



Cooperative Research to Study Dive Patterns of Sperm Whales in the Atlantic Ocean



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EXECUTIVE SUMMARY

The National Marine Fisheries Service (NMFS) is required to produce stock assessments for all marine mammal stocks within the U.S. Exclusive Economic Zone. The Minerals Management Service (MMS) is evaluating potential environmental impacts of offshore oil and gas activities on marine mammals. Both agencies have a need for similar information on sperm whales and this is the basis for the cooperative research outlined here. This study, conducted in July 2003, has started a baseline of line-transect, photo-identification, oceanographic and genetic data for the Atlantic sperm whale. Compared with the Delta region in the Gulf of Mexico, parts of the Atlantic Ocean may serve as a control population of sperm whales with little exposure to sounds of oil and gas related activities.

A total of 12 sperm whales were tagged during the four-week, July 2003 cruise yielding a substantial data set spanning both deep foraging and socializing from 9 of the 12 tagged animals. These tag recordings represent the first acquisition of sound and movement data from sperm whales in the North Atlantic. Visual and acoustic surveys were performed whenever weather permitted throughout the cruise and visual focal follows were made when tags were deployed. Complimentary data products included physical oceanographic measurements and skin and fecal samples from tagged and neighboring whales. The tag data set from the cruise has been examined using techniques developed on the Sperm Whale Seismic Study (SWSS) program to parameterize foraging and social behaviors. The data set has also been integrated into a combined data set covering the Gulf of Mexico, North Atlantic and Mediterranean seas to enable comparative analyses. We found that the North Atlantic whales follow a foraging and socializing cycle similar to the Gulf of Mexico whales but dive significantly deeper to forage. Foraging largely occurs at 500-1,100 m but a small amount of food may be taken in water as shallow as 300 m. A wide range of codas was produced but even fairly closely located groups appeared to prefer distinct codas.

An unusually high rate of breaching, possibly associated with tag attachment, limited the longevity of the tag attachment. The maximum attachment duration of six hours in this Atlantic Ocean study compares unfavorably with 16 hours in the Gulf of Mexico and Mediterranean. The unknown reason for why there were few long attachments may reduce the number of future successful tagging events from whales in the Atlantic. Breaching, possibly associated with tag attachment, has been observed in other areas, and those breaching rates varied from year to year. So, perhaps this first year in the Atlantic is just on the high side of the inter-annual variability. Further work is needed to address this. In addition, there are areas in the Atlantic, such as off Virginia, where there are, at times, a substantial amount of low frequency impulsive sounds from underwater explosions in Navy test ranges. Such times and areas should not be considered as a future controlled exposure study area.

Acoustic data could potentially be used in two ways to improve the sperm whale abundance estimates. One way is to utilize both visual and passive acoustic detections to estimate the abundance. A new project to advance development of such methods was recently funded. The visual and acoustic data collected during the Search Mode in this cruise will be used as a test case.

Another way acoustic data could be used to improve visual line-transect abundance estimates is to use the dive time pattern data collected on the acoustic tag (DTAG) in surfacing-based line-transect analysis methods. If we assume the tagged animals are representative of the dive patterns of the Atlantic population, then there is a 27% (CV=0.46) chance that a single sperm whale is at the surface to be able to be detected by a visual sighting team. A simple implementation of using these dive data is to estimate total abundance of sperm whales as a function of (i) the abundance using standard visual line-transect methods, assuming this is an abundance estimate of surface animals and (ii) the percentage of time whales are at the surface using the tag data. Using this over-simplified method the dive time corrected total abundance of sperm whales would then be 14,922 (CV=0.60), which is about 3.5 times greater than the standard visual abundance estimate. However, this abundance estimate is biased upwards due to the facts that the standard abundance estimate is based on detection of groups of whales, where groups are usually greater than one, while the probability of a whale being at the surface using the tag data is based on singleton whales, and individual sperm whales do not dive totally independent of the other animals in its group. Thus, surface-based, not group-based, line-transect analysis methods are required to properly account for the confounding facts. These methods are explained in this report and are under development, thus results are not currently available.

Another objective of this and the SWSS cruises is to address the question "Do sperm whales have preferred habitats that can be defined physiologically and/or with oceanographically?" One way to

address this is to model the distribution and abundance of the sperm whales with respect to physical and biological parameters, such as water depth, bottom slope, sea-surface temperature, salinity at the surface, mixed layer depth, surface color (primary productivity), and distribution and abundance of other trophic levels (such as that obtained from bongo samples). Such a model can also include nuisance variables, such as Beaufort sea state, which affects the sightability of the whales, but probably does not affect the actual distribution of the whales. To start this process, five-day composites from the middle of the cruise of sea surface temperature (SST) and chlorophyll-a (chl-a) using satellite pictures were produced and the sightings were overlaid. Interestingly, sperm whales appear to be present in more diverse combinations of SST and chl-a than many of the other cetacean species detected during this cruise. This could imply that sperm whales are not cueing in on these two parameters, like some other species do. Or, sperm whales are generalists and so can utilize a variety of habitats or perhaps sperm whales are not cueing in on ocean surface factors but are cueing on ocean bottom factors. More data are needed to address this. Because this cruise concentrated on putting tags on sperm whales and not investigating many type of potential habitats, this cruise surveyed a limited number of types of potential habitats. However, the NEFSC conducted a large scale line transect abundance survey in 1998 and is currently conducting one during the summer of 2004. The plan is to merge the line transect data of the 1998, 2003, and 2004 surveys to investigate habitat preferences of sperm whales in the Atlantic. Stepwise selection of Generalized Additive Models (GAM) will be used to define a model that uses physical and biological parameters to describe the sperm whale habitat. To start this modeling exercise, the 1998 data were used to model the distribution and abundance of sperm whales in five nautical mile sections of the track line. The stepwise GAM determined depth and an interaction between two groups of plankton species (groups 2 and 3) were the best predictors for sperm whale distribution and abundance, where depth was the most influential factor. Sperm whales were inversely related to Plankton group 3, which are species generally associated with warm core rings. Sperm whales were positively related to Plankton group 2, which are species most often associated with cooler waters, such as those on the outside edge of a ring or in between warm core rings. Thus, these GAM results can be interpreted as Atlantic sperm whales are most commonly found in waters approximately 2000 meters deep, when those waters are cool, like those found on the outside or in between warm core rings.

TABLE OF CONTENTS

| | <u>Page</u> |
|---|-------------|
| LIST OF FIGURES | ix |
| LIST OF TABLES | xi |
| 1. INTRODUCTION | 1 |
| 2. FIELD METHODS | 2 |
| 2.1 DTAG | 2 |
| 2.2 Visual and Acoustic Data Acquisition | 3 |
| 2.3 Tagging Method..... | 3 |
| 2.4 Environmental Data Acquisition..... | 4 |
| 2.5 Photo-identification (Photo-ID) Data Acquisition..... | 4 |
| 2.6 Diet and Foraging Success Data Acquisition..... | 4 |
| 3. CRUISE SUMMARY | 5 |
| 4. DATA SUMMARY | 10 |
| 4.1 DTAG Data..... | 10 |
| 4.2 Permit Data/Close Observations from RHIB..... | 10 |
| 4.3 Visual Data..... | 10 |
| 4.4 Acoustic Data..... | 11 |
| 4.5 Skin and Fecal Samples | 11 |
| 4.6 CTD Data..... | 11 |
| 4.7 Environmental and Ship Location Data | 11 |
| 5. DATA ANALYSES AND RESULTS..... | 13 |
| 5.1 Tag Data..... | 13 |
| 5.1.1 Dive Behavior | 13 |
| 5.1.2 Foraging Behavior..... | 15 |
| 5.1.3 Social Behavior | 24 |
| 5.2 Dive Time Correction for Abundance Estimates..... | 31 |
| 5.2.1 Visual and Passive Acoustic Data..... | 31 |
| 5.2.2 Visual and Acoustic Tag Data | 32 |
| 5.3 Habitat Preferences | 33 |
| 6. LITERATURE CITED | 40 |

LIST OF FIGURES

| | | <u>Page</u> |
|------------|---|-------------|
| Figure 1. | DTAG deployed on a sperm whale in the North Atlantic..... | 2 |
| Figure 2. | Acoustic survey track lines for the <i>R/V Delaware</i> cruise..... | 8 |
| Figure 3. | Visual survey and focal follow tracklines for the <i>R/V Delaware</i> cruise. | 9 |
| Figure 4. | Example of a visual observation chart produced by the SACLANT-WHOI system. | 12 |
| Figure 5. | Typical elements in a normal dive profile..... | 14 |
| Figure 6. | Average normalized foraging dive profile for sperm whales in the Gulf of Mexico, Atlantic, and Mediterranean..... | 17 |
| Figure 7. | Dive profile indicating sound events for sw03_197a..... | 18 |
| Figure 8. | Dive profile indicating sound events for sw03_201b. | 19 |
| Figure 9. | Dive profile indicating sound events for sw03_202a..... | 20 |
| Figure 10. | Dive profile indicating sound events for sw03_202b. | 21 |
| Figure 11. | Dive profile indicating sound events for sw03_206c..... | 22 |
| Figure 12. | Dive profile indicating sound events for sw03_207a..... | 23 |
| Figure 13. | Depth occurrence of codas normalized by dive depth produced by tagged sperm whales in the Gulf of Mexico, the Atlantic, and the Mediterranean. | 25 |
| Figure 14. | Depth occurrence of codas normalized by dive depth produced by untagged sperm whales in the Gulf of Mexico, the Atlantic, and the Mediterranean. | 26 |
| Figure 15. | Average number of codas produced and heard per animal per descent in the Gulf of Mexico, Atlantic, and Mediterranean..... | 27 |
| Figure 16. | Average number of codas produced and heard per animal per ascent in the Gulf of Mexico, Atlantic, and Mediterranean..... | 28 |
| Figure 17. | Average number of codas produced and heard per animal per inter-dive interval in the Gulf of Mexico, Atlantic, and Mediterranean. | 29 |
| Figure 18. | Average number of codas produced and heard per animal per surface interval in the Gulf of Mexico, Atlantic, and Mediterranean. | 30 |
| Figure 19. | Distribution of sperm whales seen during 2003 cruise overlaid on a 5-day composite of the sea surface temperature (SST) from the middle of the cruise. | 35 |
| Figure 20. | Distribution of sperm whales seen during 2003 cruise overlaid on a 5-day composite from the middle of the cruise of the chlorophyll-a as measured from SeaWiFS. | 36 |
| Figure 21. | Distribution of cetaceans with respect to sea surface temperature (SST) and Chlorophyll-a (CHLOR-A) for all species detected during Survey Mode. | 38 |
| Figure 22. | Results of applying Generalize Additive Modeling (GAM) techniques to model the abundance and distribution of sperm whales using water depth and the abundance of Plankton Group 2 and Plankton Group 3. | 39 |
| Figure 23. | Location of sperm whale sightings (+) with respect to the shelf edge, two warm core rings, and levels of abundance of Plankton Group 2 and 3 (the taller the bar, the more plankton of that group there are at the locations of the sperm whale sightings. | 39 |

LIST OF TABLES

| | <u>Page</u> |
|--|-------------|
| Table 1. Number of Groups and Animals Detected during Survey Mode | 6 |
| Table 2. DTAG Data Sets for the <i>R/V Delaware</i> Cruise, North Atlantic, July 2003 | 7 |
| Table 3. Dives Recorded by DTAG during the <i>R/V Delaware</i> Cruise..... | 15 |
| Table 4. Average Duration (in minutes) and Depth (in meters) of Dive Features (defined in Figure 5) from Animals Tagged in the North Atlantic, Gulf of Mexico, and Mediterranean | 15 |
| Table 5. Regular Clicks and Creaks Recorded by DTAGs on Atlantic Sperm Whales..... | 16 |
| Table 6. Codas Recorded on DTAGs during the <i>R/V Delaware</i> Cruise | 24 |
| Table 7. Numbers of Different Types of Codas Produced by the Tagged or Focal Whale (F) and Non-focal Whales (NF) in the Atlantic for Three of Four Tags Containing Codas..... | 31 |

1. INTRODUCTION

The National Marine Fisheries Service (NMFS) is required to produce stock assessments for all marine mammal stocks within the U.S. Exclusive Economic Zone. The Minerals Management Service (MMS) is evaluating potential environmental impacts of offshore oil and gas activities on marine mammals. Both agencies have a need for similar information on sperm whales and this is the basis for the cooperative research outlined here.

To contribute to information needs of both agencies, the Sperm Whale Seismic Study (SWSS) program research started in 2000 to address the following questions regarding sperm whales in the Gulf of Mexico:

1. What are the sources and levels of anthropogenic noise?
2. What are the effects of anthropogenic noise (e.g., seismic activity) on the distribution, behavior, and vocalization patterns of sperm whales?
3. What is the stock status of sperm whales that inhabit the Gulf of Mexico compared to the adjacent Atlantic Ocean and Caribbean Sea?
4. Will surveys using both acoustic and visual methods improve (change) the NMFS' absolute abundance estimates of sperm whales in U.S. waters?
5. Is the social structure of sperm whales in the Gulf of Mexico similar or different compared to sperm whales in other parts of the world?
6. How do sperm whales spatially use the Gulf of Mexico? Are there specific feeding, breeding, socializing, and resting areas? How do these areas relate to offshore oil and gas activities?
7. Do sperm whales have preferred habitats that can be defined physiographically and/or oceanographically?

The knowledge and techniques developed during the Gulf of Mexico 2000-2003 studies were built on to collect data to address questions 2 to 5, and 7. This study centered on a cruise onboard the NOAA *R/V Delaware* in July 2003. This study has started a baseline of line-transect, photo-identification, oceanographic and genetic data for the Atlantic sperm whale. Compared to the Delta region in the Gulf of Mexico, parts of the Atlantic Ocean may serve as a control population of sperm whales with little exposure to sounds of oil and gas related activities.

During the cruise, scientists from NMFS and Woods Hole Oceanographic Institution (WHOI) simultaneously conducted line-transect marine mammal visual, passive acoustic, oceanographic, and plankton surveys. Satellite data on ocean color and sea surface temperature were also collected. When concentrations of sperm whales were located, DTAGs were placed on the sperm whales to continuously record the acoustic stimulus impinging on the sperm whale, hydrostatic pressure, water temperature, and the animal's pitch, roll, and compass heading. When animals were tagged, photographs were taken for photo-id studies, biopsy and skin samples were collected for genetic analyses, and visual behavioral studies were conducted. Additional chlorophyll-a and oceanographic data were also collected.

The *R/V Delaware* study was designed to start collecting data to address the following questions posed by the Gulf of Mexico SWSS project. Behavioral pattern data from the Atlantic Ocean could be compared to behavioral pattern data of sperm whales that are around oil and gas platforms in the Gulf of Mexico (Question 2). Dive-time data could be used to reduce the availability bias of previous and future abundance estimates of Atlantic sperm whales (Question 4). Visual and acoustic data could be used to develop methods to utilize both visual and acoustic detections to improve abundance estimates of sperm whales (Question 4). Genetic data could be used to improve the stock structure knowledge of Atlantic sperm whales and could be compared to Gulf of Mexico sperm whales (Question 3). Behavioral data could be used to learn about the social structure of Atlantic sperm whales and could be compared to the social structure of Gulf of Mexico sperm whales (Question 5). The integration of the line transect, plankton, DTAG, and oceanographic data could be used to model the preferred habitat of the Atlantic

sperm whales, which could then be compared to the preferences of the Gulf of Mexico sperm whales (Question 7).

2. FIELD METHODS

The data collection systems and methodologies used for the DTAG component of the Atlantic *R/V Delaware* cruise were based on those developed for the Gulf of Mexico SWSS '02 and '03 cruises, details are below.

2.1 DTAG

In 1999, the DTAG was developed by WHOI investigators using ONR and WHOI endowments (Johnson and Tyack 2003). 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. The tag records data digitally for between 10 and 24 hours, depending on sampling rate, with enough resolution to track individual fluke strokes and is sensitive enough to record sounds from distant whales and ships. A new version of the DTAG, called DTAG-2, was used in the *R/V Delaware* cruise and in the SWSS'03 cruise preceding it. This device has more recording capacity and a higher audio sampling rate and resolution than the original version. It is also one half the size and weight (300g in air). The improved recording capacity is achieved using a loss-less compression algorithm to increase the storage efficiency of the audio data. This algorithm gives a consistent compression factor of between 3 and 4 (i.e., the effective memory capacity is 3-4 times the nominal value). With the 3GByte memories used on the 2003 DTAG-2s, it is possible to record 96 kHz, 16 bit audio for over 16 hours. The sensitivity of the DTAGs used in the SWSS'03 and *R/V Delaware* cruises was approximately -193 dB re μPa (pp) (this is also the clipping level or loudest sound level accurately recorded by the tag).

The DTAG is housed in a plastic fairing and is attached to the whale with a set of four small suction cups. The tag has a low profile on the whale (Figure 1) to minimize the risk of tag removal by conspecific rubbing. The tag has been successfully deployed on more than 60 sperm whales, 25 pilot whales and 5 beaked whales, with deployment durations of up to 30 hours. In the SWSS'03 cruise in the Gulf of Mexico immediately prior to the *R/V Delaware* cruise, tag attachments of up to 17 hours with an 8 hour average were achieved with the new tag. The tag has a VHF beacon which broadcasts a signal in the 2m band (148-150 MHz) every second for tracking and recovery of the tag. Data is off-loaded from the tag via an infra-red interface. The tag battery can be recharged while data is off-loading maximizing the availability of the device.



Figure 1. DTAG deployed on a sperm whale in the North Atlantic.

2.2 VISUAL AND ACOUSTIC DATA ACQUISITION

Continuous visual and acoustic observation was critical not only to locate and close on sperm whales but also to provide a context for the data collected by the DTAG. Visual observations while following a tagged whale (i.e., during a focal follow) provided a surface track for the tagged whale and anchored the movement data collected on the DTAG into a geographic frame. Visual and acoustic observations were also used to define the group size and distance between whales, important data for understanding the social behavior of the tagged whale. Acoustic tracking was also essential to stay with a tagged whale overnight or during bad weather.

During the search phase of operations (Survey mode), sperm whales were located using visual and acoustic techniques. Visual observers (two teams of three people each rotating every two hours) scanned for whales using 25x150 powered 'Big-Eye' binoculars while steaming at 4-6 knots and using standard line transect protocols. Weather permitting, visual surveying was conducted from sunrise (6 am) to sunset (8 pm). The Visual Team recorded range and relative bearing to whales, group size, initial cue, behavior and direction the group was swimming in. The visual and acoustics data were entered into logging software that was also interfaced with the ship's navigation network to precisely locate each observation. Real-time displays of all the visual and acoustic contacts were maintained in both the acoustics laboratory and on the flying bridge to help the two teams communicate. The software for this system was developed cooperatively by WHOI and SACLANTCEN NATO Undersea Research Center in La Spezia, Italy and was managed by Marilena Quero of WHOI.

The WHOI-supplied three-element hydrophone array was built for the SWSS program and deployed from the *R/V Delaware* as a streaming array (i.e., without a depressor) using a mechanical capstan. Acoustic observers (three observers rotating on a four-hour schedule 24-hours a day) detected and located sperm whales by listening for their vocalizations on a towed hydrophone array. During Survey mode, the acoustic environment was recorded for one minute every ten minutes. In addition, a log of acoustic events was updated every five minutes. These data included who was monitoring the equipment, what type of survey mode the observers were in, and the presence and magnitude of the following: sperm whale-like clicks, high and low frequency whistles, clicks, bursts, ship noise, sonar-like sounds, or none of the above. Thus, the acoustic data were used not only to detect clicks of sperm whales, but also to monitor dolphins, and ship noise. Two software systems were used in parallel for acoustic tracking. The first, Rainbow Click from the International Fund for Animal Welfare (IFAW), provided reliable bearing estimates for distant sperm whales. The other program, developed by Walter Zimmer of the SACLANTCEN NATO Undersea Research Center was most effective for close whales and was used during focal follows. Sound from the array was recorded continuously on an Alesis hard-drive recorder at a sampling-rate of 48 kHz while tracking and 96 kHz during focal follows. Acoustic observations were logged using custom software also developed by Zimmer. Sound samples were acquired digitally using Logger software from IFAW.

Once whales were detected, Survey mode ended and Tracking mode started. At this time, the *R/V Delaware* was steered toward the whales, and the Visual and Acoustic Teams, following protocols developed under SWSS, provided directions to the tag boat, monitored sperm whale activity in the area and recorded behavioral observations of any target species. The Acoustic Team monitored the diving sperm whales to assist in determining where and when a diving animal would come up to the surface.

2.3 TAGGING METHOD

Approaches to large whales were conducted under authority of the Marine Mammal and Endangered Species Scientific Permit #917, and CITES Permit # US 789250 issued to NOAA/Northeast Fisheries Science Center. Tagging was conducted under authority of the Marine Mammal and Endangered Species Scientific Permit #981-1707-00 issued to Dr. Peter Tyack of WHOI. Once whales were located and the *R/V Delaware* moved close to the animals, a WHOI provided 24' rigid-hulled inflatable boat (RHIB) was deployed with a 3- or 4-person tagging team to attach DTAGs to whales. The tag boat was a fiberglass-hulled Novurania, called the *Balena*. The *Balena* was captained by Wayne Hoggard from NMFS/Southeast Fisheries Science Center, an expert boat operator with experience of approaching sperm whales gained during the MMS-funded 2000-2001 Sperm Whale Acoustic Monitoring Program (SWAMP) trials. The *Balena* has two counter-rotating 4-stroke Yamaha 110 hp outboard motors. The *Balena* was stowed on the aft deck of the *R/V Delaware* and lowered over the starboard side using the

main crane. On the RHIB, a directional hydrophone was used to locate and close on sperm whales. Visual and acoustic observers on the research vessel supported the tagging effort by providing surfacing positions and acoustic bearings of whales to the RHIB team. A 46' cantilevered pole, made of carbon fiber, was used to deliver the tag allowing the approach vessel to remain well behind the flukes of the target animal. Visual and acoustic observations from the nearby *R/V Delaware* recorded the social and geographical context of the whales' behavior, before, during, and after tagging. After attaching a tag, the length of the whale was measured using photogrammetry and photographs of the fluke and other distinguishing features were taken for photo-identification. Whether a tag was attached or not, no more than three approaches were made to any individual or tight group of whales, in keeping with the requirements of the Permit issued to Peter Tyack. After each approach, the whale's surfacing location was inspected to search for feces or skin, and a data sheet was filled out detailing the position, approach number and response of the whale. Once a whale was tagged and photographed, the RHIB either returned to the *R/V Delaware* or attempted to tag another whale. No more than three whales were tagged at a time.

2.4 ENVIRONMENTAL DATA ACQUISITION

Environmental data were collected continuously from the ship's thermo-salinograph and other instrumentation. The data included time, position, wind direction and speed, and the ship's course, bearing and speed. CTD's were deployed periodically. In addition, water samples were collected during the CTD cast to be used to calibrate the CTD.

Satellite sensors (AVHRR, GOES, SeaWiFS, MODIS, QuikSCAT) provided high resolution synoptic views of the near surface oceanic ecosystem, depicting areas of surface chlorophyll concentrations, upwelling-downwelling features, turbidity, nutrient enrichment, surface temperature and winds, and principal circulation forces all of which are closely linked to ocean productivity. Before, during and after the survey, such satellite data were collected, and processed. During the survey the satellite data were emailed to the ship from the NMFS Narragansett Lab.

2.5 PHOTO-IDENTIFICATION (PHOTO-ID) DATA ACQUISITION

Photo-ID was conducted from the RHIB. The animals were approached to at least 100 m, preferably 30 m, to photograph the underside of the whale's flukes as they were lifted out of the water prior to a dive. Digital cameras and color slide film 35 mm autofocus, autoadvance cameras with a 200-300 zoom lens were used. Photographs were also taken opportunistically from the *R/V Delaware*. A photographer was on the *R/V Delaware* during all operations to photograph/video flukes, when possible.

Between groups of animals "blank" shots were taken as reference points. Rolls of film were labeled with a number that was also written on a film sheet. Film sheets contained the following information for each photograph: date, position, frame number, time, part of whale photographed, number of whales and photographer's initials.

Color slide film was professionally developed and each slide was evaluated based on: focus, percent of the slide the fluke comprises, tilt of the fluke, exposure, orientation and percent of area of fluke in the photograph. Slides were given a "Q value" representing zero for non-identification and 5 for absolute certainty of identification. Slides will be examined for matches and whales that do not match whales in the catalog will be given a new number.

In addition to the slides for photo-ID, a digital video camera was used to record behavior of sperm whales at the surface and to capture images of the sperm whale flukes.

2.6 DIET AND FORAGING SUCCESS DATA ACQUISITION

Because of physiological constraints associated with diving deeply, sperm whales that defecated at the surface provided an opportunity, through collecting and analyzing fecal material, to study the diet of living sperm whales. Whenever possible fecal material left at the surface were collected to study the diet of sperm whales.

3. CRUISE SUMMARY

Leg 1. Gear was loaded onto the *R/V Delaware* on July 7, 2003. We left Woods Hole, MA on July 8th at 2pm and steamed to Hydrographer Canyon on the southern edge of Georges Bank. At 6am on July 9 we were in our study area and the tag boat was deployed to calibrate and check all the equipment and computer programs. By 10am, everything was checked out and surveying started. During Leg 1, the area covered included waters on the southern edge of Georges Bank between Hydrographer and Munson Canyons (Figure 1). Surveying, tracking and tagging continued until 2pm on July 17, at which time we started steaming back to Woods Hole, MA to refuel the ship and change personnel. We arrived at Woods Hole, MA at 10am on July 18th.

Leg 2. We departed Woods Hole at 11:30am on July 19th. Arrived at the new study area, Block Canyon, at 10pm on July 19th, at which time acoustic surveying commenced. The study area during Leg 2 was in two separate areas: around Hudson Canyon (off of New Jersey), and on the shelf edge/Gulf Stream off Norfolk, Virginia (Figure 1). Surveying, tracking and tagging continued until 11:30am on July 31, at which time we started to steam for home. We arrived at Woods Hole at 6am, and removing the gear from the ship by about 1pm.

Good weather conditions, preferably less than 12 knots of wind with swells less than 2 feet, were required to safely deploy/retrieve the tag boat and put tags on the sperm whales. Unfortunately, these conditions are not common in the Atlantic and this survey was no exception. Of the 21 days allocated to this project where we were not transiting, only 10 days had weather conditions sufficient to attempt tagging animals. This percentage of good weather days is slightly less than that typical seen in these offshore Atlantic waters. A summary of time expenditure on the cruise is given below.

| | |
|----------------------------------|----|
| Total cruise days | 26 |
| Comprising: | |
| Survey only (winds > 12 knots) | 11 |
| Successful tagging | 6 |
| In-transit or dock-side | 5 |
| Good weather but no sperm whales | 1 |
| Unsuccessful tagging | 3 |

Considering that on many of the bad weather days sperm whales were located and tracked by the *R/V Delaware*, the encounter rate of sperm whales was excellent.

A summary of the tracklines covered by acoustic watches and where sperm whales were heard is shown in Figure 2. Acoustic watches were manned for nearly 24 hours per day at sea. The acoustic data collection effort operated well. The array that was used throughout the experiment performed well.

The tag boat, *Balena*, was stowed on the aft deck of the *R/V Delaware* and lowered over the starboard side using the main crane. The tight fit of the *Balena* on the deck made deployment challenging; however, there were no incidents during deployment or operation of the small boat.

The visual team worked for over 55 hours during Survey Mode and for about 155 hours during Tracking Mode. The visual data collection effort operated well throughout the cruise with the results summarized in Figure 3. During Tracking Mode, 205 surfacings of 292 animals were recorded. Note, these animals were not identified to individuals or individual groups; many of the individuals and groups were recorded multiple times. During Survey Mode, 92 cetacean groups consisting of 1139 individuals were detected (Table 1).

A total of 12 tags (Table 2) were attached to sperm whales within the 10 days that had suitable conditions to tag whales. On 6 of the 10 suitable days we were successful in finding and tagging sperm whales. Overall, we found the sperm whales straightforward to approach—comparable to the most successful year in the Gulf of Mexico. Twenty-four approaches to sperm whales and 14 tag attempts resulted in the delivery of 12 tags. Three approaches to pilot whales resulted in no tag attempts and no tagged pilot whales. On half of the days that were suitable for tagging (10 days) we delivered two or more tags.

Table 1.

Number of Groups and Animals Detected during Survey Mode

| Species | Number of | |
|------------------------------------|-----------|---------|
| | Groups | Animals |
| <i>Balaenoptera physalus</i> | 15 | 19 |
| <i>Balaenoptera sp.</i> | 2 | 2 |
| <i>Delphinus delphis</i> | 8 | 419 |
| <i>Globicephala sp.</i> | 3 | 58 |
| <i>Grampus griseus</i> | 7 | 56 |
| <i>Megaptera novaengliae</i> | 1 | 1 |
| <i>Orcinus orca</i> | 3 | 15 |
| <i>Physeter macrocephalus</i> | 13 | 15 |
| <i>Stenella coeruleoalba</i> | 4 | 171 |
| <i>Tursiops truncatus</i> | 13 | 221 |
| <i>Tursiops truncatus</i> offshore | 1 | 15 |
| Undetermined cetacean | 2 | 2 |
| Undetermined dolphin | 13 | 134 |
| Undetermined large whale | 7 | 11 |
| Total | 92 | 1139 |

Nighttime recoveries of tags were achieved fairly efficiently from the *R/V Delaware* although, at times, this required the acoustic array be winched in.

With two exceptions, the attachment durations were fairly short (1.0-6.4 hours, see Table 2). This was, in part, due to a large number of breaches: 4 out of 12 tagged whales breached, in most cases ending the attachment. Similar high breaching rates were seen on the SWAMP'01 trial in the Gulf of Mexico, whereas in other years in the Gulf of Mexico, few breaches were seen. It is not yet clear whether the breaches were in response to the tag.

Within 33.6 hours for which a whale carried a tag, we received 27.2 hours of recorded data (Table 2). The difference in the carry time and record time is due to one tag that was attached but the battery failed so no data were collected. Three tags failed to yield a dataset: one tag was not recovered, a second tag had a battery failure and so did not record, and the third tag fell off the sperm whale when it breached nearly immediately after the tag was attached. The battery failure problem had been identified and rectified in a slightly modified design.

Despite the short attachments, we sampled each of the usual behavioral modes of sperm whales: foraging dives, socializing, resting, and traveling. A set of 18 deep dives provides a strong initial baseline for estimates of foraging success and energy expenditure using metrics developed in the SWAMP and SWSS programs. Two of the tagged animals stayed near the surface for the entire carry time, thus, displaying typical resting behaviors and so having no full deep dives (Table 2). In addition to sperm whale vocalizations, the tags recorded sounds from other nearby odontocetes including pilot whales, bottlenose dolphins and spotted dolphins. The sounds of passing vessels and explosions from a distant naval exercise were also collected.

Environmental data were collected continuously from the ship's thermo-salinograph and other instrumentation. Eleven CTD's were deployed while the ship traveled at 2-3 knots when the acoustic array was also deployed. The ship must continue to move to keep the acoustic array near the surface. More CTD's would have been deployed if we had realized earlier that the ship could be traveling, have the array out, and still deploy a CTD. No bongos were deployed. On nearly a daily basis, Dr. Jay O'Reilly from the NMFS Narragansett Lab emailed to the ship sea surface temperature and chlorophyll maps. These were very useful to help find new potential concentrations of sperm whales and to help interpret the distribution and abundance of sperm whales that we did detect.

No biopsies were attempted from the tag boat. Three biopsies were attempted from the bow of the *R/V Delaware* to get a sample of bow riding dolphins. No samples were obtained.

A high percentage (75%) of tags yielded skin samples (Table 2) and these will be analyzed for gender and to assess the relatedness of the study whales with those in the Gulf of Mexico. Fecal samples were collected from two of the animals that were tagged (Table 2).

Overall we found the study area to be an exceptionally good site for sperm whale tagging. However the potential for poor weather and the unknown reason for why there were few long attachments may reduce the number of future successful tagging events. Also, if this area is to be considered a “control” for the Gulf of Mexico, then future Atlantic tagging should not be done in the Virginia area were there are frequent naval exercises that may pre-expose the population to impulsive sounds. At least during this survey, the southern Georges Bank region had many sperm whales and no Naval exercises that made impulsive sounds.

Table 2.

DTAG Data Sets for the *R/V Delaware* Cruise, North Atlantic, July 2003
(Carry time indicates the amount of time that a tag is on a whale.
Record time indicates the amount of time that dive data were
successfully recorded. Number of full deep dives indicates the number
of dives that exceeded 50 feet depth.)

| Date | Time | ID | Tag id | Record time / carry time (hours) | # of full deep dives | Sampling Rate, kHz | Skin/ Fecal sample | Comments |
|---------|----------|--------|--------|----------------------------------|----------------------|--------------------|--------------------|-----------------|
| 7/16/03 | 10:44:17 | sw197a | 202 | 2.1 / 2.1 | 2 | 96 | S | |
| 7/16/03 | 12:01:41 | sw197b | 209 | 2.4 / 2.4 | 2 | 96 | S | Breached off |
| 7/20/03 | 11:42:10 | sw201a | 202 | 3.7 / 3.7 | 0 | 96 | S | Breached off |
| 7/20/03 | 15:15:13 | sw201b | 207 | 3.2 / 3.2 | 2 | 96 | - | |
| 7/21/03 | 12:10:59 | sw202a | 202 | 1.0 / 1.0 | 1 | 96 | S | Breached off |
| 7/21/03 | 12:55:43 | sw202b | 209 | 2.0 / 2.0 | 0 | 96 | S | |
| 7/25/03 | 11:59:02 | sw206a | 202 | 3.8 / 3.8 | 4 | 96 | S | |
| 7/25/03 | - | sw206b | 205 | 0 / 6.3 | - | 96 | F | Battery failure |
| 7/25/03 | 13:12:45 | sw206c | 209 | 2.6 / 2.6 | 3 | 96 | S | |
| 7/26/03 | 11:28:00 | sw207a | 202 | 6.4 / 6.4 | 4 | 96 | S | |
| 7/26/03 | - | sw207b | 209 | 0 / ? | - | 96 | S,F | Lost at sea |
| 7/31/03 | - | sw212a | 13 | 0 / 0 | 0 | 32 | - | Breached off |

Acoustic survey. De03

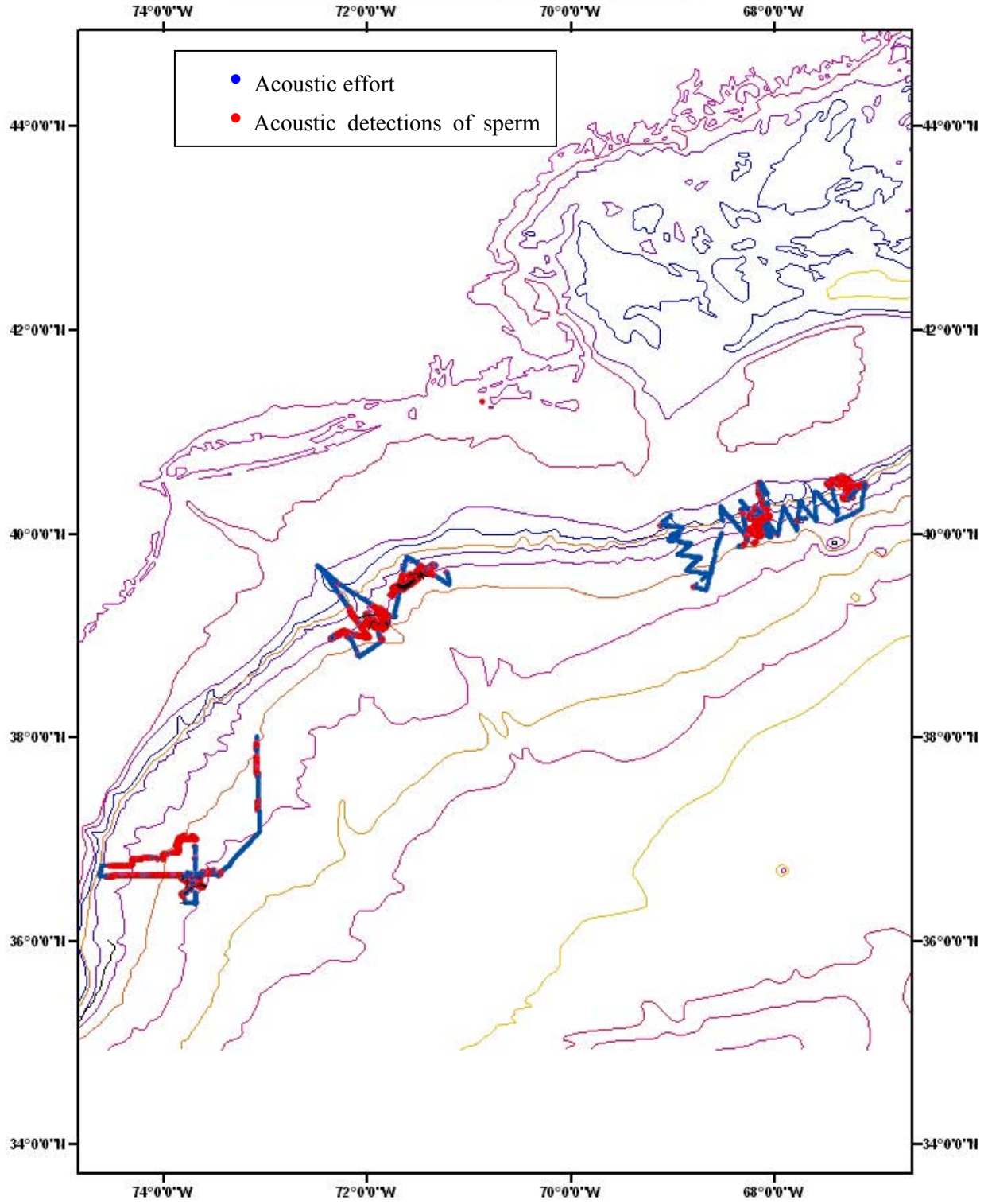


Figure 2. Acoustic survey track lines for the R/V Delaware cruise.

Visual effort and Tags locations

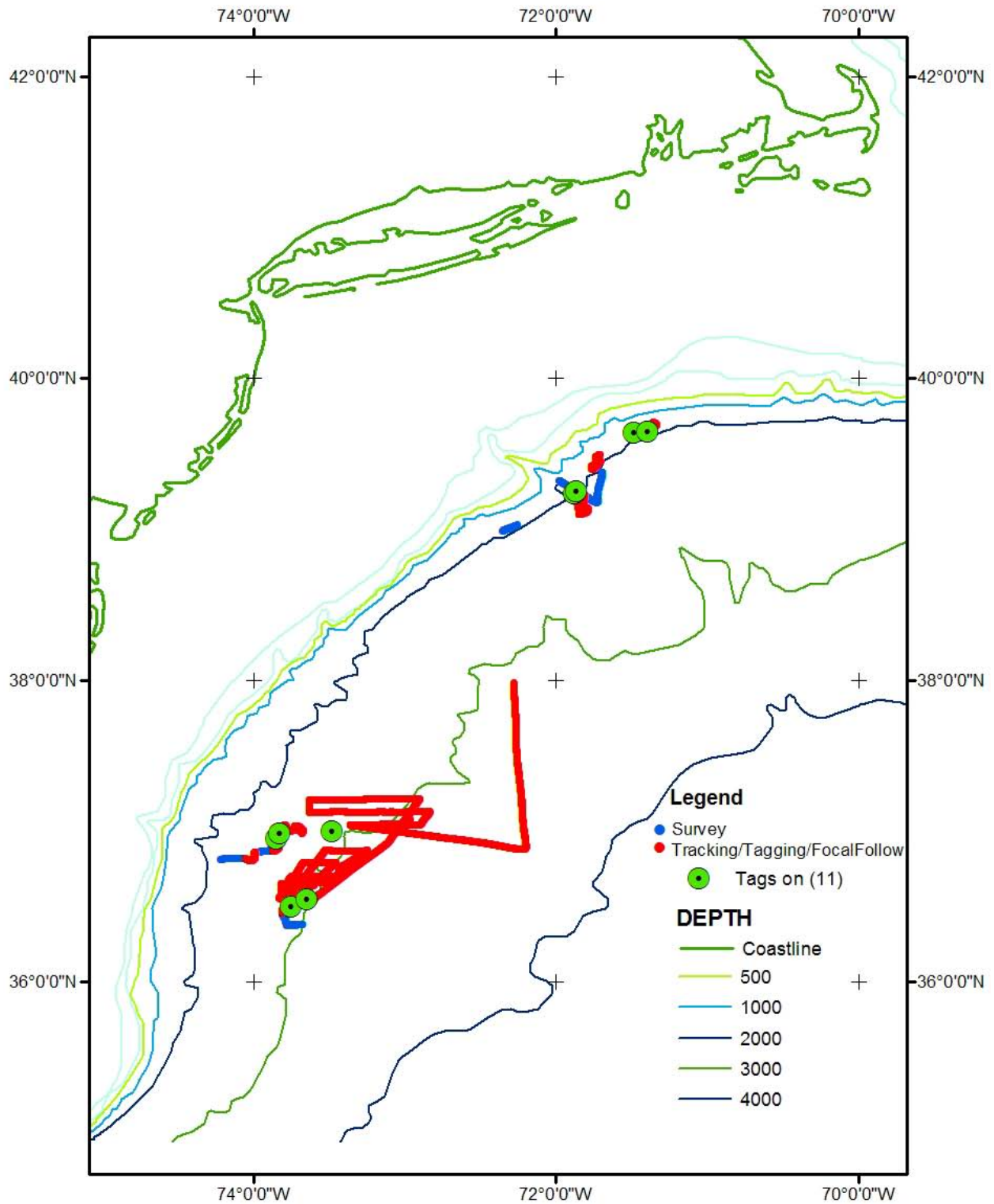


Figure 3. Visual survey and focal follow tracklines for the *R/V Delaware* cruise.

4. DATA SUMMARY

As shown in Table 2, a total of 12 DTAGs were deployed which yielded nine data sets of dive patterns. In addition, shipboard acoustic recordings and visual sightings of cetaceans were also collected. A full copy of all data was provided to NEFSC at the end of the cruise for archiving. The procedure for quality assurance, archiving and handling each data source is described below.

4.1 DTAG DATA

The tag data comprises two streams: the audio recording and the sensor stream. Sound from the tag is archived to a sequence of audio files in WAV format. The sampling rate for all tags except sw212a was 96kHz and the resolution was 16 bits (Table 2). The data in the WAV files corresponds to the raw analog acquisition: a magnitude of 32,768 corresponds to a full-scale input on the analog-to-digital converter. The frequency range of the audio acquisition was from about 100Hz to 46kHz with a flat response from 400Hz to 45kHz. The format for audio data as stored on the tag contains a built-in quality check with regularly spaced repeated samples and cyclic-redundancy error checking. The sensor data from the tag are archived in a sequence of 12-channel WAV format files. Each channel corresponds to a physical sensor channel, namely: accelerometer x, y, and z axes, magnetometer x, y and z axes, depth, temperature, and four variables related to engineering variables within the tag. The sampling rate of each sensor channel is 50Hz. The raw tag data are archived on CDs in WHOI's marine mammal center managed by Research Assistant Amanda Hansen. The large WAV files are available on hard drives or can be regenerated from the raw data files on any PC. Sensor data are analyzed as described in Johnson and Tyack (2003), which also describes methods for quality assurance. Acoustic records are completely audited to produce a catalog of sounds produced by the tagged whale as well as other natural and man-made sounds recorded by the tag.

4.2 PERMIT DATA/CLOSE OBSERVATIONS FROM RHIB

During close approaches of the RHIB to whales, a range of data is collected for permit compliance, and for sizing and identifying individuals. These data include tagging location, reaction of the whale to tagging, tag placement, videogrammetry, and fluke identification photography. Visual observations are recorded on data sheets. Data sheets are copied while in the field for archival and a copy is maintained in the WHOI marine mammal laboratory. Video recordings are streamed into a computer using FireWire and back-ups made on CD. Fluke-shots and other images are extracted as high-quality bit-map images and contributed to local identification catalogues where they exist. A description of each whale approach is generated for Permit reporting purposes.

4.3 VISUAL DATA

The SACLANT-WHOI visual data collection system acquires ship location and heading at one-second intervals and stores this along with visual observations in a Microsoft Access format database. The visual observation data include the range and bearing from the ship to a whale and the aspect (i.e., the heading) of the whale. These data are used to produce a surface track of focal whales (see, for example, Figure 4) and to correct the dead-reckoned track derived from the tag data. Other visual data recorded include the species location and number of other species as well as the environmental conditions. Locations of whales sighted through the Big-Eye binoculars are determined from their relative bearing and reticle distance. The standard algorithm is used to convert reticles to distance in meters, based on the height from the water-line to the binoculars. The visual database is checked daily during the cruise to ensure that group ID's are correct, and that focal whales were correctly identified. The database is archived on CDs held at the WHOI marine mammal lab. After the cruise, surfacing locations of whales are plotted in MATLAB or Arcview and integrated with positions of the observation-boat.

4.4 ACOUSTIC DATA

Acoustic data comprise recordings made on the Alesis recorders, audio samples taken with Logger, and observations recorded with AcLogger. The recordings were backed up using external hard drives and these copies are maintained in the WHOI marine mammal lab. The start and end time of each recording is listed on a data sheet and the disks are sampled to check the recording quality. The AcLogger database was stored in Microsoft Access format and, during the cruise, was periodically archived to CD. A final copy is kept in the WHOI marine mammal lab. The acoustic recordings are used in after-the-fact data analysis for passive tracking and to link acoustic activity to sounds recorded on the tag.

4.5 SKIN AND FECAL SAMPLES

Feces and sloughed skin material were occasionally collected during close approaches to whales using a dip-net. Skin was also sometimes found on the DTAG suction cups after tag recovery. Anticipating this, the suction cups are sterilized before each deployment. The location and ID of the animal from which the material was collected are recorded on data sheets. A total of nine skin samples and two fecal samples were collected from tags or during tagging on the *R/V Delaware* cruise. Skin samples were stored in vials of DMSO during the cruise and then split for analysis by two separate laboratories. One set of samples was sent to Dan Englehaupt at the University of Durham to determine gender and relatedness. Dan has processed samples collected with DTAGs from the Gulf of Mexico and the Mediterranean and will examine relatedness of the North Atlantic whales with these populations. The other set of samples will be analyzed at the NMFS laboratories to compare against samples from previous biopsy efforts in the North Atlantic. For samples with substantial material, excess material will be added to a library of genetic material maintained by NMFS. Fecal samples were first checked for skin that was removed and handled as above. Filtered fecal material was frozen and then taken by NEFSC for analysis.

4.6 CTD DATA

Eleven CTD casts were deployed during this cruise. During each cast the depth, salinity, and temperature were recorded continuously as the CTD was lowered to 200m or to near the bottom, whichever was shallower. These data were recorded on a ship's computer in real-time as the CTD was deployed. After the deployment the data were checked, printed, and a backup copy was made. After the cruise, these data were processed, checked, and then archived by NEFSC staff in the Oceanography Branch. The data are available on line after they pass QC tests.

4.7 ENVIRONMENTAL AND SHIP LOCATION DATA

Environmental and ship location data are continuously collected 24-hours a day. Data fields include time, location, wind speed and direction, depth, chlorophyll-a, and barometric pressure. At the end of each cruise these data are routinely archived at the NEFSC.

July25_sw206A&B&C

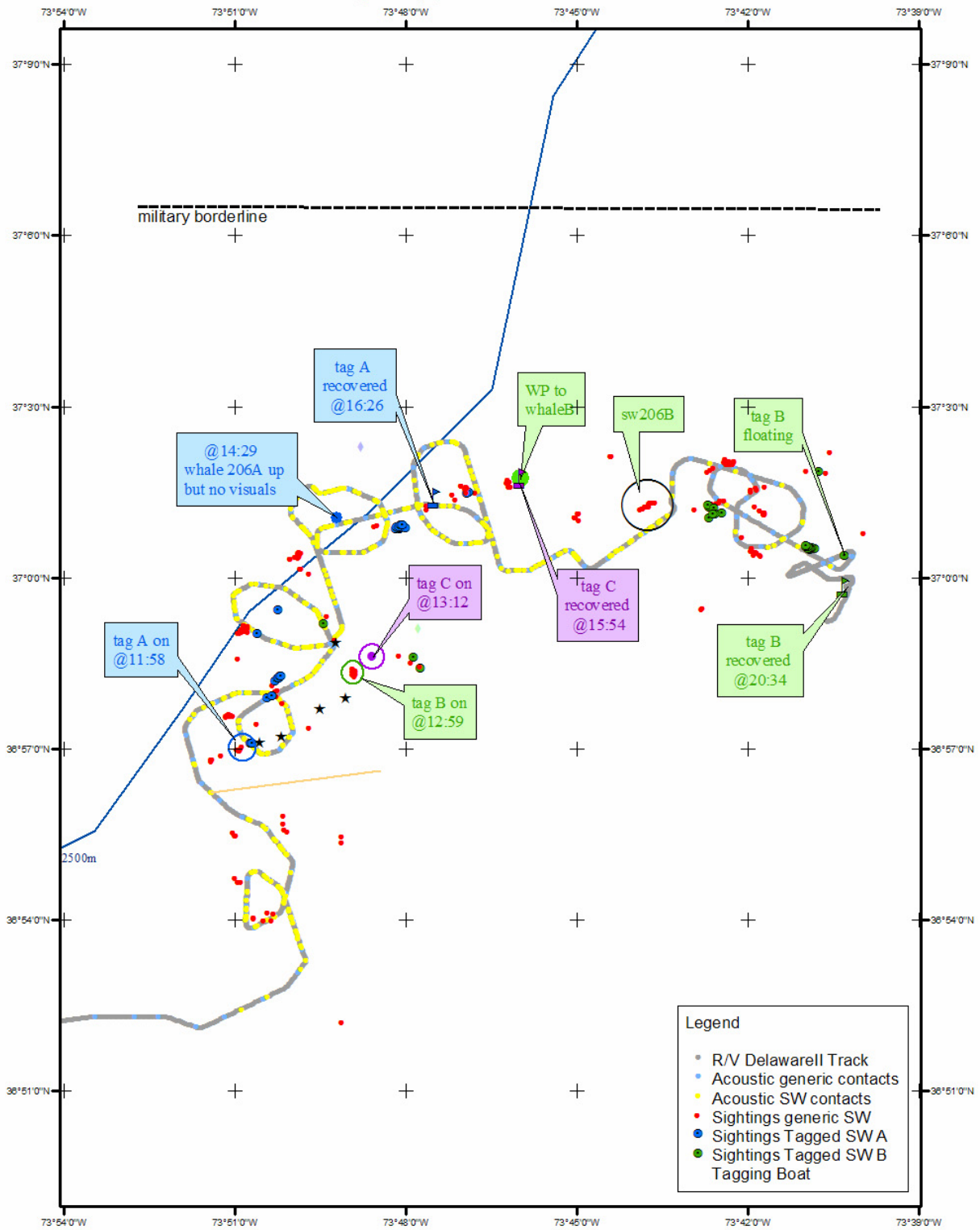


Figure 4. Example of a visual observation chart produced by the SACLANT-WHOI system.

5. DATA ANALYSES AND RESULTS

5.1 TAG DATA

Analysis of the tag and supporting data proceeds in two phases. The first phase consists of low level auditing of the data. In this phase, the sensor data are calibrated based on laboratory and field calibration values and checked for quality. The data from the orientation sensors (magnetometer and accelerometer) must also be corrected for the tag position on the whale that is estimated from visual sightings of whale aspect (i.e., compass heading) during surfacings as well as photographs and video taken from the tag boat. The tag position is then refined iteratively in order to maximize the consistency of the data. This technique, developed under the SWSS program, takes advantage of the fact that, in normal diving behavior, a sperm whale has a zero mean pitch and roll while at the surface and does not roll during the initial few seconds of a steep (i.e., non-social) dive. This method can also be used to detect a change in placement of the tag that could occur due to sliding. The end result is an accurate time series of the whale orientation parameterized by the Euler angles pitch, roll, and yaw. The accelerometer used to determine pitch and roll is inherently sensitive to sudden changes of movement as well as orientation and these give rise to an error in the orientation estimate. Fortunately the occasional episodes with strong dynamics due to sharp acceleration or turning can be readily identified in the data and flagged as inaccurate. The final step in the sensor data preparation is to combine the visual tracks with the DTAG pitch and roll time series to produce a dead-reckoned 3-dimensional track of the whale.

The initial processing of the audio data from the tag involves careful listening of the entire recording by expert listeners. A data sheet is used to record every vocalization from the tagged whale and other nearby whales as well as sounds from movement, vessels etc. Key features are entered into a database. These include creaks (fast click sequences associated with foraging, also referred to as buzzes), codas (stereotypical click sequences associated with socializing), and the start and end of regular clicking in each dive. The audio data are also inspected for echoes from the sea floor to determine the depth of the whale relative to the bottom.

The second phase of data analysis is to examine the meta-data products produced in the first phase (described above) to determine behavioral states, estimate foraging efficiency, look for evidence of foraging specialization, and to examine social interactions. The same low-level processing has also been performed for tag data acquired during the SWSS and Mediterranean studies. The resulting meta-data has a well-defined format facilitating comparisons between data sets and so the analytic value of the North Atlantic tag data will extend well beyond the time frame of the current project.

We are in the process of preparing a paper based on the North Atlantic data and present here an overview of the two main behavioral states represented in the data: foraging and socializing.

The following are key definitions. “Foraging dives” are defined as a deep, typically U- or V-shaped dive (Figure 5). “Foraging dive series” are foraging dives separated by an “inter-dive interval”, defined as a brief time near the surface (Figure 5). Foraging dive series are separated by “surface intervals”, defined as an extended near-surface period (Figure 5). Foraging dives consist of an “ascent” and “descent” phase (Figure 5). The descent is the period of time from where the whale left the surface until the pitch first became positive (whale was no longer oriented downward). The ascent started when the whale was last oriented downward ($\text{pitch} \leq 0$) and ended when the whale reached the surface.

5.1.1 Dive Behavior

The North Atlantic tags recorded sequences of deep and shallow dives, similar to those observed elsewhere. Table 3 summarizes the dive parameters (as defined in Figure 5) of the tagged animals from the North Atlantic. The dive times and descent/ascent rates are typical of sperm whales in other study areas (Table 4). Dive depths were on average deeper than in the Gulf of Mexico: four of seven deep-diving whales in the North Atlantic dove below 1000m with a deepest dive depth of 1186m. This is more similar to the diving behavior recorded from isolated large males in the Mediterranean, where dives to 1250m have been recorded. According to published bathymetry, the water depth at the North Atlantic tagging locations was between 1500m and 3000m. No bottom echoes have been found in the tag audio data indicating that the whales were at least 500m above the bottom and suggesting that the tagged whales were foraging in the mid-water column, like those in the Mediterranean deep water. In contrast, whales tagged in the Gulf of Mexico and in the Gulf of Genova in the Mediterranean often dove close to the

bottom that was at a depth of between 600 and 1000m, so there were bottom echoes on these tag audio data.

The tag audio recording was typical of that recorded in the Gulf of Mexico. Deep dives contained regular clicking with interspersed creaks while codas were common in shallow dives and during the near-surface portions of deep dives. The following sections describe the occurrence of sounds in these two dive classes in more detail.

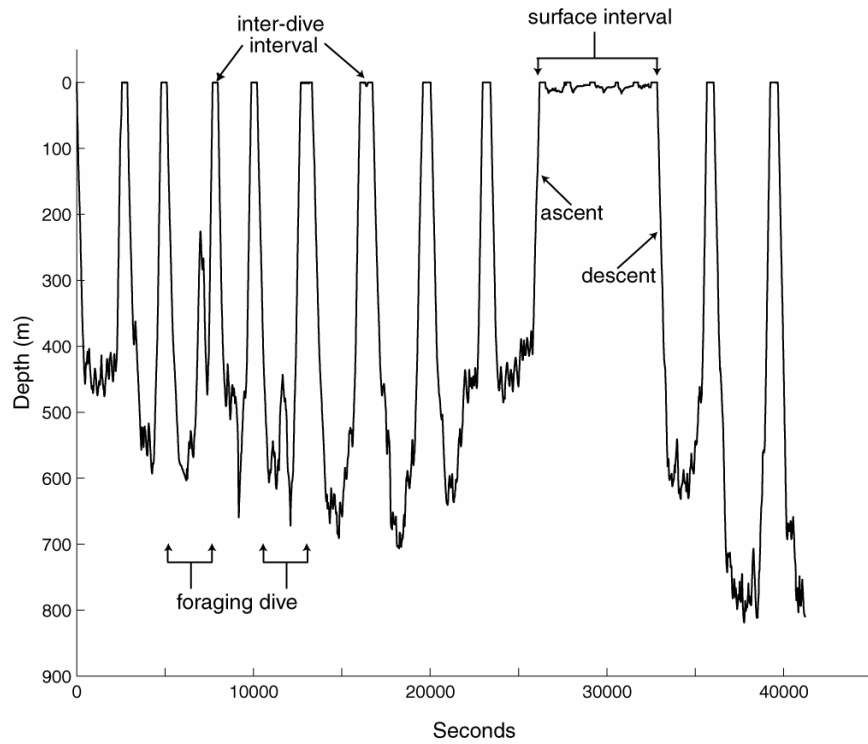


Figure 5. Typical elements in a normal dive profile.

Table 3.

Dives Recorded by DTAG during the *R/V Delaware* Cruise

| Whale | # Full dives | Dive duration (min) | Surface time (min) | Descent rate (m/sec) | Ascent rate (m/sec) | Max depth (m) |
|-------|--------------|------------------------|-----------------------|-------------------------|------------------------|------------------|
| 197A | 2 | 53 | 26 | 1.3 | 1.5 | 720 |
| | | 50 | | 1.1 | 1.2 | 821 |
| 197B | 2 | 42 | 73 | 1.0 | 1.2 | 816 |
| | | 40 | | 1.1 | 1.0 | 986 |
| 201A | 0 | - | 221 | - | - | 49 |
| 201B | 2 | 55 | 72 | 1.3 | 1.4 | 970 |
| | | 55 | | 1.2 | 1.2 | 1186 |
| 202A | 1 | 39 | 21 | 1.1 | 1.5 | 920 |
| 202B | 0 | - | 120 | - | - | 17 |
| 206A | 4 | 41 | 39 | 1.3 | 1.3 | 952 |
| | | 42 | | 1.1 | 2.2 | 942 |
| | | 40 | | 1.4 | 1.7 | 927 |
| | | 39 | | 0.9 | 2.0 | 1016 |
| 206C | 3 | 47 | 31 | 0.9 | 1.4 | 976 |
| | | 43 | | 1.6 | 1.3 | 947 |
| | | 43 | | 1.0 | 1.6 | 1040 |
| 207A | 4 | 45 | 194 | 1.2 | 1.4 | 891 |
| | | 43 | | 1.1 | 1.4 | 915 |
| | | 46 | | 0.9 | 1.7 | 1013 |
| | | 41 | | 1.3 | 1.1 | 871 |

Table 4.

Average Duration (in minutes) and Depth (in meters) of Dive Features (defined in Figure 5) from Animals Tagged in the North Atlantic, Gulf of Mexico, and Mediterranean

| Area | Average Duration (min) | | | | |
|----------------|---------------------------------|---------|---------------------|---------------------|------------------|
| | Foraging Dive | | | Inter-Dive Interval | Surface Interval |
| | Total | Descent | Ascent | | |
| North Atlantic | 44.6 | 24.4 | 20.2 | 7.1 | 70.0 |
| Gulf of Mexico | 44.7 | 22.2 | 22.4 | 8.2 | 63.7 |
| Mediterranean | 40.3 | 24.4 | 19.3 | 9.7 | 57.5 |
| Area | Average Depth (m) | | | | |
| | Maximum Depth of Foraging Dives | | Inter-Dive Interval | Surface Interval | |
| | | | | | |
| North Atlantic | 933.9 | | 1.15 | 5.6 | |
| Gulf of Mexico | 638.7 | | 0.45 | 4.6 | |
| Mediterranean | 797.3 | | 0.34 | 4.9 | |

5.1.2 Foraging Behavior

Table 5 lists the key acoustic features of the deep foraging dives recorded in the North Atlantic. Regular clicks started at depths typically seen in other areas, but some animals kept clicking on the ascent (see especially sw03_201b), which had not commonly been documented before. Looking at the depth distribution of whales from the three study sites, shown in Figure 6, it appears that the North Atlantic whales spend comparatively less time at the maximum dive depths and rather more at intermediate

depths. This is in agreement with the observation that the North Atlantic profiles are somewhat more V-shaped than those seen elsewhere. Some example dive profiles are shown in Figures 7 to 12 with acoustic features superimposed. Creaks also occur over a much broader depth range than that documented in the other study sites. Although the majority of creaks still occur near the base of the dive, the occasional shallow creaks and continued clicking through the ascent may indicate opportunistic foraging at shallower depths perhaps taking advantage of dispersed layers of prey. This represents a point of difference as compared to the Gulf of Mexico and Mediterranean data in which foraging appears to be limited to the base of the dive or to several distinct deep layers. Sperm whales, although primarily teutophagus, are known to also eat fish. In future work, we plan to examine fisheries information for the North Atlantic to identify possible meso-pelagic prey species.

Table 5.

Regular Clicks and Creaks Recorded by DTAGs on Atlantic Sperm Whales

| Whale | Dive | Regular clicks start (m) | Regular clicks stop (m) | # Creaks/dive | Creak depth |
|-------|------|--------------------------|-------------------------|---------------|-------------|
| 197A | 1 | 130 | 527 | 20 | 537-720 |
| | 2 | 147 | 508 | 17 | 636-803 |
| 197B | 1 | 154 | 640 | 8 | 653-816 |
| | 2 | 130 | 587 | 7 | 613-917 |
| 201A | | | | | |
| 201B | 1 | 253 | 157 | 32 | 225-975 |
| | 2 | 110 | 483 | 30 | 583-1192 |
| 202A | 1 | 340 | 628 | 18 | 598-923 |
| 202B | | | | | |
| 206A | 1 | 370 | 483 | 23 | 589-954 |
| | 2 | 225 | 652 | 29 | 657-952 |
| 206C | 1 | 86 | 543 | 27 | 635-986 |
| | 2 | 342 | 673 | 29 | 675-923 |
| | 3 | 339 | 649 | 30 | 543-1032 |
| 207A | 1 | 378 | 503 | 29 | 743-893 |
| | 2 | 331 | 339 | 25 | 415-918 |
| | 3 | 317 | 461 | 32 | 501-873 |
| | 4 | 373 | 461 | 18 | 461-596 |

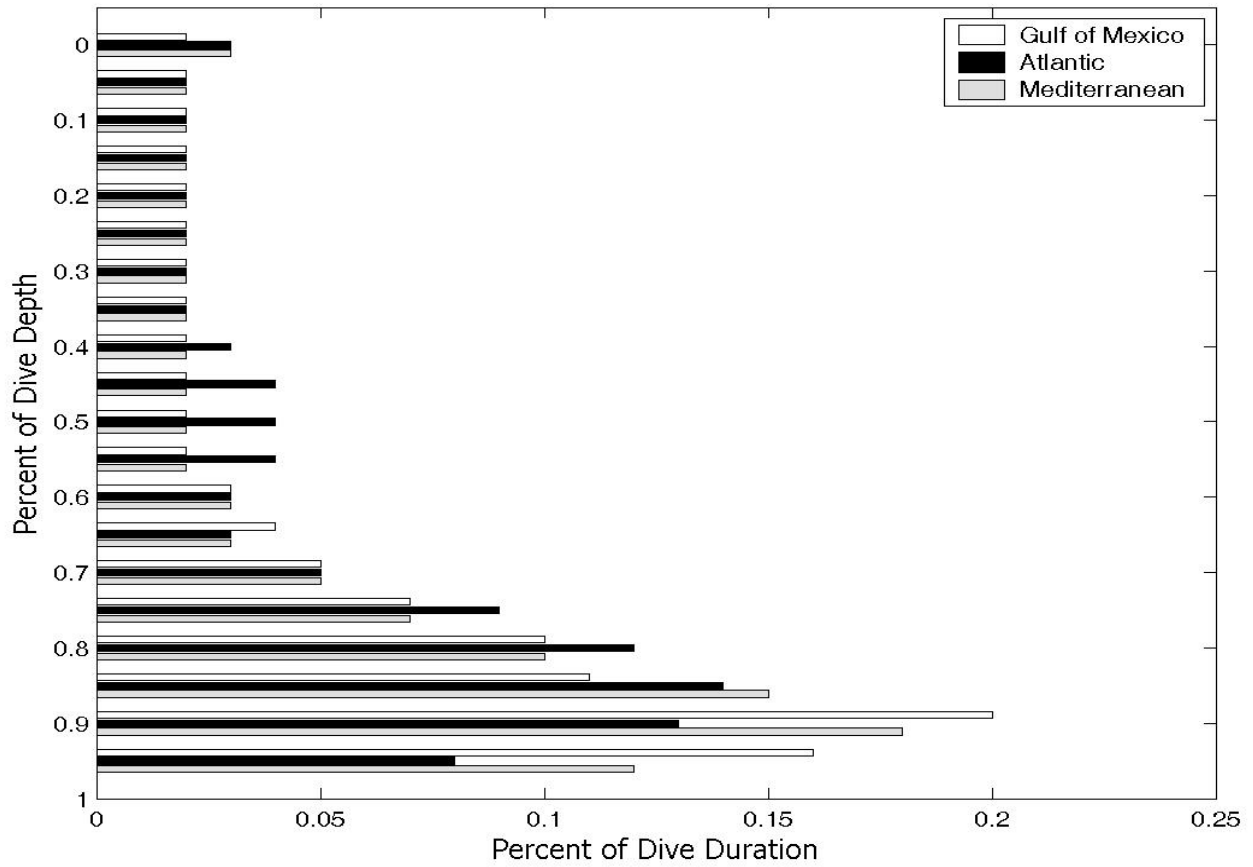


Figure 6. Average normalized foraging dive profile for sperm whales in the Gulf of Mexico, Atlantic, and Mediterranean.

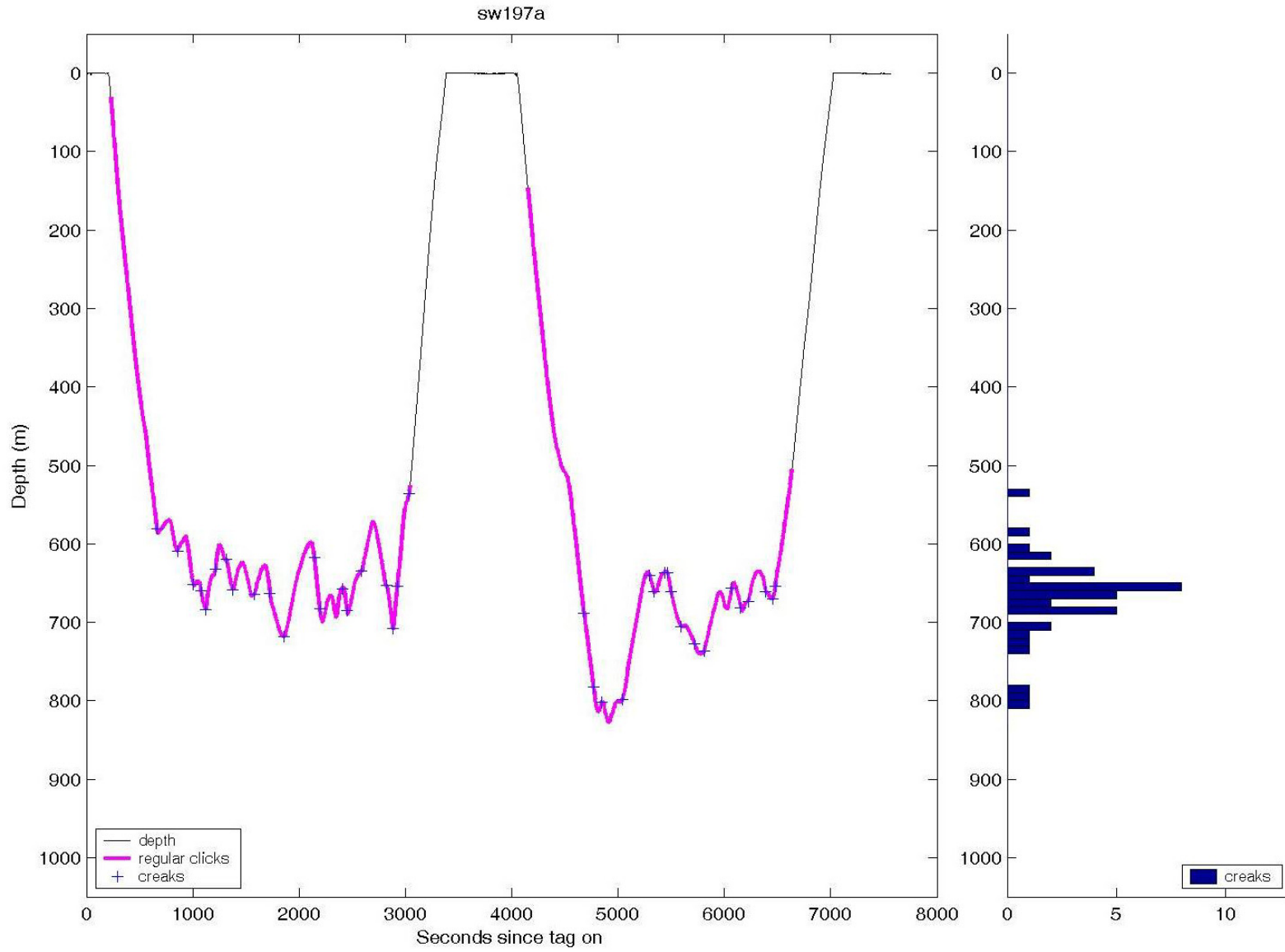


Figure 7. Dive profile indicating sound events for sw03_197a.

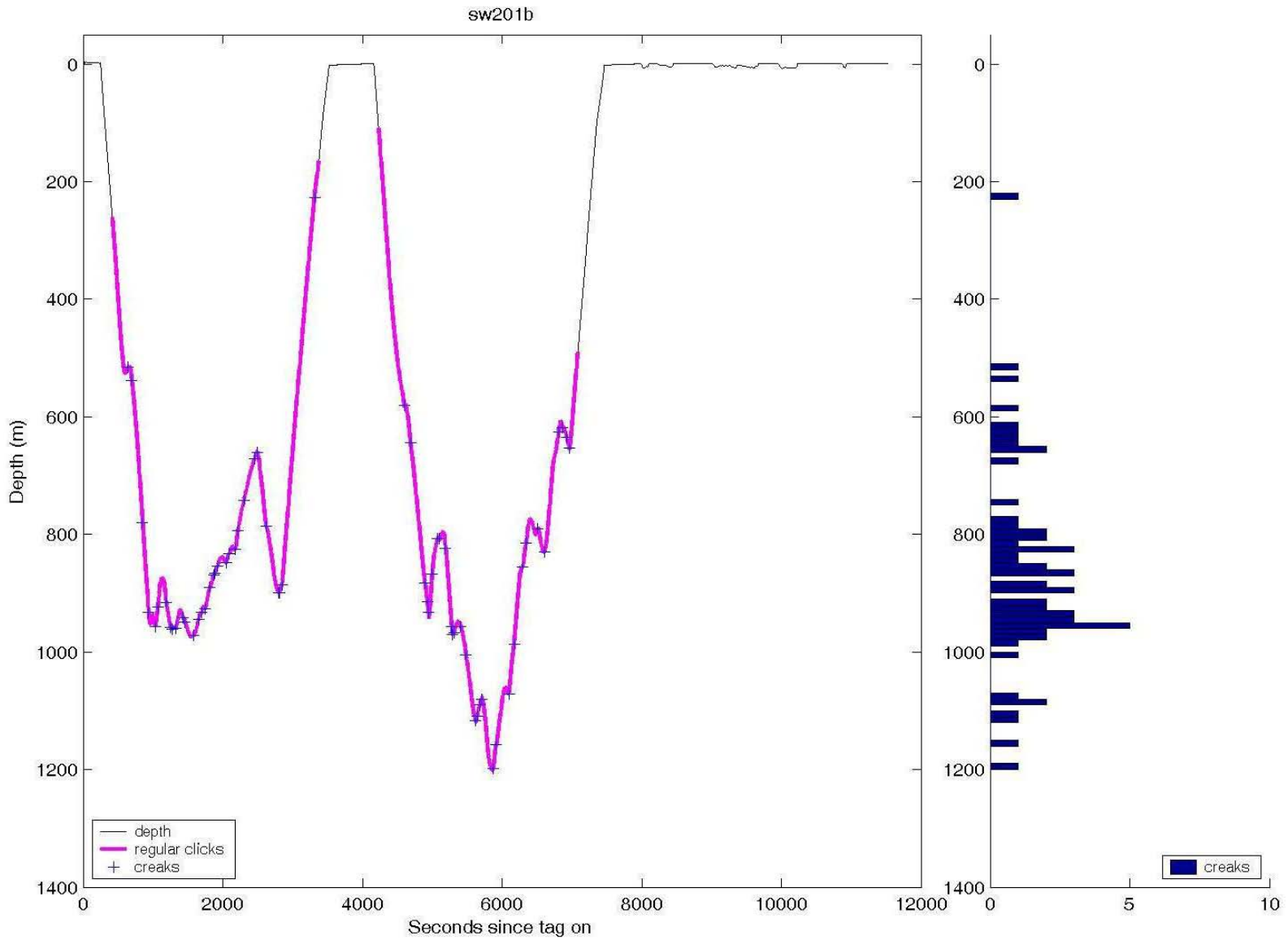


Figure 8. Dive profile indicating sound events for sw03_201b.

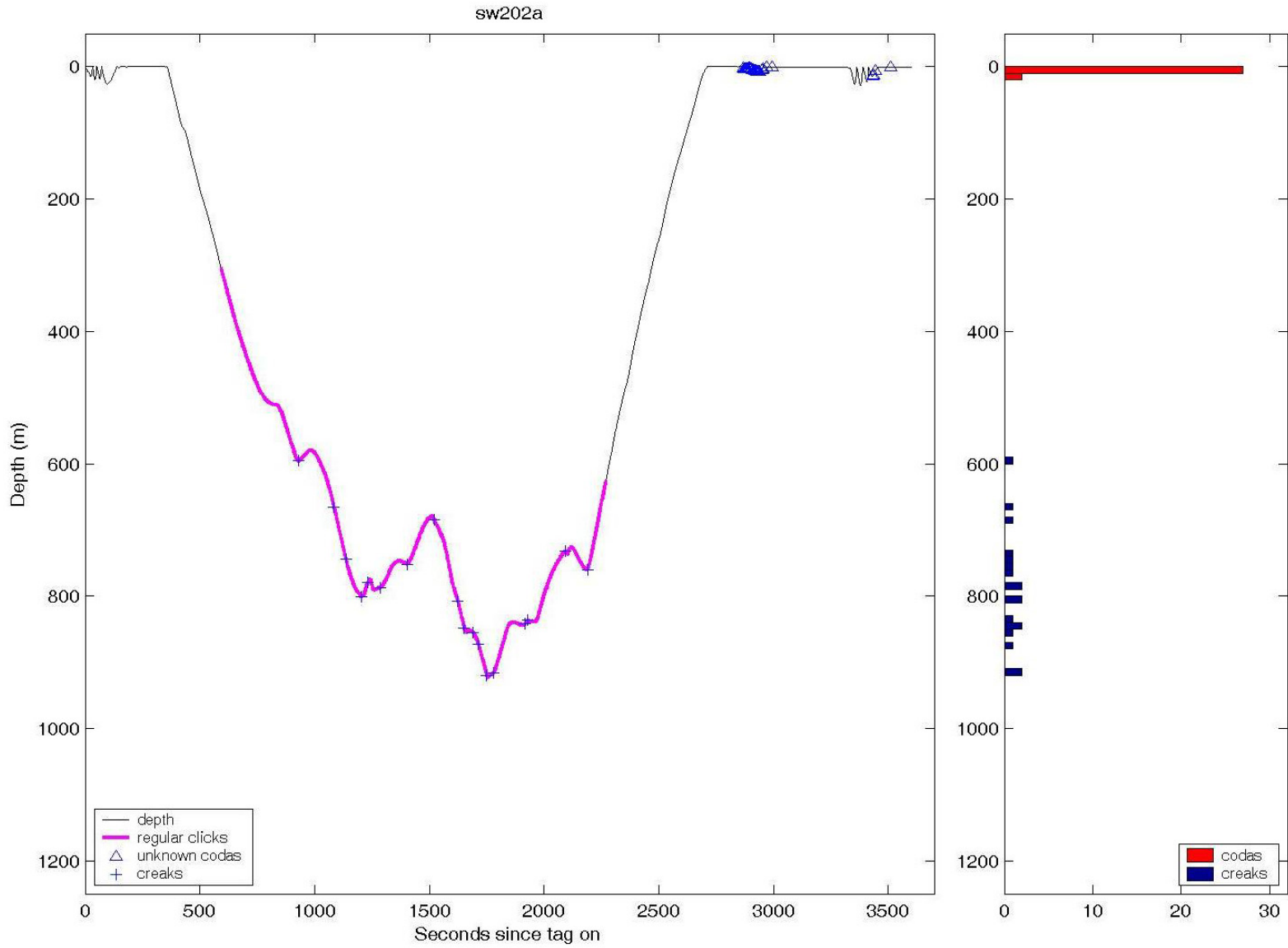


Figure 9. Dive profile indicating sound events for sw03_202a.

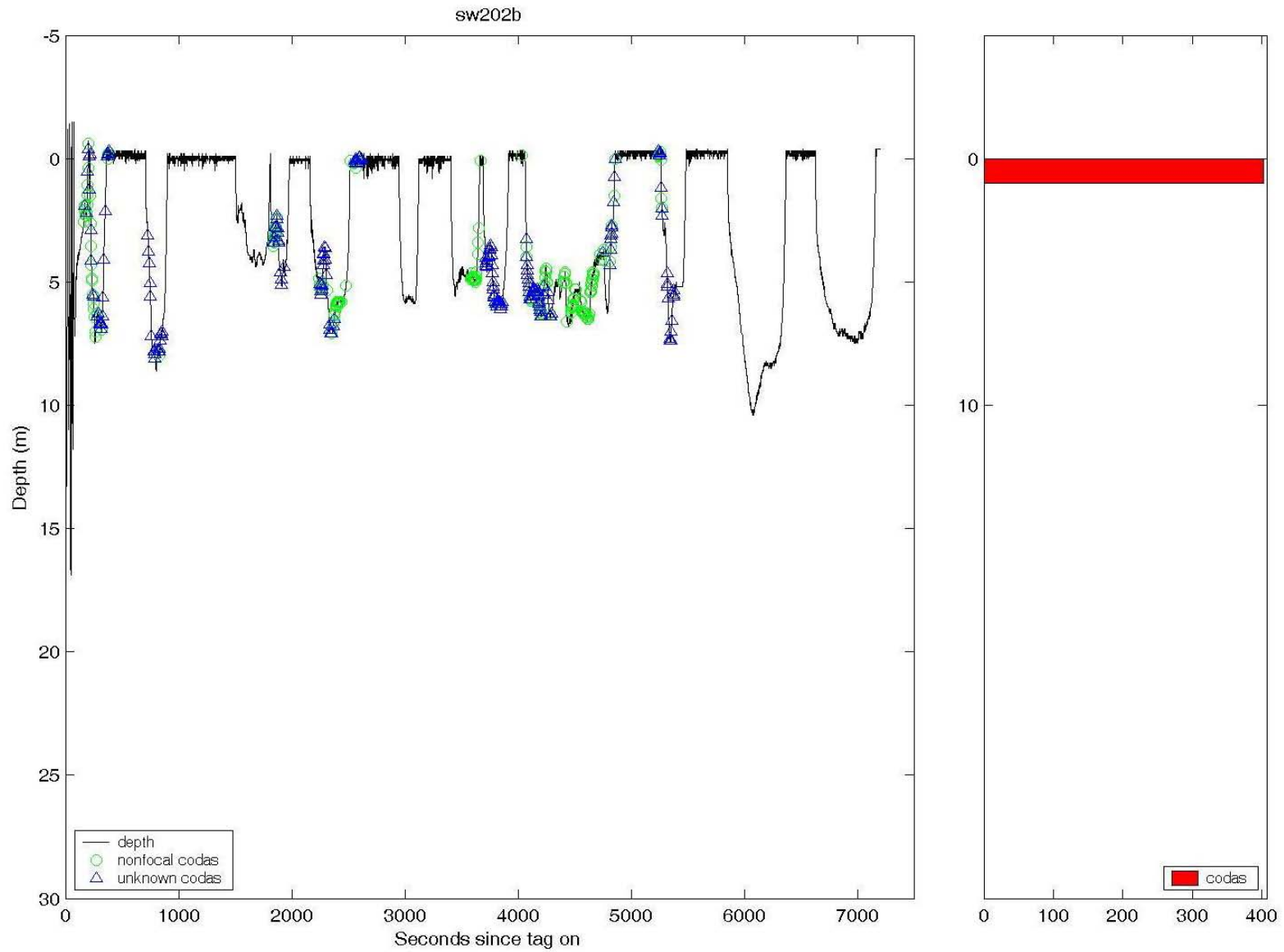


Figure 10. Dive profile indicating sound events for sw03_202b.

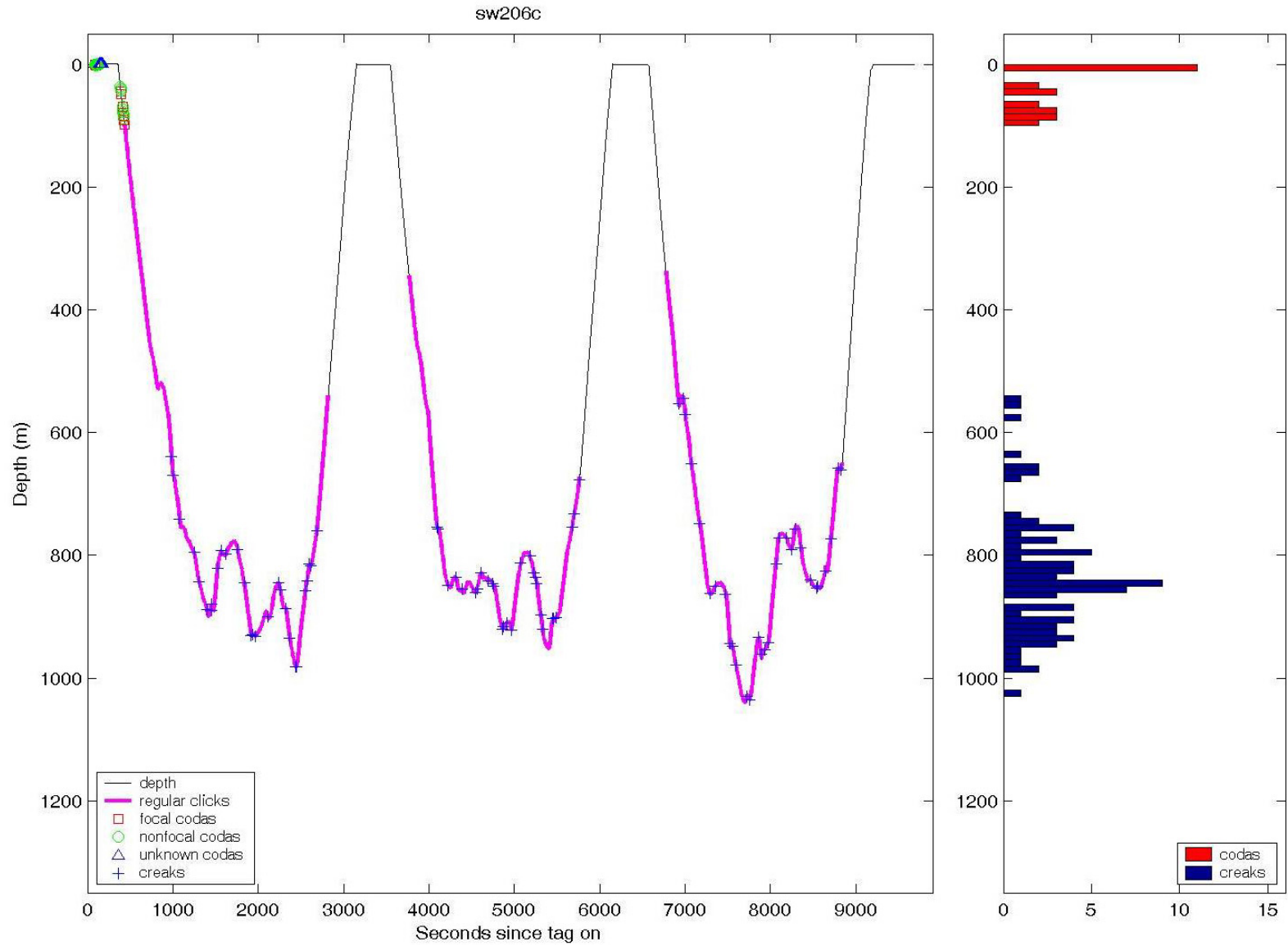


Figure 11. Dive profile indicating sound events for sw03_206c.

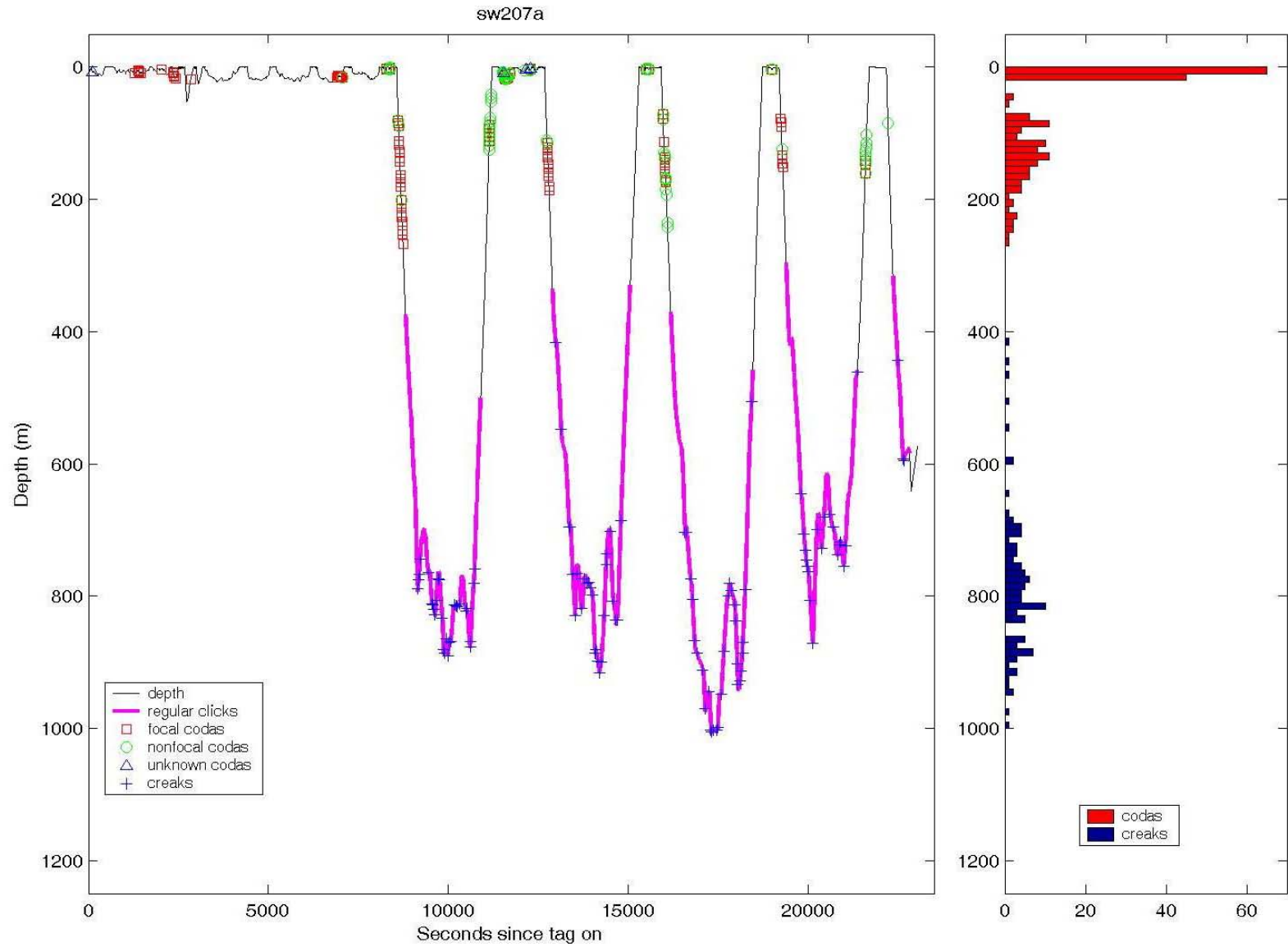


Figure 12. Dive profile indicating sound events for sw03_207a.

5.1.3 Social Behavior

As shown in Figures 7 to 12, codas (stereotypical click patterns) were often heard near the surface. Codas were made both by deep-diving whales during the descent and ascent, and by whales performing shallow dives. A number of tag recordings made on the *R/V Delaware* cruise contained extended periods with shallow (<50m) dives and many codas. Codas are considered strong indicators of social behavior and were frequently accompanied, in the tag recordings, by sounds from other nearby conspecifics (usually also codas) and rubbing sounds from body contact. Out of the nine DTAG recordings, four contained codas (Table 6). Although it can be difficult to judge if a particular sound was made by the tagged whale or by another whale nearby, codas were identified in two recordings that were unambiguously produced by the tagged whale. On average, there were 121 codas on a given tag, with 45 being assigned to the tagged whale.

Table 6.

Codas Recorded on DTAGs during the *R/V Delaware* Cruise

| Data set | Tagged whale | Untagged whale | Unknown |
|----------|--------------|----------------|---------|
| 202A | 0 | 0 | 29 |
| 202B | 0 | 201 | 224 |
| 206C | 17 | 20 | 4 |
| 207A | 118 | 85 | 4 |

Figures 13 and 14 show the depth histogram of coda production in the three study sites divided according to whether the coda was produced by the tagged (focal) whale or the untagged (nonfocal) whale. Whales in the North Atlantic tended to produce most of their codas in the shallowest part of the foraging dive (i.e., at the very beginning and end of the dive). No codas were recorded below 300 m. In the Gulf of Mexico, whales tended to produce codas throughout the upper 50% of their foraging dives. Most codas were produced above 300 m, although two whales produced codas between 300 m and 400 m. Tagged whales in the Mediterranean produced codas at up to 70% of their maximum dive depth, far deeper than in the other two regions. Three Mediterranean whales produced codas between 500 m and 700 m.

Figure 14 shows the depths at which codas from an untagged whale were recorded by the tag. This figure has a similar form to Figure 13, indicating that focal sperm whales tend to produce codas when they hear them from other animals and that other animals respond to codas produced by the focal whale.

Figures 15 to 18 show the average number of codas produced by tagged and untagged whales during foraging dive descents (Figure 15), ascents (Figure 16), inter-dive intervals (Figure 17), and surface intervals (Figure 18). Although codas were produced and heard during all phases of the dive cycle, by far most codas were produced during surface intervals. However animals tend to spend less of their day in the surface behavioral mode than in foraging dives, and so the low number of codas produced in each foraging dive still represent a significant portion of the total coda count. Codas were rarely produced during inter-dive intervals, i.e., between foraging dives.

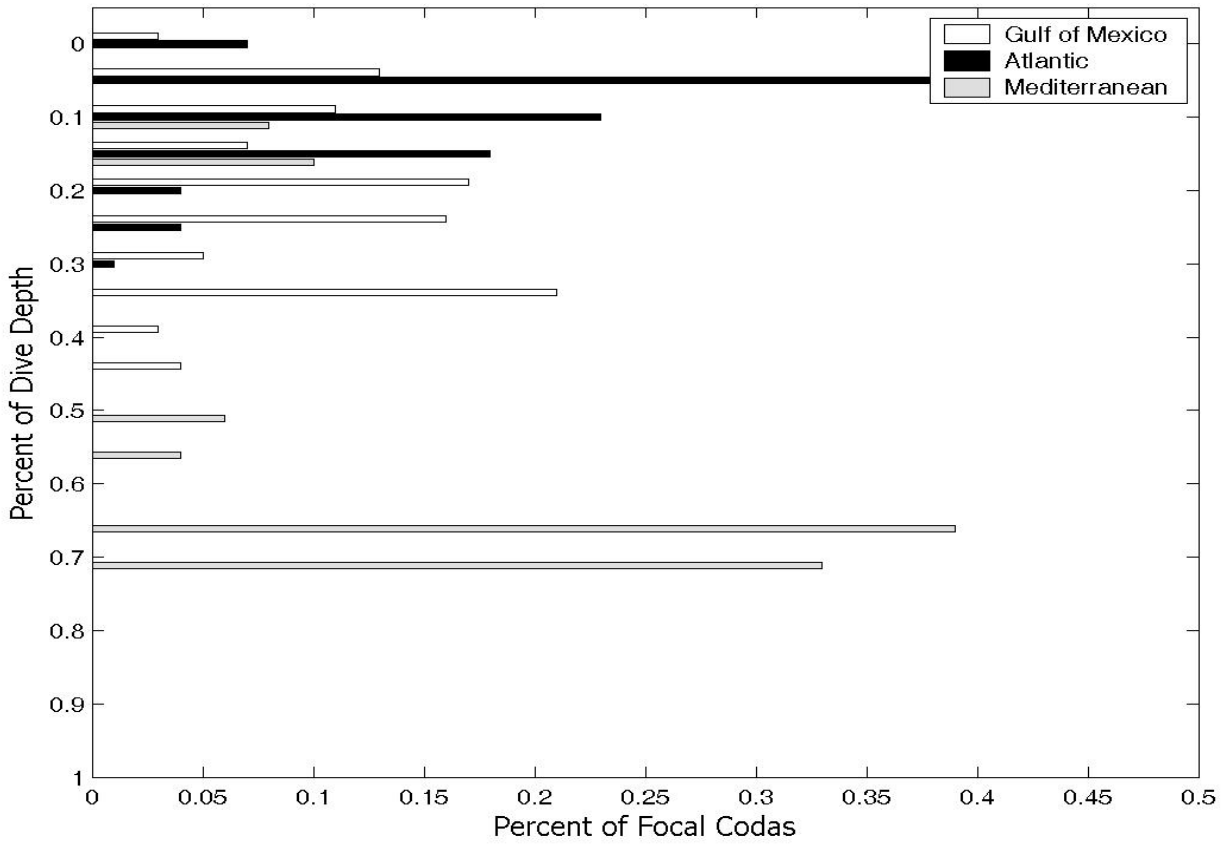


Figure 13. Depth occurrence of codas normalized by dive depth produced by tagged sperm whales in the Gulf of Mexico, the Atlantic, and the Mediterranean.

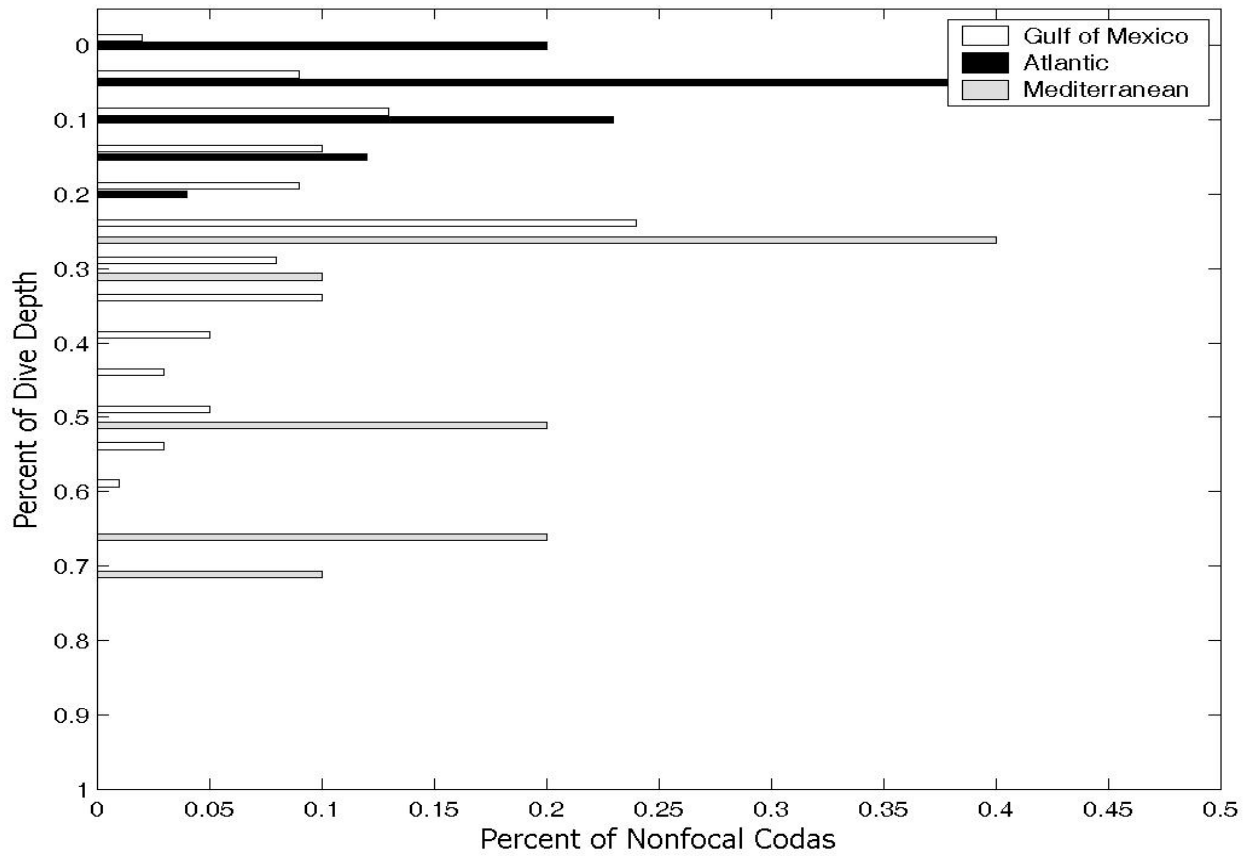


Figure 14. Depth occurrence of codas normalized by dive depth produced by untagged sperm whales in the Gulf of Mexico, the Atlantic, and the Mediterranean.

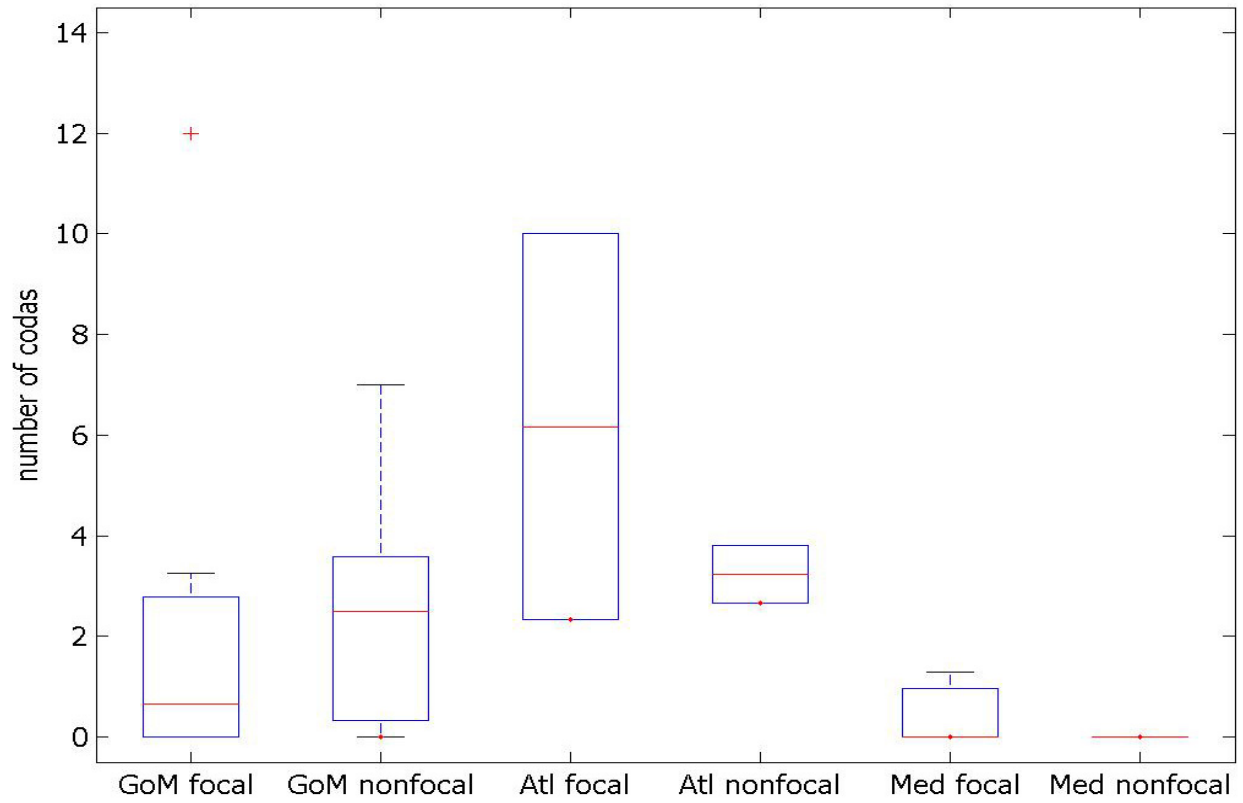


Figure 15. Average number of codas produced and heard per animal per descent in the Gulf of Mexico, Atlantic, and Mediterranean. The box has lines at the lower quartile, median, and upper quartile.

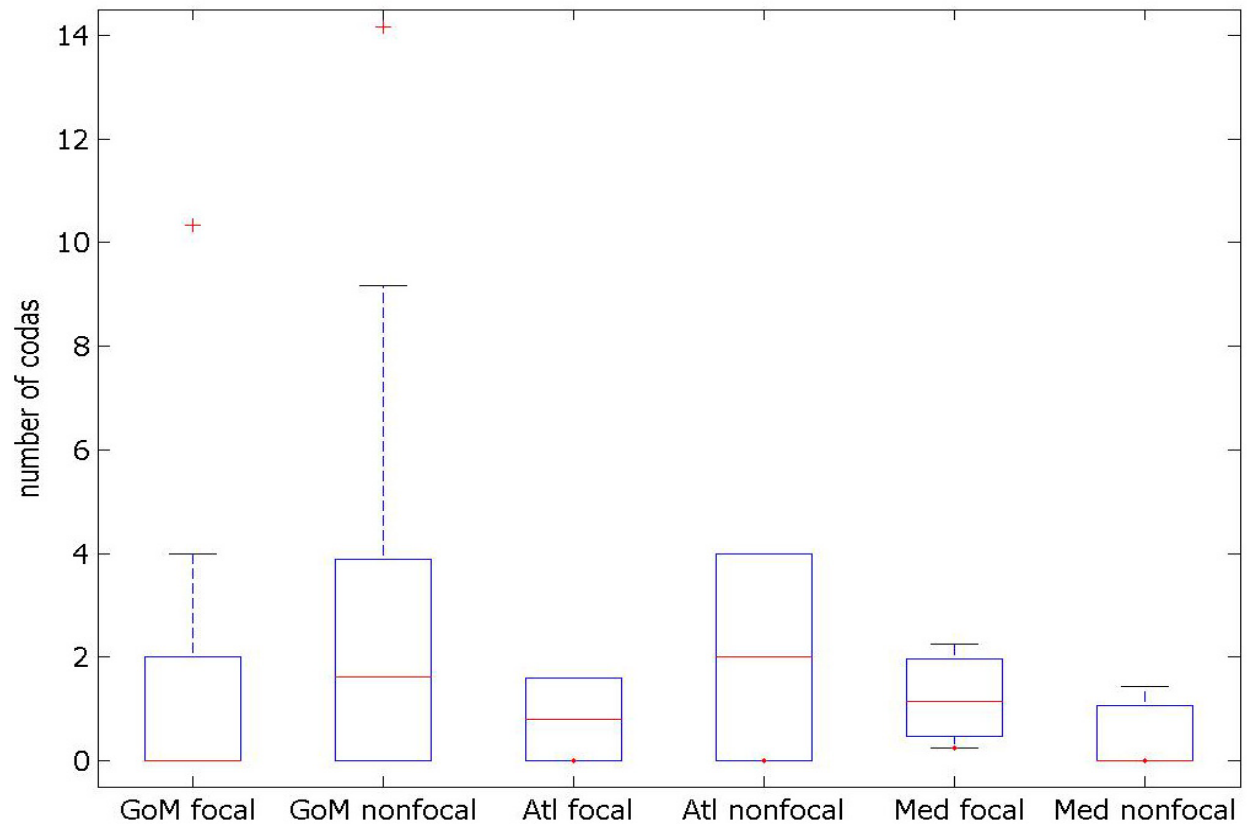


Figure 16. Average number of codas produced and heard per animal per ascent in the Gulf of Mexico, Atlantic, and Mediterranean. The box has lines at the lower quartile, median, and upper quartile.

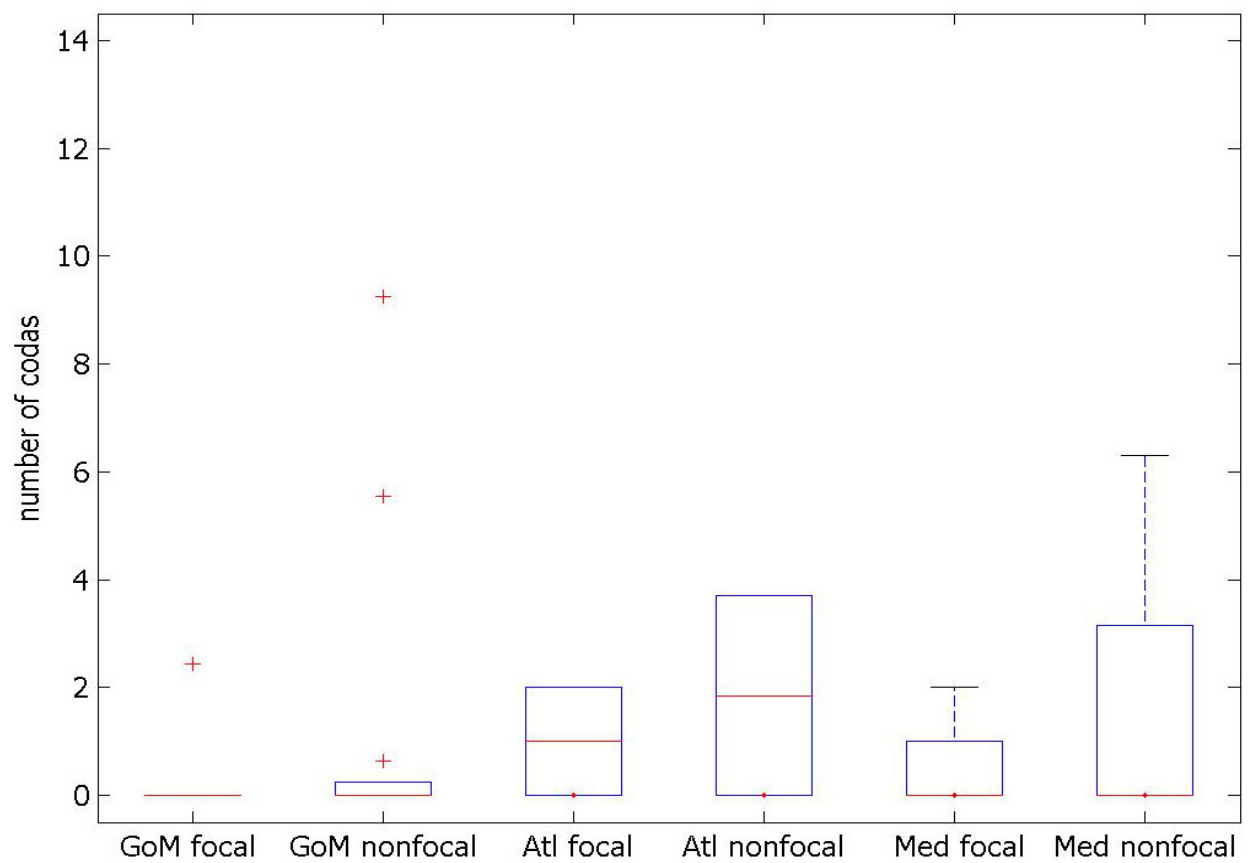


Figure 17. Average number of codas produced and heard per animal per inter-dive interval in the Gulf of Mexico, Atlantic, and Mediterranean. The box has lines at the lower quartile, median, and upper quartile.

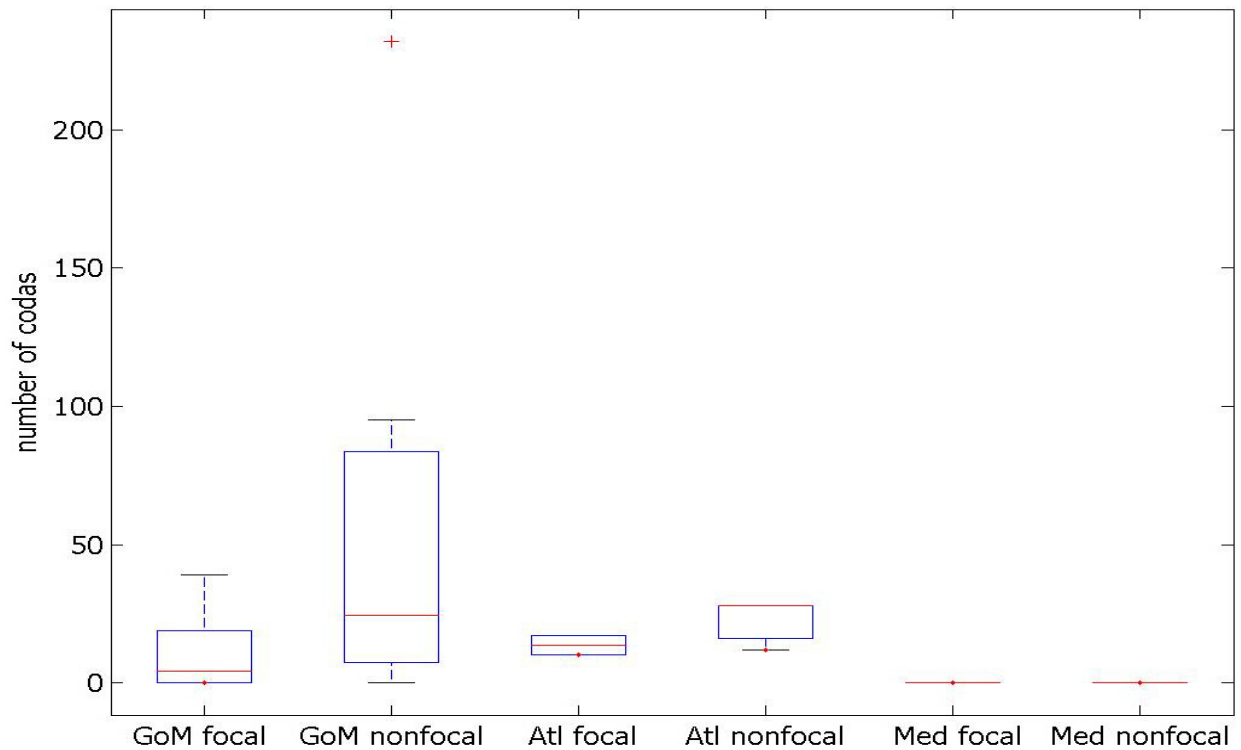


Figure 18. Average number of codas produced and heard per animal per surface interval in the Gulf of Mexico, Atlantic, and Mediterranean. The box has lines at the lower quartile, median, and upper quartile.

Codas have previously been described as being produced primarily by animals tightly aggregated at the surface and during surface intervals. The data presented here demonstrate that codas are produced by animals during the descent and ascent portions of foraging dives as well, and are even produced at considerable depth (>500 m in the Mediterranean). This suggests that codas may be used generally by animals to maintain contact at all times, not just when at the surface.

The specific pattern of clicks in a coda has long been thought to indicate group allegiance or correspond to geographic location. Table 7 lists the numbers of distinct coda types recorded by tags in the North Atlantic. Although a wide variety of codas were heard, a majority of codas were of types 1 to 6. Nine, eight, and two click codas were common to two or more of the tag recordings, while all other coda types were only heard on a single tag recording. Tagged and untagged whales on the same tag recording seem to produce similar types of codas but whales tagged on adjacent days in close geographic proximity such as 206c and 207a do not seem to use similar coda types. This may reflect a diverse population in the North Atlantic or broad repertoire of codas. Work is continuing to compare coda usage between the three study sites.

Table 7.

Numbers of Different Types of Codas Produced by the Tagged or Focal Whale (F) and Non-focal Whales (NF) in the Atlantic for Three of Four Tags Containing Codas.

| Coda Type | sw03_206c | | sw03_207a | | Sw03_202b | |
|-----------|-----------|----|-----------|----|-----------|----|
| | F | NF | F | NF | F | NF |
| 1+4+1 | | | 52 | 58 | | |
| 2 | | | 26 | 21 | | 6 |
| 9 | 2 | 12 | 1 | | | 16 |
| 2+3+1 | | | 26 | | | |
| 8 | 11 | 3 | | | | 1 |
| 5+1 | | | 9 | 3 | | |
| 10 | 1 | | | | | 3 |
| 6 | | 2 | | | | |
| 1+3+1 | | | 1 | 1 | | |
| 11 | | 2 | | | | |
| 5 | | 1 | | | | |
| 2+1 | | | | | | 1 |
| 7 | 1 | | | | | |
| 4+2 | | | 1 | | | |
| 1+4 | | | | 1 | | |
| 8+1 | 1 | | | | | |
| 1+3+2 | | | | | | 1 |
| 1+4+2 | | | 1 | | | |
| 2+4+1 | | | 1 | | | |
| 10+1 | 1 | | | | | |

5.2 DIVE TIME CORRECTION FOR ABUNDANCE ESTIMATES

Abundance estimates of sperm whales have commonly been estimated from visual line-transect sighting surveys. That is, an observation platform (usually a ship or airplane) traverses a series of transect lines, and all detected animals of the target species are recorded, together with the perpendicular distance between the location of the group and the transect line. These perpendicular distances are then used to estimate the proportion of target animals that were missed within the searched area. Standard line transect approaches assume that detection of animals exactly on the transect line are seen with certainty. This assumption can be relaxed using multiple observation platforms, such as two teams of visual observers on one ship, as is used on abundance surveys conducted by the NEFSC (e.g. Palka 1995). However, for species, such as sperm whales, that spend a large percentage of their time below the surface, resulting visual abundance estimates even when using the two-team survey methods can still be severely under-estimated. Acoustic data could potentially be used in two ways to improve the sperm whale abundance estimates. One way is to utilize both visual and passive acoustic detections to estimate the abundance. The other way is to use acoustic tag (DTAG) data in surfacing-based analyses of visual line transect data. Both ways are discussed below.

5.2.1 Visual and Passive Acoustic Data

One approach to estimate abundance from visual surveys when detection on the track line is not certain is to combine distance sampling and mark-recapture methods and use multiple observation platforms. The most benefit is gained when the two teams use independent detection methods.

Following this logic, fundamentally, one platform could be the visual observers detecting surfacing sperm whales and the other platform could be the passive acoustic observers detecting below-surface vocalizing sperm whales. In addition, acoustic platforms are able to collect data in some conditions in which visual platforms cannot collect data, such as at night or in bad weather. However, the methodology for combining visual and acoustic surveys needs to be developed more fully. Currently, there is a new project to advance this method development that was recently funded by the Office of Naval Research. In this project the skills of survey specialists (Dr. David Borcher and Dr. Debra Palka), acoustic specialists (Dr. Jonathan Gordon, Dr. Doug Gillespie and Dr. Russell Leaper) and statisticians (Dr. Len Thompson) are joined to work together to develop the theoretical and practical aspects of this new method. Preliminary development of this method focused on visual-acoustic surveys of harbor porpoises (Borchers 2002). The intent of the new project is to expand these methods to utilize survey data from sperm whales. Actual data collected in the field are necessary to develop and test any analytical method. To fill this need, the visual and acoustic data collected during this cruise will be helpful. Though the main purpose of the cruise was not to conduct an extensive visual-acoustic abundance survey, the data collected during the Search Mode can be used as a test case. This new project has just been funded and so work has not yet started, but it is expected that the visual-acoustic data collected during the present cruise could be an extremely useful test case.

5.2.2 Visual and Acoustic Tag Data

Another way acoustic data could be used to improve visual line-transect abundance estimates is to use the dive time pattern data collected on the acoustic tag (DTAG) in a surfacing-based line-transect analysis method. Surface-based methods differ from conventional line-transect methods in that they involve modeling the probability that an individual surfacing of a whale will be at the surface and detected, whereas conventional line-transect analysis methods merely involves modeling the probability that a whale group will be detected, conditional that it is at the surface.

A simple implementation of using the dive time pattern data is to estimate total abundance of sperm whales that are at and below the surface as a function of: (i) the abundance using standard visual line-transect methods, assuming this is an abundance estimate of surface animals, and (ii) the percentage of time whales are at the surface. That is,

$$\text{total abundance} = \frac{\text{abundance at surface}}{\text{probability sperm whales are at the surface}} \quad \text{Equation 1}$$

Given the accuracy of the tag data and the fact that it is possible to see cetaceans when they are just under the surface, the animals can be assumed to be detectable by a visual sighting team when the tag records the animal is at or above 1 m depth. Of the nine animals with tag data, there are examples of animals diving deep and other animals making shallow dives. The percentage of time spent at the surface for the tagged animals varied from 16% to 50%, with a mean of 0.27 (CV = 0.46). If we assume these nine animals are representative of the dive patterns of the population, then there is a 27% (CV=0.46) chance that a single sperm whale is at the surface to be able to be detected by a visual sighting team. The sperm whale abundance estimated during the last Atlantic abundance survey in 1998 was 4029 with a CV of 0.38 (Waring et al. 2004). Using Equation 1, the dive time corrected total abundance of sperm whales would then be 14,922 (CV=0.60). However, this abundance estimate is biased upwards. This bias is due to the standard abundance estimate being based on detection of groups of whales that are typically greater than one and the probability of a whale being at the surface being based on singleton whales. The bias is due to the fact that individual sperm whales do not dive totally independent of the other animals in its group. During previous abundance surveys, the average group size ranged between two and three, however, there were groups of a dozen or so. This method is very simple and should not be considered as the best method to obtain the corrected total abundance estimate of a long diving animal. A more precise method is described below.

Surface-based line transect analysis methods, first suggested by Schweder (1977), takes explicit account of the fact that sperm whales are only visible when surfacing and can treat all animals separate of its group. A surfacing can be regarded as a single event. The surface-based approach then involves the estimation of the probability that a single surfacing will be detected, as a function of its location relative to the ship and the surfacing patterns of the whales. The conventional line transect detection function

uses a conditional detection function ($p(y)$), that is, the probability of a whale at a specific location relative to the ship will be seen is conditional on the whale not previously having been seen by that platform, where y is the perpendicular distance between the track line and the surfaced animal. The surface-based line transect uses an unconditional detection function ($q(y)$), that is, the probability that the surfacing whale is seen and no previous surfacing of that whale had been seen. An explicitly specified set of surfacing sequences can be used in the unconditional detection function or it can be assumed the surfacing pattern of a whale follows a specific process, typically the Poisson process. Since we have a set of surfacing sequences we can avoid assuming a parametric specification of the surfacing model.

In conventional line transect analyzes, the estimated abundance is:

$$N = nA / 2Lw \quad \text{Equation 2}$$

where n is the number of whales sighted, A is the area of the survey region, L is the total length of the track line and the effective half-strip width is:

$$w = \int_0^{\infty} p(y) dy \quad \text{Equation 3}$$

where $p(y)$ = the probability of a whale at a perpendicular distance of y will be seen, conditional on the whale not previously having been seen by that platform.

In the surface-based analysis method, the probability that a whale is at perpendicular distance y from the track line will be detected at least once is:

$$g(y) = (\alpha / v) \int_0^{\infty} q(x, y) dx \quad \text{Equation 4}$$

where α is the surfacing rate and v is the speed of the ship, x is the forward distance in Cartesian coordinates and

$$q(x, y, \beta)_i = p(x, y, \beta) \prod_{j=i+1}^{\infty} \left\{ 1 - p\left(x + v \sum_{k=1}^{j-1} D_k, y : \beta\right) \right\} \quad \text{Equation 5}$$

where β are the parameters of the model for $q(x,y)$, i is the i th surfacing in a long sequence of recorded dive times, D_k is the time interval between the k th and the $(k+1)$ surfacing in the dive sequence, and $p(x,y)$ is the conditional detection function which is the probability that a surfacing of a whale at a given position will be seen from a platform, conditional on the whale not being seen previously by that platform.

If the end of the dive sequence of one animal is reached, the sequence is assumed to move to the next animal and then when the last dive of the last animal is reached, the sequence is repeated. The value of $q(x,y)$ for a random surfacing at position (x,y) is the average $q(x,y)_i$ over the entire sequence.

There are several options for the functional form of $p(x,y)$. The preferred option is the logistic regression method used by Borchers et al. (1998) and Okamura et al. (2003):

$$p_i(y, z) = \frac{\exp\left(\theta_{i0} + \theta_{i1}y + \sum_{r=1}^R \theta_{i(r+1)}z_r\right)}{1 + \exp\left(\theta_{i0} + \theta_{i1}y + \sum_{r=1}^R \theta_{i(r+1)}z_r\right)} = \text{logit}^{-1}\left(\theta_{i0} + \theta_{i1}y + \sum_{r=1}^R \theta_{i(r+1)}z_r\right) \quad \text{Equation 6}$$

However other functions that could be investigated include the r-logx model from Schweder et al. (1997) and the product model from Cooke (1997).

The estimation of abundance using this method is presently underway, so results are not available.

5.3 HABITAT PREFERENCES

Another objective of this cruise and the SWSS cruises is to address the question, “Do sperm whales have preferred habitats that can be defined physiographically and/or oceanographically?” One way to address this is to model the distribution and abundance of the sperm whales with respect to physical and biological parameters, such as water depth, bottom slope, sea surface temperature, salinity at the surface, mixed layer depth, surface color (primary productivity), and distribution and abundance of other trophic

levels (such as that described from bongo samples). Such a model can also include nuisance variables, such as Beaufort sea state, which effects the sightability of the whales, but probably do not effect the actual distribution of the whales.

Before we can create a habitat model, the first step is to gather and process the data. For the 2003 cruise, satellite pictures of sea surface temperature (SST) and chlorophyll-a (chl-a) were obtained. A five-day composite from the middle of the cruise was produced by Dr. Jay O'Reilly of NEFSC at the Narragansett Lab in Narragansett, RI. Figures 19 and 20 show the sperm whale sightings overlaid on the 5-day composite of SST and chl-a, respectively. Such pictures have been produced for all the species detected during this cruise, however, due to space, they are not all displayed in this report. To further investigate any potential relationship with both SST and chl-a, plots of the locations of cetacean species with respect to the SST and chl-a were produced (Figure 21). Interestingly, sperm whales appear to be present in the most diverse combinations of SST and chl-a. This could mean they are not cueing in these two parameters. Perhaps because the sperm whales are generalists and so they are cueing on ocean bottom characteristics, not surface characteristics, like those measured by satellites.

The second step is to model the sperm whale distribution information. Because this cruise concentrated on putting tags on sperm whales and not investigating many type of potential habitats, not all types of potential habitats were sampled. However, the NEFSC, Woods Hole conducted a large scale line transect abundance survey in 1998 and is currently conducting one during the summer of 2004. The plan is to merge the line transect data of the 1998, 2003, and 2004 surveys to investigate habitat preferences of sperm whales in the Atlantic.

Stepwise selection of Generalized Additive Models (GAM) will be used to define a model that uses physical and biological parameters to describe the sperm whale habitat. An example of this type of analysis is using the 1998 data to model the distribution and abundance of sperm whales in five nautical mile sections of the track line with the following potential habitat descriptors: SST, water depth, plankton species groups, and Beaufort sea state. The stepwise GAM determined depth and an interaction between two groups of plankton species (groups 2 and 3) were the best predictors for sperm whale distribution and abundance (Figure 22), where depth was the most influential factor. Locations of sperm whales were inversely correlated to the location of Plankton group 3, which are species generally associated with warm core rings, and positively correlated with Plankton group 2, which are species most often associated with cooler waters, such as those on the outside edge of a ring or in between warm core rings. Thus, these GAM results can be interpreted as Atlantic sperm whales are found in waters approximately 2000 meters deep, when those waters are cool, like those found on the outside or in between warm core rings (Figure 23).

In future analyses using the three years of line transect data, environmental variables such as bottom slope, surface salinity, mixed layer depth, and surface chlorophyll-a levels will also be used as potential habitat descriptors, in addition to those in the 1998 analyses described above.

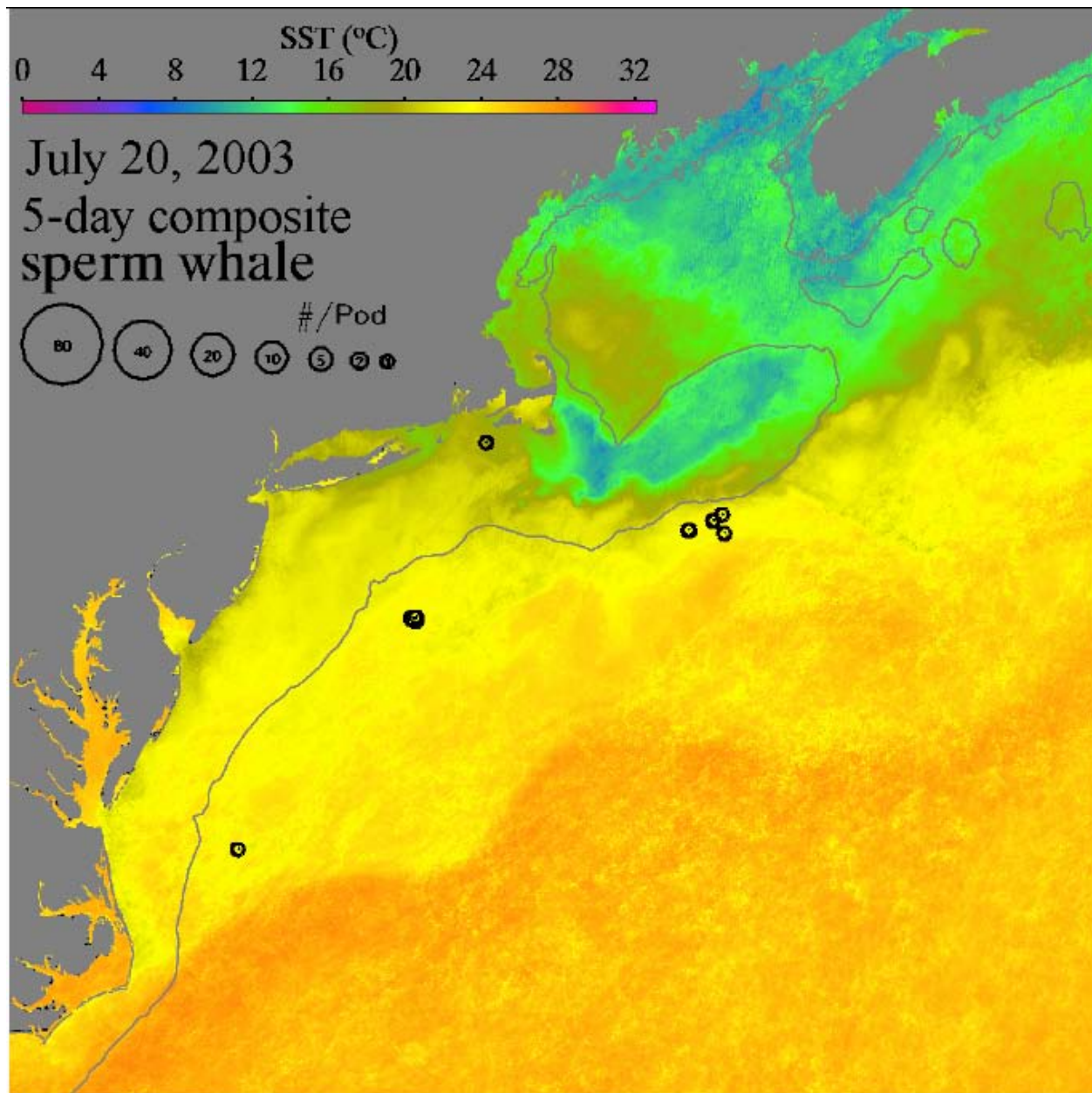


Figure 19. Distribution of sperm whales seen during 2003 cruise overlaid on a 5-day composite of the sea surface temperature (SST) from the middle of the cruise.

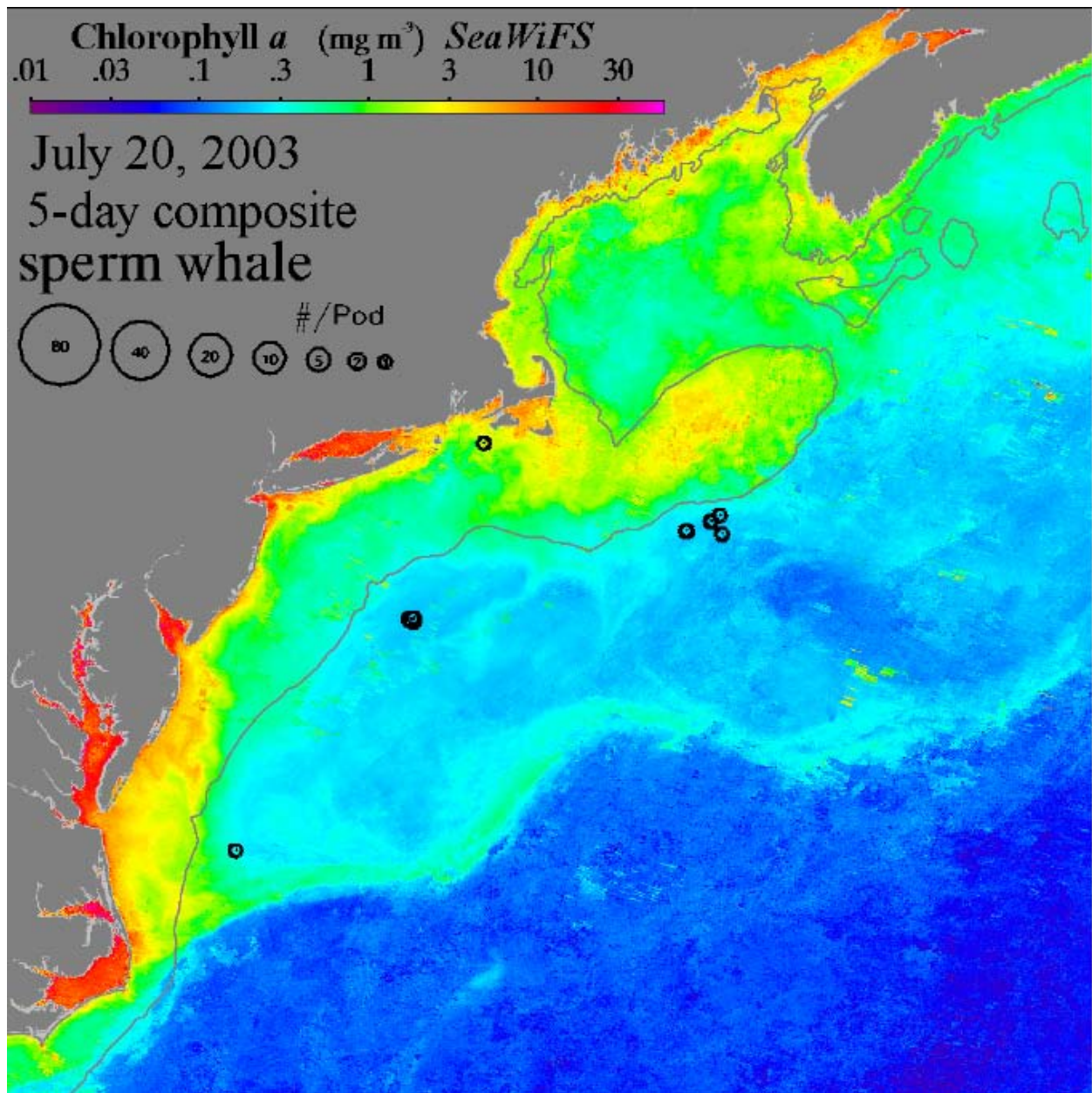


Figure 20. Distribution of sperm whales seen during 2003 cruise overlaid on a 5-day composite from the middle of the cruise of the chlorophyll-a as measured from SeaWiFS.

WHALES_2003_SURVEY SST vs CHLOR_A
 July 09 2003 - July 31 2003

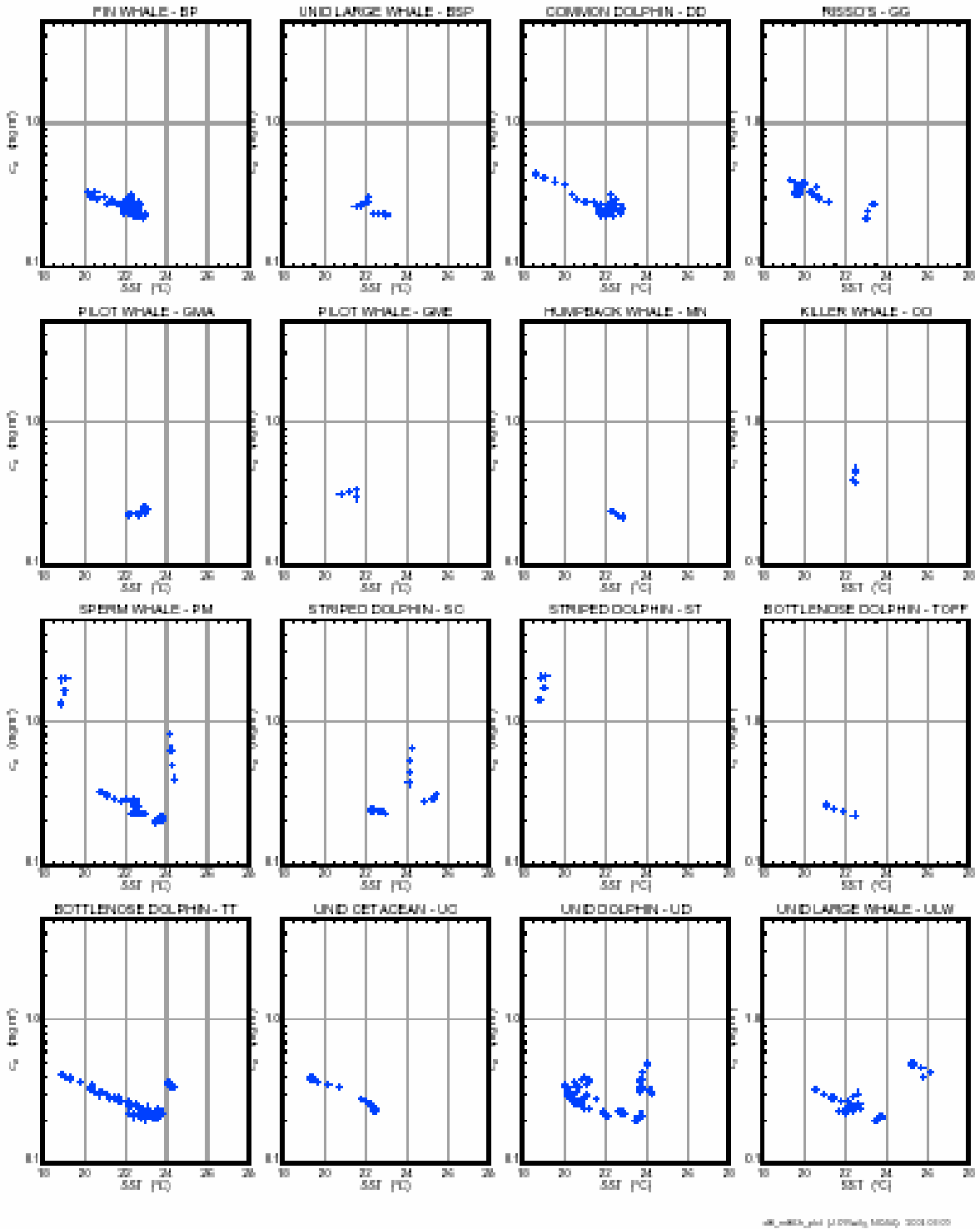
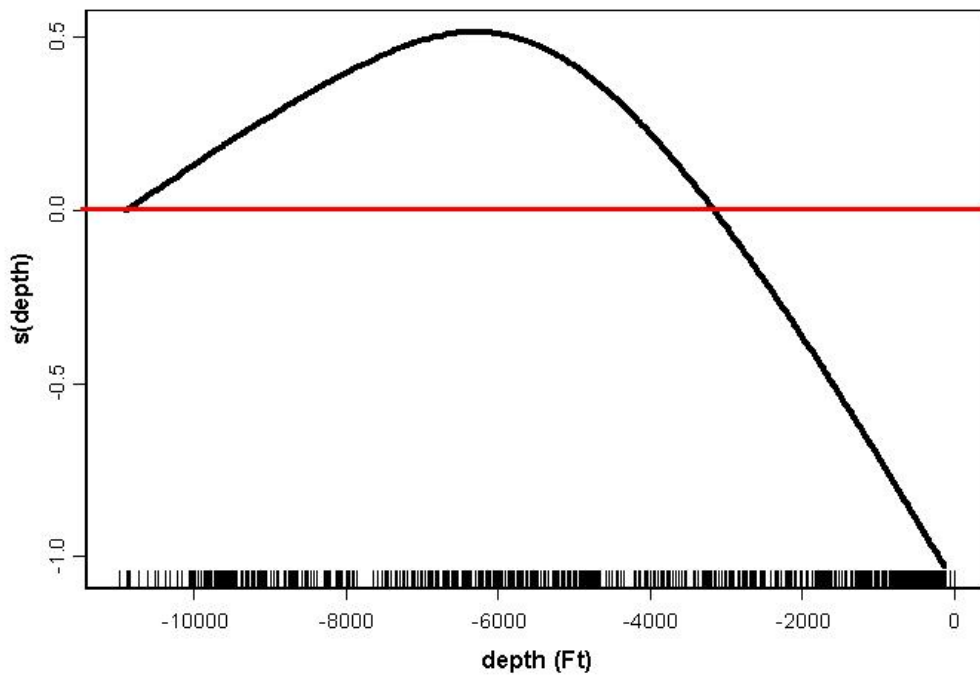


Figure 21. Distribution of cetaceans with respect to sea surface temperature (SST) and Chlorophyll-a (CHLOR-A) for all species detected during Survey Mode.

GAM for Sperm Whales



GAM for sperm whales

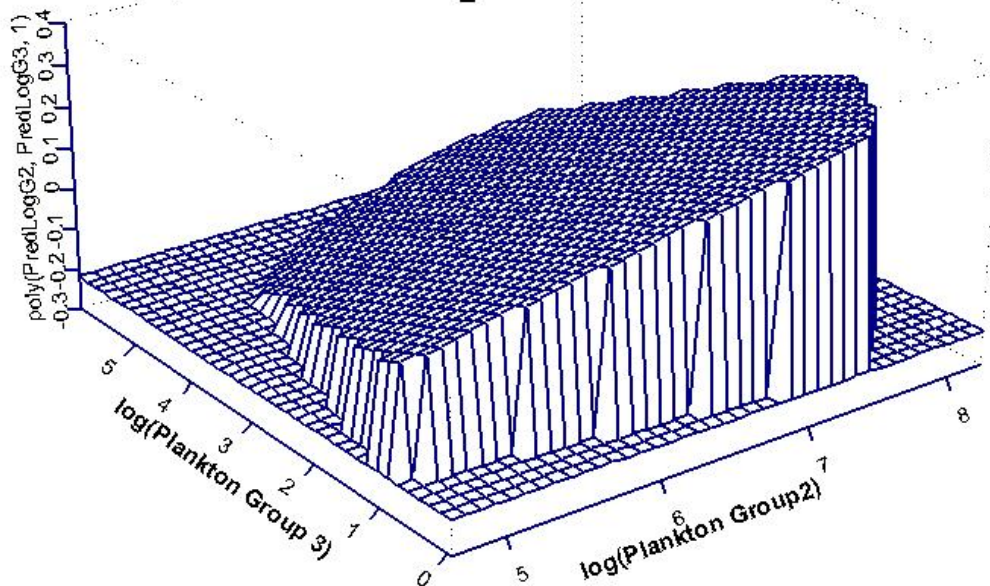


Figure 22. Results of applying Generalize Additive Modeling (GAM) techniques to model the abundance and distribution of sperm whales using water depth and the abundance of Plankton Group 2 and Plankton Group 3.

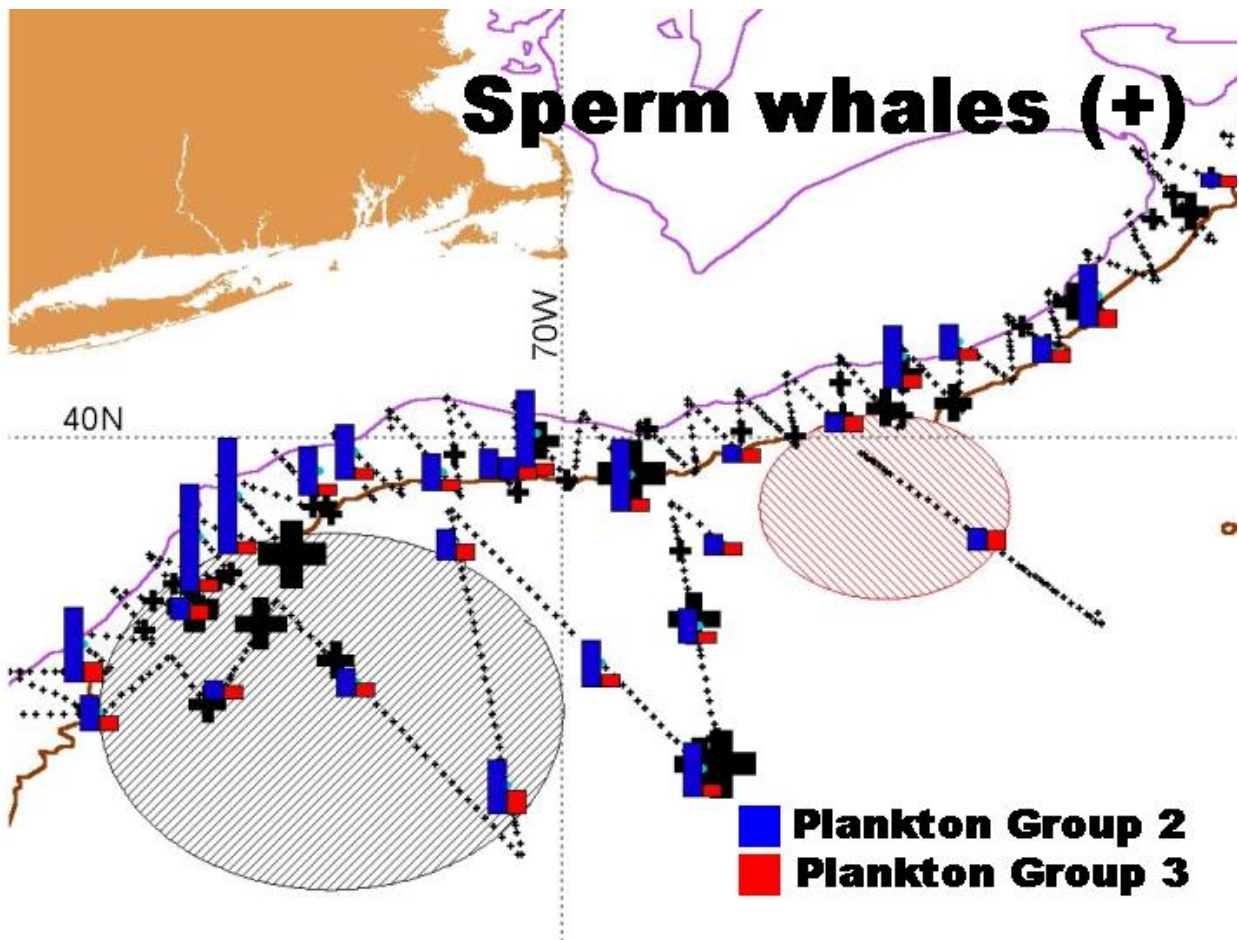


Figure 23. Location of sperm whale sightings (+) with respect to the shelf edge, two warm core rings, and levels of abundance of Plankton Group 2 and 3 (the taller the bar, the more plankton of that group there are at the locations of the sperm whale sightings).

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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.