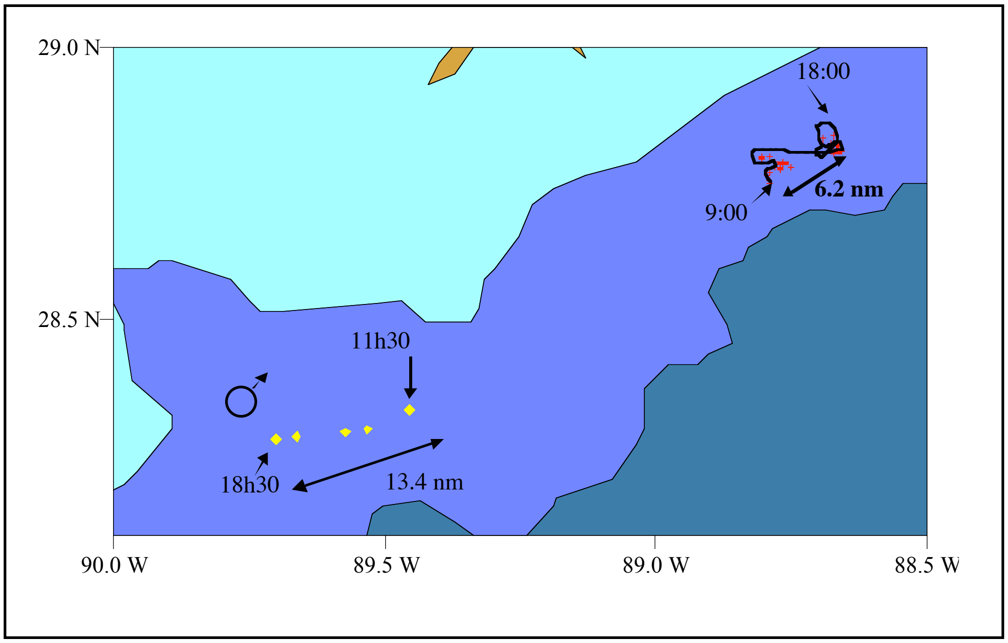


Figure 5.1.4 Example of small-scale movements. Each symbol represents the location of the fluke-up of one identified individual. Red: small-scale movement of a group of female and immature sperm whales followed on 3 July 2002. Yellow: small-scale movement of a lone medium size male sperm whale followed on 4 July 2002.

away from seismic sources. However, a better analysis could be conducted if the location and activity of seismic vessels in the area was known rather than relying on acoustic localisation.

Coda Analysis: Codas are stereotyped patterns of clicks made by sperm whales in social situations. There is growing evidence that coda repertoires vary between different regions and between different social groupings. Indeed, an exciting new paper (Rendell and Whitehead, in press) suggests that coda repertoires reflect broad-scale cultural clans within sperm whale populations. The existence of such "cultural" population structure could have important management consequences. Clans may differ in experience and in many learned behaviours, for example in the way they respond to perturbations such as human activity. These indications of "cultural" population structure compliment the insights on population structure that genetic analysis can provide.

Again, we are at a preliminary stage of analysis but indications are that the coda repertoires of Gulf of Mexico sperm whales are quite different from those in the Azores and strikingly distinct from codas recorded in the Windward Islands.

Table 5.1.1

Sperm whale resightings from SWSS 2002 S-tag cruise data
(The time between resightings is given in days (d) for matches in 2002 and in years (y) for matches between SWSS 2002 and Gulf of Mexico catalogue of 58 individuals.)

No. of individuals sighted togethe	**Date first sighted**	**Date resighted**	**Time between resightings**	**Distance between resightings (nm)**
		Matches within SWSS 2002		
1	2 July 02	7 July 02	5 d	11.22
4	3 July 02	7 July 02	4 d	6.96
2	2 July 02	3 July 02	1 d	7.02
1	6 July 02	7 July 02	1 d	14.77
		Matches between SWSS 2002 and Gulf of Mexico catalogue (58 Individuals)		
1	23 Aug 94	3 July 02	8 y	5.6
1	26 Aug 96	3 July 02	6 y	2.8
2	19 July 00	3 July 02	2 y	22.0
1	30 June 00	6 July 02	2 y	9.4
1	15 July 00	3 July 02	2 y	67.0
1	28 July 01	2 July 02	1 y	18.8
2	18 August 01	6 July 02	1 y	30.0

5.2 Identifying the Seasonal Distribution of Sperm Whales in the Gulf of Mexico with Satellite-Monitored Radio Tags

Dr. Bruce Mate, Oregon State University, Hatfield Marine Science Center, Newport, OR 97365

Background

Knowledge of the seasonal distribution of sperm whales has been limited to stranding data and by the expense of logistics for recent aerial and vessel-based surveys (GulfCet and SWAMP). These surveys identified a few "hot spots" of seasonally concentrated sperm whales in the vicinity of the Mississippi Canyon and Delta region, as well as DeSoto Canyon. In 2001, a 10-day cruise for tagging sperm whales was restricted by Tropical Storm Barry to just 3.5 days of operation. Four tagging attempts resulted in one successful tagging, which operated for 137 days before the batteries were exhausted. The tagged whale spent 95 days in the Northern Gulf—from eastern Louisiana to western Florida—generally along the slope edge and roughly along the 900-m depth contour. The whale then traversed the upper Gulf in 23 days, traveling at an average speed of 3.7 km/h and an average distance of 191km from shore over waters up to 3,000m deep (average = 1,677 m) to arrive in the Gulf of Campeche, Mexico, where 19 days of activity were recorded before the tag's batteries were exhausted. Dive rates were highest during the high-speed directed movements as the whale moved from the upper Gulf to Mexico.

Analysis of 2001 Tagging Data with Seismic Survey Data

An analysis was done on the movements of the 2001 S-tagged whale during the time a single seismic vessel, the *Polar Search*, was active in the same general vicinity off the Mississippi Delta (seismic vessel data courtesy of Phil Fontana, IAGC). Because of the tag's low duty-cycle (4 h/d) and the polar orbiting nature of satellites carrying Argos receivers, we obtained an average of only 1.7 locations per day. Thirty-four percent of all locations were of excellent location quality (with location error of <150 m to 1,000 m). The whale's locations were an average of 46.7 km from seismic track lines (range 6.6 to 133.0 km), but these cannot be interpreted as either tolerance or flight from seismic activities. On the large scale, it is obvious that the whale did not leave the general Mississippi Delta region during the seismic surveys. Using these same high quality locations, there was only a single day when two locations were determined <30 km from the vessel track line but within 10 hours of each other. The locations were 45 minutes apart and showed the whale moving from 3.4 to 6.6 km away from the vessel's projected trackline at a speed of ~3.7 km/h. This single "sample" is too small to warrant any serious attention.

2002 Studies

At its completion, the track of a single whale in 2001 constituted 95% of everything known about the movements of individual sperm whales in the Gulf and became the model (expectation) around which 2002 tagging studies were planned. Improvements in tag attachment techniques and changing the tag's transmission schedule provided the opportunity for tags lasting up to one year. Multiple duty cycles were incorporated to: 1) provide locations every third day for the first 55 days; 2) operate daily for 35 days (starting 5 days before the D-tag experiment); and 3) then provide locations every fourth day to extend operation as far into the rest of the year as possible.

The cruise to apply satellite-monitored tags (S-tag cruise) ran from 19 June to 9 July 2002 aboard the Texas A&M research vessel *Gyre*, starting from Galveston, Texas, and ending in Gulfport, Mississippi. It included visual and acoustic survey efforts along a saw-tooth pattern, generally centered along the 1,000-m contour, as well as photo-identification and behavioral studies once whales were found. We did not see whales during the first 4 days due in part to poor weather. When the weather improved, whales were not sighted consistently.

Eighteen sperm whales were tagged during the cruise between 24 June and 7 July (Table 5.2.1 and Figure 5.2.1). Location data were received from all of the tags. Because sperm whales rest at

Table 5.2.1

Date and location of S-tag deployments

Tagging #	PTT #	Date and Time	Lat	Lon	Days Tracked*
1	5660	24-Jun-02 18:36	28.011	-89.913	63.7
2	5654	24-Jun-02 23:06	27.993	-89.913	122.6
3	5648	26-Jun-02 23:03	29.207	-87.178	75.0
4	5685	01-Jul-02 19:35	28.958	-88.109	252.8
5	5650	01-Jul-02 19:48	28.956	-88.109	249.3
6	5726	01-Jul-02 20:16	28.950	-88.113	248.8
7	5725	01-Jul-02 21:40	28.903	-88.099	248.8
8	5647	01-Jul-02 21:58	28.903	-88.092	135.7
9	5678	02-Jul-02 23:10	28.860	-88.529	17.1
10	5719	03-Jul-02 15:24	28.793	-88.808	70.7
11	5709	03-Jul-02 16:49	28.788	-88.764	247.0
12	5670	03-Jul-02 19:48	28.840	-88.692	243.4
13	5720	03-Jul-02 20:09	28.850	-88.673	30.8
14	5655	03-Jul-02 20:47	28.839	-88.687	74.6
15	5669	03-Jul-02 23:07	28.804	-88.693	243.3
16	5701	03-Jul-02 23:42	28.805	-88.698	247.2
17	5710	07-Jul-02 19:25	28.732	-88.923	82.4
18	5649	07-Jul-02 20:20	28.708	-88.911	246.2

* Some tagged whales are still transmitting. This information is updated to 11 March 2003.

the surface for prolonged periods (usually >10 minutes) after long dives (often > 40 minutes), higher quality locations are achieved with this species than for any other large whale tracked by satellite thus far. Only two tags were not deployed completely and these were the only tags to last <60 days. At this writing, six months after tagging, eight tags are still operational. So far, the 18 whales have been tracked >47,000 km during 2,286 tag-tracking days and individuals have moved >4,600 km. Figure 5.2.2 shows the distribution of the last location reported from each tagged whale as of 31 December 2002. Tagged whales have ranged over most of the upper Gulf, from Florida to the U.S./Mexico border with a strong preference for slope and canyon regions. However, several individuals have gone offshore into waters more than 3,000 m deep. None of the whales has yet gone into the Gulf of Campeche or left the Gulf of Mexico, begging the question as to whether this contrast to last year's tagged whale is due to small sample size and individual variability or year-to-year variation in the Gulf environment (possible El Niño effect). Many interesting observations on social structure have been made, especially in relation to the composition of pods, their geographic range and temporal stability, which may be unique to the Gulf, but are not yet analyzed in sufficient detail to be reported here. Some interpretations of these data will require the use of biopsy data that are not yet completed.

Continued analyses will include more detailed assessments of the type revealed here and tendencies for whales to associate with temporal oceanographic features (SST from AVHRR, chlorophyll concentrations from SeaWiFS, and fronts and cold and warm core rings identified from TOPEX data). Analyses are ongoing and preliminary at the present time as the experiment is still underway, so data should not be quoted without consulting the principle investigator.

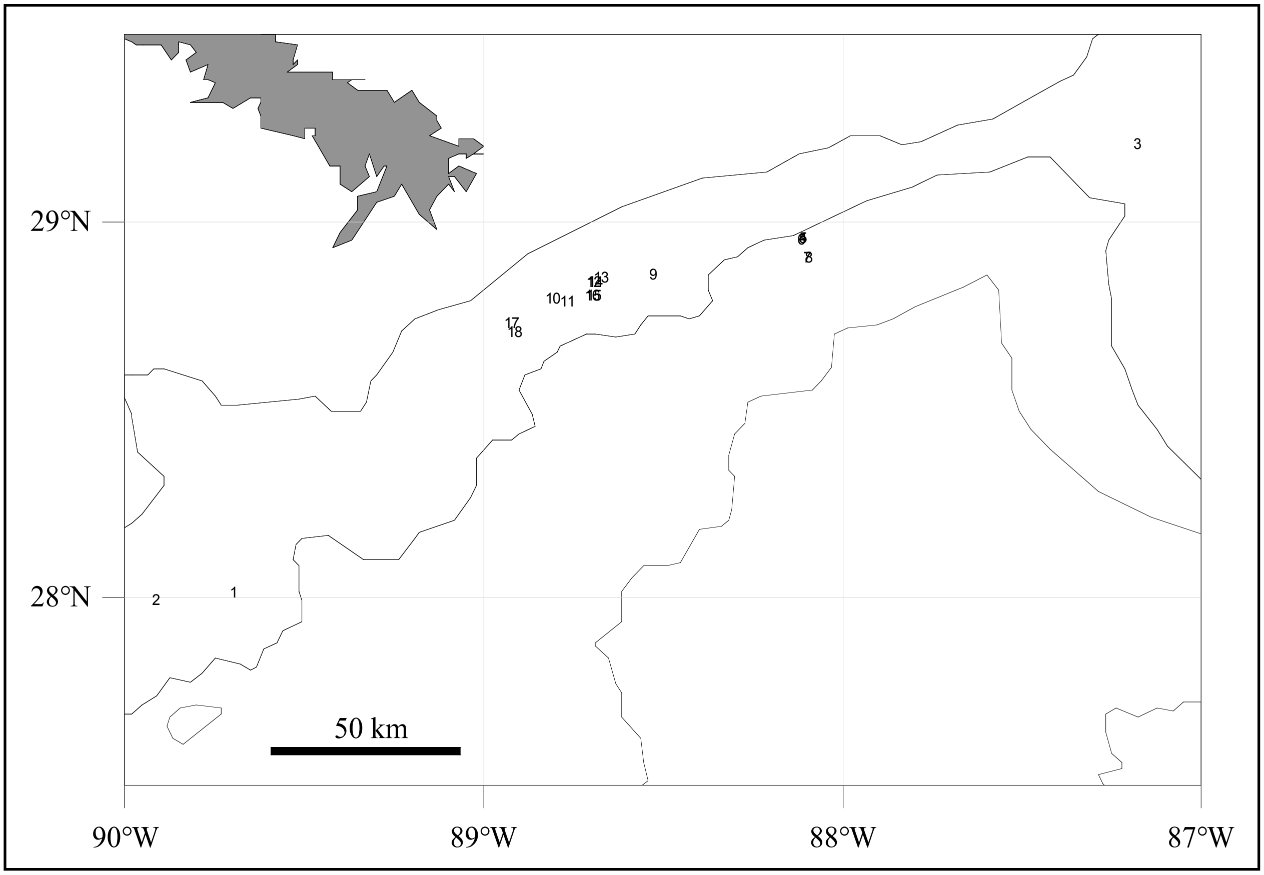


Figure 5.2.1. Locations of S-tag deployments. Numbers indicate the successive tagging number indicated in Table 5.2.1. Contour lines indicate the 200-m, 1000-m, 2000-m, and 3000-m isobaths.

Follow-up Observations

MMS approved funding for winter follow-up observations to determine possible adverse effects of tags to whales, the social affiliates of tagged whales, and the behavior of tagged whales during a period, when reproductive behavior might be expected. Logistics were originally planned for follow-up observations in Mexico as the 2001 tagged whale had moved to the Campeche Gulf. By late November, none of the 2002 tagged whales had moved into the Gulf of Campeche. However, six of the tagged whales were within 50 km of the Mississippi River mouth, so winter re-sighting field efforts were re-directed to that area. As of the ITM, a limited number of attempts had been made to re-sight tagged whales. Several untagged whales had been sighted in the area of locations reported for tagged whales. Subsequent to the ITM, two tagged whales with tags still attached and one which had lost its tag were sighted. All three were judged to be in good condition.

Planning for 2003 Field Work and Beyond

In planning for 2003, we considered three additional strategies that could be directed at the seismic effects objectives of SWSS at a variety of spatial and temporal scales: 1) present Argos tags can be programmed with a different duty cycle to achieve higher resolution (more locations per day), but at the sacrifice of longer-term seasonal distribution data; 2) a depth-sensing S-tag (presently under slow development because it is not funded) could describe the whale's use of the

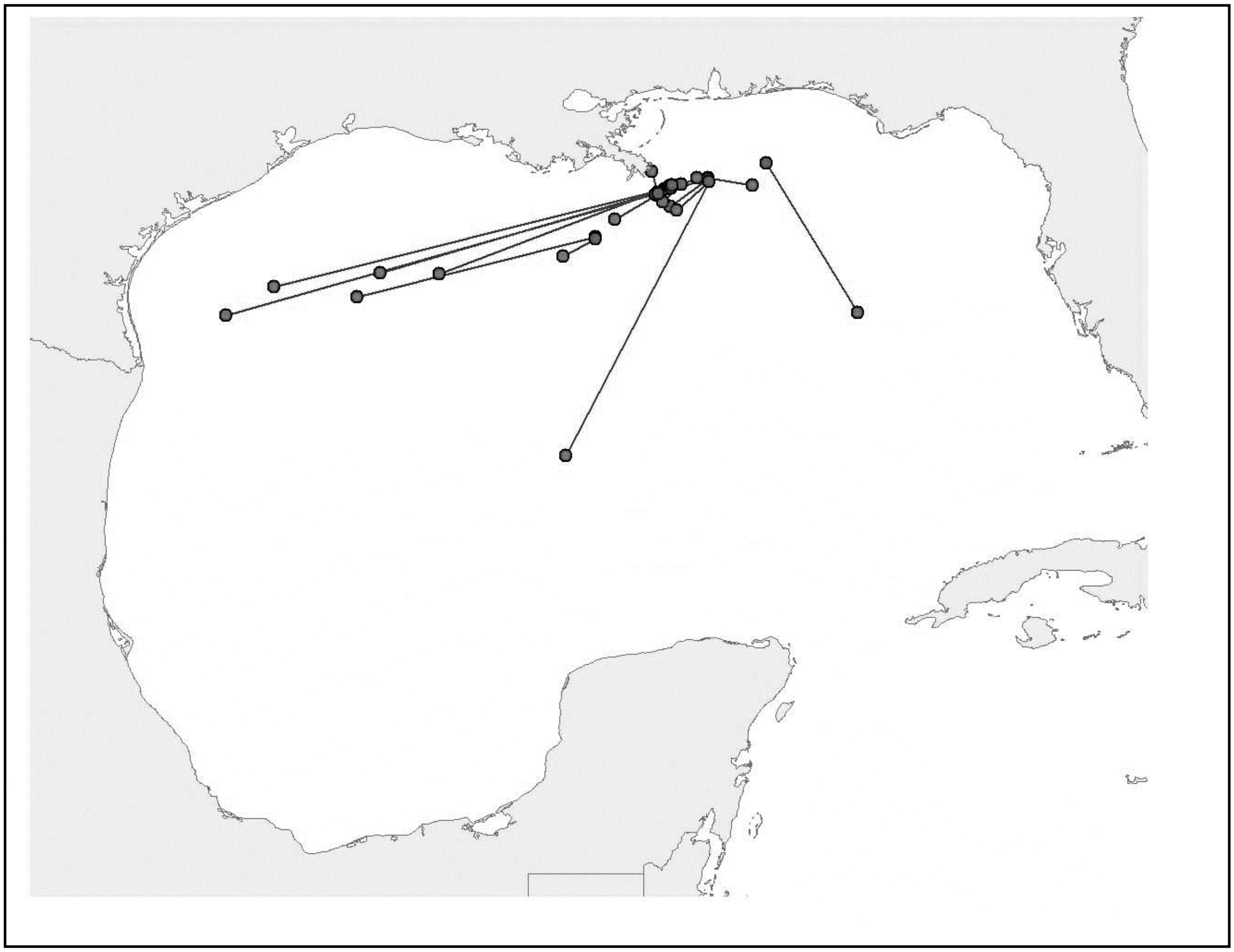


Figure 5.2.2. S-tag deployment locations and last location determined from transmissions to 21 December 2002.

water column over a period of 4 months. These intermediate-duration tracks with summaries of dive activities (depths, durations, surface times, percent of time in specific depth strata) would be useful in estimating sperm whale exposure to seismic sounds. The technology is similar, but smaller, to that used by Krutzikowsky and Mate (2000) in their bowhead whale study; 3) with additional funding, a GPS-linked Argos tag can be developed for the 2004 field season, which would provide one or more precise locations after every long dive (~36/d) for up to about 40 days. Such precision, resulting in directional vectors, could produce useful information for evaluating the responses of whales to seismic surveys in either a controlled-exposure experiment (CEE) or by analyzing seismic vessel operations, which happen to occur in the vicinity of tagged whales. A CEE is the only way to assure that an adequate sample size of such circumstances would be achieved for a definitive analysis of "immediate response".

After discussion of these options at the January 2003 Information Transfer Meeting, it was decided that the S-tag project would continue to emphasize the development of seasonal distribution information, but that supplemental budgets for the dive tag, further winter re-sighting efforts in 2004, analyses of seismic vessel and tagged whales interactions, and GPS tag developments will be supplied to MMS by SWSS management team so that they can chose what route(s) they might wish to pursue.

5.3 Analysis of Sperm Whale Vocalizations from a Towed Passive Acoustic Array

Dr. Aaron Thode, Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla CA 92093

The 2002 SWSS D-tag cruise on the *R/V Gyre* contained an onboard passive acoustics team, comprised of Natascha Aguilar de Soto, Matt Grund, Aaron Thode, and Sarah Tsoflias. The acoustics team had both short-term "tactical" and long-term scientific goals. The tactical goal was to perform real-time monitoring and tracking of sperm-whale sounds, to guide the tagging vessel to areas where tagging could be performed, starting at first daylight. Potential longer-term scientific goals included (1) an analysis of the possible effects of the tagging boat on acoustic contact times for individual whales, and (2) passive 3D acoustic tracking of the animals at close ranges, either via combining acoustic tag data with towed array data, or by deploying two towed arrays simultaneously. The tactical role was performed well, despite equipment failures and limited tracking range due to poor acoustic propagation conditions. Some of the scientific goals were also demonstrated to be achievable in principle.

Herein is contained a brief description of the acoustic system, an analysis of potential correlations between acoustic contact times and presence of tag boat, and a proof-of-concept demonstration of passive range-depth tracking using two arrays, for possible use in extending analysis of tagging effects to baseline behavior.

Acoustic Equipment and Procedures

The acoustics team used two arrays: a three element "WHOI" array with ~150 m of cable terminating in a tow-fish instrumented with a pressure/depth sensor, and a two-element "Ecologic" array with 300 m cable. Both arrays had been previously used on the S-tag cruise. A variety of software was used for the real-time tracking. The primary monitoring tool was Rainbowclick, developed by Doug Gillespie at the International Fund for Animal Welfare (IFAW). When fewer numbers of animals were present, or the acoustic contacts were faint, the program Ishmael, developed by David Mellinger of Oregon State University, proved very useful. In order to record notes and record signals to hard disk, the program Logger 2000 was used, also written by Doug Gillespie of IFAW. Arrays were monitored 24 hours a day, and were deployed during 20 of 25 days at sea. The only time when arrays were out of the water was during long-distance transits, when large distances needed to be covered.

A fundamental performance metric of an acoustic tracking system is the maximum range at which signals of interest (e.g., sperm whales) can be detected above the background noise level. Twice during the cruise experiments were performed to estimate the detection range of the arrays. Results of two separate detection range tests suggested an effective detection range of about 4 km at 4 knot tow speed for both arrays. Acoustic modeling of sound propagation in the region using the normal mode code KRAKEN produced similar detection range estimates, and suggested that deep sensors would have a detection range of around 10 km.

Analysis of Acoustic Contact Times

Tagging an animal is an intrusive process, and it remains unknown to what degree, if any, the effect of either tagging or the attached tag has on fine-scale animal behavior. Ideally, detailed visual and acoustic observations of a single "focal" animal should be made prior to tagging, but establishing a long-term acoustic follow was difficult in the Gulf, due to the large number of animals present at any given time, and the emphasis placed on placing tags as quickly as possible. Instead, the acoustic team investigated two alternative approaches for statistically measuring baseline dive behavior of untagged animals: statistical analysis of acoustic contact times, and the use of three-dimensional passive acoustic tracking to measure descent rates and maximum dive depths.

Figure 5.3.1 shows computed distributions of all daylight acoustic contact times, considered here as a proxy of animal dive times. Contact times have also been broken down into times where the tagging boat was in or out of the water. The wide variance in acoustic contacts, particular the large number of 10 minute and 2 hr+ contacts, is not an accurate measure of the true distribution of animal dive times, for two reasons. First, during a large fraction of the daytime observations the visual observations and tagging operations had control of the ship, so the passive acoustic monitoring was not able to position the vessel to optimize acoustic tracking. As a result acoustic bearings often merged, split, or faded away before the start or end of a dive could be ascertained, biasing the data toward short dive times. Second, Thode made an early decision to focus most monitoring effort during the day, with much more casual monitoring protocols during the evening. In retrospect, this decision was probably a mistake, in that higher quality dive time measurements could have been made in the night, when acoustics had control of the ship motion.

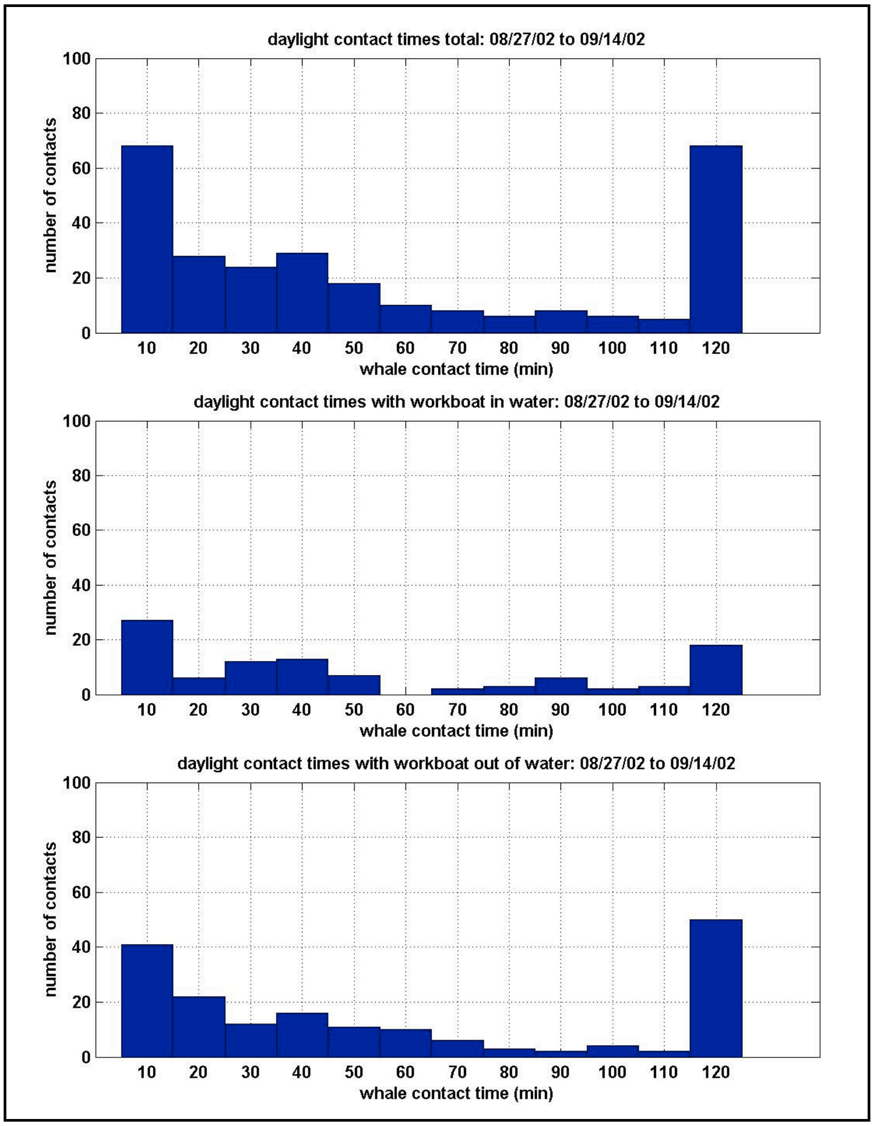
Despite these confounding factors, a distribution of dive times with a center moment between 30-40 min. is visible in the data. The problems with relatively small sample size are starkly visible here in the form of wide histogram bin widths, so it appears that multiple years of data would need to be collected to establish a sufficient sample size to make statistically significant conclusions about potential tagging effects on animal dive time. That said, to within the uncertainty caused by the small sample sizes, there seems to be no obvious difference caused by the deployment of the tagging boat.

Passive Acoustic Range-Depth Tracking for Pre-exposure Studies

Passive acoustic three-dimensional localization of sperm whales provides another possible approach for measuring baseline diving behavior, before exposure to tagging and/or seismic operations. This approach, if successful, could yield behavioral parameters besides total dive time that could be compared with data collected by the tag, including initial dive descent rate, maximum dive depth, and location of an animal during certain acoustic events. In theory only two hydrophones, deployed with a 100-200 m aperture, are needed to make range-depth measurements, by exploiting surface echoes to create a virtual planar array. In order to obtain azimuth a third hydrophone needs to be placed adjacent to one of the other two. The tracking performance would be poor whenever the animals are broadside of the arrays, but much better whenever the animals are directly ahead or behind the ship.

On 5 September 2002, both arrays were deployed to explore whether range-depth localizations could be achieved with the array hardware. Four hours of data were collected for analysis, and the best result over a fifteen minute period between 22:15 and 22:30 is shown in Figure 5.3.2. The red and green tracks were obtained from whales forward of the ship, while the blue track was derived from a whale broadside to the arrays, which yielded an unstable inversion, as is apparent from the figure.

The computed whale depths in Figure 5.3.2, 200 and 300 m, are shallower than what one would expect from standard sperm whale dives, but several tagged animals dove to similar depths during a similar time period. More convincing, the descent rates of the animals obtained from the depth subplot are 91 and 96 meters per minute, respectively. A tag deployed on an animal from the same group the following morning (249a) had descent rates of 88 and 79 meters per minute for the two dives recorded. Thus the passive acoustic trajectory estimates are consistent with tag measurements, and the feasibility test seems successful. The key to the success of the technique is a wide separation between the two arrays, and a quiet ship, so that the whales' baseline behavior is not disturbed by platform noise. Both conditions were not quite met during the present cruise, but if appropriate equipment is available in the future, passive three-D tracking may provide additional pre-exposure data on the baseline behavior of tagged and untagged sperm whales.


daylight contact times total: 08/27/02 to 09/14/02

daylight contact times with workboat in water: 08/27/02 to 09/14/02

daylight contact times with workboat out of water: 08/27/02 to 09/14/02

Figure 5.3.1. Distribution of acoustic contact times, broken down into times measured with or without a tagging workboat present in the water during daylight hours. The large numbers of extremely short and extremely long dive times are artifacts of the operational and logging protocols.

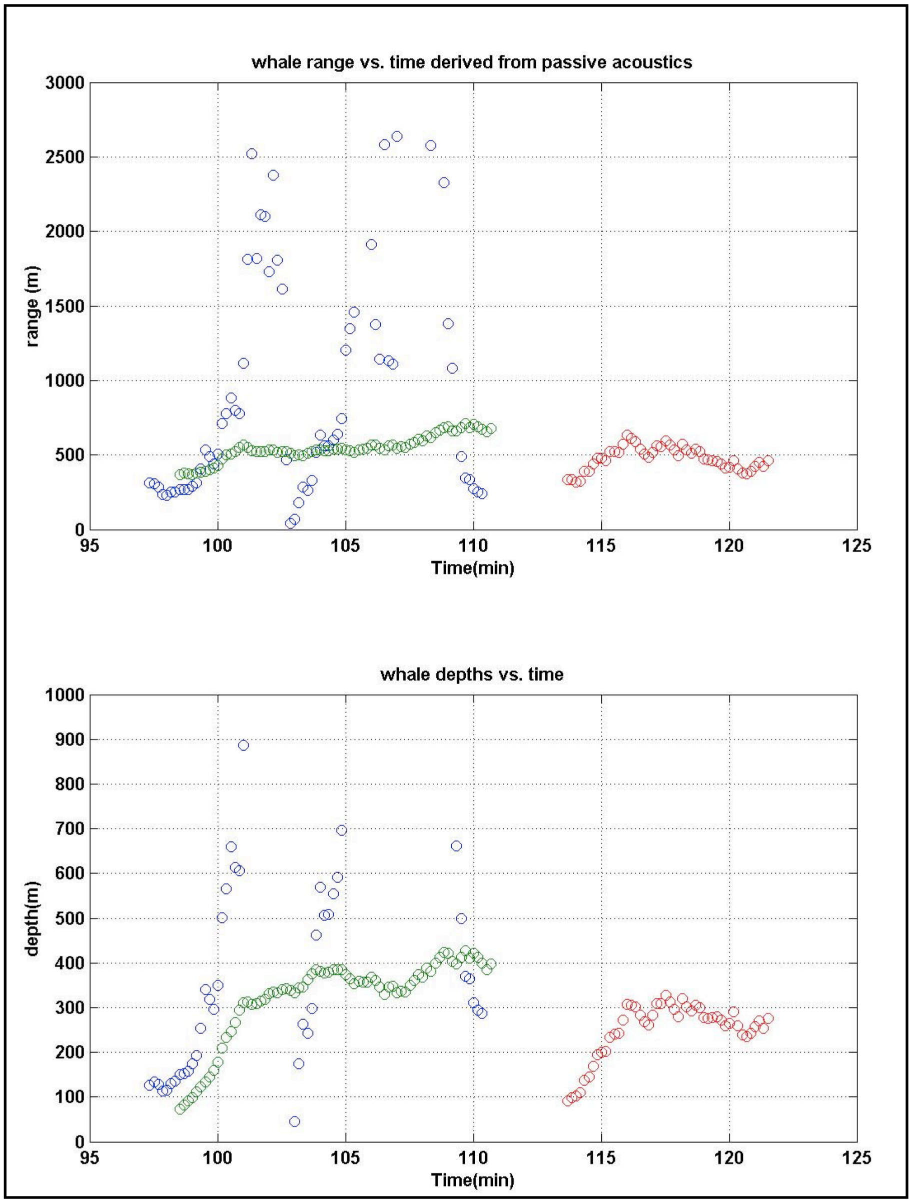


Figure 5.3.2. Derived ranges and depths of three whales using a two-array passive acoustic localization algorithm. The green and red trajectories are derived from whales forward or behind the ship, while the blue trajectory was from a whale broadside to the two arrays, a situation that makes the inversion unstable.

5.4 Synopsis of Diving Behavior of D-tagged Sperm Whales

Dr. Patrick Miller, Dr. Peter Tyack and Dr. Mark Johnson, Woods Hole Oceanographic Institution, Woods Hole, MA 02543

The Digital Acoustic Recording tag (D-tag) was developed to enable controlled exposure experiments for deep divers. It was designed to

1. Track responses of marine mammals, especially deep divers, throughout their dives
2. Improve understanding of functions and costs of behaviors in order to infer biological significance of behavioral disruption
3. Develop a dose:response technique to measure received level of stimulus at whale while also measuring behavioral and physiological responses.

This presentation addresses points #1 and 2, while the presentation in Section 5.7 focuses on point #3.

The scientific literature regarding the effects of airgun sounds on sperm whales is limited, and largely consists of anecdotal observations suggesting that animals silence or move away from survey vessels. Such naturalistic observations are potentially biased and provide little information to understand the biological significance of observed reactions. Experimental exposure of animals to carefully controlled sounds, while recording the response of the whale on a state-of-the-art digital recording tag (D-tag), offers the potential to: 1) observe even subtle responses by whales to noise; 2) evaluate the effect of the noise level on the likelihood of disturbance; and 3) infer the biological significance of disturbance reactions.

In our 2003 ITM presentation, we combined findings from SWSS 2002 and previous sperm whale tagging cruises to describe the diving behavior of sperm whales. During SWSS 2002, we tagged a total of 19 sperm whales with the suction-cup attached D-tag, and recorded at least one deep dive from 14 whales. On-animal recording time totaled 76 hours or more than 13 Gigabytes of data recording animal movement and sounds heard and produced by the whale.

The rich acoustic data-set recorded by D-tag includes natural and man-made sounds including seismics with received levels up to 143 dB re 1 μPa. Natural sounds include: codas, that often lead to physical contact between whales; regular clicks, that produce audible echoes from the sea-surface and sea-floor; and rapid-series clicks called "creaks" that appear to mark prey-capture events. Echoes from the seafloor can be used to identify different foraging modes, "open-water" and "bottom" foraging. Previous work during SWAMP 2001 suggested that animals might specialize in one foraging strategy. Bottom-foraging was exclusively observed in one animal "Deep-Dan" tagged in DeSoto Canyon. The data from SWSS 2002, however, showed a significant number of animals employing a mixed feeding strategy. These animals combined open-water and bottom foraging in the same dive, suggesting flexibility in hunting techniques and prey choice. We suggest that the whales make use of echoes to orient to the sea-bottom, and also to the sea surface.

With the addition of 14 deep-diving animals recorded during SWSS 2002, we have found greater diversity in swimming patterns during descent and ascent. The most common pattern is limited gliding (<10%) during descent, and extensive gliding (>40%) during ascent. Certain whales, however, made prolonged ascent glides of over 350m in length after steady fluking during descent. Others glided extensively during descent, but fluked steadily on the ascent. Based on our model of animal drag, air-buoyancy, and tissue buoyancy forces acting on gliding sperm whales, we suggest these different fluking patterns result from differences in tissue buoyancy. The most likely explanation is that these swimming patterns reflect differences in fat stores carried by the tagged whales. Our model of forces acting on sperm whales is useful to explain these swimming behaviors and provides a quantitative index of the effort expended by animals to forage at depth.

Data from SWSS 2002 also confirms our earlier finding that rapid-series "creaks" occur at outlier points on the depth record during deep dives. Also, animal movement roughly doubles at the end of creaks. This pattern of behavior supports the hypothesis that creaks mark the capture phase of foraging. While every capture event may not be successful, creak-rates over whole dives are likely to correlate with feeding by the whale. Thus, we propose to use creak-rates as a measure of feeding disruption during controlled exposure experiments.

The SWSS 2002 data set is rich in social "coda" sounds, and the coda exchanges commonly result in approach and physical contact between whales. We were able to conduct one successful trial of a coda playback in SWSS 2002. The tag recorded the unfamiliar Mediterranean coda as the whale ascended after a 40-minute dive. The tagged whale and other nearby whales produced extensive codas during the subsequent surfacing. More replicates of these playbacks are needed to experimentally explore how sperm whales use codas in communication and how noise might affect this type of communication.

A significant breakthrough in SWSS 2002 was the first simultaneous tagging of multiple sperm whales with D-tags. Our primary motivation for tagging multiple animals is to increase the chance that a tag will stay on a whale for sufficient time to conduct a controlled-exposure experiment (roughly 5 hours). Based on longevities of 40 tag deployments, 50% of tags that stay on for an hour remain attached for 5 hours or more. Thus it is critical to attempt to tag multiple animals prior to conducting a controlled exposure experiment.

Simultaneous tagging of multiple animals also has revealed a promising new technique to study social coordination and communication in sperm whales. Measure of dive synchrony, underwater spacing, and acoustic exchanges enable a much more powerful study of natural social behavior in sperm whales. This knowledge will help us to understand the biological consequences of disturbance by noise sources.

5.5 Molecular Ecology of Sperm Whales (*Physeter macrocephalus*) in the Northern Gulf of Mexico

Dan Engelhaupt, University of Durham, Dept. of Biological Sciences, Durham, England

Background

Several fundamental genetic related aspects for endangered sperm whales occurring in the northern Gulf of Mexico were assessed during the 2000-2002 SWAMP and SWSS cruises. A deeper understanding of the population structure and social structure of sperm whales using genetic techniques is presently being integrated with a variety of ongoing research projects such as digital acoustic recording tagging (D-tag), satellite-monitored radio tagging, distribution and abundance estimates, habitat use patterns, and behavioral information to help establish realistic conservation and management strategies for these whales. In addition to providing important gender information for whales that have been satellite and D-tag tagged, our project provides essential data on social and population structure required to fully assess the impacts that the oil and gas industry and seismic exploration may or may not have on endangered sperm whales occupying potentially critical habitat areas in the northern Gulf. Sperm whales are highly social whales that occur in small clusters to large aggregations, in many cases, maintaining long-term bonds between female group members. Their dependence on acoustic communication between members and use of echolocation when feeding at depth make them vulnerable to anthropogenic noise. Could an outside noise influence disturb the dynamics of the group, or on a much larger scale, the population over time? The quantity and quality of knowledge gained from the combination of genetic (via degrees of relatedness among associates), satellite-monitored radio tagging, and behavioral studies provides the essential components to accurately describe social structure on a detailed scale. The original designation of a single Gulf sperm whale stock that is separate from the adjacent Atlantic and Caribbean is thought to be conservative. Stocks must be defined using several parameters including genetics. Once stocks are defined, human-caused disturbances or mortalities that occur to a stock can be managed appropriately. Such information is vital for creating meaningful management strategies for these animals in general, and relative to petroleum exploration and production in particular.

SWAMP and SWSS Cruise Sample Analyses

Tissue samples were collected during both SWAMP and SWSS cruises throughout 2000, 2001 and 2002. Overall, eighty-nine individuals (including satellite-tagged, D-tag tagged, opportunistic, and stranded whales) were genotyped using both mtDNA and microsatellite techniques. Gender was determined for nearly all of these samples using molecular sexing techniques.

Population Structure and Male-Mediated Paternal Gene Flow: A comparative analysis of matrilineal mtDNA and biparentally inherited nuclear genetic markers (microsatellites) have begun to show population structure for female lineages, which is expected given previous findings on social and reproductive behavior in this species. Nuclear DNA variation across oceans appears non-significant suggesting males disperse and spread their genes to the more site-faithful females. Of particular interest are four individuals located within three separate geographic regions (the Gulf of Mexico (N=2), Mediterranean Sea (N=1), and the North Sea (N=1)) that appear to be paternally related at the level of half-siblings. This trans-oceanic paternal gene flow concept provides genetic evidence that sexually mature males may be ranging over 12,000 km to breed with females from multiple geographic populations.

Group Structure: Members of 'groups' were predominately females, although some groups appeared to contain only males, suggesting that bachelor groups may reside in the Gulf. During the 2002 SWSS cruise, multiple members from two groups of whales (Group 3 and 5) were tagged with satellite transmitters and subsequently biopsy sampled for genetic analyses. Relatedness levels for each satellite-tagged group (and groups in general) suggest that the overall group is often unrelated, although groups did contain related whales. Analyses of mtDNA showed that groups are comprised of both single and multiple matrilines, which combined with the relatedness levels, may provide additional evidence to the idea of 'constant companions and casual acquaintances' among sperm whale groups.

Future Goals for 2003

Genetic techniques supply a powerful set of detailed data that can be directly integrated with both the movements of satellite tagged whales and the dive profile data of D-tagged whales. The gender of a tagged whale may prove crucial to better our understanding of movement patterns and dive profile data (i.e., do males and females react differently to anthropogenic noise influences?). Simple modifications are underway to provide a skin sample from all whales tagged with D-tags which will significantly increase our dataset with very minimal additional effort or cost. Future work will continue to build on previous year's population and social structure results by incorporating biopsy sampling with both satellite-tagging and opportunistic sampling of whales, particularly focusing on whales of sexually mature size. This population has already been subjected to many years of human activity and there is likely to be major oil-related activity offshore here for many years to come. Social organization is an important component for sperm whale survival yet seems vulnerable to disruption by disturbance. Understanding sperm whale social organization in this putative population before it is exposed to any more disturbance, and exploring whether it is affected by offshore activity is thus a priority. To increase the resolution for population structure and trans-oceanic gene flow analyses, we recommend sampling sperm whales located in additional geographic areas. A continuation of the genetic components previously described will maintain both the quality and quantity of information required for management purposes.

5.6 Ship and Satellite Studies of Sperm Whale Habitat

Dr. Douglas C. Biggs, Dr. Matthew K. Howard, Dr. Ann E. Jochens, Dr. Steven F. DiMarco, Department of Oceanography, Texas A&M University, College Station TX 77843
Dr. Robert R. Leben, Colorado Center for Astrodynamics Research, University of Colorado, Boulder CO 80309
Dr. Chuanmin Hu, College of Marine Science, University of South Florida, St Petersburg FL 33701

To characterize the physical and biological environmental patterns where sperm whales were encountered along the continental margin of the northern Gulf of Mexico in summer 2002, hydrographic data from two cruises of *R/V Gyre* were combined with remote sensing of sea surface height (SSH) using the TOPEX/POSEIDON and ERS-2 satellite altimeters and of ocean color mapped by the SeaWiFS satellite. Texas A&M University oceanographers are responsible for the hydrographic data collection and for the overall program management that is in place among the several universities that are cooperating on the Sperm Whale Seismic Study (SWSS). We collected a standard suite of oceanographic data, and also measured *in vivo* chlorophyll fluorescence to estimate phytoplankton standing stocks. Our co-authors from the University of Colorado and the University of South Florida provided weekly averages of sea surface height and ocean color from January 2002 through September 2002 and daily satellite fields for the June-July and August-September SWSS fieldwork periods when *R/V Gyre* was at sea. In this summary, we first provide some background on the remote sensing measurements, circulation features in the northern Gulf of Mexico, and factors influencing the biological productivity, and then we discuss the data collected and some preliminary results.

Satellite altimeters are radars that measure the satellite height above the ocean. Because the satellite orbit is known with high precision, these radar measurements are used to calculate the fine structure of the sea surface. Thus, how high or low a particular region is relative to long-term average sea surface height can be determined. These sea surface heights, in turn, provide information on the currents and circulation. Variations in ocean color, which in deepwater come mostly from chlorophyll-containing plant (phyto) plankton, give information about the time rate of change of food stocks at the base of the oceanic food chain.

The Loop Current is a main driving force for circulation in the deepwater Gulf of Mexico. This current enters the semi-enclosed Gulf basin through the Yucatan Channel, turns anticyclonically, and exits through the Straits of Florida. This energetic current episodically sheds large warm-core anticyclonic eddies that are 200-400 km in diameter. When they interact with the continental margin, these anticyclones may spin down, shed filaments to form smaller-scale warm slope eddies, or shed counter-rotating cold slope eddies. As they interact with the continental margin, the anticyclones can spin up cyclones. The cyclones can be distinguished from the anticyclones by measuring the depth of their 15°C isotherm. In cyclones, this isotherm domes upward and nutrient-rich mid-depth water is domed close to the surface. This nutrient-rich water has been shown to increase primary productivity in the mixed layer and to support increased zooplankton and micronekton biomass, making the interiors of cyclones biological "oases". In contrast, surface water downwells in anticyclones, so the interior regions are nutrient-poor biological "deserts".

SWSS Leg One: R/V Gyre cruise 02G08 (SWSS Leg One) surveyed for sperm whales along the middle continental slope of the north central Gulf of Mexico from 94.7°W to 86.4°W. The cruise departed Galveston, TX, on 19 June 2002, and concluded in Gulfport, MS, on 9 July 2002. From 20 June through 8 July, five CTD stations were made, thirty-five T7 XBTs were dropped to profile temperature in the upper 760 m, and seven supplemental drops were made with T10 XBTs to collect additional data from the upper 200 m (Figure 3.1.1). Ocean current velocity was logged every five minutes from two hull-mounted acoustic Doppler current profilers (ADCPs).

Near-surface water was pumped from the ship's hull depth of 3.5 m through SeaBird temperature and conductivity sensors and a Turner Designs Model 10 fluorometer to log surface temperature, salinity, and chlorophyll fluorescence once per minute. Although the ship track was centered on water depths of 900-1000 m, the SWSS Leg One survey generally followed a zig-zag course between water depths from 575-820 m (zigs upslope) to 1125-1430 m (zags downslope).

During daylight, when the whales were visible to visual observers, they were seen mostly in 7 locations, as groups of 5 to more than 13 animals (Figure 3.1.2). These groups were not encountered randomly in time or space, but instead most were heard or seen when the ship was between 89.9°W and 87.1°W. Most of the contacts with whales were in water depths of 900-1000 m, although some whales were heard or seen in water depths both shallower (to 700 m) and deeper (to 1300 m).

At the start of Leg One, there was a gradient of increasing SSH from north to south along most of the margin (Figure 3.1.5). Because water flows downhill, the SSH indicated that the currents would flow mostly west to east, or southwest to northeast. Thus, currents would run along margin or from off-margin to on-margin.

The first week of Leg One, *Gyre* surveyed between 94.75°W to 88°W. This survey confirmed flow was along margin or on-margin almost everywhere from 94°W to 90°W. The second week, *Gyre* worked east from 90°W to the eastern side of DeSoto Canyon, and also made a quick run to Gulfport. The survey again found flow was mostly on-margin, except at one location just east of 89°W where Mississippi River outflow was encountered out on the 1000-m isobath, and another near 87°W where off-margin confluence flow set up along the eastern side of the clockwise-circulating warm slope eddy over DeSoto Canyon. The third week, whales were studied from 88°W back towards Mississippi Canyon before the cruise ended in Gulfport on 9 July.

The ADCP record shows that currents generally ran directly on to or along the margin, tracking anticyclonically around the northern edge of the warm-slope eddy seen in the SSH field between 92-89°W (Figure 5.6.1). Although the Leg One cruise track did not extend south far enough to reach the center of that warm slope eddy, the 15°C depths were documented by XBT drops to be more than 270 m at the deeper (southernmost) zags downslope from the 1000-m isobath. The 15°C depths confirms the ship penetrated into the northern edge of the warm slope eddy with 15°C depths > 250 m.

Our colleagues at Oregon State University are determining the frequency with which whales they radio tagged in the northern part of the warm slope eddy ranged seaward from the 900-1000 m isobath into eddy interior, and into the deepwater regions of cyclonic circulation to the east and southeast of this anticyclone. Most places where whales were seen in June and July were high salinity blue water rather than low salinity green water environments. Specifically, surface salinity was generally > 36 between 94°W and 89°W, and in most of the region from 89°W to 86.5°W surface salinity was generally > 34.

Along-track *in vivo* fluorescence indicated there were only in 3 places along the mid-slope that were biological 'hot spots' of chlorophyll > 1 μg/L documented locally. Figure 5.6.2 shows the property-property relationship of *in vivo* fluorescence (left-hand y-axis) as a function of salinity (x-axis). The corresponding chlorophyll concentrations are shown on the right hand y-axis. The first order, straight line relationship indicates that the higher chlorophyll in low salinity water, which originates inshore and gets transported out to the 1000-m isobath, is simply diluted when it mixed with the more saline oceanic water. This straight-line relationship is typical of the classical, conservative mixing diagram. Simply put, there is no further biological production when this low salinity water gets transported offshore; the chlorophyll it contains is merely diluted.

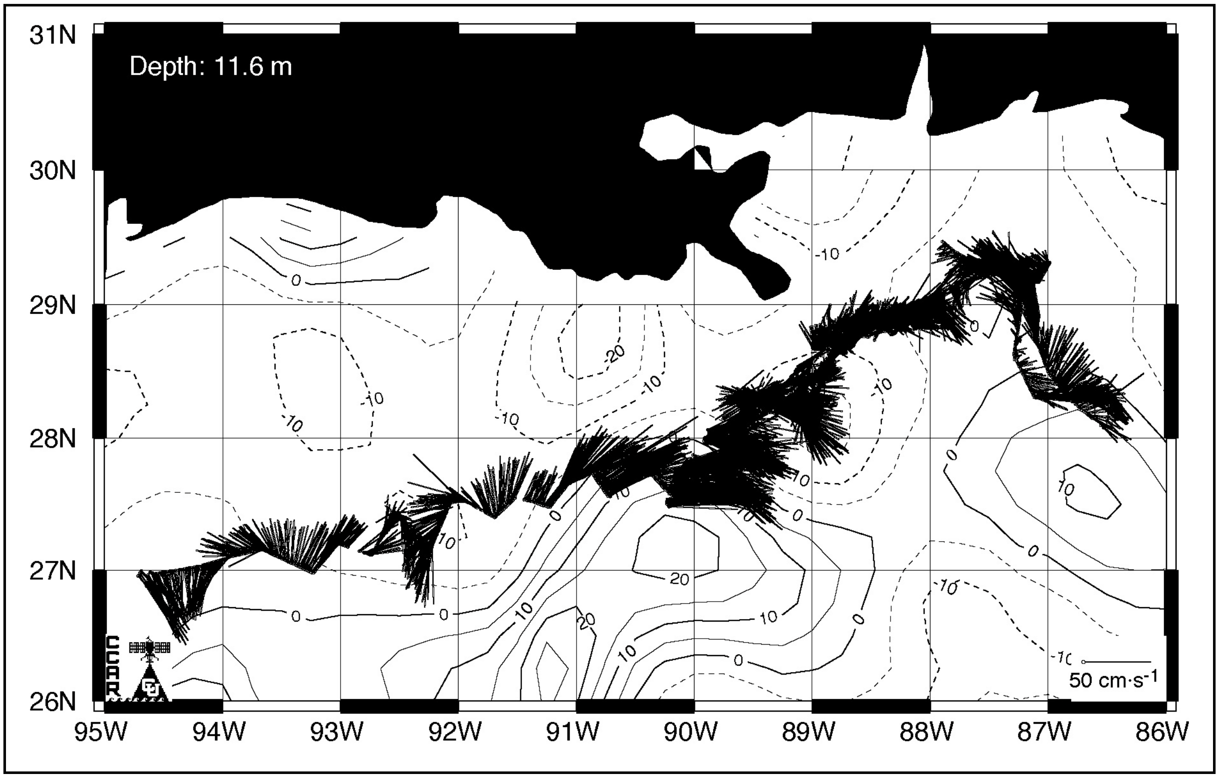


Figure 5.6.1. Caterpillar plot of currents, measured during 2002 SWSS Leg One by the ship's 153-kHz ADCP, superimposed on the composite map of sea surface height anomaly (cm) for 3 July 2003. SSH was determined from remote sensing by altimeters in earth orbit for the ten day period 24 June – 3 July 2002.

In contrast, biological hot spots show up as deviations from the straight-line mixing line. They show more chlorophyll than would be predicted from simple mixing alone. Near 89°W, where Mississippi River water was encountered out on the 1000-m isobath, this water contained far more chlorophyll than the "typical" margin water. Note though, that this Mississippi River water shows no further biological production when it is transported offshore; the high chlorophyll it contains also is merely diluted with oceanic water.

At two other locations, near 88°W and 87°W, there also was enhanced biological production. In these locations, there is *more* chlorophyll than would be predicted on the basis of *simple dilution* mixing of shelf water with oceanic water. These are locations in which "new" nutrients must have been introduced to stimulate local growth of additional chlorophyll in deep water.

The three "hot spots" of locally high chlorophyll along the 1000-m isobath thus mark locations of nutrient addition. At 89°W the source is the Mississippi River. At 88°W and 87°W the source is apparently the "new" nutrients being mixed upwards by locally enhanced vertical mixing along salinity fronts, tidal fronts, or other high shear environments. We stress, though, that such "hot spots" of locally high chlorophyll were the exception, rather than the rule, during Leg One. In contrast, hot spots of chlorophyll > 1 μg/L were the *rule* rather than the exception for Leg Two.

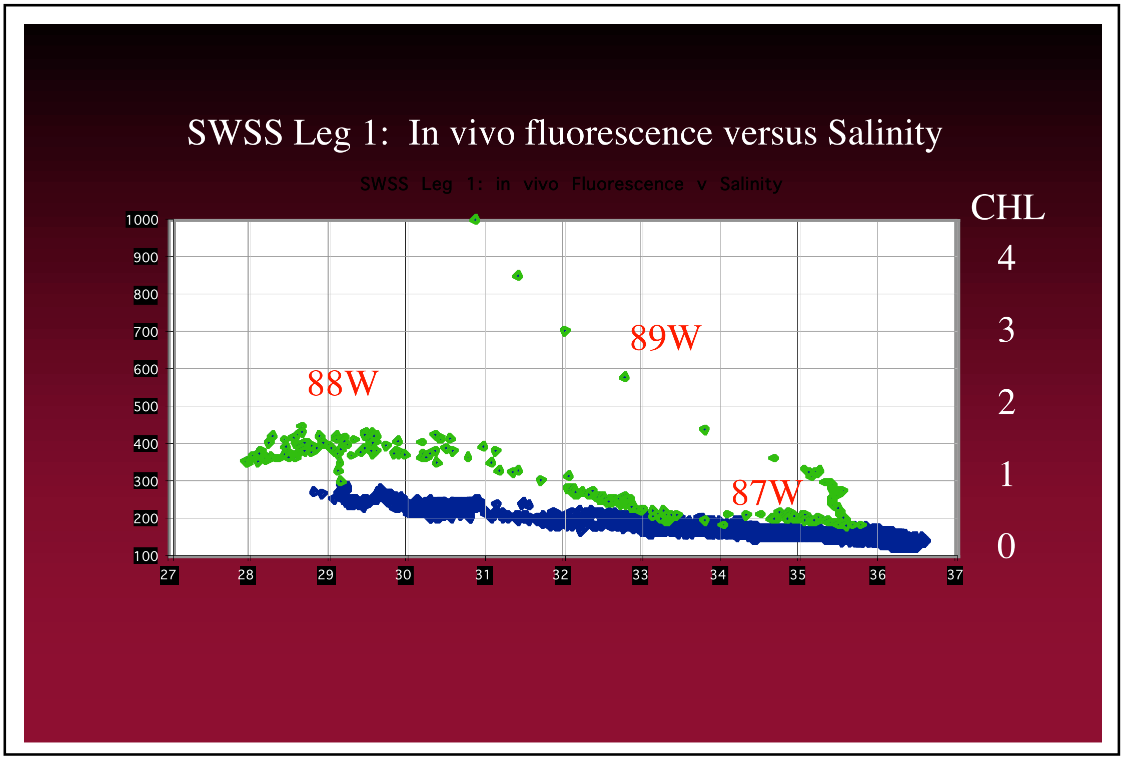


Figure 5.6.2. Property-property plot of *in vivo* fluorescence versus salinity for SWSS 2002 Leg One, S-tag cruise. Note the fluorescence in "hot spots" of anomalously high chlorophyll plots above the straight line mixing curve.

SWSS Leg Two: R/V Gyre cruise 02G11 (SWSS Leg Two) departed Galveston, TX, on 20 August 2002 and returned to Galveston again on 16 September 2002. Eight CTD stations were made and thirty-eight T7 XBTs were dropped to profile temperature in the upper 760 m (Figure 3.2.14). For most of the cruise the ship worked a geographically limited area of the middle continental slope between 90°W and 88°W, in and around the Mississippi Canyon to the head of DeSoto Canyon (Figure 3.2.1). Water was again pumped to temperature, salinity, and chlorophyll fluorescence sensors in the main lab, but during Leg Two the ship's ADCPs were run only during transits into and away from the principal operations areas.

During Leg Two, low salinity green water was found along a much greater area of the middle continental slope than on Leg One. Only west of 91°W, where salinity was generally > 32, are property-property plots of *in vivo* chlorophyll fluorescence versus salinity generally similar to the straight-line dilution curves typical of Leg One (Figures 5.6.3 and 5.6.4). All that changes east of 91°W. From 26 August on, property-property plots show multiple sources of high-chlorophyll water. Property-property plots of *in vivo* chlorophyll fluorescence versus salinity were mostly non-linear, with "hot spots" of chlorophyll > 1 μg/L along the middle continental slope in a wide range of surface salinity (27-34). These surface hot spots occurred over water depths of 700 m to 1000 m throughout most of the region from 91°W to 88°W, as "new" deepwater primary production was enhanced in salinity fronts. Most of the sperm whales seen during Leg Two were in green water environments. In these green water environments, more than two animals at a time were frequently heard by the acoustics team.

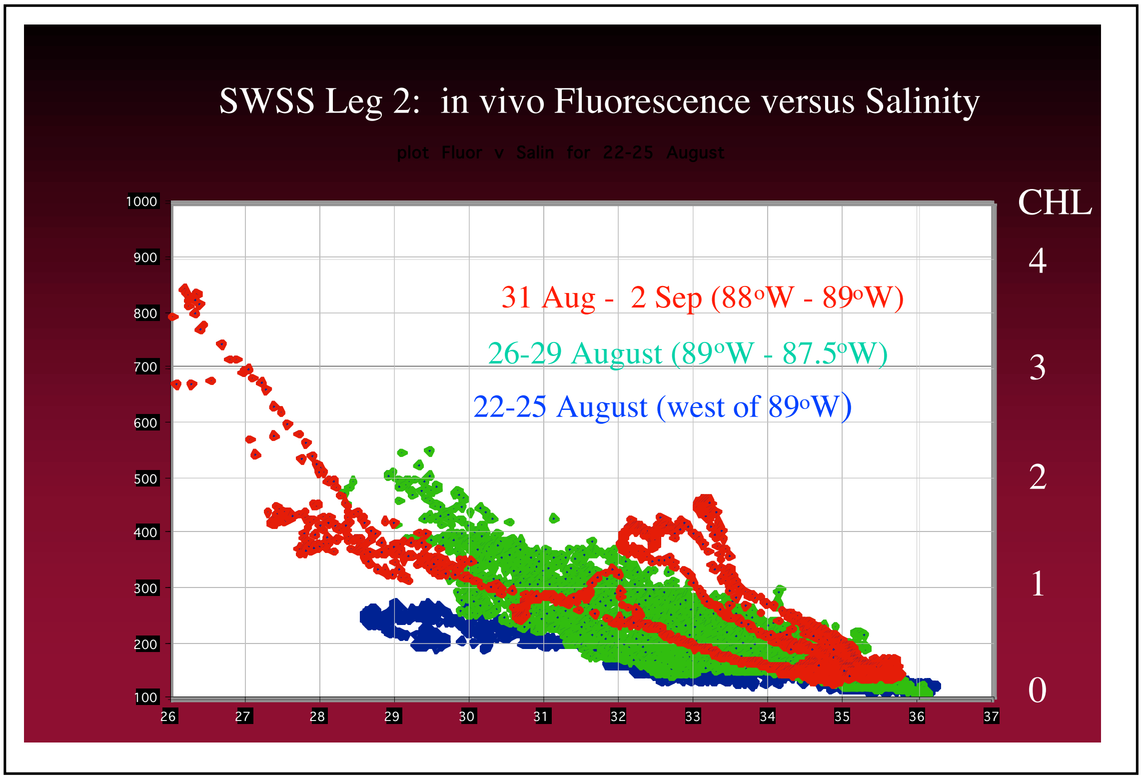


Figure 5.6.3. Property-property plot of *in vivo* fluorescence versus salinity for SWSS 2002 Leg Two during 22 August through 2 September 2002. Note that fluorescence is above the straight-line mixing curve for most of the data collected after 26 August (east of 89°W).

The range of physical processes that create and maintain such surface hot spots of chlorophyll in the Gulf of Mexico are becoming better understood (Walsh *et al*., 1989; Muller-Karger *et al*., 1991; Wiseman and Sturges, 1999; Biggs and Ressler, 2001). However, because sperm whales eat squid and they forage for squid at depth rather than at the surface, it is unlikely these apex carnivores respond immediately or directly to surface salinity, surface chlorophyll, or other surface conditions. Thus, encounters with sperm whales may show only limited correlation with "snapshot" surface conditions during individual cruises. On the other hand, sperm whales do appear to aggregate in deepwater areas of the Gulf of Mexico where time-averaged planktonic productivity has been greater than usual for time-scales of weeks to months (Biggs *et al*., 2000). Finding the location of such areas, which may be spatially variable while being temporally persistent, is best accomplished by remote sensing using a combination of altimetry and ocean color.

The SSH anomaly data show a gradient of increasing SSH from north to south (from shelf to slope) over most of the north central Gulf of Mexico for most of the first four months of 2002. This is evident in animations of the near-real-time data as a temporally persistent although spatially variable region of negative-to-positive sea surface height anomaly. In the negative SSH part of this gradient, which usually includes the 800-m to 1000-m isobaths, the doming of nutrient-rich mid-water close to the surface favors enhanced planktonic new production along

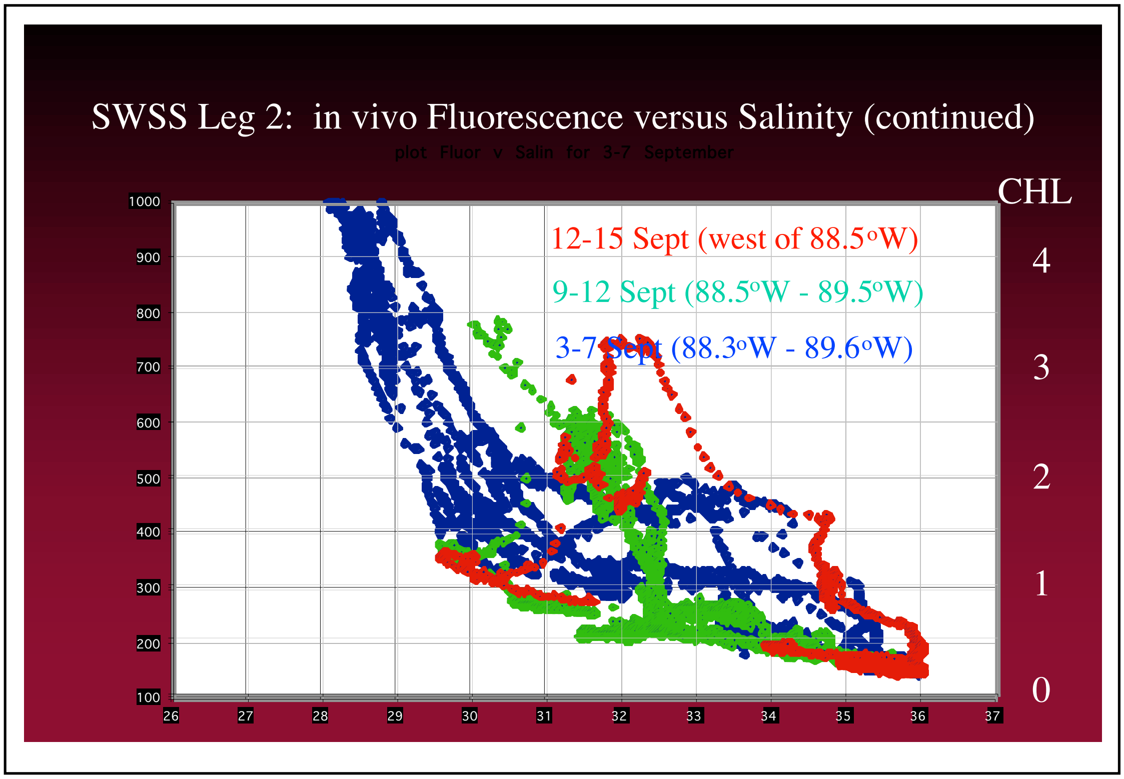


Figure 5.6.4. Property-property plot of *in vivo* fluorescence versus salinity for SWSS 2002 Leg Two during 3-15 September 2002. Note that fluorescence is above the straight-line mixing curve for most of the data collected east of 88.5°W.

this continental margin. In March 2002, the Loop Current shed a Loop Current Eddy (LCE) and in April 2002, this LCE in turn shed a warm filament that extended north into the DeSoto Canyon. By May 2002, this warm filament had consolidated into a warm slope eddy (WSE), the inshore edge of which reached the Mississippi Canyon region south of the Mississippi River delta. The SeaWiFS ocean color imagery shows that the anticyclonic circulation around this WSE pulled green water offshore into the eastern part of the SWSS field area, and that by late May to early June 2002, this off-margin flow was best developed east of 88°W.

By mid-June, the gradient of increasing SSH over the slope from 94°W to 88°W indicates west to east flow along most of the 1000-m isobath, but off margin flow west of 94°W and east of 88°W. Leg One XBT, CTD, and ADCP data confirmed that off-margin flow was present in both of these areas. However, subsequent SSH altimetry maps indicate that what on Leg One had been large-scale anticyclonic circulation in deepwater south of 27°N had between early July and mid August 2002 broken up into several much smaller anticyclonic eddies. By mid-August, these minor eddies were distributed pretty much all along the continental margin of the north central Gulf. By combining altimetry with ocean color, it can be seen that a pair of WSEs south of Mississippi Canyon and in DeSoto Canyon were entraining green water from the shelf and transporting this off margin (e.g., see Figures 3.2.17 and 3.2.18).

SWSS Leg Two confirmed that off-margin flow of low salinity green water was present in most of the region from 90°W to 88°W and also documented locally high chlorophyll in a "bulls-eye" of high ocean color visible in SeaWiFS imagery in deepwater southeast of Mississippi Canyon (Figure 3.2.19). The radio-tag location data that were reported by Dr. Bruce Mate in the morning session of the 15 January ITM 2003 showed that one of the sperm whales he tagged during Leg One had moved out into this deepwater hot spot of chlorophyll by August and that it stayed in or near this hot spot for 2-3 weeks. However, most of the other radio-tagged whales remained either in the green water between 91°W to 88°W along the 1000-m isobath or ranged west to the Texas continental margin.

Summary: Cyclonic and anticyclonic eddies contribute biological and physical heterogeneity along the continental margin of the northern Gulf of Mexico. Temporal and spatial variations in the geometry of the eddy field along the 800- to 1000-m isobaths determine whether low salinity green water flows off margin or high salinity blue water flows on margin. Green water is biologically rich and will support more food for the squid upon which sperm whales prey. Locally high chlorophyll also can develop when or where nutrient-rich water domes upward in cyclonic eddies. Cyclonic eddies and other nutrient-rich features that persist for 3-4 months in time may be important feeding grounds for sperm whales along the Gulf of Mexico continental slope.

[Note: TAMU and CCAR support came from MMS-TAMU cooperative agreement 1435-01-02-CA-85186. USF support came from OCS studies 98-0060, 99-0051, and 99-0054, and from NASA contracts NAS5-97128 and NAG5-10738. SeaWiFS data are the property of Orbimage Corporation and data use here is in accordance with the SeaWiFS Research Data Use Terms and Conditions Agreement of the SeaWiFS project.]

5.7 Tracking Responses of Sperm Whales to Experimental Exposures of Airguns

Dr. Peter Tyack, Dr. Mark Johnson, and Dr. Patrick Miller, Woods Hole Oceanographic Institution, Woods Hole, MA 02543

This section picks up after Section 5.4 that summarized information on the Digital Acoustic Recording tag, which was developed to enable controlled exposure experiments for deep divers. To review, the D-tag was designed to

1. Track responses of marine mammals, especially deep divers, throughout their dives
2. Improve understanding of functions and costs of behaviors in order to infer biological significance of behavioral disruption
3. Develop dose:response technique to measure received level of stimulus at whale while also measuring behavioral and physiological responses

The SWAMP cruises demonstrated our ability to track details of behavior of tagged deep divers. We focus here on item #2 to select specific measures for behavioral disruption. These are

- Avoidance
- Evaluation of energetic costs and benefits of foraging dives -- critical for growth
  – Benefit of dive: successful foraging runs
  – Cost of dive: Measure drag, calculate work done by flukebeats
- Social disruption: response to coda contact, masking of codas

During the SWSS cruise, we were able to conduct two controlled exposure experiments to study the responses of tagged sperm whales to sounds of an airgun array.

Figure 5.7.1 shows a map of the first experiment on 10 September 2002. The red dots on the *Gyre* track mark the location of the ship when visual observers spotted the tagged whale at the location of the red dots to the left of the *Gyre* track. The next surfacing is marked with blue dots, and the third with green. The track of the source vessel is indicated on the lower left, with colors indicating the number of airguns that were firing.

The tag was able to record the sounds of these airgun signals, and this showed different spectra for airgun pulses recorded at different depths. As seen in Figure 5.7.2, the airgun signature from the shallow, 20-m depth has much stronger high frequency components than the same airgun array recorded at a depth of 600 m. We developed a MATLAB tool to estimate the received level of these pulses. Figure 5.7.3 shows the received level analysis for an airgun impulse recorded at 600 m depth and 10 nautical miles from the array. This pulse was logged as having a received level of 143 decibels.

The primary analysis we conducted to test for responses of this sperm whale to these airgun pulses was to tally the rate of creaks, which the Section 5.4 presentation describes as a proxy for feeding events. Thus, creak rates should indicate foraging success of the tagged whale. Figure 5.7.4 shows the dive pattern of this whale, along with creak rates, before, during, and after exposure to the airgun impulses. During the pre-exposure dive, the whale made 10.6 creaks/hour, during exposure, 16.4 and during the post exposure interval, 13.7.

The second controlled exposure experiment was conducted on 11 September 2002 with three whales each of which was simultaneously carrying a D-tag. These whales were so close together that the map plotting their movements shows just one track. In Figure 5.7.5, the source vessel is indicated in the upper left, the *Gyre* track is indicated by the long black line, and the pseudotrack of the tagged whales is indicated by the colored line starting to the left, crossing, and then

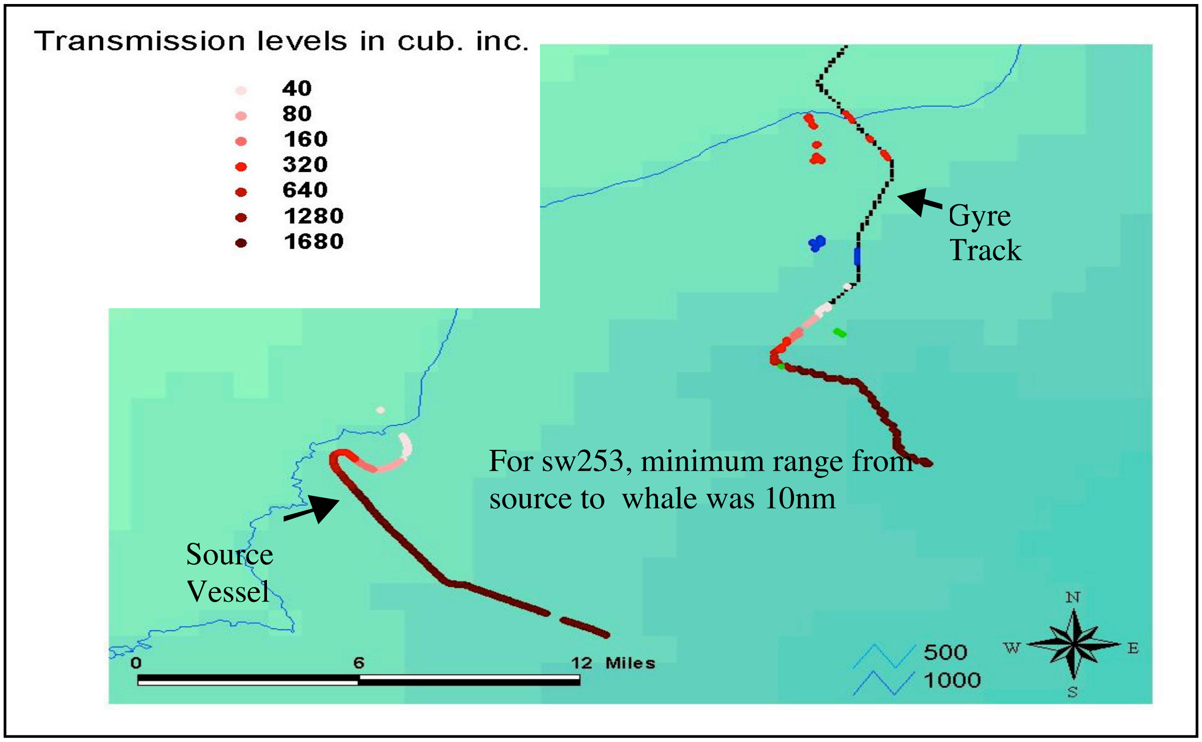


Figure 5.7.1. Track of vessels and sound transmission levels for the controlled exposure experiment conducted on 10 September 2002.

finishing to the right of the *Gyre* track. The seismic vessel more or less paralleled the tagged whales. Its closest point of approach was 4.5 nautical miles, at which time the whales were exposed to a maximum received level of 148 dB. There is no indication that the whales showed horizontal avoidance of the seismic vessel. Figure 5.7.6 shows the dive profiles and creak rates of all three tagged whales during this experiment. We can summarize the variation in creak rates before, during, and after exposure as shown in Figure 5.7.7. If we compare the difference in creak rates before versus during exposure to 143-148 dB, there is no indication of a change in creak rate (see Figure 5.7.8). However, this apparent lack of reaction comes with the caveat that it represents a small sample size, especially when one considers that the three whales tagged at the same time may not represent independent samples. This presentation should be taken as an example with pilot data of our experimental approach. The top priority for the next field season will be to increase the sample size, especially at higher exposure levels.

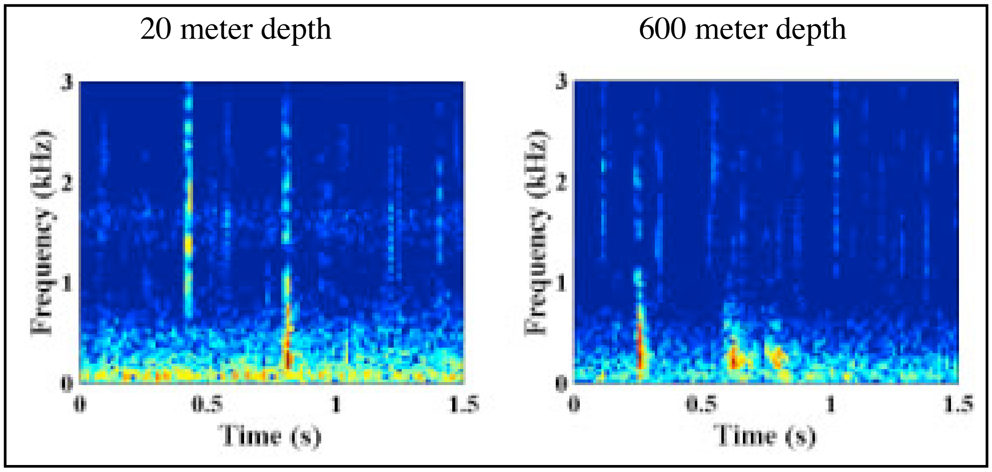


Figure 5.7.2. Example of spectra for airgun pulses from CEE conducted 10 September 2002.

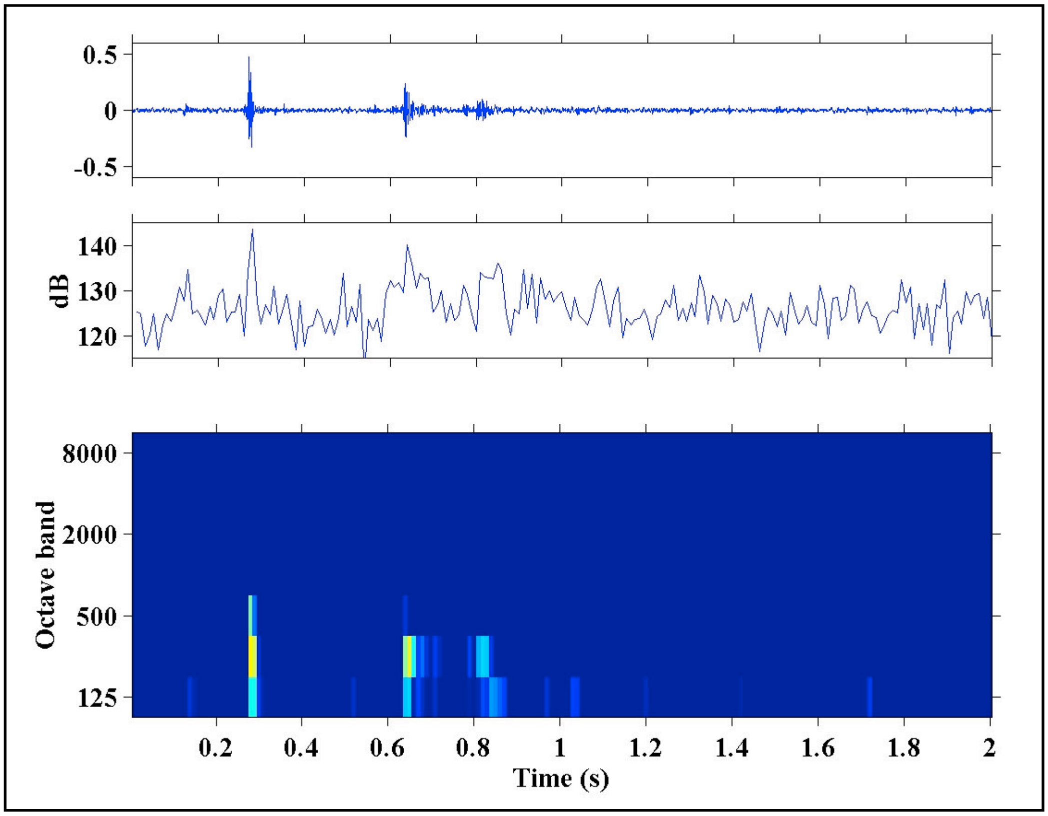


Figure 5.7.3. Received level analysis for airgun impulse. Recording was at the 600-m depth and 10 nm from the airgun array.

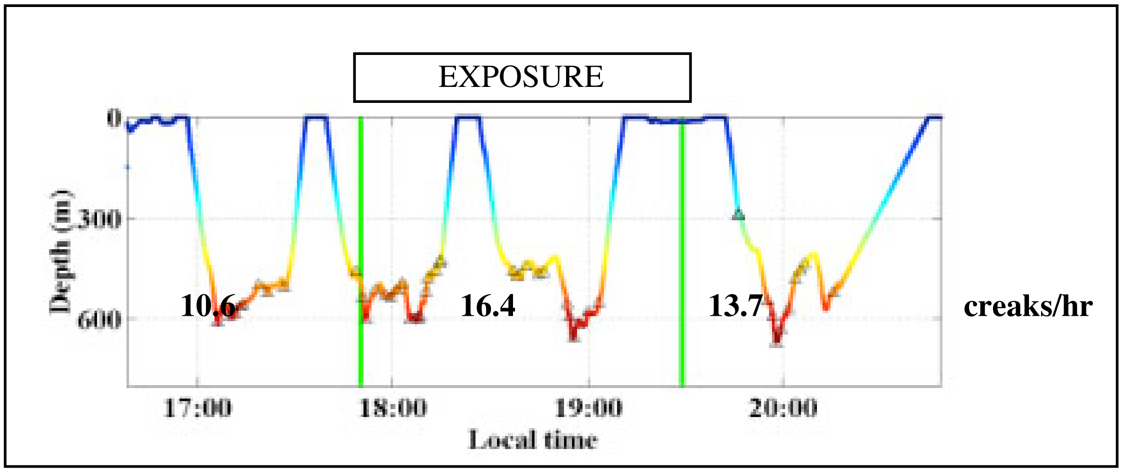


Figure 5.7.4. Dive pattern of sperm whale tagged for CEE conducted on 10 September 2002.

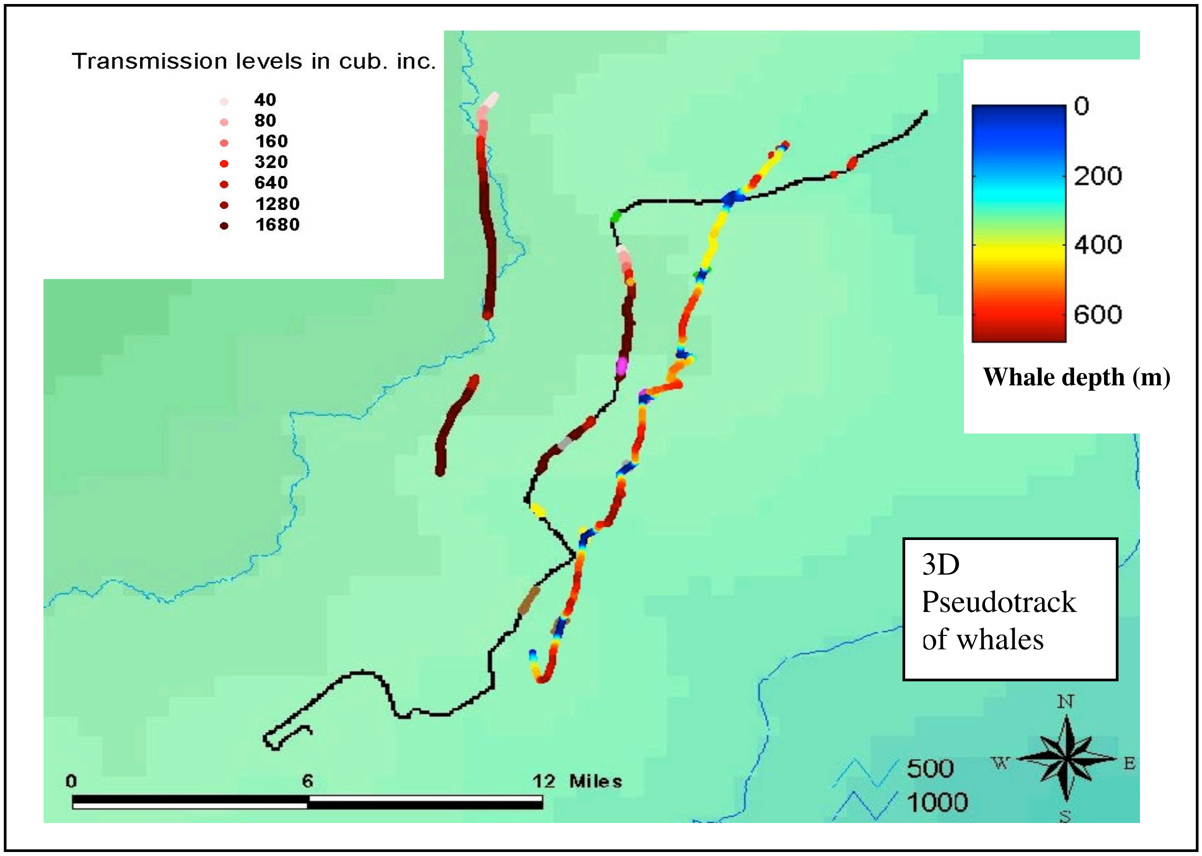


Figure 5.7.5. Tracks of vessels, airgun transmission levels, and whale movements during controlled exposure experiment conducted 11 September 2002. The source vessel is indicated by the line coded by transmission level on the left, the *Gyre* by the long black line mainly in the middle; and the three tagged whales by the pseudotrack mostly on the right.

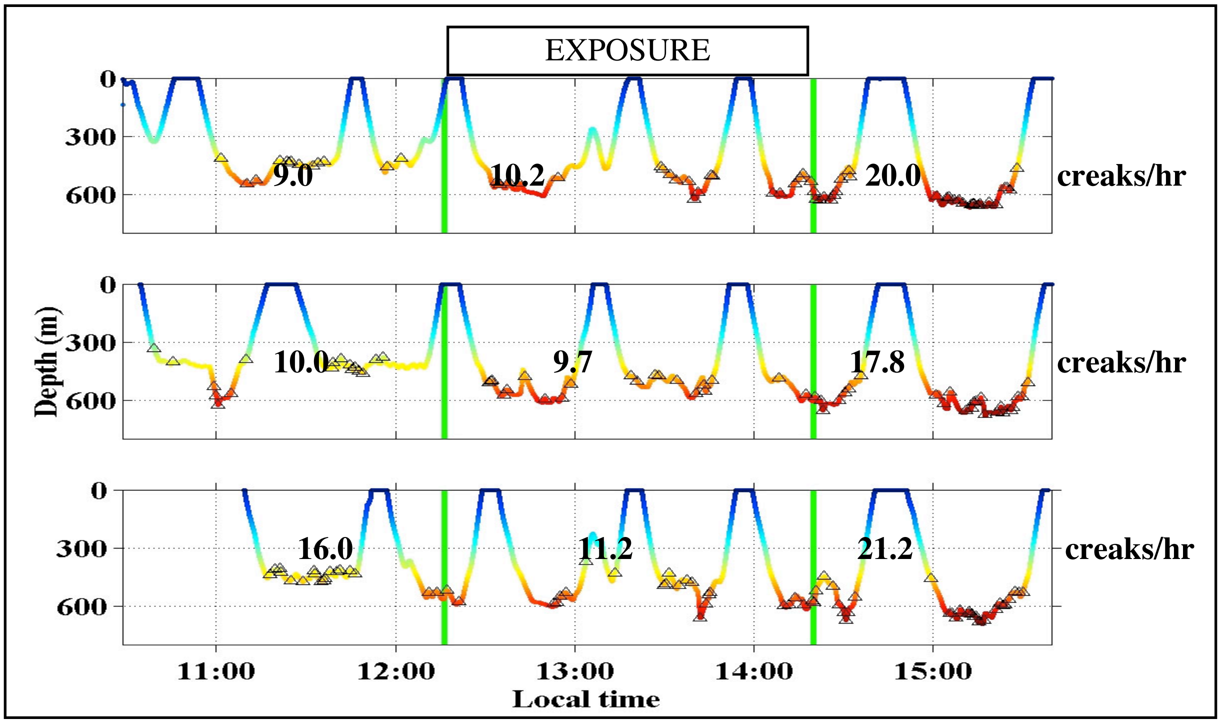


Figure 5.7.6. Dive profiles and creak rates for the three whales tagged for the CEE on 11 September 2002.

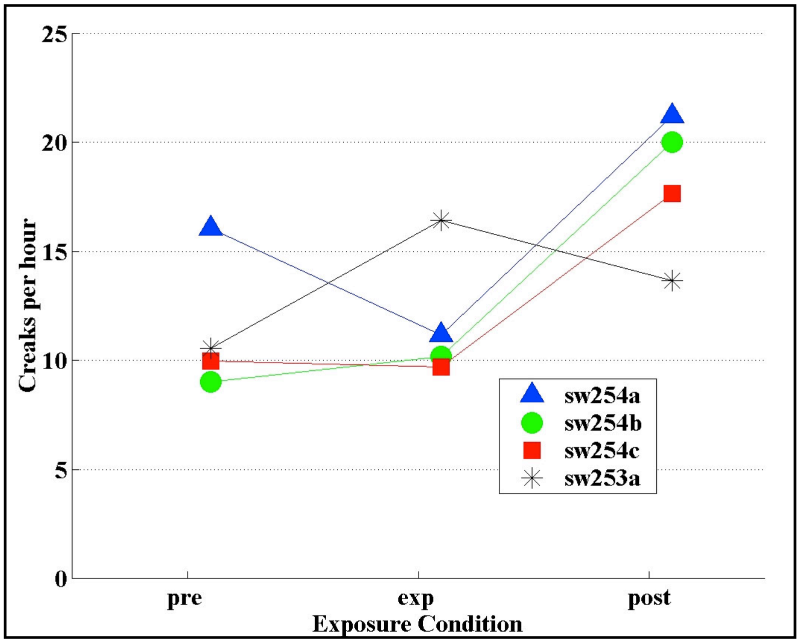


Figure 5.7.7. Creak rates before (pre), during (exp), and after (post) exposure to airgun sounds for the four tagged whales in the CEE conducted on 10-11 September 2002.

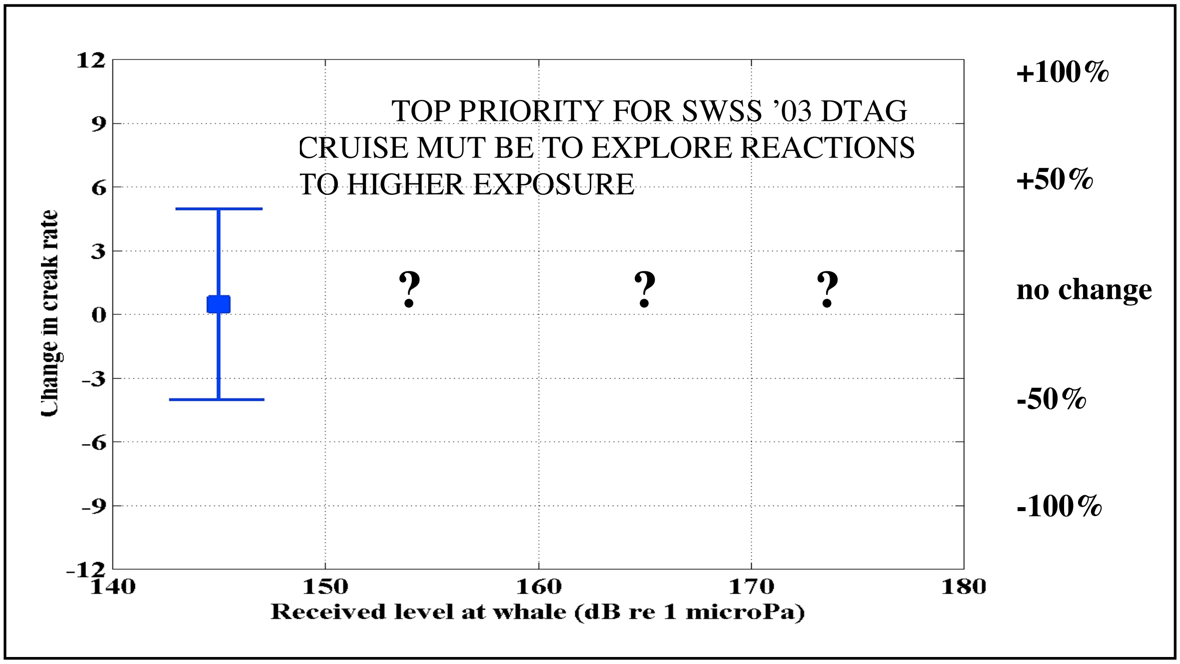


Figure 5.7.8. Difference in creak rates before versus during exposure to 143-148 dB indicates there is no change in creak rate.

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The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection