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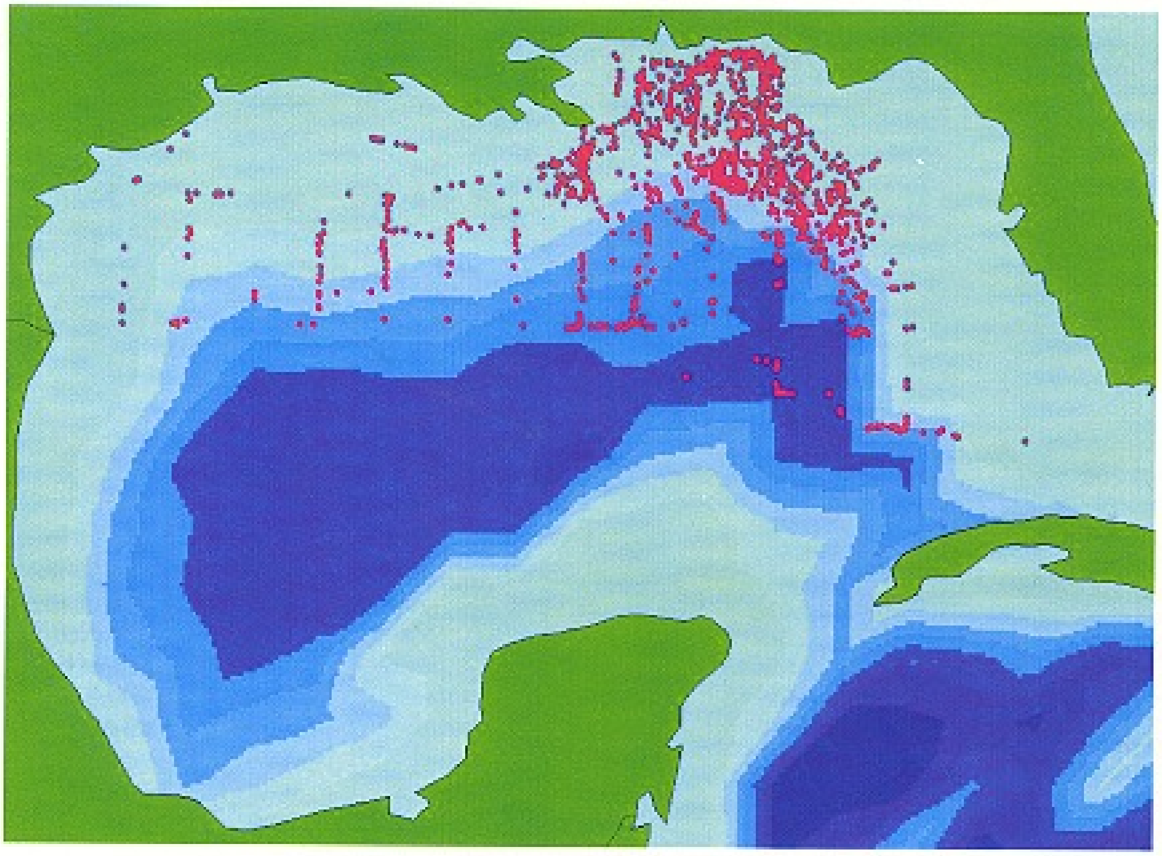

Cetaceans, Sea Turtles and Seabirds in the Northern Gulf of Mexico: Distribution, Abundance and Habitat Associations

Volume II: Technical Report

U.S. Department of the Interior
U.S. Geological Survey
Biological Resources Division

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

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Volume II: Technical Report

Editors

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by
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In cooperation with the
U.S. Department of the Interior
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Gulf of Mexico OCS Region

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This study was procured to meet information needs identified by the Minerals Management Service (MMS) in concert with the U.S. Geological Survey, Biological Resources Division (BRD).

DISCLAIMER

This report was prepared under contract between the U.S. Geological Survey, Biological Resources Division (BRD), Texas A&M University, and the National Marine Fisheries Service. This report has been technically reviewed by the BRD and the Minerals Management Service (MMS), and has been approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the BRD or MMS, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. It is, however, exempt from review and compliance with the MMS editorial standards.

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PREFACE

This study entitled "Cetaceans, Sea Turtles and Seabirds in the Northern Gulf of Mexico: Distribution, Abundance and Habitat Associations", also known as the GulfCet II study, provides synoptic data and analyses on the species diversity, abundance, and habitat characteristics for cetaceans, sea turtles and seabirds in the northern Gulf of Mexico. Results of the study are described in three volumes including this volume ("Volume II: Technical Report"), "Volume I: Executive Summary" and "Volume III: Data Appendix."

This study was sponsored and administered by the U.S. Department of Interior, U.S. Geological Survey, Biological Resources Division to provide environmental information to the U.S. Department of Interior, Minerals Management Service. It was managed by Texas A&M University at Galveston in partnership with the National Marine Fisheries Service at the Southeast Fisheries Science Center.

ABSTRACT

The Gulf of Mexico is a semi-enclosed, intercontinental sea with a total area of about 1.5 million square kilometers. As a large marine ecosystem, it has a unique bathymetry, hydrography and productivity. Cetaceans, sea turtles and seabirds are upper trophic level predators that play an important role in the pelagic marine ecosystem of the Gulf of Mexico. These are highly valued taxa, protected by national laws and international agreements, and knowledge of their distribution, abundance and ecology is vital to their protection. GulfCet II was planned to help resolve issues concerning the potential impacts of various oil and gas activities on cetaceans, sea turtles and seabirds that inhabit the northern and eastern regions of the Gulf of Mexico, emphasizing the continental slope where water depths range from 100 to 2,000 m. The objectives of the GulfCet II field studies (1996-97) were to: 1) expand the geographical coverage of ship and aerial surveys that were conducted previously during GulfCet I (1992-94), which surveyed the north-central and northwestern Gulf of Mexico, 2) estimate the minimum abundances of cetaceans and sea turtles in areas surveyed during 1996-97, 3) collect simultaneous hydrographic data and biological samples during the ship surveys to better define the habitat associations of cetaceans and seabirds, and 4) collect acoustic data on cetacean sounds and identify and record other natural and man-made underwater sounds to provide additional insights into cetacean distribution and behavior, particularly in relation to noise from seismic exploration vessels.

We hypothesized that hydrographic features in the study area had different levels of potential prey that influence cetacean and seabird distribution. We further hypothesized that these food stocks would be locally concentrated in nutrient-rich areas offshore from the Mississippi River, within cyclonic eddies, and along the high-shear edges of cyclonic eddies.

An integrated methodology was used that included visual surveys from ships and aircraft, and acoustic recordings and hydrographic collections from ships. Near real-time sea surface altimetry from the TOPEX/POSEIDON and ERS satellites was used during ship surveys to determine the location of hydrographic features (e.g., cyclones, anticyclones and confluence zones). Archival satellite sea surface altimetry data were used to retrospectively determine the location of hydrographic features for analysis with cetacean sightings collected during GulfCet I. We measured zooplankton and micronekton biomass derived from both net and acoustic sampling to indicate the amount of potential food available for higher trophic level foraging by cetaceans and seabirds.

Nineteen cetacean species were identified in the oceanic northern Gulf of Mexico (398,960 km^2) during GulfCet II surveys. The estimated minimum abundance of all cetaceans in the oceanic northern Gulf based on shipboard surveys was 86,705 animals. Pantropical spotted dolphins were the most abundant species with an estimated 46,625 animals, followed by spinner dolphins (11,251) and clymene dolphins (10,093). Estimates for bottlenose dolphins, striped dolphins, melon-headed whales, Risso's dolphins and short-finned pilot whales ranged from 4,381 to 1,471 animals. Abundances of all other species were less than 1,000 animals. Cetaceans were sighted throughout the study area, but fewer were sighted in the western Gulf. There are now sighting records during three or more seasons for at least 16 cetacean species.

Seventeen cetacean species were sighted in the Minerals Management Service's Eastern Planning Area (EPA, 70,470 km^2). The abundance estimate based on aerial surveys (which were more extensive than the ship surveys in the EPA) was 38,184 total animals. In general, cetaceans were found throughout the EPA each season. The most abundant species were pantropical spotted dolphin (13,649) and spinner dolphin (8,670). Other species with abundance estimates over 1,000 based on aerial surveys were bottlenose dolphin, Atlantic spotted dolphin, Risso's dolphin, striped dolphin and clymene dolphin. The seasonal abundance of some species may vary regionally in continental slope waters. For example, dwarf/pygmy sperm whales were nine-times more abundant in the summer than in the winter.

Cetaceans in the northeastern and oceanic northern Gulf of Mexico were concentrated along the continental slope in or near cyclones and the confluence of cyclone-anticyclone eddy pairs. Net tows and acoustic backscatter measurements with an Acoustic Doppler Current Profiler showed that cyclonic eddies and confluence areas are mesoscale features with locally concentrated zooplankton and micronekton stocks that appear to develop in response to increased nutrient-rich water and primary production in the mixed layer. A significant relationship existed between integrated zooplankton biomass and integrated cephalopod (a major component of cetacean prey) paralarvae numbers, indicating that higher zooplankton and micronekton biomass may correlate with higher concentrations of cetacean prey. In the north-central Gulf, an additional factor affecting cetacean distribution may be the narrow continental shelf south of the Mississippi River delta. Low salinity, nutrient-rich water may occur over the continental slope near the mouth of the Mississippi River (MOM) or be entrained within the confluence of a cyclone-anticyclone eddy pair and transported beyond the continental slope. This creates a deep-water environment with locally enhanced primary and secondary productivity and may explain the presence of a resident, breeding population of endangered sperm whales within 50 km of the Mississippi River delta. We suggest that this area may be essential habitat for sperm whales in the northern Gulf. Overall, the results suggest that the amount of potential prey for cetaceans (and seabirds) may be consistently greater in the cyclone, confluence areas, and south of the MOM, making them preferential areas for foraging. Since cyclones in the northern Gulf are dynamic and usually associated with westward moving cyclone-anticyclone pairs, cetacean distribution will be dynamic. However, with near real-time satellite remote sensing of sea surface altimetry, these features can be tracked and used to predict where pelagic cetaceans may be concentrated. The exceptions are bottlenose dolphins, Atlantic spotted dolphins and possibly Bryde's whales that typically occur on the continental shelf or along the shelf break outside of major influences of eddies.

An acoustic survey was performed using a towed hydrophone array to describe the distribution of cetaceans based on species-specific vocalizations and to record man-made noise. Sperm whales and pantropical spotted dolphins were the most commonly identified cetaceans, although recordings were also made for clymene dolphins, spinner dolphins, striped dolphins, Atlantic spotted dolphins, false killer whales, bottlenose dolphins, rough-toothed dolphins and Fraser's dolphins. The whistles of nine dolphin species were characterized based on species-specific patterns of whistle usage and acoustic structure. A diversity of anthropogenic signals was recorded, many of which were low frequency seismic exploration signals. Seismic exploration signals were detected during 21% of recordings, although there was no significant difference in the cetacean sighting frequency for low, medium, and high noise levels in different hydrographic features.

GulfCet II aerial surveys provided the first assessment of sea turtle abundance and distribution over a large area of the oceanic northeastern Gulf of Mexico. Three sea turtle species occurred in the EPA study area: loggerhead, Kemp's ridley, and leatherback. The leatherback and Kemp's ridley sea turtles are listed as endangered, and the loggerhead sea turtle is listed as threatened. The overall density of loggerhead sea turtles in the EPA shelf was 20 times that of the EPA slope. The majority of loggerheads over the EPA slope were sighted during winter. While many winter sightings were near the 100 m isobath, there were sightings of loggerheads over very deep waters (i.e., >1000 m). Leatherbacks were sighted throughout the EPA slope and were about 12 times more abundant in winter than summer. The nearly disjunct summer and winter distributions of leatherbacks indicates that specific areas may be important to this species either seasonally or for short periods of time.

Seabird species present in the Gulf of Mexico varied by season. The species composition of the sightings during late summer reflected a pattern of migration and transition to a winter distribution. Two of the three most commonly identified species (laughing gull and royal tern) in late summer are considered year-round residents in the Gulf. Pomarine jaegers, a wintering marine species in the Gulf, were the third most commonly identified species. During mid-summer, the black tern was the most abundant species, followed by band-rumped storm-petrels (summer migrant pelagic), frigatebirds (permanent resident), Audubon's shearwaters (summer migrant pelagic) and sooty terns (summer resident).

Cyclones had the greatest diversity of seabird species, although habitat use varied among species. Pomarine jaegers were more likely to be present in the MOM area during late summer. Audubon's shearwaters were more likely to be encountered inside a cyclone, while band-rumped storm-petrels were more likely to be present in the areas other than cyclones, anticyclones or confluence zones during mid-summer. Black terns were encountered more frequently in the MOM area during mid-summer. Generalized additive models incorporating indicators of plankton standing stock (surface chlorophyll and predicted mean biomass of zooplankton and micronekton) best predicted seabird presence for five of the seven species analyzed. Other predictive models were: sea surface properties of temperature and salinity for black tern, sooty tern, and laughing gull; sea surface height for pomarine jaeger; and bathymetry for Audubon's shearwater. Seasonal surveys are needed to better assess community structure and seabird-habitat associations.

Eighty-three percent of the crude oil and 99% of the gas production in United States federal waters occurs in the Gulf of Mexico, primarily along the Texas-Louisiana continental shelf and slope. By 2003, oil production in the Gulf is projected to increase 43%. Production from deepwater fields (depth >305 m) will account for about 59% of the daily oil production and 27% of the daily gas production in the Gulf. In addition to oil and gas exploration and production, this area has considerable commercial shipping traffic that enters the northern Gulf ports. The long-term forecast for petroleum transportation is for the total volume to increase into the next century. The cumulative impact of these multiple, potential impact-producing factors on cetaceans in the northern Gulf cannot be predicted with certainty. However, it can be anticipated that cetaceans along the continental slope will encounter increasing oil and gas exploration and production activities. There are significant uncertainties in our understanding of short and long-term effects of seismic and other loud industrial sounds on the behavior and distribution of Gulf cetaceans. Against the background of growing oil and gas exploration and development, continued research and monitoring are needed to assess the potential impacts of these activities on pelagic cetaceans, sea turtles and seabirds in the Gulf of Mexico.

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LIST OF ABBREVIATIONS AND ACRONYMS

The following acronyms and abbreviations are used throughout this report:

ADCP	Acoustic Doppler Current Profiler
AVHRR	Advanced Very High Resolution Radiometer
BRD	Biological Resources Division
CCAR	Colorado Center for Astrodynamics Research, University of Colorado
CCR	Cold-core Ring
CHL	Chlorophyll
CI	Confidence Interval
CON	Confluence between ring structures
CTD	Conductivity, Temperature, and Depth Profiler
CV	Coefficient of Variation
dB rel µP	Decibels relative to 1 micro Pascal
DCM	Deep Chlorophyll Maximum
DFA	Discriminant Function Analysis
EPA	Eastern Planning Area
GIS	Geographic Information System
GPS	Global Positioning System
GulfCet I	Distribution and Abundance of Cetaceans in the North-Central and Western Gulf of Mexico (1991-1995)
GulfCet II	Cetaceans, Sea Turtles and Seabirds in the Northern Gulf of Mexico: Distribution, Abundance and Habitat Associations (this study)
HCLS	High Chlorophyll, Low Salinity
HPLC	High Pressure Liquid Chromatography
IKMT	Isaacs Kidd Midwater Trawl
LC	Loop Current
LCE	Loop Current Eddy
MAR	Mississippi-Atchafalaya River
MLD	Mixed Layer Depth
MOCNESS	Multiple Opening/Closing Net and Environmental Sampling System
MOM	Mouth of the Mississippi
MMS	Minerals Management Service
NE	Northeast
NEGOM	Northeastern Gulf of Mexico
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OCS	Outer Continental Shelf
PER	Periphery of ring structures
PMB	Predicted Mean Biomass
PSD	Perpendicular Sighting Distance
SAIL	Serial ASCII Interface Loop
SD	Standard Deviation
SEFSC	Southeast Fisheries Science Center, NMFS
SSH	Sea Surface Height

SST	Sea Surface Temperature
Stenellids	Dolphins of the genus *Stenella*
S_v	Acoustic backscattering strength
TAMU	Texas A&M University (College Station)
TAMUG	Texas A&M University at Galveston
TOPEX/ERS	Topography Experiment Mission/European Research Satellite
TOPEX/POSEIDON	Topography Experiment Mission/Poseidon
T-S	Temperature-salinity Relationship
UC	University of Colorado
USGS	United States Geological Survey
WCR	Warm-Core Ring
WCWRU	Wisconsin Cooperative Wildlife Research Unit
XBT	Expendable Bathythermograph

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Special thanks to the Scientific Review Board members Daryl Boness, Roger Hanlon and Lawrence Pomeroy for their thoughtful review and comments on the goals and results of this project, and very special thanks to BRD Contracting Officers Technical Representative Gary Brewer and MMS Contract Inspectors Robert Avent and Dagmar Fertl for their guidance in the writing of this report.

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Chapter 1

Introduction

Randall W. Davis and William E. Evans

1.1 Background

1.1.1 Federal Requirement for the Program

The mission of the U.S. Geological Survey (USGS) Biological Resources Division (BRD) is to provide the scientific understanding and technologies needed to support the sound management and conservation of the nation's biological resources. The BRD endeavors to meet its goals by:

- developing scientific and statistically reliable methods and protocols to assess the status and trends of the nation's biological resources
- utilizing tools from the biological, physical and social sciences to understand the causes of biological and ecological trends and to predict the ecological consequence of management practices
- leading in the development and use of the technologies needed to synthesize, analyze and disseminate biological and ecological information
- striving for quality, integrity and credibility of its research and technology by consistently improving its scientific programs through internal quality control, external peer review and competitive funding

The U.S. Department of the Interior's Minerals Management Service (MMS) is a client agency of the BRD. The MMS has the responsibility for leasing, minerals exploration and development of submerged Federal lands on the U.S. Outer Continental Shelf (OCS) under the provisions of the OCS Lands Act Amendments of 1978. The National Environmental Policy Act of 1969 requires that all Federal Agencies use a systematic, interdisciplinary approach that will ensure integrated use of the natural and social sciences in any planning and decision making that may have an effect on the human environment.

The BRD administered this study, hereafter called the GulfCet II program. It is a continuation of research begun with the GulfCet I program (1991-95). Both programs were designed to help MMS assess the potential effects of deepwater oil and gas exploration and production (e.g., ship activity, seismic exploration, pollution) on cetaceans, sea turtles and seabirds in the northern Gulf of Mexico by providing synoptic data on species diversity, abundance and habitat. As of April 1999, there were over 3,000 oil and gas platforms in the northern Gulf (Figure 1.1). Most of these were located on the continental shelf along the coast of Texas and Louisiana. However, new technology is now allowing oil and gas exploration and production to expand beyond the continental shelf and onto the upper continental slope.

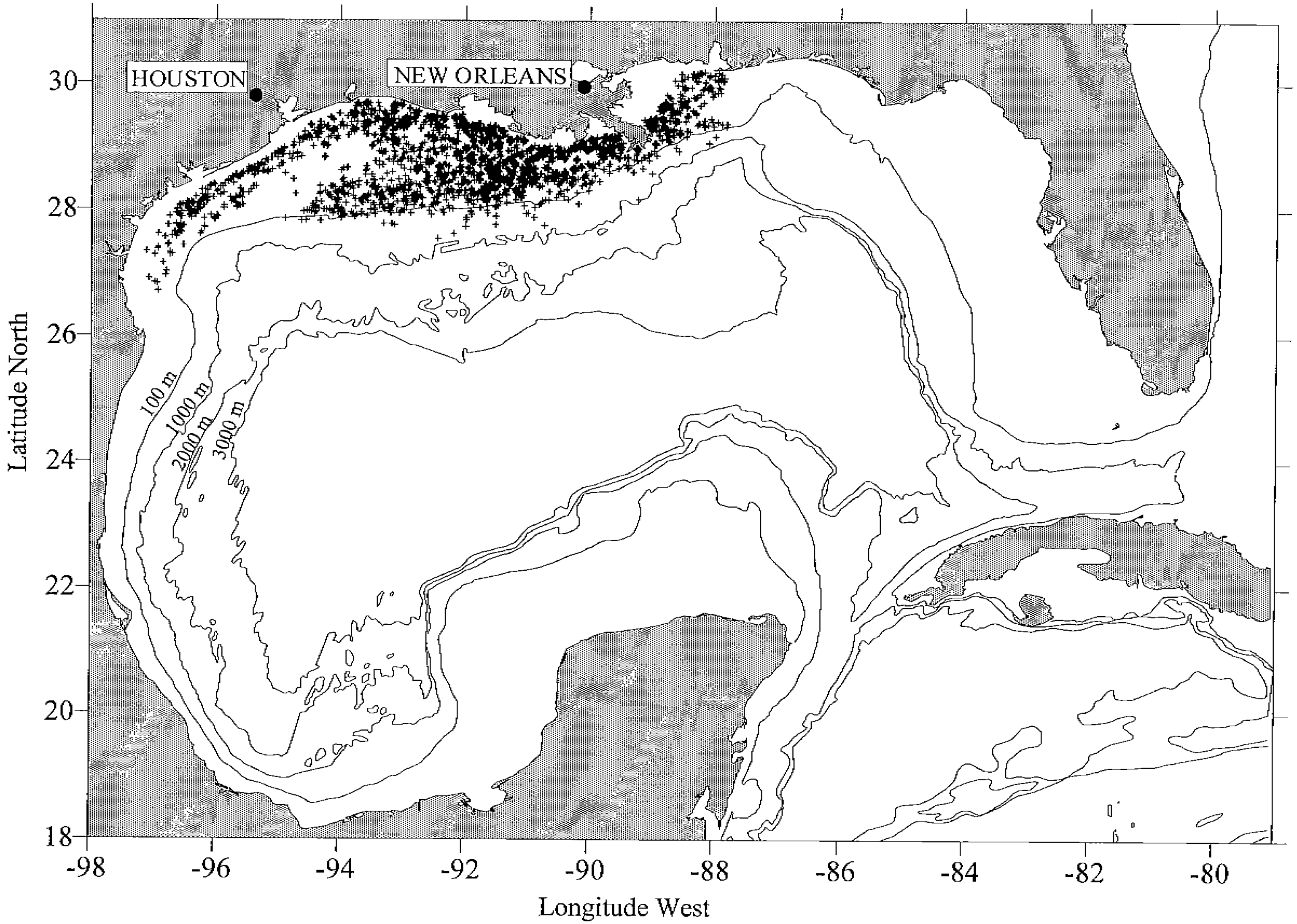

Figure 1.1. Location of oil and gas platforms in the northern Gulf of Mexico as of April 1999 (Data source: MMS).

1.1.2 Program Participants

The GulfCet II Program was managed by Texas A&M University at Galveston (TAMUG) in partnership with the National Marine Fisheries Service (NMFS) at the Southeast Fisheries Science Centers (SEFSC). The Texas Institute of Oceanography provided support for graduate student participation at TAMUG. A list of the program's participants is shown in Table 1.1. The GulfCet II program had a Scientific Review Board (SRB) composed of three scientists who reviewed and commented on the project's goals, methodologies, results, analyses and conclusions.

1.1.3 Cetacean Surveys of the Northern Gulf Prior to 1994

There are several sources of information on the distribution, abundance and diversity of cetaceans in the Gulf of Mexico (for a review see Jefferson and Schiro 1997). Cetacean stranding information has been systematically collected since the late 1970's. A considerable amount of research has been conducted on localized populations of bottlenose dolphins (Shane et al. 1986, Scott and Hansen 1989, Leatherwood and Reeves 1990). From 1983-86, the NMFS investigated the distribution, abundance and diversity of cetaceans in U.S. Gulf of Mexico waters less than 200 m deep, which in some areas extended to 280 km offshore (a total area of about 360,000 km^2) (Scott et al. 1989). Other directed studies, historic whaling records, animal strandings and opportunistic sightings have expanded the list of cetacean species known to occur in the Gulf (Mullin et al. 1994c, Jefferson and Schiro 1997) (Table 1.2).

Until recently, relatively little was known about cetaceans inhabiting deeper waters of the Gulf of Mexico. The MMS and U.S. Fish and Wildlife Service supported aerial surveys of birds, sea turtles and cetaceans in the Gulf from 1981-82 (Fritts et al. 1983). From July 1989 through June 1990, the NMFS conducted aerial surveys of cetaceans along the continental slope of the north-central Gulf of Mexico in waters ranging from 180-1,800 m deep (Mullin et al. 1991, Mullin et al. 1994c).

The most extensive survey of cetaceans in the offshore waters (100-2,000 m deep) of the north-central and western Gulf of Mexico (Figure 1.2) was conducted jointly by Texas A&M University and the NMFS, Southeast Fisheries Science Center beginning in 1992 and called the GulfCet I program (Davis and Fargion 1996, Baumgartner 1997, Davis et al. 1998). This three-year study provided synoptic information on the distribution and abundance of cetaceans using both visual and acoustic survey techniques. It also provided limited information on cetacean-habitat associations.

During GulfCet I, bottlenose dolphin, pantropical spotted dolphin and sperm whale were the most commonly sighted species; each was sighted more than 70 times. Risso's dolphin, clymene dolphin, dwarf sperm whale, striped dolphin and unidentified ziphiids were each sighted 21 to 44 times, with the other species sighted less than 20 times. Average group sizes ranged from 1.2 for

Table 1.1. GulfCet II participants, including program managers, principal investigators, Scientific Review Board members, government scientists, and their affiliations.

Randall Davis	Program Manager, Principal Investigator, Editor	TAMUG
William Evans	Deputy Program Manager, Principal Investigator, Co-editor	TAMUG
Bernd Würsig	Principal Investigator, Co-editor	TAMUG
Gerald Scott	Program Manager for SEFSC	NMFS, SEFSC, Miami Laboratory
Keith Mullin	Principal Investigator	NMFS, SEFSC, Pascagoula Laboratory
Douglas Biggs	Principal Investigator	TAMU
Jeff Norris	Principal Investigator	TAMUG
John Wormuth	Principal Investigator	TAMU
Christine Ribic	Principal Investigator	BRD, WCWRU, UW
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TAMUG = Texas A&M University at Galveston
TAMU = Texas A&M University, College Station
NMFS, SEFSC = National Marine Fisheries Service, Southeast Fisheries Science Center
BRD, WCWRU, UW = BRD Wisconsin Cooperative Wildlife Research Unit, University of Wisconsin
CCAR, UC = Colorado Center for Astrodynamic Research, University of Colorado

Table 1.2. Cetaceans of the Gulf of Mexico. The (E) next to the common name indicates that the species is listed under the Endangered Species Act of 1973 as endangered.

	Balaenidae	
Northern right whale (E)		*Eubalaena glacialis*
	Balaenopteridae	
Blue whale (E)		*Balaenoptera musculus*
Fin whale (E)		*Balaenoptera physalus*
Sei whale (E)		*Balaenoptera borealis*
Bryde's whale		*Balaenoptera edeni*
Minke whale		*Balaenoptera acutorostrata*
Humpback whale (E)		*Megaptera novaeangliae*
	Physeteridae	
Sperm whale (E)		*Physeter macrocephalus*
	Kogiidae	
Pygmy sperm whale		*Kogia breviceps*
Dwarf sperm whale		*Kogia simus*
	Ziphiidae	
Cuvier's beaked whale		*Ziphius cavirostris*
Blainville's beaked whale		*Mesoplodon densirostris*
Sowerby's beaked whale		*Mesoplodon bidens*
Gervais' beaked whale		*Mesoplodon europaeus*
	Delphinidae	
Melon-headed whale		*Peponocephala electra*
Pygmy killer whale		*Feresa attenuata*
False killer whale		*Pseudorca crassidens*
Killer whale		*Orcinus orca*
Short-finned pilot whale		*Globicephala macrorhynchus*
Rough-toothed dolphin		*Steno bredanensis*
Fraser's dolphin		*Lagenodelphis hosei*
Bottlenose dolphin		*Tursiops truncatus*
Risso's dolphin		*Grampus griseus*
Atlantic spotted dolphin		*Stenella frontalis*
Pantropical spotted dolphin		*Stenella attenuata*
Striped dolphin		*Stenelia coeruleoalba*
Spinner dolphin		*Stenella longirostris*
Clymene dolphin		*Stenella clymene*

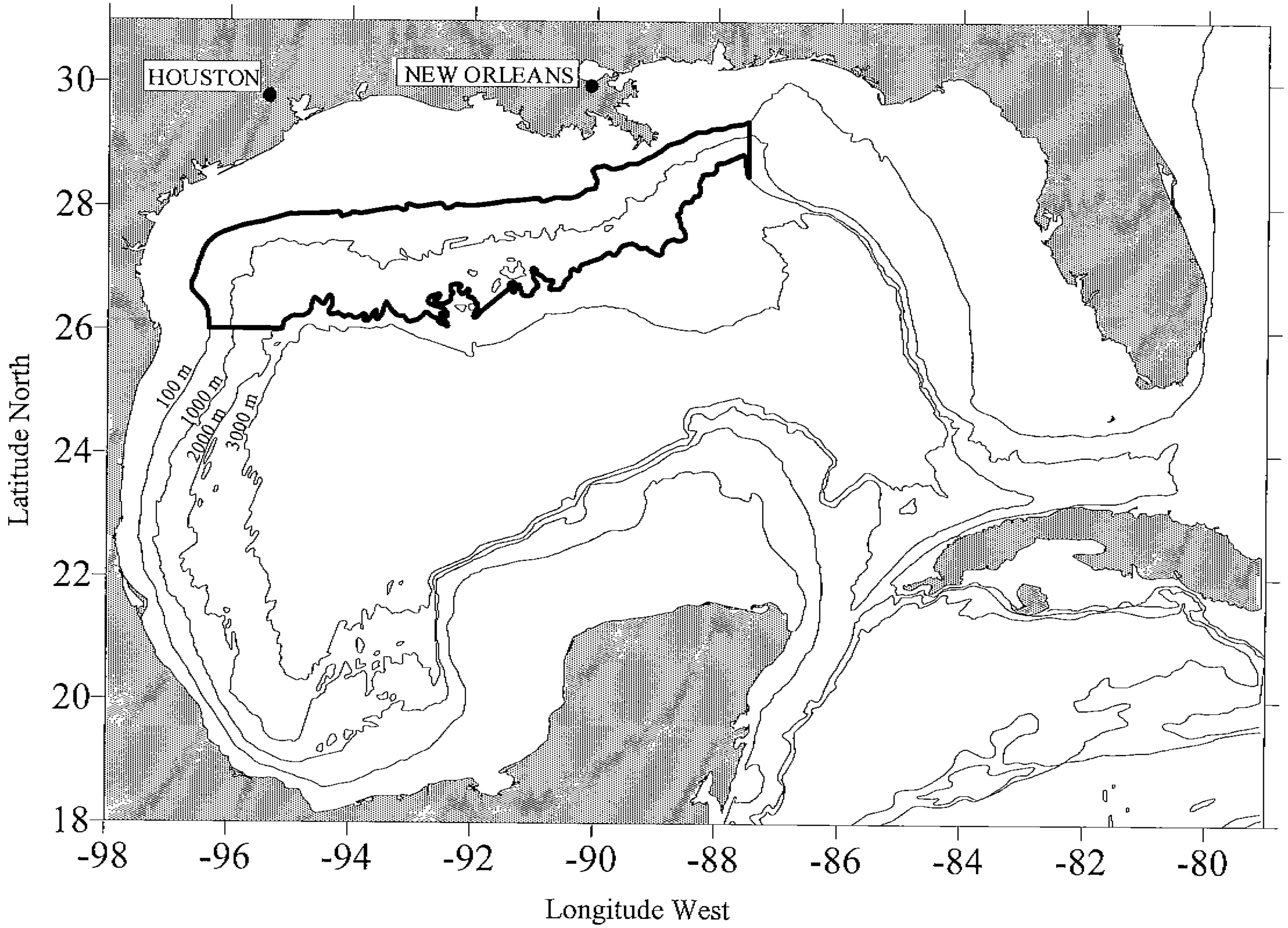

Figure 1.2. GulfCet I study area in the western and north-central Gulf between the 100-2,000 m isobaths.

pygmy sperm whales and Cuvier's beaked whales to 141 for melon-headed whales. The estimated minimum abundance of cetaceans in the GulfCet I study area was 19,145 (CV = 0.12) animals (Table 1.3). The most common species were pantropical spotted dolphin, bottlenose dolphin, striped dolphin and melon-headed whale. Clymene dolphin and Atlantic spotted dolphin were the only other species with estimates of over 1,000 animals. The estimated minimum abundance of endangered sperm whales was 313 (0.25) animals. Other species with estimates of more than 200 animals were spinner dolphin, Risso's dolphin and the short-finned pilot whale.

The GulfCet I program provided limited information on habitat preference, which showed the strongest correlation of species distribution with ocean depth (Davis et al. 1998). However, this study failed to establish strong correlations with other hydrographic variables such as sea surface temperature, salinity, water column structure and distinctive features such as cyclonic (cold-core) eddies. This may have resulted from the design of the shipboard surveys that was intended to provide a synoptic view of cetacean distribution and an estimation of minimum abundance. These surveys were not designed to determine mesoscale habitat preference of cetaceans.

In addition to cetaceans, the GulfCet I program provided synoptic information on the distribution and abundance of sea turtles using aerial survey techniques. All five species of sea turtles in the Gulf of Mexico are protected under the Endangered Species Act of 1973. The leatherback (*Dermochelys coriacea*), Kemp's ridley (*Lepidochelys kempi*) and hawksbill (*Eretmochelys imbricata*) sea turtles are listed as endangered and the loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) sea turtles are listed as threatened. Three sea turtle species occurred in the GulfCet I study area: loggerhead, Kemp's ridley and leatherback. The leatherback sea turtle occurred in significant numbers throughout the year, especially in the region between the Mississippi and DeSoto Canyons. These canyons are located along the continental slope 85 km southwest and 220 km east, respectively, of the Mississippi River delta. Finally, over 30 species of seabirds were sighted during visual shipboard surveys of the study area (Davis and Fargion 1996).

1.2 General Oceanography of the Gulf of Mexico

The Gulf of Mexico is a dynamic body of water dominated by two major circulation features. The Loop Current, formed by the interconnection of the Yucatan and Florida Currents, governs the circulation of the eastern (east of the ca. 87.5°W longitude) Gulf. In the central (ca. 87.5-94.0°W longitude) and western (ca. west of 94.0°W longitude) Gulf, anticyclonic eddies and their associated cyclonic eddies are the primary circulatory features. The Loop Current enters the Gulf in a nearly annual cycle. TOPEX/ERS satellites produce sea surface altimetry maps that show Gulf anticyclonic eddies originating as pinched-off, northward penetrations of Loop current meanders (Figure 1.3). After their separation from the Loop Current, these anticyclonic eddies drift westward until their progress is eventually constrained by shoaling topography over the northwestern continental slope of the Gulf. They remain in this region, slowly decaying or coalescing with another approaching eddy. The overall resulting circulation of the Gulf of Mexico is remarkable because of its inter-annual variability and intensity. The dynamics of the Gulf are made more complex by the large fresh water inflow. Nearly two-thirds of the U.S.

Table 1.3. Estimated minimum abundance (N) of cetacean species based on GulfCet I ship surveys (1992-94) in the north-central and western Gulf of Mexico between the 100-2,000 m isobaths (Davis and Fargion 1996). CV = coefficient of variation.

Family and common name	Species name	N	CV
Balaenopteridae			
Bryde's whale	*Balaenoptera edeni*	3	0.81
Physeteridae			
Sperm whale	*Physeter macrocephalus*	313	0.25
Kogiidae			
Pygmy sperm whale	*Kogia breviceps*	19	0.40
Dwarf sperm whale	*Kogia simus*	88	0.34
Ziphiidae			
Cuvier's beaked whale	*Ziphius cavirostris*	14	0.41
Unidentified Ziphiidae		124	0.29
Delphinidae			
Melon-headed whale	*Peponocephala electra*	2,067	0.34
Pygmy killer whale	*Feresa attenuata*	36	0.64
False killer whale	*Pseudorca crassidens*	10	0.63
Killer whale	*Orcinus orca*	71	0.46
Short-finned pilot whale	*Globicephala macrorhynchus*	215	0.50
Rough-toothed dolphin	*Steno bredanensis*	177	0.35
Fraser's dolphin	*Lagenodelphis hosei*	65	1.17
Bottlenose dolphin	*Tursiops truncatus*	2,538	0.26
Risso's dolphin	*Grampus griseus*	529	0.26
Atlantic spotted dolphin	*Stenella frontalis*	1,145	0.37
Pantropical spotted dolphin	*Stenella attenuata*	7,105	0.22
Striped dolphin	*Stenella coeruleoalba*	2,091	0.52
Spinner dolphin	*Stenella longirostris*	840	0.60
Clymene dolphin	*Stenella clymene*	1,695	0.37
Total		19,145	

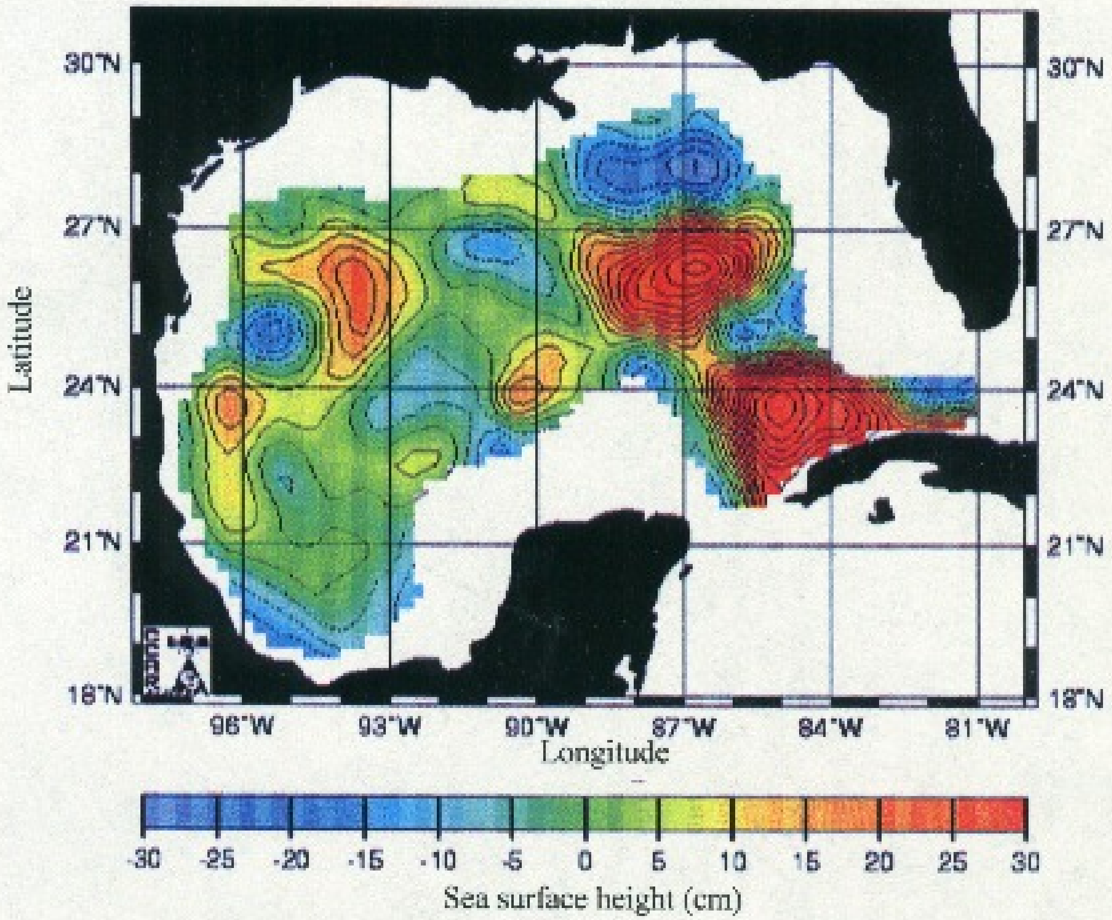

Figure 1.3. Contour map of the sea surface height for the Gulf of Mexico showing major hydrographic features of the region. Data were collected by altimeters aboard the TOPEX/POSEIDON and ERS-2 satellites and used to objectively map the height field for August 1, 1997. The northward penetration of the Loop Current (red) into the eastern Gulf has resulted in the separation of an anticyclone (warm-core eddy), identified by the large region of closed contours in red around a high in the sea surface height. Cyclonic, cold-core eddies (blue) are lows in the sea surface height and visible on the periphery of the anticyclone. The eddy field in the western gulf is made up of anticyclones and companion cyclones that are remnants of an older Loop Current eddy interacting with the continental slope along the Texas and Mexican coasts. Data for ocean depths less than 200 meters have been masked.

mainland and half the area of Mexico drains into the Gulf. The Mississippi River discharges into the northern Gulf through the Balize and Atchafalaya delta regions. Approximately 30% of the Mississippi River enters the northern Gulf through the Atchafalaya, and the remaining 70% goes through the Balize bird-foot delta. The Mississippi and other rivers with their associated pollutants, nutrients, and sediment loads have a great impact on all aspects of continental shelf oceanography in the northern Gulf. The input of nutrients ensures high phytoplankton production and thus higher zooplankton productivity (Lohrenz et al. 1990). Twenty-eight percent of the total U.S. commercial fish catch is from the Louisiana/Texas shelf (Walker and Rouse 1993). Spawning of key species, such as Gulf menhaden, is also concentrated around the Mississippi delta. River discharge into the Gulf is distinctly seasonal, with the highest flow occurring from March through May, and the lowest flow occurring from August through October. Wind forcing and shelf currents are major factors controlling the distribution of Mississippi River outflow onto the continental shelf. Loop Current eddies and filaments provide the major control of plume circulation over the continental slope and into the northern Gulf. The fresh water of the Mississippi River affects the spatial and temporal distribution of areas of higher primary and secondary production that may influence the distribution of cetaceans in the Gulf of Mexico.

1.3 GulfCet II Study Area and Objectives

In the GulfCet II program, studies of cetaceans in the northern Gulf of Mexico were continued to determine their seasonal and geographic distribution in areas potentially affected by oil and gas activities now or in the future. This program included systematic aerial surveys and shipboard visual and acoustic surveys to document cetacean and sea turtle populations (Table 1.4). This work was accompanied by data acquisition designed to further characterize habitat and reveal cetacean-habitat associations. This study was intended as a spatial and temporal extension of the GulfCet I program.

1.3.1 Study Area

The GulfCet II study area included:

(1) Eastern Planning Area (EPA) continental slope from 100-2,000 m deep east of 88°10.0'W and north of 26°00.0'N (70,470 km^2) and the EPA continental shelf (12,326 km^2) located from 18.5 km offshore to 100 m deep between 88°10.0'W and 85°55.0'W (Figure 1.4). This area was surveyed using both aircraft and ships (R/V *Oregon II and* R/V *Gyre*).

(2) GulfCet I Study Area (154,621 km^2) (Figure 1.2). U.S. waters from 100-2,000 m deep west of 87°30.0'W. This area is a subset of the oceanic northern Gulf study area (Figure 1.4) and was surveyed during spring with the R/V *Oregon II.*

(3) Oceanic northern Gulf of Mexico (398,960 km^2) (Figure 1.5). Waters within the U.S. Economic Exclusive Zone (EEZ) greater than 100 m deep. This area was surveyed using the R/V *Oregon II* during spring.

Table 1.4. Types of data collected by season and survey for the GulfCet II program. Abbreviations: CTD = conductivity/temperature casts; XBT = expendable bathythermograph; SST = sea surface temperature; SSS = sea surface salinity; ADCP = Acoustic Doppler Current Profiler; MOCNESS = Multiple Opening and Closing Net and Environmental System; SSH = sea surface height.

			Marine Mammal Surveys		Hydrographic Surveys								
Survey		Dates	Visual	Acoustic	CTD	XBT	Chlorophyll	SST	SSS	Nutrients	ADCP	MOCNESS	Satellite SSH
SPRING 1996													
R/V *Oregon II*	Cruise 220												
	Leg 1	17 Apr-4 May 1996											✓
	Leg 2	8-25 May 1996	✓										✓
	Leg 3	29 May-8 Jun 1996	✓		✓	✓							✓
SUMMER 1996													
Aerial 9		11-31 Jul 1996	✓										✓
LATE SUMMER 1996													
R/V *Gyre*	Cruise *Gyre*96G06	11-19 Oct 1996	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
WINTER 1997													
Aerial 10		7 Feb-20 Mar 1997	✓										✓
SPRING 1997													
R/V *Oregon II*	Cruise 222												
	Leg 1	17 Apr-5 May 1997	✓										✓
	Leg 2	9-25 May 1997	✓										✓
	Leg 3	29 May-9 Jun 1997	✓	✓	✓	✓							✓
SUMMER 1997													
Aerial 11		15 Jul-6 Aug 1997	✓										✓
R/V *Gyre*	Cruise *Gyre*97G08	6-20 Aug 1997	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
WINTER 1998													
Aerial 12		8 Feb-14 Mar 1998	✓										✓

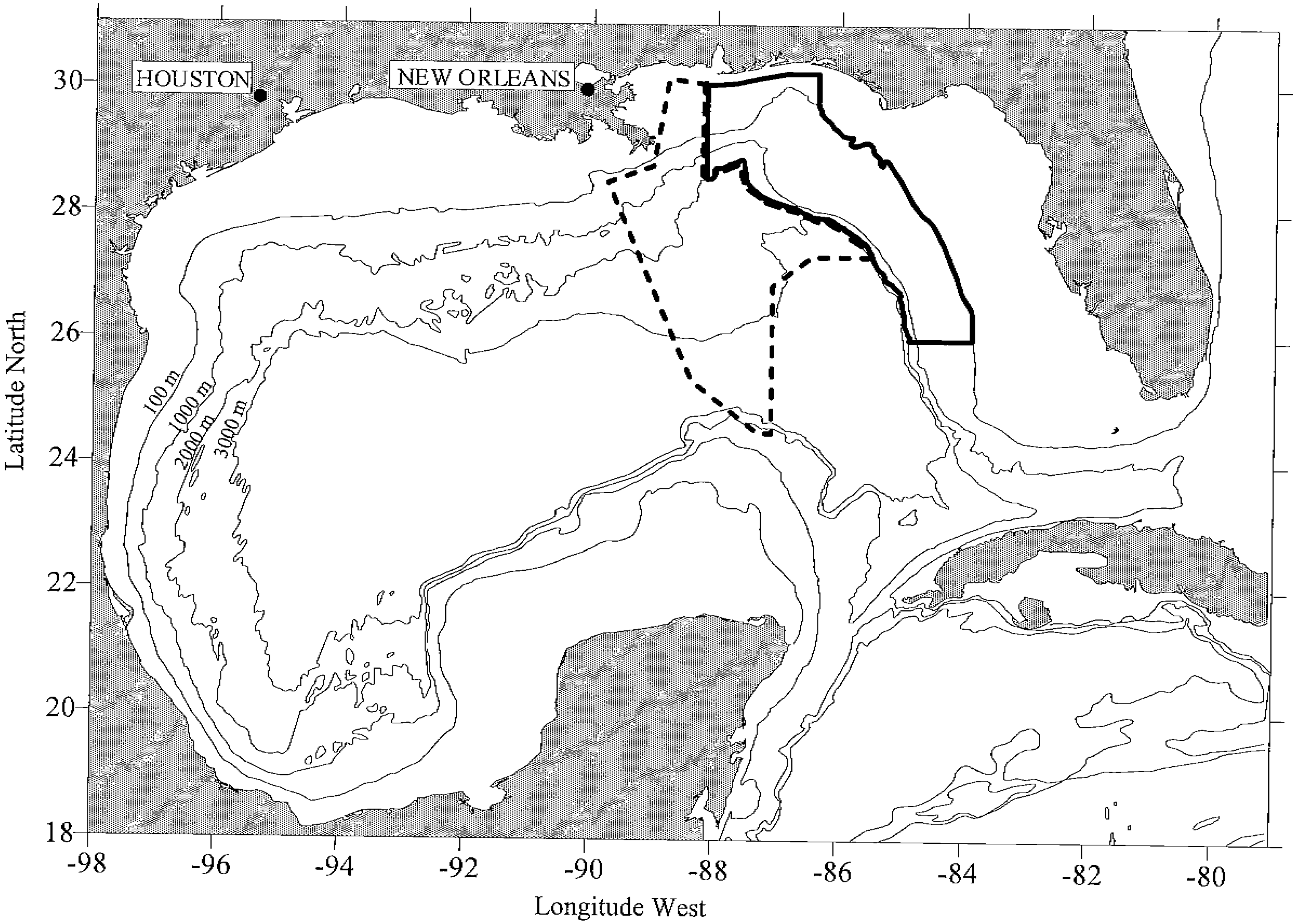

Figure 1.4. GulfCet II study area including the Minerals Management Service's Eastern Planning Area (bold line) and the focal study area for cetacean habitat surveys (dashed line).

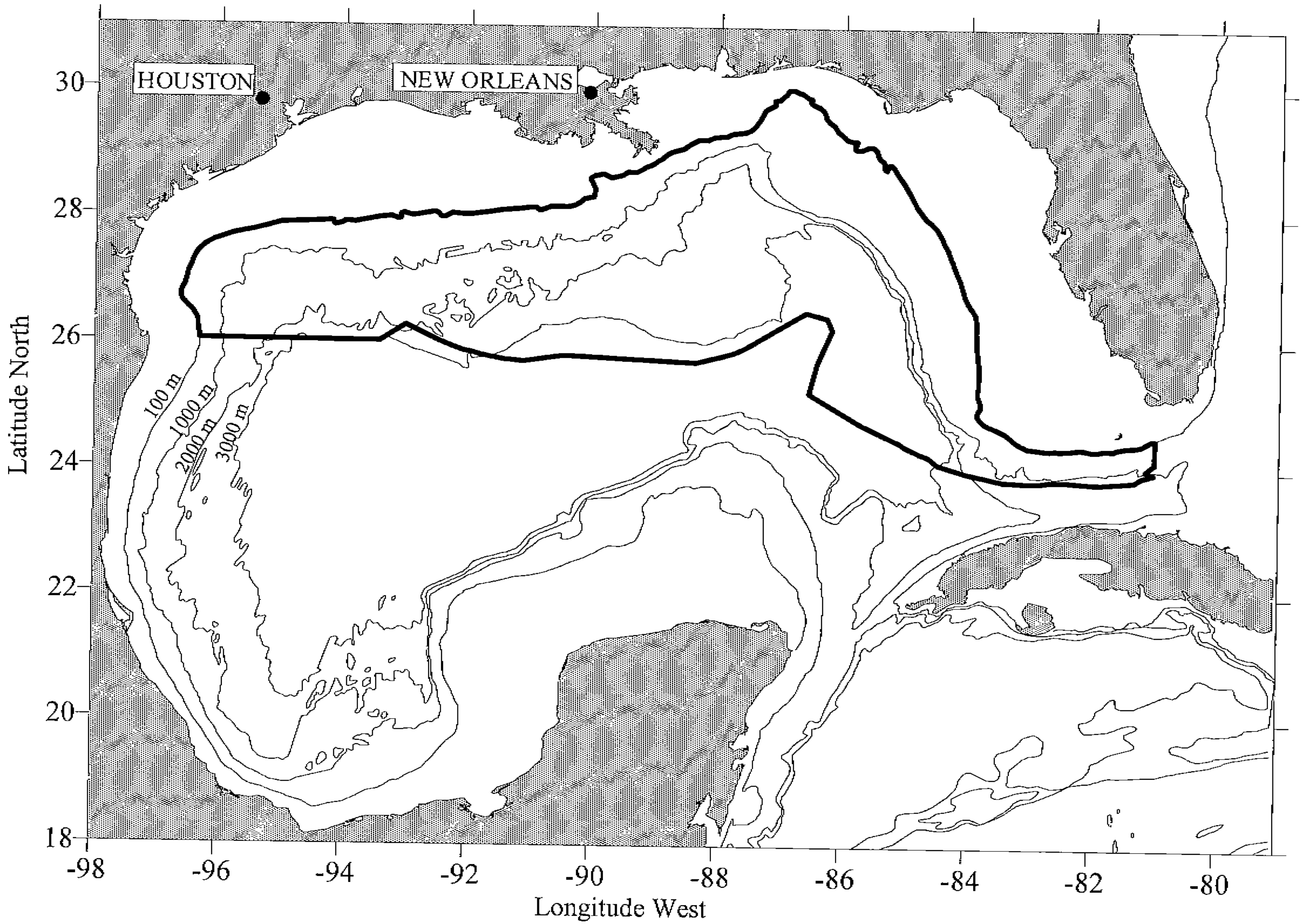

Figure 1.5. U.S. oceanic northern Gulf of Mexico.

(4) Focal study area for cetacean habitat surveys (Figure 1.4). This area was surveyed during late summer 1996 and mid-summer 1997 by the R/V *Gyre* to assess the relationship between cetacean distribution and habitat characteristics (i.e., bathymetry, hydrography and biological oceanography).

Both the EPA slope and GulfCet I study areas are within the boundaries of the oceanic northern Gulf study area.

1.3.2 Specific Objectives

The specific objectives of the study were to:

(1) Obtain data on temporal and spatial patterns of distribution and minimum abundance of cetaceans using line-transect and acoustic survey techniques directly comparable to those used in previous surveys. This included incidental sightings of sea turtles and seabirds.

(2) Identify possible associations between cetacean high-use habitats and the ocean environment, and attempt to explain any relationships that appear to be important to cetacean distributions.

Objective 1 was a continuation of surveys in the north-central and western Gulf that began during the GulfCet I Program and extended into MMS's Eastern Planning Area. To accomplish this objective, we conducted aerial surveys and simultaneous shipboard visual and acoustic surveys using line-transect methods.

To characterize cetacean and seabird habitat (Objective 2), we used an integrated approach that included the analysis of hydrographic and bathymetric features (e.g., anticyclonic and cyclonic eddies, ocean depth). In addition to physical features, we measured zooplankton and micronekton biomass derived from both net and acoustic sampling to indicate the amount of potential food available for higher trophic level foraging by cetaceans and seabirds. Although the diets of most cetaceans and seabirds in the Gulf are poorly known, we hypothesized that hydrographic regimes in the study area have different levels of potential prey that influence their distribution. We further hypothesized that these food stocks would be locally concentrated in nutrient-rich areas offshore from the Mississippi River, within cyclonic eddies, and along the high-shear edges of anticyclonic eddies.

Chapter 2

Environmental Patterns and Oceanographic Processes: Hydrography and Mesoscale Circulation of the Continental Margin of the Northeastern Gulf of Mexico, 1996 and 1997

Douglas C. Biggs

2.1 Introduction

The physical forcing functions for the circulation over the continental margin of the northeastern Gulf of Mexico are river discharge, wind stress, and the Loop Current (LC) and its derived circulation phenomena. The major river system influencing this region is the Mississippi-Atchafalaya River (MAR). The U.S. Army Corps of Engineers regulates MAR flow so that two-thirds of the total discharge enters the Gulf of Mexico at the birdsfoot delta, while the other one-third is shunted to enter via the Atchafalaya Bay. Most of the combined outflow is downcoast to the west (Cochrane and Kelly 1986), although under some wind conditions a substantial fraction of the discharge of this system may spread eastward to influence the northeastern Gulf (Walker et al. 1994).

The inner shelf flow is largely wind-driven, with contributions due to buoyancy forcing by river discharge. Seaward of the shelf-slope break, the LC is the major dynamic, circulation feature in the Gulf of Mexico. The mesoscale circulation of this deepwater region is largely determined by the changing geometry of the LC and its associated cold-core and warm-core mesoscale eddies. Once or twice annually (on average), the LC sheds anticyclonic, mesoscale eddies (LCEs), that are also called warm-core rings (WCRs). These LCEs have potential lifetimes longer than one year and typically migrate westward; they spawn cyclonic eddies during interaction with one another and/or with the continental slope. When the LC pushes into the northern part of the eastern Gulf, warm-surface-temperature filaments often extend from its northern wall to the upper continental slope and outer continental shelf of the northeastern Gulf.

Remote sensing data processed at the University of Colorado Center for Astrodynamics Research (CCAR) show that a broad area of cold-core circulation was located in the northeastern Gulf throughout calendar year 1996. This cyclonic eddy shows up persistently in weekly and monthly altimetry maps as a region of negative sea surface height (SSH) anomaly, depressed 20 cm or more relative to the climatological mean surface (Yi, 1995). This cyclone was there January through October in the region 27-29°N, 88-84°W, even though for much of the year the northern edge of the LC extended north of 25°N and the LC shed two LCEs during 1996.

In January 1996, the LC extended north of 26°N in the eastern Gulf, with LC Eddy A to the west and centered at 90-92°W. This anticyclonic eddy had separated from the LC the previous August-September 1995, so by January 1996, Eddy A was 4-5 months old. LC Eddy B separated from the LC between mid-April and mid-May, but since Eddy B remained centered east of 90°W for several months, its eastern edge apparently interacted with the LC through about mid-July. LC Eddy C separated from the LC in August-September 1996, about the time that eddies A and

B were merging and beginning to spin down in the western Gulf. By year's end, secondary LC Eddy D was in the process of splitting away from the northeast corner of Eddy C.

Eddy E separated from the LC in June-July 1997. As in 1996, a region of cyclonic circulation persisted in the northeastern Gulf for several months before and after this eddy shedding event. This eddy shedding periodicity, combined with the persistence of cyclonic circulation again in the region 27-29°N, 88-84°W, created mesoscale circulation conditions in the northeastern Gulf in early and late summer 1997 that were remarkably similar to those in early and late summer 1996.

The late summer (October) 1996 R/V *Gyre* cruise (*Gyre*96G06) surveyed the deepwater LCE C and cyclone pair. The mid-summer (August) 1997 *Gyre* cruise (*Gyre*97G08) surveyed the analog deepwater LCE E and cyclone pair. These "focal" surveys of cyclone-anticyclone pairs were designed using near real-time altimetry maps to determine the approximate dimensions of and center locations for the cyclone and anticyclone. Cruise tracks were then plotted to cross the cyclone with five or six lines of closely spaced expendable bathythermograph (XBT) stations, each of which would also extend into the northern part of the anticyclone. Both of these *Gyre* cruises also surveyed the continental margin with closely-spaced XBT stations between water depths of 100-1000 m to the north and east of the cyclone-anticyclone pair, because this is the region which MMS has designated its Eastern Planning Area (EPA). In the early summer of 1996 and again in the early summer of 1997, the third leg of NMFS cruises 220 and 225 aboard R/V *Oregon II* also surveyed the EPA, between water depths of 100-1000 m, with closely spaced XBT stations.

Together, these four cruises surveyed the continental margin of the northeastern Gulf with 560 closely spaced hydrographic stations at which XBT data were collected. These were supplemented with conductivity-temperature-depth (CTD) and bottle data that were collected at 32 locations. The cruise-by-cruise distribution of these stations is summarized in Table 2.1 and Figure 2.1. Table 2.2 provides additional detail by grouping the stations into five hydrographic "environments": (1) deepwater cyclone, (2) deepwater LC Eddy, (3) flow confluence between cyclone and LCE, (4) mouth of the Mississippi River (MOM) region of the continental slope close off the MAR birdsfoot delta, and (5) other margin (EPA). Figure 2.2 shows the subset of hydrostations on all four cruises that were made in EPA and MOM environments.

This chapter describes how the stations on each of the four cruises were partitioned into these five hydrographic environments, and further describes each environment in terms of: (a) mixed layer depth, (b) 19°C depth, and (c) 15°C depth and dynamic topography. The goal was to represent this series of five environments, which form a continuum ranging from convergence regions (LCEs) to divergence regions (cyclones), by a few summary statistical parameters. In Chapters 6 and 8, these environmental parameters were used in logistic regression and general linear models to identify cetacean and seabird-habitat associations.

Table 2.1. Summary of hydrographic stations made in early and late summer 1996 and in early and mid-summer 1997 in the northeast Gulf of Mexico.

Hydrographic Survey	Total number of stations	Survey of Continental Margin MMS Eastern Planning Area: XBT stations + CTD stations		Focal Survey of Deepwater Cyclone-Anticyclone pair: XBT stations + CTD stations
June 96 (*Oregon II* cruise 220 Leg 3)	79 =	75 + 4		No deepwater survey was done.
Oct 96 (*Gyre* 96G06)	241 =	85 + 4	and	144 + 8
June 97 (*Oregon II* cruise 225 Leg 3)	81 =	77 + 4		No deepwater survey was done.
Aug 97 (*Gyre* 97G08)	181 =	67 + 7	and	102 + 5

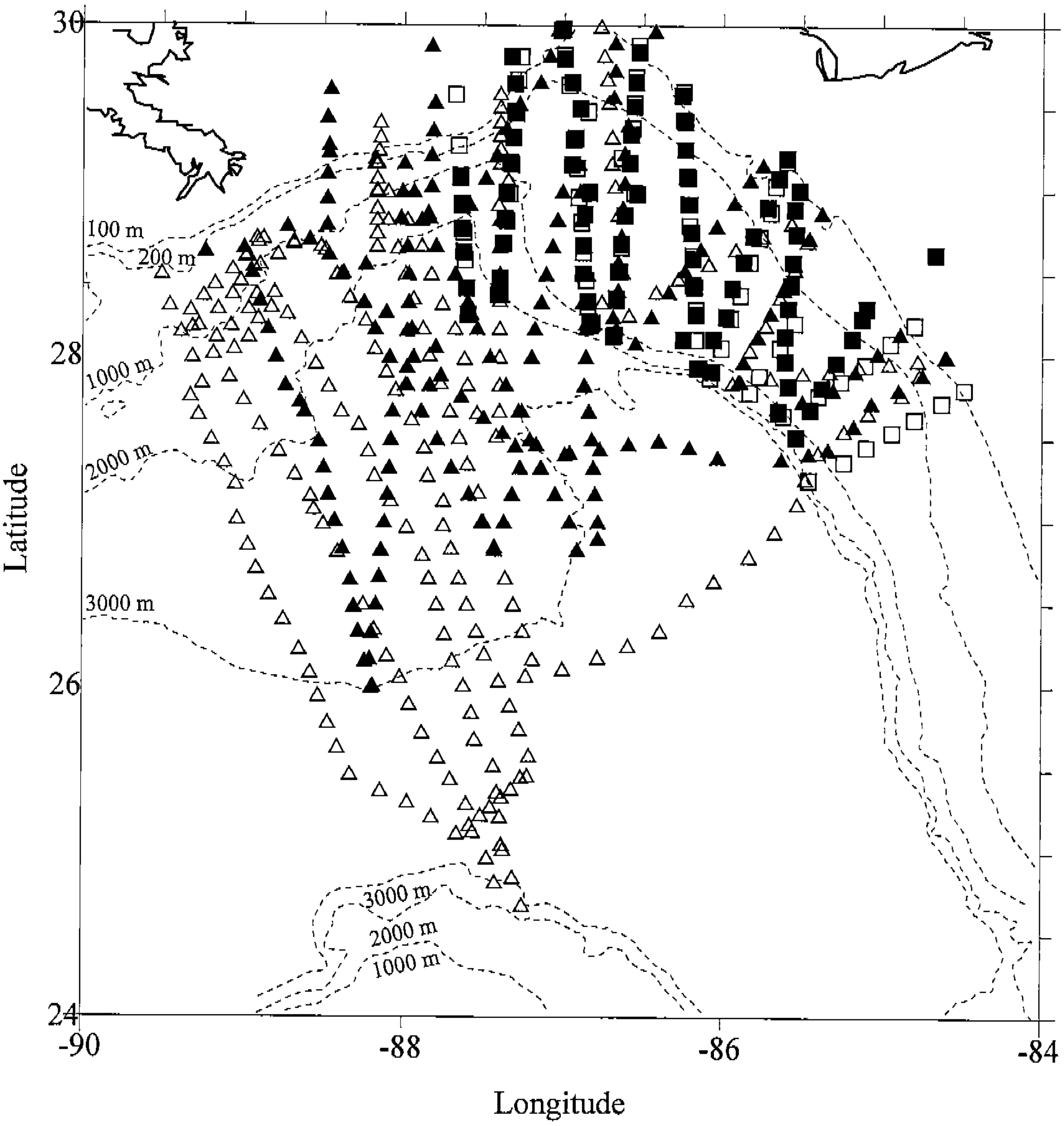

Figure 2.1. Location of hydrographic stations made by R/V *Gyre* (triangles) and R/V *Oregon II* (squares) during four GulfCet II cruises that surveyed the northeast Gulf of Mexico in early and late summer 1996 (open symbols) and early and mid-summer 1997 (filled symbols).

Table 2.2. Hydrographic stations from summer survey cruises grouped into five hydrographic environments.

		Hydrographic Environments Surveyed in the NE Gulf					
Hydrographic Survey	Number of Stations	Cyclone	Confluence	LCE	MOM	Other Margin	Total
June 96 (*Oregon II* cruise 220 Leg 3)	XBTs	8*	none	none	none	67	75
	CTDs	2*	none	none	none	2	4
Oct 96 (*Gyre* 96G06)	XBTs	68	26	26	18	91	229
	CTDs	4	0	3	1	4	12
June 97 (*Oregon II* cruise 225 Leg 3)	XBTs	3*	none	none	none	74	77
	CTDs	2*	none	none	none	2	4
Aug 97 (*Gyre* 97G08)	XBTs	33	26	36	6	68	169
	CTDs	3	1	2	1	5	12

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* *Oregon II* stations were made along the northern periphery of the cyclone (dyn ht anomaly –1 to –5 cm, relative to 800 m), but none of the survey lines extended seaward into the interior of cyclone.

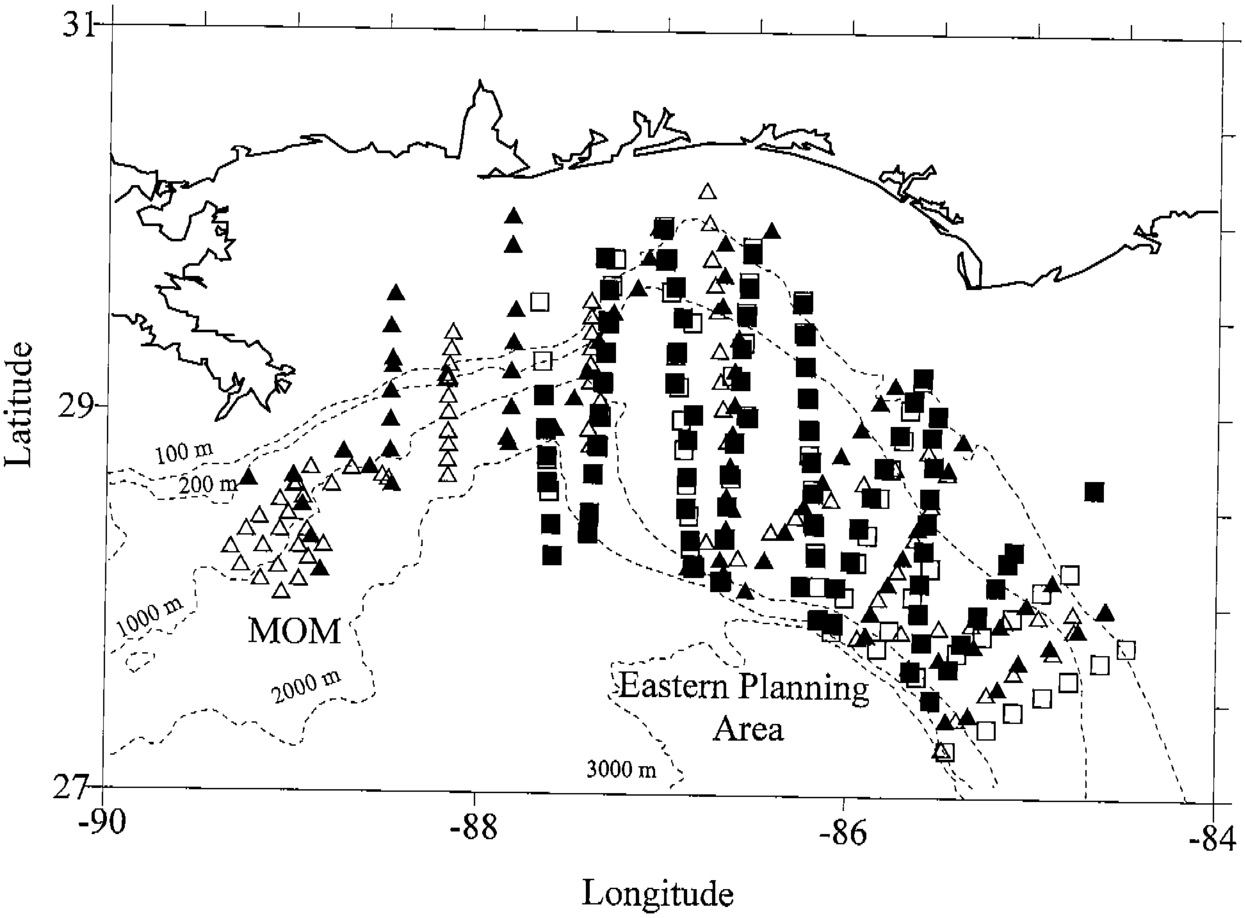


Figure 2.2. Location of hydrographic stations made over the continental margin of the MMS Eastern Planning Area and the mouth of the Mississippi River (MOM) area in water depths of 100-1000 m by R/V *Gyre* and R/V *Oregon II* during the four GulfCet II cruises that surveyed the northeast Gulf of Mexico in early and late summer 1996 and early and mid-summer 1997. Symbols are as in Figure 2.1.

2.2 Methods

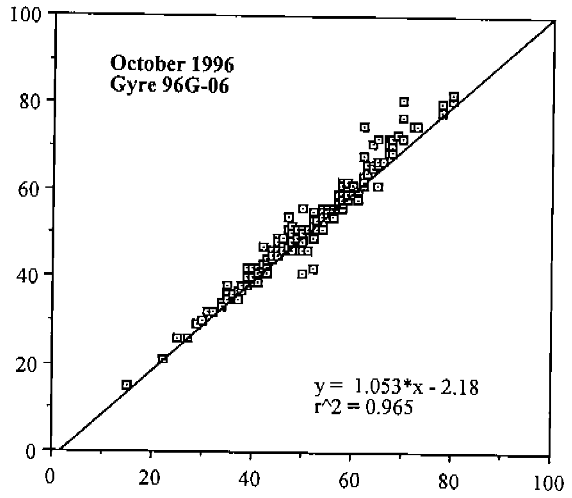
2.2.1 Primary Data

Mixed layer depth (MLD) and 19°C and 15°C depths were read from the XBT data after correcting the raw data for drop-rate error (due to the fact that the Sippican manufacturer's software underestimates the fall rate of T10 and T7 probes by about 5%) (Biggs 1992). For each of the four cruises, the bottom of the mixed layer was chosen as the depth at which surface temperature was 1°C lower than that at the surface. For two of the four cruises in which surface salinity was routinely measured (see Section 2.2.3), sigma-theta density was also calculated and MLD was computed, for comparison, as the depth at which sigma-theta density increased 0.5 above its value at the surface. These two measures of MLD agreed extremely well in late summer 1996 (upper panel of Figure 2.3), when surface salinity and surface sigma-theta were both high (>34 psu and 22.5–24.0, respectively). In contrast, MLD was overestimated by the 1°C temperature difference method in mid-summer 1997 (see lower panel of Figure 2.3). The overestimation was largest when surface salinity and surface sigma-theta were both locally low (Figure 2.4).

The 19°C and 15°C depths are useful as summary statistics of nitracline depth and eddy dynamic topography, respectively. Bottle samples analyzed from the late summer 1996 fieldwork showed that at temperatures below about 22°C, there was a highly predictable negative first order relationship between temperature and nitrate concentration (Figure 2.5). As demonstrated by Atkinson et al. (1978), temperature can thus be a proxy for nitrate concentration. In particular, in the Gulf of Mexico the depth of the 19°C isotherm is a good estimation of the depth of the 10 μM nitrate concentration (Figure 2.5). Other fieldwork (Biggs et al. 1988, Biggs et al. 1996) had documented that the 15°C isotherm of the main thermocline is depressed to >250 m in strong anticyclones and domes to <170 m in strong cyclones. Over deepwater with bottom depths >800 m, the 15°C depth in late and mid-summer was well correlated with upper layer dynamic height (cm) relative to 800 m and with dynamic height anomaly (Figure 2.6).

The basis for the anomaly computation changes seasonally, as the near surface water is heated to stand about 10 cm higher in mid-summer than in early summer. In early summer, the mean dynamic height for the deepwater continental margin away from the LC or its associated eddies was 95 dyn cm relative to 800 m. This mean dynamic height increased to 105 dyn cm by mid-summer, and then relaxed to 100 cm by late summer, as the near surface water began to lose heat after passage of atmospheric cold fronts in September and October. Operationally, early summer stations with dynamic height relative to 800 m of ≤ 95 dyn cm were grouped as "cyclone." At these stations, 15°C depth was shallower than 170 m. However, the dynamic height anomaly of these stations relative to the average deepwater dynamic height for early summer was just -1 to -5 cm (see spreadsheet hydrographic data table for all four cruises in the Appendix). Therefore, these stations must have been at the northern periphery of the cyclone rather than in its interior.

Similarly, late summer 1996 deepwater hydrostations with <100 dyn cm were grouped as "cyclone," those >125 dyn cm were grouped as LC Eddy C; and those 100-125 dyn cm were grouped as "confluence," "other margin," or "MOM," depending on their geographic location in relation to the cyclone-anticyclone. The operational cut-offs for grouping mid-summer 1997



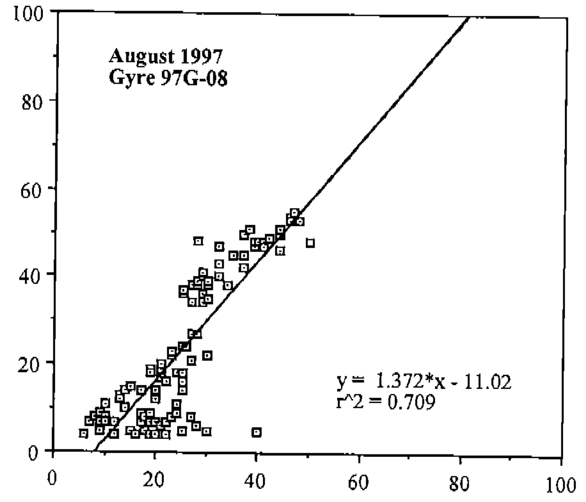


Figure 2.3. Property-property plots illustrating relationship between mixed layer depth (MLD) calculated as [surface temperature - 1°C] and [surface sigma-theta + 0.5], in late versus mid-summer.

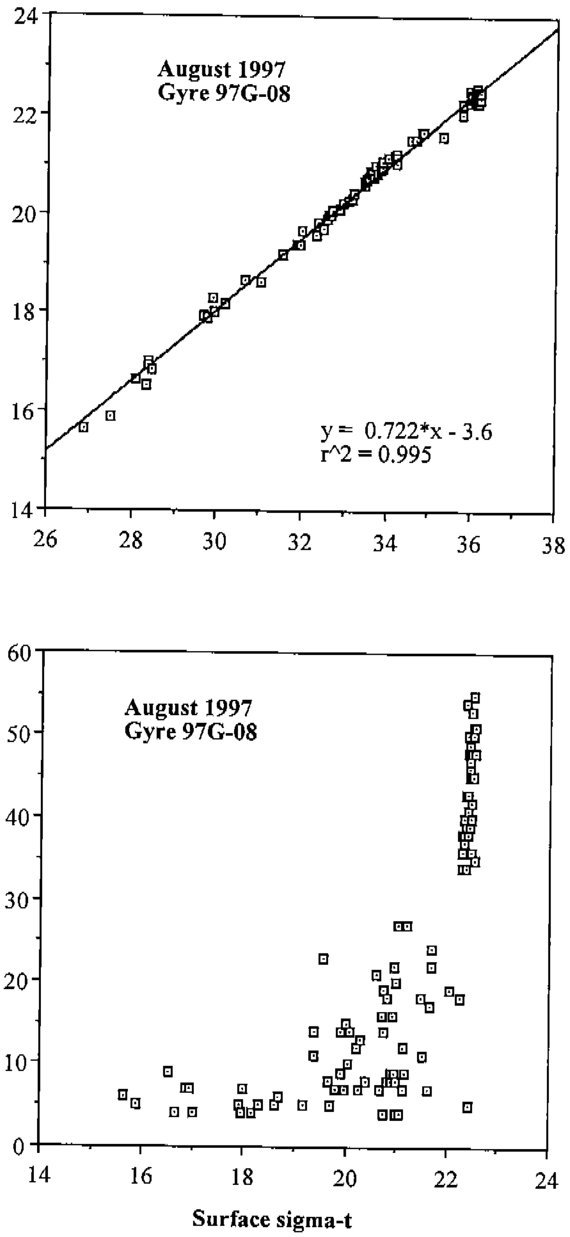


Figure 2.4. Property-property plots illustrating the influence of surface salinity on surface sigma-theta and the nonlinear relationship between mixed layer depth and surface sigma-theta in August 1997.

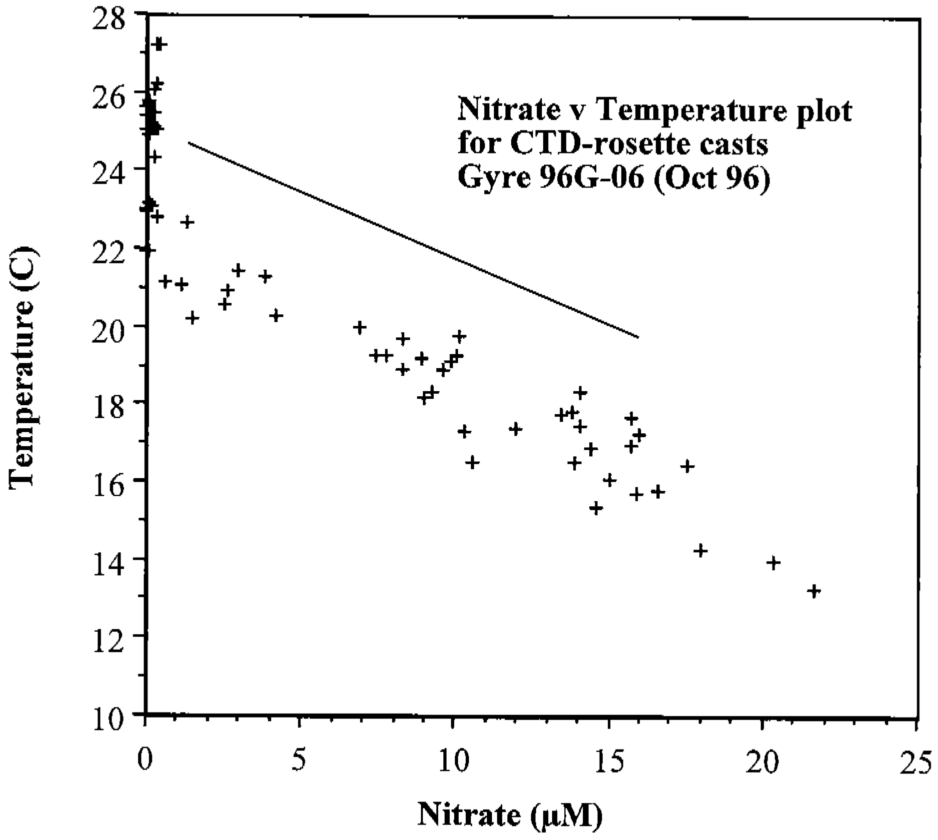
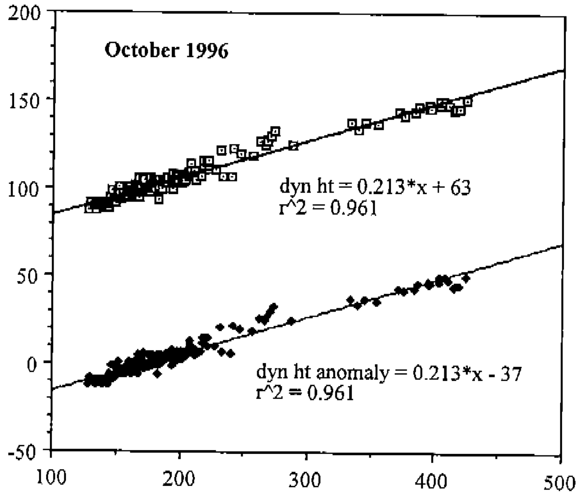


Figure 2.5. A negative functional relationship between nitrate and temperature allowed the 19°C depth to be used as a proxy for 10 µM of nitrate.



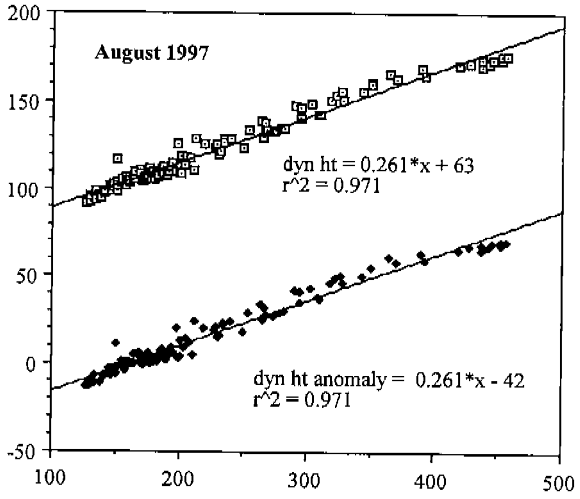


Figure 2.6. Property-property plots illustrating use of 15°C depth (m) as a proxy for deepwater dynamic height (cm) relative to 800 m and for deepwater dynamic height anomaly (cm) relative to the seasonal mean.

deepwater hydrostations as "cyclone" versus "confluence" versus "LCE-E" were <105 dyn cm, 105-130 dyn cm, and >130 dyn cm, respectively. Stations made in water depths <800 m were grouped on the basis of 15°C depth. Operationally, stations with 15°C depth <170 m were grouped as "cyclone"; stations with 15°C depth >250 m were grouped as LCE; and stations with 15°C depth 170-250 m were grouped as "confluence," "other margin," or "MOM," depending on their geographic location in relation to the cyclone-anticyclone pair.

2.2.2 Between Cruise Differences

Since the two *Gyre* cruises surveyed the northeastern Gulf in different months in 1996 and 1997, between-cruise differences in MLD and 19°C depth likely reflect within-season differences between mid-summer and late summer rather than year-to-year differences. The third legs of the 1996 and the 1997 *Oregon II* cruises, however, both surveyed the EPA at the same time of year (Julian days 151-161). Moreover, most of the hydrostations were co-located at the same (or nearly identical) water depths and latitude-longitude positions, so differences in MLD and 19°C depth between these cruises do represent year-to-year differences. Figure 2.7 shows the location of the seven cross-margin transects on which the between-cruise-differences in water depth and station location are smallest.

Stations on transects A through F in and around DeSoto Canyon were similar in location in 1996 and 1997. Stations on transect G on the West Florida Terrace and West Florida Shelf were similar in water depth, although there was up to 30 km difference in locations between 1996 and 1997.

2.2.3 Other Hydrographic Data

The *Gyre* is equipped with a through-the-hull pumped seawater system and a 153 kHz Rowe Deines Instruments narrowband Acoustic Doppler Current Profiler (ADCP). Data from both systems were logged during the late summer and mid-summer cruises, and these data will be summarized in this chapter to supplement the MLD, 19°C depth and 15°C depth data that were collected in common by both ships.

Near-surface temperature, conductivity and fluorescence were logged every two minutes throughout both cruises with *Gyre*'s Serial ASCII Interface Loop (SAIL) system. Temperature and conductivity were measured using Sea-Bird Electronics Corporation in-line sensors, and fluorescence was measured using a Turner Designs model 10 laboratory fluorometer that was equipped for flow-through operation.

The ADCP data were not collected by the ship's SAIL system, but were instead downloaded directly to a PC and then binned into five minute ensembles by the manufacturer's software. The raw binary data were then converted to ASCII format for subsequent processing ashore on UNIX workstations. The ADCP raw data were analyzed by Dr. Steve DiMarco, following quality assurance and quality control procedures used to process ADCP data that were collected later in 1997 and in 1998 by the Northeastern Gulf of Mexico Chemical Oceanography and Hydrography Study (NEGOM). Jochens and Nowlin (1998) give details about this data processing in section 3.3.3 of the first Annual Report for the NEGOM study. Figures 2.8 and 2.9 are plots of the late

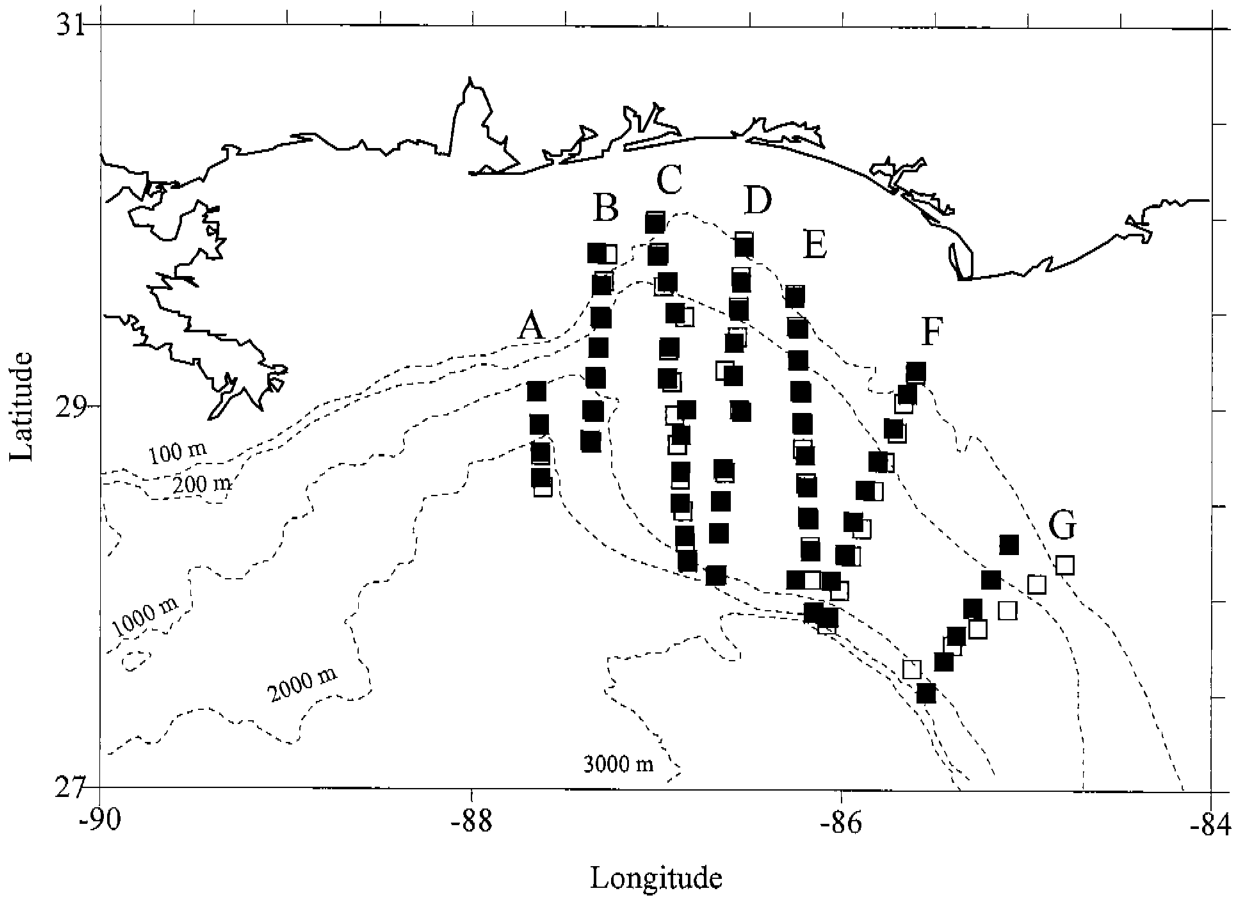


Figure 2.7. Stations along seven of the closely-spaced XBT transects made by R/V *Oregon II* in the MMS Eastern Planning Area were done at very similar locations and water depths in early summer 1997 as they had been done in early summer 1996. These are designated as transects A to G. Symbols are as in Figure 2.1.

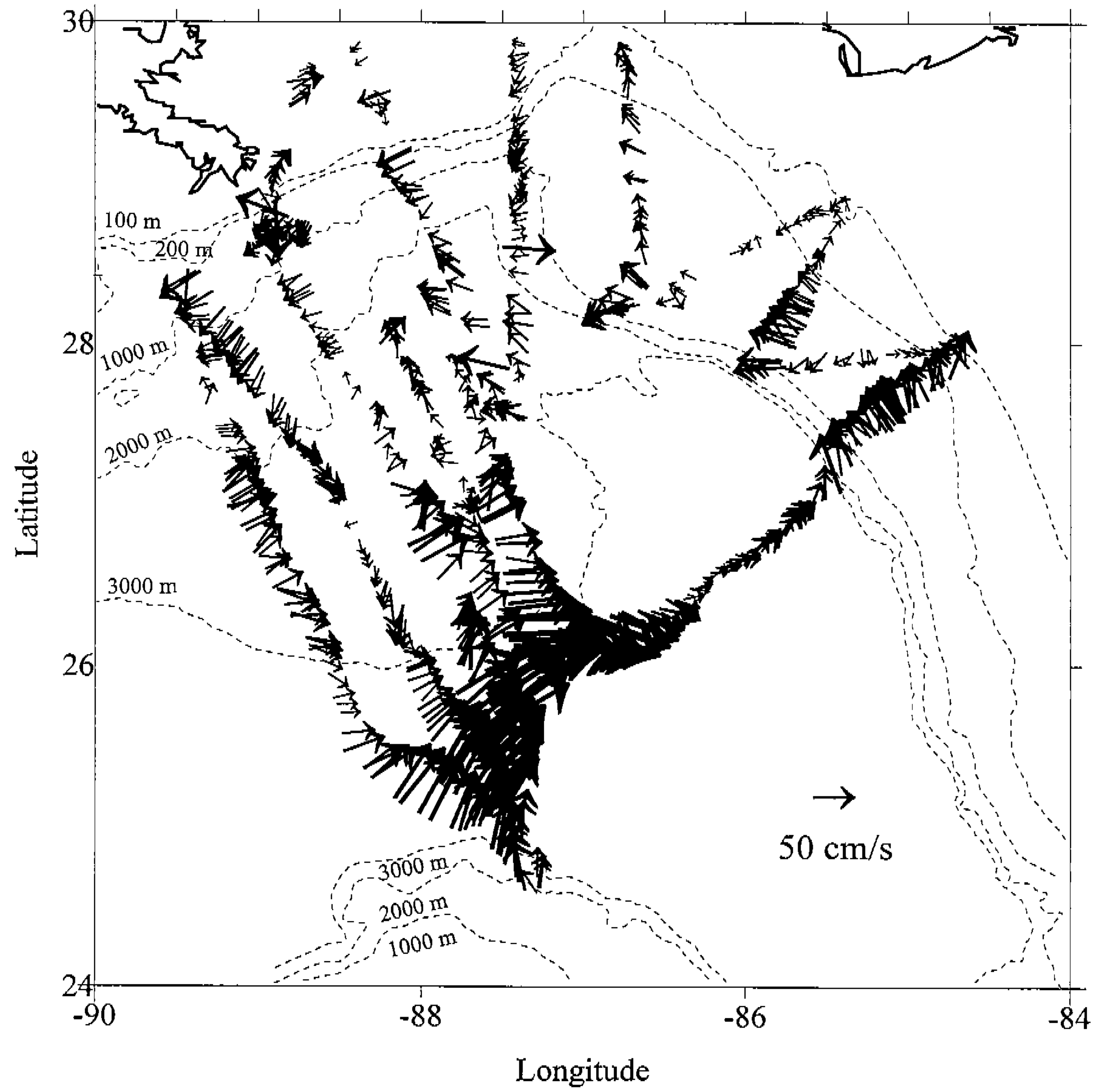


Figure 2.8. Along-track current velocity at 10 m depth, measured by acoustic Doppler current profiler (ADCP) during R/V *Gyre* cruise 96G06.

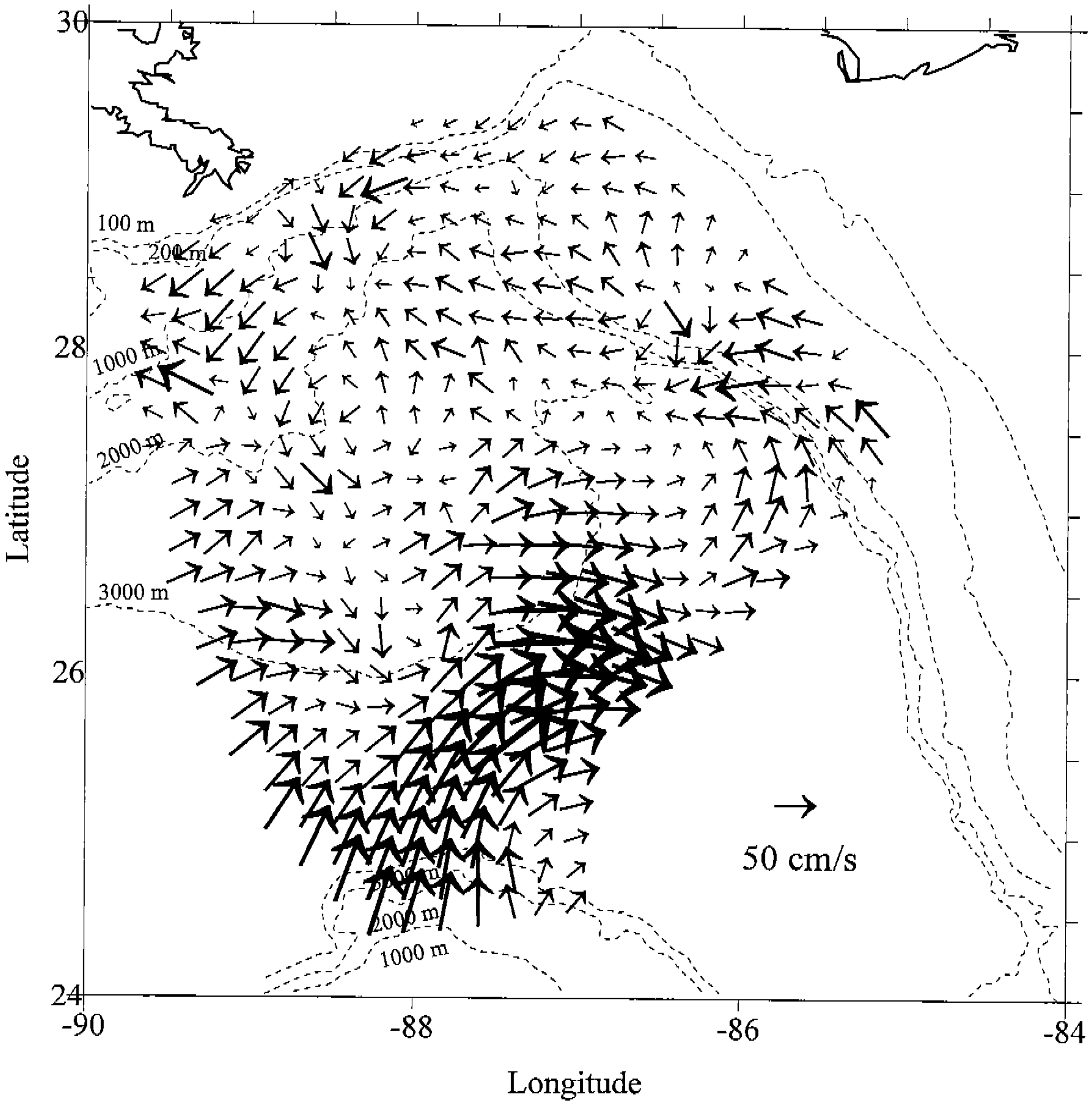


Figure 2.9. Gridded ADCP current vectors within the deepwater focal and continental margin areas of the northeast Gulf of Mexico surveyed by R/V *Gyre* cruise 96G06.

summer ADCP currents at z = 10 m, the uppermost depth bin for which data are available. Figure 2.8 shows post sigma QA/QC (grossly anomalous velocity vectors greater than three standard deviations from the average value removed). In Figure 2.9, the data have been optimally interpolated and gridded to more clearly illustrate the mean field. Figures 2.10 and 2.11 are similar plots of the mid-summer ADCP currents at z = 10 m.

2.3 Results

2.3.1 Hydrography of the Continental Margin of the MMS Eastern Planning Area

Contour plots of 15°C depth, 19°C depth and mixed layer depth (MLD) for the four cruises that surveyed the MMS EPA are given as Figures 2.12–2.23. Because these surveys concentrated on the depth range 100-1000 m while cyclone and LCEs were usually centered seaward of the 1000 m depth, each of these variables on any individual cruise usually had limited dynamic range over most of this margin.

It is evident from the depth of the 15°C isotherm that a secondary warm eddy was present over this continental margin in early summer 1996, and again in early summer 1997. In Figures 2.12 and 2.15, these warm-core eddies can be seen as elliptical regions about 30 x 60 n miles in size, where the 15°C depth was >190 m. These secondary eddies form when warm filaments extend north and then separate from the deepwater LCEs. Although these secondary warm eddies have an anticyclonic circulation, CTD vertical profiles show that they contain little or no subtropical underwater; that is, subsurface salinity in these secondary warm eddies rarely exceeded the 36.5 practical salinity units that is diagnostic of LC water of Caribbean Sea origin. These secondary warm eddies show up in Figures 2.13 and 2.14, and in Figures 2.16 and 2.17, as elliptical regions in which 19°C depth and MLD are locally deeper than over the adjacent slope.

The depth of the nitracline, as determined from 19°C depth, was more than 20 m shallower in the northern edges of the cyclones that were surveyed in early summer 1996 and 1997 than in these secondary warm eddies. However, locally shallow nitracline depths were also found along the shelf margin. Figure 2.13 shows that the 19°C isotherm domed shallower than 50 m from the surface along the upper slope of the EPA in early summer 1996. Figure 2.16 shows that such shelf edge upwelling was also present in early summer 1997, although the 19°C depth did not reach as shallow.

In addition, it is evident that surface temperature over most of the continental margin was 1-2°C warmer in June 1997 (Figure 2.24a). Similarly, MLD was generally 10-20 m shallower in June 1996 than in June 1997 (Figure 2.24b), and so was 19°C depth (Figure 2.24c). Below the nitracline, however, interannual differences were small: 15°C depth was highly similar between June 1996 and June 1997 at each of the stations along transects A to F (Figure 2.24d).

Later in the summer of both years, shelf-edge upwelling appeared to relax. Based on Figure 2.21, there is no evidence of the 15°C isotherm doming over the upper slope in mid-summer 1997, although the 19°C isotherm (Figure 2.22) is domed by 10-30 m shallower. Similarly, Figure 2.18 and Figure 2.19 shows no doming of either isotherm over the upper slope in late summer 1996. The strength of this shelf-edge upwelling probably varies seasonally, for it was

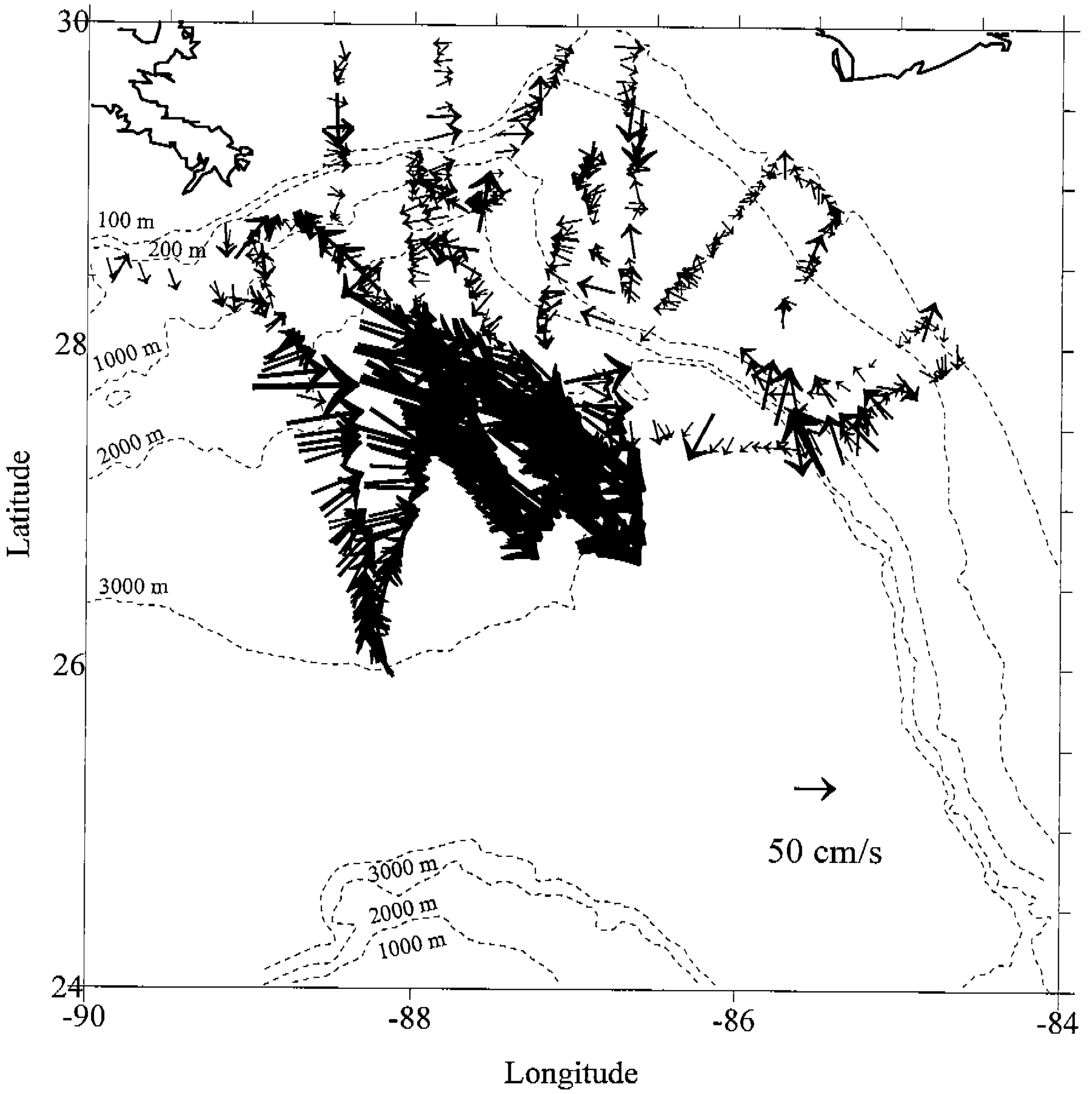


Figure 2.10. Along-track current velocity at 10 m depth, measured by acoustic Doppler current profiler (ADCP) during R/V *Gyre* cruise 97G08.

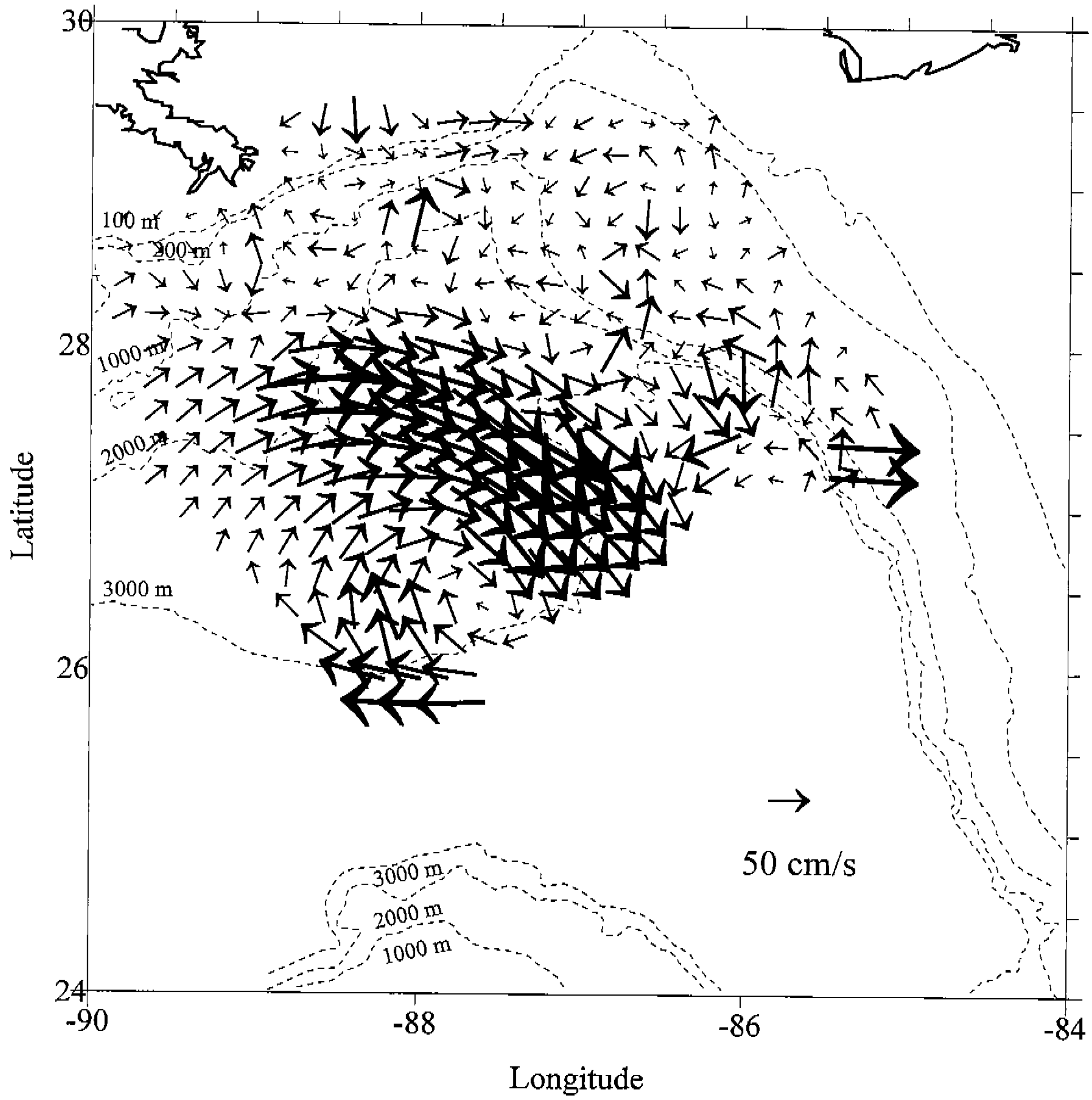


Figure 2.11. Gridded ADCP current vectors within the deepwater focal and continental margin areas of the northeast Gulf of Mexico surveyed by R/V *Gyre* cruise 97G08.

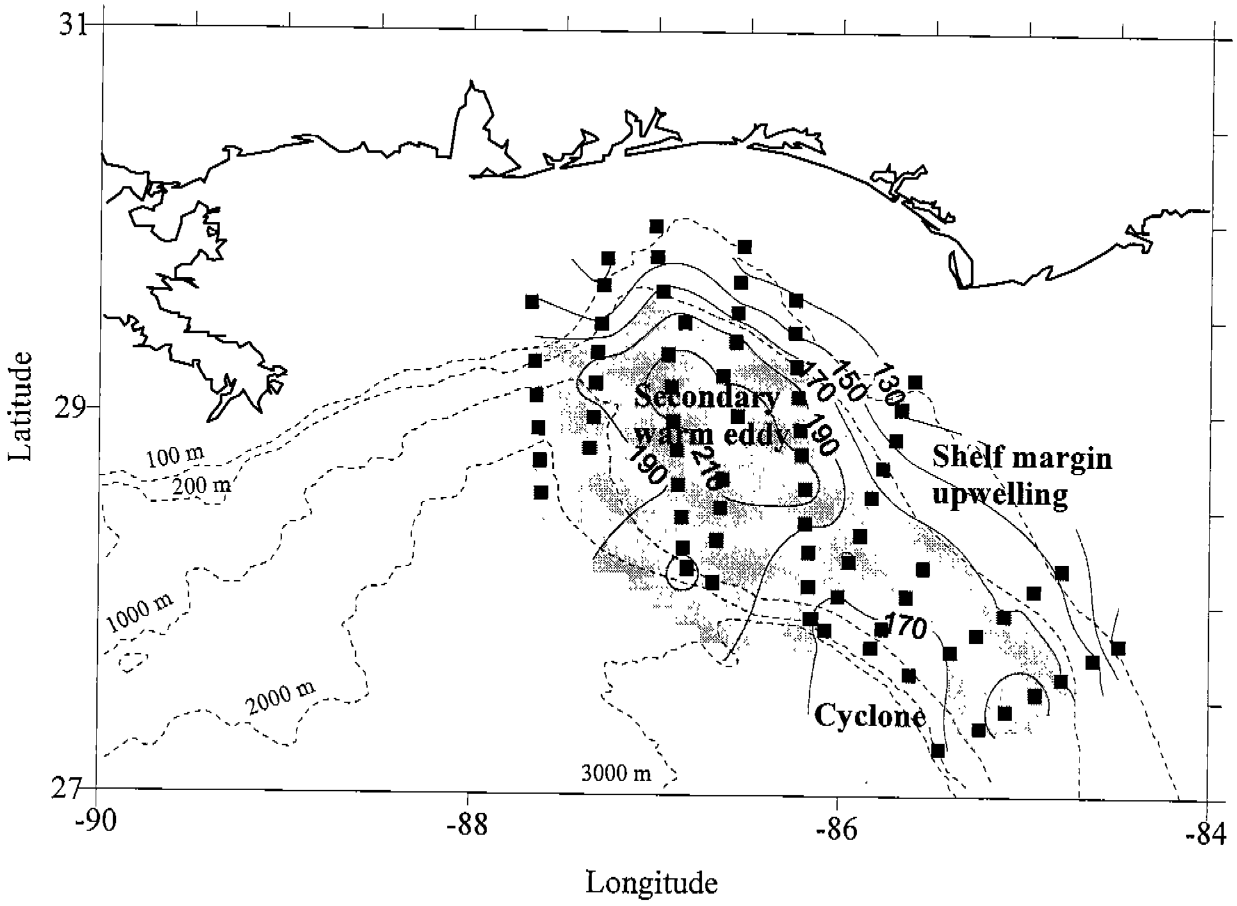


Figure 2.12. Contour map of 15°C depth on the continental margin of the northeast Gulf of Mexico, as determined from 79 hydrographic stations (filled squares) made on R/V *Oregon II* cruise 220, Leg 3. The gray scale shading deliniates local areas where isotherms shoal (lightest gray) and deepen (darkest gray) relative to their seasonal average depth on the continental margin.

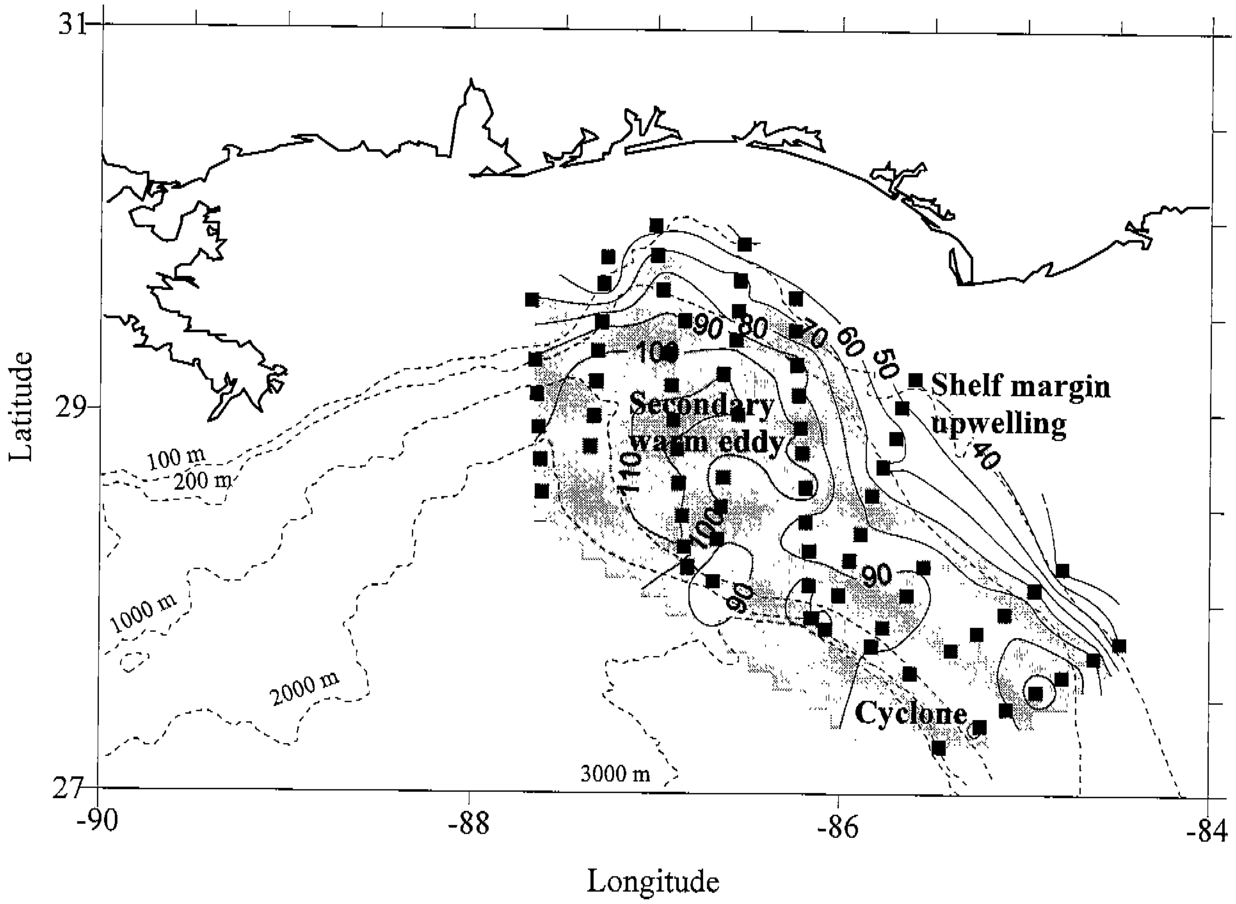


Figure 2.13. Contour map of 19°C depth on the continental margin of the northeast Gulf of Mexico, as determined from 79 hydrographic stations made on R/V *Oregon II* cruise 220, Leg 3. Symbols and shading as in Figure 2.12.

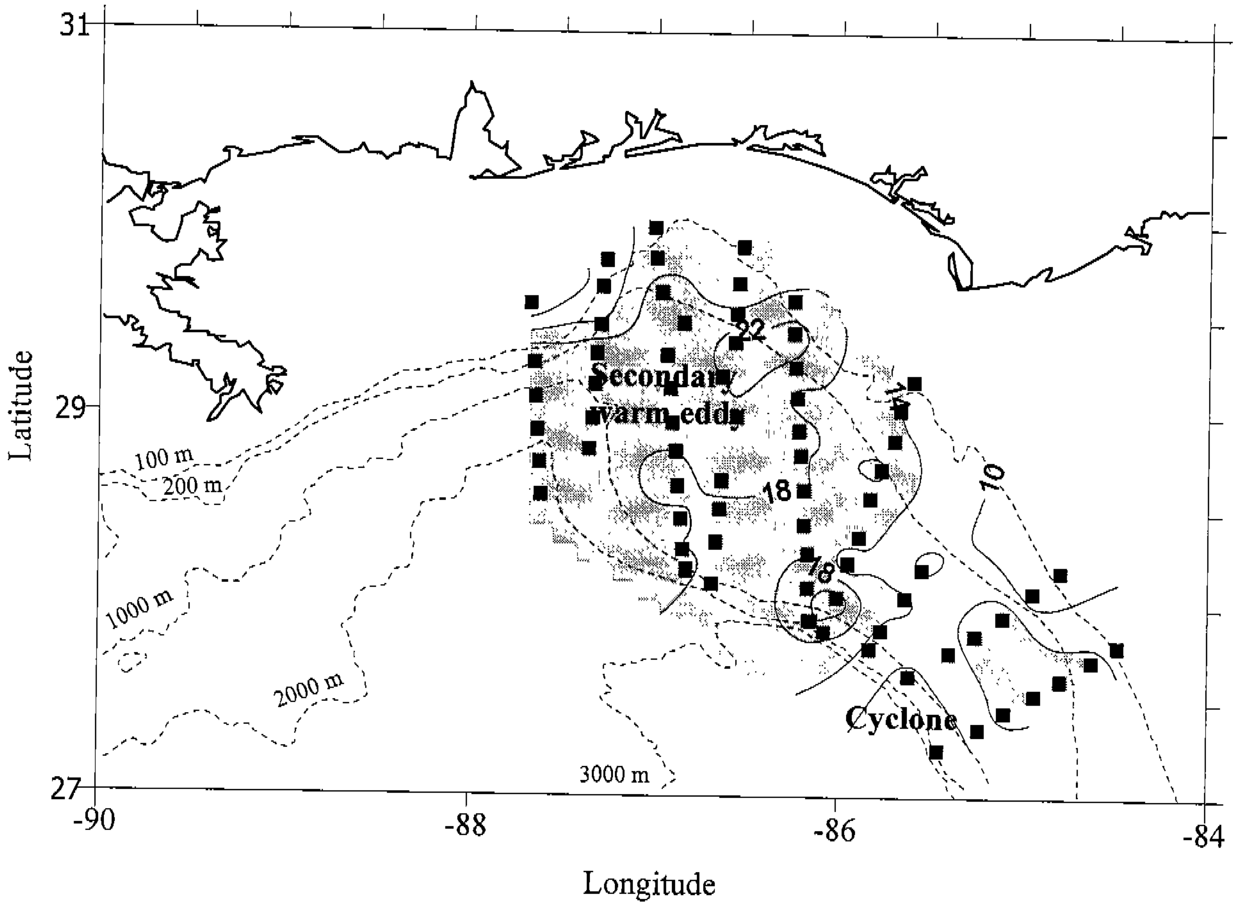


Figure 2.14. Contour map of mixed layer depth (MLD) on the continental margin of the northeast Gulf of Mexico, as determined from 79 hydrographic stations made on R/V *Oregon II* cruise 220, Leg 3. The gray scale shading deliniates local areas where MLD shoals (lightest gray) and deepens (darkest gray) relative to its seasonal average depth on the continental margin.

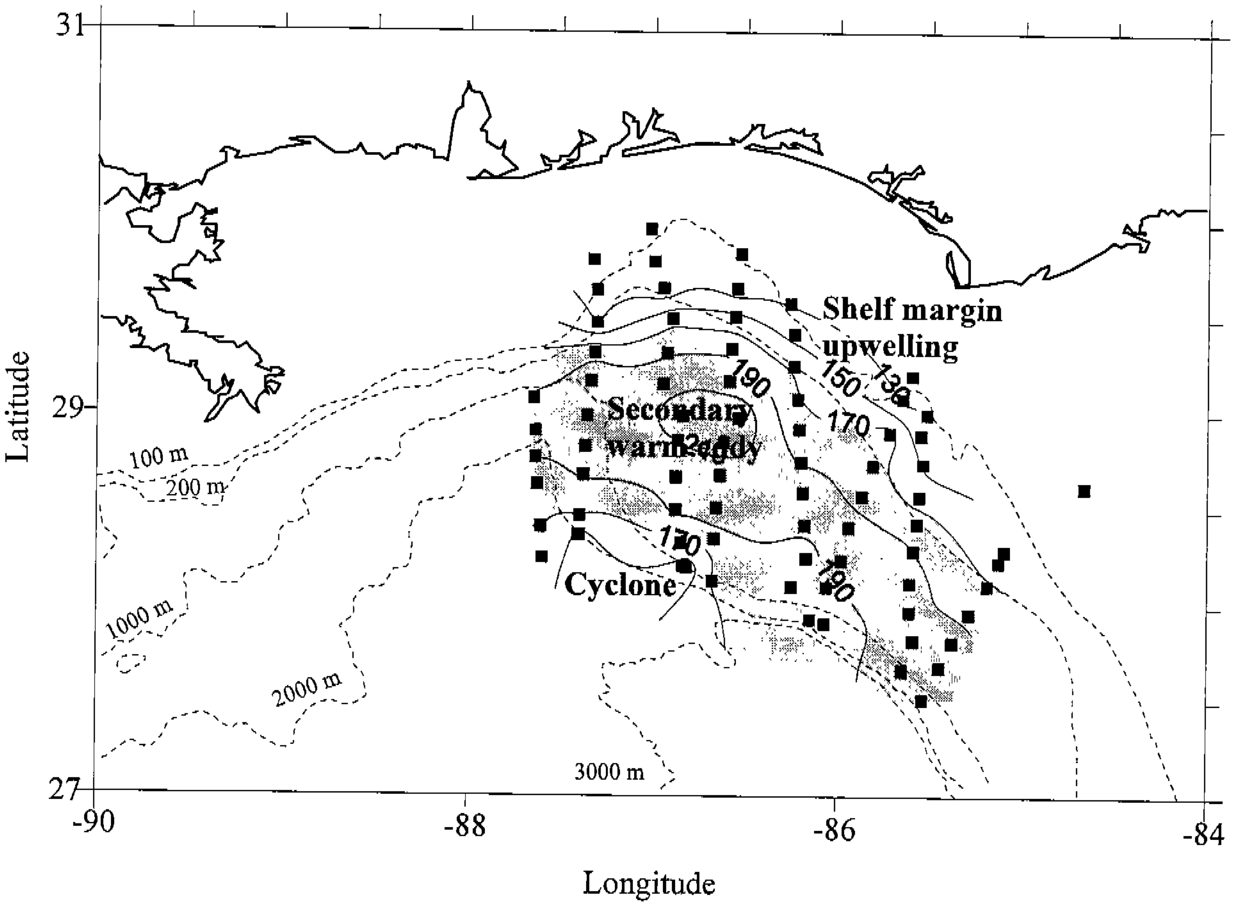


Figure 2.15. Contour map of 15°C depth on the continental margin of the northeast Gulf of Mexico, as determined from 79 hydrographic stations made on R/V *Oregon II* cruise 225, Leg 3. Symbols and shading as in Figure 2.12.

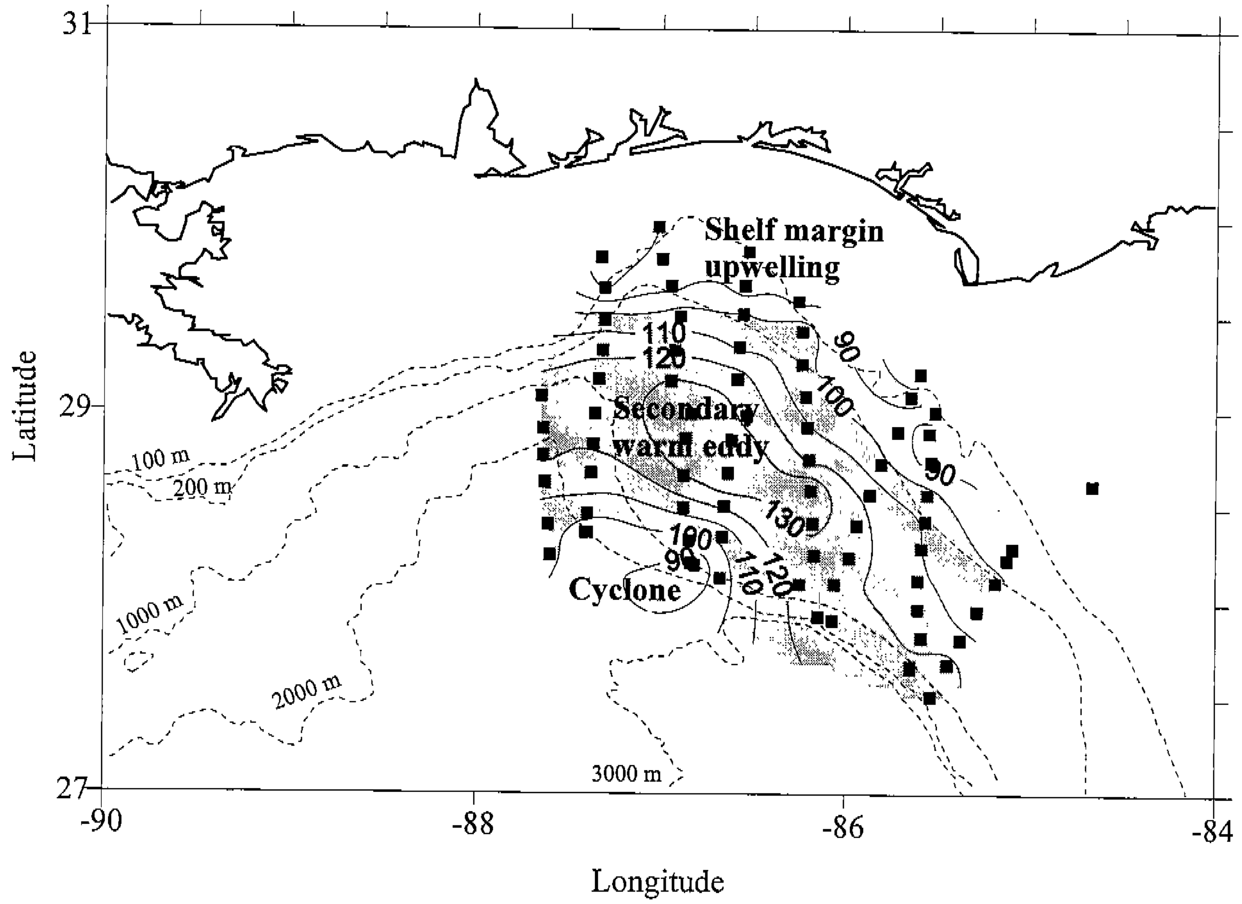


Figure 2.16. Contour map of 19°C depth on the continental margin of the northeast Gulf of Mexico, as determined from 81 hydrographic stations made on R/V *Oregon II* cruise 225, Leg 3. Symbols and shading as in Figure 2.12.

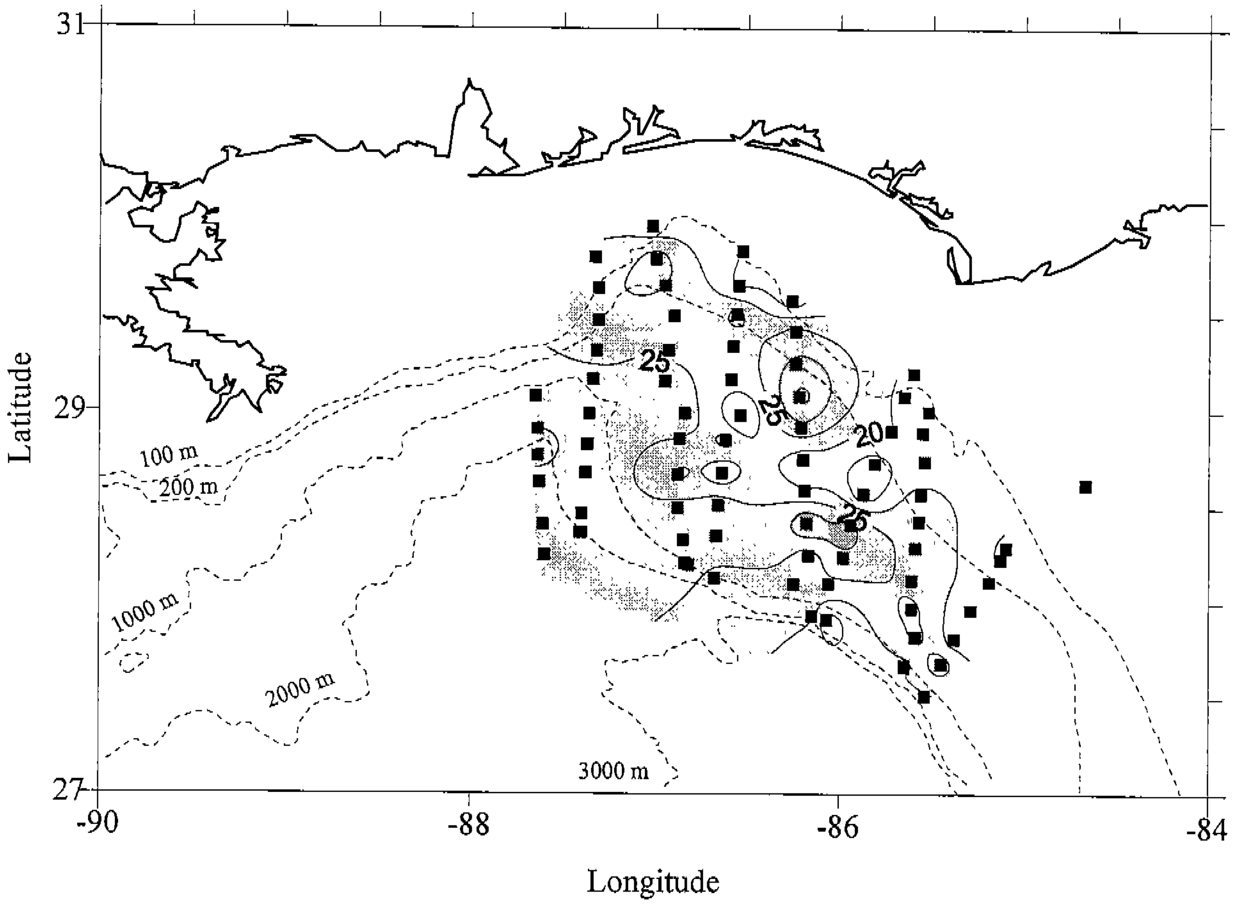


Figure 2.17. Contour map of mixed layer depth on the continental margin of the northeast Gulf of Mexico, as determined from 81 hydrographic stations made on R/V *Oregon II* cruise 225, Leg 3. Symbols and shading as in Figure 2.14.

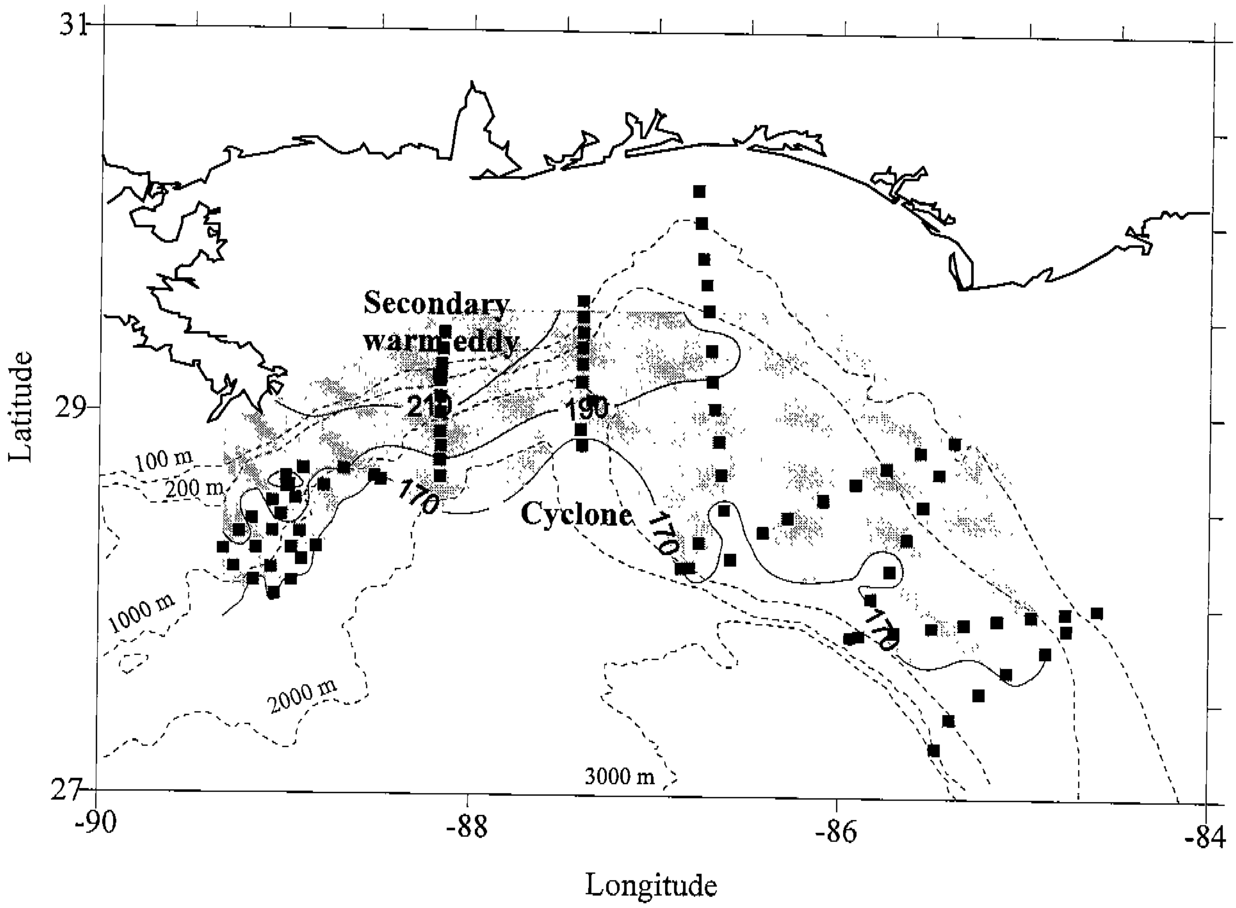


Figure 2.18. Contour map of 15°C depth on the continental margin of the northeast Gulf of Mexico, as determined from 89 hydrographic stations made on R/V *Gyre* cruise 96G06. Symbols and shading as in Figure 2.12.

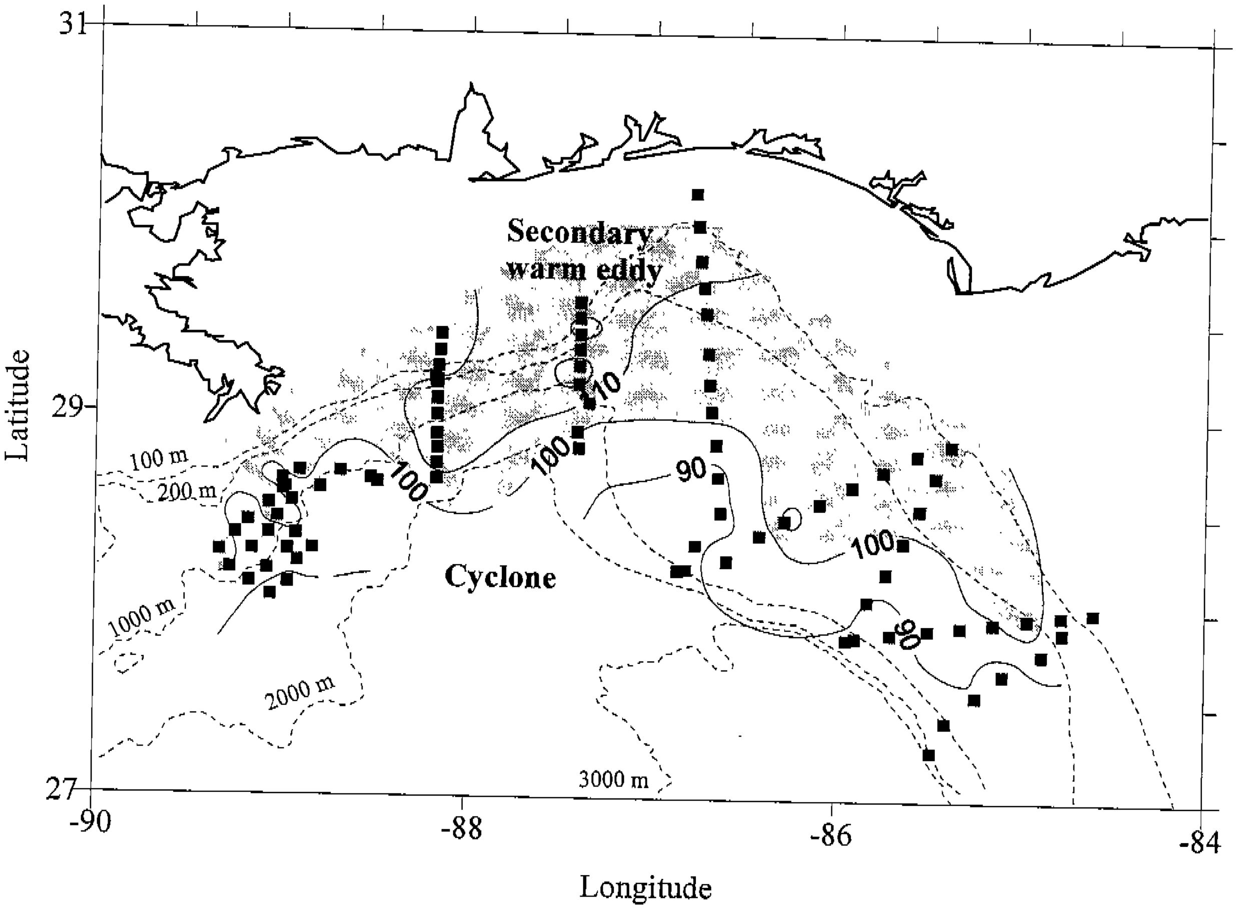


Figure 2.19. Contour map of 19°C depth on the continental margin of the northeast Gulf of Mexico, as determined from 89 hydrographic stations made on R/V *Gyre* cruise 96G06. Symbols and shading as in Figure 2.12.

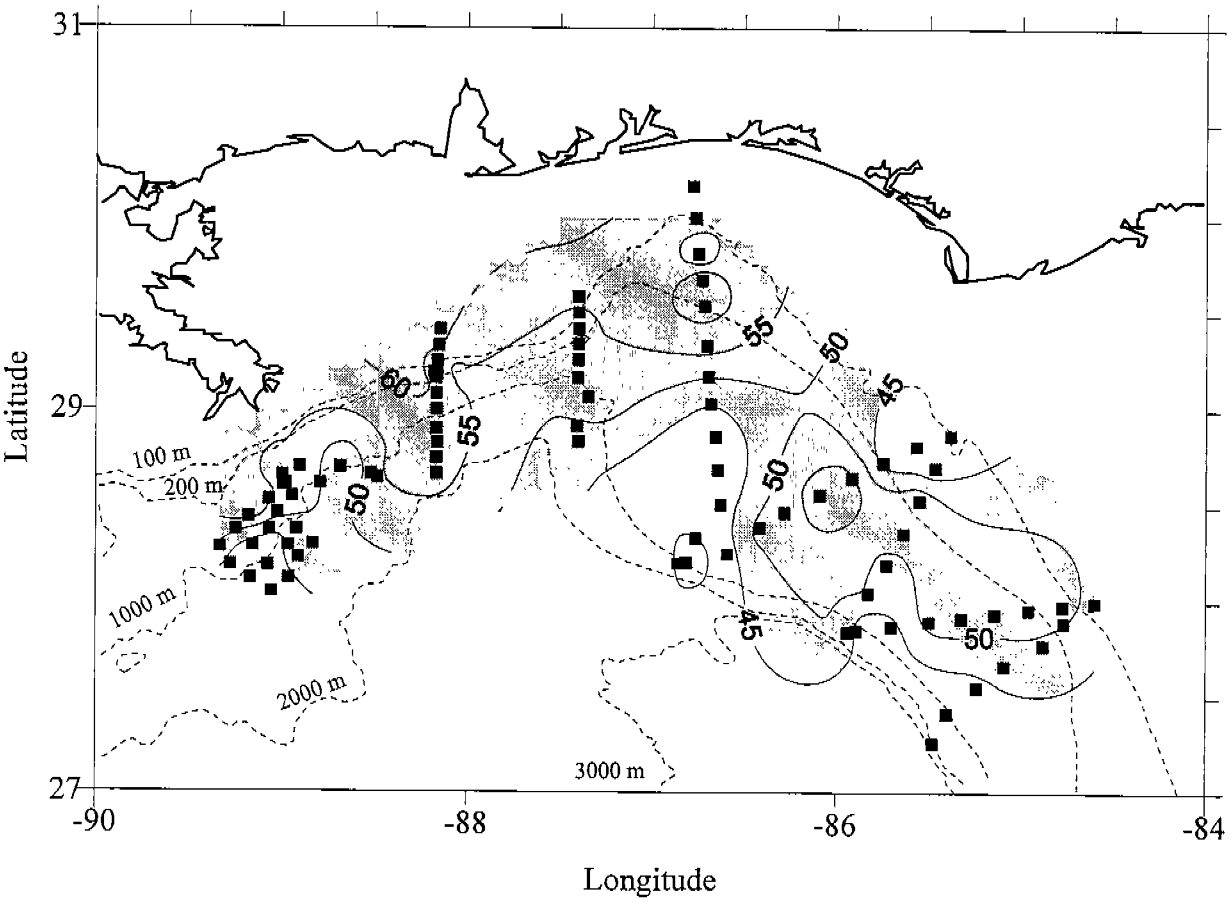


Figure 2.20. Contour map of mixed layer depth on the continental margin of the northeast Gulf of Mexico, as determined from 89 hydrographic stations made on R/V *Gyre* cruise 96G06. Symbols and shading as in Figure 2.14.

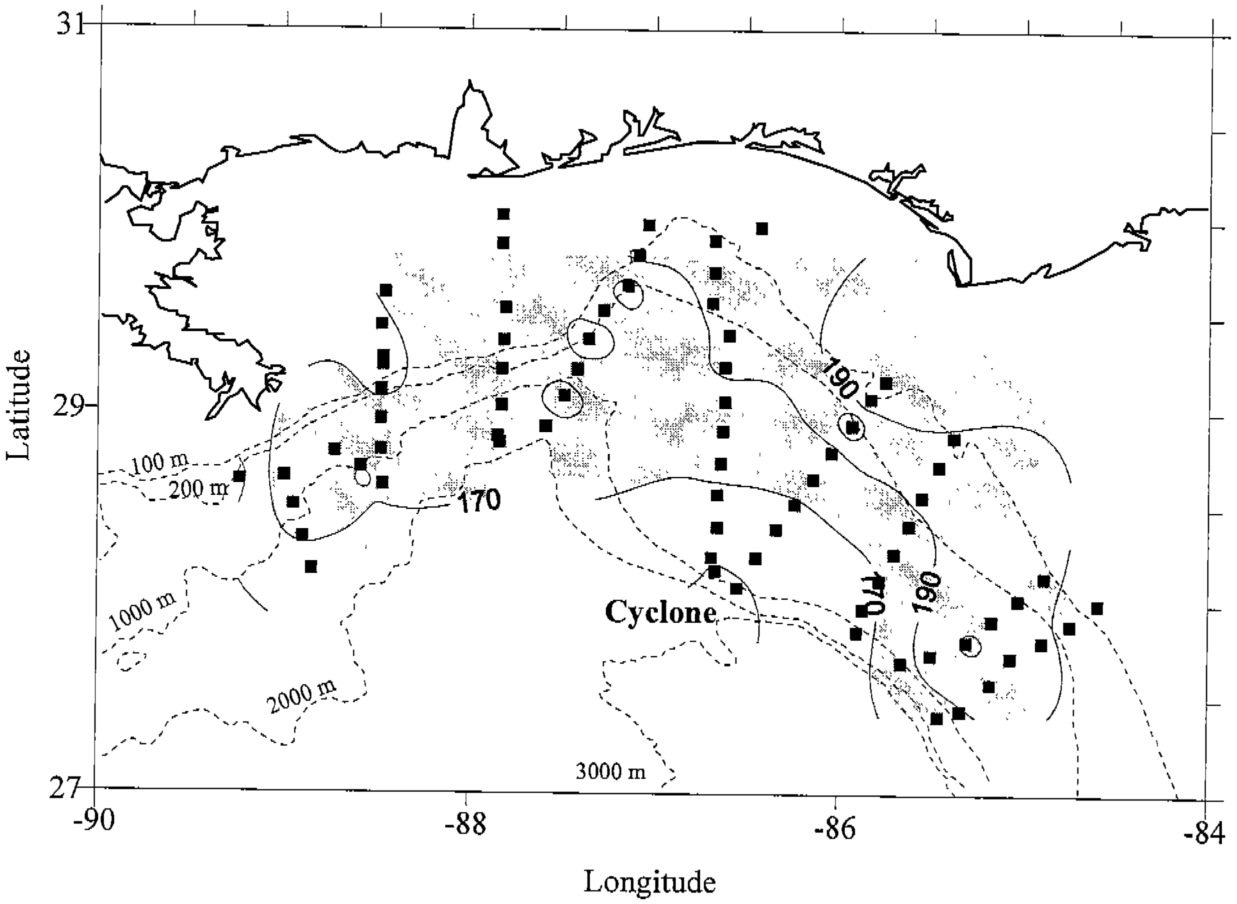


Figure 2.21. Contour map of 15°C depth on the continental margin of the northeast Gulf of Mexico, as determined from 74 hydrographic stations made on R/V *Gyre* cruise 97G08. Symbols and shading as in Figure 2.12.

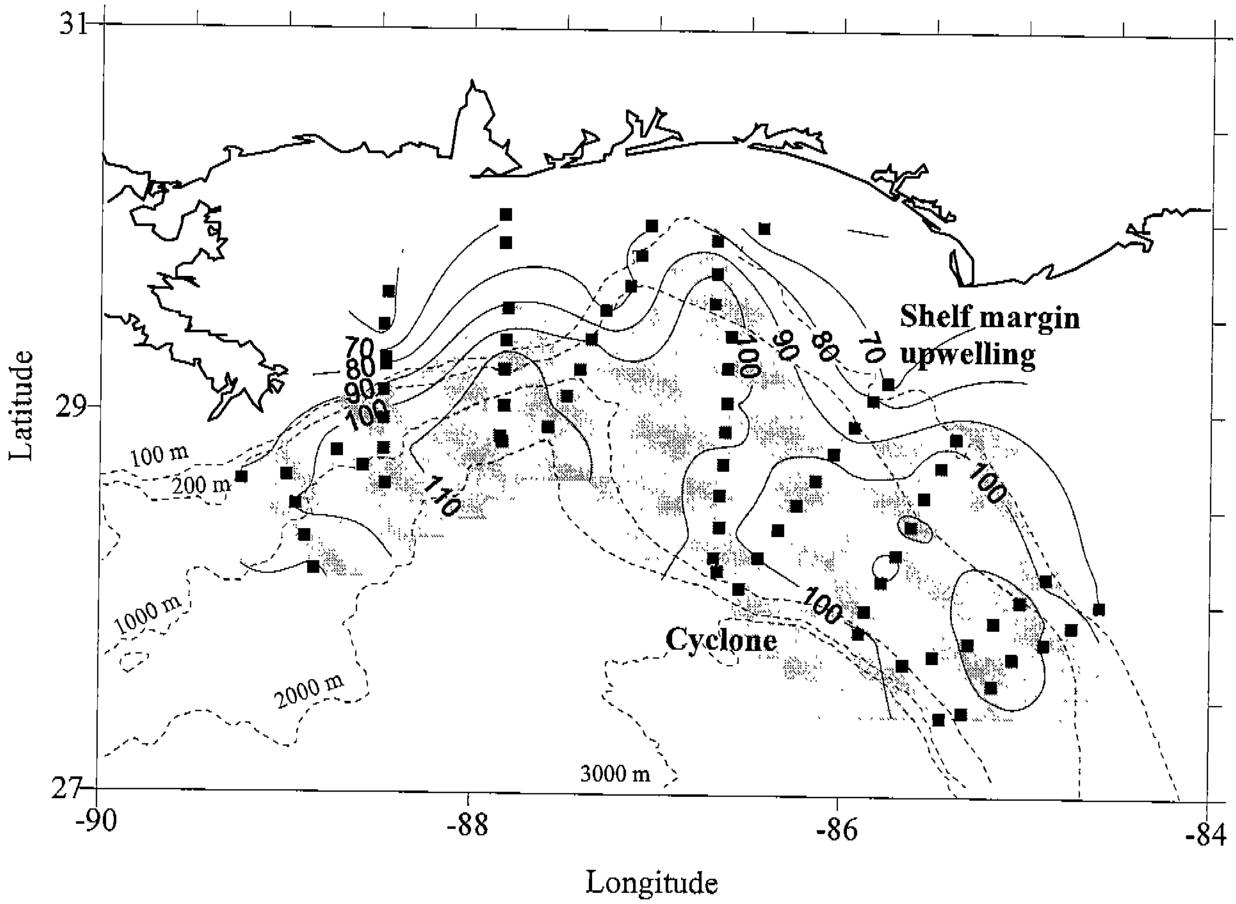


Figure 2.22. Contour map of 19°C depth on the continental margin of the northeast Gulf of Mexico, as determined from 74 hydrographic stations made on R/V *Gyre* cruise 97G08. Symbols and shading as in Figure 2.12.

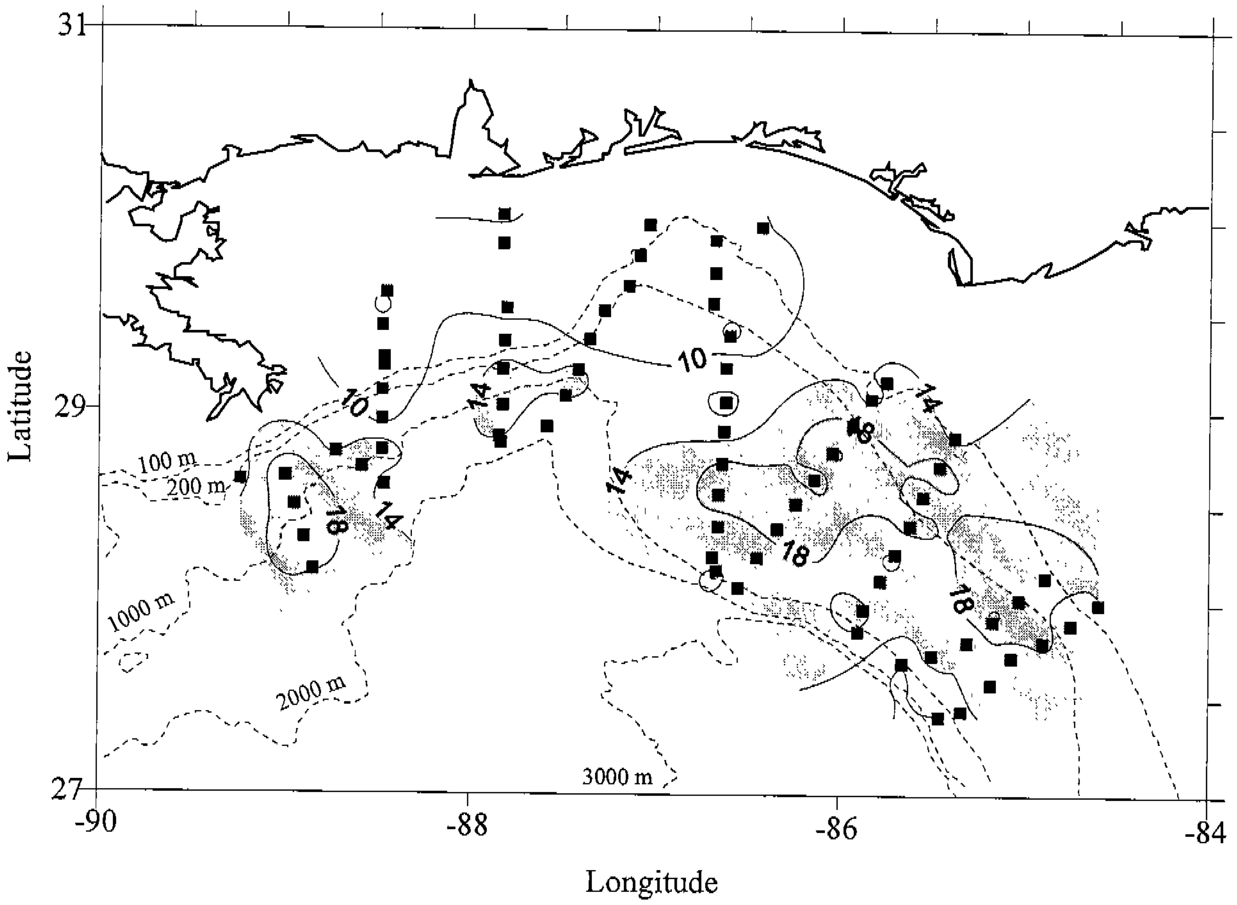


Figure 2.23. Contour map of mixed layer depth on the continental margin of the northeast Gulf of Mexico, as determined from 74 hydrographic stations made on R/V *Gyre* cruise 97G08. Symbols and shading as in Figure 2.14.

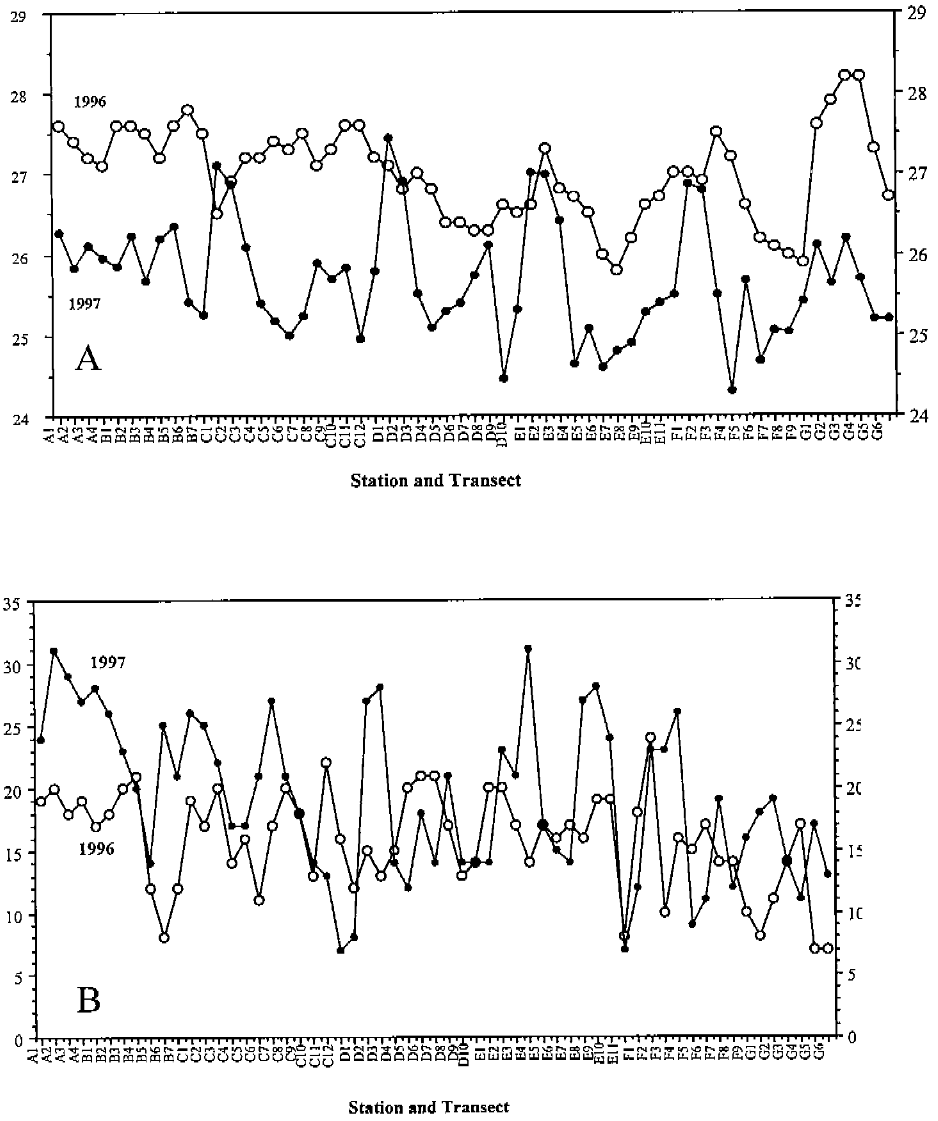


Figure 2.24. Between year variation in a) surface temperature, and b) mixed layer depth for stations along EPA transect lines A-G.

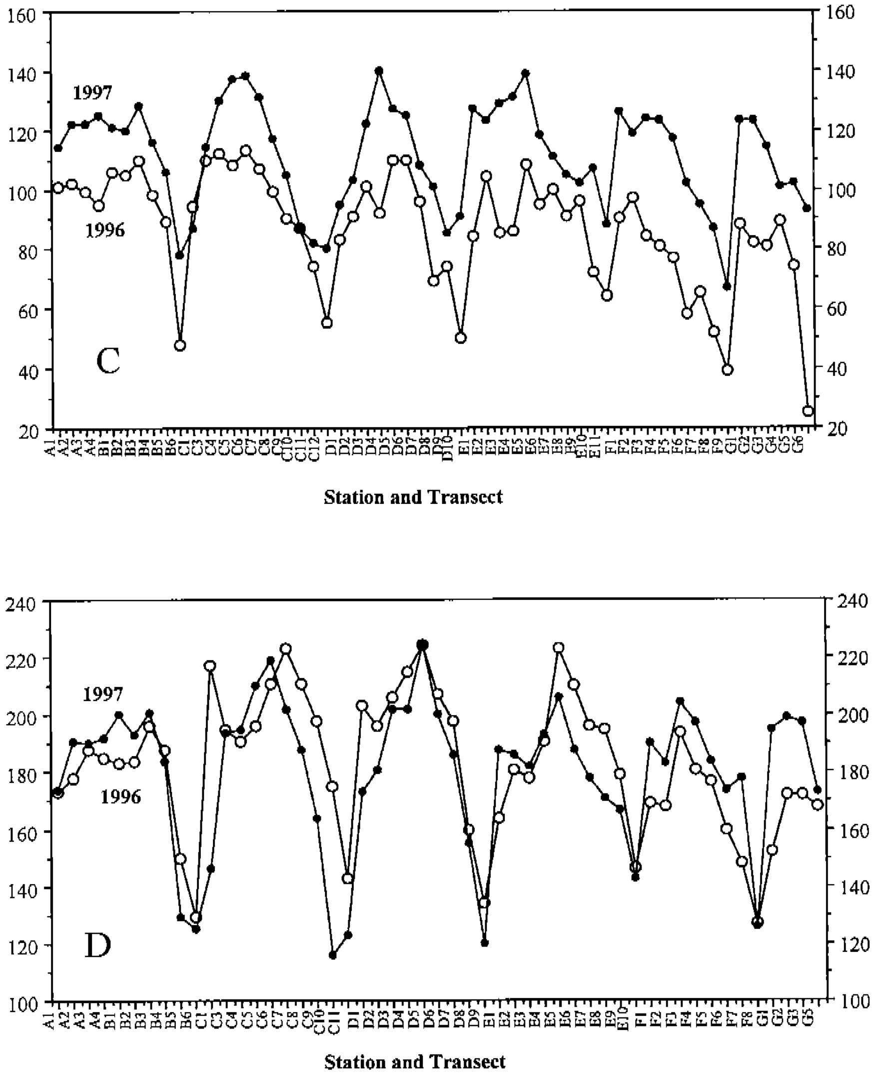


Figure 2.24. (continued): Between year variation in c) 19°C depth and d) 15°C depth for stations along EPA transect lines A-G.

strongest in early summer of both 1996 and 1997, present but restricted to temperatures above 15°C in mid-summer 1997, and not evident in late summer 1996. As a corollary, such shelf-edge upwelling does not appear to have been caused by the presence of a secondary warm eddy, because a secondary eddy was present over the MMS EPA in late summer.

The ADCP currents at z = 10 m show that surface flow in late summer 1996 was generally from east to west along most of the continental margin seaward of the 1000 m isobath, at velocities <1 knot (Figure 2.9). Shoreward of the z = 1000 m isobath, there were locally fast surface currents in the east, over the outer shelf and slope south of Florida's Big Bend, and in the west, in the MOM area. In contrast, the surface flow field was less uniform in mid-summer 1997. While flow was downcoast over the inner shelf, the flow was offshelf in the MOM area and strongly cyclonic over the West Florida Terrace and West Florida Shelf (Figure 2.11). Between the two regions, there was a zone of high shear in surface current (strong surface flow offshelf, near 89°W, and strong surface flow onshelf, near 88°W.

Auto-correlation function analysis of the surface temperature and salinity data showed that cross-margin length scales for surface temperature and surface salinity over the EPA continental margin averaged about 18 km (10 nautical miles).

2.3.2 Hydrography of the MOM area

The MOM area was surveyed on both GulfCet II *Gyre* cruises, since during GulfCet I this had been the geographic region in which sperm whales were most likely to be encountered. In late summer 1996, sperm whale cows and calves were seen in this area on 20 and 28 October. However, at least in its summary hydrographic characteristics, the MOM environment was quite similar to the continental margin to the east and to the cyclone to the south. Table 2.3 shows that surface temperature (± one standard deviation) averaged 25.8 ± 0.3°C. Surface salinity averaged 35.8 ± 0.1 psu, and surface chlorophyll was low and ranged from 0.09-0.11 µg/l. Property-property plots showed little along-track variation (no fronts) in surface temperature, salinity or chlorophyll. Nor was this a region of particularly shallow MLD, 19°C or 15°C depth, for in late summer 1996 these depths averaged 10 m, 13 m and 28 m deeper, respectively, in the MOM area than in the interior of the cyclone to the south. Surface currents in the MOM environment were low (<1 knot), and flow was along bathymetry rather than cross-slope.

In mid-summer 1997, the clockwise flow field around secondary Eddy D to the west and the counterclockwise flow around the cyclone to the east turned the MOM area into an environment of strong cross-slope flow. Low salinity MAR water was entrained into this flow and carried ESE into the confluence between the cyclone and LC Eddy E. As a result, mean surface sigma-t was lower here than over the "other margin" or in the cyclone (Table 2.4). Apart from being fresher in salinity and higher in chlorophyll concentration, the MOM area in mid-summer 1997 showed no marked differences in subsurface properties (e.g., 19°C or 15°C depth) when compared with the "other margin" or the cyclone. This time, no local aggregations of sperm whales were encountered in the MOM area; on the contrary, most contacts with sperm whales were made in the deepwater cyclone that was centered 100 nautical miles to the east of the MOM.

Table 2.3. Temperature, density and dynamic topography of the five hydrographic environments surveyed on the late summer R/V *Gyre* cruise (*Gyre*96G06).

Late Summer 1996		Cyclone	Confluence	LCE	MOM	Other Margin
		n=72	n=26	n=29	n=19	n=95
Surface Temp (°C)	max	27.6	28.4	28.3	26.3	27.5
	min	25.2	26.0	27.3	25.2	24.1
	mean	26.2	27.5	27.7	25.8	26.0
	std dev	±0.6	±0.5	±0.2	±0.3	±0.6
Surface Sigma-theta	max	23.9	23.9	23.7	24.0	24.0
	min	23.0	23.3	23.3	23.4	22.5
	mean	23.6	23.6	23.5	23.6	23.7
	std dev	±0.2	±0.2	±0.1	±0.2	±0.1
Mixed Layer Depth (m)	max	53	80	80	60	78
	min	22	35	54	41	15
	mean	39	56	65	49	51
	std dev	± 6	±10	± 6	± 5	± 8
19°C depth (m)	max	101	162	272	107	160
	min	67	93	160	91	83
	mean	85	126	227	98	103
	std dev	± 8	±18	± 35	± 5	± 13
15°C depth (m)	max	183	256	424	207	247
	min	128	171	262	166	152
	mean	155	205	359	183	187
	std dev	± 15	± 20	± 57	± 14	± 20
Dynamic Height (cm) relative to 800 m	max	100	122	150	111	120
	min	88	100	125	100	100
	mean	95	107	140	104	104
	std dev	± 4	± 7	+ 9	± 3	± 4
Dyn Height Anomaly (cm) relative to 100 cm mean	max	0	22	50	11	20
	min	-12	0	25	0	0
	mean	- 5	+ 7	+ 40	+ 4	+ 4
	std dev	± 4	± 7	± 9	± 3	± 4

Table 2.4. Temperature density, and dynamic topography of the five hydrographic environments surveyed on the mid-summer R/V *Gyre* cruise (*Gyre*97G08).

Mid-summer 1997		Cyclone n=36	Confluence n=27	LCE n=38	MOM n= 7	Other Margin n=73
Surface Temp (°C)	max	31.2	31.7	30.9	31.4	31.7
	min	29.4	29.5	30.1	29.2	29.3
	mean	30.1	30.5	30.5	29.9	30.4
	std dev	±0.5	±0.6	±0.2	±0.8	±0.5
Surface Sigma-theta	max	22.1	22.5	22.5	18.7	20.8
	min	19.7	15.7	22.3	16.7	16.9
	mean	21.1	20.3	22.4	17.6	19.6
	std dev	±0.5	±2.4	±0.1	±0.8	±1.1
Mixed Layer Depth (m)	max	27	50	47	22	23
	min	9	8	23	13	5
	mean	19	25	35	18	13
	std dev	± 5	± 10	± 7	± 4	± 4
19°C depth (m)	max	105	167	303	106	125
	min	83	91	163	88	57
	mean	94	127	240	97	101
	std dev	± 6	± 21	± 50	± 7	± 15
15°C depth (m)	max	172	249	457	190	228
	min	126	151	254	143	155
	mean	150	201	347	170	183
	std dev	± 11	± 28	± 69	± 16	± 15
Dynamic Height (cm) relative to 800 m	max	105	129	176	109	112
	min	92	105	130	106	106
	mean	100	117	154	108	108
	std dev	± 4	± 8	± 16	± 1	± 2
Dyn Height Anomaly (cm) relative to 105 cm mean	max	0	24	71	4	7
	min	-13	0	25	1	1
	mean	- 5	+ 12	+ 49	+ 3	+ 3
	std dev	± 4	± 8	± 16	± 1	± 2

2.3.3 Deepwater Cyclone-Anticyclone Pair

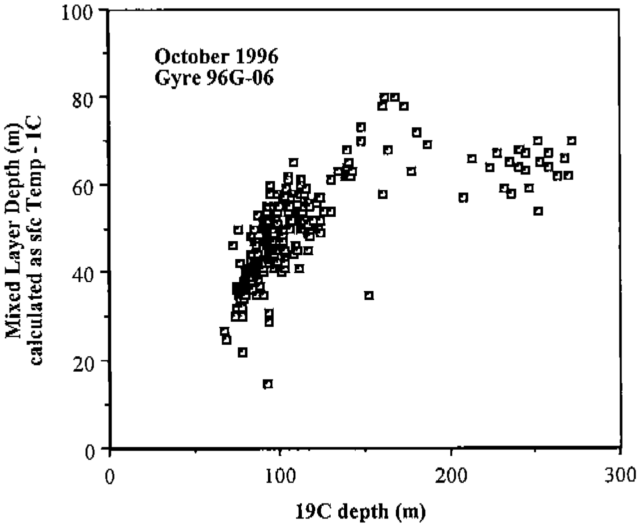
From Tables 2.3 and 2.4, it can be seen that MLD and 19°C depth were, on average, shallower in the cyclone than in the confluence or LCE in late summer 1996 and mid-summer 1997. Property-property plots show this even more clearly. Stations with locally shallow MLD had locally shallow 19°C depth (Figure 2.25), and a locally shallow nitracline was characteristic of stations between 27-28°N Latitude in the interior of the cyclone (Figure 2.26). The Deep Chlorophyll Maximum (DCM) was located at or just above the depth at which nitrate first was analytically detectable; this averaged 50 m below the surface in the cyclone, and 100 m in the LCEs (Figure 2.27). This DCM was not only higher up in the water column in the cyclone, but subsurface maximum concentrations of chlorophyll were higher there than in the LCEs. The physics of convergence versus divergence clearly forced the biological patterns that were seen. On the other hand, when the area under the chlorophyll profiles was integrated between the surface and 150 m, it was evident that standing stocks of chlorophyll expressed as mg per square meter were about equal in Eddy C as in the cyclone.

Contour plots of deepwater dynamic topography relative to 800 m and of deepwater surface current vectors computed by standard geostrophic methods from the dynamic height data are shown in Figures 2.28–2.33. These plots show that the five transects that were run in late summer 1996 between the MOM and the interior of LC Eddy C provide radial as well as tangential sections through the cyclone. The shallowest 15°C depths were in the interior of the cyclone (<130 m) and the deepest were in the interior of LC Eddy C (>420 m).

This >290 meter difference in 15°C depth was equivalent to a 62 dyn cm gradient in dynamic height between the interior of the two features (88 dyn cm in the cyclone to 150 dyn cm in LC Eddy C). The corresponding upper layer geostrophic volume transport between the interior of the two features was 24 x 10^6 m^3 s^{-1} (24 Sverdrups). In the flow confluence from 25.5°-26.5°N that separated the two features, geostrophic current velocity at the surface exceeded 1.5 knots (>75 cm s^{-1}).

Geostrophic flow created by the cyclone-anticyclone pair that was surveyed in mid-summer 1997 was even stronger. The shallowest 15°C depth in the interior of the cyclone was again <130 m, but the deepest 15°C depth in the interior of LCE-E was now >450 m. This 320 m difference in the 15°C depth was equivalent to an 84 dyn cm gradient in dynamic height between the interior of the two features (92 dyn cm in the cyclone to 176 dyn cm in LC Eddy E). The corresponding upper layer geostrophic volume transport between the interior of the two features was 31 x 10^6 m^3 s^{-1} (31 Sverdrups). In the flow confluence from 26°-27.5°N that separated these two features, geostrophic current velocity at the surface exceeded 2 knots (>100 cm s^{-1}).

A geostrophic volume transport of 24-31 Sverdrups (Sv) is a large volume of water. For example, the inflow into the Gulf of Mexico through the Yucatan Channel and the outflow from the Gulf of Mexico through the Florida Strait both average about 30 Sv relative to 800 m. The outflow through the Florida Straits feeds into the western boundary current of the North Atlantic Ocean (i.e., the Gulf Stream). Off Cape Hatteras, where the surface current velocity of the Gulf Stream may reach 4-5 knots, the geostrophic transport may reach 90 Sv. From a global



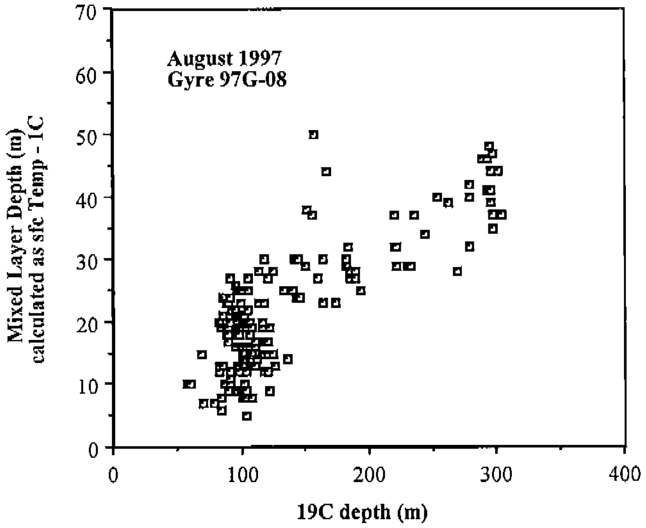
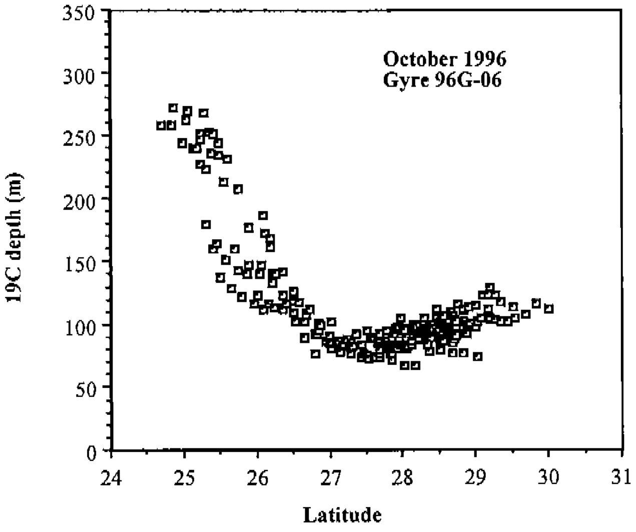


Figure 2.25. Property-property plot of data from the two R/V *Gyre* cruises showing relationship between mixed layer depth and nitracline depth in late summer 1996 and mid-summer 1997. Note that stations at which the nitracline domed close to surface had a shallow mixed layer depth.



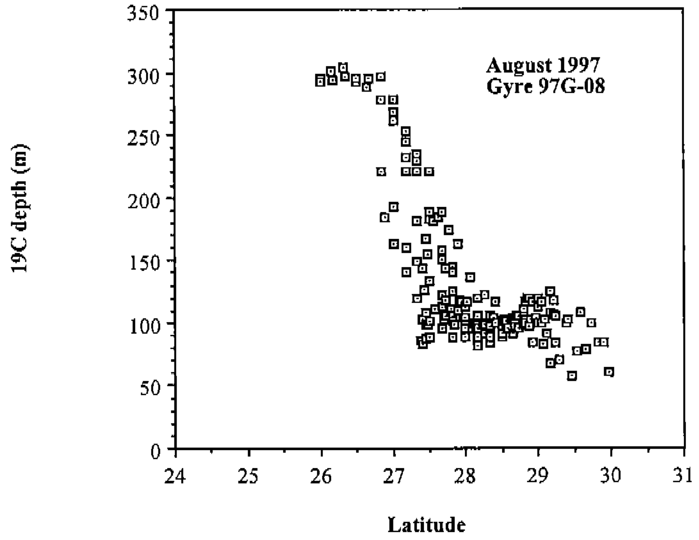


Figure 2.26. Property-property plot of data from the same two R/V *Gyre* cruises showing that stations where nitracline domed closest to surface waters were inside the cyclone (26.5 - 28.5°N) in late summer 1996, and in the cyclone (27.5 - 29°N) and on the continental margin to the north of the cyclone in mid-summer 1997.

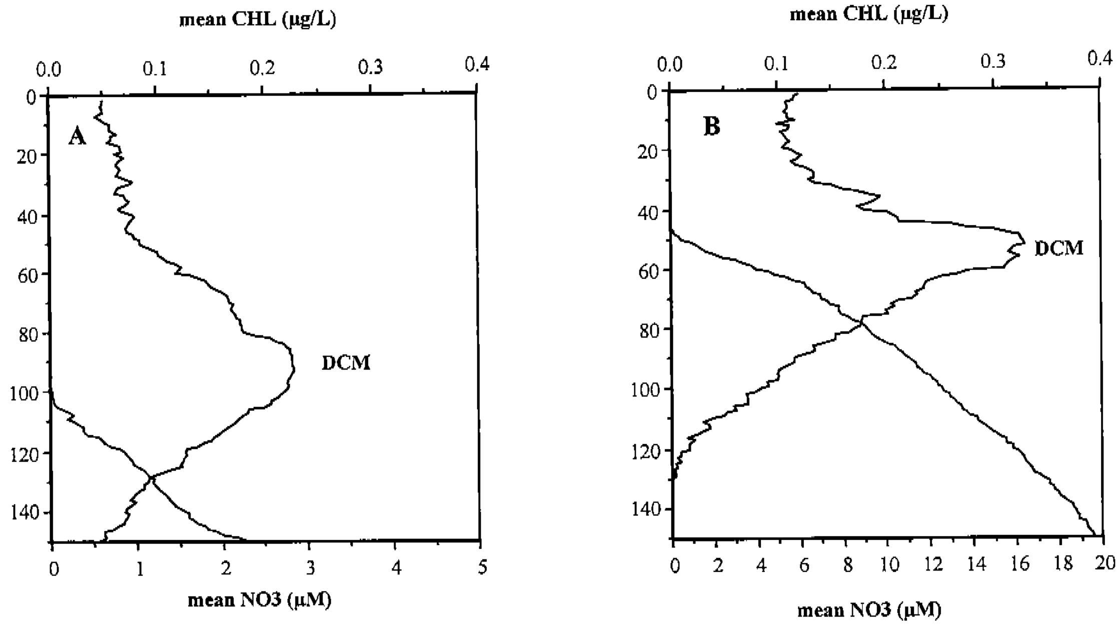


Figure 2.27. Differences in average deep chlorophyll maximum (DCM) depth and average nitracline depth between a) Loop Current Eddy C, and b) the mesoscale cyclone to the north, from 3 CTD casts made in each feature during October 1996 on R/V *Gyre* cruise 96G06.

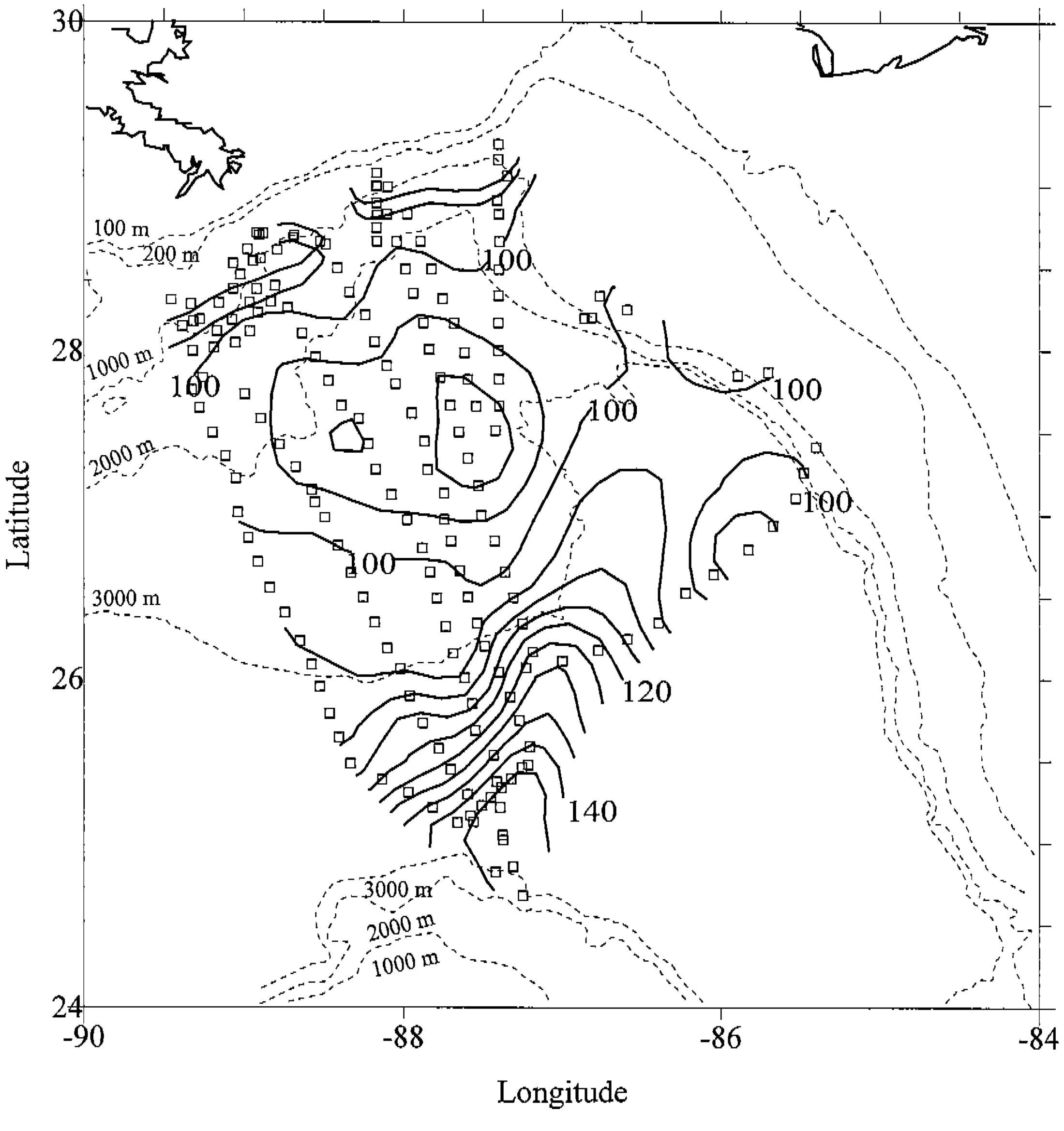


Figure 2.28. Dynamic topography (cm, 0 m relative to 800 m) of the deepwater focal area, as determined from 152 hydrographic stations made on R/V *Gyre* cruise 96G06.

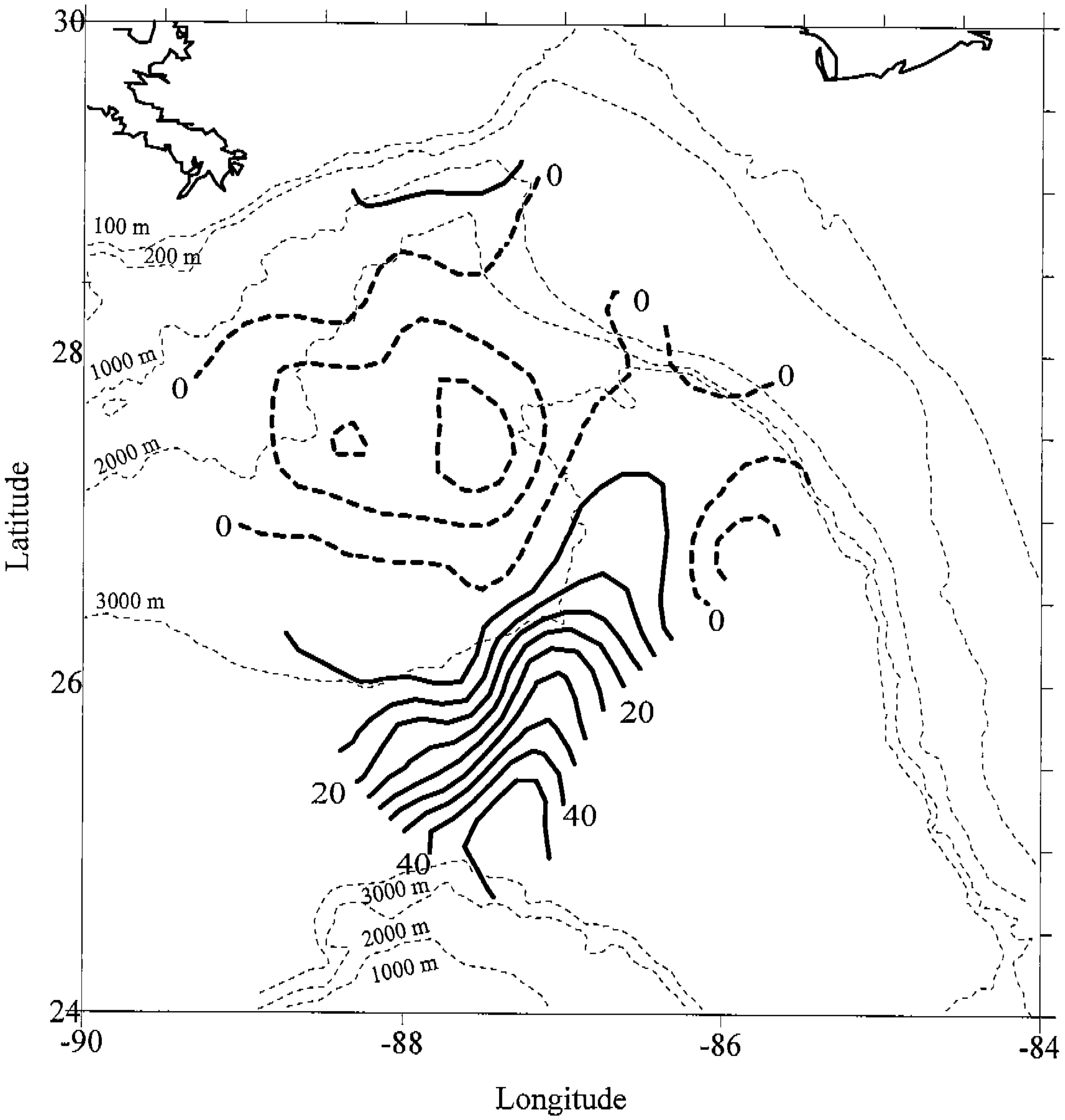


Figure 2.29. Dynamic height anomaly of the shipboard data presented in Figure 2.28. Negative height (cyclone) is designated by heavy dash lines; positive height (confluence and anticyclone) by heavy solid lines.

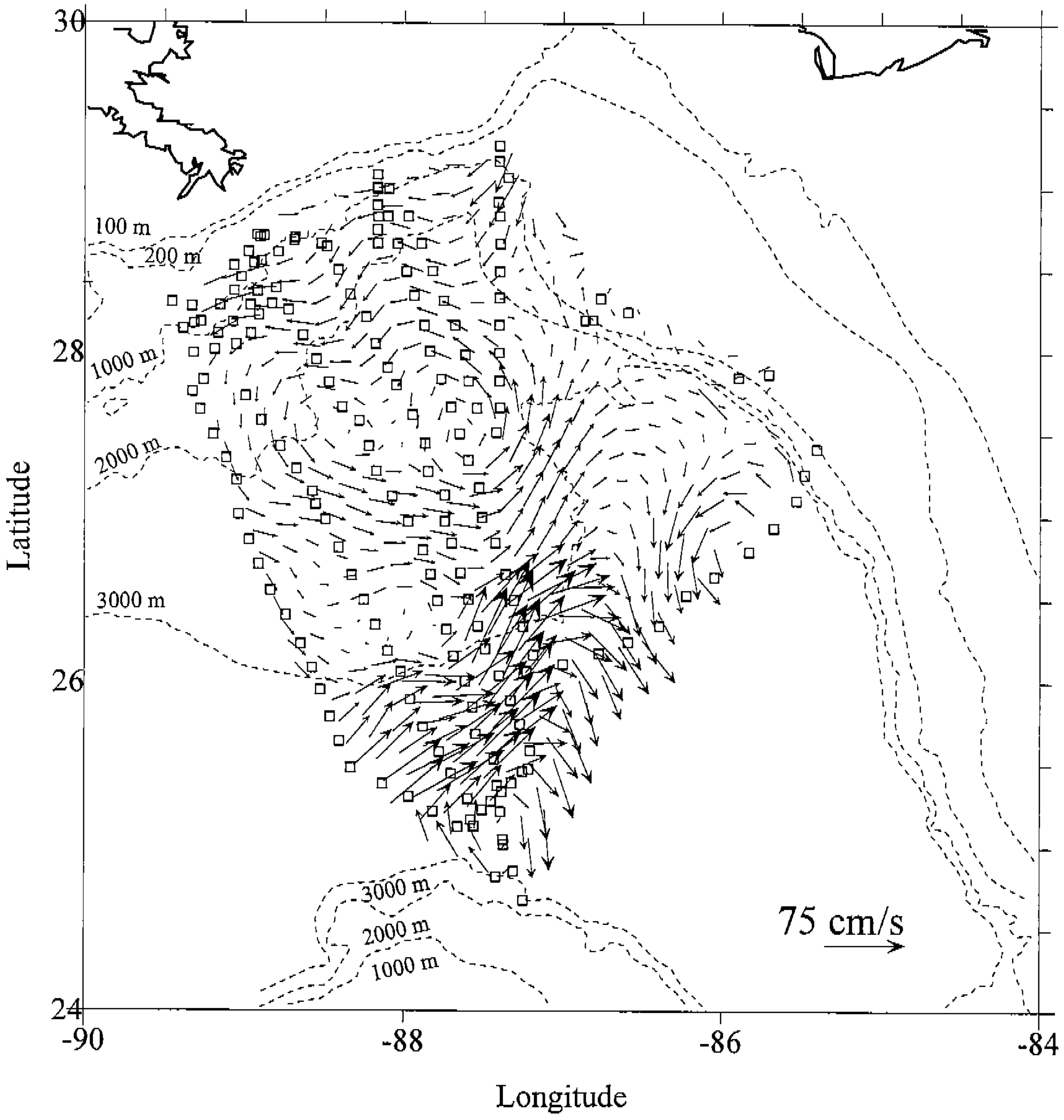


Figure 2.30. Gridded upper layer geostrophic velocity (0 m relative to 800 m) of the deepwater focal area, as computed from the October 1996 dynamic topography (Figure 2.28).

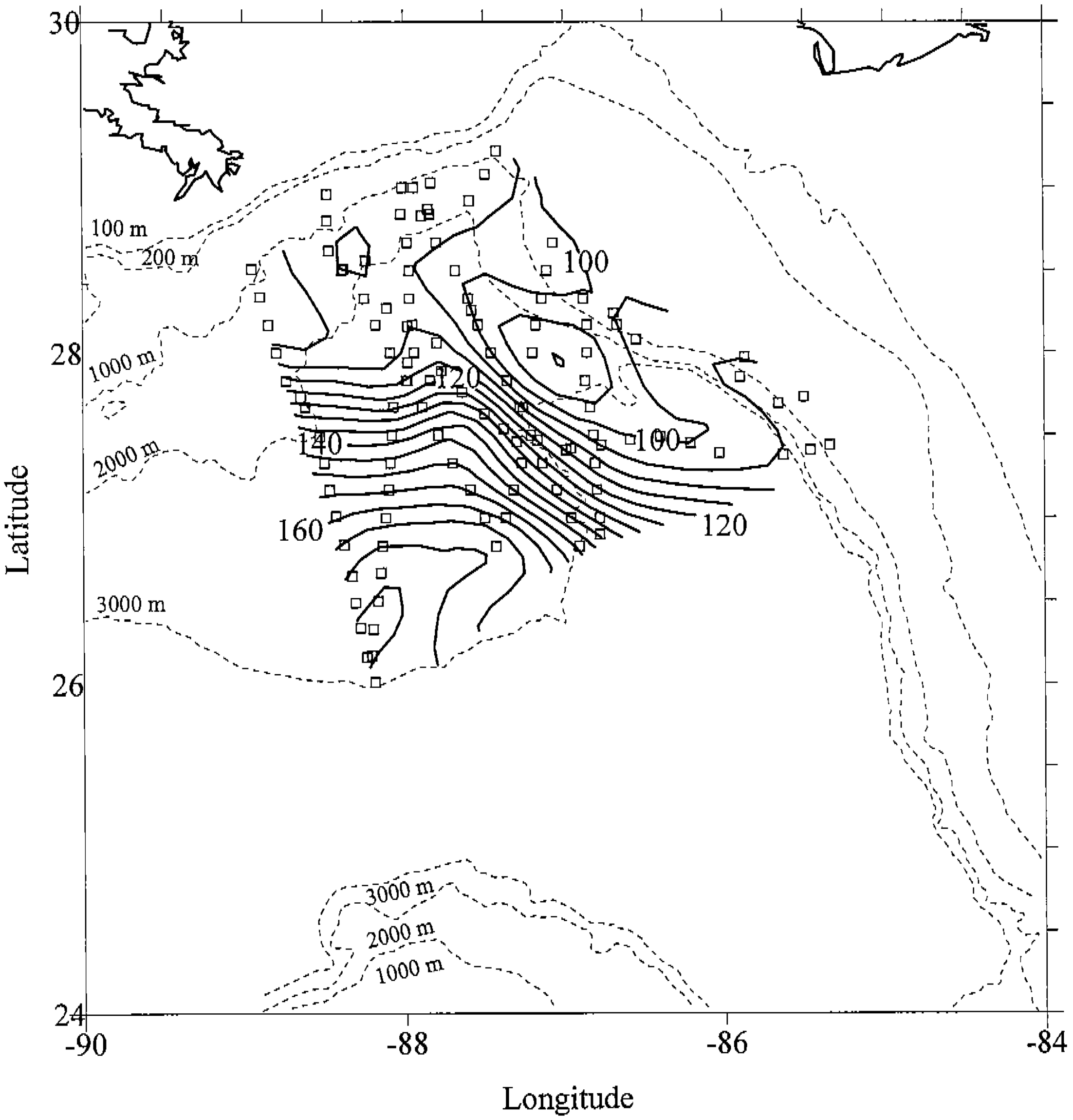


Figure 2.31. Dynamic topography (cm, 0 m relative to 800 m) of the deepwater focal area, as determined from 107 hydrographic stations made on R/V *Gyre* cruise 97G08.

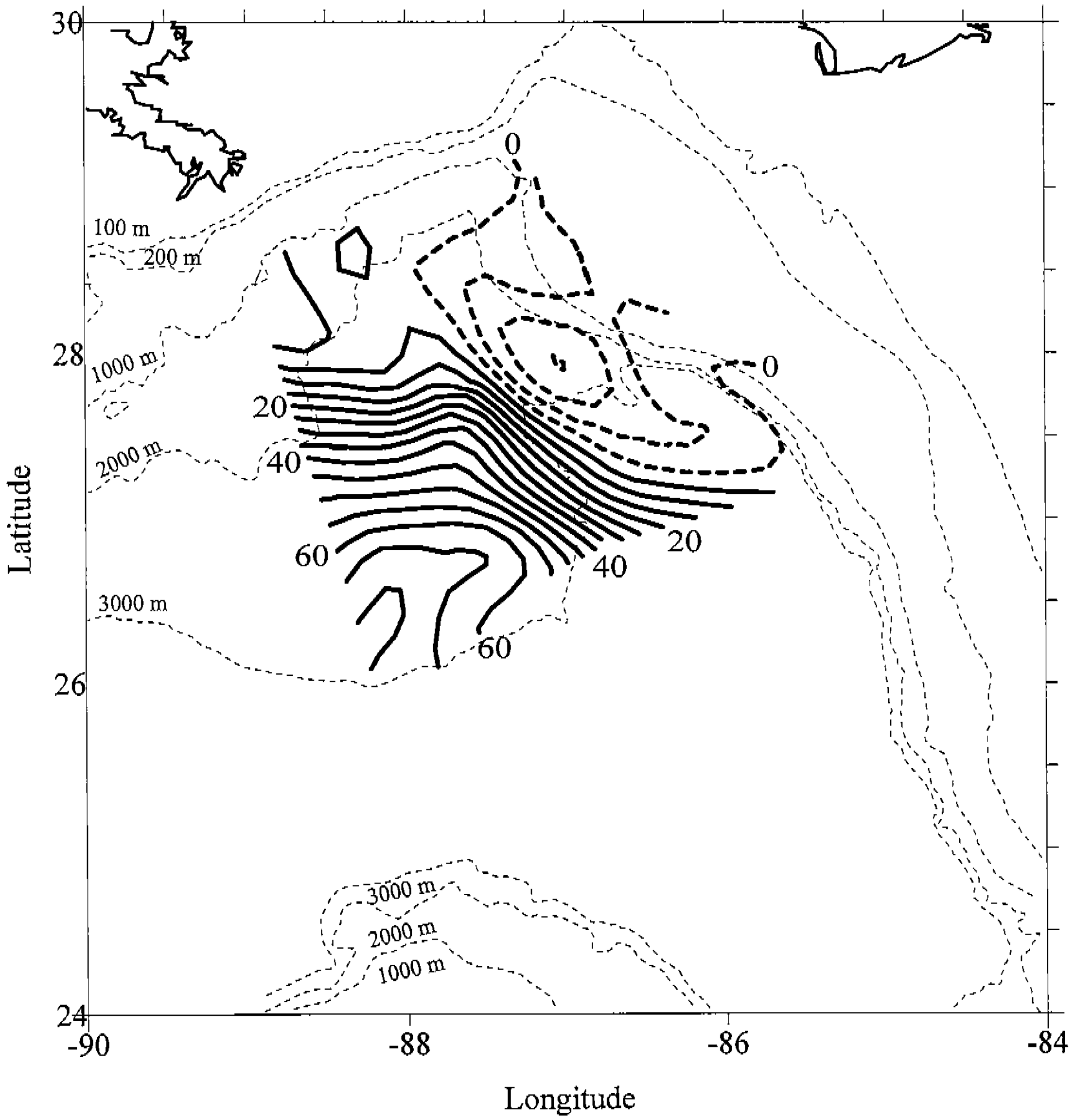


Figure 2.32. Dynamic height anomaly of the shipboard data presented in Figure 2.31. Negative height (cyclone) is designated by heavy dash lines; positive height (confluence and anticyclone) by heavy solid lines.

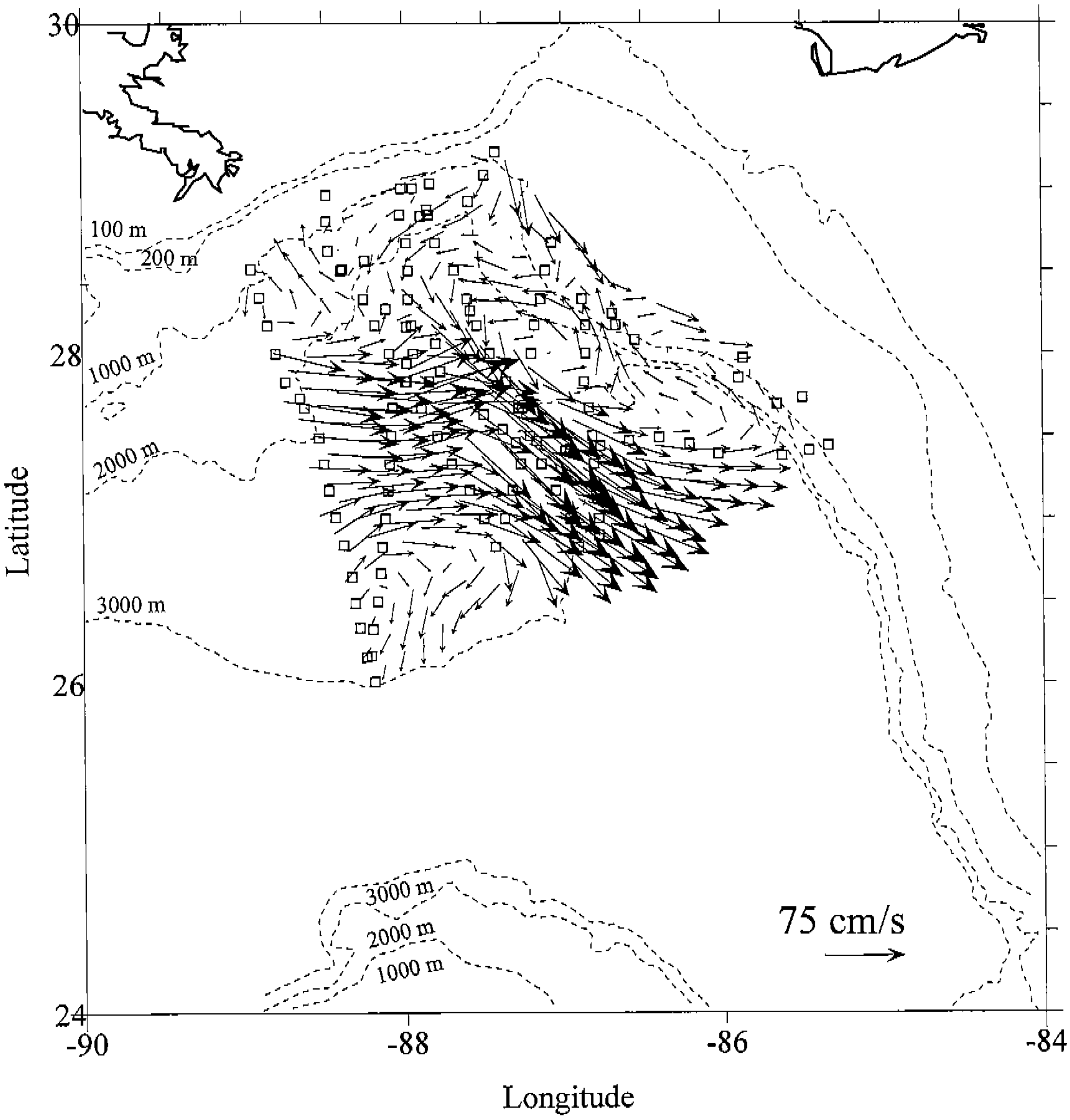


Figure 2.33. Gridded upper layer geostrophic velocity (0 m relative to 800 m) of the deepwater focal area, as computed from the August 1997 dynamic topography (Figure 2.31).

perspective, the upper 800 m of the eastern Gulf of Mexico is characterized by vigorous circulation that is very dynamic.

The deepwater cyclone was distinguishable from the anticyclone in surface temperature, surface salinity and surface chlorophyll characteristics, both in late summer 1996 and mid-summer 1997. Figures 2.34–2.36 are contour plots of data that were collected every two minutes throughout late summer 1996. Surface water pumped from a depth of 3.5 m into the main laboratory aboard the *Gyre*, where some of the flow was shunted through temperature and conductivity sensors and through a flow-through laboratory fluorometer. Figures 2.34 and 2.35 show that in late summer, surface waters of the cyclone averaged 1°C cooler and 1 practical salinity unit less saline than surface waters of the anticyclone. Surface chlorophyll was lower than 0.05 µg/L in the warm, nutrient-depleted surface waters of the anticyclone, while within the cyclone and over the rest of the continental margin, surface chlorophyll concentrations ranged 0.05-0.3 µg/L. The highest surface chlorophyll concentrations were encountered on or adjacent to the continental shelf, in local areas of greatest freshwater input. A comparison of Figure 2.35 with Figure 2.36 shows that high chlorophyll, low salinity (HCLS) surface water was seen along the ship's track northeast of the MOM, and along the east side of the delta. A third area of HCLS surface water was encountered on the upper continental slope southwest of the MOM. Surface salinity increased and surface chlorophyll concentration decreased rapidly from 18-25 km (10-15 nautical miles) of these regions.

Figures 2.37–2.39 are contour plots of surface temperature, surface salinity, and surface chlorophyll concentrations in mid-summer 1997. Although surface temperatures over most of the continental margin ranged from 30-31°C, the cyclone appeared as a region of cooler surface temperature (i.e., 29-30°C). Freshwater from the Mississippi River reached much farther offshore in mid-summer 1997 than it had in late summer 1996. As a result, the amount of high chlorophyll surface water over the continental margin was also greater in extent in mid-summer 1997. Low salinity Mississippi River water was entrained into the flow confluence between cyclone and LCE-E, which can be seen in Figure 2.38 as two tongues of locally low salinity water: one reaching east of the delta and the other reaching southeast from the southern tip of the delta. Figure 2.38 shows that low salinity patches of this river water are wrapped anti-clockwise around the periphery of the cyclone. A comparison of Figures 2.39 and 2.38 shows that surface chlorophyll concentrations in this river water reached 2.0 µg/L, and that especially in the concentration range 0.1-0.4 µg/L, the patches of highest surface chlorophyll correspond spatially to patches of lowest surface salinity. As in late summer 1996, surface chlorophyll levels in the interior of the cyclone ranged 0.05-0.15 µg/L, while in interior of LCE-E, surface chlorophyll concentrations were extremely low (<0.05 µg/L).

2.4 Discussion

Since Iles and Sinclair (1982) proposed that larval retention zones can be caused by oceanographic features, the relationships between stocks of phytoplankton, zooplankton, nekton and frontal zones have been an area of intense research. For example, it is known that local aggregations of phytoplankton develop along and within weekly-period meanders and eddies in the Gulf Stream (Lee et al. 1991) and that elevated fish stocks often co-occur in these frontal

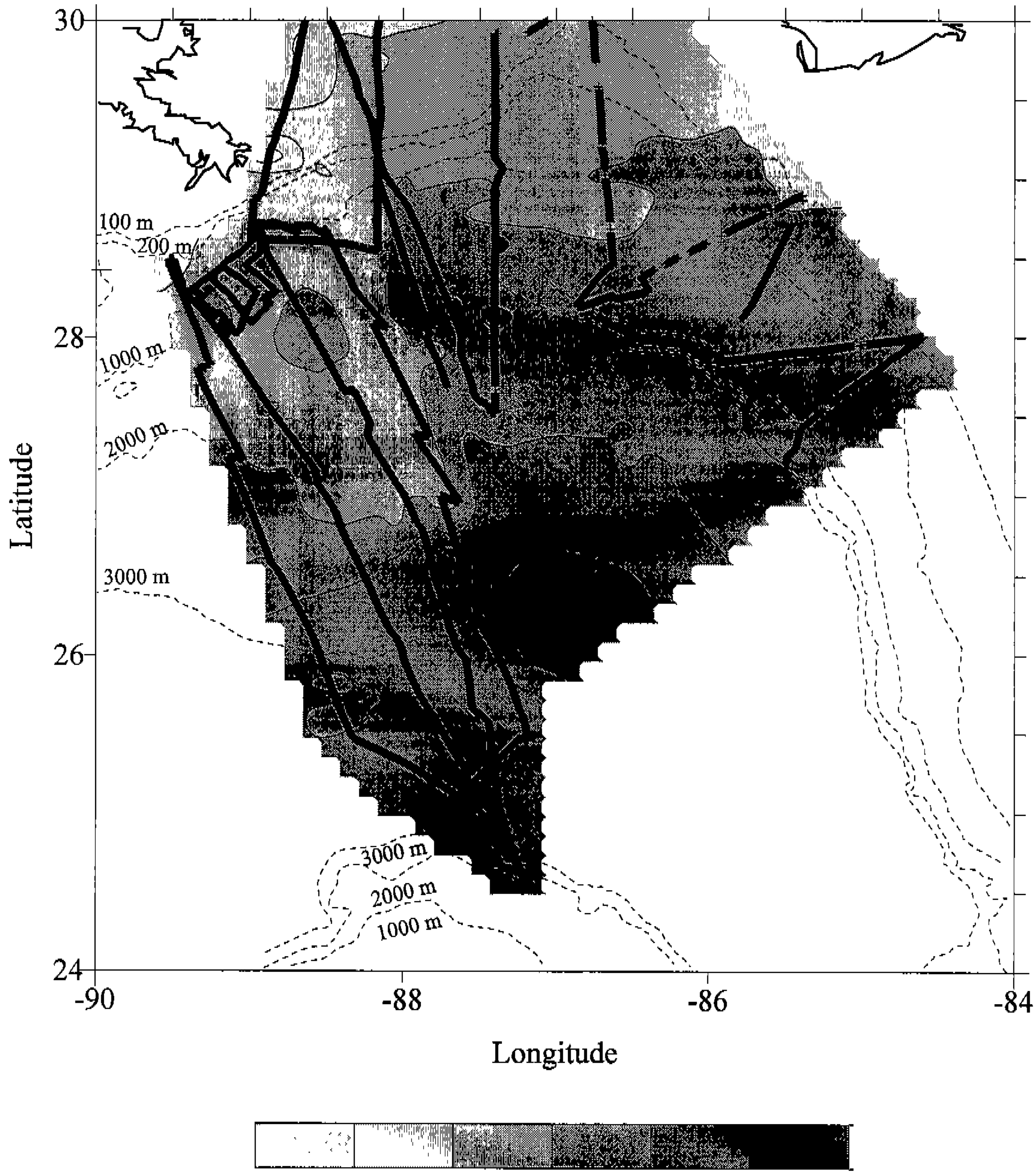


Figure 2.34. Contour map of surface temperature (°C), as measured every 2 minutes throughout R/V *Gyre* cruise 96G06 using the ship's SAIL data logging system. Small "+" symbols, usually so close together that they appear as a broad, dark line, indicate data points used to generate the contours.

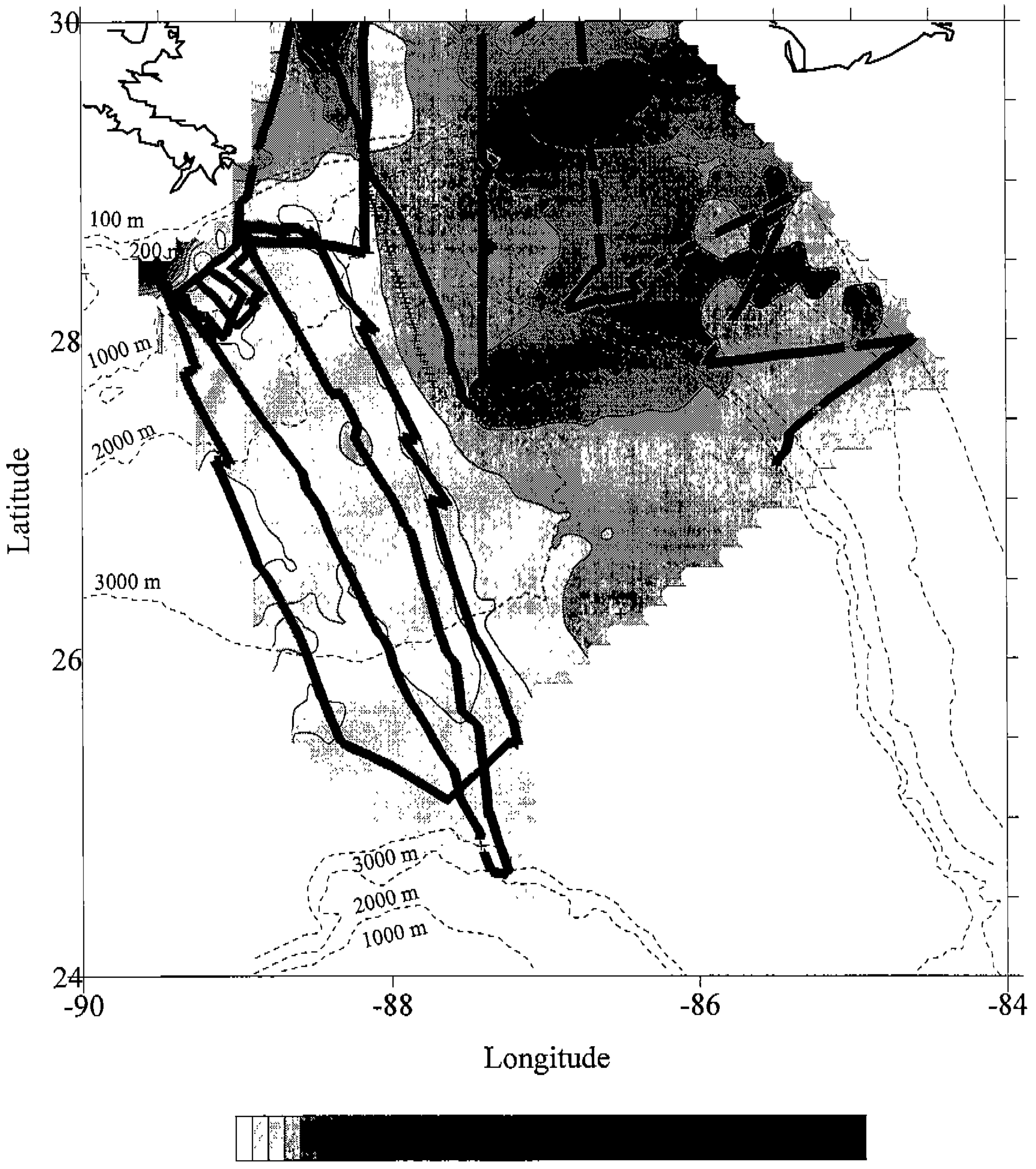


Figure 2.36. Contour map of surface chlorophyll (μg/L), as measured every 2 minutes throughout R/V *Gyre* cruise 96G06 using the ship's SAIL data logging system.

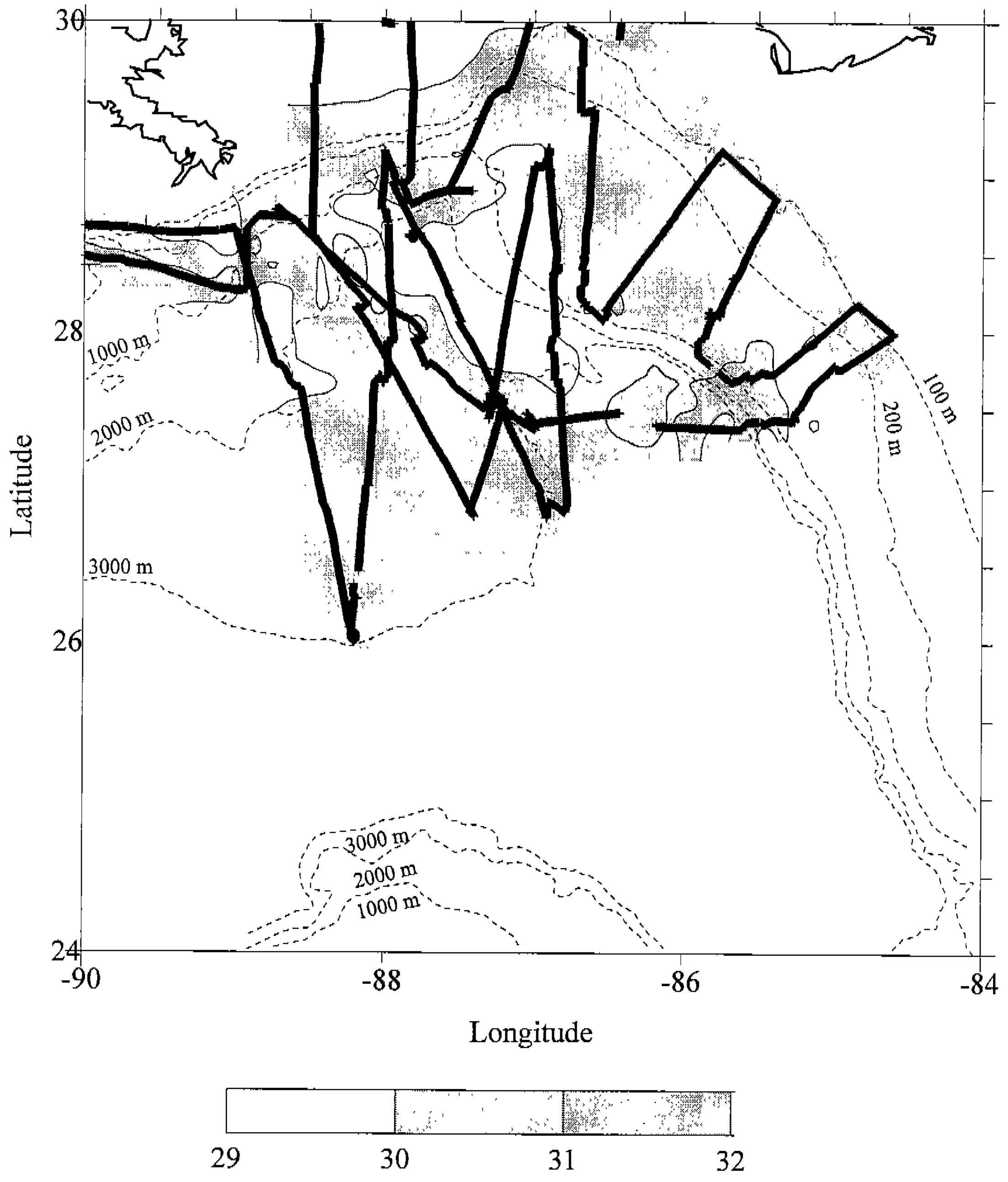


Figure 2.37. Contour map of surface temperature (°C), as measured every 2 minutes throughout R/V *Gyre* cruise 97G08 using the ship's SAIL data logging system.

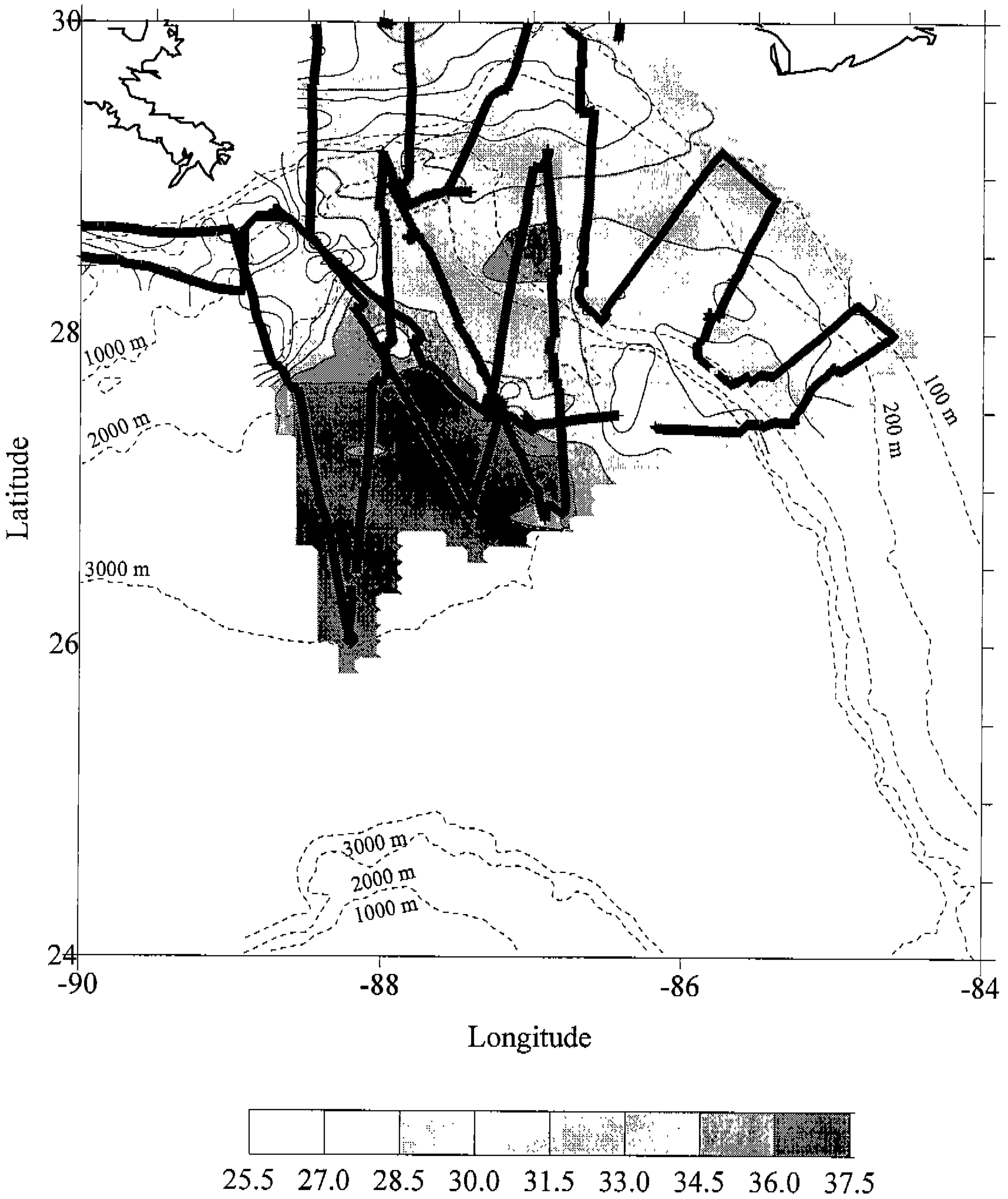


Figure 2.38. Contour map of surface salinity (standard salinity units), as measured every 2 minutes throughout R/V *Gyre* cruise 97G08 using the ship's SAIL data logging system.

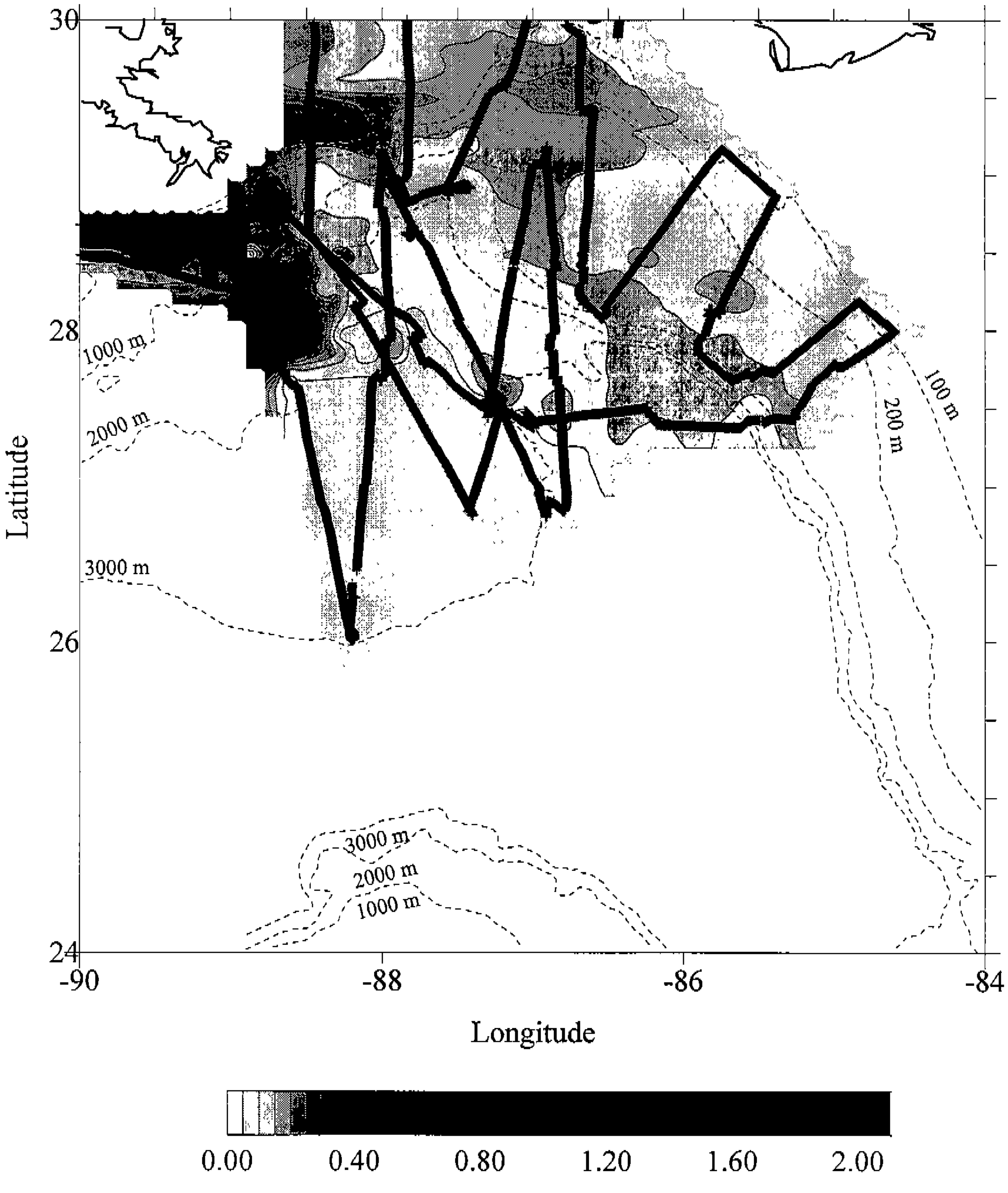


Figure 2.39. Contour map of surface chlorophyll (µg/L), as measured every 2 minutes throughout R/V *Gyre* cruise 97G08 using the ship's SAIL data logging system.

disturbances (Atkinson and Targett 1983). However, along the Atlantic coast most of the phytoplankton production tends to be swept back into the Gulf Stream, whereas in the Gulf of Mexico, if ungrazed, it may move down and along the continental slope.

In the Gulf of Mexico, frontal zones at the periphery of meanders and eddies that are seaward of the continental margin are typically expressed as sharp gradients in temperature. These may have secondary expression as gradients in salinity, particularly in local convergences that entrain low salinity water and transport it off-shelf as plumes or jets. For example, Biggs and Müller-Karger (1994) reported that some cyclone-anticyclone geometries in the Gulf of Mexico create flow confluence zones that can transport high-chlorophyll shelf water seaward several hundreds of kilometers. Sharp frontal zones may also be created during periods of northern extensions of the Loop Current. Lamkin (1997) found a significant positive correlation between the abundance of larval nomeid fish and the location of the northern edge of Loop Current by analyzing NOAA annual icthyoplankton survey data from 1983-88. Lamkin's data indicate that *Cubiceps pauciradiatus*, in particular, is a species whose adult spawning grounds and larval habitat are tied to sharp temperature gradients. Peak larval abundance was found close to the frontal interface, with peak abundance occurring just up slope of the region of peak SST gradient. Lamkin went on to speculate that the extent of the frontal systems in the Gulf of Mexico would be expected to impact annual recruitment of a species that is tied to a frontal habitat.

On shorter time scales, the biological implications of thermal fronts in the Gulf of Mexico are widely recognized by fishermen: many of them preferentially fish in areas where sea surface temperature imagery shows sharp temperature gradients over short (<10 km) distances. Skipjack (*Katsuwonus pelamis*), blackfin tuna (*Thunnas atlanticus*), swordfish (*Xiphias gladius*), and blue marlin (*Makaira indica*) have been reported by fisherman to be locally abundant in these areas (Roffer's Ocean Fishing Forecasting Service, pers. com.). Clearly, populations of apex predators like these are not likely to be sustained by low or infrequent episodes of enhanced secondary productivity.

The current paradigm in biological oceanography is that the relative amounts of "new" versus "regenerated" nitrogen ultimately determine the biological carrying capacity of the surface mixed layer. Eppley and Petersen (1979) hypothesized that any mechanism that accelerates the introduction of "new" nitrogen into the mixed layer should increase the biological productivity of higher trophic levels or (if ungrazed within the upper ocean) be available for export from the system. For the NE Gulf of Mexico, this hypothesis appears to be especially valid, since anticyclones that were surveyed during the deepwater focal studies were depleted in nitrate and other nutrients. Just one to two months had elapsed between the time that LCE C separated from the LC in July-August and when it was surveyed in late summer 1996. Similarly, just one to two months had elapsed since LCE E had separated in June-July and when it was surveyed in mid-summer 1997. High subsurface salinity >36.8 in the depth range 150-250 m confirmed the LC affinity of both of these features. In both LCEs, near surface temperatures greater than 22°C in the upper 150 m are diagnostic that the photic zone was nutrient depleted.

In contrast, the cyclones that were surveyed in late summer 1996 and mid-summer 1997 had high nitrate concentrations closer to the surface. The 19°C depths were as shallow as 67 m (mean depth = 85 m) in late summer 1996 and 83 m (mean depth = 94 m) in mid-summer 1997, so

10 μM of nitrate should have domed to these depths. Lower but still analytically detectable nitrate reached well into the photic zone. Although we did not measure primary production during the GulfCet II cruises (this would have required light bottle and dark bottle incubations), it is stimulated by the introduction of new nitrogen (Biggs and Sanchez 1997, Gonzales-Rodas 1999), particularly if it continues for weeks-to-months in time.

From the TOPEX/Poseidon altimeter time series of SSH anomaly, we know that cyclones in the NE Gulf are temporally persistent yet spatially variable. They typically persist in any one region for several months, but seldom longer than 12 months. Since the cyclone surveyed in late summer 1996 had been around since January of that year, it eventually spun down. As a result, the cyclone surveyed in mid-summer 1997 was not the same cyclone that had been surveyed the year before. In both years, however, the cyclones were visible in the altimetry for more than six months before they were surveyed by the *Gyre*. We hypothesize that six months was sufficient time for nutrients-phytoplankton-zooplankton processes to produce higher standing stocks of zooplankton and micronekton, which in turn provide food for the vertically migrating larger nekton that are preyed upon by cetaceans.

2.5 Conclusions

The physical forcing functions for the circulation over the continental margin of the northeastern Gulf of Mexico are river discharge, wind stress, and the LC and its derived circulation phenomena. When these forcing functions introduce new nutrients into the upper region of the water column, they stimulate planktonic plant production at the base of the food chain that is fed on, in turn, by zooplankton, nekton, squid and marine mammals. LCEs are warm-core, nutrient-poor, surface convergence areas. In contrast, the cyclonic, cold-core eddies that are often found in association with LCEs are regions of local divergence in which locally high nitrate concentrations dome close to the base of the mixed layer. Deep chlorophyll maxima (DCMs) occur shallower and chlorophyll reaches higher concentrations within these cyclones than within the LCEs, and so the cyclones are regarded as biological "oases" while the interior of the LCEs are biological "deserts."

Ship surveys sampled a deepwater cyclone-anticyclone pair and surface flow confluence in late summer of 1996 and in mid-summer of 1997. The latter survey found that a 6-10 m thick lens of low salinity river water was being transported across the shelf and entrained into the flow confluence. This water of river origin had locally high surface chlorophyll, resulting in more chlorophyll within the confluence than would have been predicted from DCM characteristics alone. The shipboard surveys also found evidence for upwelling at the shelf break based on doming of the 19°C isotherm in late spring and early summer of both 1996 and 1997. This shelf break upwelling was less strong in mid-summer and apparently had ceased by late summer.

Chapter 3

Biological Oceanography

John H. Wormuth, Patrick H. Ressler, Robert B. Cady, and Elizabeth J. Harris

3.1 Introduction

Direct sampling of zooplankton (small, drifting animals) and micronekton (fishes, crustaceans and cephalopods from 1 to 10 cm, Blackburn 1968) biomass with a variety of towed nets can provide important information on marine ecosystems (Hopkins 1982; Passarella and Hopkins 1991). In this study, net sampling was used to provide estimates of the biomass and taxonomic composition of zooplankton and micronekton within the study area. However, due to the finite time available for sample collection and post-cruise analysis, these net measurements were necessarily limited in number and spatial coverage. Therefore, as a supplement to the net sampling program, acoustic measurements of volume backscattering strength (S_v) were made using an Acoustic Doppler Current Profiler (ADCP). ADCPs have been used as a method for making indirect measurements of zooplankton and micronekton biomass continuously while the vessel is underway (Ashjian et al. 1994; Zhou et al. 1994; Zimmerman and Biggs 1999). When both direct and indirect measurements of zooplankton and micronekton are taken over a wide geographic or hydrographic range, differences in biomass can be interpreted as differences in the amount of potential food for higher trophic levels, much the same as regional phytoplankton mapping is used to infer differences in zooplankton biomass. For the GulfCet II Program, the biological oceanographic sampling with the nets and the ADCP was used to test the hypothesis that different hydrographic regimes in the study area have different levels of available prey items, and these prey items influence the distributions of cetaceans and seabirds.

Measurements of zooplankton and micronekton biomass derived from both net and acoustic sampling were used to provide a summary of the amount of potential food available for higher trophic level foraging. In addition, the abundance of cephalopods and myctophids, two important prey items found abundantly in a wide variety of cetacean and seabird stomachs (Fitch and Brownell 1968; Perrin et al. 1973; Clarke 1996; Croxall and Prince 1996), was used to explore the hypothesized link between higher zooplankton biomass levels and richer cetacean prey resources.

Cephalopods are oceanic fauna that range in size from planktonic to some of the largest nekton (*Architeuthis*) (Roper et al. 1984). Both juvenile and adult cephalopods are voracious predators and sometimes are found in abundance. They are, in turn, preyed upon by many marine mammals, marine fish, and seabirds (Clarke 1977, 1996; Croxall and Prince 1996). Therefore, cephalopod distribution and abundance may influence the distribution and abundance of their predators. However, adult cephalopods, due to their agility and keen eyesight, are extremely difficult to catch. Consequently, "paralarval" cephalopods were used in this study as the link to adult cephalopods. A paralarval squid is defined by Young and Harman (1989) as a "cephalopod of the first post-hatching growth stage that is pelagic in near-surface waters during the day and that has a distinctly different mode-of-life from that of older conspecific individuals".

Among small midwater fishes, myctophids (or lanternfish) dominate the fish remains found in cetacean stomachs, often comprising 89% or higher of the total otoliths (ear bones) found (Fitch and Brownell 1968). Because of their worldwide abundance and abundance in the net samples collected, myctophids were chosen to represent the influence of midwater fishes on cetacean prey distributions in GulfCet II. There are 32 genera of myctophids, including 17 in the Gulf of Mexico, which occur in a variety of habitats ranging from the open ocean to the continental shelf (McEachran and Fechhelm 1998). Almost all species of myctophids are vertical migrators, with the myctophids in the eastern Gulf of Mexico concentrating in the upper 150 m at night and from 300 to 900 m during the day (Gartner et al. 1987). Myctophids are an important food source for cephalopods, sea birds, game fish, and cetaceans. Predator fish include salmon, cod, redfish, tuna, and swordfish (Nafpaktitis et al. 1977). Cetacean species with documented evidence of myctophid remains in their stomachs include dwarf sperm whales, spinner dolphins, pantropical spotted dolphins, striped dolphins, clymene dolphins, and Bryde's whales (Fitch and Brownell 1968; Perrin et al. 1973; Perrin and Gilpatrick 1994; Perrin and Hohn 1994; Perrin et al. 1994; Perrin and Mead 1994; Kawaguchi and Kawamura 1981). All of these cetacean species have been observed during GulfCet I and/or GulfCet II. While the presence of myctophid otoliths in cetacean stomachs does suggest the whales are eating these fish, Fitch and Brownell (1968) stipulate that at least some of the otoliths could be present because they were first ingested by cephalopods. Regardless of whether myctophids are being eaten by cetaceans directly or secondarily through cephalopods, a high abundance of myctophids may indicate a preferred foraging region for cetaceans.

ADCPs are normally used by physical oceanographers to measure the velocity of ocean currents. The ADCP transmits a sound pulse into the water, and the Doppler-shifted sound scattered back from drifting particles in the water is used to obtain estimates of current velocities. However, the ADCP also measures the intensity of backscattered sound. Since this intensity is proportional to the number and backscattering cross sections of particles in an ensonified volume of water (Clay and Medwin 1977; Medwin and Clay 1998), ADCP measurements using sound frequencies of 153 and 307 kHz have been used to estimate the concentration of sound scattering particles such as zooplankton and micronekton (Flagg and Smith 1989; Roe and Griffiths 1993; Ashjian et al. 1994; Zhou et al. 1994; Griffiths and Diaz 1996; Ressler et al. 1998). Under typical open ocean conditions, the particles responsible for the backscattering at these frequencies are likely to be zooplankton and micronekton (Stanton et al. 1994; Wiebe et al. 1997; Medwin and Clay 1998). Therefore, with a calibrated measure of S_v (acoustic volume backscattering strength) obtained from an ADCP and intensive “sea-truth” sampling of the numbers and kinds of potential sound-scattering organisms, quantitative estimates of the standing stocks of zooplankton and micronekton in the ocean can be made. Acoustic methods are currently recognized as an important way of studying zooplankton and micronekton (Greene and Wiebe 1990; Wiebe et al. 1997), and there is precedent for their use in assessment of zooplankton and micronekton stocks in cetacean habitat studies (Macaulay et al. 1995; Beardsley et al. 1996; Croll et al. 1998). In fact, in the eastern Pacific, Fiedler et al. (1998a) recently described the use of a 153 kHz ADCP to examine spatial and temporal variability in the biomass of potential dolphin prey stocks consisting of zooplankton, micronekton, and squid.

3.2 Methods

3.2.1 Net Sampling

The samples for both zooplankton and micronekton were taken on the October 1996 and August 1997 R/V *Gyre* cruises (*Gyre* 96G6 and *Gyre* 97G8). Three types of sampling equipment were used. The 1 m^2 Multiple Opening/Closing Net and Environmental Sampling System (MOCNESS) with a mesh size of 333 μm was used on Leg II of the October 1996 cruise and on all of the August 1997 cruise. The MOCNESS is commonly used in several sizes, which refer to the net's vertical mouth area when towing at a 45° angle to the vertical. The pertinent characteristics of the MOCNESS system are: (1) it allows up to nine discrete samples to be collected during one tow, sampling either obliquely or horizontally; (2) it collects water temperature, depth and salinity data and displays it in real time to allow changes in sampling strategy during the course of a tow; and (3) it monitors net angle and computes volume filtered for each individual net (Wiebe et al. 1976). During sampling in October 1996, the first net of the MOCNESS was used to collect an oblique sample during all tows; in August 1997 the MOCNESS was fished during descent, yielding nine, depth-discrete samples. The 1 m^2 MOCNESS was towed at speeds of 1.5 - 2.0 knots.

On Leg I of the October 1996 cruise, a 4 m^2 version of the MOCNESS with a mesh size of 3 mm was used, allowing collection of seven discrete samples also at a towing speed of 1.5 - 2.0 knots. In May 1997, a 15' Isaacs Kidd Midwater Trawl (IKMT) with a mouth opening of 14.7 m^2 and a mesh size of 4 mm was tested. The IKMT, which collects only one sample, was towed obliquely. Volume was recorded by a flowmeter suspended in the mouth of the net. Maximum depth of tow was determined by the wire length and wire angle method. Unlike the MOCNESS nets, the IKMT was towed at 4.0 - 5.0 knots. The advantage of this faster towing speed is a reduction in the effects of net avoidance by more actively swimming organisms (e.g., cephalopods and myctophids). The catches with the IKMT were much larger than those from the 4 m^2 MOCNESS. Therefore, despite the loss of depth-discrete data, the IKMT was used instead of the 4 m^2 MOCNESS on the August 1997 cruise. Depth-discrete data for the zooplankton biomass and cephalopod paralarvae was obtained from the 1 m^2 MOCNESS, which was always towed immediately before or after each IKMT tow.

Locations for all tows depended on the ship's location following daylight cetacean observations. As a result, sufficient sampling for most statistical procedures in different environmental features was difficult to obtain. The environment of each tow was characterized by its temperature and salinity profile as determined by sensors on the MOCNESS, by XBT (expendable bathythermograph) and/or CTD (Conductivity-Temperature-Depth) sampling during, before, or after each tow, or by sea surface topography derived from the hydrographic data.

3.2.2 Zooplankton

Samples were preserved in 10% buffered formalin on the ship. On the October 1996 cruise, 199 samples were collected (171 1 m^2 MOCNESS samples and 28 4 m^2 MOCNESS samples). On the August 1997 cruise, 177 samples were collected (162 1 m^2 MOCNESS samples and 15 IKMT samples). After a minimum of two weeks preservation, the displacement volumes were determined in the 1 m^2 MOCNESS samples in the following manner: Draining the sample of formalin, rinsing it into a graduated cylinder, using distilled water to raise the sample volume to a standard volume, draining it through a concentrating funnel, and shaking the contents of the concentrating funnel into another graduated cylinder to remove interstitial water. The difference between the initial and final volume is the displacement volume. Displacement volumes were determined for all samples. This process took approximately 30 minutes per sample. Displacement values were divided by the volume of water filtered for each net to give a biomass per volume expressed in cc m^{-3}. When the displacement volume for each tow had been determined, the interval biomass values were multiplied by the interval thickness and summed to give integrated biomass (cc m^{-2}), a quantitative measure of the zooplankton biomass under one square meter of sea surface. Due to large differences in mesh size from the 1 m^2 MOCNESS, biomass values from the 4 m^2 MOCNESS and the IKMT are not comparable and therefore were not calculated.

3.2.3 Cephalopod Paralarvae

After the displacement volumes were determined, all samples (1 m^2 MOCNESS, 4 m^2 MOCNESS, and 15' IKMT) were sorted for paralarval cephalopods. There was a very good linear relationship between the displacement volume of a sample and the sorting time for cephalopod paralarvae ($r^2 = 0.95$). For GulfCet II, on average, 25 minutes of sorting were spent per sample. The cephalopods were then identified to the family taxonomic level. To calculate number of paralarvae per m^2 for the MOCNESS, the number of cephalopods per sample was divided by the volume of water filtered per net. When each sample for each tow was complete, the interval concentration values were multiplied by the interval thickness and summed to give integrated paralarvae or number of paralarvae per m^2. However, for the IKMT, the total paralarvae per tow were divided by the volume of water filtered, and this number was then multiplied by the maximum depth of tow to give the number of paralarvae per m^2. These are all quantitative measures of the number of paralarvae under one square meter of sea surface.

3.2.4 Myctophids

While myctophids were present in some of the 1 m^2 MOCNESS samples, they were smaller in size and much lower in number than in the IKMT tows. They were not captured at all in many of the 1 m^2 MOCNESS tows. This may have been due to the ability of myctophids to avoid the smaller, slower MOCNESS, as well as due to the much smaller volume of water filtered by each 1 m^2 MOCNESS net relative to the IKMT. The IKMT tows contained larger and more plentiful myctophids, and thus were given first priority for analysis. Three of the IKMT tows were chosen for an initial description of myctophid abundance and generic diversity. Each represented a specific feature: IKMT#9 from the cyclone margin (NW), IKMT#11 from the anticyclone, and IKMT#7 from the confluence. These three trawls were taken at similar time periods (late evening) over a two day period. This reduced the possibility of variation due to temporal factors. The maximum depths of these trawls were similar (153 m, 141 m, and 221 m, respectively). The number of myctophids was divided by the volume and then multiplied by the maximum depth of each tow to calculate the number of myctophids per m^2. The myctophids were identified to genus by the location of photophores and other luminous tissue on their bodies.

3.2.5 ADCP

A 153 kHz narrowband Rowe Deines Instruments (RDI) ADCP was used to collect acoustic backscatter data during both cruises. The ADCP was installed in a 'moon-pool' in *Gyre*'s hull, with its four acoustic transducers facing downward from the bottom of the ship in a concave configuration. Backscatter data were collected continuously except during data backup. The signals from all four beams were averaged. These averages were converted from the 'echo intensity' units, recorded by the ADCP's automatic gain control (AGC) circuitry, into a calibrated measure of volume backscattering strength (S_v), using measured system calibration values and hydrographic parameters affecting the speed and absorption of sound in seawater. (See R.D. Instruments (1990) and Zimmerman (1997) for details of this procedure.) S_v was analyzed over a depth range of 10 - 202 m: 10 m is the upper limit of the data collected, while 202 m was used as the lower limit because the signal to noise ratio decreases appreciably below this depth. S_v was measured during day and night, both while on-station and while underway, enabling an examination of both temporal and spatial trends in acoustic backscatter.

Biomass estimates of zooplankton and micronekton were produced using an empirical calibration of the acoustic signal from the ADCP with samples of zooplankton and micronekton taken from the 1 m^2 MOCNESS (Flagg and Smith 1989; Ashjian et al. 1994; Zhou et al. 1994; Zimmerman 1997; Ressler et al. 1998). For each 1 m^2 MOCNESS tow, the mean S_v measured at a given depth during the tow was matched with the measured displacement volume biomass from the corresponding depth-discrete net sample. Since S_v was analyzed from 10 - 50 m (approximately equal to the mixed layer depth) and 10-202 m (maximum depth range), only MOCNESS samples from the depth range 10-202 m were included in the calibration. Linear regression of the $\log_{10}$ of MOCNESS displacement volume biomass (in cc $m^{-3} * 10^3$) as a function of mean S_v (in dB re m^{-1} $4\pi^{-1}$) was used as a first-order empirical model of Predicted Mean Biomass (PMB) in units of cc m^{-3}.

During both October 1996 and August 1997, there was a positive functional relationship between biomass and S_v. However, statistical testing of the two regression models indicated that they were significantly different (see Section 3.4.4). Hence, a different regression equation was used for each of the *Gyre* cruises to make predictions of PMB. PMB values (based on S_v data averaged every 300 seconds) have a horizontal resolution of 0.3 - 1.5 km, depending on ship speed, and a vertical resolution of 4 m.

To provide a summary of the biomass in the water column to compare with cetacean or seabird sightings at a given location, the PMB estimates (cc m^{-3}) were vertically integrated (in the same manner as the 1 m^2 MOCNESS displacement volume measurements were integrated, as described earlier) from 10 - 50 m depth, giving a summary PMB value in units of cc m^{-2} at each location where an acoustic measurement was made.

The integrated PMB data set was further filtered as follows:

(1) PMB data containing on-station artifacts (anomalously low returns while the ship maneuvered to hold station during CTD casts), or data collected from locations with

bottom depths shallower than 200 m (there were no shallow water 1 m^2 MOCNESS calibration samples) were eliminated.

(2) PMB data were separated by night and day before being analyzed for spatial variation or compared with cetacean or bird sightings, because biomass sampled by the MOCNESS and/or the ADCP in the upper 200 m is always higher at night than during the day because of the diel vertical migration of many zooplankton and micronekton. This phenomenon is common to all phyla of both marine and freshwater zooplankton (Huntley 1985) and is documented for zooplankton, micronekton (Hopkins 1982) and adult squid (Passarella and Hopkins 1991) in the Gulf of Mexico. However, the diel migration pattern differs by particular organism, region, and season and therefore is not easily modeled. To account for the diel pattern in the habitat association analysis, the PMB data were split into three divisions based on the diel pattern in each cruise. 'Migration' was defined as the time period during which an apparent upward or downward migration of high backscatter was seen (which occurred regularly at dawn and dusk). 'Day' was defined as the time period after the dawn migration but before the dusk migration, and 'Night' was defined as the period between dusk migration and the dawn migration.

Data were separated for each cruise to account for the temporal trends as follows:

<u>October 1996</u>
Day (10.3 hours)-- 0705 - 1725 CDT (Central Daylight Time)
Migration (1.5 hours)-- 1730 - 1900 CDT
Night (10.8 hours)-- 1905 - 0555 CDT
Migration (1.0 hours)-- 0600 - 0700 CDT

<u>August 1997</u>
Day (11.0 hours)-- 0730 - 1830 CDT
Migration (2.3 hours)-- 1835 - 2055 CDT
Night (8.0 hours)-- 2100 - 0500 CDT
Migration (2.3 hours)-- 0505 - 0725 CDT

(3) There is one additional caveat regarding the October 1996 data set. Due to strong breezes and whitecapped, 8 - 10 ft. seas during the early part of this cruise (morning of 10/12 through morning of 10/14), the ADCP data collected during that period have a lower signal to noise ratio due to these rough conditions. None of the data used to generate the empirical model used for that cruise came from this period, nor were there any sightings of cetaceans or birds.

Ninety-five percent confidence intervals (CI) and 95% prediction intervals (PI) were calculated for the predictions of biomass generated from the regression. PMB values were then compared with values of integrated displacement volume biomass from 1 m^2 MOCNESS samples to assess their agreement. In addition, PMB was plotted as a function of time to provide a qualitative depiction of temporal trends in biomass, and then as a function of 15°C depth (a proxy for hydrographic regime; see Chapter 2) to visualize spatial patterns only. Also, interpolated contour maps of daytime and nighttime PMB in the 10 - 50 m depth range were made to show spatial variation in PMB with respect to geographic location and hydrographic features for each cruise. Finally, these PMB data were used as a variable in the statistical analysis of cetacean and seabird abundance and distribution patterns (see Chapters 6 and 8).

3.3 Results

3.3.1 Zooplankton

The data on tow number, location, depth, biomass, number of cephalopod paralarvae, and environment are shown in Table 3.1. Figures 3.1 and 3.2 show the locations and integrated zooplankton biomass for the 1 m^2 MOCNESS tows during the October 1996 cruise and the August 1997 cruise, respectively. Figures 3.3 and 3.4 show locations for the 4 m^2 MOCNESS tows during the October 1996 cruise and the IKMT tows during the August 1997 cruise. All locations are superimposed upon sea surface dynamic height anomalies. A summary of zooplankton biomass in all environmental categories by year is shown in Figure 3.5. The zooplankton biomass in the anticyclone for October 1996 is significantly different from that for either the cyclone or cyclone margin, but not for the confluence tows. Zooplankton biomass in the confluence for August 1997 is significantly different from the cyclone margin and the anticyclone but not the anticyclone margin. A summary of zooplankton biomass by those environments having two or more observations for both cruises is shown in Figure 3.6. This figure shows that in all possible comparisons, the August 1997 values were significantly higher than those from October 1996.

3.3.2 Cephalopod Paralarvae

The five most abundant families obtained from the 1 m^2 MOCNESS and IKMT tows (the 4 m^2 MOCNESS samples lacked cephalopods) were: Enoploteuthidae, Ommastrephidae, Pyroteuthidae, Cranchiidae, and Onychoteuthidae. Within both the 1 m^2 MOCNESS samples and the IKMT tows, the family Enoploteuthidae was by far the most abundant. However, the rank order of the additional four families varied slightly. These five families constituted approximately 95% of cephalopods collected (a combined total of 1673 cephalopods) and were the only families used in calculations (Table 3.1). The 1 m^2 MOCNESS samples also revealed that the paralarvae were generally concentrated in the upper 75 - 150 m (See Appendix for Data).

The integrated water column values for the number of paralarvae per m^2 are plotted in Figures 3.7 - 3.9. A comparison of all 1 m^2 MOCNESS samples from the different environmental regimes having two or more observations for both cruises shows there are no statistical differences among tows during a given cruise (Figure 3.10). Nevertheless, it can be seen that the numbers of paralarvae per square meter were, on average, three times higher during August 1997 when compared with October 1996 (Figure 3.11).

In addition, a comparison of all 1 m^2 MOCNESS tows from both cruises (n = 36 from 333 samples) was made using cephalopod paralarvae (# m^{-2}) and zooplankton biomass (cc m^{-2}). The Spearman Rank Correlation, a nonparametric test which uses only ranks and therefore is less sensitive to outliers, was chosen. The correlation coefficient was 0.73 ($p < 0.001$). The positive

Table 3.1. Summary of 1 m^2 MOCNESS tows, 4 m^2 MOCNESS tows and 15' IKMT tows.

Tow #	Date	Time (local)	Position Lat (N)	Long (W)	Integrated Biomass (cc m^{-2})	Integrated Paralarvae (# m^{-2})	Depth of Tow (m)	Depth of 15°C Isotherm	Environment
MOC1-180	10/20/96	1441-1803	28.71	88.81	3.2	0.91	111	178	Cyclone Margin (NW)
MOC1-181	10/20/96	2036-2224	28.71	88.83	4.3	0.85	121	181	Cyclone Margin (NW)
MOC1-182	10/21/96	1324-1540	27.05	88.02	4.7	0.50	190	147	Cyclone
MOC1-183	10/21/96	2108-2330	26.23	87.70	5.5	1.05	190	188	Confluence
MOC1-184	10/22/96	0350-0543	25.65	87.53	2.7	0.57	189	267	Anticyclone
MOC1-185	10/22/96	2000-2305	25.19	87.57	1.6	0.04	193	333	Anticyclone
MOC1-186	10/23/96	0431-0539	26.00	88.00	2.7	0.09	193	212	Confluence
MOC1-187	10/23/96	1635-1812	27.10	88.56	3.9	0.42	187	164	Cyclone
MOC1-188	10/23/96	2015-2200	27.30	88.68	4.1	0.53	183	156	Cyclone
MOC1-189	10/24/96	2024-2239	27.23	89.07	5	0.21	385	168	Cyclone Margin (W)
MOC1-190	10/25/96	0336-0508	26.66	88.89	6.5	0.87	385	172	Cyclone Margin (SW)
MOC1-191	10/26/96	1353-1523	26.99	87.72	4.3	0.39	393	146	Cyclone
MOC1-192	10/26/96	1944-2121	27.38	87.89	4.4	0.34	393	134	Cyclone
MOC1-193	10/27/96	0350-0440	28.08	88.16	4.3	0.26	191	154	Cyclone
MOC1-194	10/27/96	1950-2050	28.25	88.90	3.9	0.17	183	166	Cyclone Margin (NW)
MOC1-195	10/28/96	2353-0109	28.21	89.08	4.7	0.19	181	171	Cyclone Margin (NW)
MOC1-196	10/28/96	0347-0440	28.44	89.17	4.3	0.92	187	179	Cyclone Margin (NW)
MOC1-197	10/28/96	1300-1430	28.01	89.17	5.3	1.53	190	168	Cyclone Margin (NW)
MOC1-198	10/28/96	1618-1702	28.19	89.27	3.5	0.32	189	176	Cyclone Margin (NW)
MOC1-208	8/6/97	2108-2150	26.89	88.40	5.6	1.01	200	351	Anticyclone
MOC1-209	8/6/97	2345-0033	26.82	88.37	6.8	5.27	200	393	Anticyclone
MOC1-210	8/8/97	0019-0101	27.72	88.02	13	3.67	200	234	Confluence
MOC1-211	8/8/97	1821-1907	28.98	87.93	6.6	1.26	209	192	Other Margin

Table 3.1. (continued) Summary of 1 m^2 MOCNESS tows, 4 m^2 MOCNESS tows and 15' IKMT tows.

Tow #	Date	Time (local)	Position Lat (N)	Long (W)	Integrated Biomass (cc m^{-2})	Integrated Paralarvae (# m^{-2})	Depth of Tow (m)	Depth of 15°C Isotherm	Environment
MOC1-212	8/8/97	2217-2338	28.63	87.79	6.3	0.73	175	173	Cyclone Margin (NW)
MOC1-213	8/9/97	0123-0216	28.64	87.80	12.4	1.95	150	148	Cyclone Margin (NW)
MOC1-214	8/9/97	1641-1747	26.96	86.96	6	0.69	200	308	Anticyclone Margin
MOC1-215	8/9/97	2006-2128	26.91	86.91	8.9	1.31	200	318	Anticyclone Margin
MOC1-216	8/9/97	2317-0031	26.87	86.79	8.8	1.86	200	294	Anticyclone Margin
MOC1-217	8/10/97	2306-0028	29.18	86.91	8.9	0.84	200	162	Cyclone Margin (N)
MOC1-218	8/11/97	0158-0317	29.08	86.94	8.6	1.63	175	162	Cyclone Margin (N)
MOC1-219	8/11/97	1653-1836	27.61	87.29	12.5	1.26	400	219	Confluence
MOC1-220	8/14/97	2045-2216	28.87	87.56	7.2	0.54	200	183	Cyclone Margin (N)
MOC1-221	8/15/97	0011-0125	28.94	87.45	8.3	1.42	200	183	Cyclone Margin (N)
MOC1-222	8/17/97	0125-0222	28.80	86.63	10.1	1.18	200	171	Cyclone Margin (N)
MOC1-223	8/17/97	0420-0514	28.69	86.65	8.6	1.31	200	180	Cyclone Margin (N)
MOC1-224	8/20/97	0458-0726	27.48	87.05	NA	NA	150	187	Confluence
MOC1-225	8/21/97	0150-0241	28.73	88.62	9.4	0.75	200	166	MOM Region
MOC 4-1	10/12/96	0036-0210	29.12	87.35	0.98	ND	400	135	Cyclone
MOC 4-2	10/16/96	2258-0051	29.12	87.39	0.25	ND	400	197	Slope N Cyclone
MOC 4-3	10/17/96	0220-0408	29.06	87.36	0.54	ND	400	179	Slope N Cyclone
MOC 4-4	10/17/96	1903-2110	27.55	87.44	0.99	ND	400	132	Cyclone
IKMT#5	8/6/97	0505-0600	28.66	89	ND	0.181	212	181	MOM Region
IKMT#6	8/6/97	2234-2330	26.84	88.38	ND	0.023	212	393	Anticyclone
IKMT#7	8/7/97	2300-0000	27.7	88.05	ND	0.089	221	234	Confluence
IKMT#8	8/8/97	0157-0300	27.68	88.02	ND	0.115	229	205	Confluence
IKMT#9	8/8/97	2358-0106	28.63	87.83	ND	0.091	153	173	Cyclone Margin (NW)
IKMT#10	8/9/97	1801-1900	26.87	86.94	ND	0.071	212	308	Anticyclone Margin

Table 3.1. (continued) Summary of 1 m^2 MOCNESS tows, 4 m^2 MOCNESS tows and 15' IKMT tows.

Tow #	Date	Time (local)	Position Lat (N)	Long (W)	Integrated Biomass (cc m^{-2})	Integrated Paralarvae (# m^{-2})	Depth of Tow (m)	Depth of 15°C Isotherm	Environment
IKMT#11	8/9/97	2147-2300	26.85	86.79	ND	0.048	141	294	Anticyclone Margin
IKMT#12	8/10/97	1601-1647	28.39	86.85	ND	0.000	225	134	Cyclone
IKMT#13	8/11/97	0046-0146	29.13	86.91	ND	0.121	225	162	Cyclone Margin (N)
IKMT#14	8/12/97	0150-0410	26.82	87.4	ND	0.008	153	389	Anticyclone
IKMT#15	8/14/97	2229-2352	28.92	87.53	ND	0.013	106	183	Cyclone Margin (N)
IKMT#16	8/17/97	0253-0410	28.74	86.64	ND	0.020	141	171	Cyclone Margin (N)
IKMT#17	8/18/97	0330-0523	28.67	85.48	ND	0.023	141	193	Shallow Shelf
IKMT#18	8/20/97	0023-0225	27.42	86.99	ND	0.080	354	187	Confluence
IKMT#19	8/21/97	0308-0440	28.76	88.67	ND	0.062	254	166	MOM Region

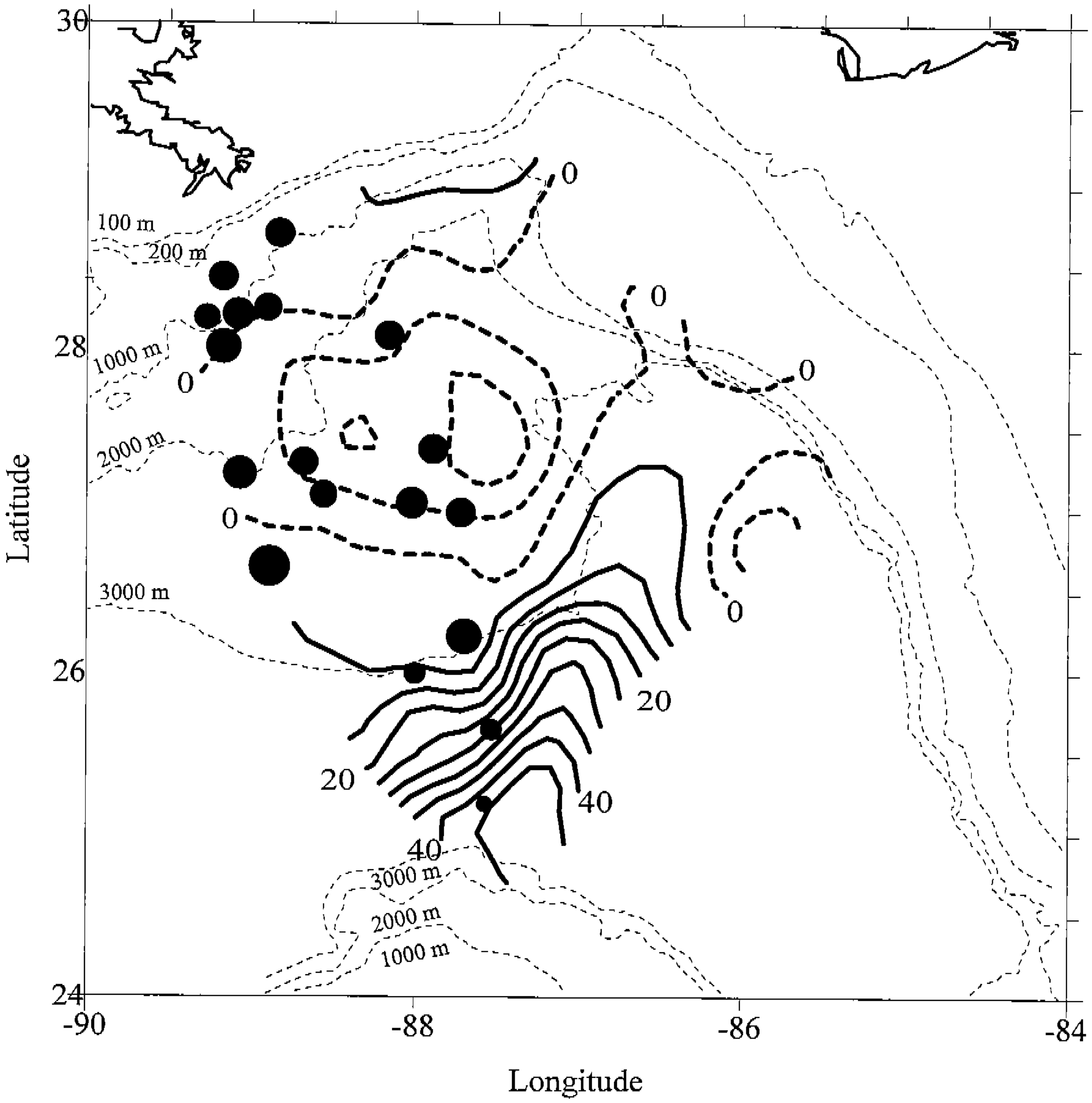


Figure 3.1. Integrated zooplankton biomass (cc m^{-2}) from $1m^2$ MOCNESS samples taken during late summer 1996. The diameter of each circle is directly proportional to its integrated biomass.

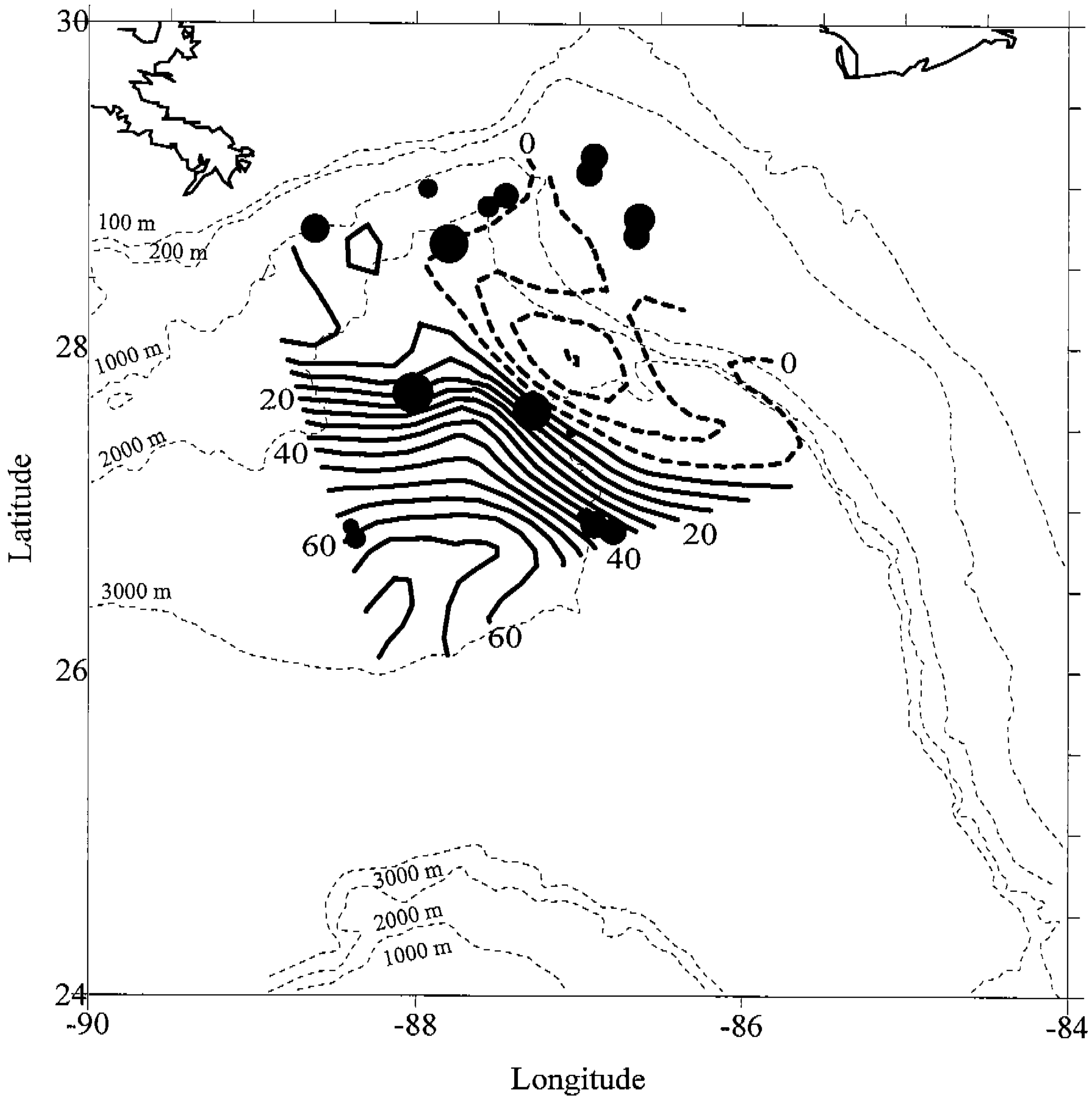


Figure 3.2. Integrated zooplankton biomass (cc m^{-2}) from $1m^2$ MOCNESS samples taken during mid-summer 1997. The diameter of each circle is directly proportional to its integrated biomass.

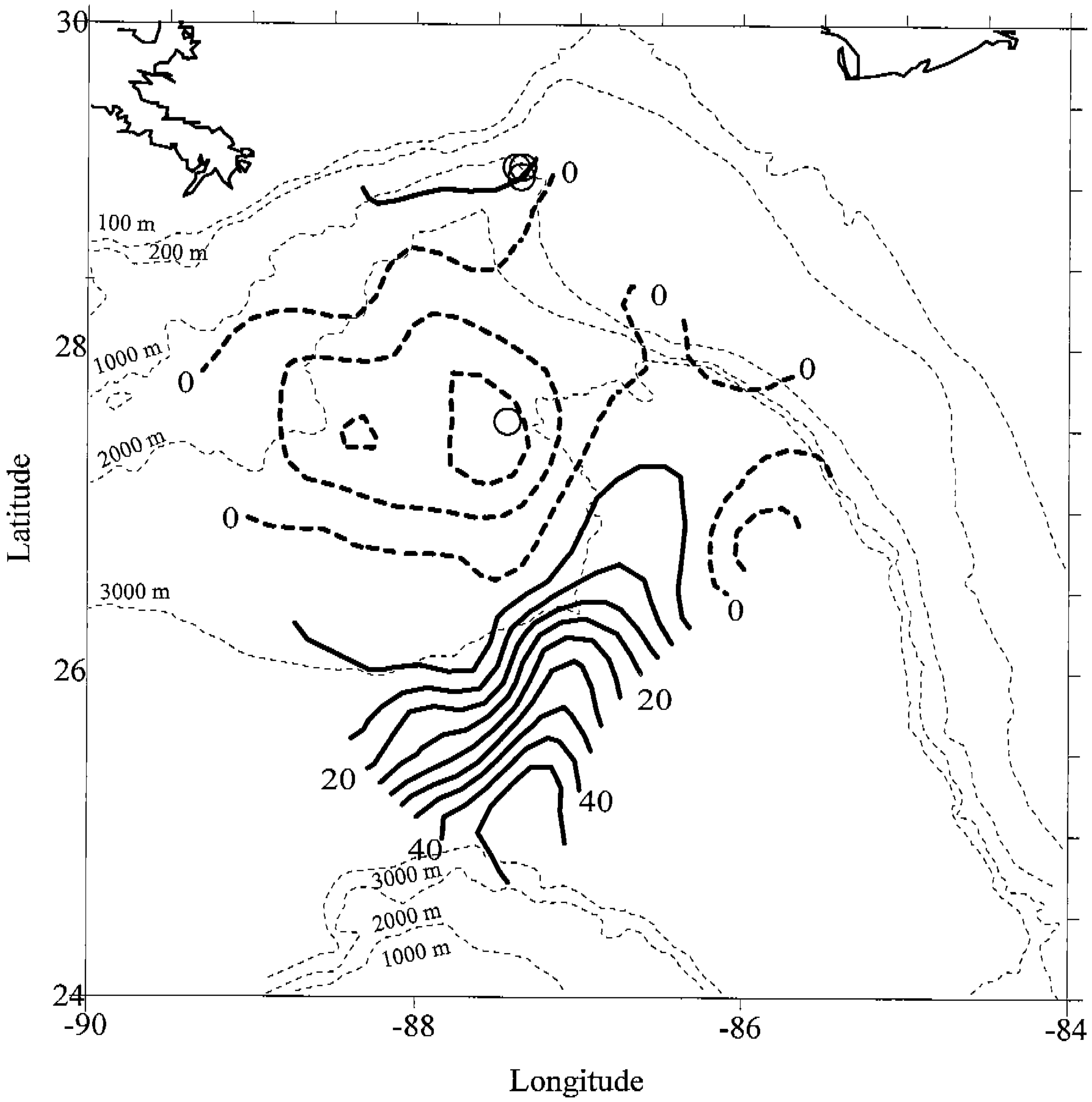


Figure 3.3. Tow locations for the $4m^2$ MOCNESS samples taken during late summer 1996.

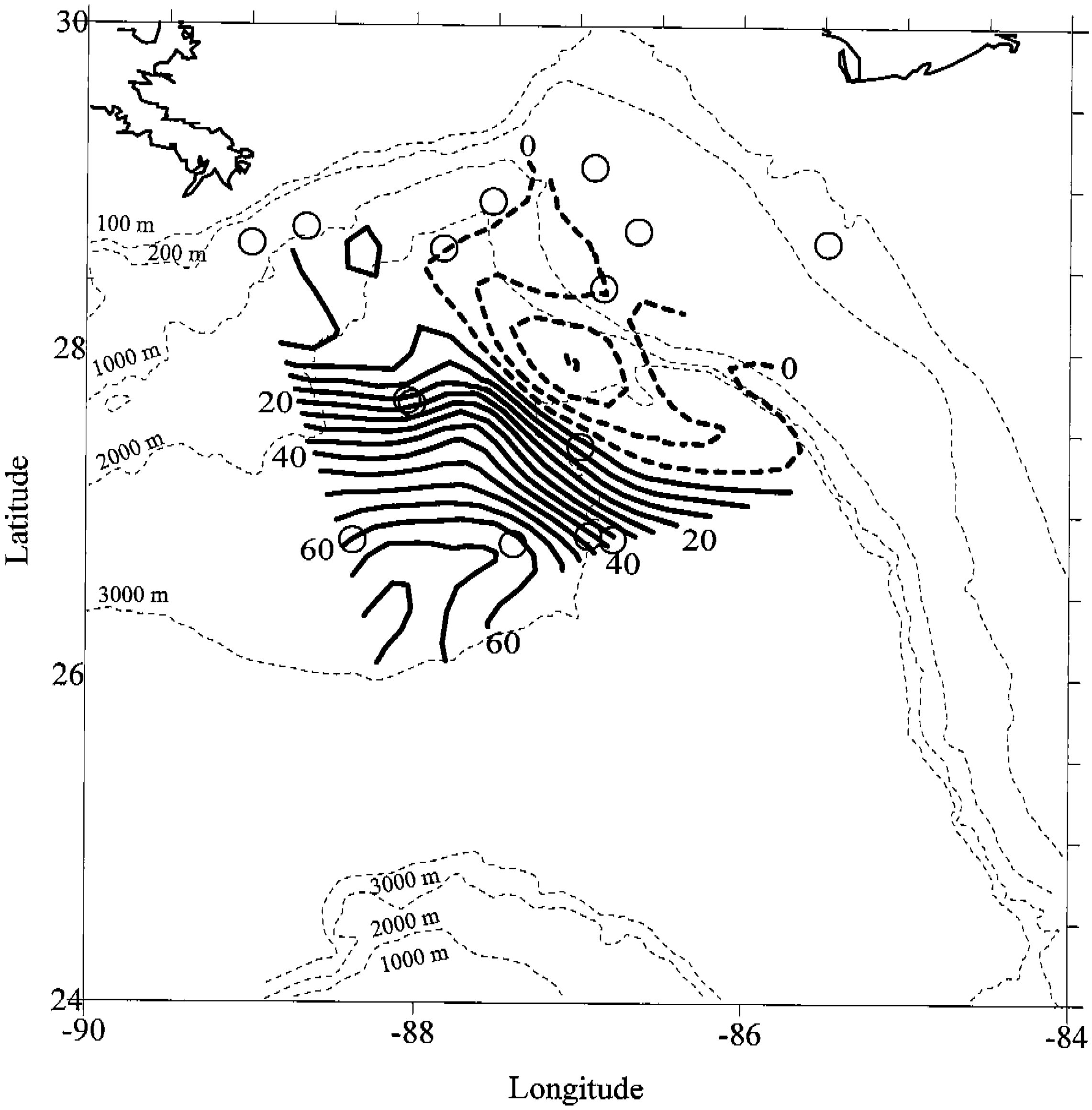


Figure 3.4. Tow locations for the 15' Isaacs Kidd Midwater Trawl tows taken during mid-summer 1997.

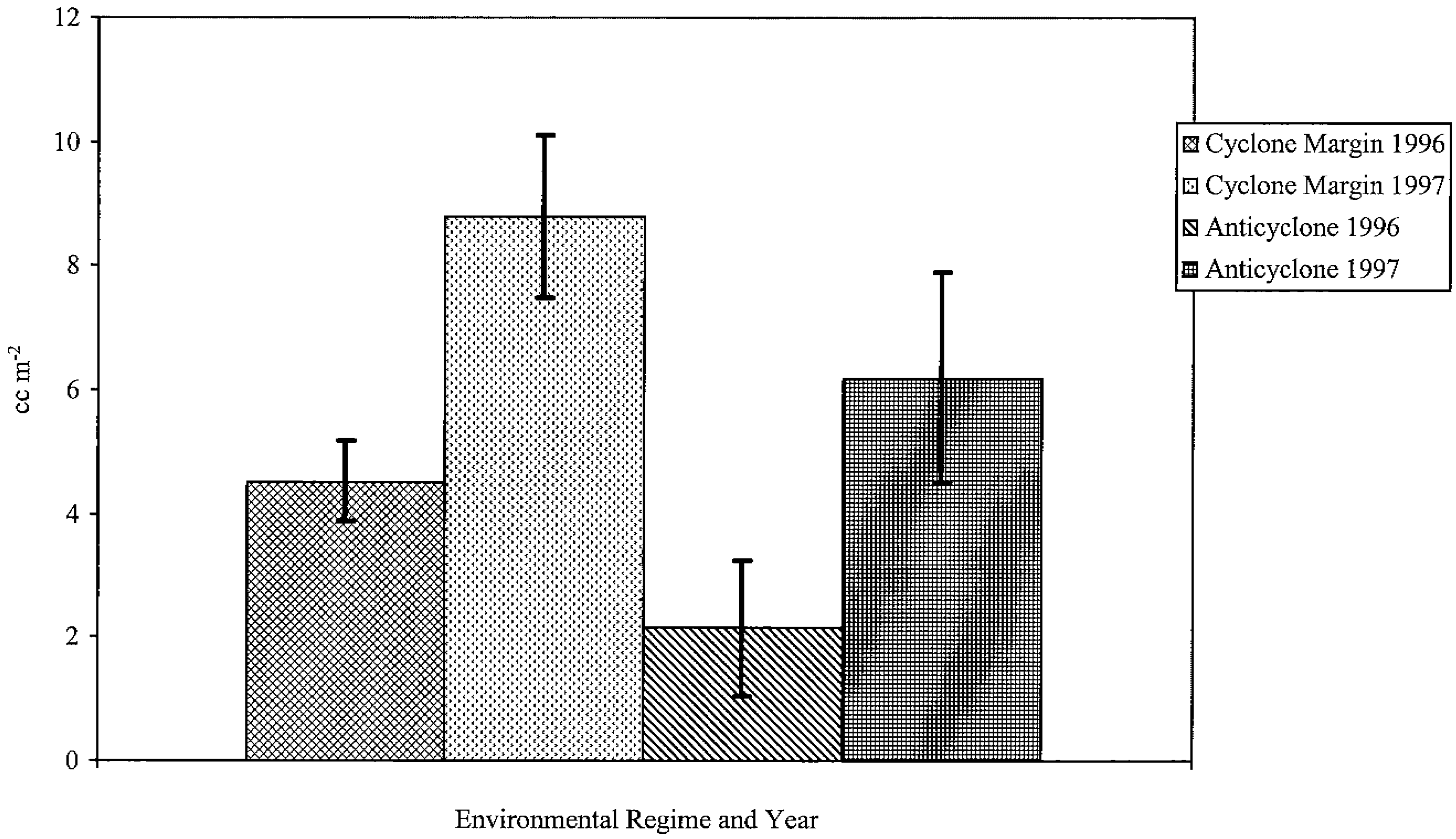


Figure 3.6. A within feature comparison of integrated zooplankton biomass (cc m^{-2}) between late summer 1996 and mid-summer- 1997. The vertical bars represent the mean values and the brackets represent the upper and lower 95% confidence limits.

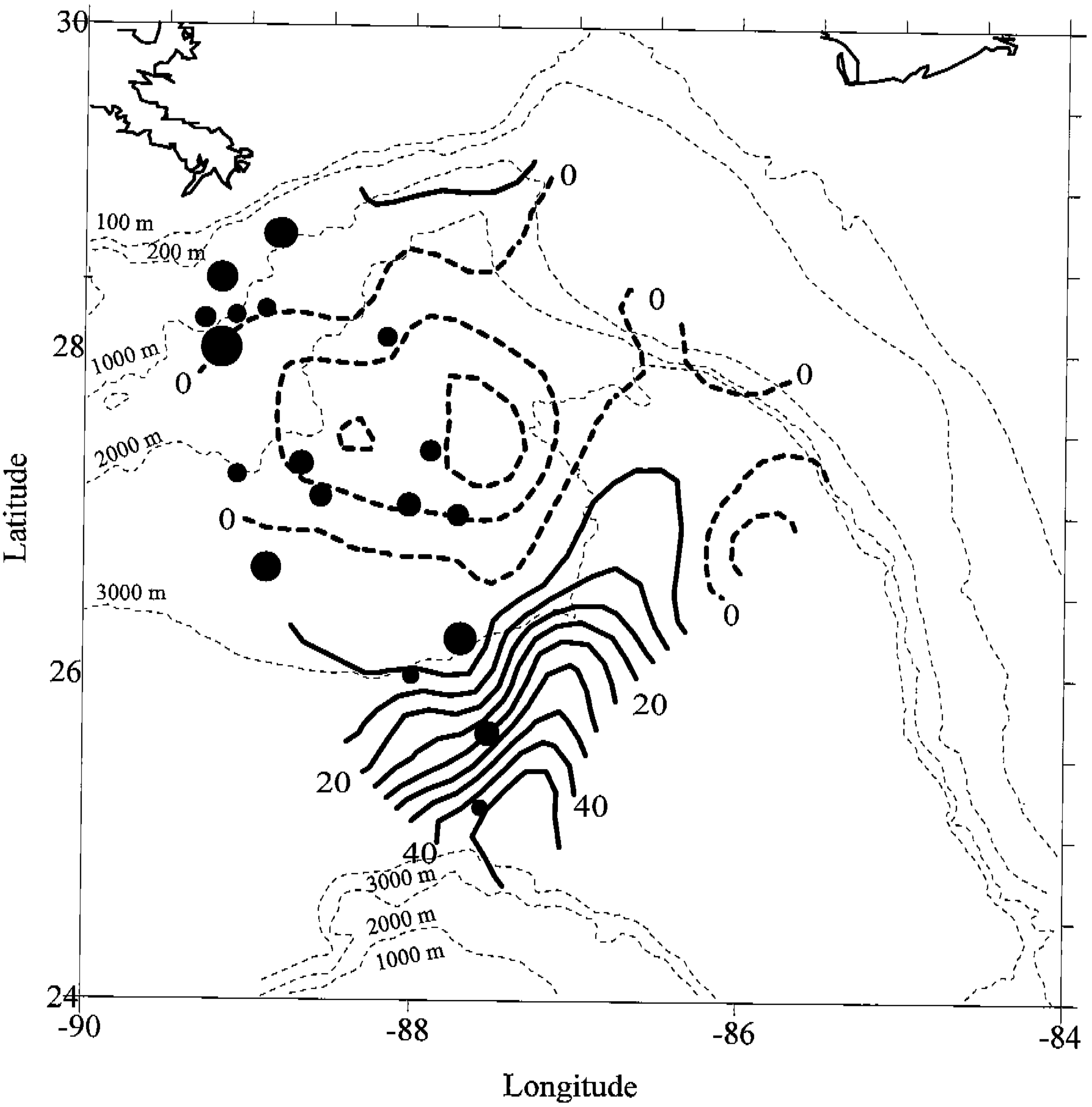


Figure 3.7. Integrated cephalopod paralarvae abundance (# m^{-2}) from 1 m^2 MOCNESS samples taken during late summer 1996. The diameter of each circle is directly proportional to its integrated abundance.

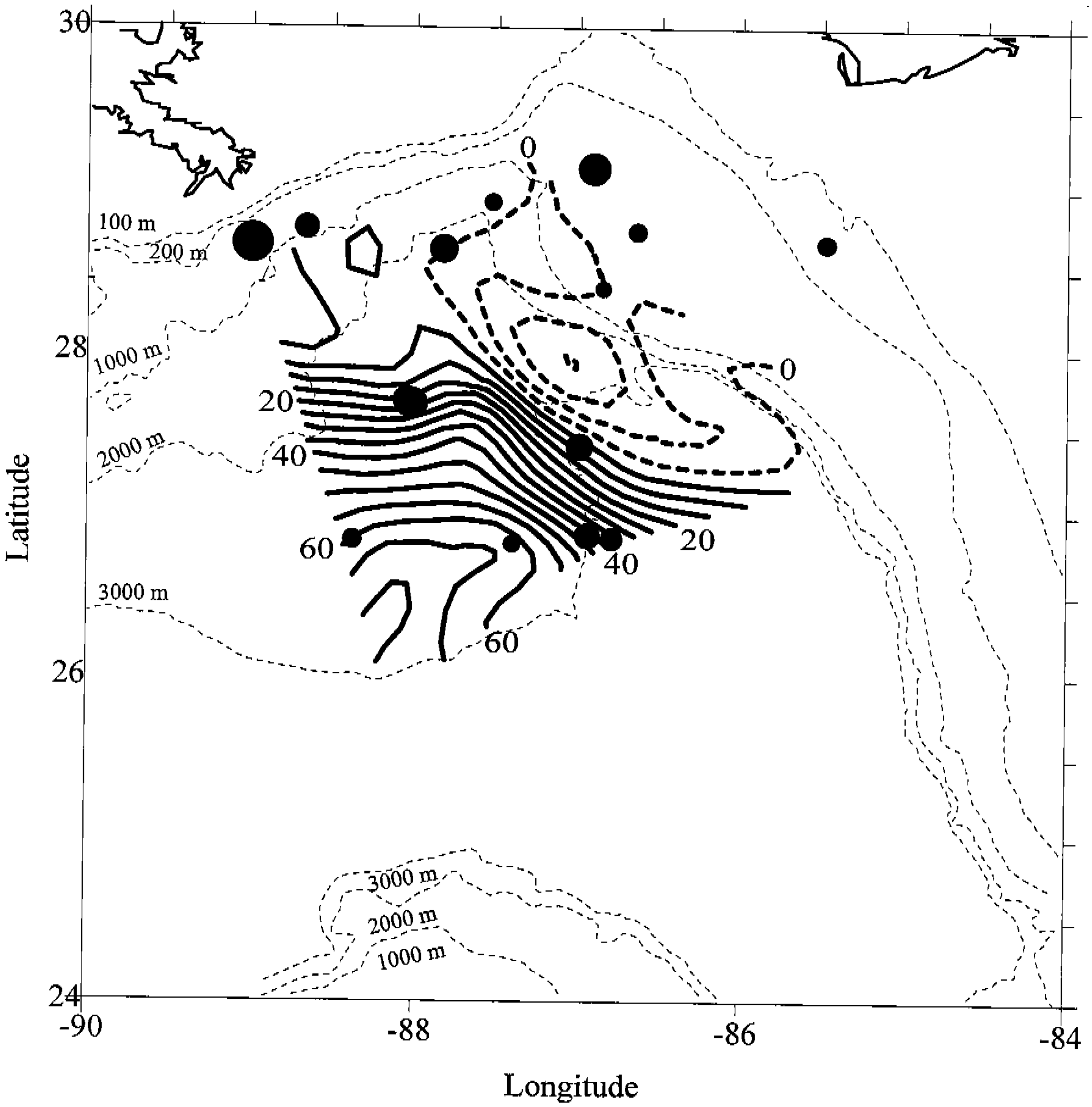


Figure 3.9. Integrated cephalopod paralarvae abundance (# m^{-2}) from the 15' Isaacs Kidd Midwater Trawl tows taken during mid-summer 1997. The diameter of each circle is directly proportional to its integrated abundance.

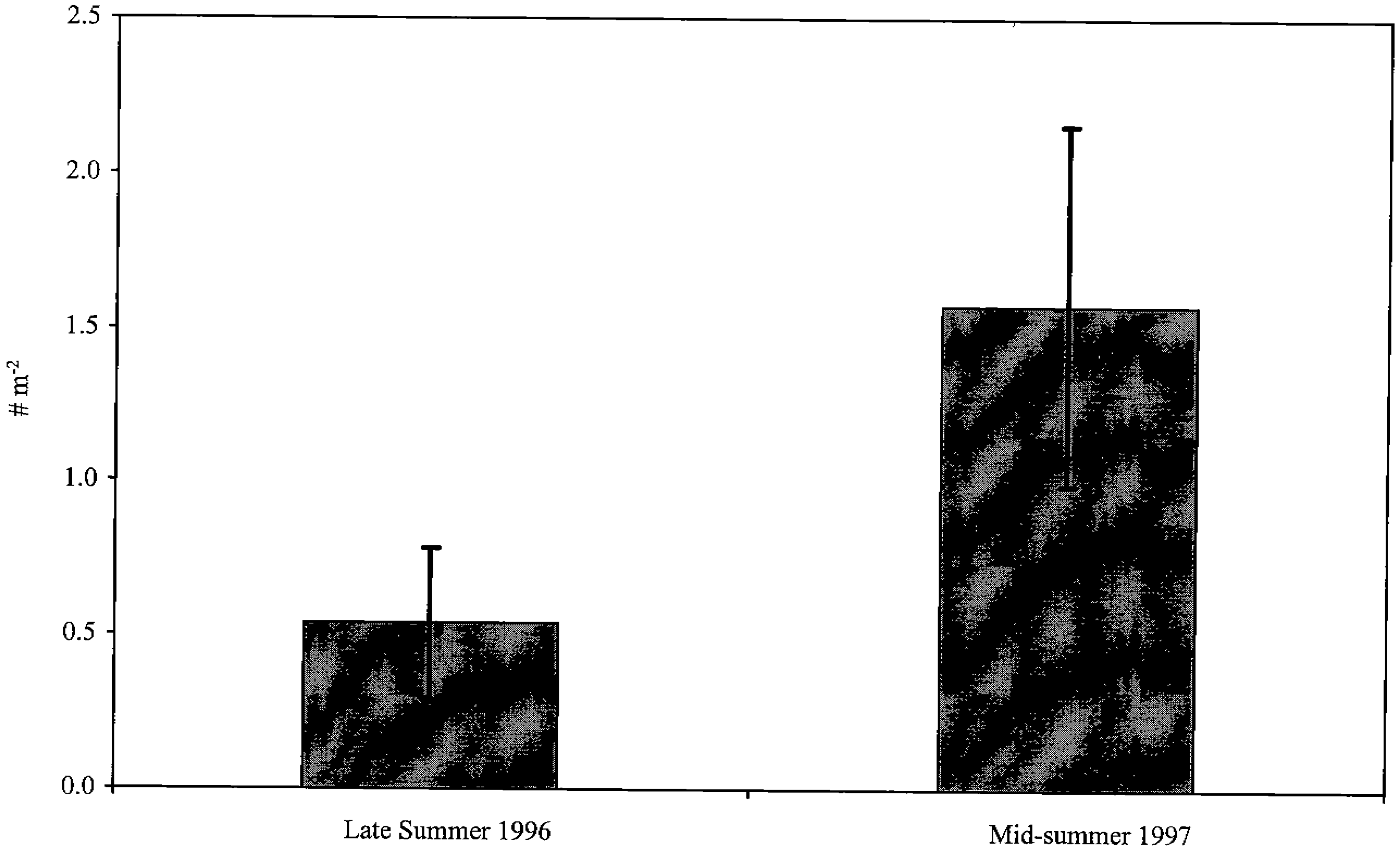


Figure 3.11. Integrated cephalopod paralarvae (# m^{-2}) compared between years with all environments and samples pooled. The vertical bars represent the mean values and the brackets represent the upper and lower 95% confidence limits.

Table 3.2. Myctophid abundance (# m^{-2}) by genera within analyzed 15' Isaacs Kidd Midwater Trawl tows taken during mid-summer 1997.

CYCLONE MARGIN		**CONFLUENCE**		**ANTICYCLONE**	
(IKMT#9; n = 357)		(IKMT#7; n = 167)		(IKMT#11; n = 94)	
Volume: 67,203 m^3		Volume: 64,404 m^3		Volume: 87,733 m^3	
Max. Depth: 153 m		Max. Depth: 221 m		Max. Depth: 141 m	
Genus	(# m^{-2})	Genus	(# m^{-2})	Genus	(# m^{-2})
Diaphus	0.212	Ceratoscopelus	0.161	Diaphus	0.061
Lampanyctus	0.157	Diaphus	0.110	Benthosema	0.037
Ceratoscopelus	0.116	Lampanyctus	0.079	Lepidophanes	0.026
Benthosema	0.091	Benthosema	0.055	Diogenichthys	0.013
Lepidophanes	0.071	Notolynchus	0.051	Ceratoscopelus	0.006
Hygophum	0.052	Lepidophanes	0.027	Bolinichthys	0.003
Diogenichthys	0.023	Notoscopelus	0.024	Myctophum	0.002
Bolinichthys	0.020	Diogenichthys	0.014	Hygophum	0.002
Myctophum	0.011	Myctophum	0.014		
Notoscopelus	0.009	Lampadena	0.007		
Notolynchus	0.007	Bolinichthys	0.003		
Lampadena	0.007	Hygophum	0.003		
Lobianchia	0.002	Lobianchia	0.003		
		Symbolophorus	0.003		
Unidentified	0.034	Unidentified	0.017	Unidentified	0.002
TOTAL	**0.813**	**TOTAL**	**0.573**	**TOTAL**	**0.151**
13 Genera		14 Genera		08 Genera	

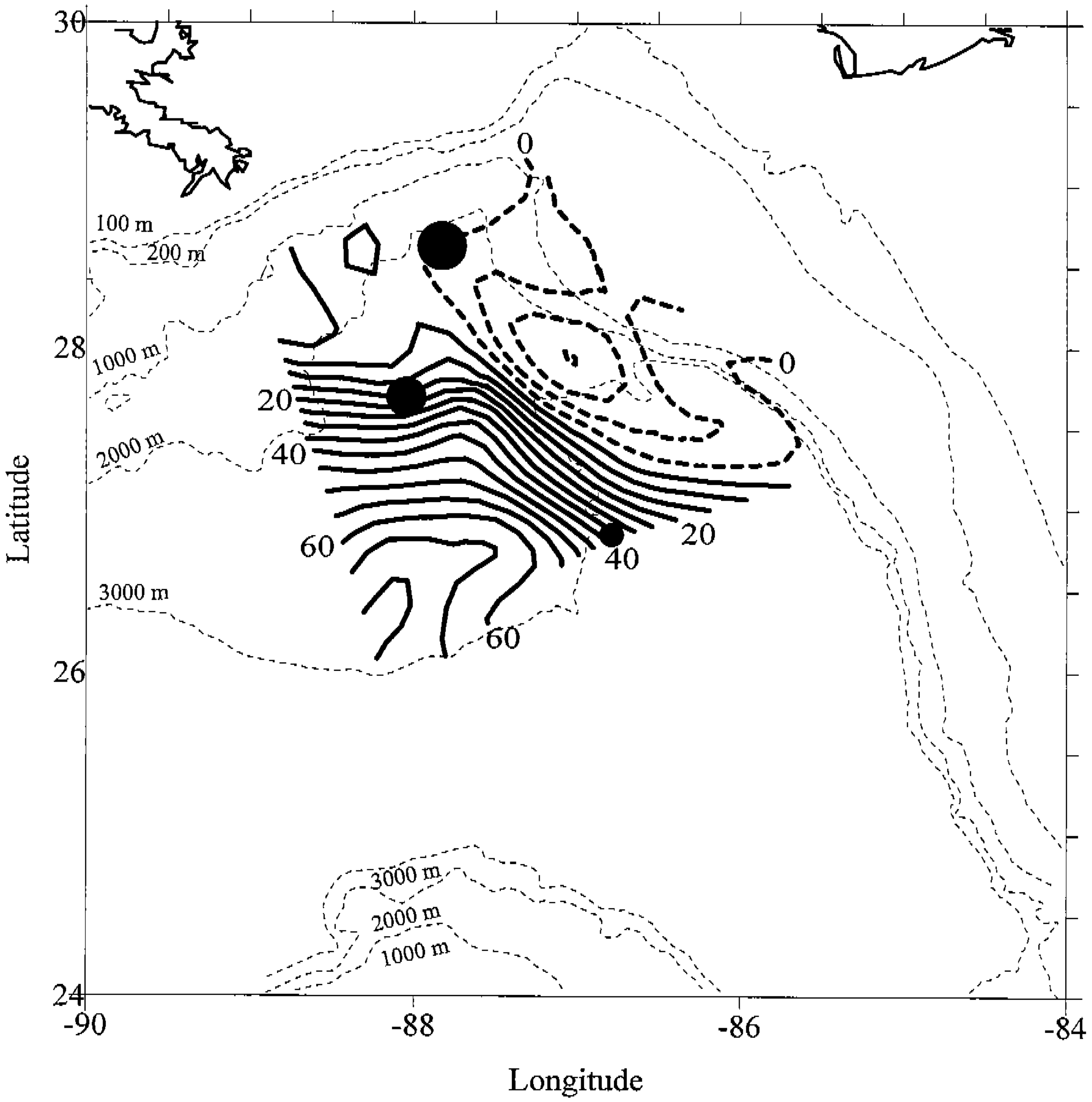


Figure 3.12. Integrated myctophid abundance (# m^{-2}) from the 15' Isaacs Kidd Midwater Trawl tows taken during mid-summer 1997. The diameter of each circle is directly proportional to its integrated abundance.

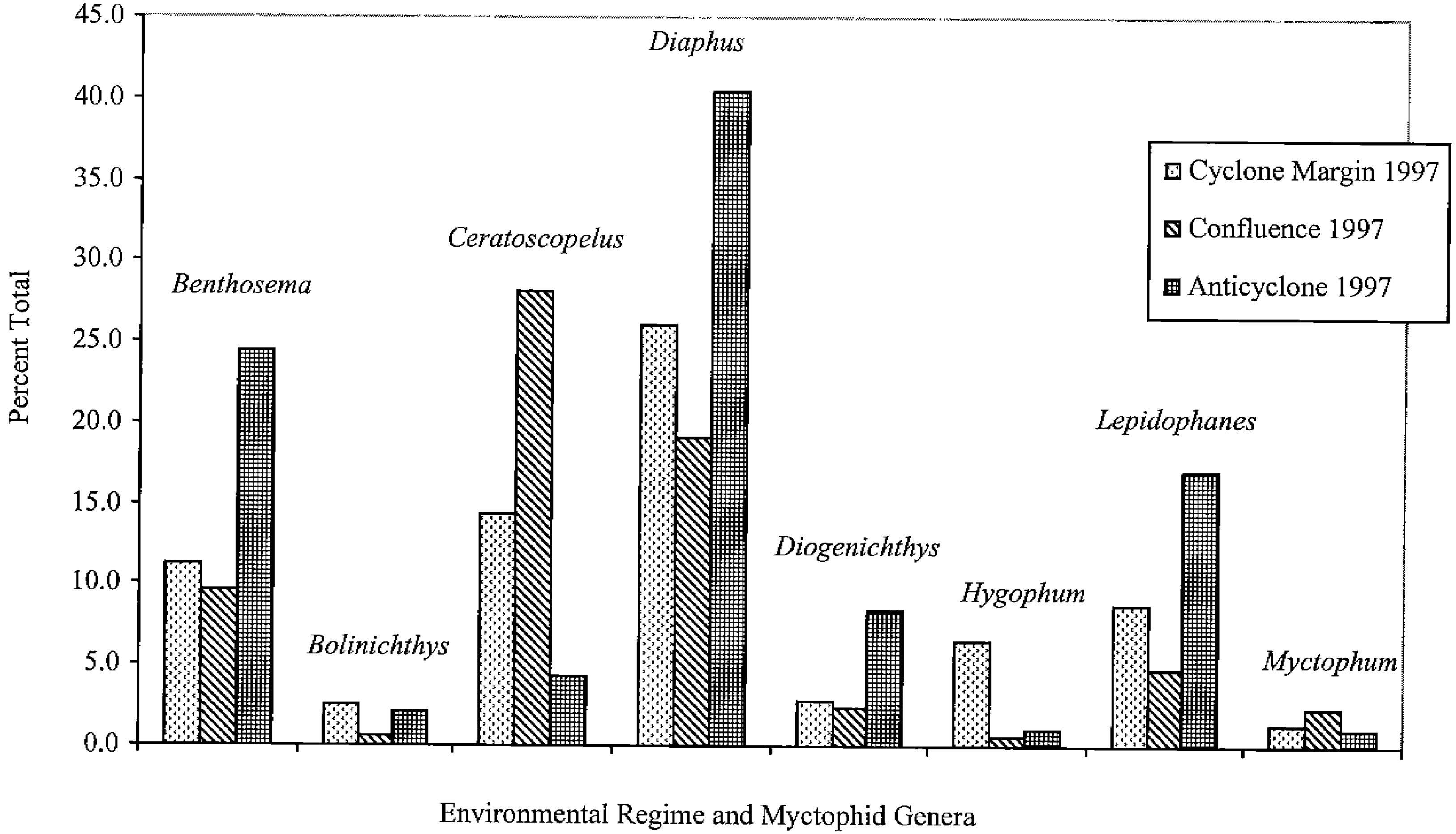


Figure 3.13. Relative abundance of common myctophid genera by percentage of total in three 15' Isaacs Kidd Midwater Trawls taken during mid-summer 1997 (data from Table 3.2).

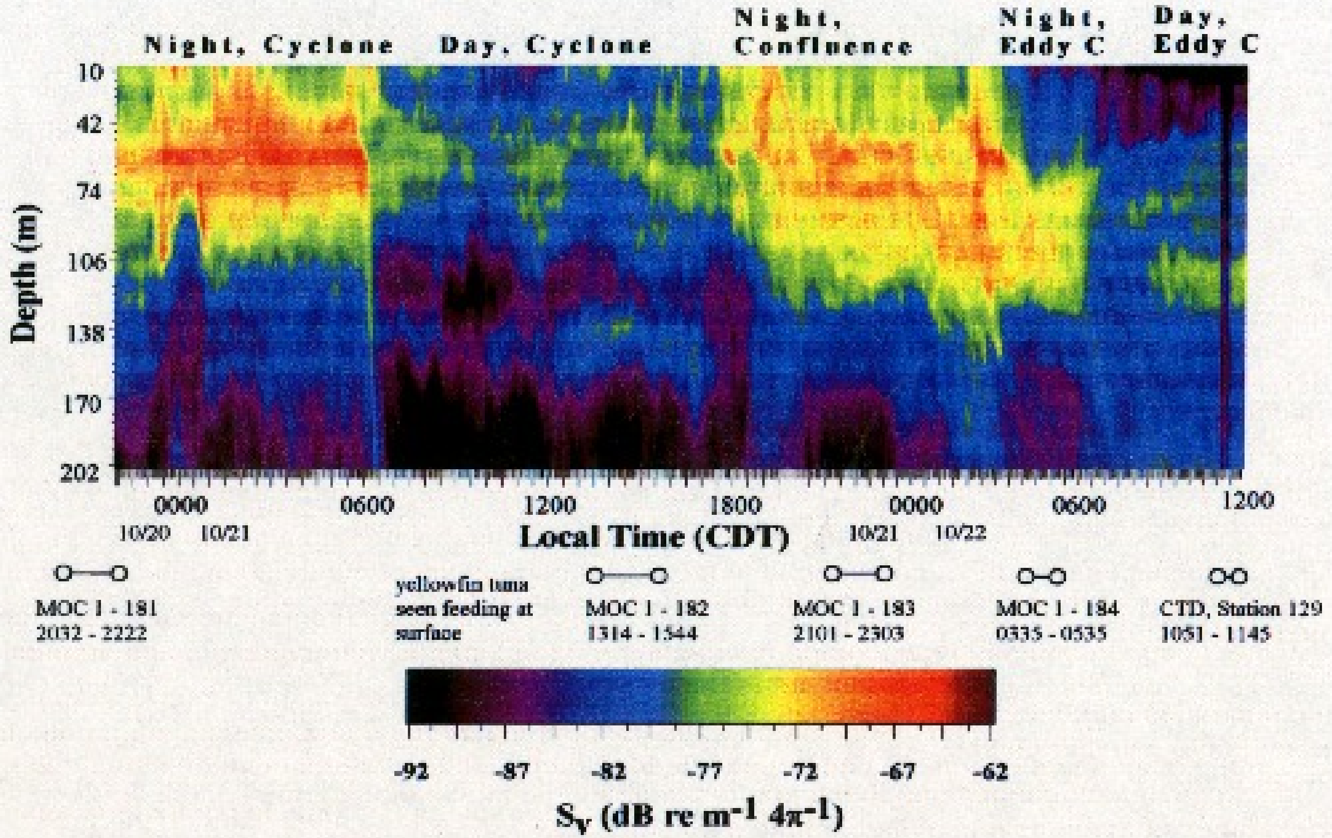


Figure 3.14. False color running plot of S_v collected along a north-south transect line from the MOM region, through the cyclone, and into Loop Current Eddy C during the late summer 1996 cruise. Depth is shown on the y-axis, while both time and location are changing along the x-axis. Periods of time corresponding to 1 m^2 MOCNESS tows and other events of interest are indicated below the x-axis. Reds and yellows on the plot indicate higher S_v, while blue and black colors indicate less intense returns. Note that both a temporal signal (higher S_v at night than in the daytime) and also a spatial signal (higher S_v in the cyclone than in the anticyclonic Eddy C) are evident.

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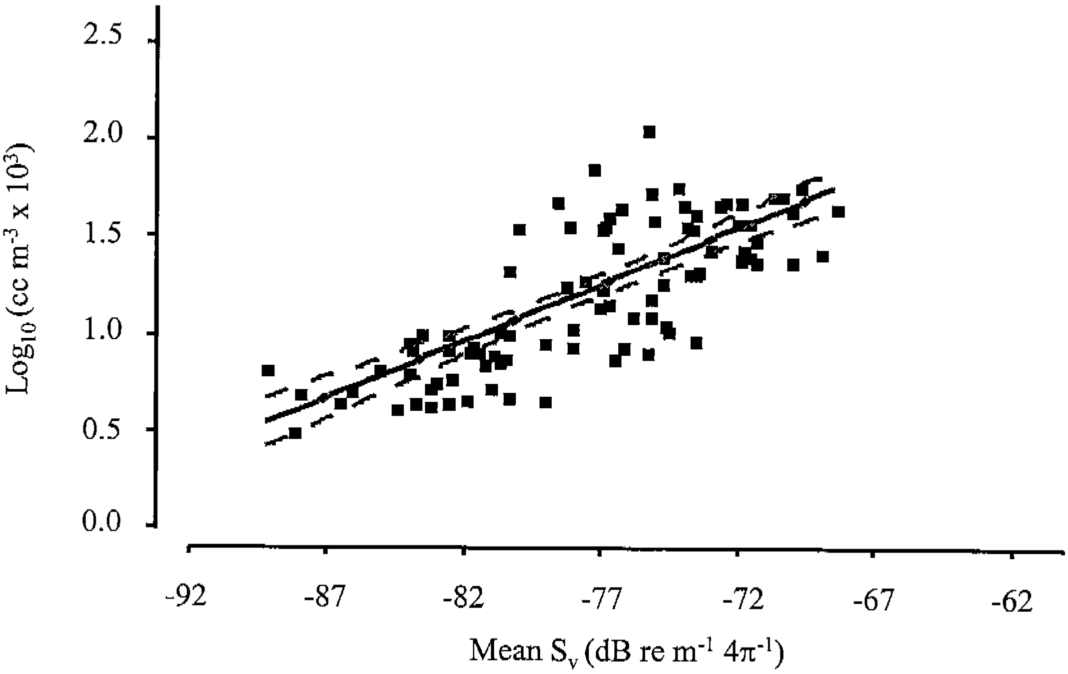

Figure 3.15. Scatterplot of the late summer 1996 MOCNESS displacement volume biomass as a function of S_V. The regression was described by the equation $y = 0.0587x + 5.7692$ ($r^2 = 0.5871$, $n = 91$). Dotted lines indicate 95% confidence bands.

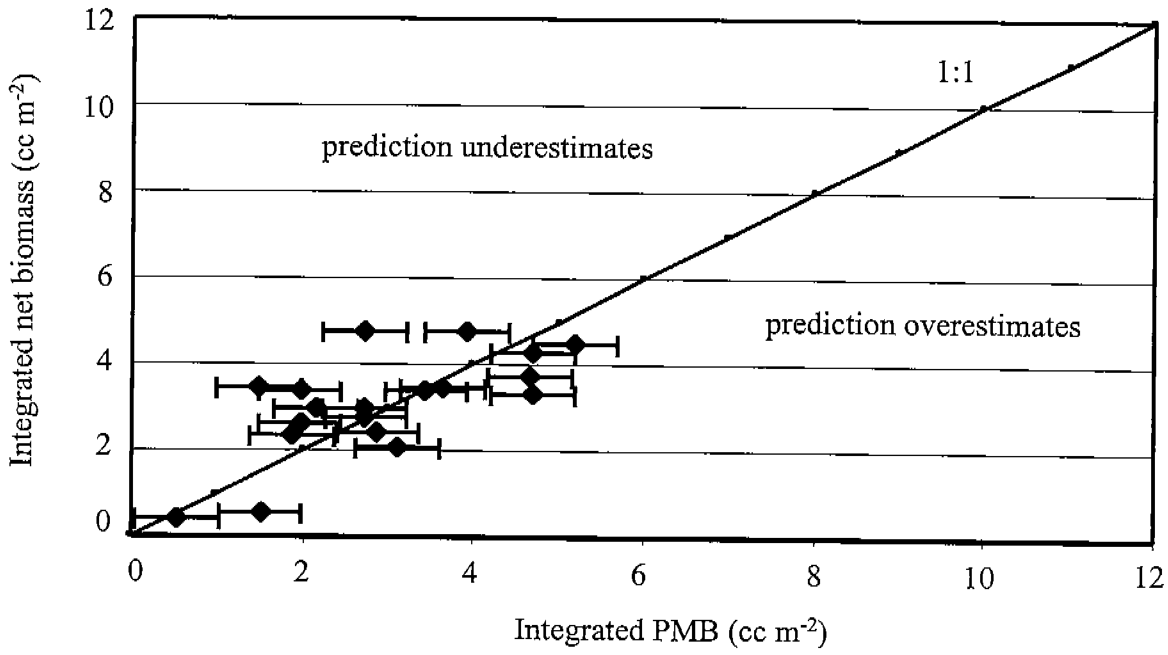

Figure 3.16. Integrated MOCNESS biomass and integrated predicted mean biomass (PMB) from late summer 1996 are compared for matching locations and depth intervals. The error bars are 95% prediction intervals.

fit (Flagg and Smith 1989; Ashjian et al. 1994). Since the model met the required statistical assumptions of normal residuals and homogeneity of variance, it was considered a valid first-order model with which to estimate the expected mean zooplankton and micronekton biomass at a given location. The predicted biomass estimate was denoted as PMB or "predicted mean biomass."

A plot of the integrated MOCNESS displacement volume as a function of integrated PMB values for the October 1996 cruise shows that the regression makes reasonable predictions of the actual biomass sampled with the net (Figure 3.16). Seven of the points have 95% prediction intervals that include the 1:1 reference line shown on the plot, and all of the other points agree within a factor of 2. There is no clear pattern of over- or under-estimation by the regression.

Diel fluctuation due to the vertical migration of zooplankton and micronekton was apparent in a line plot of PMB integrated from 10 - 50 m as a function of time: PMB was high at night and low during the day (Figure 3.17). This showed that the acoustic signal has a biological origin, but spatial patterns due to environmental differences were superimposed on this temporal pattern, making them more difficult to discern. However, when PMB was plotted as a function of the depth of the 15°C isotherm, spatial patterns became apparent (Figure 3.18). The 15°C isotherm was used as an index for hydrographic regime: A shallower 15°C depth indicated shoaling isotherms and cyclonic, upwelling conditions that could cause higher biological productivity. During day and night, areas with a relatively deep 15°C isotherm (and thus lower near-surface nutrient levels), such as the anticyclonic LC eddies, were characterized by the lowest values of PMB. Indeed, statistical testing revealed that integrated PMB varied significantly across the three hydrographic regimes. Using the operational definition for the three feature classifications based on 15°C depth given in Chapter 2 of this report, the data shown in Figure 3.18 were defined as 'cyclone', 'confluence and other margin', or 'Loop Current Eddy C'. A non-parametric analysis of variance by ranks (Kruskall-Wallis test) indicated that integrated PMB varied significantly across feature classification during day and night ($p < 0.0001$).

To better visualize the spatial patterns in the biomass predictions, PMB was gridded (using kriging) and contoured with Surfer, Version 6 (Golden Software 1997). PMB during daytime was low throughout the study area (0.2 - 1.2 cc m^{-2}) (Figure 3.19). PMB was lowest in the anticyclonic eddy C (0.2 - 0.7 cc m^{-2}) and in patches at the western and eastern edges of the cyclone; it was highest (0.7 - 1.2 cc m^{-2}) near the Mississippi delta along the continental slope, in the center of the cyclone, and throughout the confluence between the cyclone and Eddy C.

At night (Figure 3.20), PMB was higher (as high as 3.2 cc m^{-2}) than during the day due to diel vertical migration. Nevertheless, many of the same spatial patterns seen during the day were apparent at night: PMB was highest in the center of the cyclone, in areas along the continental slope and in the confluence zone. PMB was lowest in LCE-C.

3.3.4.2 August 1997

Linear regression of S_v as a function of MOCNESS displacement volume biomass was also used for the August 1997 cruise (Figure 3.21). A logarithmic transformation was applied to the MOCNESS data before the regression on S_v was performed. The residuals from this regression

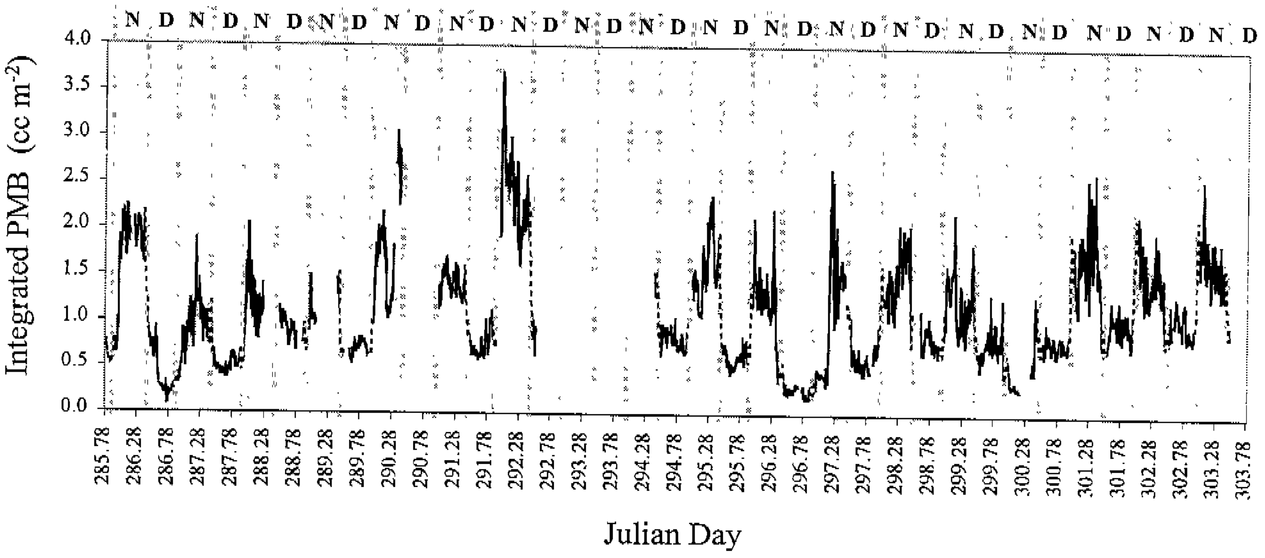

Figure 3.17. PMB for the depth interval 10 - 50 m is shown as a function of time for the late summer 1996 cruise: 1846 GMT on 11 October to 1919 GMT on 29 October [Julian days 285.78 - 303.80]. Daytime (D, white) and nighttime (N, shaded) periods are indicated on the plot. The median 95% CI was +/- 0.01.)

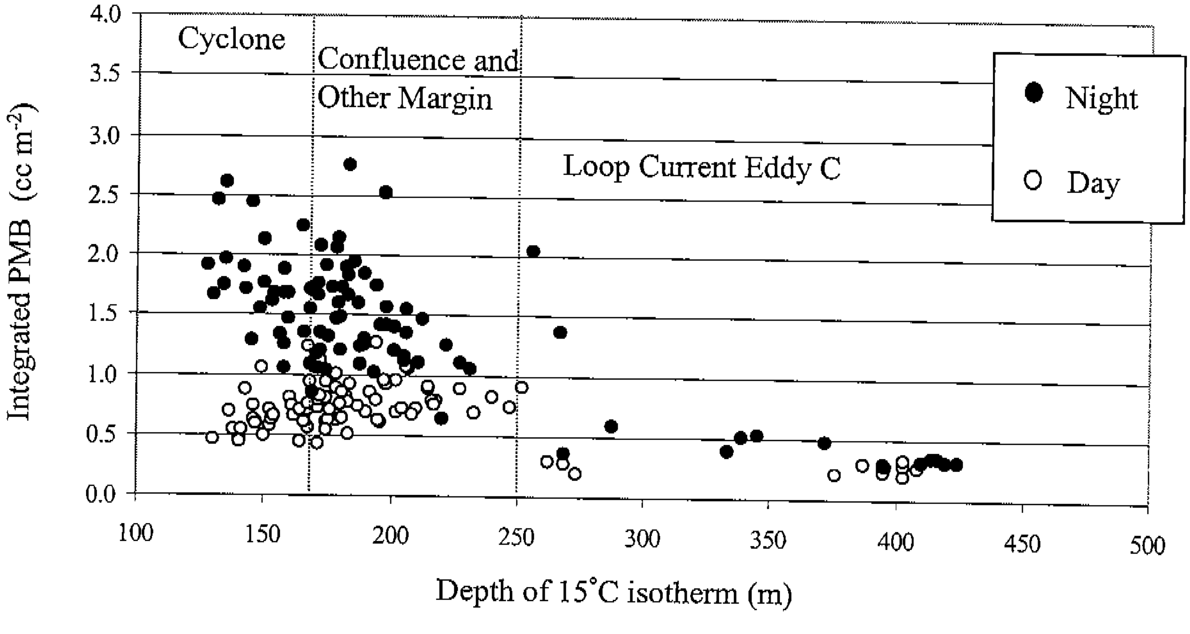

Figure 3.18. Scatterplot of PMB integrated from 10 - 50 m as a function of 15°C depth at deepwater hydrographic stations of the late summer 1996 cruise. The median 95% CI was +/- 0.01.

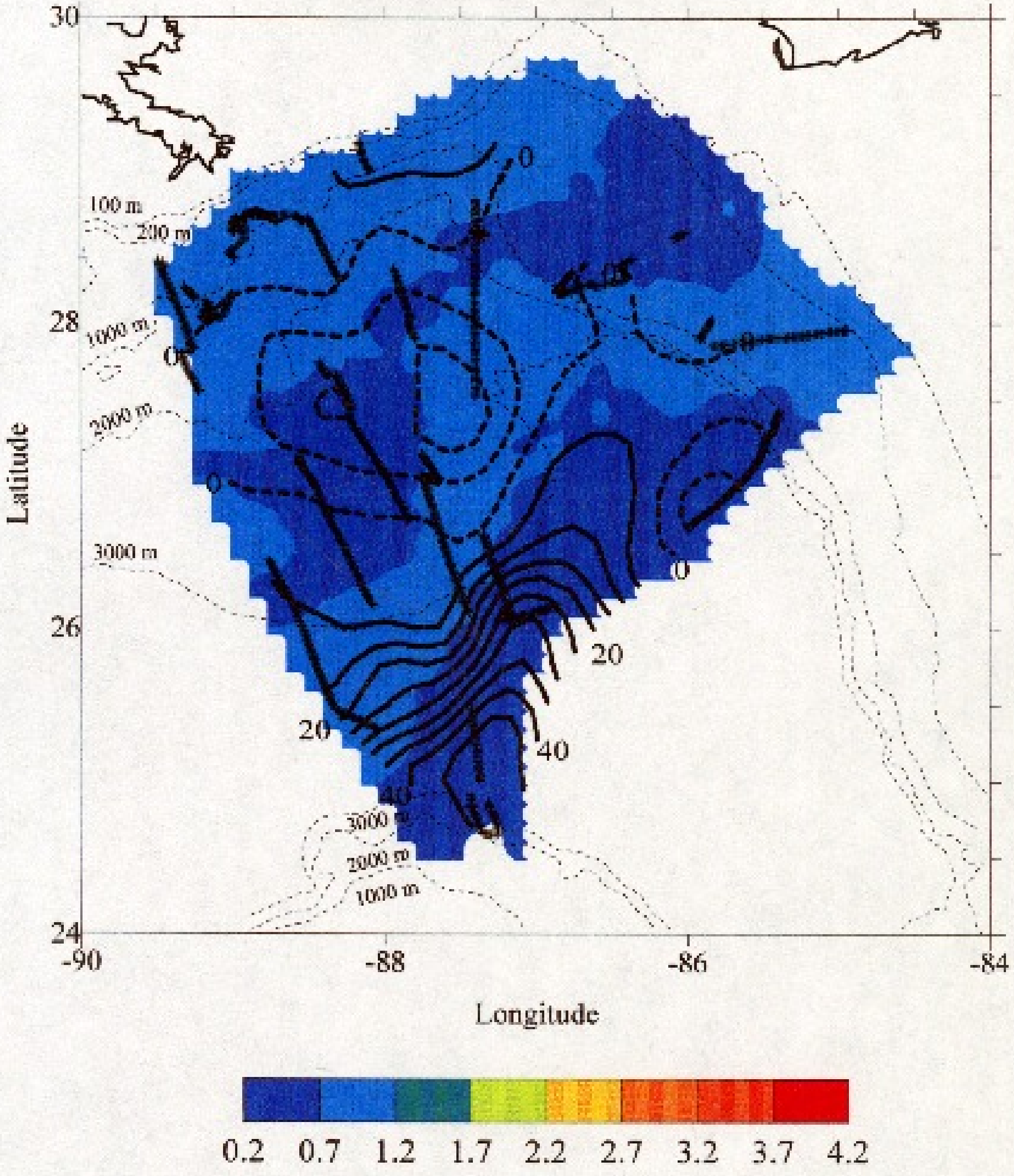

Figure 3.19. Predicted mean biomass (PMB) (cc m^{-2}) in the depth interval 10-50 m during **daytime** is shown by the color contours for the late summer 1996 cruise. The very heavy dark lines indicate the locations of the data used to generate the biomass contours. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 100 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -12 cm, the confluence between 0 and 22 cm, and the anticyclone between 25 and 50 cm.

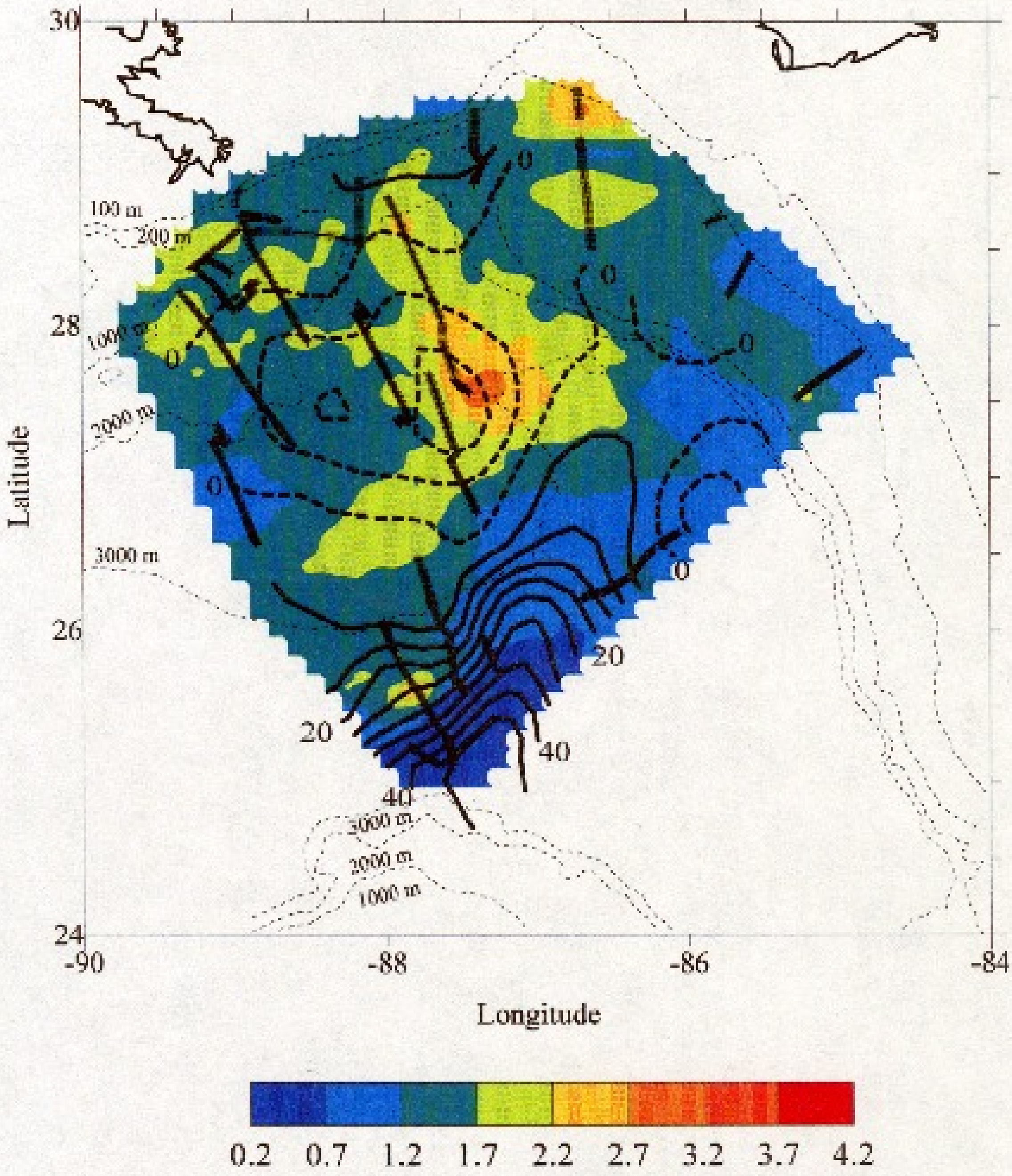

Figure 3.20. Predicted mean biomass (PMB) (cc m^{-2}) in the depth interval 10-50 m during **nighttime** is shown by the color contours for the late summer 1996 cruise. The very heavy dark lines indicate the locations of the data used to generate the biomass contours. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 100 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -12 cm, the confluence between 0 and 22 cm, and the anticyclone between 25 and 50 cm.

were tested for normality: According to the Kolmogorov D test, the null hypothesis of normally distributed residuals was narrowly retained for this cruise at the 0.01 level ($p = 0.0156$). The variance of the residuals was also checked and found to be approximately constant. As indicated by the coefficient of determination, the fit of the August 1997 model (0.3748) was not as good as that found using the data from the October 1996 cruise (0.5871), but there was still a positive trend of increasing biomass with increasing S_v. With the same caveats mentioned during the discussion of the October 1996 regression above, this simple linear model was accepted for first-order approximation of the PMB at a given location for August 1997.

A comparison of PMB and integrated MOCNESS biomass for August 1997 (Figure 3.22) shows that although the comparison appears more variable than that from October 1996, again all of the points agree within a factor of 2 or less with the 1:1 reference line. It should be noted that integrated PMB values were generally higher during August 1997 relative to October 1996, an observation confirmed by the net collections. As before, there is no definite pattern of over- or under-estimation by the regression, although there are more under-estimates here than there were on the October 1996 plot.

The diel fluctuation seen in the October 1996 data due to the vertical migration of zooplankton and micronekton is apparent in August 1997 (Figure 3.23), again showing that the acoustic signal is sensitive to the twice-daily migration of zooplankton and micronekton. When integrated PMB is plotted as a function of 15°C depth (Figure 3.24), spatial patterns are evident. PMB integrated from 10 - 50 m at deepwater hydrographic stations (as defined in Chapter 2) from August 1997 was lower when the 15°C isotherm was deep during both night and day, which is the same trend seen in October 1996. When the data were classified by hydrographic feature ('cyclone', 'confluence and other margin', and 'Loop Current Eddy E' as described for the data in Figure 3.18), statistical testing using the Kruskall-Wallis analysis of variance by ranks again indicated significant variation across these three feature types ($p < 0.0001$ and $p < 0.0002$ for day and night, respectively). Gridding and contouring of the August 1997 data showed that during the daytime, integrated PMB (Figure 3.25) ranged from 0.7 - 2.2 cc m^{-2}, and again appeared lower in the LCE (0.7 - 1.2 cc m^{-2}) than in the confluence and cyclone (1.2 - 1.7 cc m^{-2}) or the continental slope (1.2 - 2.2 cc m^{-2}). At night, as in October of the previous year, integrated PMB was greater than during the daytime (Figure 3.26). Finally, just as during daylight hours, predicted biomass at night was lowest in the center of the LCE (1.2 - 1.7 cc m^{-2}) and highest in the cyclone and confluence and along the continental shelf (1.7 - 2.7 cc m^{-2}).

3.4 Discussion

3.4.1 Zooplankton

There are obvious hydrographic and seasonal differences in integrated zooplankton biomass. These differences are statistically significant and may have important ramifications for the distribution and abundance of cetaceans and seabirds. The cyclone and confluence regions have significantly higher biomass compared to the anticyclone, regardless of season. Mid-summer values are significantly higher than late summer values, regardless of hydrographic regime.

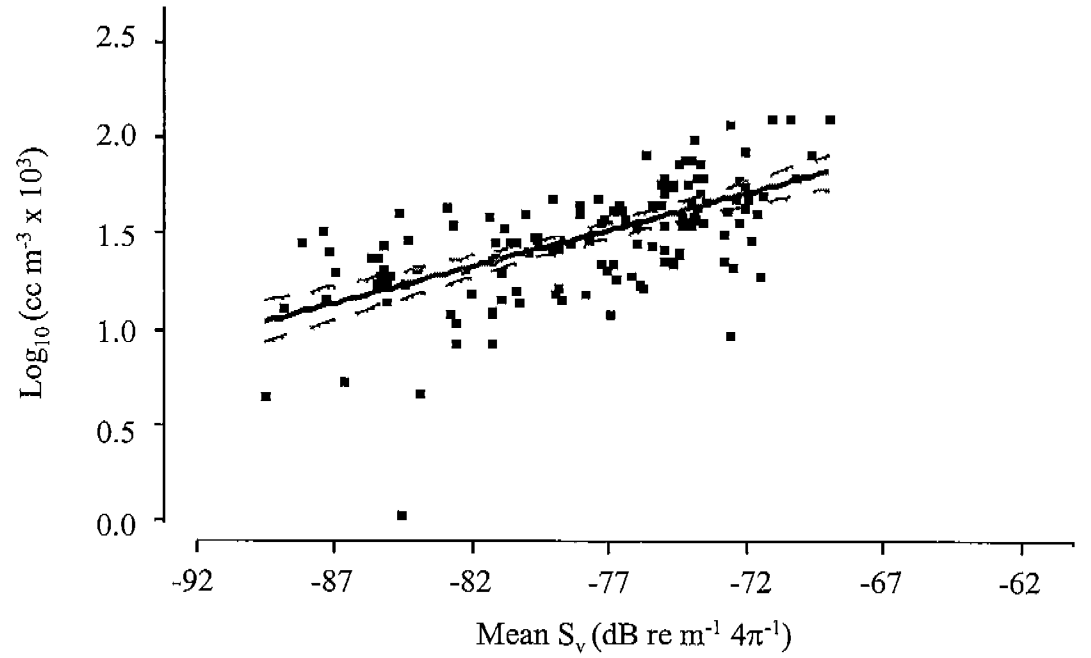

Figure 3.21. Scatterplot of the mid-summer 1997 MOCNESS displacement volume biomass as a function of S_v. The regression was described by the equation $y = 0.0386x + 4.4935$ ($r^2 = 0.3748$, $n = 134$). Dotted lines indicate 95% confidence bands.

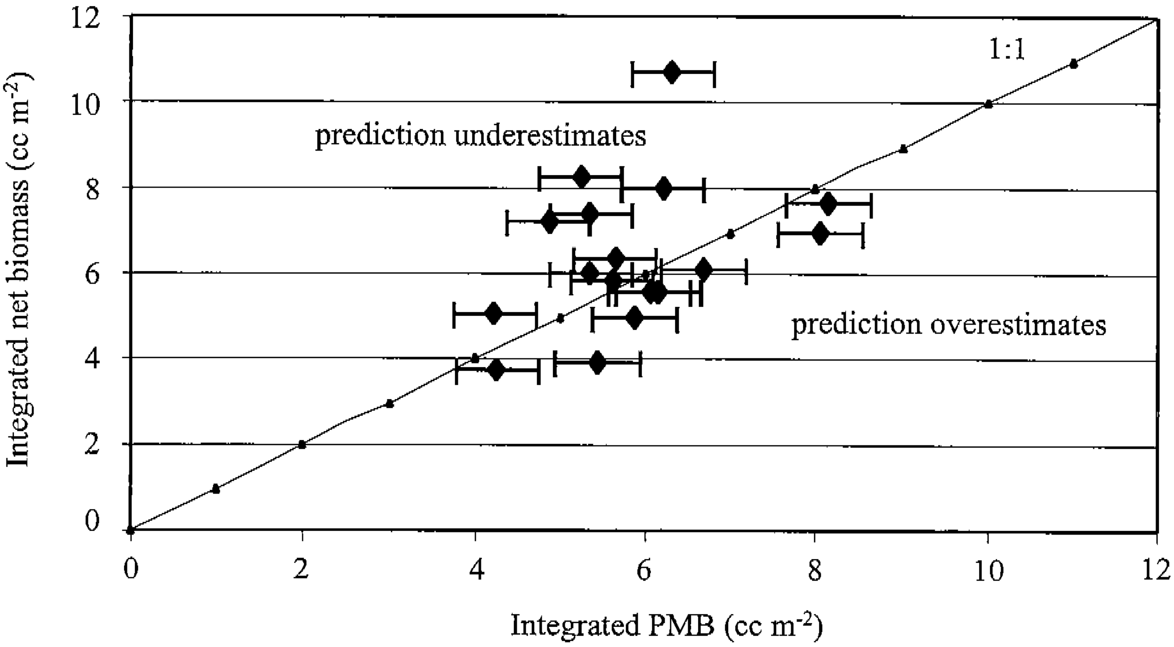

Figure 3.22. Integrated MOCNESS biomass and integrated predicted mean biomass (PMB) from mid-summer 1997 are compared for matching locations and depth intervals. The error bars are 95% prediction intervals.

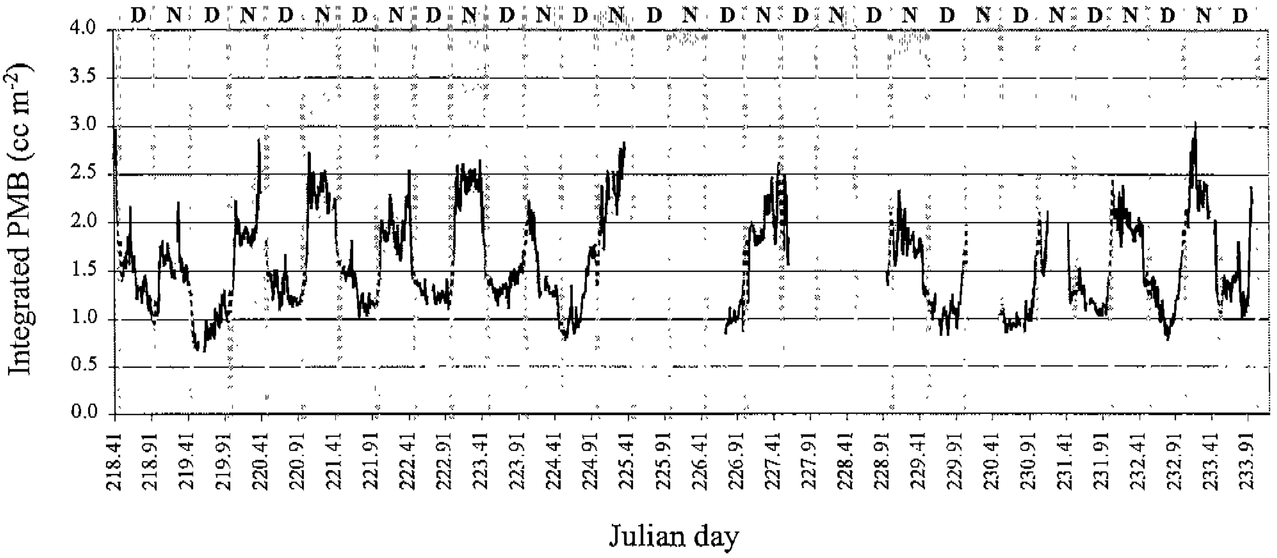

Figure 3.23. PMB for the depth interval 10-50 m is shown as a function of time for the mid-summer 1997 cruise: 0946 GMT on 6 August to 0513 GMT on 22 August [Julian days 218.41 – 234.21]. Day (D) and Night (N) periods are demarcated by the dotted lines and letters. The median 95% CI was +/- 0.02.

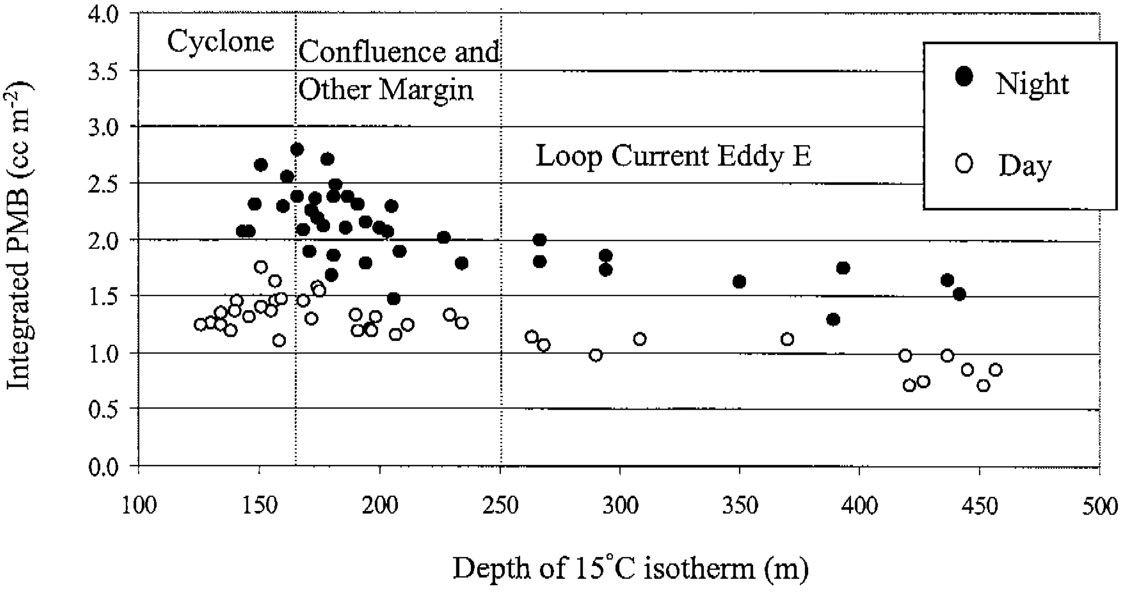

Figure 3.24. Scatterplot of PMB integrated from 10–50 m as a function of the 15°C depth at deepwater hydrographic stations during the mid-summer 1997 cruise. The median 95% CI was +/- 0.02.

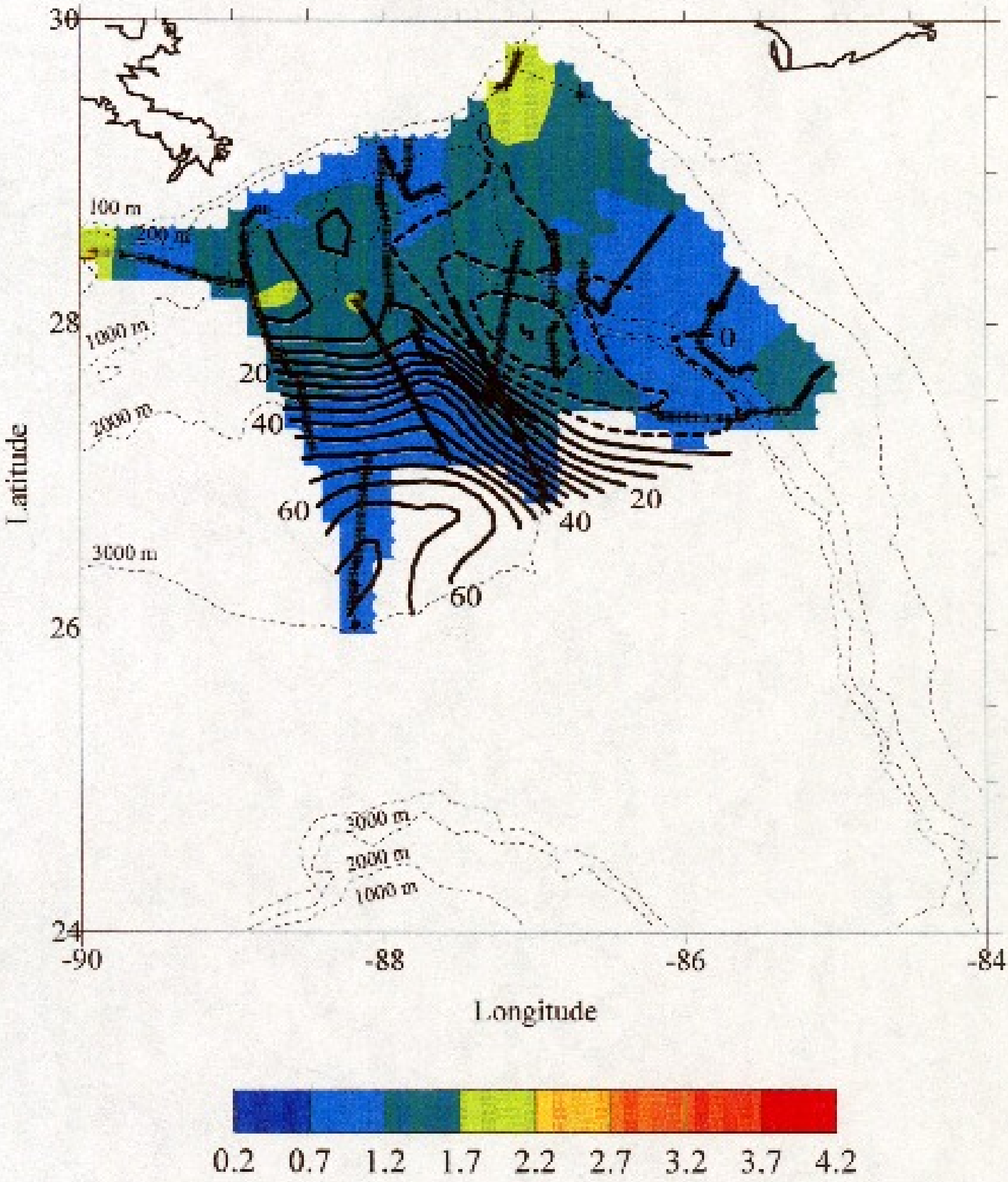

Figure 3.25. Predicted mean biomass (PMB) (cc m^{-2}) in the depth interval 10-50 m during **daytime** is shown by the color contours for the mid-summer 1997 cruise. The very heavy dark lines indicate the locations of the data used to generate the biomass contours. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 105 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -13 cm, the confluence between 0 and 24 cm, and the anticyclone between 25 and 71 cm.

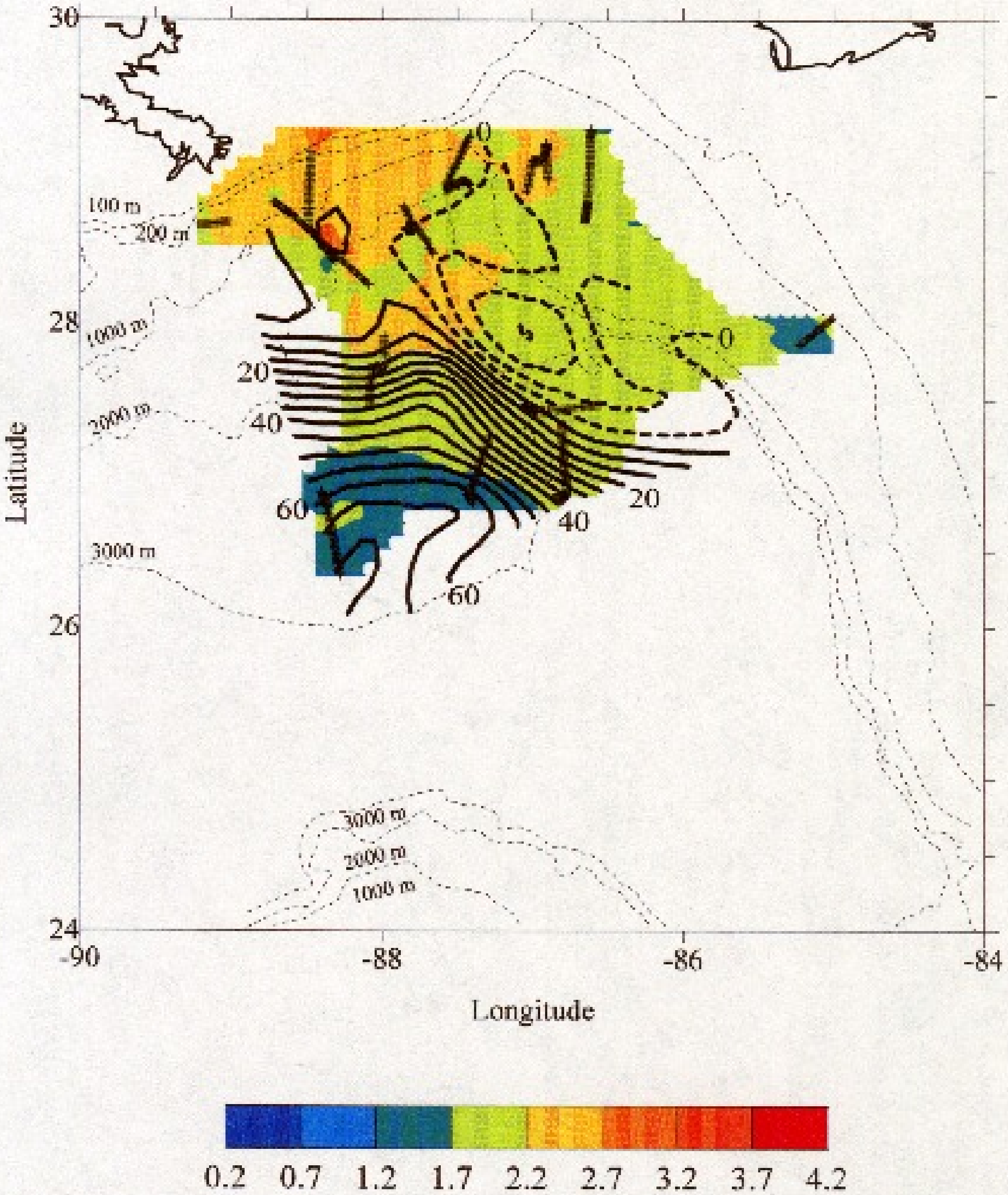

Figure 3.26. Predicted mean biomass (PMB) (cc m^{-2}) in the depth interval 10-50 m during **nighttime** is shown by the color contours for the mid-summer 1997 cruise. The very heavy dark lines indicate the locations of data used to generate the biomass contours. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 105 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -13 cm, the confluence between 0 and 24 cm, and the anticyclone between 25 and 71 cm.

3.4.2 Cephalopod Paralarvae

According to Clarke (1996), "…cephalopods form an appreciable part of the diet in all the families and in all [exclusively] marine odontocete genera…". Specifically, 28 cephalopod families are represented in the diet of cetaceans while cephalopods are the main food constituent of 28 odontocetes. Clarke also found that while the ommastrephids and cranchiids are dominantly preferred, onychoteuthids, enoploteuthids, and octopoteuthids also form a large portion of cetacean diets. All of these cephalopod families were found within GulfCet II samples. A cephalopod species composition study conducted by Passarella and Hopkins (1991) in the Eastern Gulf of Mexico (in the vicinity of 27°N, 86°W) revealed that the order Teuthoidea, specifically the families Enoploteuthidae and Cranchiidae, dominate in these waters. Results from October 1996 and August 1997 reveal similar patterns of abundance. Furthermore, the samples from GulfCet II illustrate that the paralarvae were concentrated in the upper 75 - 150 m of the water column in accordance with the vertical distributions of paralarvae as reviewed by Sweeney et al. (1992).

The most important food items for the sperm whale are squid, followed by fish (Kawakami 1980). Among squids, the numerically important families include the onychoteuthids (globally) and both the cranchiids and ommastrephids in some regions (Clarke 1996). These three families are among the five most abundant found in samples collected during this study. An extensive analysis of cephalopod remains from the stomachs of sperm whales taken in the southeastern Pacific from 1958 to 1962 showed that larger sperm whales ate larger Humbolt squid *(Dosidicus gigas)* and that in areas where larger squid were present, they were eaten preferentially to smaller ones (Clarke and Paliza, in review). Perrin et al. (1973) analyzed the stomach contents from *Stenella attenuata* and *longirostris* and found that the families Ommastrephidae, Onychoteuthidae, and Enoploteuthidae were the most important food items in both volume and number. Wolff (1982) also concluded that the family Ommastrephidae dominates in terms of number, frequency of occurrence and weight in the stomach contents of *Stenella attenuata,* while members of the families Enoploteuthidae and Cranchiidae were also listed as prey items. These families constituted three of the five most abundant families from samples collected during this study. Ashmole and Ashmole (1967) analyzed the feeding ecology of seabirds and found that the sooty tern on Christmas Island fed predominantly on Ommastrephid squid, specifically *Symplectoteuthis*. They found that the diet of the terns consisted of 62% squid and 38% fish by volume, and 40% squid and 60% fish by numbers. Furthermore, Croxall and Prince (1996) determined that seabirds (terns and petrels) fed on ommastrephids and onychoteuthids while cranchiids and enoploteuthids also formed an important part of their diets. More specifically, they found that the principal food component of petrels was the juvenile stages of cephalopods in the ommastrephid, lycoteuthid, and onychoteuthid families, all of which were collected during GulfCet II.

3.4.3 Myctophids

The patterns suggested by the limited myctophid data are that the cyclone margins appear to host the highest abundance of myctophids, with the confluences having the next highest abundance and the anticyclones having much less abundance. If these patterns are confirmed through analysis of other IKMT tows, predator species such as cetaceans would be more likely to find the visible surface fronts during the August 1997 cruise. The elevated surface chlorophyll in areas of low salinity may indicate a phytoplankton growth response to nutrient rich Mississippi River water that was drawn seaward into the confluence circulation of the cyclone and LCE-E.

A comparison of the contour maps of surface chlorophyll (see Figures 2.36 and 2.39) with those of PMB (this chapter) does not support the classic inverse relationship between the two quantities, i.e., high zooplankton biomass after phytoplankton standing stocks have been grazed down. Instead, the August 1997 data show higher standing stocks of surface chlorophyll spatially concurrent with higher standing stocks of zooplankton. Surface chlorophyll and zooplankton biomass as measured in this study may not be closely coupled; some authors have reported uncertainty and variability in the trophic interactions between zooplankton and phytoplankton in the northern Gulf of Mexico (Strom and Strom 1996). How long these conditions had existed before the cruise, or whether they persisted thereafter, is unknown. However, the October 1996 data do suggest that surface phytoplankton biomass could change on a time scale of one to two weeks. The first four deepwater transits through the cyclone-anticyclone pair encountered higher surface chlorophyll stocks (0.05 - 0.10 $\mu g\ L^{-1}$ in the cyclone), while the last transits completed one week later found no chlorophyll concentrations higher than 0.05 $\mu g\ L^{-1}$ in either feature. Whether this was caused by grazing, sinking of the surface phytoplankton bloom, or wind-induced mixing is unclear.

3.4.5 Acoustic Predicted Mean Biomass (PMB)

The acoustic sampling was intended to provide an along-track index of the zooplankton and micronekton biomass being sampled by the 1 m^2 MOCNESS. Cetaceans and birds are not likely to be feeding directly on the relatively small organisms that make up most of the biomass caught in those samples. However, larger organisms that cetaceans or birds might take as prey would depend upon the abundance of animals at these lower trophic levels for their food. Thus, just as measurements of chlorophyll concentration or primary productivity might be used to evaluate whether a habitat is rich or poor in terms of food resources that might translate up the food chain into elevated stocks of zooplankton and micronekton, the biomass of zooplankton and micronekton sampled by the MOCNESS and ADCP might be used to make inferences about the potential of an area for supporting the prey of apex predators, such as cetaceans and birds.

3.4.6 Habitat Differences

During October 1996 and August 1997, there was a pronounced diel fluctuation in integrated PMB, probably due to the vertical migration of sound-scattering organisms. Superimposed on this were spatial patterns that were most likely due to habitat variation. When the 10 - 50 m depth interval is considered, integrated PMB showed statistically significant variation across environments: It was greater in the areas of shallow 15°C depth (e.g. cyclonic features) relative to areas of deep 15°C depth (e.g. anticyclonic LC eddies) during both cruises. When the contour plots of PMB from both cruises (day or night) are considered, cyclones in the deepwater part of the study area appear richer in zooplankton and micronekton biomass relative to the anticyclonic LCEs. Encouragingly, direct net sampling with the 1 m^2 MOCNESS showed a similar pattern across these environments (Figure 3.1 - 3.2, 3.5). Both lines of evidence lend support to the hypothesis that cyclonic circulation features in the Gulf of Mexico might be areas of locally high zooplankton stocks, due to increased primary production in the mixed layer supported by the doming of nutrient rich water within them (Biggs et al. 1988). If nutrient-rich midwater is indeed being supplied to the surface and allowing increases in phytoplankton stocks, then zooplankton, fish, and cephalopods may become more abundant as these features persist, thus providing greater food resources to attract higher-trophic level predators, such as cetaceans and seabirds.

As mentioned in the comparison of the two cruises at the beginning of this section, there was an important difference in the pattern of zooplankton and micronekton biomass between cruises. Both the net and the acoustic sampling demonstrated that the zooplankton and micronekton biomass was generally higher during August 1997 relative to October 1996, suggesting a difference in the biological processes in the survey area between cruises. This difference could simply be due to interannual variability in zooplankton stocks, or, it could reflect seasonal changes in the zooplankton community. As previously stated, there were environmental differences between years: August 1997 was characterized by the presence of fresher, higher chlorophyll surface water relative to October 1996, which may have indicated the presence of greater nutrient supply and phytoplankton production. Nevertheless, without knowing how long those conditions existed before the cruise, only speculation is possible regarding whether this might have supported a greater abundance of zooplankton.

3.5 Conclusions

Both integrated zooplankton biomass and integrated cephalopod paralarvae numbers in the study area showed higher values in the cyclone and confluence as opposed to the anticyclonic Loop Current Eddy during both October 1996 and August 1997. PMB estimates, derived from the significant positive relationship between integrated zooplankton biomass (as determined by direct net sampling and underway measurements of S_v using an ADCP), also show that the cyclone and confluence areas were enriched in integrated zooplankton and micronekton biomass relative to the anticyclonic Loop Current Eddies. Further, a statistically significant relationship existed between integrated zooplankton biomass and integrated cephalopod paralarvae (a major component of cetacean prey) numbers, implying that higher zooplankton and micronekton biomass do indicate richer concentrations of cetacean prey. Finally, the abundance and diversity of myctophids, a second important cetacean prey group, appear to be greater in the cyclones and confluence regions than in the anticyclones. All of these measures suggest that the amount of prey for cetaceans and seabirds may be consistently greater in the cyclone and confluence regimes (as opposed to anticyclonic Loop Current Eddies), making these preferential habitats for foraging.

These observations support the analysis of cetacean distribution for both cruises (see Chapter 6), which concluded that the presence of cetacean species or groups is correlated with the locations of these mesoscale hydrographic features. The means by which predatory marine mammals track these food-enriched hydrographic features as they move remains a topic for further investigation. In addition, the analysis in Chapter 8 showed that the distribution of predatory seabirds was influenced by mesoscale hydrography. Presumably, the birds were similarly responding to prey abundance: The derived PMB estimates described in this chapter were found to be among the best predictors of seabird distribution in the study area.

The analysis of the net sampling and acoustic data collected on these cruises is continuing. Further investigation of the abundance and distribution of cetacean prey items is needed, and future field experiments should improve the sampling coverage in the different mesoscale hydrographic environments that exist in the study area. Low catch numbers of some prey items, such as cephalopod paralarvae, suggest that larger volume net tows are preferable. However, since sorting time is positively correlated to the amount of zooplankton biomass caught, microscope and analysis time would increase. Acoustic sampling can be used to cover a much larger area than that covered by net sampling and with a much lower level of effort, but net sampling is a necessary complement in order to identify specific prey items and to evaluate the potential influence of zooplankton and micronekton taxonomic composition on S_v measurements.

Chapter 4

Visual Surveys of Cetaceans and Sea Turtles from Aircraft and Ships

Keith D. Mullin and Wayne Hoggard

4.1 Introduction

Visual surveys conducted from ships and aircraft during GulfCet I provided information to the MMS on seasonal abundance and distribution of cetaceans and sea turtles in continental shelf and slope waters (100-2,000 m) of the north-central and northwestern Gulf of Mexico (Hansen et al. 1996). Nineteen species of cetaceans were identified in the GulfCet I study area. Pantropical spotted dolphins, bottlenose dolphins, striped dolphins, melon-headed whales, clymene dolphins and Atlantic spotted dolphins were all estimated to have minimum populations of more than 1,000 individuals, and all were widely distributed in the GulfCet I study area (Figure 1.2), albeit in different water depth ranges. While less abundant, sperm whales were thought to be ecologically important because of their large food requirements (Mullin and Hansen, in press). Seasonal aerial surveys indicated that the abundance of some species, such as Risso's dolphins, dwarf/pygmy sperm whales and pantropical spotted dolphins, might vary seasonally. The leatherback sea turtle was the most common sea turtle, and it occurred in similar numbers throughout the year. Loggerhead and Kemp's ridley sea turtles were also sighted in the GulfCet I study area.

Because similar seasonal information on cetaceans and sea turtles was lacking for the continental shelf and slope in the northeastern Gulf of Mexico, aerial and ship surveys were initiated under the GulfCet II Program to complement those of GulfCet I. Abundance surveys in the northeastern Gulf of Mexico focused on continental slope waters with bottom depths of 100-2,000 m and a portion of the continental shelf (waters <100 m). The continental shelf encompassed a portion of the MMS Eastern Planning Area (EPA), including the region known as Destin Dome, as specified by the MMS. Aerial surveys were designed to cover both the warm and cold oceanographic seasons and were conducted during summer 1996 and 1997, and winter 1997 and 1998 (Table 1.4). Ship-based abundance and distribution surveys were conducted in the northeastern Gulf during the spring and early summer 1996 and 1997, late summer 1996, and mid-summer 1997. In the spring, ship surveys were also conducted in oceanic waters of the entire U.S. Gulf of Mexico (waters >100 m deep) that overlapped the GulfCet I study area. Seasons for both ship and aerial surveys were defined oceanographically as follows: summer, June - October; fall, November - December; winter, January - mid-March; and spring, mid-March - May. Surveys were not conducted in the fall. The primary objectives of the GulfCet II visual aerial and ship surveys were as follows:

(1) obtain a minimum abundance estimate for each cetacean and sea turtle species in the northeastern Gulf to establish a baseline for monitoring trends in abundance over time

(2) study the seasonal abundance and distribution patterns of cetacean and sea turtle species in the northeastern Gulf

(3) compare spring abundance estimates of cetacean species in continental slope waters of the north-central and northwestern Gulf (GulfCet I study area) to those made by Hansen et al. (1996) for the same area from 1991-94 data

(4) compare ship-based spring abundance estimates of cetacean species in the oceanic northern Gulf to those made by Hansen et al. (1995) for the same area from 1991-94 data

4.2 Study Areas

The four GulfCet II visual sampling study areas were as follows (area in parentheses):

(1) *EPA Continental Shelf (12,326 km^2).* Located in the northeastern Gulf south of the western Florida Panhandle in waters from 18.5 km offshore to 100 m deep between 88°10.0'W and 85°55.0'W. This area was surveyed using both aircraft and ships (Figures 4.1-4.3).

(2) *EPA Continental Slope (70,470 km^2).* Waters from 100-2,000 m deep east of 88°10.0'W and north of 26°00.0'N. This area was surveyed using both aircraft and ships (Figures 4.1-4.3).

(3) *GulfCet I Study Area (154,621 km^2).* U.S. waters from 100-2,000 m deep west of 87°30.0'W (Figure 4.4). This area is a subset of the oceanic northern Gulf study area and was surveyed during spring with a ship.

(4) *Oceanic Northern Gulf of Mexico (398,960 km^2).* Waters within the U.S. Economic Exclusive Zone (EEZ) greater than 100 m deep (Figure 4.4). This area was surveyed using a ship during spring.

Both the EPA slope and GulfCet I study areas are within the boundaries of the oceanic northern Gulf study area.

4.3 Methods

4.3.1 Data Acquisition

For all ship surveys, two teams of three observers collected line-transect data during daylight hours, weather permitting (i.e., no rain, Beaufort sea state < 4). Observers used standard ship survey data collection methods for cetaceans that were similar to those used during GulfCet I (Buckland et al. 1993, Hansen et al. 1996). Each team had at least two members experienced in shipboard cetacean observation and identification techniques. Two observers searched for cetaceans using 25x binoculars mounted on the ship's flying bridge. The third observer maintained a search of the area near the ship using unaided eye or 7x hand-held binoculars, and recorded data. The observers rotated through each of these three stations every 30-40 minutes, and each team alternated two-hour watches throughout daylight. The ship speed was usually 18 km/hr but varied with sea conditions. Data were recorded on a computer with a global positioning system (GPS) using a data acquisition program. Data collected included species, group-size, bearing and reticle

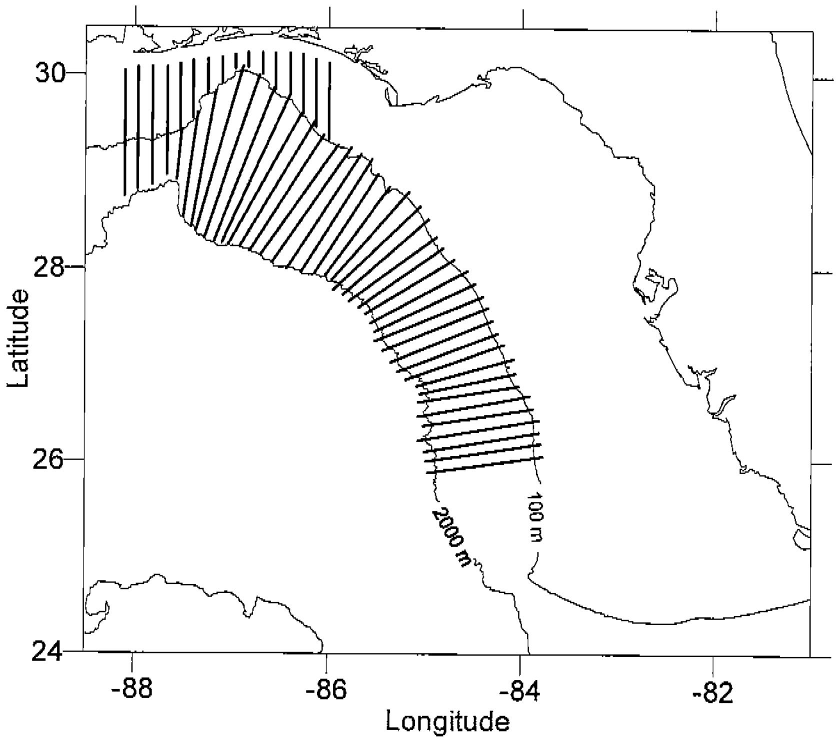

Figure 4.1. Aerial survey transect lines in the Eastern Planning Area (EPA) study areas (EPA Shelf, <100 m; EPA Slope, 100-2,000 m).

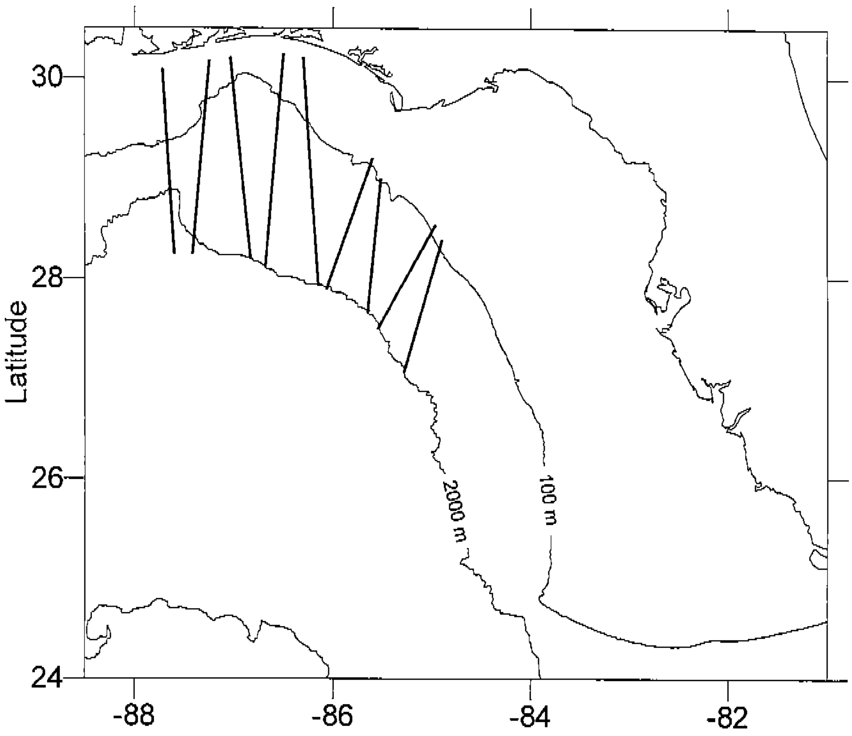

Figure 4.2. Transect lines in the Eastern Planning Area surveyed from NOAA Ship *Oregon II* during early summer 1996 and 1997 (EPA Shelf, <100 m; EPA Slope, 100-2,000 m).

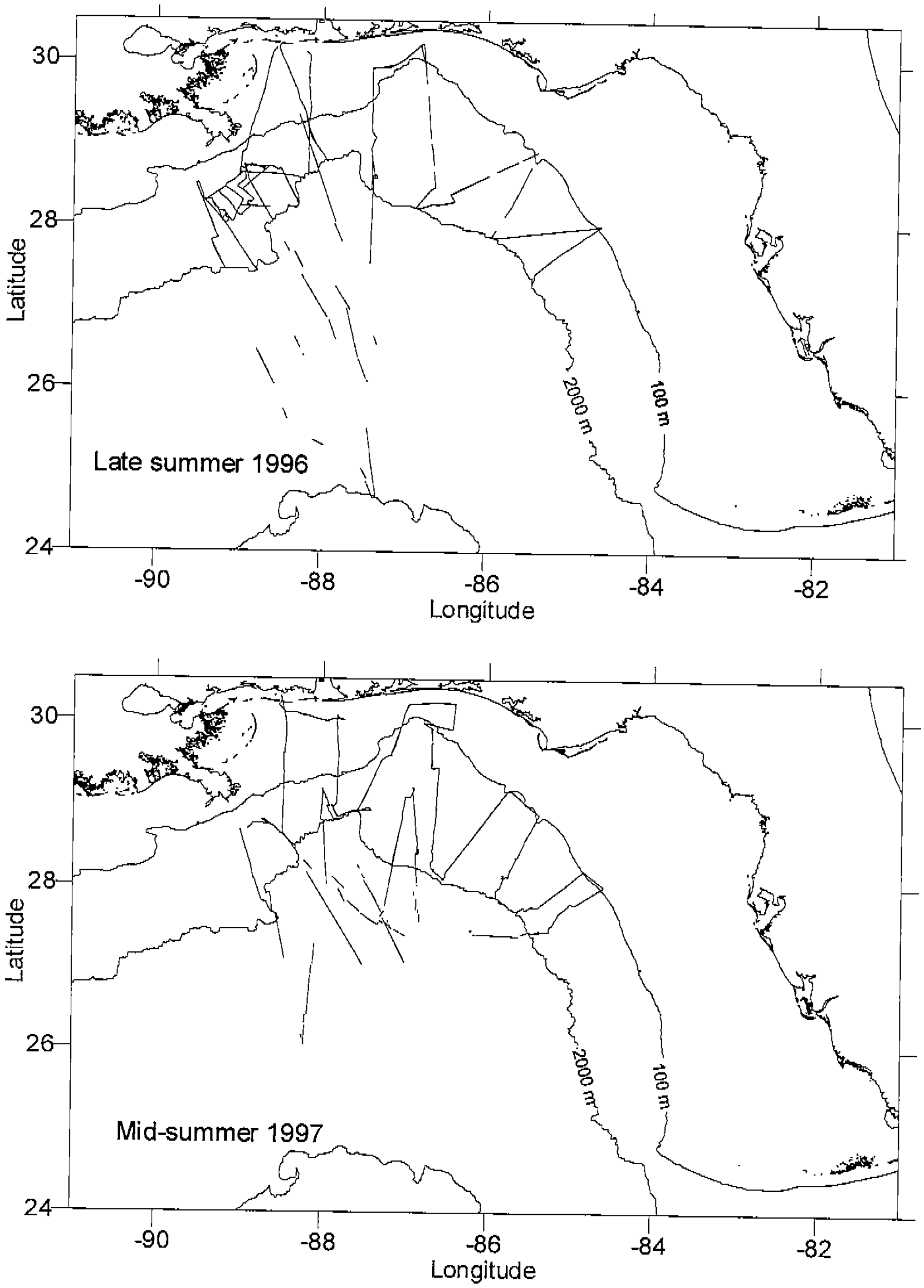

Figure 4.3. Cruise track of R/V *Gyre* during late summer 1996 and mid-summer 1997. (East of 88.0° W : EPA Shelf, <100m; EPA Slope, 100-2,000 m).

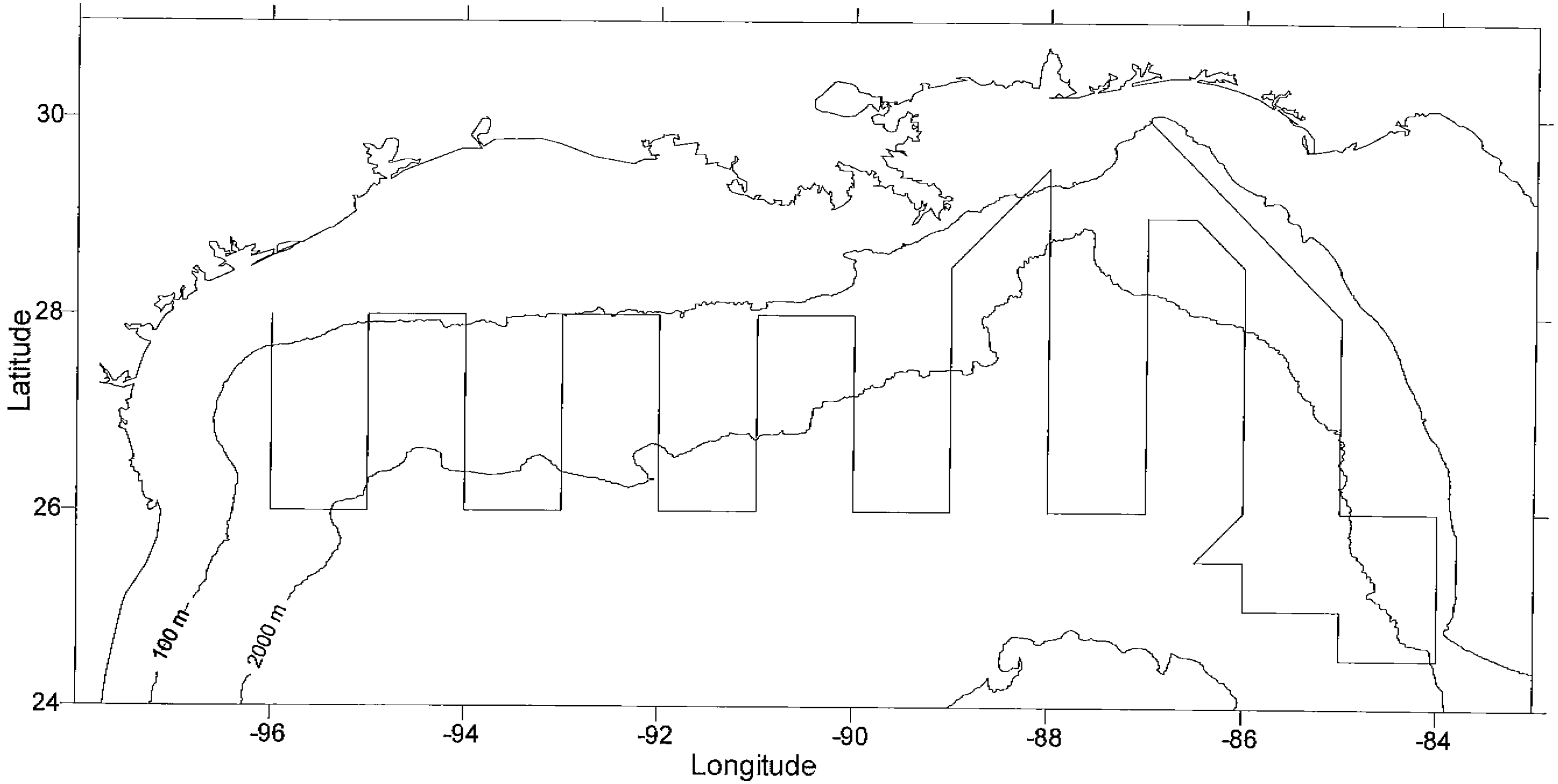

Figure 4.4. NOAA Ship *Oregon II* ichthyoplankton/marine mammal cruise track in the northern U.S. Gulf of Mexico (oceanic northern Gulf study area) surveyed during spring 1996 and 1997. This track was transited 24 hours a day with line-transect surveys occurring during daylight. The GulfCet I study area extends from the 100 to 2,000 m isobath and west of 87.5° W and north of 26.0° N.

(a measure of radial distance) of a sighting (Figure 4.5), and data on environmental conditions (e.g., Beaufort sea state, sun position, etc.) that could affect the observers' ability to sight animals. The reticle relative to a sighting was measured using an eyepiece with a graduated scale in the binoculars. The bearing of a sighting relative to the transect line was measured using a 360° graduated scale attached to the base of the binoculars. Ancillary data were also collected and included, but were not limited to, time of day, latitude and longitude, behavior, and associated animals. Typically, the ship was diverted from the transect line to identify species and obtain group-size estimates. For each sighting, the final group-size estimate was the average of the independent estimates made by individual observers.

As required by Marine Mammal Research Permits Numbers 738 and 779-1339 issued to the Southeast Fisheries Science Center (SEFSC) under Marine Mammal Protection Act, data on the behavioral responses of cetaceans to the survey ships or aircraft were recorded. A complete set of these responses can be obtained from the SEFSC Pascagoula Laboratory.

During both the ship and aerial surveys, cetaceans and sea turtles were identified to the lowest taxonomic level possible based on descriptions in field guides and scientific literature (e.g., Leatherwood and Reeves 1983, Carwardine 1995). The ability to make an identification was dependent upon water clarity, sea state and animal behavior. Identifications to species level were not always possible for some genera or groups of species. For example, dwarf and pygmy sperm whales could not be distinguished from each other from aircraft and could not be reliably distinguished from each other from ships, and were identified as dwarf/pygmy sperm whales. In some cases, cetaceans could only be identified as large whales (>7 m long), small whales (non-dolphin, <7 m), dolphins, odontocetes, and turtles as unidentified chelonids.

4.3.2 Survey Design

In spring and early summer 1996 and 1997, ship surveys were conducted in three "legs" each year. The survey platform was the NOAA Ship *Oregon II,* which has been used extensively since 1990 for cetacean surveys in the Gulf of Mexico (Hansen et al. 1995, Hansen et al. 1996).

Each year during spring, Legs 1 and 2 (19-21 days duration each) were conducted in conjunction with SEFSC bluefin tuna ichthyoplankton sampling (performed by a separate team of scientists). Ichthyoplankton sampling was conducted along a predetermined trackline at stations uniformly spaced throughout the oceanic northern Gulf (Figure 4.4). This trackline was transited 24-hours a day. Line-transect sampling was conducted while traveling between stations during daylight and was latitudinal or longitudinal, or a combination of both.

For this study, Leg 3 (13-14 days duration) was a dedicated cetacean survey of the EPA shelf and slope study areas during early summer. The EPA trackline was designed specifically for visual sampling of cetaceans along transect lines nearly perpendicular to the depth gradient. Surveys were conducted along nine transect lines that totaled 1,736 km each year (Figure 4.2). The five western transect lines extended from 18.5 km offshore of the mainland to the 2,000 m isobath. The four eastern transect lines extended from the 100-2,000 m isobaths. The survey stopped at night and resumed the following morning at about the same location so that all or most of each line was visually surveyed.

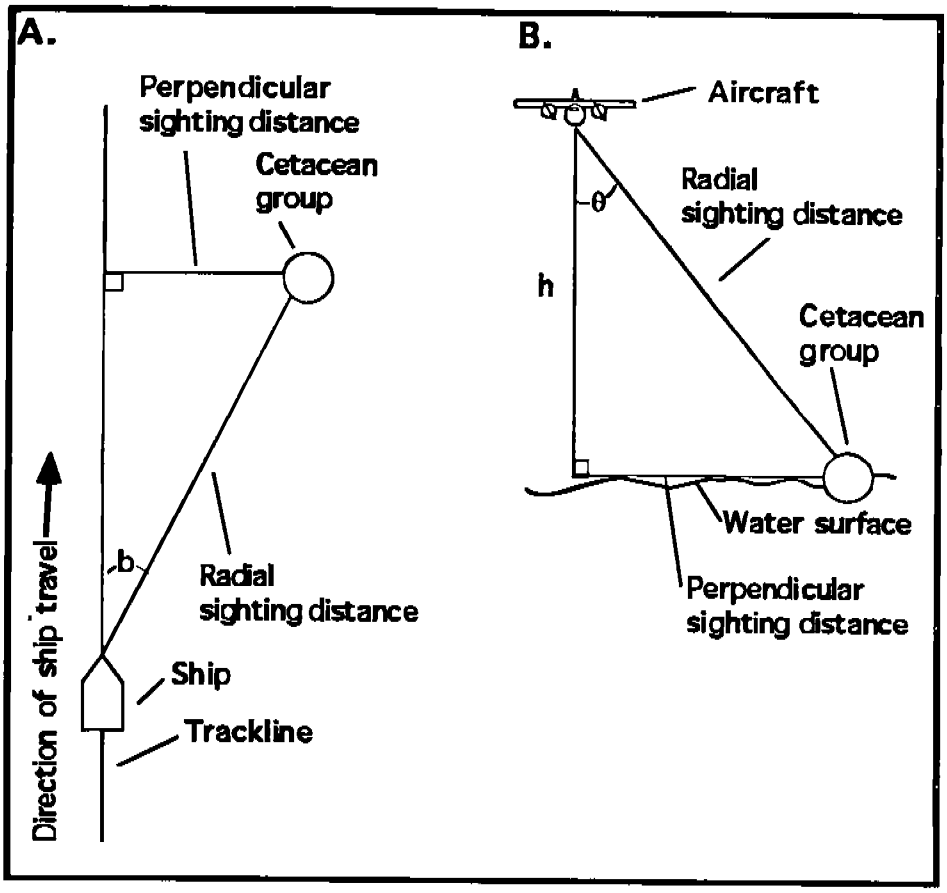

Figure 4.5 Diagram of perpendicular sighting distance (PSD) and other sighting parameters for shipboard (A) and aerial (B) surveys (b and θ = angle between trackline and cetacean group, h = altitude).

The R/V *Gyre* was used to conduct surveys in late summer 1996 (*Gyre*96G06) and mid-summer 1997 (*Gyre*97G08). Three areas were surveyed: the EPA shelf, the EPA slope, and a deepwater focal area in the north-central Gulf (Figure 4.3). The focal area was chosen based on oceanographic considerations (see Chapter 2). The surveys were conducted in two legs. The focal area was sampled by five (1996) and seven (1997) tracklines oriented NW-SE, south of Louisiana and Mississippi (from 28°30.0'N, 89°00.0'W to 25°00.0'N, 88°00.0'W). These tracklines resulted in tangential, as well as radial sections through the cyclone-anticyclone pair and the area of flow confluence between them. The EPA trackline (Fig. 4.3) was made up of eight transect lines. The northern ends of the four western EPA lines each ran from 18.5 km offshore to the 2,000 m isobath. The four eastern lines began at the 100 m isobath and ended at the 2,000 m isobath. Transect lines were generally oriented perpendicular to bathymetry. In general, the trackline was transited 24-hours per day to accommodate acoustic sampling. Line-transect visual sampling was conducted while traveling during daylight hours.

The GulfCet II aerial surveys were a continuation of aerial surveys reported by Hansen et al. (1996) from GulfCet I. Seasonal sampling intensity in the EPA shelf and slope study areas was similar to that expended during GulfCet I. Systematic transects with a random start that generally crossed isobaths orthogonally were uniformly spaced throughout the aerial survey area (Figure 4.1). This design ensured that transects were randomly situated with respect to cetacean density and allowed examination of cetacean distribution throughout the study area. Each season the goal was to survey 58 transect lines (spaced every 13.5 km) totaling 6,133 km of transect effort. They included 42 transect lines (total of 5,220 km) on the continental slope (waters 100-2,000 m deep) and 16 transect lines (total 913 km) on the continental shelf (waters <100 m deep). Aerial surveys were conducted during summer 1996 and 1997, and winter 1997 and 1998. As in GulfCet I, effort was based on projected availability of acceptable survey conditions and flight times to the study area.

A DeHavilland DHC-6 Twin-Otter with large, convex "bubble" windows on each side of the fuselage was used as the survey platform. The bubble window provided observers an unobstructed view of the transect line. A period of 45 days and about 100 flight hours were allocated for each seasonal survey. Survey flights were conducted only on days with good visibility (i.e., no rain or fog) when there were no or few whitecaps (Beaufort sea state 0-4). Survey flights typically began at 0800 hours and lasted 6.5 hours. Surveys were conducted from an altitude of 229 m (750 feet) at a speed of 204 km/hour (110 knots). A pilot, co-pilot and four observers participated in each flight. At least two observers on each flight were trained and experienced in marine mammal aerial survey techniques. The observers were stationed at each of the two bubble windows and at a computer (data entry) station. Observers searched waters primarily on and near the transect line and scanned periodically out to the horizon. Only sightings made from the bubble windows were used in the abundance estimates. To avoid fatigue, observers rotated through stations about every 30 minutes. Pilots and observers communicated through headsets with voice-activated microphones. Data were entered on a computer interfaced with a GPS/LORAN-C navigation receiver using a data acquisition program. Sighting data included species, group-size, and sighting angle or interval (for estimating perpendicular sighting distance, PSD). Effort status, observer positions, and a suite of data characterizing survey conditions (e.g., sea state, weather, visibility and water color) were updated throughout the day whenever a change in any parameter occurred. The date, time, and location were automatically recorded with each sighting.

The sighting angle between a cetacean group or sea turtle and the transect line was measured with an inclinometer if the angle was less than 60°. Each bubble window was also divided into seven 10° intervals and one interval >80° corresponding to interval endpoints with PSD equal to 40, 83, 132, 192, 273, 397, 629, 1300 or >1300 m (Figure 4.5). If the inclinometer malfunctioned or if the sighting angle was greater than 60°, the interval was recorded.

When a cetacean group was sighted, the sighting angle or the interval was noted, a dye-marker was usually dropped to mark the position, and the aircraft was diverted to circle the group. Before continuing the transect, the species was identified and group-size was estimated by a consensus of the three observers. The identifying characteristics of each species and any anecdotal information were noted on a standardized form.

4.3.3 Data Analysis Techniques

Line transect methods (Buckland et al. 1993), implemented with the program DISTANCE™ (Laake et al. 1993), were used to make cetacean and sea turtle abundance estimates. For aerial surveys, abundance estimates were calculated separately for the EPA shelf and slope study areas as follows:

(1) for each species for the entire study (i.e., for all four seasonal surveys combined)

(2) for summer and winter (i.e., summer 1996 and 1997 data sets combined, and winter 1997 and 1998 data set combined) for each species with 15 or more on-effort sightings

(3) for all species combined for the entire study, for summer and winter, and for each seasonal survey (i.e., summer 1996, winter 1997, summer 1997, and winter 1998)

For the spring and early summer ship surveys, cetacean abundance estimates were made for each species in the EPA shelf and slope for early summer, and the oceanic northern Gulf and GulfCet I study areas for spring. Although the EPA slope study area is located within the boundaries of the oceanic northern Gulf study area, only data collected during dedicated surveys of the EPA slope were used in abundance estimates for this area. The surveys were designed specifically to provide an unbiased sample of the relatively small EPA slope study area. Use of data from the EPA slope for oceanic northern Gulf abundance estimates would have caused biases. Also note that the GulfCet I study area is located within the boundaries of the oceanic northern Gulf. The data set used for abundance estimates for the GulfCet I study area is a subset of the oceanic northern Gulf data set because the sampling design was similar to that used during 1991-94.

Data from the late summer 1996 and mid-summer 1997 *Gyre* surveys were not used for abundance estimates because very little visual effort occurred in the EPA slope and shelf study areas, and the effort that did occur was not evenly distributed in either season (Figure 4.3).

In each case, the formula used to estimate abundance (N) was:

$$N = \frac{A \cdot n \cdot S \cdot f(0)}{2 \cdot L}$$

where A = area of the study area
n = number of on-effort group sightings
S = mean group-size or expected group-size
f(0) = sighting probability density function at perpendicular distance zero
L = total length of transect lines sampled.

Because abundance estimates are a product of estimates, they tend to have skewed distributions. Therefore, the log-normal 95% confidence interval was computed for each abundance estimate.

The parameter f(0) was estimated using a hazard-rate, uniform or half-normal model (Buckland et al. 1993, see below). The program fit the f(0) parameter using a maximum likelihood estimator with exact sighting distances for the ship surveys and with grouped sighting distances for the aerial surveys. Model selection of f(0) was determined using Akaike's Information Criterion (AIC, Buckland et al. 1993). No attempt was made to estimate the probability of sighting animals on the transect line, g(0). The resulting estimates do not account for animals that were not sighted due to observer error (i.e., on the transect but missed) or that may have been unavailable for sighting (i.e., on the transect but submerged). Therefore, estimates of abundance are negatively biased (see Discussion).

The variance of N was estimated as:

$$\mathrm{var}(N) = N^2 \left[\frac{\mathrm{var}(n)}{n^2} + \frac{\mathrm{var}(S)}{S^2} + \frac{\mathrm{var}[f(0)]}{f(0)^2} \right]$$

and coefficient of variation (CV) was estimated as:

$$CV(N) = \frac{\sqrt{\mathrm{var}(N)}}{N}$$

The sampling unit for the ship surveys was a day's visual sighting effort, and for the aerial surveys, a transect. For each abundance estimate, the variance estimate of n was based on the variation in the number of on-effort group sightings between sampling units. Since the sampling units were of variable length, the estimated variance of n was length weighted. The estimated variance of S was based on the variation in group-size. The estimated variance of f(0) was based on the variation between expected versus actual PSD distributions (see below).

In some cases, the group-sizes for some species tended to be inversely related to PSD, a feature that results from size bias (i.e., larger groups are easier to see at distance than small groups). Therefore, in these cases, the arithmetic mean of group-size was probably an overestimate of the true mean group-size and could have lead to positively biased abundance estimates. A regression of the group-size by PSD was implemented on program DISTANCE™ to generate a mean "expected group-size." The expected group-size was used in the estimate of abundance if it was significantly smaller than the arithmetic mean group-size ($p<0.10$, Student's t-test, Buckland et al. 1993).

4.3.4 Estimation of Perpendicular Sighting Distance and f(0)

The PSD was estimated on ship surveys using bearing and reticle measurements (Figure 4.5). Examination of the bearing and reticle measurements indicated that most were rounded to the nearest 5 units (5 degrees for bearing, 0.5 for reticle readings). To reduce the potential for artificial grouping of sighting distances due to rounding of measurements, the bearing and reticle data for each sighting were smeared by adding a randomly selected value between -5 and 5 for the bearing, and between -0.5 and 0.5 for the reticle readings. The smeared reticle readings were converted to radial sighting distance (R) by the method of Lerczak and Hobbs (1998). PSDs were calculated as: $PSD = R \sin(b)$, where b = smeared angle between the sighting and the transect line.

An exploratory analysis indicated that the use of non-25x binocular sightings (about 11% of all sightings) made at small radial distances (<0.41 km) resulted in a spike in sighting probability density function at PSD = 0. This spike would positively bias estimates of f(0) and N. Many of these sightings were of animals that were probably attracted to the ship to bowride. One requirement for unbiased estimates of abundance is that the sighting target(s) should not move in response to the observer or the observation platform (Burnham et al. 1980, Buckland et al. 1993). To reduce the potential for positive bias due to attraction to the ship, only sightings made at radial distances of >0.41 km were included in the data used for estimating abundance.

The sample sizes (number of groups sighted) of most species were considered insufficient to obtain accurate and precise estimates of f(0). Therefore, sightings of species with similar sighting characteristics (i.e., body size, group-size, surface behavior) were pooled to estimate f(0) for five species categories (Table 4.1). *Large Whales* were species with adult lengths over 7 m. *Cryptic Whales* were species with lengths from 2.5 to 7 m that generally do not make pronounced blows, are not active at the surface (i.e., create very few splashes), and occur in small groups (e.g., <5 animals). *Small Whales/Large Dolphins* were species with adult lengths over 2.5 m that are, in general, moderately active at the surface and occur in groups of about 5 to 40 animals. *Small Dolphins* were species with lengths <2.5 m that are very active at the surface and typically occur in groups of >40 animals. Due to the small number of sightings of species in the Large Whale, Cryptic Whale and Unidentified Dolphin categories during GulfCet II, sightings from GulfCet I spring ship surveys were included to increase the sample size to estimate f(0). The abundance for each species was estimated using the pooled f(0) and variance for its category. By pooling, the variance, CV and confidence interval of each abundance estimate were probably underestimated because the variance of f(0) was based on an artificially high sample size.

For aerial surveys, the PSD from the transect line to the group was calculated as: $PSD = h \tan(\theta)$, where θ = angle between the transect line and the group, and h = altitude (229 m) (Figure 4.5). The inclinometer could measure distances from 0-60°. Therefore, for sightings from

Table 4.1. Estimate of the parameter f(0) for each species group from *ship* surveys (n = number of sightings used for the estimate, see text; ESW = effective strip width).

Species Group	n	f(0) (km^{-1})	CV [f(0)]	Truncation (m)	ESW (m)
Large Whales	71	0.467	0.12	4,600	4,282
Bryde's whale					
Sperm whale					
Unidentified large whale					
Cryptic Whales	110	0.810	0.10	3,300	2,469
Dwarf/pygmy sperm whale					
Cuvier's beaked whale					
Mesoplodon spp.					
Unidentified Ziphiidae					
Unidentified small whale					
Unidentified odontocete					
Small Whales/Large Dolphins	131	0.556	0.05	5,500	3,597
False killer whale					
Killer whale					
Short-finned pilot whale					
Bottlenose dolphin					
Risso's dolphin					
Atlantic spotted dolphin					
T. truncatus/S. frontalis					
Rough-toothed dolphin					
Small Dolphins	121	0.598	0.06	5,500	3,344
Melon-headed whale					
Pygmy killer whale					
Peponocephala/Feresa					
Pantropical spotted dolphin					
Striped dolphin					
Spinner dolphin					
Clymene dolphin					
Fraser's dolphin					
Unidentified dolphins	81	0.450	0.13	5,500	4,444

60-70° and from 70-80°, the midpoint of the interval was used as the PSD and was treated as an exact distance. Sightings at angles >80° were excluded from the analysis. As in ship surveys, the number of sightings for most species was too small to obtain an accurate and precise estimate of f(0). Therefore, species with similar sightability from aircraft were pooled into four categories, and an estimate of f(0) was made for each category (Table 4.2). Because of the small number of sightings of species in the Large Whale category during GulfCet II, Large Whale sightings from GulfCet I aerial surveys were pooled to estimate f(0) for this category. For each species, the value of f(0) and variance for its category were used in abundance estimates. Again, by pooling, the variance, CV and confidence interval of each abundance estimate were probably underestimated. Exploratory analyses using exact PSDs and various PSD distance interval combinations were performed to achieve a good fit of the model to the data (i.e., low χ^2 value and decreased CV[f(0)]. For each f(0) estimate, a model was fit to PSD data grouped into intervals: 0-132, 133-273, 274-397, 398-629 and 630-1,300 m.

As recommended by Buckland et al. (1993) for both aerial and ship survey species categories, 5 to 10% of the largest PSDs for each category were truncated from the sighting data to improve the fit of each model. Due to typical sighting characteristics, some species are easier to see at large PSDs than others and the truncation distance varied by species category (Tables 4.1 and 4.2).

4.3.5 Statistical Comparison of Abundance Estimates

Forney and Barlow (1998) provide an overview of the problems associated with statistical comparison of animal abundance estimates. Because estimates of animal abundance have positively skewed distributions, standard *t* and *z* tests based on normal distributions are not appropriate. A test that uses non-overlapping confidence intervals as the criteria for rejecting the null hypothesis of no difference between estimates was shown by Lo (1994) to be extremely difficult to interpret; alpha levels and power varied unsystematically between normal, log-normal, gamma, and Poisson distributions. Lo (1994) demonstrated that a method based on the confidence interval (CI) of the difference between means (d) was much more consistent. If the CI of d does not contain zero, the two means are significantly different at the alpha level used to construct the CI. Forney and Barlow (1998) employed this method to compare seasonal abundances of cetaceans in California waters. However, instead of calculating the analytical CI of d, they used a bootstrap method. The bootstrap method is computationally intensive whereas the analytical CI of d can be calculated with just the abundance estimates and their respective CVs. Given that the bootstrap method is extremely new, we were not able to use it for our comparisons, and our interest was in the analytical method.

An alpha level of 0.05 was initially used. However, it was discovered that in most cases the differences were not significant. Since the results were generally similar to Forney and Barlow's in terms of the range of CVs and the magnitude of the difference between means, their cetacean abundance and CV results were used to perform the difference test with analytical CIs. Of the six cases where the bootstrap results were significant ($p<0.05$), the analytical method showed a significant difference ($p<0.05$) in only two. In both cases the bootstrap alpha levels were less than 0.005. When the alpha was increased to 0.10, five cases were found to have statistical significance where the bootstrap found significance at less than 0.05. Clearly, the bootstrap

Table 4.2. Estimate of the parameter f(0) for each species group and all sea turtles from *aerial* surveys (n = number of sightings used for the estimate, see text; ESW = strip width).

Species Group	n	f(0) (km^{-1})	CV [f(0)]	Truncation (m)	ESW (m)
Large Whales	39	1.634	0.14	1,300	1,224
Bryde's whale					
Sperm whale					
Unidentified large whale					
Cryptic Whales	111	2.869	0.07	1,300	697
Dwarf/pygmy sperm whale					
Cuvier's beaked whale					
Mesoplodon spp.					
Unidentified Ziphiidae					
Unidentified small whale					
Unidentified odontocete					
Unidentified dolphin					
Small Whales/Large Dolphins	211	2.580	0.09	1,300	775
False killer whale					
Pygmy killer whale					
Short-finned pilot whale					
Bottlenose dolphin					
Risso's dolphin					
Atlantic spotted dolphin					
T. truncatus/S. frontalis					
Rough-toothed dolphin					
Small Dolphins	62	2.508	0.17	1,300	797
Pantropical spotted dolphin					
Striped dolphin					
Spinner dolphin					
Clymene dolphin					
Sea turtles	148	3.579	0.11	629	55

method is the more powerful test when dealing with these data. The analytical method was used to compare non-zero estimates at an alpha of 0.10. In cases where one of the estimates was zero because there was no variance, only qualitative comparisons could be made.

4.3.6 Sea Turtle Density

Five species of sea turtles are known to occur in the Gulf of Mexico: leatherback, loggerhead, Kemp's ridley, green, and hawksbill (National Research Council 1990). Sea turtle densities were estimated from aerial survey data only using the program DISTANCE™. All sea turtle sightings were of large, probably adult, turtles. Species were identified on the basis of shell shape and color, and the head size relative to the overall size. Data collection procedures were essentially the same as those for cetaceans except that sea turtles were not circled. All sea turtle sightings were pooled to estimate a common f(0) that was then applied to each species. Analytical methods were the same as those for cetaceans with the following exceptions: 1) data were right-truncated at 629 m, and 2) data were grouped into intervals of 0-83, 84-192, 193-273, 274-397 and 398-629 m. Unlike cetaceans, sea turtles do not occur in social groups; each sighting was usually of a single turtle. If more than one turtle was sighted at a time, a PSD was measured to each turtle. Therefore, group-size was always one, and there was no variance in group-size.

4.4 Results

To easily find results for cetaceans and sea turtles in each study area, tables are grouped by aerial and ship survey as follows: Cetaceans, Aerial Surveys (Tables 4.3-4.7); Cetaceans, Ship Surveys (Tables 4.8-4.13); Cetaceans, Aerial and Ship Surveys (Table 4.14); and Sea Turtles, Aerial Surveys (Tables 4.15-4.16). The locations of each cetacean and sea turtle species are presented in the same species order used in the tables, with a separate composite plot for aerial and ship surveys (Figures 4.6-4.36).

4.4.1 Study Area Summaries

In the following summaries, the coefficient of variation (CV) of the mean group-size estimate and abundance estimate is shown in parentheses. Both aerial and ship survey results were used for each of the study area summaries

In total, 3,652 km of transects were sampled from the EPA shelf during the four seasonal aerial surveys (Table 4.3). All of the proposed transect lines (32 lines) were completed during both summer (1,826 km) and winter (1,826 km) aerial surveys. In total, 78 cetacean groups were sighted (36 summer, 42 winter). During spring ship surveys, 449 km of transects were surveyed and 46 cetacean groups were sighted. Ten and 13 cetacean groups were sighted during fall and summer, respectively (Tables 4.8-4.9).

Three cetacean species were sighted in the EPA shelf. Bottlenose dolphins and Atlantic spotted dolphins were sighted during all three seasons. One dwarf/pygmy sperm whale was sighted during a summer aerial survey. There is no evidence that dwarf or pygmy sperm whales are a regular inhabitants of continental shelf waters in the Gulf of Mexico. During aerial surveys, 61

Table 4.4. Cetacean species sighted and number of on-effort sightings from *aerial* surveys of the Eastern Planning Area (EPA) continental shelf and continental slope study areas during summer and winter 1996-98 (* = one off-effort sighting).

STUDY AREA	Summer			Winter			
Species	96	97	Total	97	98	Total	TOTAL
EPA CONTINENTAL SHELF							
Dwarf/pygmy sperm whale	1	0	1	0	0	0	1
Bottlenose dolphin	13	15	28	15	18	33	61
Atlantic spotted dolphin	2	1	3	2	4	6	9
T. truncatus/S. frontalis	0	4	4	1	2	3	7
Total	16	20	36	18	24	42	78
EPA CONTINENTAL SLOPE							
Bryde's whale	1	0	1	1	0	1	2
Sperm whale	3	3	6	1	3	4	10
Dwarf/pygmy sperm whale	12	6	18	2	0	2	20
Cuvier's beaked whale	1	1	2	0	1	1	3
Mesoplodon spp.	4	1	5	*	0	*	5
Pygmy killer whale	0	0	0	1	2	3	3
False killer whale	0	1	1	0	0	0	1
Short-finned pilot whale	0	0	0	0	1	1	1
Rough-toothed dolphin	0	1	1	0	0	0	1
Bottlenose dolphin	21	31	52	25	14	39	91
Risso's dolphin	7	0	7	18	6	24	31
Atlantic spotted dolphin	5	4	9	5	1	6	15
Pantropical spotted dolphin	17	17	34	8	11	19	53
Striped dolphin	1	1	2	4	2	6	8
Spinner dolphin	2	2	4	2	1	3	7
Clymene dolphin	3	0	3	0	2	2	5
T. truncatus/S. frontalis	1	2	3	2	0	2	5
Unidentified cetaceans	3	3	6	3	1	4	10
Total	81	73	154	72	45	117	271

Table 4.6. Seasonal group-size, density and abundance estimates of cetacean species from *aerial* surveys in the Eastern Planning Area (EPA) continental shelf and slope study areas during summer and winter 1996-98 (n = number of groups, S = mean group size, D = animals/100 km^2, N = abundance estimate, CV = coefficient of variation, LCI and UCI = lower and upper limits of log-normal 95% confidence interval; seasonal pairs in bold are significantly different, $p<0.10$).

STUDY AREA Species/Season	n	S	CV (S)	D	N	CV (N)	LCI	UCI
EPA CONTINENTAL SHELF								
Bottlenose dolphin								
Summer	27	13.7	0.29	**26.620**	**3,281**		**0.37**	1,593
6,757								
Winter	31	4.3	0.23	**9.075**	**1,119**		**0.30**	628
1,993								
EPA CONTINENTAL SLOPE								
Dwarf/pygmy sperm whale								
Summer	17	1.9	0.20	**0.442**	**3110.33**		164	591
Winter	2	1.5	0.33	**0.051**	**360.68**		10	135
Bottlenose dolphin								
Summer	47	7.3	0.18	4.228	2,980		0.27	1,786
4,971								
Winter	36	18.7	0.30	10.346	7,291		0.35	3,692
14,390								
Risso's dolphin								
Summer	7	12.4	0.35	1.080	7610.51		283	2,042
Winter	24	7.7	0.30	2.848	2,007		0.39	949
4,244								
Atlantic spotted dolphin								
Summer	9	14.3	0.27	1.597	1,126		0.42	495
2,560								
Winter	6	27.0	0.36	2.496	1,758		0.55	611
5,058								
Pantropical spotted dolphin								
Summer	28	75.7	0.17	25.571	18,020		0.29	10,295
31,540								

Table 4.7. Group-size, density and abundance estimates of cetaceans from *aerial* surveys of the Eastern Planning Area (EPA) continental shelf and slope study areas during summer and winter 1996-98 (n = number of groups, S = mean group size, D = animals/100 km^2, N = abundance estimate, CV = coefficient of variation, LCI and UCI = lower and upper limits of log-normal 95% confidence interval).

STUDY AREA Temporal stratum	n	S	CV (S)	D	N	CV (N)	LCI	UCI
EPA CONTINENTAL SHELF								
Overall	72	9.1	0.19	22.308	2,750	0.24	1,729	4,372
Summer	34	14.4	0.24	34.333	4,232	0.33	2,210	8,103
Summer 1996	15	11.4	0.21	23.104	2,847	0.38	1,352	5,995
Summer 1997	19	16.7	0.36	46.482	5,730	0.48	2,276	14,428
Winter	38	6.2	0.25	15.781	1,945	0.29	1,097	3,450
Winter 1997	16	4.9	0.41	10.149	1,251	0.48	490	3,196
Winter 1998	22	9.7	0.36	29.450	3,630	0.40	1,662	7,930
EPA CONTINENTAL SLOPE								
Overall	247	31.3	0.13	51.819	36,517	0.16	26,487	50,346
Summer	140	29.5	0.16	50.080	35,291	0.19	24,214	51,436
Summer 1996	75	35.3	0.19	64.323	45,327	0.24	28,541	71,984
Summer 1997	65	22.9	0.27	35.926	25,317	0.31	13,997	45,791
Winter	107	33.6	0.21	53.980	38,039	0.25	23,401	61,833
Winter 1997	70	30.5	0.34	58.291	41,076	0.37	20,040	84,192

Table 4.8. Visual survey effort in each study area during each GulfCet II *ship* survey. (The GulfCet I study area effort is a subset of the oceanic northern Gulf study area; EPA = Eastern Planning Area; na = not applicable).

Study Area	Spring 1996 (km)	Spring 1997 (km)	Spring Total (km)	Late summer 1996 (km)	Mid-summer 1997 (km)
EPA Continental Shelf	234	215	449	199	205
EPA Continental Slope	1,136	1,450	2,586	711	611
Oceanic Northern Gulf	4,481	4,115	8,596	na	na
GulfCet I Study Area	(1,635)	(1,961)	(3,596)	na	na
Deepwater Focal Area	na	na	na	703	854
TOTAL	5,851	5,780	11,631	1,613	1,670

Spring and early summer 1996 - NOAA Ship *Oregon II* (17 April - 09 June 1996)
Spring and early summer 1997 - NOAA Ship *Oregon II* (16 April - 10 June 1997)
Late summer 1996 - R/V *Gyre* (10-29 October 1996)
Mid-summer 1997- R/V *Gyre* (4-22 August 1997)

Table 4.10. Group-size, density and abundance estimates of cetaceans from *ship* surveys of the Eastern Planning Area continental shelf and slope study areas during spring 1996-97 (n = number of groups, S = mean group size, D = animals/100 km^2, N = abundance estimate, CV = coefficient of variation, LCI and UCI = lower and upper limits of log-normal 95% confidence interval).

STUDY AREA Species	n	S	CV (S)	D	N	CV (N)	LCI	UCI
EPA CONTINENTAL SHELF								
Bottlenose dolphin	15	8.7	0.13	8.567	1,056	0.33	524	2,125
Atlantic spotted dolphin	12	18.9	0.23	14.822	1,827	0.46	713	4,678
T. truncatus/S.frontalis	10	4.3	0.43	2.815	347	0.60	108	1,111
Unidentified dolphin	2	2.5	0.60	0.267	33	0.95	4	254
EPA CONTINENTAL SLOPE								
Bryde's whale	2	2.3	0.56	0.041	29	1.05	4	196
Sperm whale	3	3.0	0.28	0.081	57	0.57	19	175
Dwarf/pygmy sperm whale	6	1.0	0.00	0.094	66	0.74	17	263
False killer whale	1	40.0	-	0.441	311	0.97	58	1,680
Rough-toothed dolphin	1	2.1	-	0.023	16	0.96	3	86
Fraser's dolphin	1	115.0	-	1.337	942	1.01	163	5,465
Bottlenose dolphin	14	9.6	0.43	1.455	1,025	0.56	349	3,008
Risso's dolphin	9	9.9	0.20	0.964	679	0.67	192	2,404
Atlantic spotted dolphin	6	23.1	0.17	1.498	1,055	0.66	304	3,662
Pantropical spotted dolphin	18	50.4	0.24	10.547	7,432	0.40	3,416	16,172
Striped dolphin	2	25.4	0.17	0.591	416	0.96	77	2,246
Spinner dolphin	32	16.4	0.51	7.548	5,319	0.75	1,139	24,849
T. truncatus/S.frontalis	2	14.0	0.79	0.303	213	1.24	20	2260
Unidentified large whale	1	1.0	-	0.009	6	1.02	1	37
Unidentified small whale	2	1.0	-	0.031	22	0.88	5	107
Unidentified odontocete	1	1.0	-	0.016	11	0.96	2	60
Unidentified dolphin	9	2.6	0.23	0.200	141	0.54	50	399

Table 4.11. Group-size, density and abundance estimates of cetaceans from *ship* surveys in the oceanic northern Gulf of Mexico study area during spring 1996-97 (n = number of groups, S = mean group size, D = animals/100 km^2, N = abundance estimate, CV = coefficient of variation, LCI and UCI = lower and upper limits of log-normal 95% confidence interval).

STUDY AREA Species	n	S	CV (S)	D	N	CV (N)	LCI	UCI
OCEANIC NORTHERN GULF								
Bryde's whale	1	2.0	-	0.005	221.07		4	123
Sperm whale	26	1.4	0.15	0.097	3870.45		164	914
Dwarf/pygmy sperm whale	18	2.2	0.17	0.184	7330.53		273	1,970
Cuvier's beaked whale	3	2.8	0.33	0.040	1590.69		44	577
Mesoplodon spp.	7	1.1	0.13	0.038	1500.50		59	384
Unidentified Ziphiidae	3	1.3	0.25	0.019	750.67		22	254
Melon-headed whale	1	125.0	-	0.435	1,734		1.07	304
9,878								
Pygmy killer whale	1	12.6	-	0.044	1751.12		29	1,062
Peponocephala/Feresa	1	5.7	-	0.020	791.10		13	472
False killer whale	1	63.0	-	0.205	8171.01		152	4,381
Killer whale	2	2.7	0.62	0.017	681.01		9	497
Short-finned pilot whale	6	19.0	0.73	0.369	1,471		0.86	263
8,224								
Rough-toothed dolphin	2	17.5	0.71	0.114	4531.10		46	4,451
Bottlenose dolphin	18	13.1	0.37	0.762	3,040		0.55	1,091
8,470								
Risso's dolphin	28	8.4	0.14	0.762	3,040		0.30	1,700
5,438								
Atlantic spotted dolphin	3	13.6	0.11	0.132	5280.69		152	1,829
Pantropical spotted dolphin	74	45.4	0.13	11.687	46,625		0.24	29,362
74,039								
Striped dolphin	4	79.0	0.11	1.098	4,381		0.55	1,570
12,227								
Spinner dolphin	8	101.4	0.46	2.820	11,251		0.66	3,283
38,565								
Clymene dolphin	8	90.1	0.18	2.530	10,093		0.40	4,665
21,838								
Stenella spp.	1	4.0	-	0.014	550.94		11	273
Unidentified large whale	1	1.0	-	0.003	110.90		2	51
Unidentified small whale	3	1.7	0.40	0.024	940.69		25	352
Unidentified odontocete	6	1.2	0.14	0.033	1310.44		57	304

Table 4.12. Group-size, density and abundance estimates of cetaceans from *ship* surveys of the GulfCet I study area during spring 1996-97 (n = number of groups, S = mean group size, D = animals/100 km^2, N = abundance estimate, CV = coefficient of variation, LCI and UCI = lower and upper limits of log-normal 95% confidence interval).

STUDY AREA Species	n	S	CV (S)	D	N	CV (N)	LCI	UCI
GULFCET I								
Sperm whale	18	1.3	0.14	0.149	2300.56		79	666
Dwarf/pygmy sperm whale	12	2.2	0.20	0.299	4620.64		141	1,512
Cuvier's beaked whale	2	2.3	0.56	0.051	780.90		12	519
Mesoplodon spp.	5	1.2	0.17	0.068	1050.61		33	329
Unidentified Ziphiidae	1	1.0	-	0.011	170.80		4	73
Melon-headed whale	1125.0		-	1.040	1,607		0.97	305
8,473								
Short-finned pilot whale	4	47.1	0.33	1.457	2,253		0.58	735
6,904								
Bottlenose dolphin	6	30.1	0.47	1.396	2,158		0.76	536
8,685								
Risso's dolphin	15	10.0	0.19	1.166	1,802		0.38	860
3,775								
Atlantic spotted dolphin	2	13.7	0.19	0.211	3260.77		81	1,309
Pantropical spotted dolphin	33	38.0	0.18	10.439	16,141		0.37	7,847
33,204								
Striped dolphin	2	66.8	0.20	1.110	1,717		0.76	433
6,799								
Clymene dolphin	5102.0		0.25	4.241	6,557		0.70	1,832
23,463								
Unidentified small whale	3	1.7	0.40	0.056	870.78		21	367
Unidentified odontocete	4	1.3	0.20	0.056	870.51		33	232
Unidentified dolphin	9	3.0	0.37	0.172	2660.49		102	695

Table 4.13. Comparison of abundance estimates (N) from *ship* surveys in the oceanic northern Gulf of Mexico study area and the GulfCet I study area (NW Slope) (Estimates in bold are significantly different, $p<0.10$).

Species	Oceanic Northern Gulf of Mexico		GulfCet I (NW Slope)	
	1991-94[1] N (CV)	1996-97[2] N (CV)	1991-94[3] N (CV)	1996-97[2] N (CV)
Bryde's whale	35 (1.09)	22 (1.07)	5 (0.85)	0
Sperm whale	530 (0.31)	387 (0.45)	248 (0.30)	230 (0.56)
Dwarf/pygmy sperm whale	547 (0.28)	733 (0.53)	188 (0.26)	462 (0.64)
Cuvier's beaked whale	30 (0.28)	159 (0.69)	23 (0.43)	78 (0.90)
Melon-headed whale	3,965 (0.39)	1,734 (1.07)	2,569 (0.38)	1,607 (0.97)
Pygmy killer whale	518 (0.81)	175 (1.12)	57 (0.37)	0
Killer whale	277 (0.42)	68 (1.01)	113 (0.48)	0
False killer whale	381 (0.62)	817 (1.01)	17 (0.67)	0
Short-finned pilot whale	353 (0.52)	1,471 (0.86)	232 (0.51)	2,253 (0.58)
Rough-toothed dolphin	852 (0.31)	453 (1.10)	221 (0.39)	0
Fraser's dolphin	127 (0.89)	0	103 (1.24)	0
Bottlenose dolphin	5,618 (0.26)	3,040 (0.55)	3,335 (0.30)	2,158 (0.76)
Risso's dolphin	2,749 (0.27)	3,040 (0.30)	803 (0.27)	1,802 (0.38)
Atlantic spotted dolphin	**3,213 (0.44)**	**528 (0.69)**	**1,453 (0.42)**	**326 (0.77)**
Pantropical spotted dolphin	31,320 (0.20)	46,625 (0.24)	10,191 (0.23)	16,141 (0.37)
Striped dolphin	4,858 (0.44)	4,381 (0.55)	2,891 (0.54)	1,717 (0.76)
Spinner dolphin	6,316 (0.43)	11,251 (0.66)	1,314 (0.64)	0
Clymene dolphin	5,571 (0.37)	10,093 (0.40)	2,924 (0.38)	6,557 (0.70)

1 – NMFS, Hansen et al. (1995); 2 - GulfCet II, this study; 3 - GulfCet I, Hansen et al. (1996)

Table 4.14. Seasonal occurrence of cetacean species in the EPA study areas, and in the EPA, focal, and oceanic northern Gulf study areas combined (All Study Areas) during GulfCet II *aerial* or *ship* surveys (X = one or more on-effort sightings).

Species	EPA Shelf			EPA Slope			All Study Areas		
	Spr	Sum	Win	Spr	Sum	Win	Spr	Sum	Win
Bryde's whale	0	0	0	X	X	X	X	X	X
Sperm whale	0	0	0	X	X	X	X	X	X
Dwarf/pygmy sperm whale	0	X	0	X	X	X	X	X	X
Cuvier's beaked whale	0	0	0	0	X	X	X	X	X
Mesoplodon spp.	0	0	0	0	X	X	X	X	X
Melon-headed whale	0	0	0	0	0	0	X	0	0
Pygmy killer whale	0	0	0	0	0	X	X	0	X
Killer whale	0	0	0	0	0	0	X	0	0
False killer whale	0	0	0	X	X	0	X	X	0
Short-finned pilot whale	0	0	0	0	0	X	X	0	X
Rough-toothed dolphin	0	0	0	X	X	0	X	X	0
Fraser's dolphin	0	0	0	X	0	0	X	0	0
Bottlenose dolphin	X	X	X	X	X	X	X	X	X
Risso's dolphin	0	0	0	X	X	X	X	X	X
Atlantic spotted dolphin	X	X	X	X	X	X	X	X	X
Pantropical spotted dolphin	0	0	0	X	X	X	X	X	X
Striped dolphin	0	0	0	X	X	X	X	X	X
Spinner dolphin	0	0	0	X	X	X	X	X	X
Clymene dolphin	0	0	0	0	X	X	X	X	X
Total	2	3	2	12	14	14	19	14	14

Table 4.15. Sea turtle species sighted and number of on-effort sightings during *aerial* surveys of the Eastern Planning Area (EPA) continental shelf and continental slope study areas during summer and winter 1996-98.

STUDY AREA	Summer			Winter			
Species	96	97	Total	97	98	Total	TOTAL
EPA CONTINENTAL SHELF							
Loggerhead sea turtle	18	21	39	26	20	46	85
Kemp's ridley sea turtle	0	0	0	2	1	3	3
Leatherback sea turtle	3	1	4	0	0	0	4
Unidentified chelonid	4	0	4	3	3	6	10
Total	25	22	47	31	24	55	102
EPA CONTINENTAL SLOPE							
Loggerhead sea turtle	0	2	2	15	10	25	27
Leatherback sea turtle	15	5	20	7	1	8	28
Unidentified chelonid	1	2	3	1	2	3	6
Total	16	9	25	23	13	36	61

Table 4.16. Density and abundance estimates of sea turtles from *aerial* surveys in the Eastern Planning Area (EPA) continental shelf and slope study areas during summer and winter 1996-98 (n = number of turtles sighted, D = turtles/100 km^2, N = abundance estimate, CV = coefficient of variation, LCI and UCI = lower and upper limits of log-normal 95% confidence interval; seasonal pairs in bold are significantly different, $p<0.10$.)

STUDY AREA Species/Season	n	D	N	CV (N)	LCI	UCI
EPA CONTINENTAL SHELF						
Loggerhead						
Overall	84	4.077	503	0.20	339	745
Summer	39	3.891	480	0.30	264	873
Winter	45	4.253	524	0.23	330	832
Kemp's ridley	2	0.097	12	1.14	2	75
Leatherback	4	0.194	24	0.48	10	60
Unidentified chelonid	7	0.340	42	0.45	18	98
EPA CONTINENTAL SLOPE						
Loggerhead						
Overall	21	0.200	141	0.27	83	239
Summer	2	**0.034**	**24**	**0.77**	6	94
Winter	19	**0.406**	**286**	**0.27**	166	492
Leatherback						
Overall	25	0.238	168	0.23	107	264
Summer	19	0.327	230	0.58	142	373
Winter	6	0.128	90	0.48	36	224
Unidentified chelonid	5	0.048	34	0.43	15	75

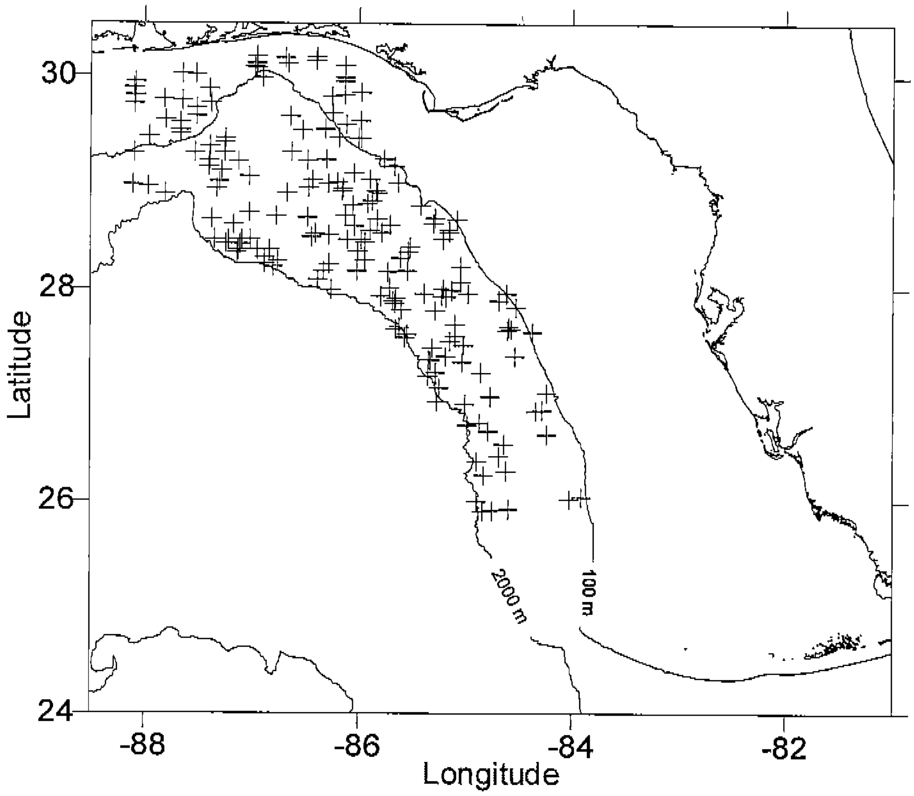

Figure 4.6. The locations of all cetacean groups sighted during summer 1996 and 1997 *aerial* surveys.

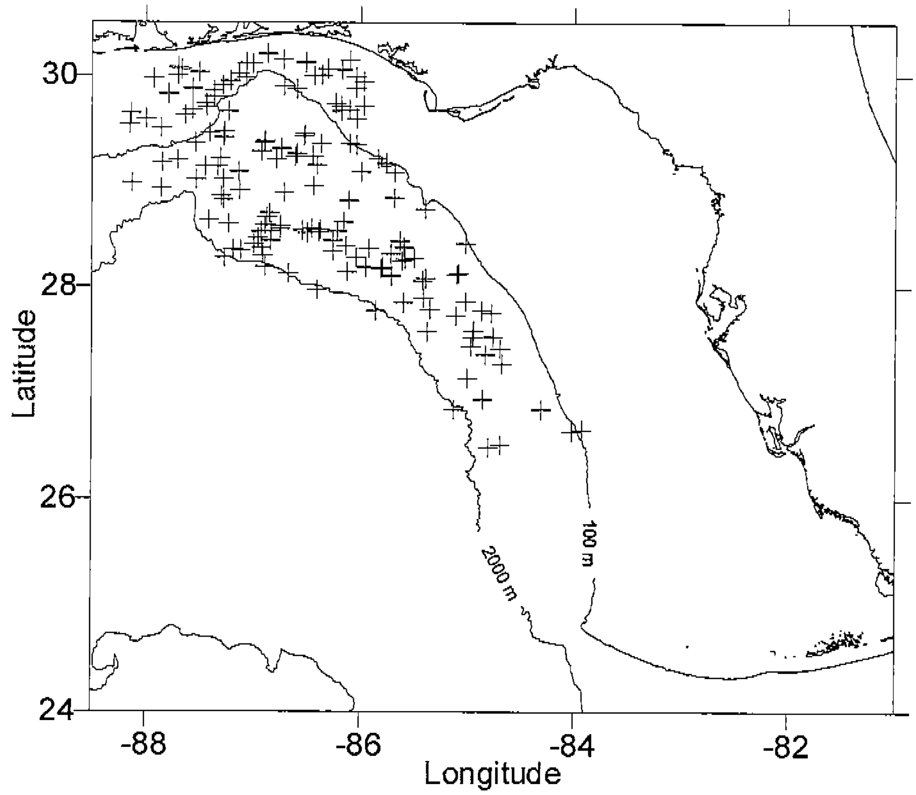

Figure 4.7. The locations of all cetacean groups sighted during winter 1997 and 1998 *aerial* surveys.

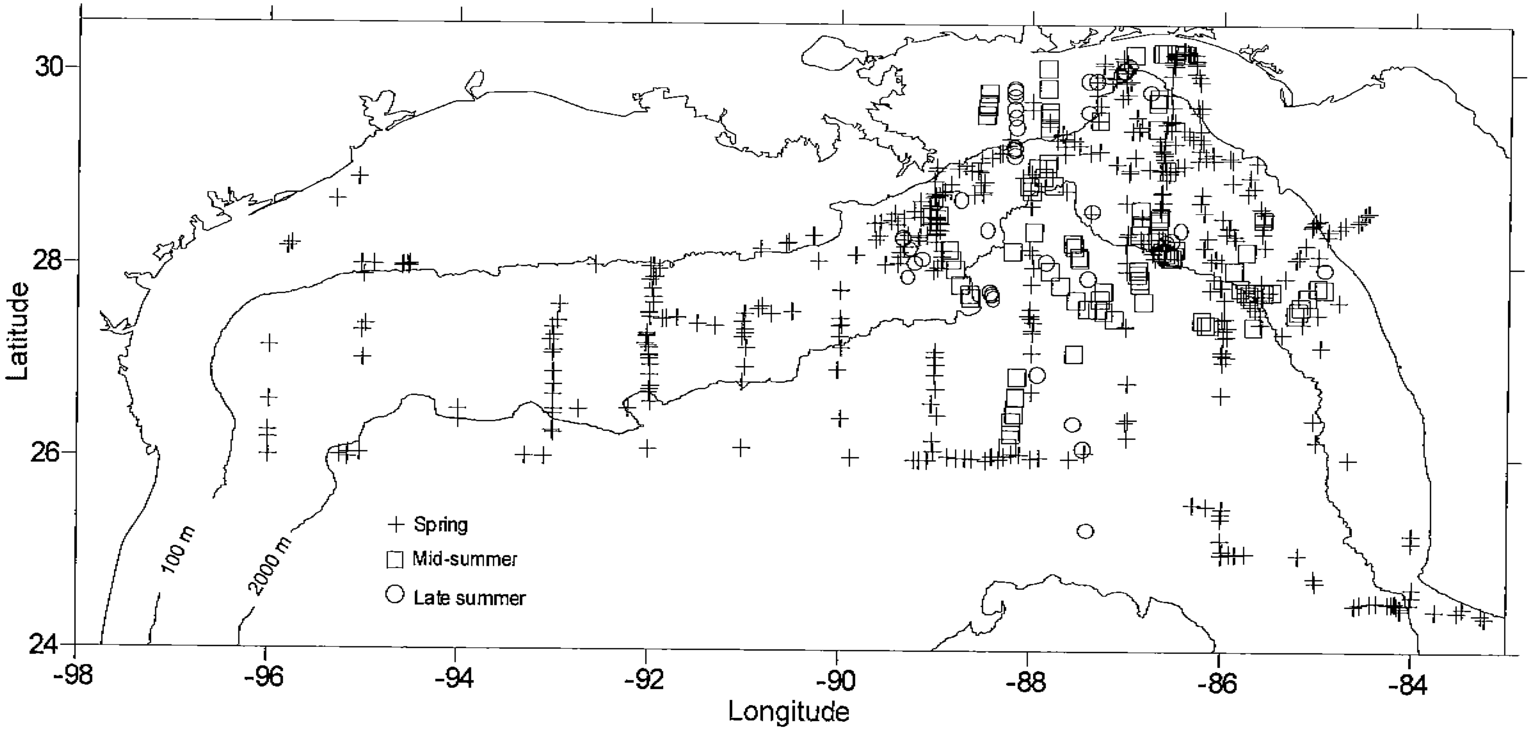

Figure 4.8. The locations of all cetacean groups sighted during the four ship surveys (spring = spring and early summer 1996, 1997; late summer 1996; mid-summer 1997). (Survey effort was greater in the eastern Gulf.)

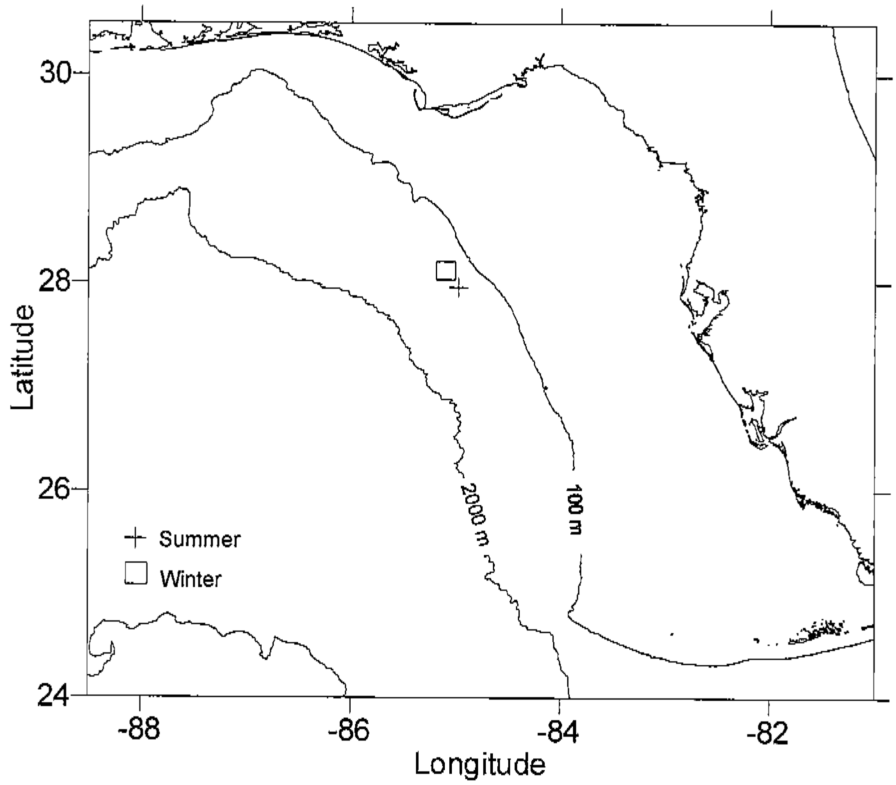

Figure 4.9. The locations of all Bryde's whale groups sighted during *aerial* surveys.

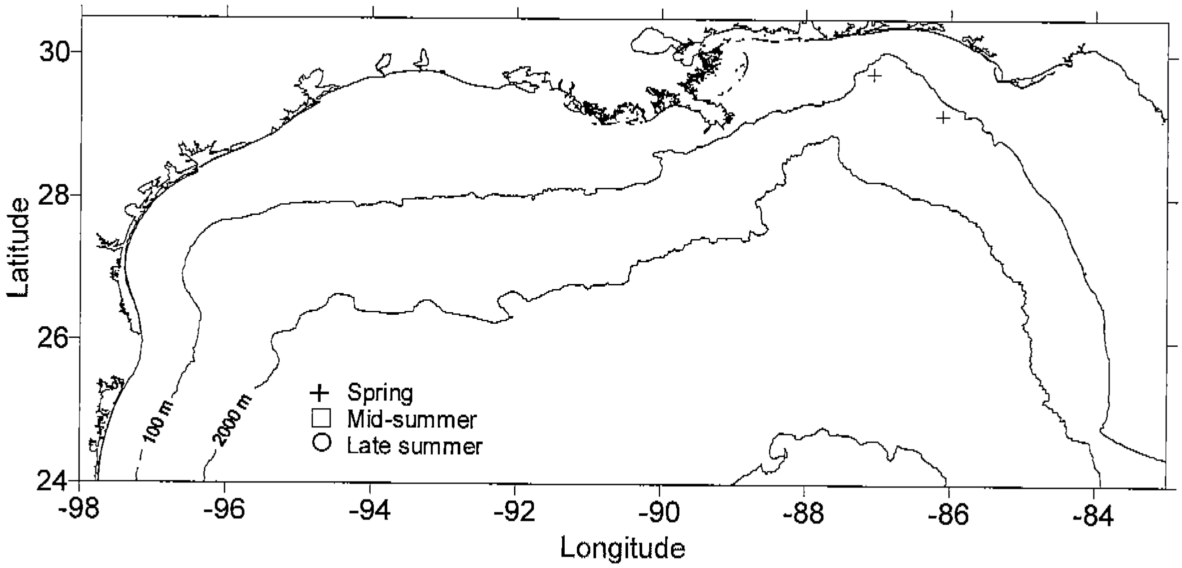

Figure 4.10. The locations of all Bryde's whale groups sighted during *ship* surveys.

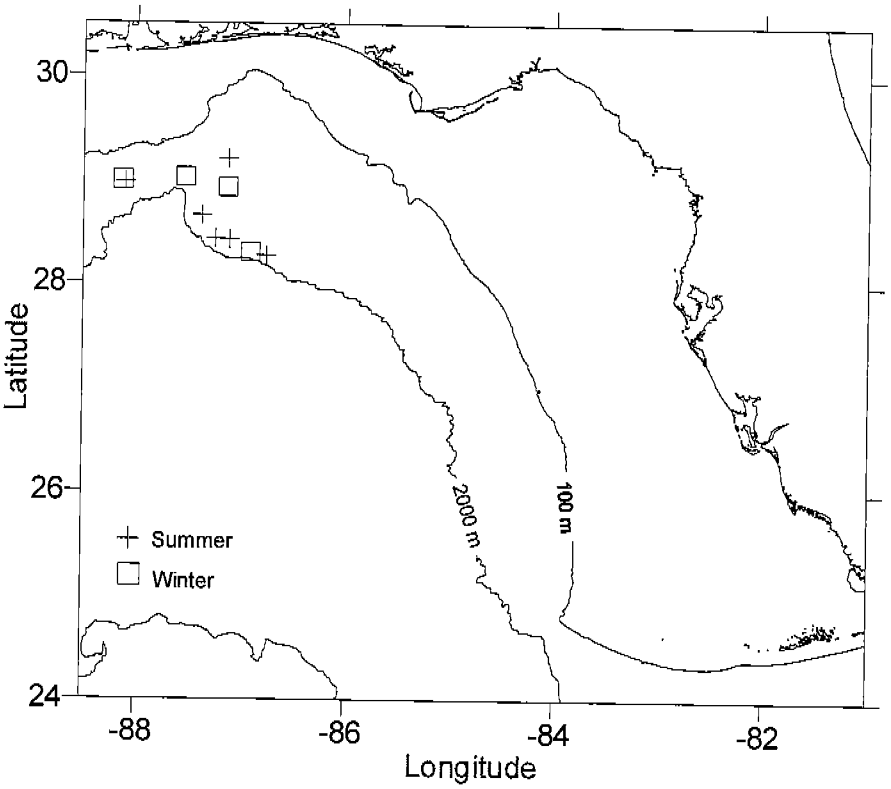

Figure 4.11. The locations of all sperm whale groups sighted during *aerial* surveys.

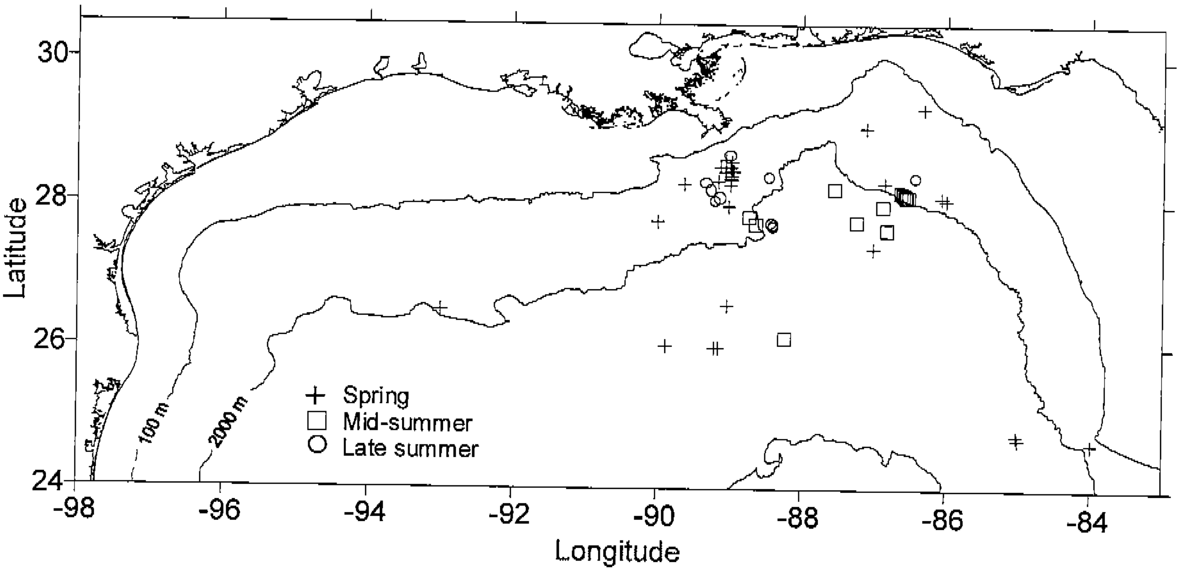

Figure 4.12. The locations of all sperm whale groups sighted during *ship* surveys.

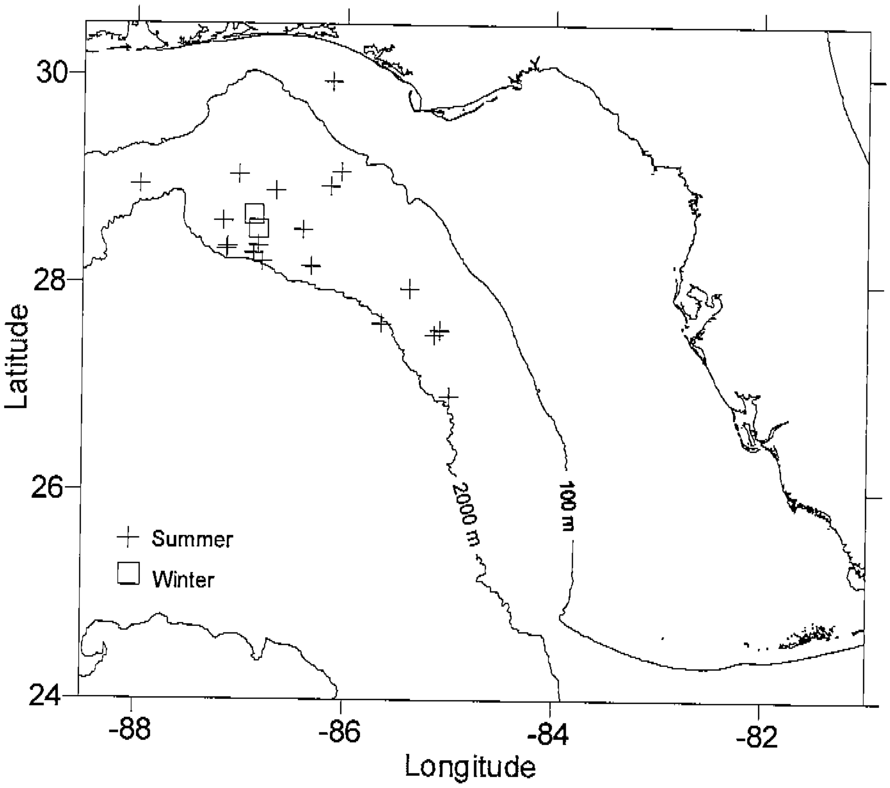

Figure 4.13. The locations of all dwarf/pygmy sperm whale groups sighted during *aerial* surveys.

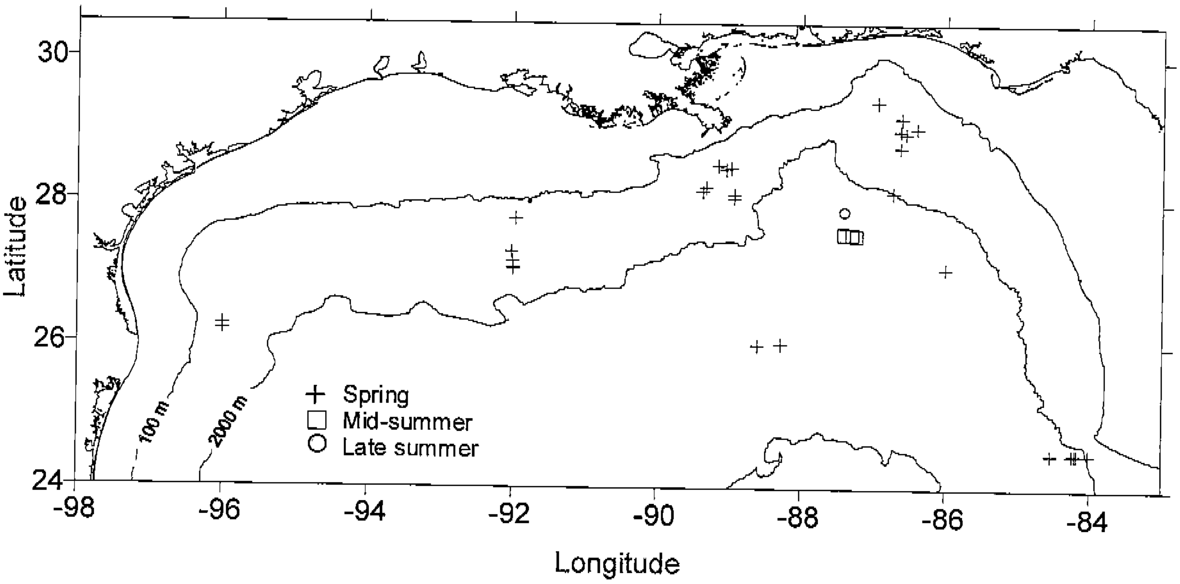

Figure 4.14. The locations of all dwarf/pygmy sperm whale groups sighted during *ship* surveys.

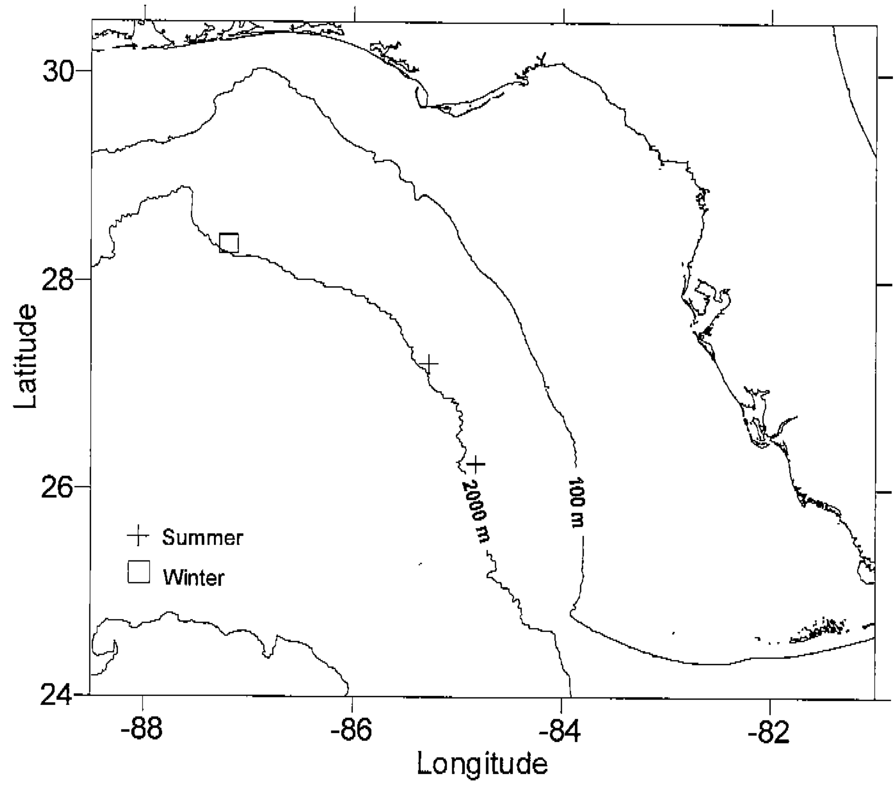

Figure 4.15. The locations of all Cuvier's beaked whale groups sighted during *aerial* surveys.

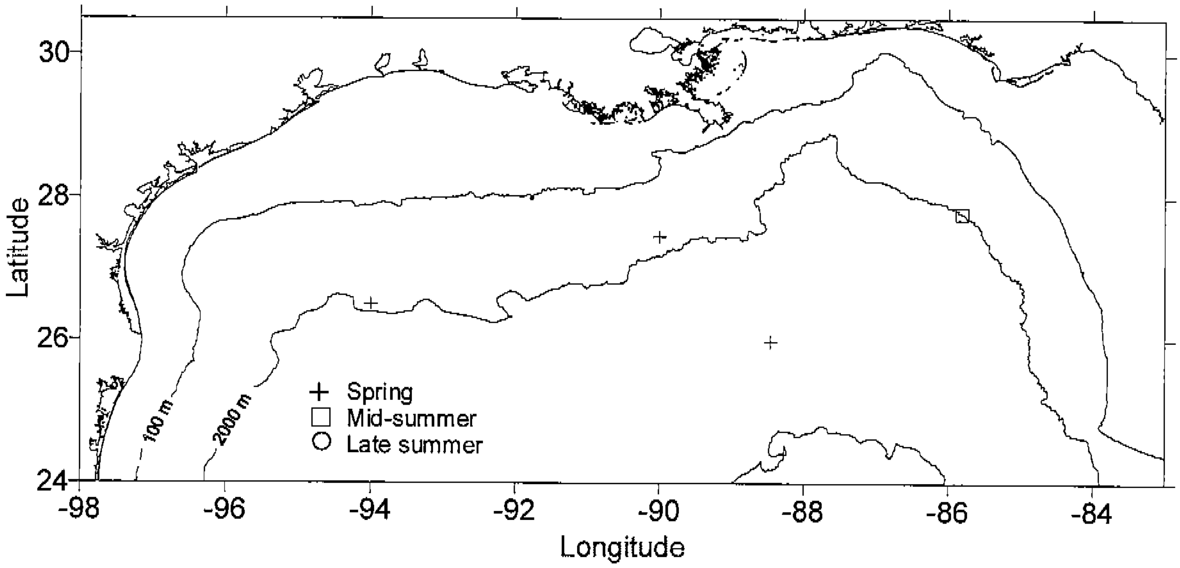

Figure 4.16. The locations of all Cuvier's beaked whale groups sighted during *ship* surveys.

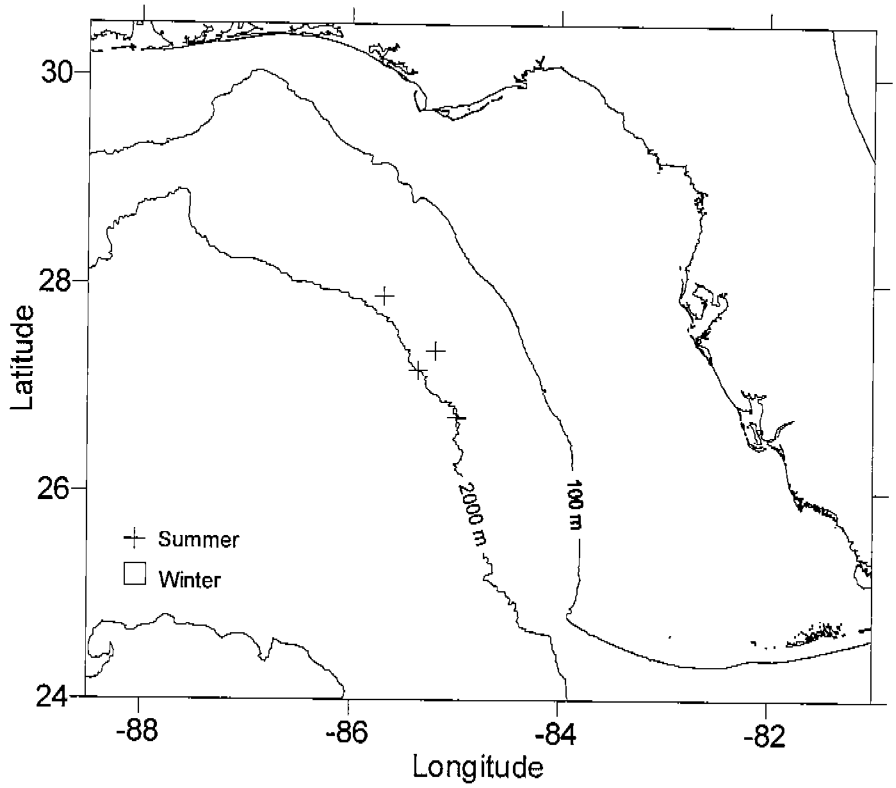

Figure 4.17. The locations of all *Mesoplodon* spp. groups sighted during *aerial* surveys.

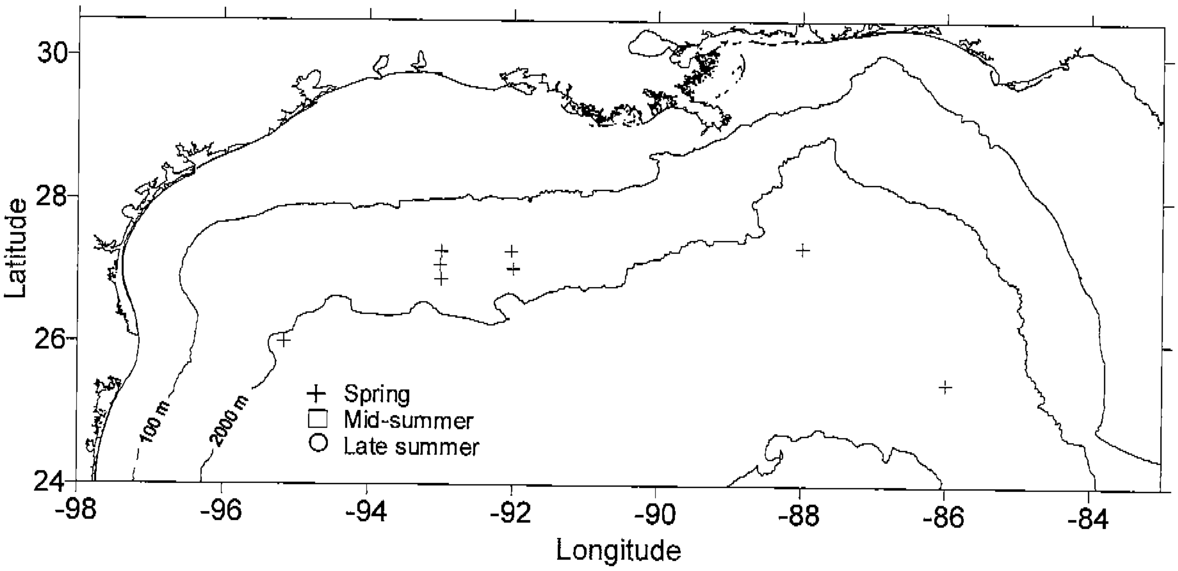

Figure 4.18. The locations of all *Mesoplodon* spp. groups sighted during *ship* surveys.

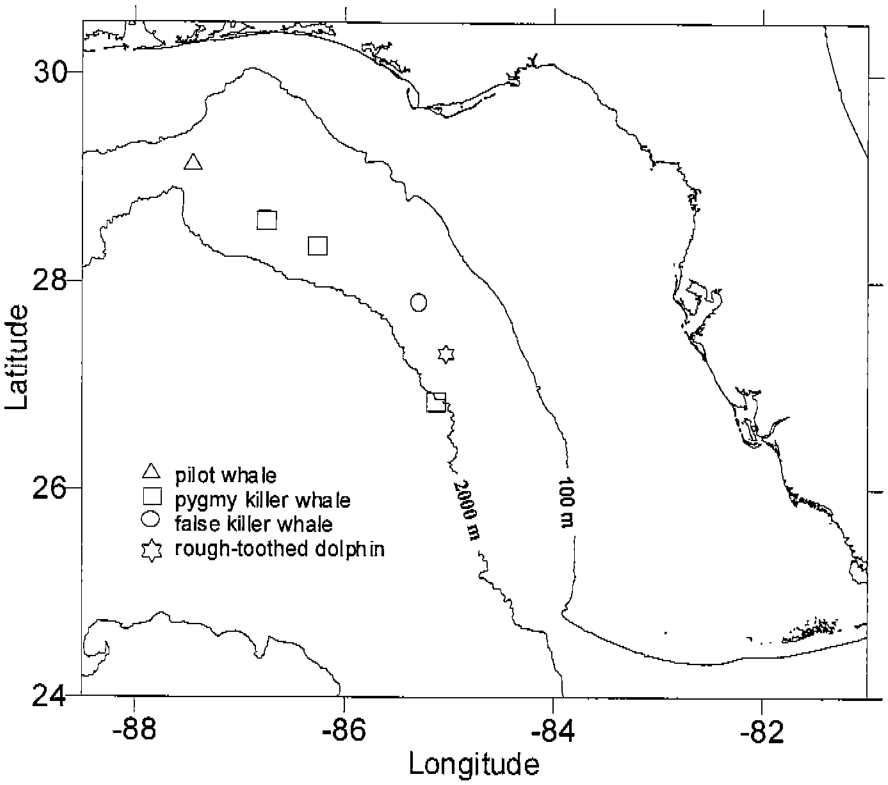

Figure 4.19. The locations of all pilot, false killer, and pygmy killer whale groups, and rough-toothed dolphin groups sighted during *aerial* surveys.

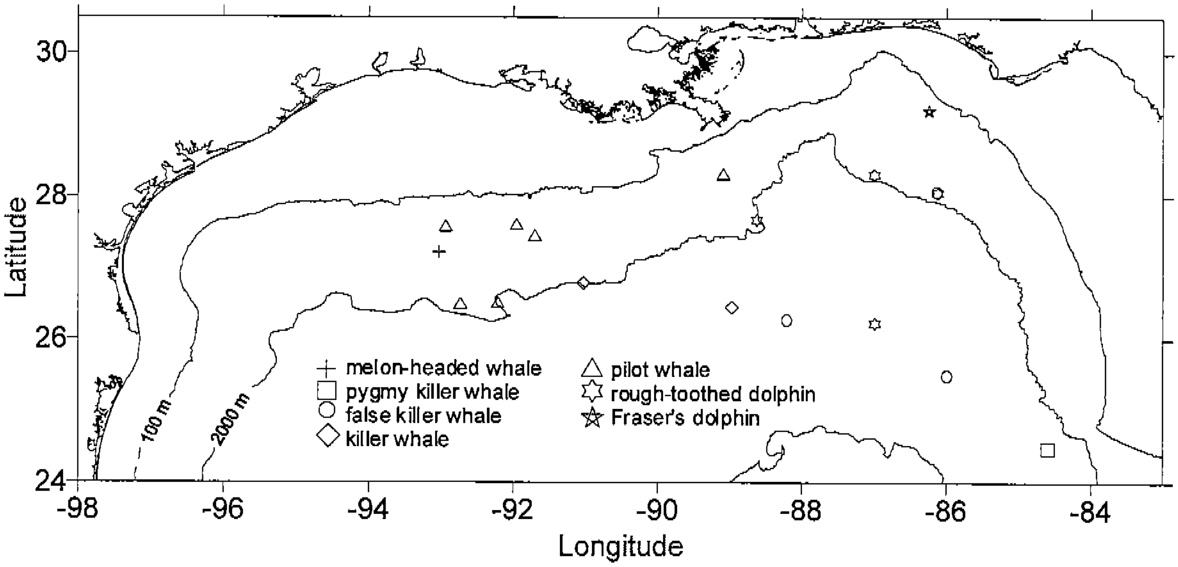

Figure 4.20. The locations of all melon-headed, pilot, false killer, pygmy killer, and killer whale groups and rough-toothed dolphin groups sighted during *ship* surveys.

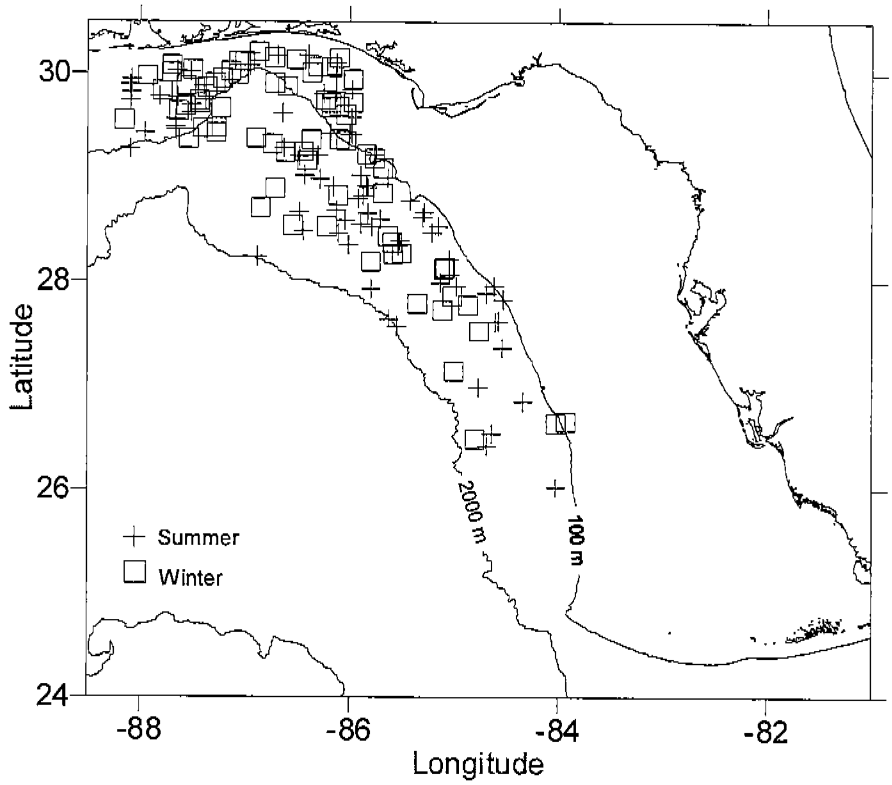

Figure 4.21. The locations of all bottlenose dolphin groups sighted during *aerial* surveys.

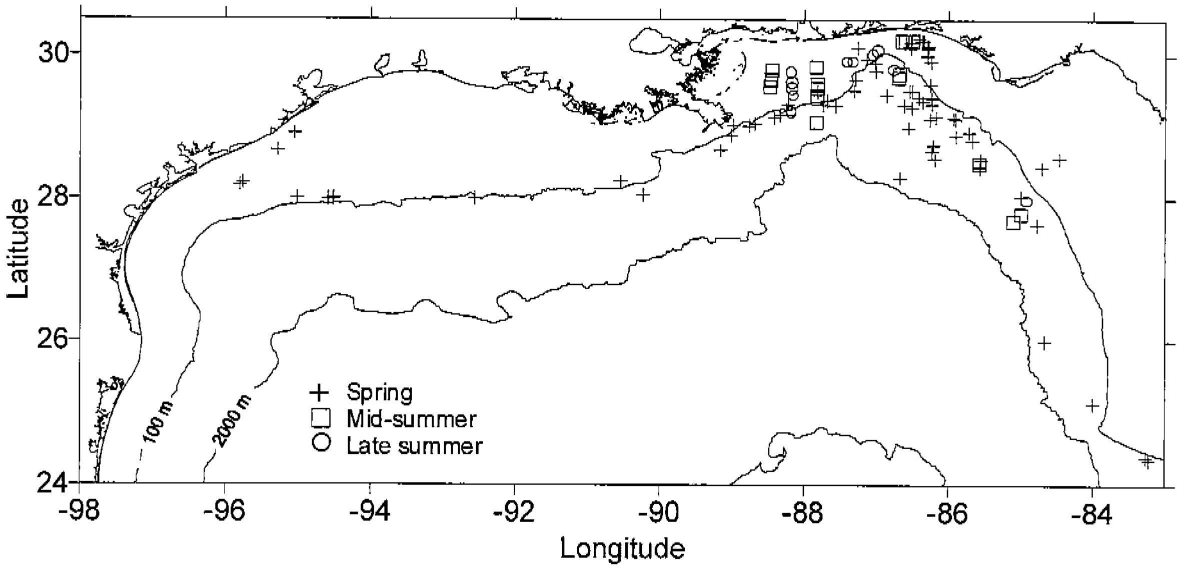

Figure 4.22. The locations of all bottlenose dolphin groups sighted during *ship* surveys.

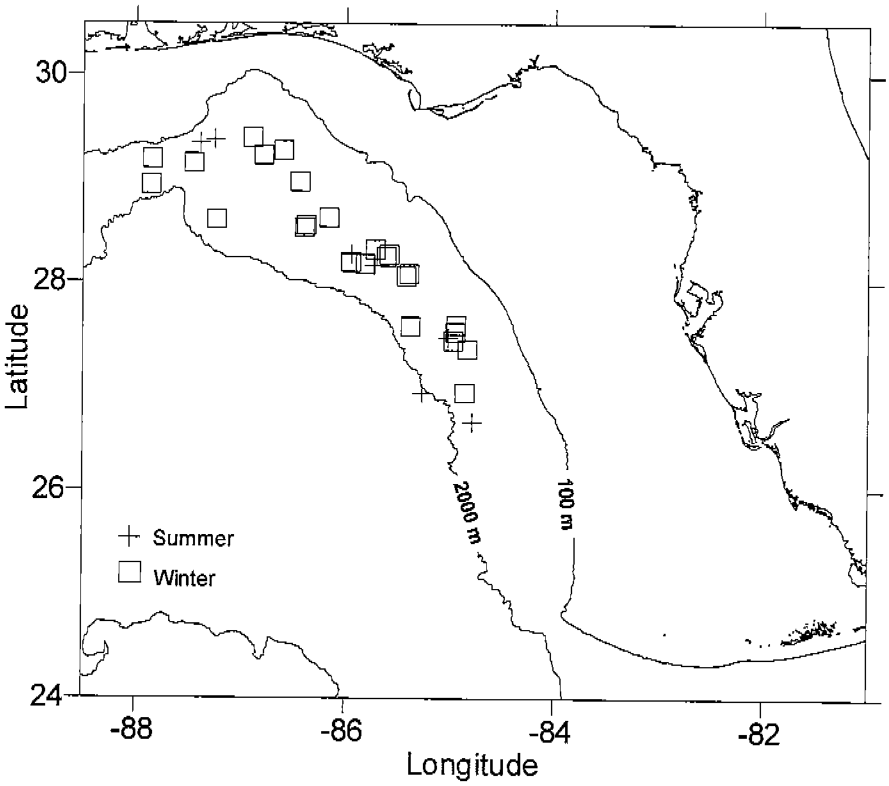

Figure 4.23. The locations of all Risso's dolphin groups sighted during *aerial* surveys.

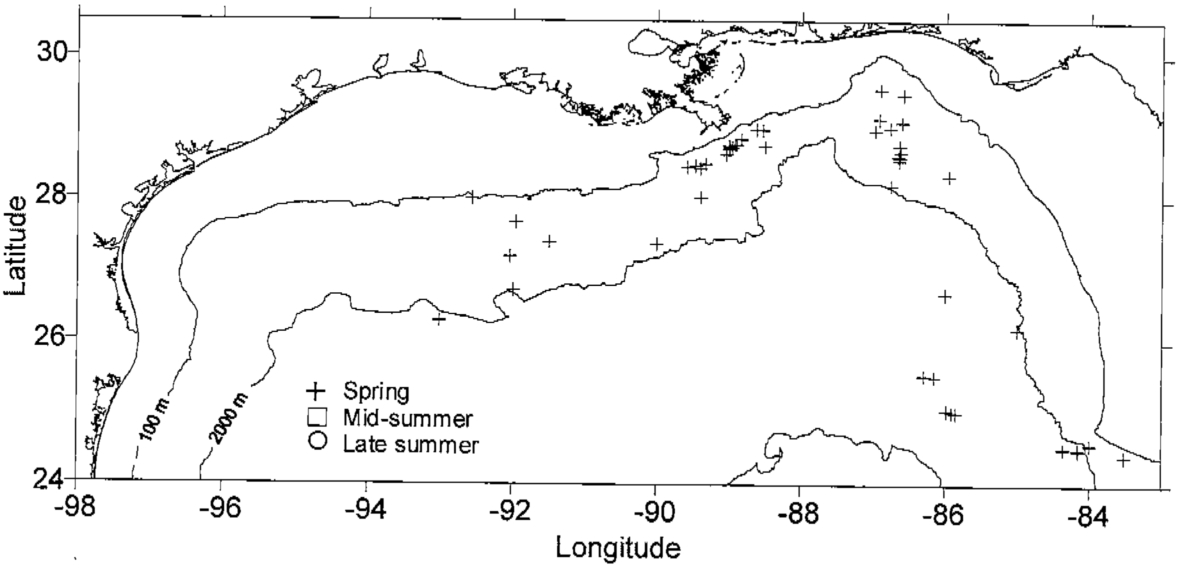

Figure 4.24. The locations of all Risso's dolphin groups sighted during *ship* surveys.

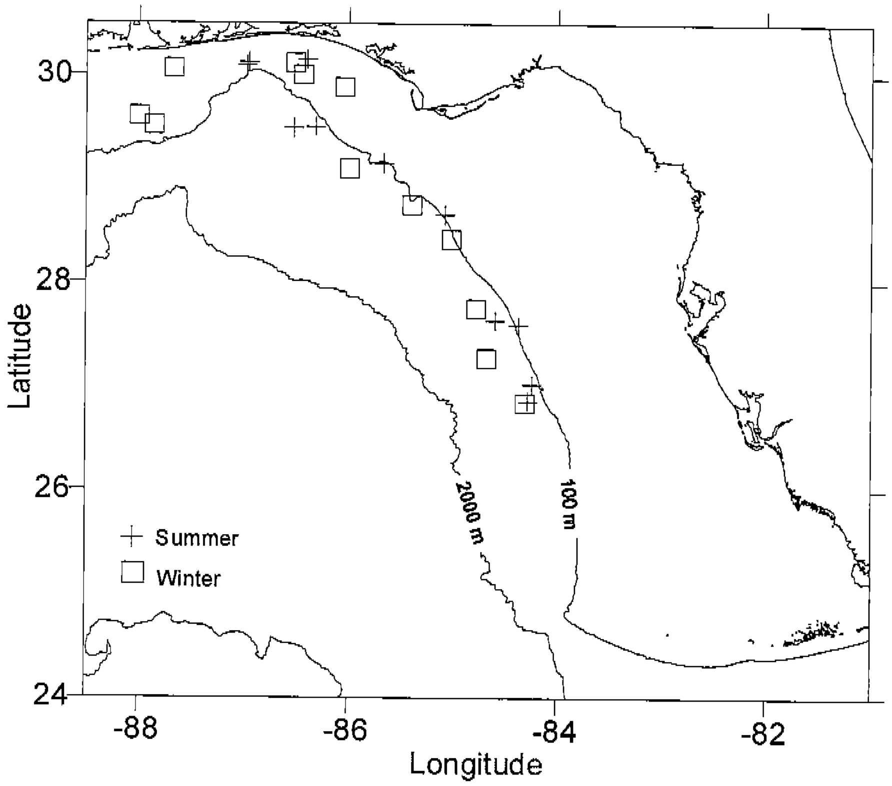

Figure 4.25. The locations of all Atlantic spotted dolphin groups sighted during *aerial* surveys.

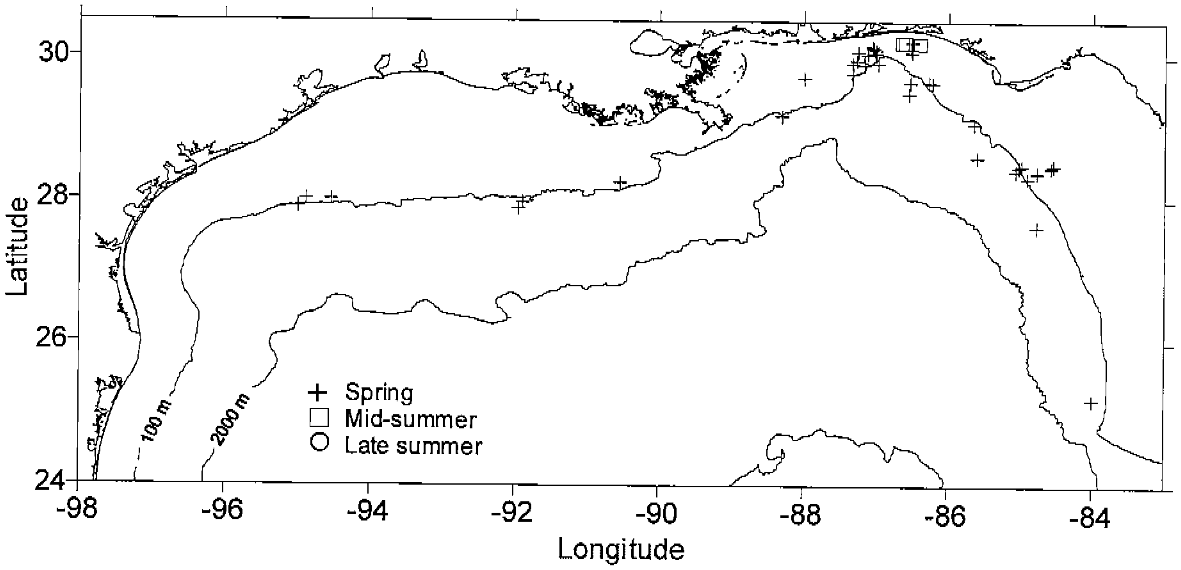

Figure 4.26. The locations of all Atlantic spotted dolphin groups sighted during *ship* surveys.

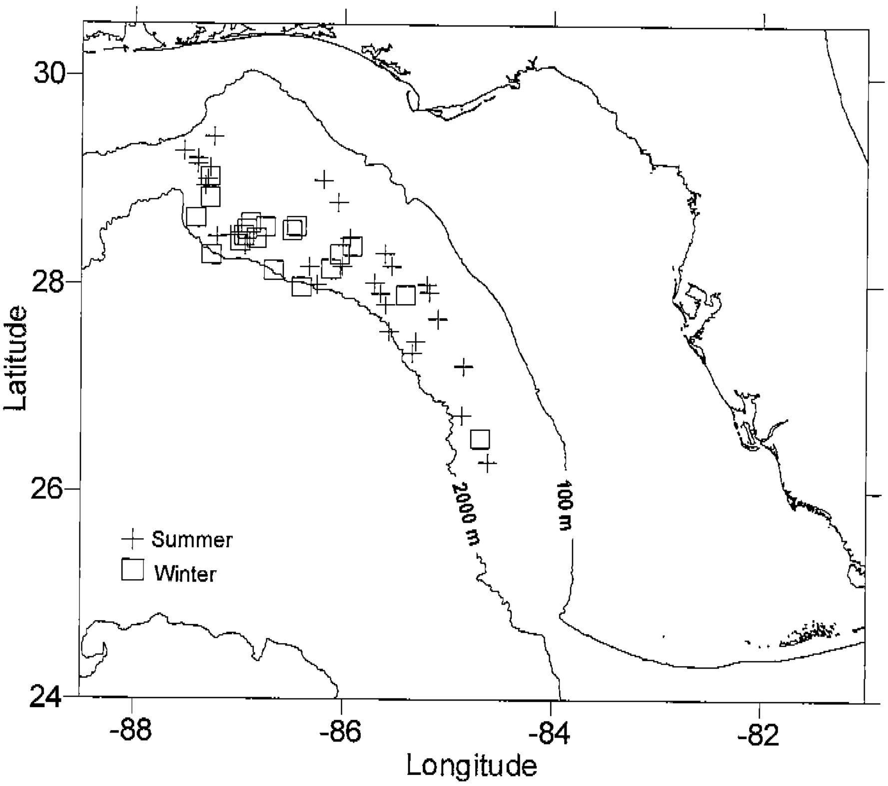

Figure 4. 27. The locations of all pantropical spotted dolphin groups sighted during *aerial* surveys.

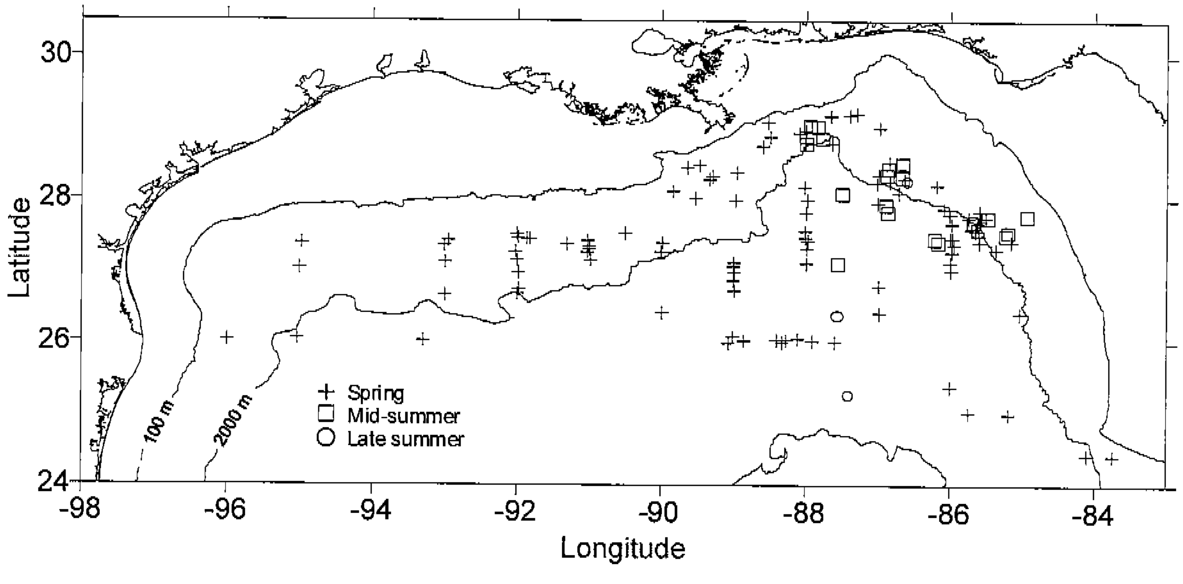

Figure 4.28. The locations of all pantropical spotted dolphin groups sighted during *ship* surveys.

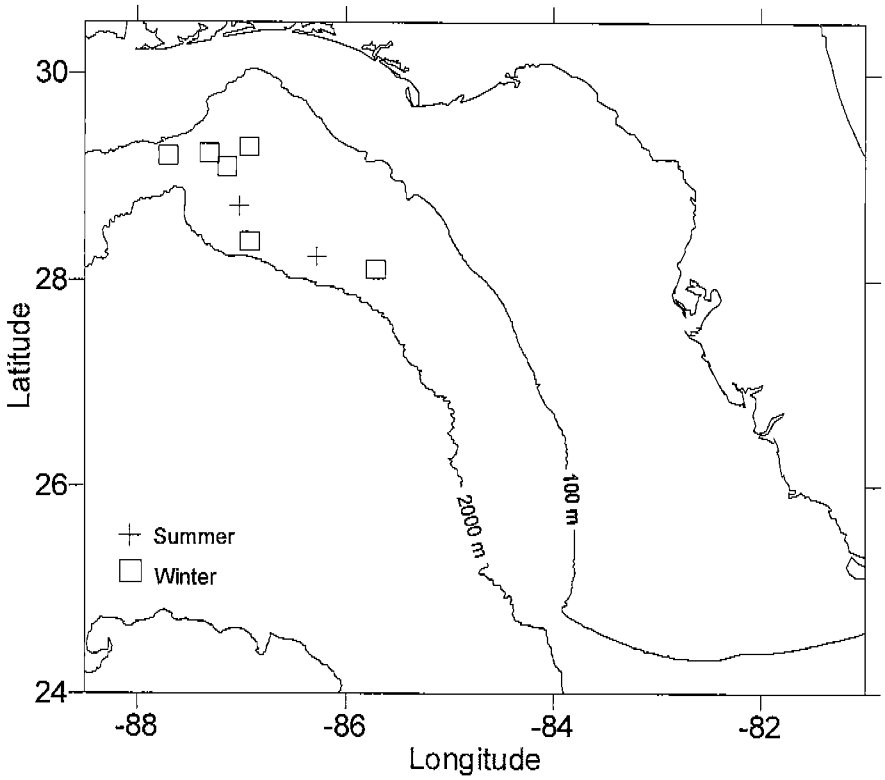

Figure 4.29. The locations of all striped dolphin groups sighted during *aerial* surveys.

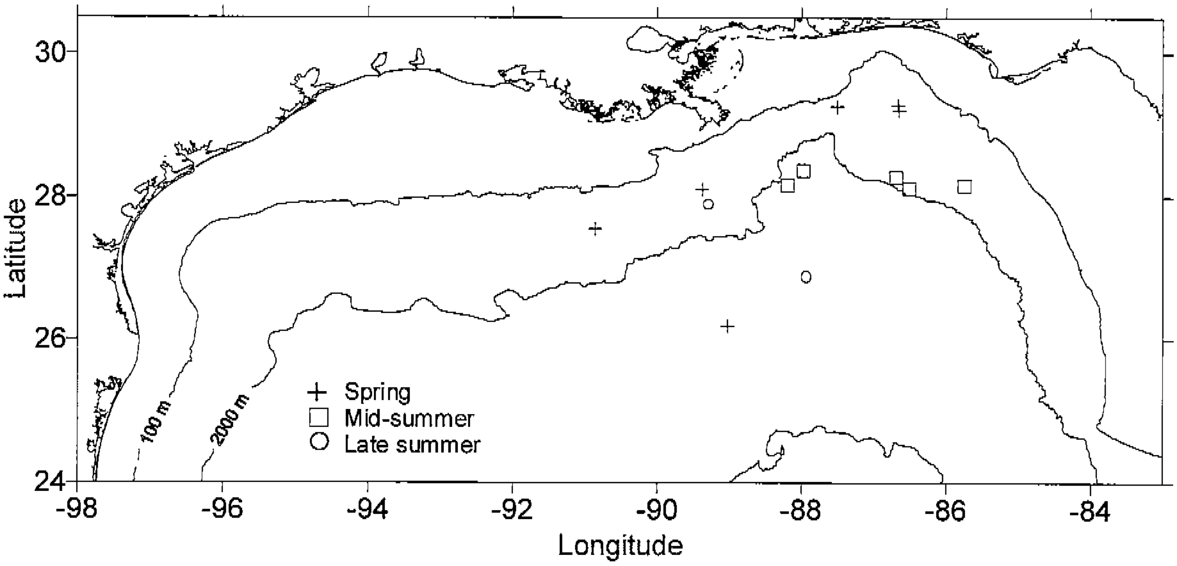

Figure 4.30. The locations of all striped dolphin groups sighted during *ship* surveys.

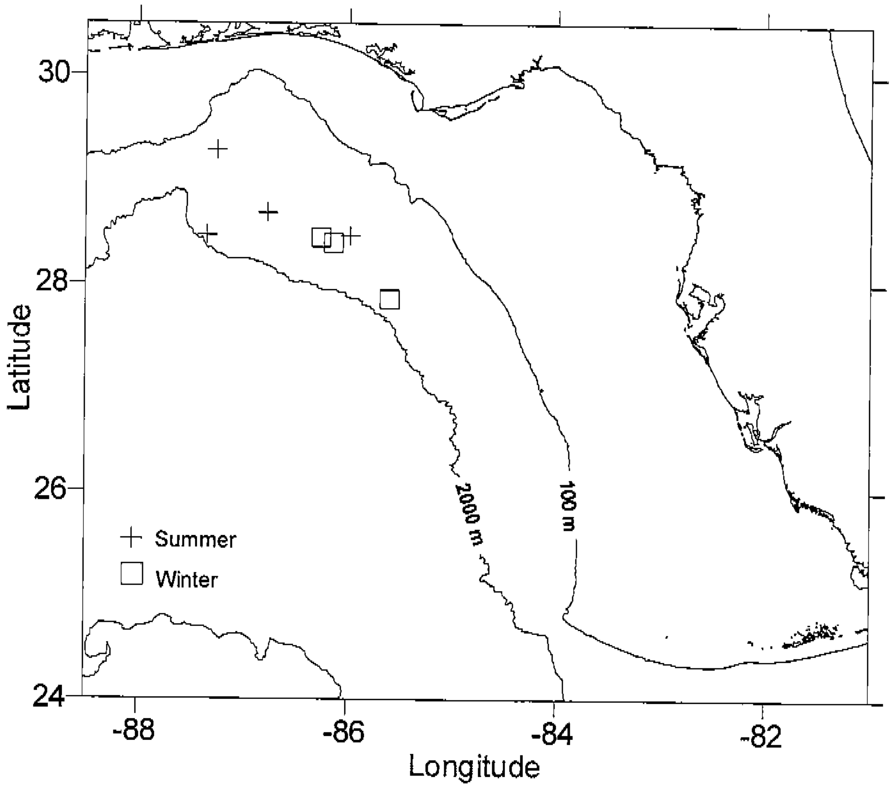

Figure 4.31. The locations of all spinner dolphin groups sighted during *aerial* surveys.

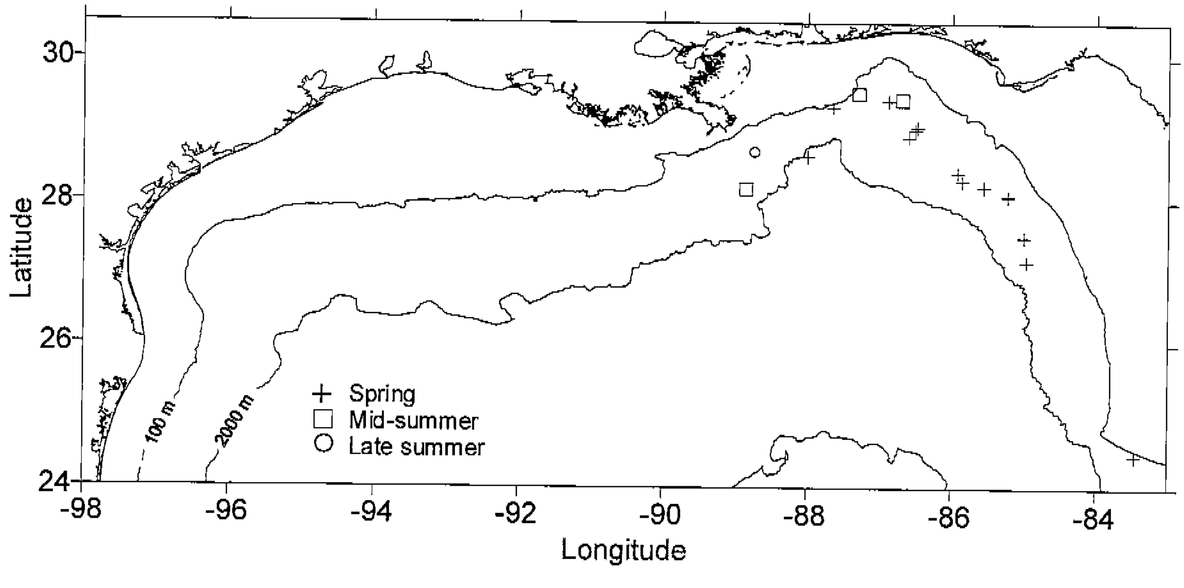

Figure 4.32. The locations of all spinner dolphin groups sighted during *ship* surveys.

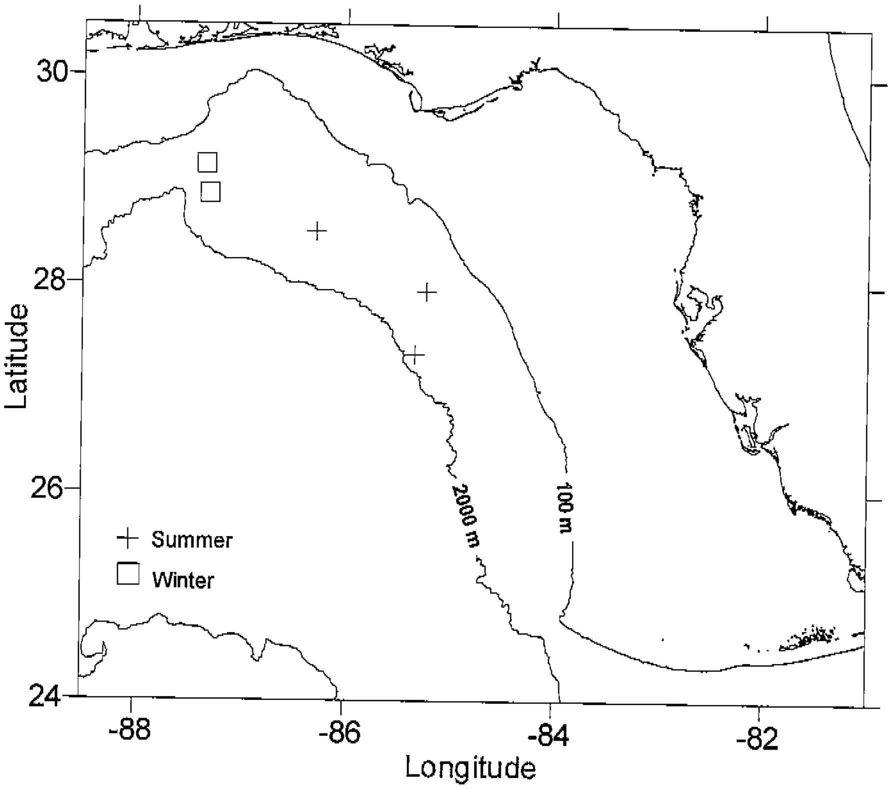

Figure 4.33. The locations of all Clymene dolphin groups sighted during *aerial* surveys.

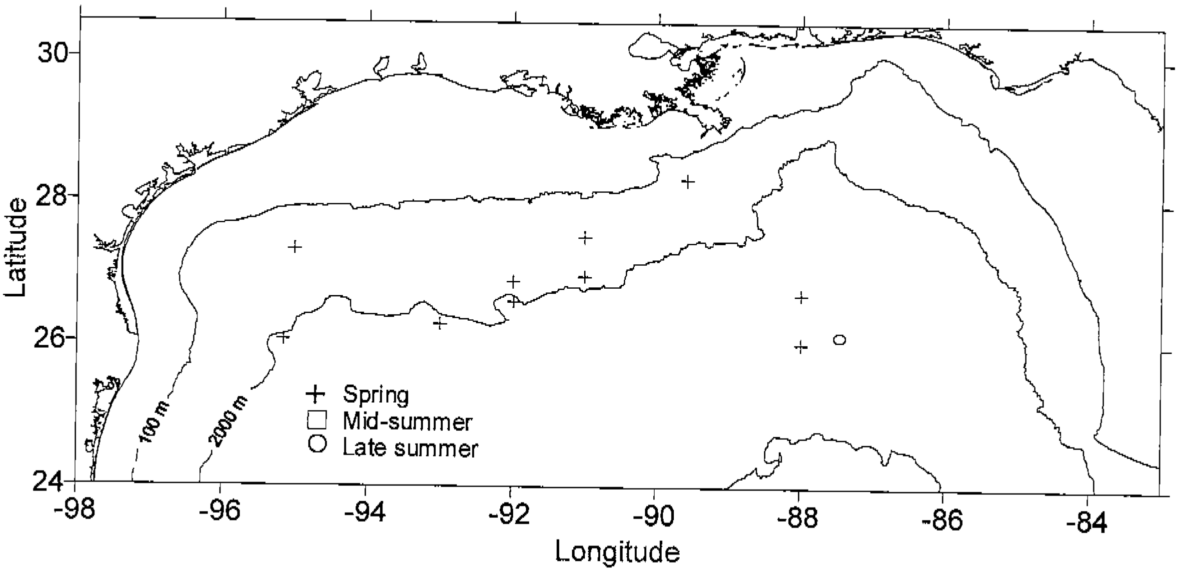

Figure 4.34. The locations of all Clymene dolphin groups sighted during *ship* surveys.

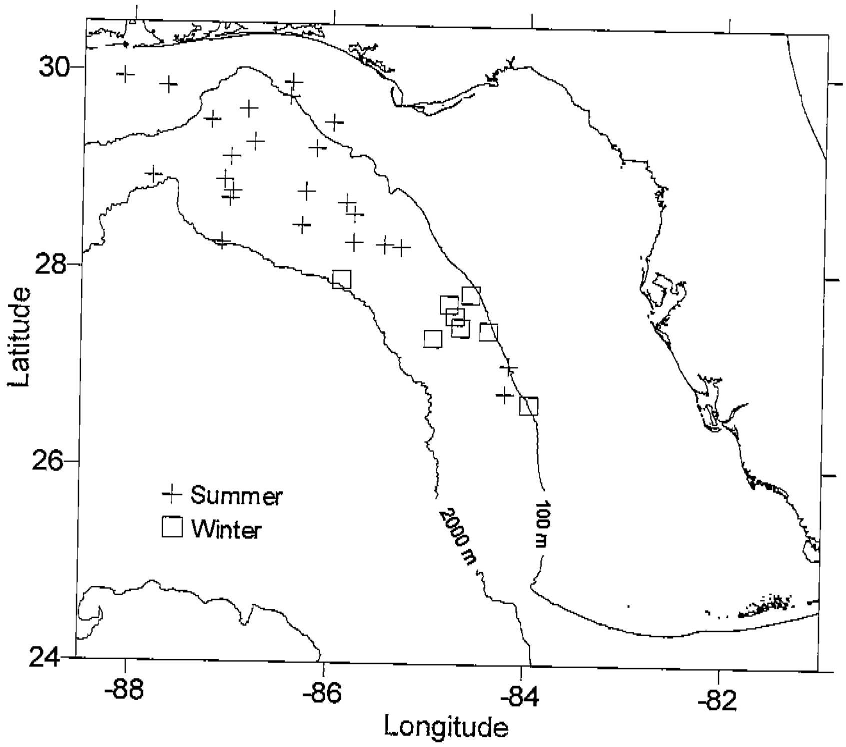

Figure 4.35. The locations of all leatherback sea turtle sightings during *aerial* surveys.

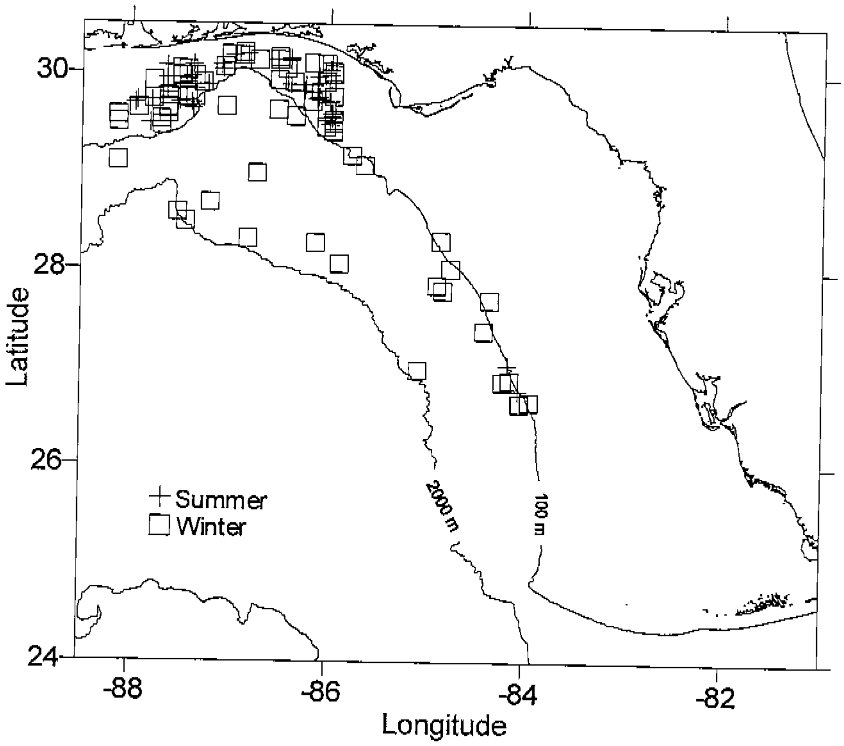

Figure 4.36. The locations of all loggerhead sea turtle sightings during *aerial* surveys.

bottlenose dolphin and nine Atlantic spotted dolphin groups were sighted (Table 4.4), and during ship surveys, 31 and 19, respectively (Table 4.9).

The overall abundance from spring ship surveys of bottlenose dolphins and Atlantic spotted dolphins was 1,056 (0.33) and 1,827 (0.46), respectively (Table 4.10). The overall abundance from aerial surveys was 1,824 (0.25) and 1,096 (0.50) for bottlenose and Atlantic spotted dolphins, respectively (Table 4.5). The abundance of bottlenose dolphins from aerial surveys during summer, 3,281 (0.37), was significantly different than the winter estimate, 1,119 (0.30) ($p<0.10$) (Table 4.6). Too few sightings of Atlantic spotted dolphins were made to examine seasonal differences in abundance.

The overall abundance of cetaceans from combined aerial surveys of the EPA shelf was 2,750 (0.24) (Table 4.7). The summer abundance, 4,232 (0.33), was about twice the winter abundance, 1,945 (0.29), but the difference was not significant ($p>0.10$). The overall abundance by survey ranged from 1,251 (0.48) for winter 1997 to 5,730 (0.48) for summer 1997.

Bottlenose dolphins were seen throughout the EPA shelf during spring, summer and winter (Figures 4.21 and 4.22). Atlantic spotted dolphins were sighted throughout the area, but few sightings were made in the extreme western portion of the area (Figures 4.25 and 4.26).

In the EPA slope, a total of 18,788 km of transects were sampled during the four seasonal aerial surveys. All of the proposed transect lines (84 lines) were completed during summer surveys (10,440 km). During winter aerial surveys, poor weather prevented all of the transects from being surveyed, and 8,348 km (80%) of the proposed effort was completed (66 lines). In total, 271 cetacean groups were sighted (154 summer, 117 winter) (Table 4.3).

In total, 2,586 km of transects were surveyed during early summer ship surveys of the EPA slope (Table 4.8). During early summer, 99 cetacean groups consisting of 12 species were sighted. Six groups (3 species) and 41 groups (6 species) were sighted during late summer and mid-summer, respectively (Tables 4.9 and 4.10).

Combining ship and aerial surveys, 17 cetacean species were sighted in the EPA slope (Table 4.14). Fifteen species were sighted during summer and 14 species in winter. Only three species were sighted during late summer when there was very little survey effort. Nine species were sighted in three or more seasons. In general, cetaceans were found throughout the study area during summer, winter and spring. However, few cetaceans were sighted in a small area in the extreme northern part of the study area during both summer and winter (Figures 4.6-4.8).

The most commonly sighted species (from aerial and ship surveys combined) in the EPA slope were bottlenose dolphins (91 and 27 sightings, respectively), pantropical spotted dolphins (53 and 37 sightings), Risso's dolphins (31 and 11 sightings) and dwarf/pygmy sperm whales (20 and 6 sightings) (Tables 4.4 and 4.9). The most abundant species from both aerial and ship surveys were the pantropical spotted and spinner dolphins. The abundance estimates of pantropical spotted dolphins were 13,649 (0.26) and 7,432 (0.40) from aerial and ship surveys, respectively (Tables 4.5 and 4.10). The abundance estimates of spinner dolphins were 8,670 (0.48) and 5,319 (0.75) from aerial and ship surveys, respectively. Other species with abundance estimates over 1,000 from aerial or ship surveys were bottlenose dolphins, Atlantic spotted dolphins, Risso's dolphins, striped dolphins, and clymene dolphins.

The summer and winter aerial survey abundance estimates of dwarf/pygmy sperm whales, bottlenose dolphins, Risso's dolphins, and pantropical spotted dolphins varied by a factor of two or more, but the difference was only significant for dwarf/pygmy sperm whales ($p<0.10$) (Table 4.6).

The overall abundance of cetaceans combined from aerial surveys was 36,517 (0.16). The summer abundance, 35,291 (0.19), was similar to the winter abundance, 38,039 (0.25). The overall abundance by survey ranged from 25,317 (0.31) for summer 1997 to 45,327 (0.24) for summer 1996 (Table 4.7).

The combined effort from the 1996 and 1997 spring ship surveys of the oceanic northern Gulf was 8,596 km (Table 4.8). This effort produced 310 cetacean group sightings (Table 4.9). Nineteen cetacean species were identified in oceanic northern Gulf waters during GulfCet II, including: 1) dwarf sperm whales and pygmy sperm whales which were each identified twice, 2) one Blainville's beaked whale, and 3) Fraser's dolphins which were sighted only during EPA slope ship surveys.

The most common species sighted were pantropical spotted dolphins (84 sightings), Risso's dolphins (36 sightings), sperm whales (33 sightings), bottlenose dolphins (26 sightings) and dwarf/pygmy sperm whales (23 sightings) (Table 4.9). By a factor of four, pantropical spotted dolphins were the most abundant species in the study area with an estimate of 46,625 (0.24) animals. This was followed by spinner dolphins with an estimate of 11,251 (0.66) and clymene dolphins with an estimate of 10,093 (0.40) animals (Table 4.11). Estimates for striped dolphins, bottlenose dolphins, Risso's dolphins, short-finned pilot whales and melon-headed whales ranged from 1,000 to 5,000. The abundance of all other species was less than 1,000 each. Cetaceans were sighted throughout the study area, but fewer were sighted in the western Gulf (Figure 4.8). The sighting rate of all cetacean groups (groups/transect km) west of 93.0°W was about half of the rate east of 93.0°W.

The abundance estimates from the GulfCet II surveys of the oceanic northern Gulf were very similar to those reported by Hansen et al. (1995) for the same area from surveys conducted from 1991-1994 (i.e., GulfCet I) (Table 4.13). However, the GulfCet II estimates were not as precise because of the smaller effort. The 1991-1994 abundance estimates were based on over 22,000 km of effort compared to 8,596 km for the GulfCet II estimates. The only significant difference in abundance was for the Atlantic spotted dolphin ($p<0.10$). Otherwise, the same species were sighted and the abundances of the more commonly sighted species were similar. These include pantropical spotted dolphins, Risso's dolphins, bottlenose dolphins, sperm whales and dwarf/pygmy sperm whales. In general, only those species for which sightings were uncommon had abundances that varied by more than a factor of two.

The combined effort from the 1996 and 1997 spring ship surveys of the GulfCet I study area was 3,596 km (Table 4.8). Fourteen cetacean species were sighted in 166 sightings (Table 4.9). The most common species sighted were pantropical spotted dolphins (41 sightings), Risso's dolphins (23 sightings), sperm whales (22 sightings), dwarf/pygmy sperm whales (14 sightings) and bottlenose dolphins (11 sightings). Pantropical spotted dolphins were the most abundant species in the study area (N= 16,141, CV =0.37) followed by clymene dolphins (6,557, 0.70), short-finned pilot whales (2,253, 0.58) and bottlenose dolphins (2,158, 0.76) (Table 4.12). Estimates for striped dolphins, Risso's dolphins and melon-headed whales ranged from 1,000 to 2,000. The abundance of all other species was less than 1,000 each.

The abundance estimates for commonly sighted species from the GulfCet II surveys of the GulfCet I study area were generally similar to those reported by Hansen et al. (1996) for the same area from spring surveys conducted from 1991-1994 (Table 4.13). These species include sperm whales, melon-headed whales, bottlenose dolphins, pantropical spotted dolphins and striped dolphins. The estimate from the GulfCet II surveys for short-finned pilot whales was about 10 times larger (but not significant, $p>0.10$), and that of Atlantic spotted dolphins was about four times smaller ($p<0.10$) than those reported by Hansen et al. (1996). The GulfCet II estimates for dwarf/pygmy sperm whales and Risso's dolphins were about two times larger but not significantly different ($p>0.10$). Because they were based on less effort, the GulfCet II estimates were not as precise as those by Hansen et al. (1996).

Seven species sighted during GulfCet I were not sighted in the GulfCet I study area during GulfCet II. These include Bryde's whales, pygmy killer whales, killer whales, false killer whales, rough-toothed dolphins and Fraser's dolphins. Sightings of these species were uncommon during GulfCet I, where the effort totaled 13,507 km. Effort during GulfCet II was about 29% of that during GulfCet I, which would reduce the chance of sighting uncommon species.

4.4.2 Species Accounts

To quickly access abundance and distribution information for each species from ship and aerial surveys of the EPA shelf and slope study areas and ship surveys of the oceanic northern Gulf, summaries for each species are provided below. Each summary includes: 1) the number of on-effort sightings (Tables 4.4 and 4.9); 2) estimates of overall mean group-size (Tables 4.5, 4.10 and 4.11); 3) the range of group-sizes based on all surveys; 4) estimates of overall abundance (Tables 4.5, 4.10 and 4.11); 5) seasonal abundance estimates from aerial surveys for those species sighted 15 or more total times (Table 4.6); and 6) a summary of distribution based on maps from all aerial and ship surveys (Figures 4.9-4.34). For each mean group-size and abundance estimate, the coefficient of variation (CV) of the estimate is given in parentheses.

Bryde's whales were sighted three times during ship surveys and two times during aerial surveys. Group-sizes averaged 2.3 (0.56) and 4.0 (0.75) animals from ship and aerial surveys of the EPA slope, respectively, and 2.0 (one sighting) animals from ship surveys of the oceanic northern Gulf. Group-sizes ranged from 1 to 7 animals. Abundance estimates were 29 (1.05) and 25 (1.06) from ship and aerial surveys of the EPA slope, respectively, and 22 (1.07) for the oceanic northern Gulf. All Bryde's whale sightings occurred in the EPA slope near the 100 m isobath (Figures 4.9 and 4.10). Bryde's whales were sighted in each of the three survey seasons.

Sperm whales were sighted 60 times during ship surveys and 10 times during aerial surveys. Group-sizes averaged 3.0 (0.28) and 1.5 (0.18) animals from ship and aerial surveys of the EPA slope, respectively, and 1.4 (0.15) animals from ship surveys of the oceanic northern Gulf. Group-sizes ranged from 1 to 6 animals. Abundance estimates were 57 (0.57) and 37 (0.42) from ship and aerial surveys of the EPA slope, respectively, and 387 (0.45) for the oceanic northern Gulf. Almost all sperm whale sightings were in the north-central and northeastern Gulf (Figures 4.11 and 4.12). There was a concentration of sightings near the Mississippi River delta. Sperm whale sightings in the EPA slope occurred primarily near the 1,000 m isobath in the northern half of the study area. Sperm whales were sighted in each survey season in the EPA slope and oceanic northern Gulf.

Dwarf/pygmy sperm whales were sighted 33 times during ship surveys and 20 times during aerial surveys. During ship surveys, dwarf sperm whales and pygmy sperm whales were each identified twice. Group-sizes averaged 1.0 (0.00) and 1.8 (0.19) animals from ship and aerial surveys of the EPA slope, respectively, and 2.2 (0.17) animals from ship surveys of the oceanic northern Gulf. Group-sizes ranged from 1 to 6 animals. Abundance estimates were 66 (0.74) and 188 (0.31) from ship and aerial surveys of the EPA slope, respectively, and 733 (0.53) for the oceanic northern Gulf. Seasonal abundance in the EPA slope was 36 (0.68) in winter and 311 (0.33) for summer. Dwarf/pygmy sperm whales were widely distributed in the oceanic northern Gulf including the EPA slope (Figures 4.13 and 4.14). One sighting occurred in the EPA shelf. Dwarf/pygmy sperm whales were sighted during each survey season in the oceanic northern Gulf and the EPA slope.

Cuvier's beaked whales were sighted four times during ship surveys and three times during aerial surveys. Group-sizes averaged 2.0 (0.50) animals from aerial surveys of the EPA slope and 2.8 (0.33) animals from ship surveys of the oceanic northern Gulf. Group-sizes ranged from 1 to 4 animals. Abundance estimates were zero and 22 (0.83) from ship and aerial surveys of the EPA slope, respectively, and 159 (0.69) for the oceanic northern Gulf. Cuvier's beaked whales were sighted on the lower continental slope near the 2,000 m isobath and beyond (Figures 4.15 and 4.16). At these depths, sightings were widely distributed in the oceanic northern Gulf and the EPA slope. Cuvier's beaked whales were sighted during each survey season in the oceanic northern Gulf and in summer in the EPA slope.

Beaked whales of the genus *Mesoplodon* were sighted eight times during ship surveys and five times during aerial surveys. One of the eight ship sightings of beaked whales from the ship was determined to be a Blainville's beaked whale. Group-sizes averaged 2.2 (0.22) animals from aerial surveys of the EPA slope and 1.1 (0.13) animals from ship surveys of the oceanic northern Gulf. Group-sizes ranged from 1 to 4 animals. Abundance estimates were zero and 59 (0.51) from ship and aerial surveys of the EPA slope, respectively, and 150 (0.50) for the oceanic northern Gulf. In general, *Mesoplodon* spp. were broadly distributed in waters greater than 1,000 m deep in the oceanic northern Gulf (Figures 4.17 and 4.18). All EPA sightings were in the southern part of the study area. *Mesoplodon* spp. were sighted in each season surveyed in the oceanic northern Gulf and in summer and winter in the EPA slope.

One melon-headed whale group of 125 was sighted during the study. It occurred in the northwestern Gulf during a spring survey of the oceanic northern Gulf (Figures 4.20). The abundance for the oceanic northern Gulf was estimated to be 1,734 (1.07).

Bottlenose dolphins were sighted 92 times during ship surveys and 152 times during aerial surveys. In the EPA shelf, group-sizes averaged 8.7 (0.13) and 7.3 (0.19) animals from ship and aerial surveys, respectively. Group-sizes ranged from 1 to 90 animals. Abundance estimates were 1,056 (0.33) and 1,824 (0.25) from ship and aerial surveys of the EPA shelf, respectively. Seasonal abundance in the EPA shelf was 1,119 (0.30) in winter and 3,281 (0.37) in summer.

In the EPA slope, bottlenose dolphin group-sizes averaged 9.6 (0.43) and 9.9 (0.16) animals from ship and aerial surveys, respectively, and 13.1 (0.37) animals from ship surveys of the oceanic northern Gulf. Group-sizes ranged from 1 to 172 animals. Abundance estimates were 1,025 (0.56) and 3,959 (0.22) from ship and aerial surveys of the EPA slope, respectively, and 3,040 (0.55) for the oceanic northern Gulf. Seasonal abundance in the EPA slope was 7,291 (0.35) in winter and 2,980 (0.27) in summer.

Bottlenose dolphins were sighted throughout the EPA shelf and were widely distributed on the upper EPA slope (100-1,000 m) (Figures 4.21 and 4.22). West of 88°W, bottlenose dolphins were widely distributed but occurred much closer to 100 m isobath. Bottlenose dolphins were sighted during each survey season in the oceanic northern Gulf, EPA slope and EPA shelf.

Risso's dolphins were sighted 47 times during ship surveys and 31 times during aerial surveys. Group-sizes averaged 9.9 (0.20) and 8.8 (0.23) animals from ship and aerial surveys of the EPA slope, respectively, and 8.4 (0.14) animals from ship surveys of the oceanic northern Gulf. Group-sizes ranged from 1 to 57 animals. Abundance estimates were 679 (0.67) and 1,317 (0.32) from ship and aerial surveys of the EPA slope, respectively, and 3,040 (0.30) for the oceanic northern Gulf. Seasonal abundance in the EPA slope was 2,007 (0.39) in winter and 761 (0.51) in summer. Risso's dolphins were widely distributed along the mid-slope in the EPA slope (Figures 4.23 and 4.24). In the oceanic northern Gulf, no groups were sighted in the extreme western Gulf. Elsewhere, they were widely distributed, but concentrations occurred on the upper slope near the Mississippi River delta. Risso's dolphins were sighted during each survey season in both the oceanic northern Gulf and EPA Slope.

Atlantic spotted dolphins were sighted 32 times during ship surveys and 24 times during aerial surveys. In the EPA shelf, group-sizes averaged 18.9 (0.23) and 31.8 (0.25) animals from ship and aerial surveys, respectively. Group-sizes ranged from 3 to 75 animals. Abundance estimates were 1,827 (0.46) and 1,096 (0.50) from ship and aerial surveys of the EPA shelf, respectively.

In the EPA slope, Atlantic spotted dolphin group-sizes averaged 23.1 (0.17) and 24.8 (0.43) animals from ship and aerial surveys, respectively, and 13.6 (0.11) animals from ship surveys of the oceanic northern Gulf. Group-sizes ranged from 1 to 85 animals. Abundance estimates were 1,055 (0.66) and 1,800 (0.43) from ship and aerial surveys of the EPA slope, respectively, and 528 (0.69) for the oceanic northern Gulf. Seasonal abundance in the EPA Slope was 1,758 (0.55) in winter and 1,126 (0.42) for summer.

Atlantic spotted dolphins were widely distributed on the EPA shelf, but fewer groups were sighted in the western portion of the study area (Figures 4.25 and 4.26). They were widely distributed in both the EPA slope and oceanic northern Gulf, but occurred only in the shelf-edge region near the 100 m isobath. Atlantic spotted dolphins were sighted during each survey season in the oceanic northern Gulf, EPA shelf, and EPA slope.

Pantropical spotted dolphins were sighted 129 times during ship surveys and 53 times during aerial surveys. Group-sizes averaged 50.4 (0.24) and 67.4 (0.13) animals from ship and aerial surveys of the EPA slope, respectively, and 45.4 (0.13) animals from ship surveys of the oceanic northern Gulf. Group-sizes ranged from 5 to 650 animals. Abundance estimates were 7,432 (0.40) and 13,649 (0.26) from ship and aerial surveys of the EPA slope, respectively, and 46,625 (0.24) for the oceanic northern Gulf. Seasonal abundance in the EPA slope was 8,226 (0.36) in winter and 18,020 (0.29) in summer. Pantropical spotted dolphins were sighted well away from the shelf edge, but otherwise throughout all waters searched in the oceanic northern Gulf and EPA slope (Figures 4.27 and 4.28). Pantropical spotted dolphins were sighted during each survey season in both the oceanic northern Gulf and EPA slope.

Striped dolphins were sighted 13 times during ship surveys and eight times during aerial surveys. Group-sizes averaged 25.4 (0.17) and 66.7 (0.26) animals from ship and aerial surveys of the EPA slope, respectively, and 79.0 (0.11) animals from ship surveys of the oceanic northern Gulf. Group-sizes ranged from 2 to 160 animals. Abundance estimates were 416 (0.96) and 2,198 (0.50) from ship and aerial surveys of the EPA slope, respectively, and 4,381 (0.55) for the oceanic northern Gulf. Striped dolphins were sighted away from the shelf edge and were widely distributed in the EPA slope and in eastern oceanic Gulf; none were sighted in the extreme western Gulf (Figures 4.29 and 4.30). Striped dolphins were sighted during each survey season in the oceanic northern Gulf and EPA slope.

Spinner dolphins were sighted 17 times during ship surveys and seven times during aerial surveys. Group-sizes averaged 216.4 (0.51) and 263.1 (0.28) animals from ship and aerial surveys of the EPA slope, respectively, and 101.4 (0.46) animals from ship surveys of the oceanic northern Gulf. Group-sizes ranged from 15 to 750 animals. Abundance estimates were 5,319 (0.75) and 8,670 (0.48) from ship and aerial surveys of the EPA slope, respectively, and 11,251 (0.66) for the oceanic northern Gulf. Spinner dolphins were sighted away from the shelf edge and were widely distributed in the EPA slope and in northeastern oceanic Gulf. None were sighted west of the Mississippi River (Figures 4.31 and 4.32). Spinner dolphins were sighted during each survey season in the oceanic northern Gulf and EPA slope.

Clymene dolphins were sighted 11 times during ship surveys and five times during aerial surveys. Group-sizes averaged 97.4 (0.22) animals from aerial surveys of the EPA slope and 90.1 (0.18) animals from ship surveys of the oceanic northern Gulf. Group-sizes ranged from 4 to 150 animals. Abundance estimates were zero and 2,292 (0.52) from ship and aerial surveys of the EPA slope, respectively, and 10,093 (0.40) for the oceanic northern Gulf. Clymene dolphins were sighted well away from the shelf edge and were widely distributed in western oceanic Gulf during spring and in the northeastern Gulf during summer and winter (Figures 4.33 and 4.34). Clymene dolphins were sighted during each survey season in the oceanic northern Gulf, and in summer and winter in the EPA slope.

4.4.3 Distribution, Density, and Abundance of Sea Turtles

Three species of sea turtles were sighted in the EPA shelf area: 85 loggerheads, four leatherbacks and three Kemp's ridleys. Ten unidentified chelonid sea turtles were also recorded. Overall and seasonal abundances of loggerheads were estimated. Because of small sample sizes, only the overall abundance of leatherbacks and Kemp's ridleys were estimated (Table 4.16).

The overall abundance of loggerhead sea turtles in the EPA shelf was 503 (0.20). Loggerhead sea turtle abundances were similar during summer and winter with 480 (0.30) and 524 (0.23), respectively (Table 4.16). Loggerhead sea turtles were sighted throughout the EPA Shelf during both summer and winter (Figure 4.36). Estimates of abundance for leatherback and Kemp's ridley sea turtles were 24 (0.48) and 12 (1.14) turtles, respectively. There were an estimated 42 (0.45) unidentified chelonids (These were probably loggerheads). The four sightings of leatherback sea turtles were widely distributed (Figure 4.35).

In the EPA slope, two species of sea turtles were sighted: 28 leatherbacks and 27 loggerheads. Six unidentified chelonid sea turtles were also recorded. Overall and seasonal abundances of leatherbacks and loggerheads were estimated (Table 4.16). The overall abundance estimate of leatherback sea turtles in EPA slope was 168 (0.23) turtles. Leatherback sea turtles were about 2.5 times more abundant in summer than winter with estimates of 230 (0.58) and 90 (0.48), respectively (Table 4.16). However, the difference was not significant ($p>0.10$). Leatherback sea turtles were sighted throughout the EPA slope. However, the majority of the summer sightings occurred in the northeastern part of the study area, whereas the winter sightings were concentrated to the southeast (Figure 4.35).

The overall abundance estimate of loggerheads was 141 (0.27). Loggerhead sea turtles were about 12 times more abundant in winter than summer with estimates of 286 (0.27) and 24 (0.77), respectively. The difference was significant ($p<0.10$). Loggerhead sea turtles were sighted throughout the EPA slope during winter. Many of the sightings occurred near the 100 m isobath (Figure 4.36).

4.5 Discussion

The results from this study of cetacean abundance and distribution are similar to those from previous studies of the northern Gulf of Mexico (Fritts et al. 1983, Blaylock and Hoggard 1994, Mullin et al. 1994c, Hansen et al. 1995, Hansen et al. 1996, Jefferson 1996, Mills and Rademacher 1996, Mullin and Hansen, in press). Bottlenose dolphins and Atlantic spotted dolphins inhabit the continental shelf and shelf-edge region almost exclusively. The oceanic cetacean community in the northern Gulf is composed of at least 19 species that usually inhabit deep, tropical waters. With exception of the clymene dolphin, which is endemic to warm Atlantic basin waters, these deep-water species have distributions that are pantropical (e.g., melon-headed whale, spinner dolphin) or broader (e.g., killer whale, sperm whale) (Jefferson et al. 1993).

Compared to other parts of the world, maximum group-sizes in the northern Gulf were generally small, and groups were almost exclusively made up of a single species. During this study, the largest group sighted was 750 spinner dolphins (27.5°N, 85.0°W). In the eastern tropical Pacific, the northwestern Atlantic, and the Pacific adjacent to California, many of the same species occur in groups that commonly exceed 1,000 animals and routinely occur in multi-cetacean species groups (Leatherwood and Reeves 1983, CeTAP 1982, Barlow 1995, Forney et al. 1995).

4.5.1. Temporal Distribution

Most of the cetacean species that are routinely sighted in the northern Gulf of Mexico apparently occur throughout the year. Including the results of this study, there are sighting records from three or more seasons of at least 16 cetacean species (Mullin et al. 1994c, Hansen et al. 1995, 1996, O'Sullivan and Mullin 1997). The seasonal abundance of several species in slope waters (e.g., dwarf/pygmy sperm whale, Risso's dolphin and pantropical spotted dolphins) may vary at least regionally. However, the seasons of a species' maximum or minimum abundance are not consistent among studies.

Hansen et al. (1996) estimated cetacean abundances for all four seasons for the GulfCet I study area. They reported maximum abundances of dwarf/pygmy sperm whales in summer and spring. Abundance estimates of Risso's dolphins in the fall were about 20% of those in the other three seasons, and the minimum abundance for pantropical spotted dolphins occurred during fall. In the EPA slope where surveys were only conducted during winter and summer, dwarf/pygmy sperm whales were estimated to be more than eight times as abundant in summer than winter ($p<0.10$) (Table 4.6). While in the EPA slope the differences were not significant ($p>0.10$), the winter and summer abundances of Risso's dolphins and pantropical spotted dolphins had opposite patterns; Risso's dolphins were most abundant in winter and pantropical spotted dolphins in summer.

Synoptic surveys of the oceanic northern Gulf have been conducted only during the spring (Hansen et al. 1995). No synoptic surveys have been conducted in the southern Gulf. Therefore, it cannot be determined whether a decline in a species' abundance in one region is matched by an increase in another. The overall abundance of cetaceans in the EPA slope was similar for summer and winter, but inter-survey abundances were more variable (Table 4.7). Hansen et al. (1996) reported a marked decline in the abundance of cetaceans during fall in the GulfCet I study area, with the other three seasons remaining similar.

The abundance of bottlenose dolphins in the EPA shelf was about three times larger in summer than winter ($p<0.10$) (Table 4.6). Scott et al. (1989) reported similar or greater seasonal variability in the abundance of bottlenose dolphins for small regions of the continental shelf in the northern Gulf, but the overall abundances for the entire continental shelf were seasonally similar.

4.5.2 Spatial Distribution

Except for the sperm whale, commonly sighted species in the EPA slope were widely distributed in the study area, albeit in many cases, at different depth ranges. Within the study area, there was no evidence of seasonal shifts in the distribution of all cetaceans in general or of each species. However, sightings of many species were too few in at least one season to speculate about seasonal differences in their spatial distributions. While there was no evidence of seasonal shifts in the locations of sightings within the study area, seasonal abundance patterns indicate that many individuals may move completely out of the study area during different seasons. Results from the GulfCet I study area were similar (Hansen et al. 1996, Davis et al. 1998).

Cetaceans were sighted throughout the oceanic northern Gulf (Figure 4.8). However, sighting rates of cetacean groups were about 80% larger east of 90.0°W compared to west. With a few exceptions noted below, the distributional results for the oceanic northern Gulf for most species were similar to previous studies (Mullin et al. 1994a and 1994b, Hansen et al. 1995, Hansen et al. 1996, O'Sullivan and Mullin 1997).

Bottlenose dolphins and Atlantic spotted dolphins were most commonly sighted in association with the continental shelf edge throughout the northern Gulf, generally near the 100 m isobath. With few exceptions, Bryde's whales were found along a narrow corridor near the 100 m isobath in the northeastern Gulf. Spinner dolphins were found primarily in the north-central and northeastern Gulf. Short-finned pilot whales and melon-headed whales were found almost exclusively in the north-central and northwestern Gulf. Pantropical spotted dolphins and striped dolphins occurred throughout the northern Gulf, but sightings of both species were rare in the extreme northwestern Gulf. Killer whales ranged throughout the northern Gulf, but most sightings occurred in a broad, but distinct region southwest of the Mississippi River delta.

Dwarf/pygmy sperm whales were found throughout the northern Gulf. These two species are very cryptic, and apparent clumps in their distribution may result because sightings only occur during excellent survey conditions. Sperm whales were also found throughout the northern Gulf, but there was usually an aggregation of sightings along the 1,000 m isobath near the Mississippi River delta. Risso's dolphins were concentrated in areas along the upper continental slope, but sightings were made throughout the northern Gulf (Baumgartner 1997, Davis et al. 1998).

False killer whales, pygmy killer whales and Fraser's dolphins were uncommon but widely distributed. *Mesoplodon* spp. and Cuvier's beaked whale were widely distributed in deep water (usually >1,000 m). In previous studies, nearly all sightings of rough-toothed dolphins and clymene dolphins were west of the Mississippi River delta, but during GulfCet II both species were sighted east of the delta. Also, bottlenose dolphins were found much further from the 100 m isobath in the northeastern Gulf where, compared to the rest of the northern Gulf, the continental slope is less precipitous to a depth of about 1,000 m. In contrast to previous studies, no striped dolphins or sperm whales were sighted in the northwestern Gulf during GulfCet II.

4.5.3 Cetacean Abundance

The oceanography of the northern Gulf is very dynamic, and there are distinct differences between the northwestern and northeastern Gulf (see Chapter 2). The cetacean distribution plots indicate that there are potential differences in species occurrence between the two regions. However, the plots may not reflect actual differences in abundance because effort was not uniformly distributed, and the plots are of groups that vary greatly in size. Density estimates from the two regions provide a more meaningful comparison. The densities of cetacean species from the GulfCet I study area from spring ship surveys reported by Hansen et al. (1995) are

Table 4.17. Comparison of density estimates (D = animals/100 km^2) of cetaceans from the GulfCet I study area to those from the EPA continental slope study area (EPA slope) as assessed by *ship* and *aerial* surveys. (Aerial survey estimates in bold are significantly different from the Ship Survey 91-94 estimates, $p<0.10$).

	NW Slope		EPA Slope	
Species	Ship Survey 91-94[1] D (CV)	Ship Surveys 96-97[2] D (CV)	Ship Surveys D (CV)	Aerial Surveys D (CV)
Bryde's whale	0.003 (0.85)	0	0.041 (1.05)	0.035 (1.06)
Sperm whale	0.160 (0.30)	0.149 (0.56)	0.081 (0.57)	**0.052 (0.42)**
Dwarf/pygmy sperm whale	0.122 (0.35)	0.299 (0.64)	0.094 (0.74)	0.267 (0.31)
Cuvier's beaked whale	0.015 (0.43)	0.051 (0.90)	0	0.031 (0.83)
Melon-headed whale	1.663 (0.38)	1.040 (0.97)	0	0
Pygmy killer whale	0.037 (0.68)	0	0	0.309 (0.75)
Killer whale	0.073 (0.48)	0	0	0
False killer whale	0.011 (0.67)	0	0.411 (0.97)	0.213 (1.06)
Short-finned pilot whale	0.150 (0.51)	1.457 (0.58)	0	0.267 (1.01)
Rough-toothed dolphin	0.143 (0.39)	0	0.023 (0.96)	0.234 (1.02)
Fraser's dolphin	0.067 (1.24)	0	1.337 (1.01)	0
Bottlenose dolphin	2.158 (0.30)	1.396 (0.76)	1.455 (0.56)	**5.617 (0.22)**
Risso's dolphin	0.520 (0.27)	1.166 (0.38)	0.960 (0.67)	**1.869 (0.32)**
Atlantic spotted dolphin	0.905 (0.42)	0.211 (0.77)	1.498 (0.66)	2.555 (0.43)
Pantropical spotted dolphin	6.596 (0.23)	10.439 (0.37)	10.547 (0.40)	**19.369 (0.26)**
Striped dolphin	1.872 (0.54)	1.110 (0.76)	0.591 (0.96)	3.119 (0.50)
Spinner dolphin	0.850 (0.64)	0	7.548 (0.75)	**12.302 (0.48)**
Clymene dolphin	1.893 (0.38)	4.241 (0.70)	0	3.253 (0.52)

1- GulfCet I, Hansen et al. (1996); 2 - GulfCet II, this study hawksbill is usually associated with reefs or similar habitats in tropical and subtropical waters and is thought to be rare in the northeastern Gulf of Mexico. The green turtle, a herbivore, is restricted to warm shallow waters with sea grass beds (National Research Council 1990). Both loggerhead and Kemp's ridley sea turtles are known to occur on the continental shelf throughout the northern Gulf of Mexico. Studies indicate that adult loggerheads and Kemp's ridley are benthic carnivores (Dodd 1988). The leatherback, which feeds primarily on jellyfish, is the most oceanic of the sea turtles. However, its distribution is not entirely oceanic, and it is commonly found in continental shelf waters along the Atlantic coast of the United States (Hoffman and Fritts 1982). Leatherbacks also occur on the continental shelf in the northern Gulf of Mexico (Fritts et al. 1983, Lohoefener et al. 1988, 1990).

The overall density of loggerhead sea turtles in the EPA shelf (4.08 turtles/100 km^2) was 20 times that of the EPA slope. The majority of loggerheads in the EPA slope (19/21) were sighted during winter. While many winter sightings were near the 100 m isobath, as in GulfCet I, there were sightings of loggerheads over very deep waters (i.e., >1000 m). It is not clear why adult loggerheads would occur in oceanic waters unless they were traveling between foraging sites on distant and disjunct areas of the continental shelf or seeking warmer waters during winter. The density of loggerheads in the GulfCet I study area was 0.048 turtles/100 km^2 (Hansen et al. 1996), about 25% of that for the EPA slope. The abundance of sea turtles in the Gulf of Mexico appears to increase dramatically east of Mobile Bay (NMFS unpublished data). Lohoefener et al. (1990) found a maximum density of 0.50 turtles/100 km^2 in continental shelf waters off Louisiana west of the Mississippi River.

Based on a summary of several studies, Hansen et al. (1996) concluded that in the northwestern Gulf the primary habitat of the leatherback sea turtle was oceanic (>200 m). In contrast, the overall densities of leatherback sea turtles in the EPA shelf and slope were similar, with estimates of 0.19 turtles/100 km^2 (0.48) and 0.24 turtles/100 km^2 (0.23), respectively. Seasonal differences in leatherback densities were not noted for the GulfCet I study area (Hansen et al. 1996). In the EPA slope, the summer density of leatherbacks was about twice that of winter, but the difference was not significant ($p>0.10$).

The overall density estimate of leatherbacks during GulfCet I (0.18 turtles/100 km^2 [0.19]) was similar to GulfCet II values. Comparatively few leatherbacks were sighted during fall SEFSC surveys of the entire northern Gulf of Mexico continental shelf (NMFS, SEFSC unpublished data). However, the majority of the sightings occurred just north of DeSoto Canyon in the vicinity of the EPA shelf. The nearly disjunct summer and winter distributions of leatherbacks indicates that specific areas may be important to this species either seasonally or for short periods of time. During the GulfCet I surveys, leatherback sightings were concentrated, indicating that their distribution patterns were irruptive in nature.

In summary, the GulfCet II aerial surveys provided the first assessment of sea turtle abundance and distribution over a large area of the oceanic northeastern Gulf of Mexico. Three sea turtle species occurred in the EPA study areas: loggerhead, Kemp's ridley, and leatherback sea turtles. The significance of the oceanic Gulf to loggerheads is not clear. However, the leatherback sea turtle, an endangered species, occurred in significant numbers inhabited the study areas during both summer and winter.

4.5.5 Bias

Without correction, both aerial and ship surveys should result in negatively biased abundance estimates (i.e., estimates are smaller than the actual number of animals). In theory, because the aircraft moves about 10 times faster than the ship, ship surveys should be less biased if availability bias is the primary source of bias (i.e., cetaceans below the surface, see below). While seasonal differences in abundance could certainly be a confounding factor, aerial survey abundances were larger than those from ship surveys for commonly sighted species in the EPA (Table 4.17). This could result from aerial observer's ability to see below the surface into the relatively clear slope waters and sight animals that would missed by shipboard observers. While no specific analysis was conducted, aerial surveys were probably conducted in better sighting conditions overall than ship surveys because researchers can be more selective of the survey conditions. Also, in less than optimal conditions (Beaufort sea state $\geq$3), cetaceans are probably seen more easily from aircraft than ships. Results from the EPA shelf were mixed when comparing aerial and ship abundance estimates. The abundance of bottlenose dolphins was larger from aircraft surveys, but the abundance for Atlantic spotted dolphins was larger from ship surveys. Despite differences in possible bias between aerial and shipboard surveys, only the abundance estimates for bottlenose dolphins were significantly different ($p<0.10$) between the two methods.

Both the aerial and ship abundance surveys were designed to meet the assumptions of line-transect theory (Buckland et al. 1993). Meeting the central assumption, that objects on the transect line are detected with certainty ($g(0) = 1$) is problematic with cetacean and sea turtle surveys. Because this assumption is violated in most cases, the abundances reported here are most certainly negatively biased ($g(0) < 1$). There are two types of bias: “availability bias” and “perception bias” (Marsh and Sinclair 1989). Cetaceans and sea turtles dive and can remain out of view during the time the survey platform is in the area. As a result, some groups on the transect line are missed because they are not “available” to be seen. Other groups on the transect line are available to be seen but are missed (not perceived) by observers.

The degree of availability bias is species and platform dependent (e.g., aircraft vs. ship, see below). Because different cetacean species feed at different depths in the water column, they have different dive cycles. For example, sperm whales have very long average dive times, whereas dive time is probably much shorter for all dolphin species. The probability that a sperm whale will be at the surface in the area that is being searched is much less than for most dolphins. Therefore, negative bias is greater for the sperm whale. Unless the dives of all members of a group are synchronous, group-size and group diving behavior is also a factor that affects availability bias. The larger the group, the higher the probability that at least one animal from the group will be on the surface. The degree of diving synchrony and the length of the dive cycle also could bias the assumption that all members of a group are counted.

The magnitude of perception bias is dependent on cetacean group-size, behavior and sighting conditions (e.g., Beaufort sea state). Large groups and/or active groups are less likely to be missed than small groups, resting groups or species whose behavior does not produce pronounced cues (e.g., blows, splashes). For example, abundance estimates for pantropical spotted dolphins are probably less negatively biased because they occur in large active groups least 16 cetacean species inhabited continental slope waters of the northeastern Gulf. Bottlenose dolphins were most common in terms of the number of sightings, but pantropical spotted dolphins and spinner dolphins occurred in much larger groups, and were the most abundant species. Comparisons of summer and winter abundance of commonly sighted species from slope waters indicated that dwarf/pygmy sperm whales and pantropical spotted dolphins may be more abundant during summer, whereas Risso's dolphins may be more abundant during winter. Loggerhead and leatherback sea turtles occurred in slope waters. Leatherbacks were widely distributed in slope waters and may have been more abundant during summer; loggerheads were much more abundant during winter. At least 17 cetacean species occurred in the oceanic northern Gulf, and pantropical spotted dolphins was the most abundant species. GulfCet II abundance estimates for the oceanic northern Gulf were similar to previous estimates based on 1991-1994 GulfCet I surveys.

Chapter 5

An Acoustic Survey of Cetaceans in the Northern Gulf of Mexico

Jeffrey C. Norris, William E. Evans and Shannon Rankin

5.1 Introduction

The primary purpose of the acoustic survey was to describe the distribution and habitats of cetaceans in the northeastern Gulf of Mexico based on species-specific vocalizations detected by a towed hydrophone array. In addition, this survey recorded man-made noise that could impact cetaceans. This information might prove useful in the management of future oil and gas development in the Gulf.

Visual and acoustic surveys of cetaceans in the northern Gulf were conducted during GulfCet I (Norris et al. 1996). Sperm whale density estimates were based on aerial visual, shipboard visual and shipboard acoustic surveys. The shipboard visual and shipboard acoustic density estimates (2.02 vs. 2.04 animals per 1000 km^2) were not significantly different using the criteria of non-overlap of 95% CI. Likewise, abundance estimates for sperm whales using acoustic and shipboard visual data were essentially identical: 316 and 313 animals, respectively. The acoustic survey estimated the presence of more dolphins in the study area than the other survey techniques. The most meaningful comparison is group density, since it avoids the estimation of group size. Using acoustic methods, the estimated group density was 8.08 groups/1000 km^2 compared to 4.39 groups/1000 km^2 for the shipboard visual survey and 4.95 groups/1000 km^2 for the aerial survey. The dolphin abundance estimates from the GulfCet I study were 1.98 times greater (36,760) than the minimum shipboard visual survey estimates (18,584) (Norris et al. 1996).

Other acoustic surveys, some using fixed arrays and others using towed systems, have been performed. Bowhead whales (*Balaena mysticetus*) were surveyed as they migrated past a linear hydrophone array that was fixed to the shore-fast ice at Pt. Barrow, Alaska (Clark et al. 1986, Clark and Ellison 1988). Other studies used concurrent visual and acoustic survey methods (Zeh et al. 1988). There have been two attempts to develop acoustic survey techniques to count and study the behavior of sperm whales. Investigators used multiple hydrophones to determine three-dimensional locations of vocalizing sperm whales in the Caribbean Sea (Watkins and Schevill 1977a) and the North Atlantic (Leaper et al. 1992). Leaper et al. used paired arrays to determine sperm whale locations, but determining the position of one array relative to the other proved difficult. Goold (1996) and Goold and Fish (1998) conducted an acoustic survey of common dolphins (*Delphinus delphis*) off the coast of Wales to determine if seismic exploration affected their distribution. They observed localized disturbances to animals within a distance of about 1 km from high source levels. They also showed that pulses from a 2,120 cubic inch air gun array have appreciable energy to at least 15 kHz. Jay Barlow (NMFS, personal comm.) recently completed an extensive acoustic survey in the eastern tropical Pacific.

Acoustic surveys significantly out-perform ship-based visual surveys (in terms of encounters per transect length) where the two methods have been directly compared (Thomas et al. 1986).

During GulfCet I, encounter rates were 22% higher for the acoustic survey than the concurrent visual survey. The acoustic survey was on effort 95% of the available time for the GulfCet cruises: total acoustic effort was 12,219 km. Poor weather can prevent visual sightings, whereas acoustic detection is rarely degraded by weather. Similarly, acoustic surveys can continue at night whereas visual surveys must stop. During GulfCet I, 65% of dolphin contacts were at night even though acoustic survey effort was evenly divided between night and day. In addition, acoustic surveys create a permanent record in the form of tape recordings that document encounters and permit future analysis. By making tape recordings of sounds heard during the survey, future researchers can verify survey results, identify and count vocalizations (and possibly individuals), and describe biases. These recordings also allow comparisons of the present acoustic environment in the northern Gulf with recordings made during future surveys.

Fourteen delphinid species are found in the northern Gulf of Mexico (Table 1.2). Relative to our ability to identify their vocalizations, these 14 species can be divided into three groups according to the size of their recorded whistle repertoire:

1) species with adequate recordings or with sufficiently distinctive vocalizations, such as the sperm whale, killer whale, and pantropical spotted dolphin.
2) common species for which there are few or no recordings, such as the Risso's dolphin
3) rare species for which there are few or no recordings, for example, Fraser's dolphin

During GulfCet I (Norris et al. 1996), recordings were made day and night and during all weather conditions. Because there was significant acoustic effort when it was impossible to visually confirm the identity of the animal, there remains a need to develop procedures to identify the source of cetacean signals in the absence of visual identification.

Characterizing the acoustic features of marine mammal signals has been attempted by a number of investigators. Fristrup and Watkins (1992) used a large set of parameters to characterize a variety of vocalizations from pinnipeds, whales and dolphins. Their goal was an automated, machine-based identification system. Steiner (1981) and Wang (1993) used a series of acoustical parameters to differentiate dolphin signals.

The difficulty in identifying an acoustic contact varies with each species. Some species are easily identified; killer whales and sperm whales, for example, have distinctive vocalizations. Other species are less easily identified. In the Gulf of Mexico, there are several closely related dolphin species (e.g., five stenellid species) with vocalizations that sound similar (to us). There are also species whose vocalizations are poorly known. For example, during GulfCet I, we made the first recordings of Fraser's dolphin (Leatherwood et al. 1993). Most of the effort described below has focused on describing the acoustic patterns and creating a classification system for the more commonly recorded cetaceans encountered in the GulfCet study area.

Many signals are used in the marine geophysical survey industry, including those used for bottom and sub-bottom profiling and to position towed hydrophone arrays. The physical characteristics of these seismic signals vary, especially the amplitude and, therefore, the distance they may affect animals. Use of intense, low frequency seismic sounds for oil exploration has been increasing in offshore waters (MMC 1998). Typical sub-bottom profiling signals (hereafter called seismic exploration signals) may have source intensities greater than 220 dB re 1 μPa at 1m, with the primary energy occurring below 500 Hz (Richardson et al. 1995). Air guns, water guns, sparkers and boomers produce these signals; each type generates different frequencies and amplitude levels (Richardson et al. 1995). The frequencies are generally lower than those used in odontocete vocalizations. However, the high intensity and regular presence of seismic exploration in the northern Gulf of Mexico has raised concerns regarding its potential impact on cetaceans.

5.2 Study Area

Acoustic surveys were conducted in the Eastern Planning Area (EPA continental shelf and slope) and adjoining offshore waters (Figure 1.2) during the late summer 1996 (Gyre96G06, October 10-29) and mid-summer 1997 (Gyre97G08, August 4-22) *Gyre* cruises. During these surveys, we made hydrophone recordings in different hydrographic features that might influence cetacean distribution, including the MOM area, cyclones, the confluence zone between the cyclone and anticyclone, and the periphery of the anticyclone. The location of hydrographic features was determined from near real-time (updated every three days) satellite data of sea surface height immediately prior to and during each cruise and later confirmed using shipboard CTD and XBT measurements.

5.3 Methods

5.3.1 Equipment

The new hydrophone array used in GulfCet II (Figure 5.1) was similar to the one used in GulfCet I, having multiple hydrophones variably spaced along a cable. The new array is spectrally flat (i.e., no peaks in sensitivity) from 6 Hz to 18 kHz, with approximately 183 dB re 1volt per μPa sensitivity at 7.2 kHz. This made it more sensitive, permitting a greater detection range for acoustic contacts. The new array was also thinner and could be towed at faster speeds. The eight hydrophones are wired in series, so that each can be independently recorded. This permits broadband recordings that are relatively omnidirectional. However, the omnidirectionality increases the detection of ship and other low frequency noise that requires low frequency filtering. Access to the signal from individual hydrophones was used to localize a sound source. The array was designed, by variably spacing the hydrophones, to have optimal reception characteristics for sperm whale vocalizations.

Three audio tape recorders were used during the late summer 1996 cruise: two eight-channel analog recorders (a Racal V-Store and a TEAC) and a two-channel cassette recorder. Researchers from TAMUG used the Racal and cassette recorders. Scientists from the Monterey Bay Aquarium Research Institute (MBARI) used the TEAC to localize recorded signals, particularly sperm whale contacts. A 3 3/4 ips recording speed with a 12.5 kHz bandwidth was used on the Racal. While at sea, acoustic signals were processed on a GulfCoast 486 microcomputer utilizing SIGNAL™ software. This software contained a subroutine that enabled real time spectrograms to be generated. The signals were also auditorally monitored with either speakers or headphones. In the acoustics laboratory at TAMUG, both SIGNAL™ and CANARY™ software were used for spectral analysis. During the mid-summer 1997 cruise,

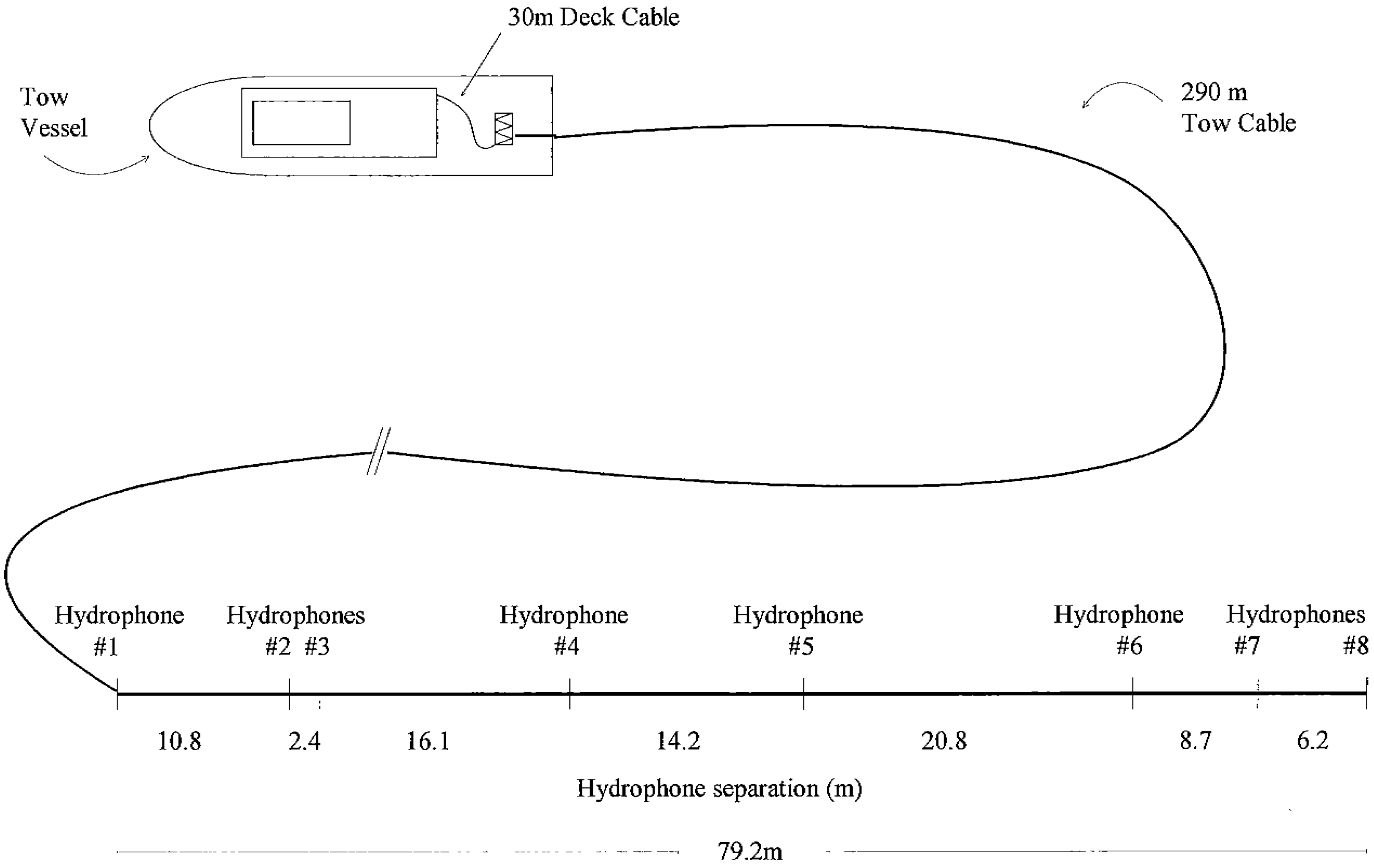

Figure 5.1. The configuration of the linear hydrophone array, including the tow vessel, tow cable and the active segment of the array. The placement and separation of the hydrophones is also indicated.

another recording system was used. Ouput from the array was split so that signals below 2 kHz were recorded on the eight channel Racal, and the higher frequency signals were recorded on either a two-channel cassette recorder or an eight-channel digital recorder (Tascam DA-88).

5.3.2 Analysis

Cataloging acoustic contacts was the first step in processing data gathered during a cruise. While at sea, written records were made of the tape number, elapsed time on the tape recorder, real-time, date and signal source (when known) of recorded sounds. On return to TAMUG, acoustic signals were reviewed, cataloged and, when possible, identified. This could be easily done for some sounds when the animal had been seen or when the signals were species specific, such as for sperm whales. Many of the unidentified signals were dolphin whistles. To identify an unknown sound, it was statistically compared to a database of signal parameters from known sources (see below for details). In addition to the analysis of cetacean vocalizations, recorded man-made signals were analyzed to assess their potential impact on cetacean distribution and behavior.

Sperm whale signals were analyzed for bearing and range using RainBow Click software written by Dr. Douglas Gillespie. Signals from two channels were analyzed three ways (Figure 5.2). The waveforms from the left and right channels were displayed, showing the time-of-arrival difference. The time difference was calculated and a bearing to the source was computed. Each pulse was charted as a single point in the bearing/time window. Multiple pulses at the same bearing produced a bearing line. Different bearing lines indicated that multiple whales were present. Since multiple animals could be on a single bearing, the pulse spectra was also compared. A reference pulse permitted comparison of pulses. The RainBow Click system was used to determine the number of vocalizing animals and the range to the whale(s). The bearing to the whale at two points a known distance apart defined a triangle, from which range to the initial contact could be calculated.

5.3.3 Characterization of Dolphin Whistles

Acoustical analyses were conducted on both identified and unidentified contacts. While the recordings from identified sources were catalogued, copies of all high quality whistles and burst pulses were made on a computer. This first group of recordings was ordered by species. The second group of recordings comprised unidentified sources. Signals were analyzed with CANARY^{TM} 1.2 bioacoustics software developed by Cornell University (Ithaca, New York). Signals were digitized at a 44.1 kHz sampling rate. Spectrograms were made using a 1,024 point, fast fourier transform resulting in a 5.805 ms frame length with a frequency resolution of 43 Hz. The filter bandwidth was 699.4 Hz. Signals were conditioned using a Hamming window. Following procedures described by Wang (1993) and Steiner (1981), a series of parameters were defined for each whistle: the frequency and time of the beginning and end of the signal; maximum and minimum frequency; center time; frequency change; duration; and peak time and peak frequency (i.e., the time and frequency of maximum amplitude in the signal). The following signal characteristics were defined based on the appearance of the spectrogram: number of inflections; whether the beginning and end frequency swept up, down, or was constant; number of contour breaks; number of steps (abrupt frequency changes); and signal type (e.g. upsweep, downsweep, and so on). Acoustic data were then exported to a spreadsheet from

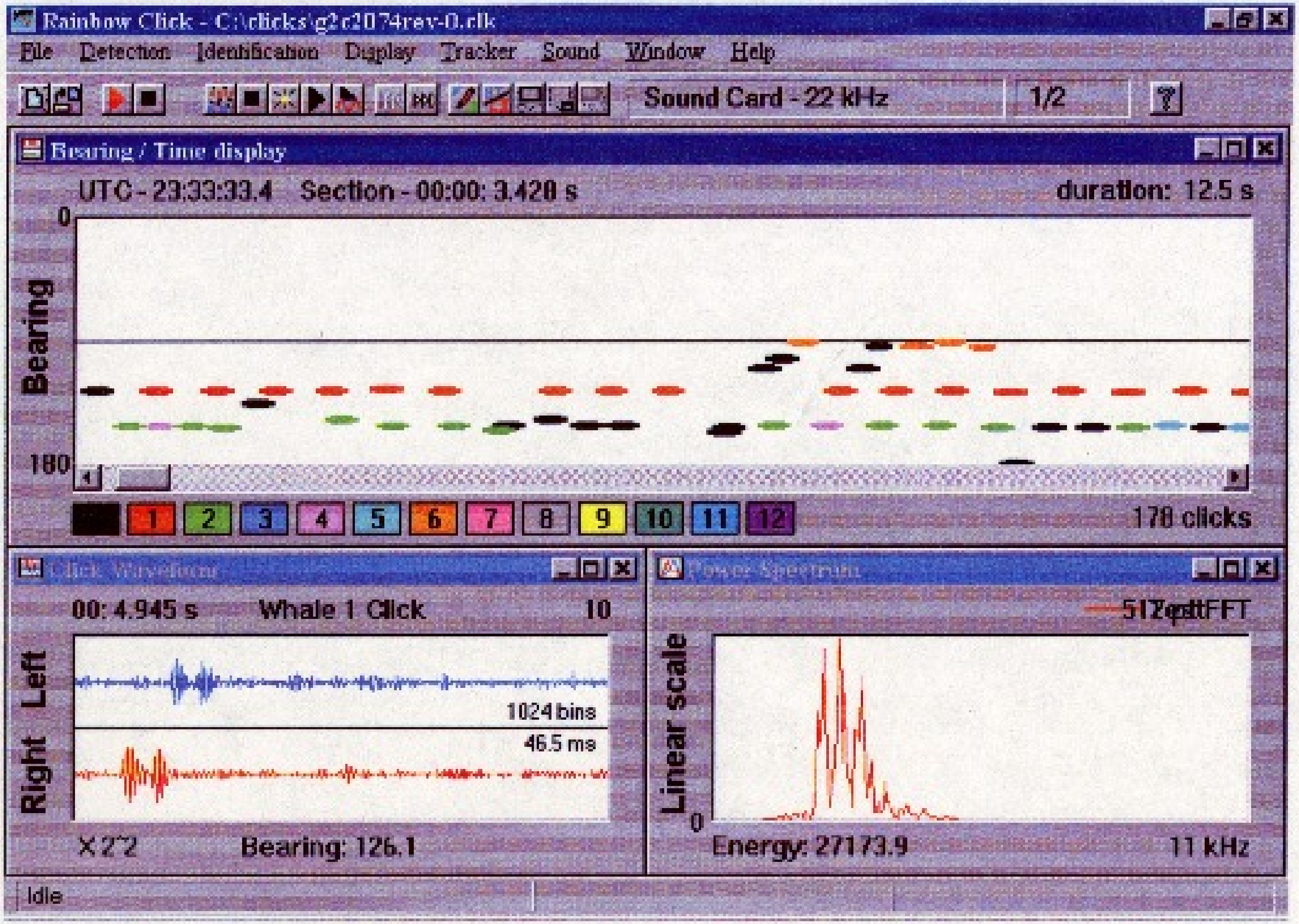

Figure 5.2. Image of the Rainbow screens. The top screen is the Bearing/Time Display, that shows three bearing lines at 94, 126, and 152 degrees. The bottom left screen shows the click waveform from the left and right channels. The bottom right screen shows the spectra of a single click.

which the final parameters were calculated. Time parameters included start and end time, duration, center time as a percentage of overall signal duration, and peak time as a percentage of overall signal duration. Frequency parameters were beginning and end frequency and their bandwidth, high and low frequency and their bandwidth, and peak frequency.

Discriminant function analysis (DFA) was used to derive classification rules from the identified signals so that, given the same parameters from an unknown species, classification could be made. DFA is based on the relationship between membership in some class (for example, species x, y, or z) and a series of variables describing common features contained by members of all classes (for example, frequency variables of the vocalizations). DFA was performed using Statistica (Statsoft, Tulsa, OK). The central premise was that each species' calls would be sufficiently distinctive to be correctly classified 75% of the time or better. Relatively simple acoustic parameters were used to classify these signals assuming there were acoustical correlates to gross morphometric differences between species. Based on our experience with both marine and terrestrial animals, larger animals produce lower frequency signals than smaller ones. According to this hypothesis, bottlenose dolphins should produce lower frequency whistles than the smaller *Stenella* species. In addition, it was assumed that sympatric species of similar sizes should encode their signals with acoustic differences that permit differentiation between species. The final identification was made by combining information on the context of the call, the lexicon used in the contact, and iterations of the DFA on a series of different calls from a single contact. A Shannon-Weiner diversity index was used to describe whistle diversity for all calls by each species. This index is a measure of the distribution of observations among categories, in this case the distribution of various vocalizations by species. If a species repeatedly used only a single vocalization, there would be no diversity in its usage and the Shannon-Weiner diversity index would equal zero. On the other hand, if a species had multiple whistles, but used each one only once, then the diversity would be highest (i.e., equal one). More typically, animals use multiple whistles to varying degrees and the diversity index for each species varies between zero and one.

5.3.4 Effects of Seismic Exploration Signals on Cetaceans

Line transect data from both GulfCet I and GulfCet II cruises were analyzed to determine the potential, large-scale effects of seismic exploration signals on marine mammal distributions. "On-effort" status for this aspect of the GulfCet study was defined as occurring when both visual and acoustic teams were "on effort. Effort lines were separated on average by 75 km, and no attempt was made to either approach or avoid seismic exploration vessels. Sounds from seismic exploration were recorded using the Racal V-Store tape recorder. Visual survey results were used for cetacean distribution. Additional information regarding the study areas and visual and acoustical data acquisition can be obtained from Norris et al. (1996).

Seismic exploration signals were recorded, digitized and then analyzed using CANARY™ digital signal processing software. Relative signal intensity, signal duration, and maximum, minimum and peak frequencies were determined for signals using the full frequency bandwidth of the program. The relative intensity of seismic signals was estimated from the signal-to-noise ratio (signal intensity in decibels above ambient). The signal-to-noise ratio was calculated by averaging the intensity of a 120 ms segment of recording, using a 180 dB bandwidth from 20 to

200 Hz, from both the background (ambient) and the seismic pulses. Signal-to-noise measurements were divided into three categories: *low*, 0 dB (no seismic signals); *moderate*, 0-12 dB; and *high*, >12 dB above ambient.

Hydrographic data were analyzed for potential interdependencies between hydrographic features, seismic exploration and presence of cetaceans. For GulfCet I, hydrographic features were defined by sea surface height measured by satellite altimetry. For GulfCet II, major hydrographic features were determined by shipboard CTD and XBT data used to compute dynamic sea surface height. Five hydrographic regions were defined: cyclone, anticyclone, periphery of the eddy, confluence zone, and "other" areas outside these defined features.

Effort was divided into 42-minute blocks for statistical analysis. Sighting rates (in sightings per hour) were determined for three cetacean categories: all species, sperm whales and pantropical spotted dolphins. A nonparametric Kruskall-Wallis test was used to determine the difference in sighting rate for each combination of cetacean category, sound level category and hydrographic feature. For additional information on the effects of seismic exploration pulses on cetacean distribution, see Rankin (1999).

5.4 Results

5.4.1 Survey Effort

There was a total of 5,228 km of acoustic survey effort, with 2,784 km during the 1996 late summer cruise and 2,444 km during the 1997 mid-summer cruise. During the late summer cruise, effort was fairly uniform throughout the study area north of 27°N, with several lines of effort as far south as 25°N (Figure 5.3). Acoustic effort occurred in waters as shallow as 50 m off of the Florida panhandle and Alabama. To the south and east, waters deeper than 3,000 m were sampled. Poor weather significantly affected both acoustic and visual sampling during this cruise, particularly at the beginning. In contrast, during the mid-summer cruise there was no effort south of 26°N (Figure 5.4), but increased effort to the east along the Florida escarpment to sample the various hydrographic features. There was relatively less acoustic effort at night due to mid-water net tows for biological sampling (see Chapter 3).

5.4.2 Cetacean Contacts

We had a total of 73 dolphin and 20 sperm whale contacts during the two GulfCet II cruises (Table 5.1). There were 1.5 times as many dolphin contacts during the mid-summer cruise compared to the late summer cruise. There were 11 and 9 sperm whale contacts during the late summer and mid-summer cruises, respectively. We had 13 and 16 unidentified dolphin contacts, respectively, during the two cruises. Sperm whales were the most commonly encountered identified cetacean during the late summer cruise, while pantropical spotted dolphins were the most commonly encountered species during the mid-summer cruise.

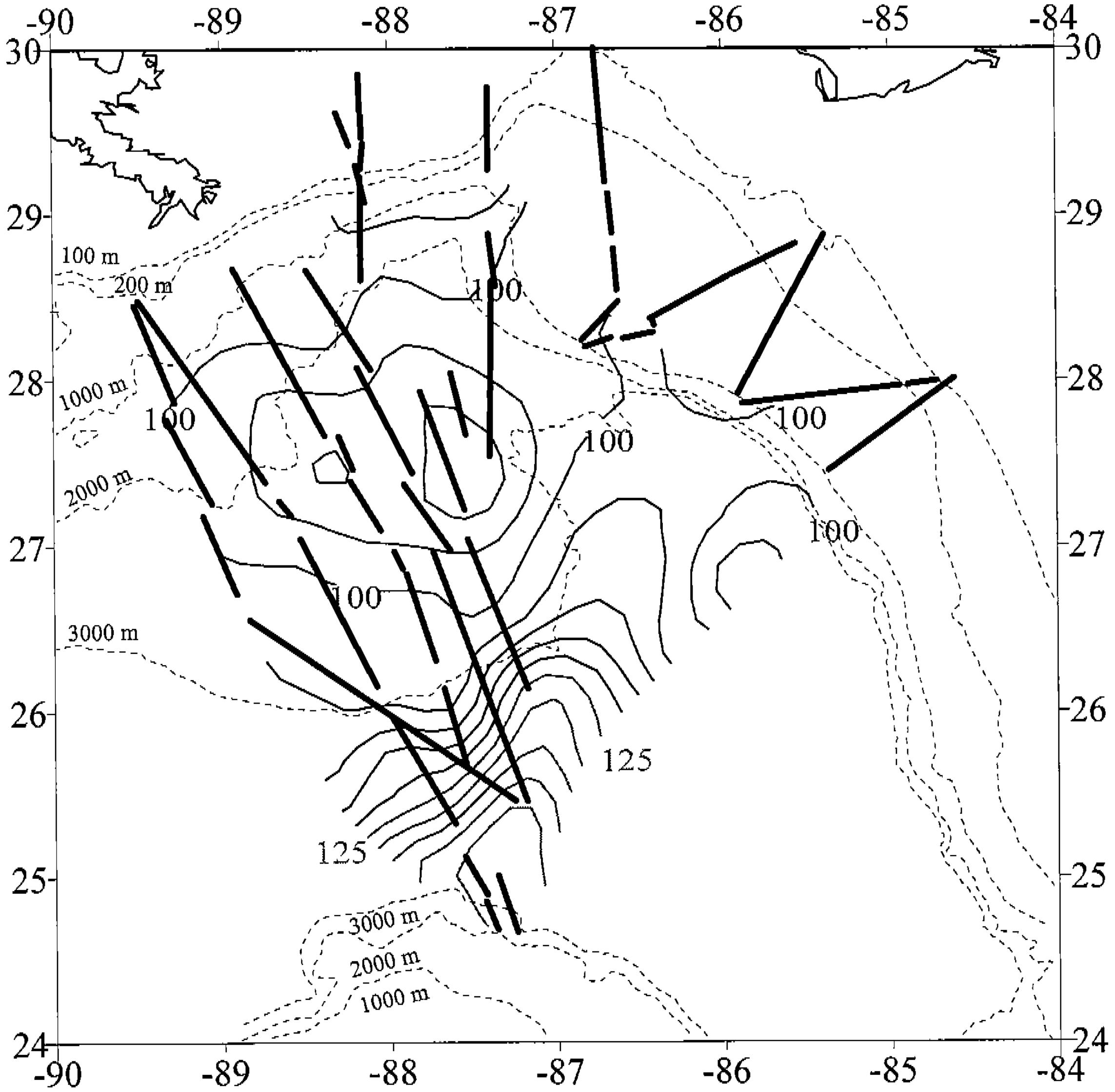

Figure 5.3. Acoustic effort transects (bold lines) conducted during late summer 1996 cruise. Dashed lines represent isobaths. Solid contour lines represent sea surface dynamic height in 5 cm intervals. The cyclone is between 88 and 100 cm, the confluence between 100 and 122 cm, and the anti-cyclone between 125 and 150 cm.

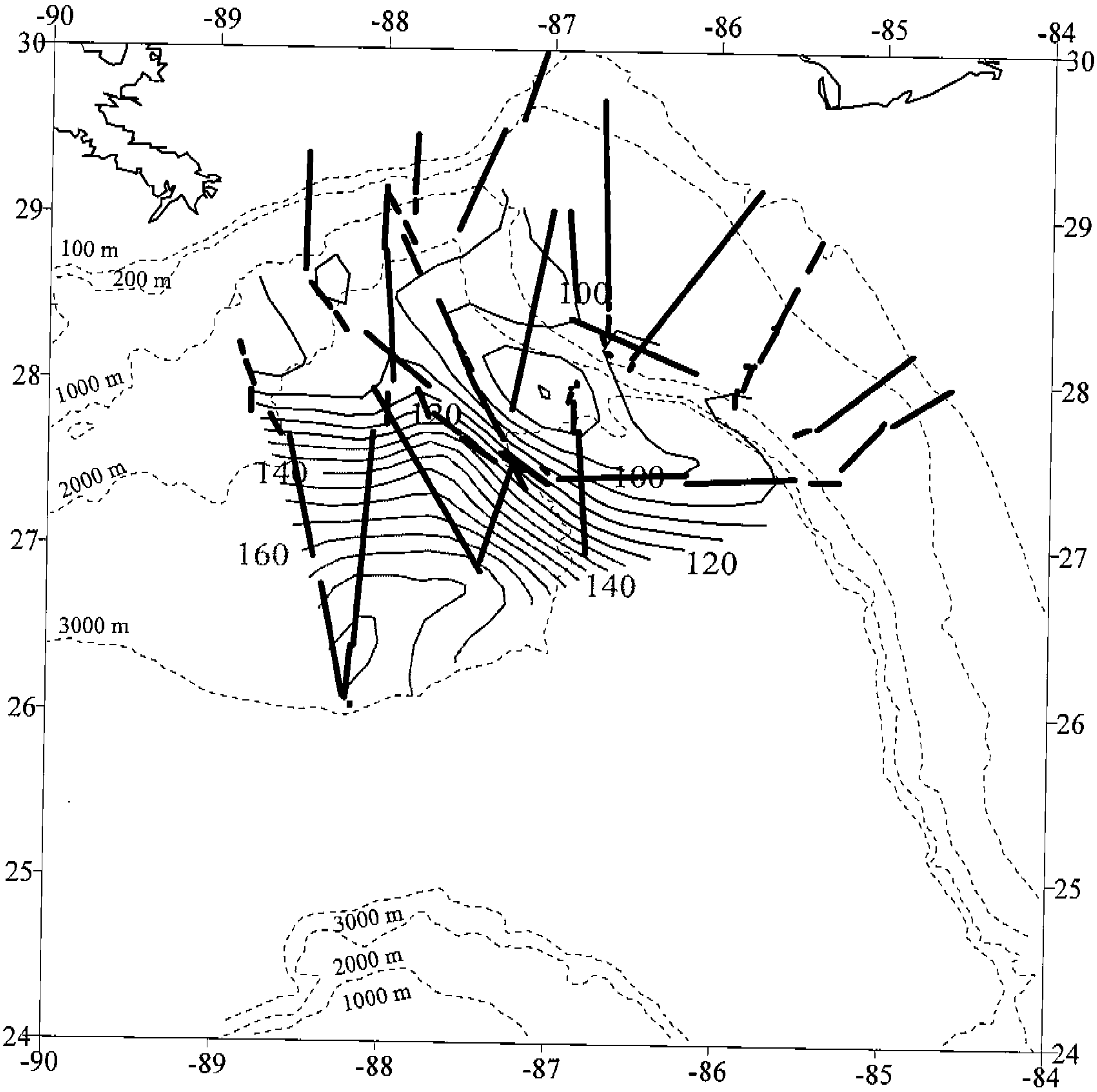

Figure 5.4. Acoustic effort transects (bold lines) completed during the mid-summer 1997 cruise. Dashed lines represent isobaths. Solid contour lines represent sea surface dynamic height in 5 cm intervals. The cyclone is between 92 and 105 cm, the confluence between 105 and 129 cm, and the anticyclone between 130 and 176 cm.

Table 5.1 Numbers of cetacean acoustic contacts by cruise and species.

Species	1996 Late Summer *Gyre* Cruise	1997 Mid-summer *Gyre* Cruise	Combined *Gyre* Cruises
Rough-toothed dolphin	1	1	2
Bottlenose dolphin	3	2	5
Pantropical spotted dolphin	6	20	26
Striped dolphin	2	1	3
Clymene dolphin	1	0	1
Spinner dolphin	0	2	2
Atlantic spotted dolphin	2	1	3
Unidentified *Stenella*	1	1	2
Unidentified dolphins	13	16	29
Total dolphins	29	44	73
Sperm whales	11	9	20
Total Cetaceans	40	53	93

5.4.3 Cetacean Distribution

5.4.3.1 Sperm Whales

The distribution of sperm whales in the central and eastern Gulf did not appear to be random during the two cruises. Rather, they appeared to be linearly related, on an approximate north-south axis during the late summer 1996 cruise (Figure 5.5), and east-west during the mid-summer 1997 cruise (Figure 5.6). Of the 11 sperm whale contacts during the late summer cruise, nine were west of 87° W. Whales were detected in the same area near the MOM as had been observed in all GulfCet I cruises. This area now contains a number of deep-water oil platforms that were not present at the beginning of GulfCet I. Sperm whales were found approximately 35 km farther south than on previous cruises, although there is no evidence that this was in response to increased oil and gas activity in the area. The findings, however, show that sperm whales still maintain a presence in offshore waters south of the MOM. No animals, however, were detected immediately east of the delta, even though there was significant survey effort. Nearly half (five of 11) of the contacts were entirely or partially in waters deeper than 2,000 m. This is in contrast to the GulfCet I results (when effort was limited to water depths less than 2,000 m) where sperm whales occurred along the mid-to-lower slope (ca. 1,200 m ocean depth). During the mid-summer cruise, sperm whale contacts were limited to a narrow band running along the 28° parallel between 89° and 86°W longitude. This was the case even though effort was basically north-south. Six of the nine contacts were in waters deeper than 2,000 m. Sperm whale contacts during the late summer cruise averaged 26 km in length ($n=11$, $\sigma = 34$, range = 1-114 km), while for the mid-summer cruise they were significantly shorter (Mann-Whitney U, $p<0.00$), averaging 5.7 km ($n=9$, $\sigma = 7.3$, range = 0.5-21.6 km).

5.4.3.2 Dolphins

Dolphins were detected throughout the study area during both cruises. Dolphin distributions during the late summer cruise were concentrated in either relatively shallow waters or within a single deep-water area (Figure 5.7). The shallow contacts, almost all in waters less than 200 m, were distributed along the continental shelf of the EPA. Almost one-third of all dolphin contacts were in deep water south of 27°N. During the mid-summer cruise, dolphins were much more uniformly distributed in pelagic waters, and there were few contacts in the shallow waters of the eastern EPA (Figure 5.8). Even in pelagic waters, there were "holes" in their distribution, with no contacts in an approximately 1° square area centered at approximately 27.5°N and 88° W.

The number and distribution of pantropical spotted dolphin contacts were markedly different between years. In late summer 1996, three of four contacts were in very southern waters, among the most southern of any contacts during either cruise (Figure 5.9). In contrast, during mid-summer 1997, most of the 20 contacts were in a narrow strip between the 1,000-2,000 m depth contours running east of 88° W longitude south of the Big Bend area of Florida.

The remaining identified dolphin contacts were a mixture of shallow-water species (i.e., bottlenose and Atlantic spotted dolphins) found along the northern edge of the study area, plus several contacts from pelagic species distributed throughout the study area (Figure 5.10).

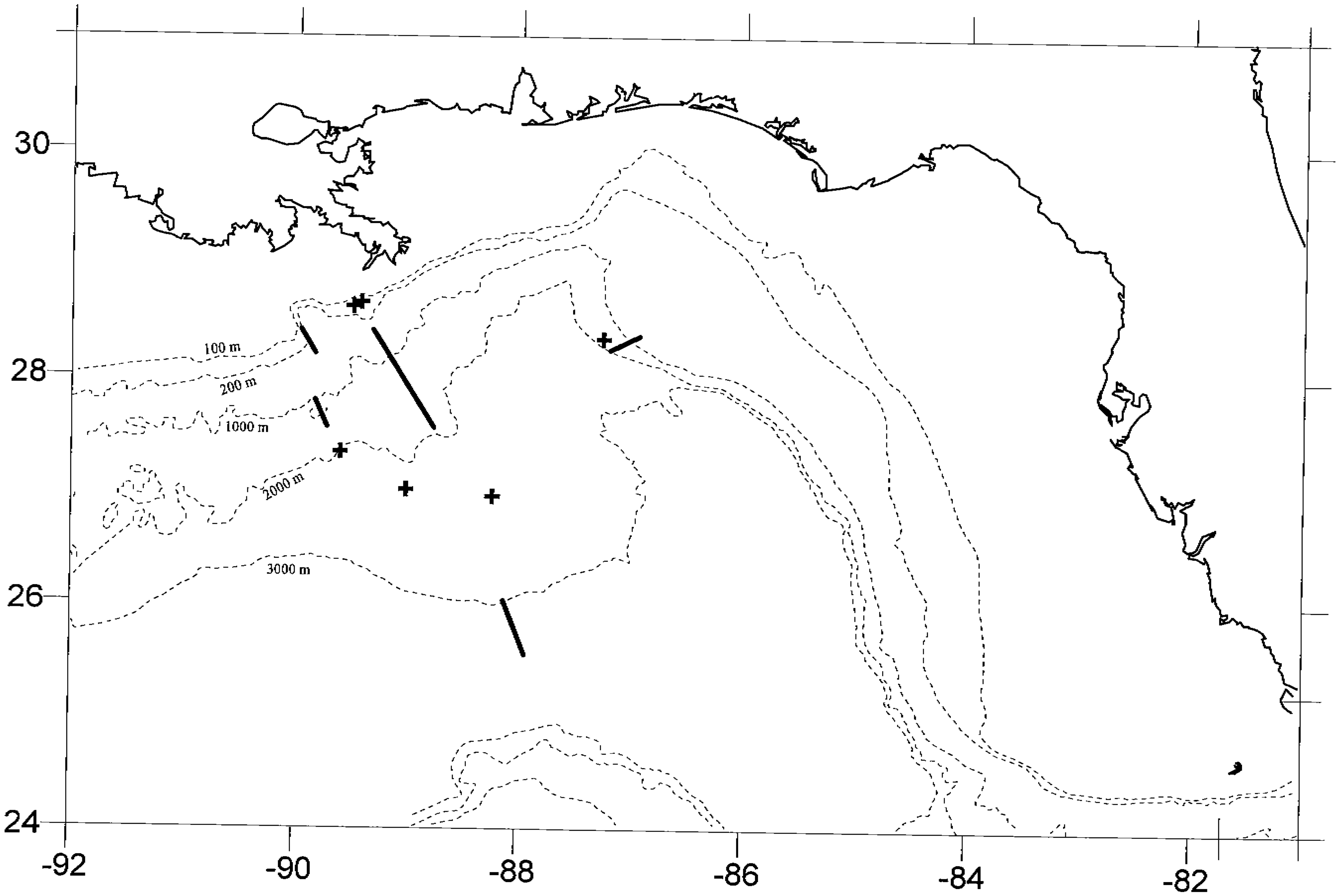

Figure 5.5. Location of acoustic contacts from sperm whales during the 1996 late summer cruise. Contacts less than 5 nm in length are represented by crosses, whereas continuous contacts longer than 5 nm are represented by lines. Contacts averaged 26 km in length.

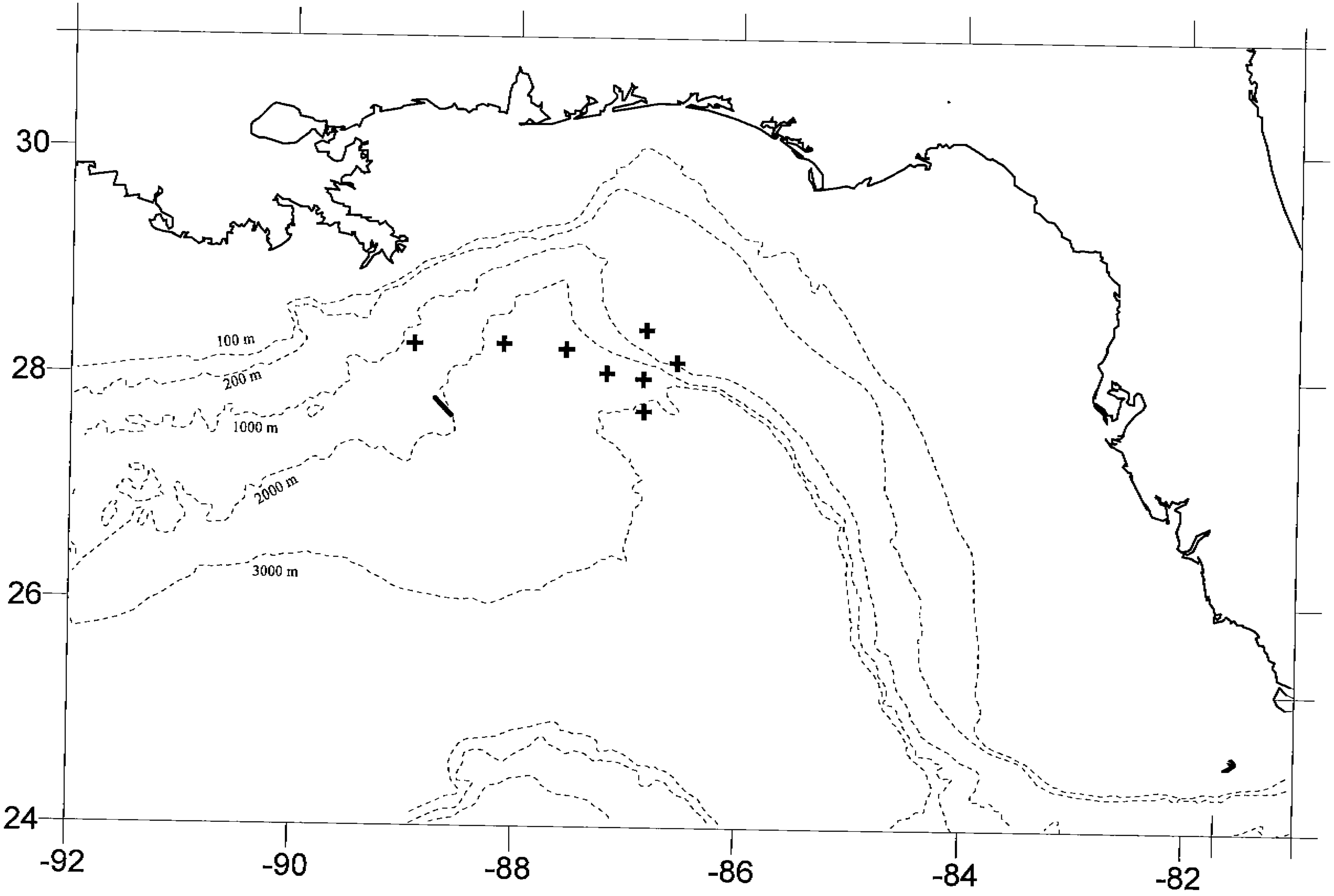

Figure 5.6. Location of acoustic contacts from sperm whales during the 1997 mid-summer cruise. Contacts less than 5 nm in length are represented by crosses, whereas continuous contacts longer than 5 nm are indicated by lines. Contacts averaged less than 6 km in length, significantly less than in 1996.

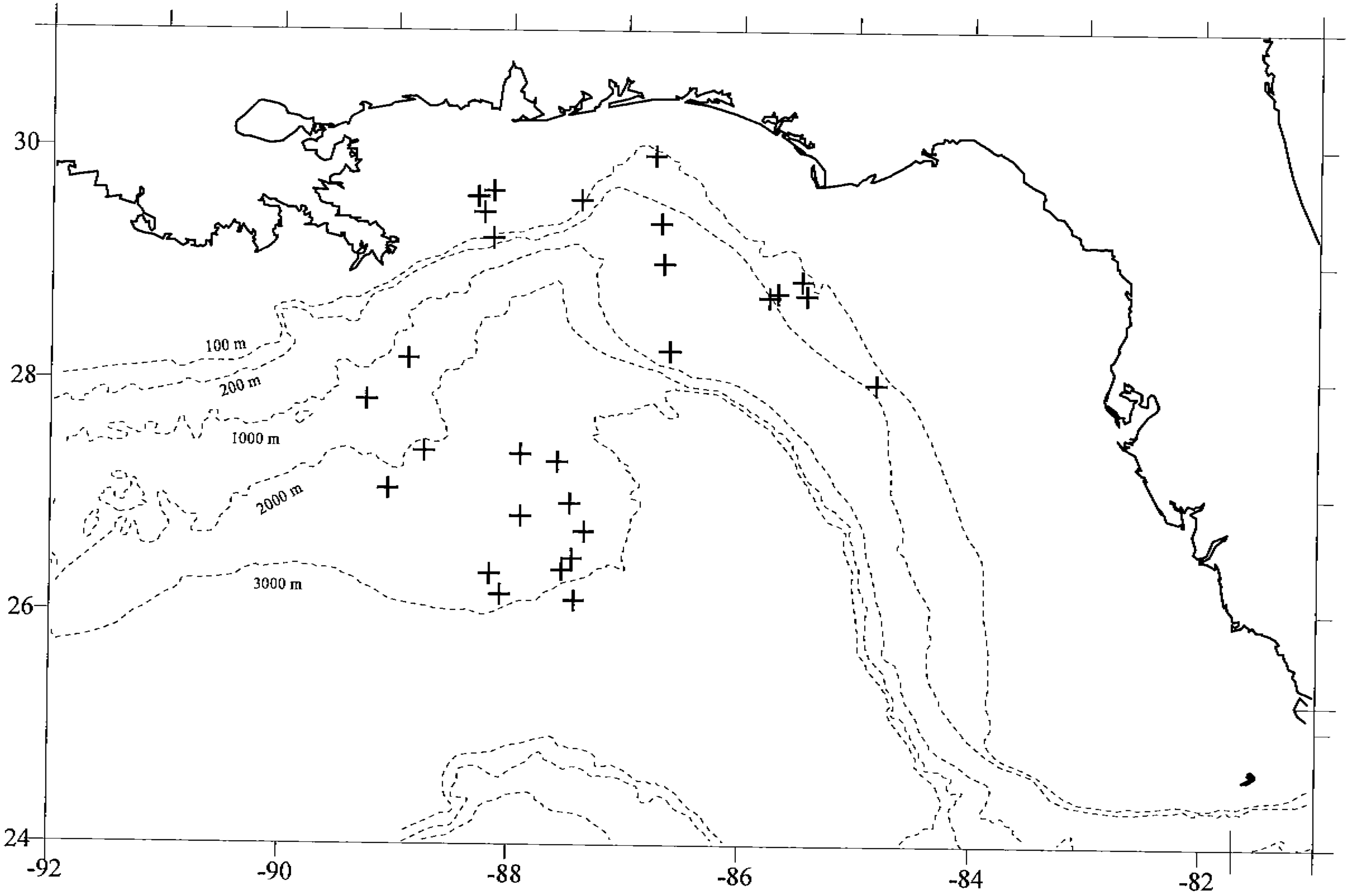

Figure 5.7. Location of acoustic contacts from all dolphins during the 1996 late summer cruise.

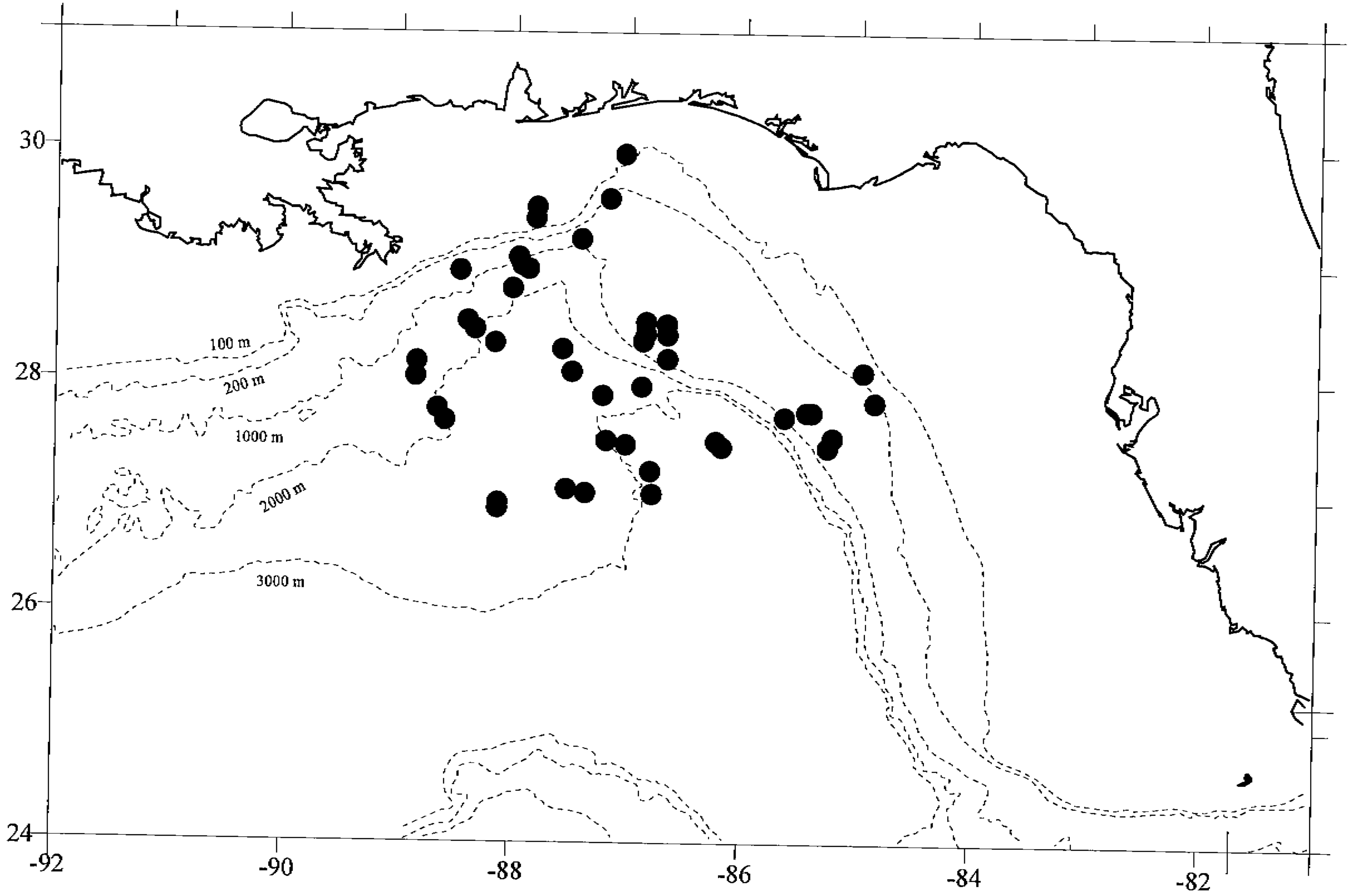

Figure 5.8. Location of acoustic contacts from all dolphins during 1997 mid-summer cruise.

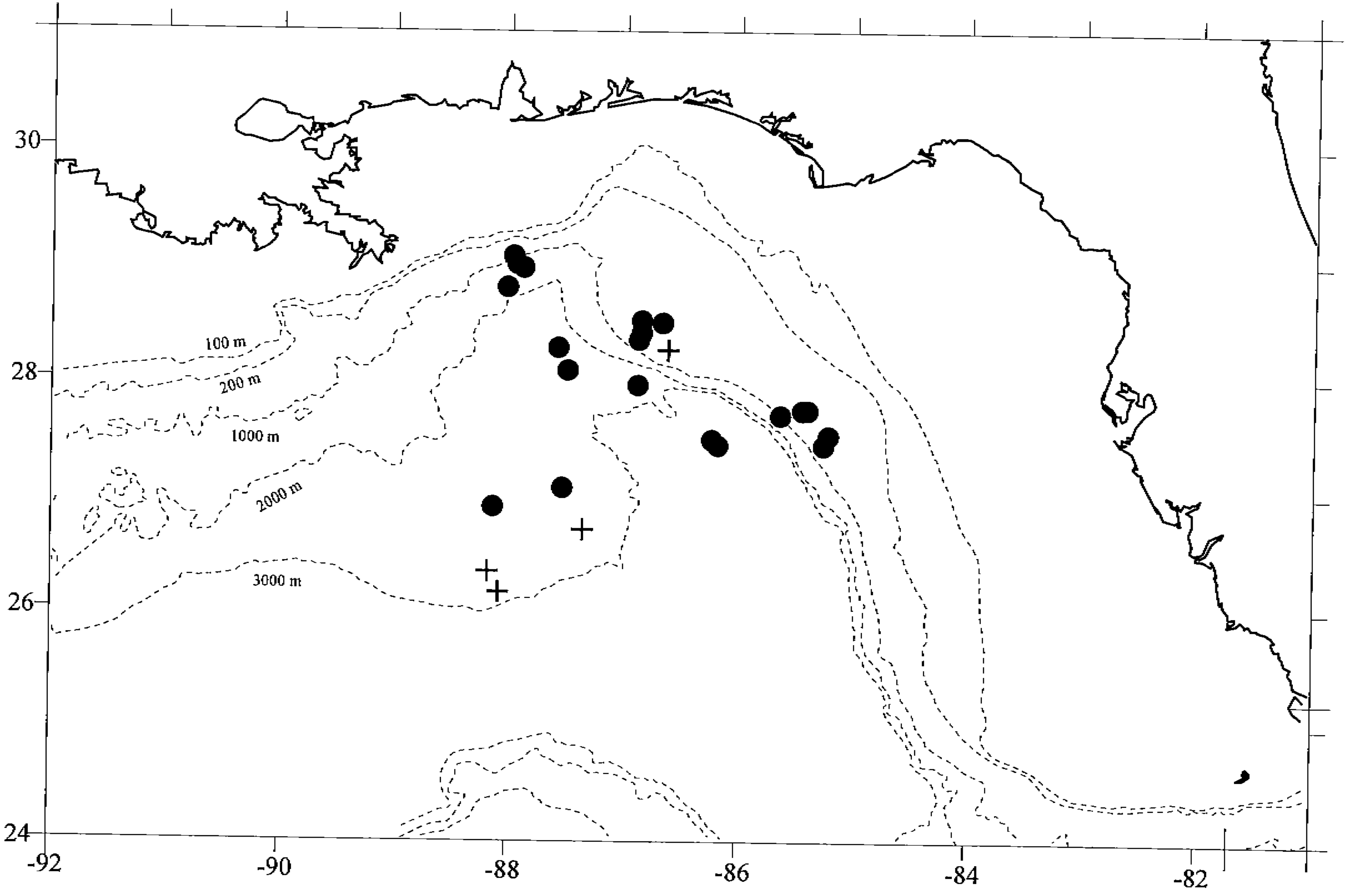

Figure 5.9. Location of acoustic contacts from pantropical spotted dolphins during the 1996 late summer cruise (crosses) and 1997 mid-summer cruise (dots). The northern most 1996 contact is actually two closely separated contacts.

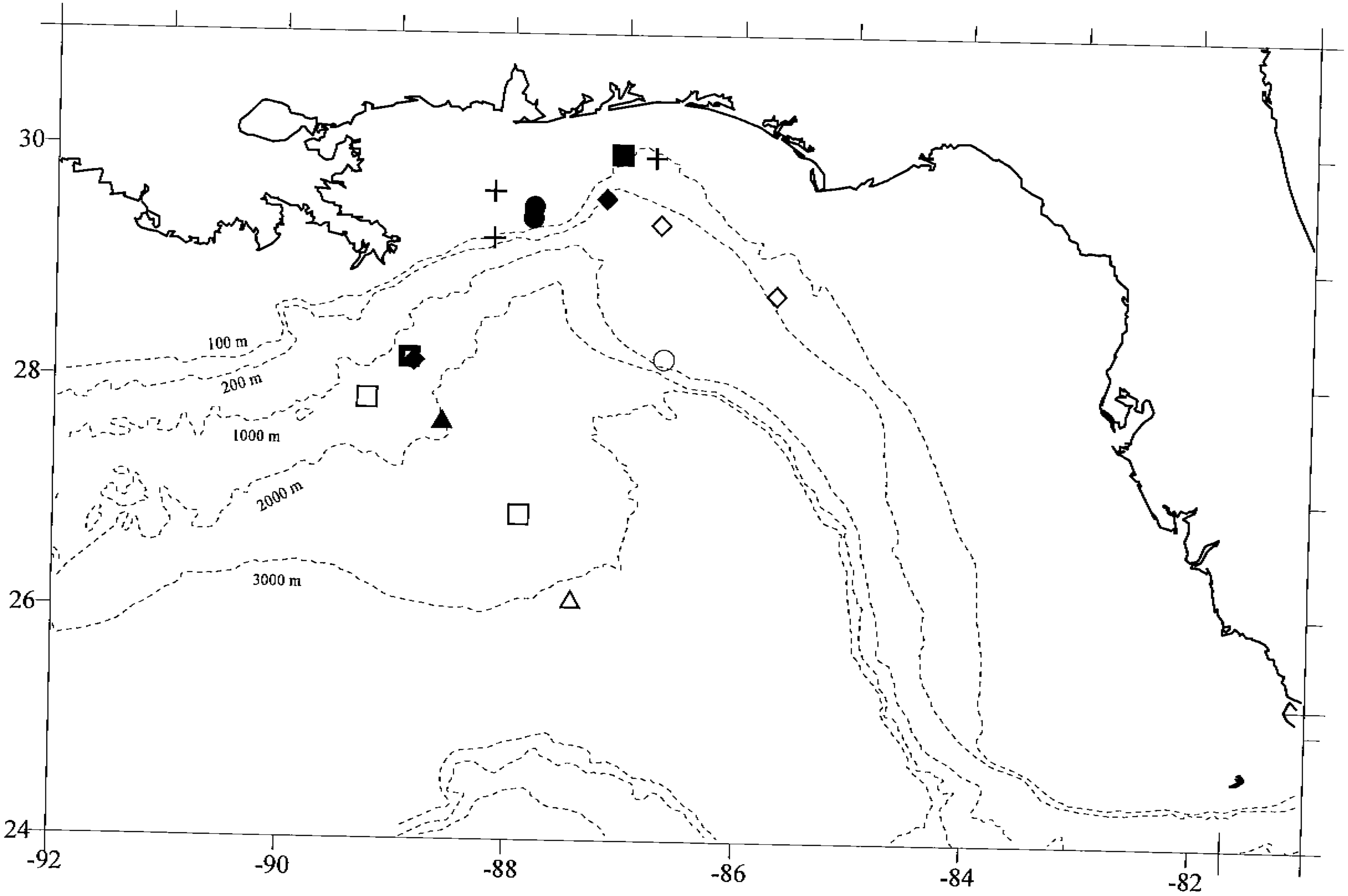

Figure 5.10. Location of acoustic contacts: bottlenose dolphins during the 1996 late summer cruise (crosses) and the 1997 mid-summer cruise (closed dots); striped dolphins during 1996 (open square) and 1997 (open circle); clymene dolphins during 1996 (open triangle); spinner dolphins during 1997 (closed triangle), Atlantic spotted dolphins during 1996 (open diamond) and 1997 (closed square); and rough-toothed dolphin during 1996 (dotted square) and 1997 (closed triangle).

In late summer, the distribution of unidentified dolphins was divided between animals in shallow waters to the north and a disjunct set of contacts far to the south (Figure 5.11). The more numerous contacts in late summer were distributed throughout the deeper waters north of 27°N.

5.4.4 Ecological Correlates

During both cruises, cetacean distributions appeared to be influenced by the presence of a cyclone to the north, paired with an anticyclone to the south. While the feature ages were similar in both years, their relative location and orientation were different. In 1996, the cyclone was centered south-southeast of the MOM and to the northwest of the anticyclone. In 1997, the cyclone was southeast of the MOM and northeast of the anticyclone, near the DeSoto Canyon. The cyclone was larger in 1996 than in 1997.

5.4.4.1 Sperm Whales

Sperm whale contacts were more dispersed and were significantly longer in length and duration in late summer 1996 compared to mid-summer 1997. With few exceptions, sperm whale contacts in late summer were on the western periphery of the cyclone, including contacts south of the MOM (Figure 5.12). One contact began on the northern periphery of the cyclone and continued into the center. Another contact ran across the confluence toward the center of the anticyclone. The dispersed distribution in 1996 contrasted with that in 1997, when sperm whale contacts were either inside or on the periphery of the cyclone (Figure 5.13). They were also farther east than the year before, probably because of the more easterly location of the cyclone. Most sperm whale contacts during mid-summer were accompanied by dolphins, often pantropical spotted dolphins. With one exception, there were no sperm whale contacts in the anticyclone.

5.4.4.2 Dolphins

The distribution of dolphin acoustic contacts during the 1996 late summer cruise was disjunct, with approximately half in shallow water along the shelf break (Figure 5.14). This area is largely unaffected by cyclones. The other half of the contacts occurred along the southern edge of the cyclone or in the confluence zone. Dolphin distribution in 1997, particularly in the north and west, appears to have been influenced by fresh water from the MOM area that was transported off the shelf by the cyclone (Figure 5.15, see Chapter 2 for details). Animals were distributed along a curve circling the upwelling cyclone and following the geostrophic flow between the eddies. There were fewer shallow water contacts during 1997.

The few pantropical spotted dolphin contacts during the late summer cruise were located in the confluence zone (Figure 5.16). During the mid-summer cruise, most pantropical spotted dolphin contacts were in or on the periphery of the cyclone or in the confluence; only two contacts occurred in the anticyclone (Figure 5.17).

During the late summer cruise, unidentified dolphins were either distributed along the shelf break (probably bottlenose or Atlantic spotted dolphins) or in the cyclone (Figure 5.18). During the mid-summer cruise, most of the unidentified dolphin contacts occurred along the periphery of the

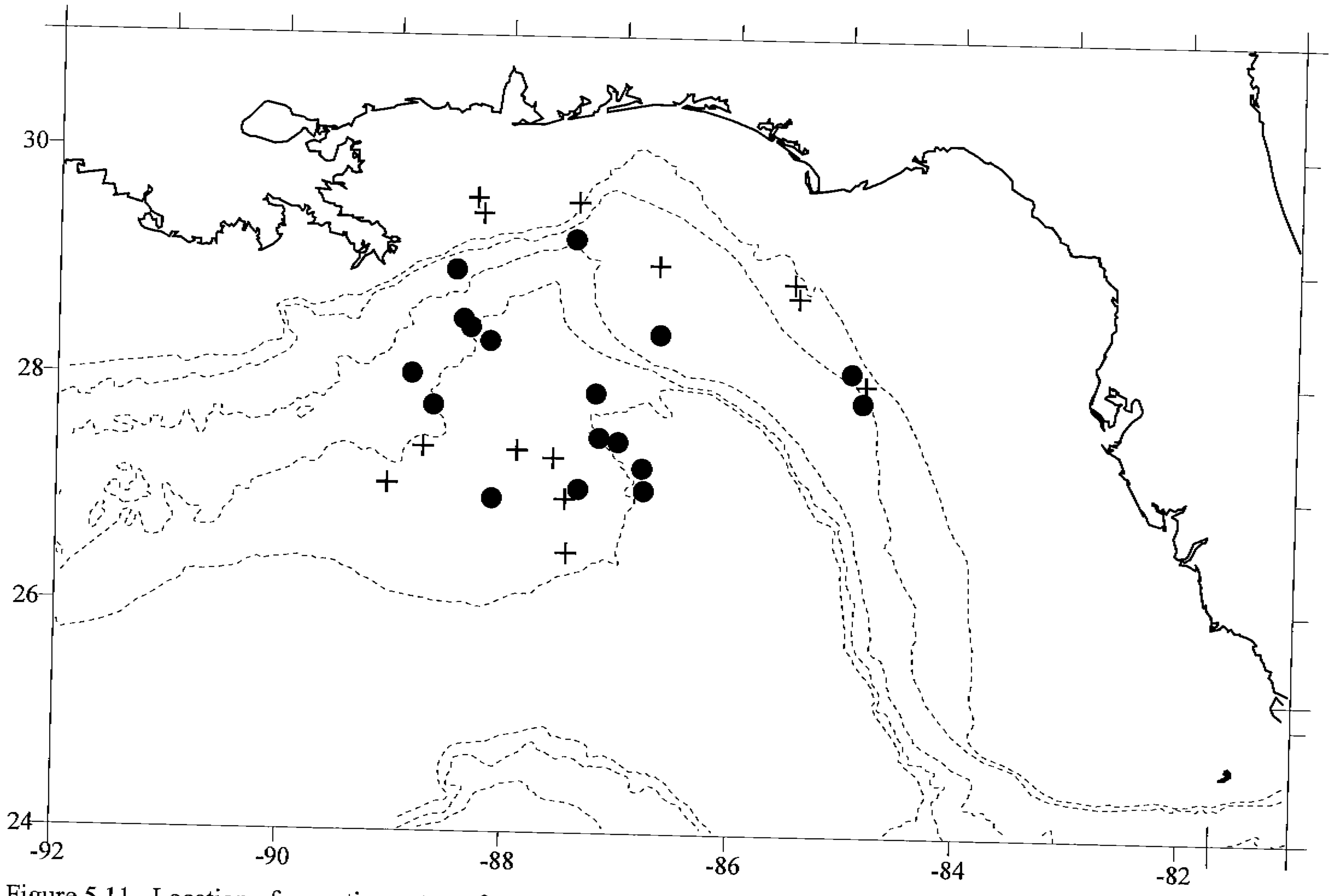

Figure 5.11. Location of acoustic contacts from unidentified dolphins during the late summer 1996 cruise (crosses) and the 1997 mid-summer cruise (dots).

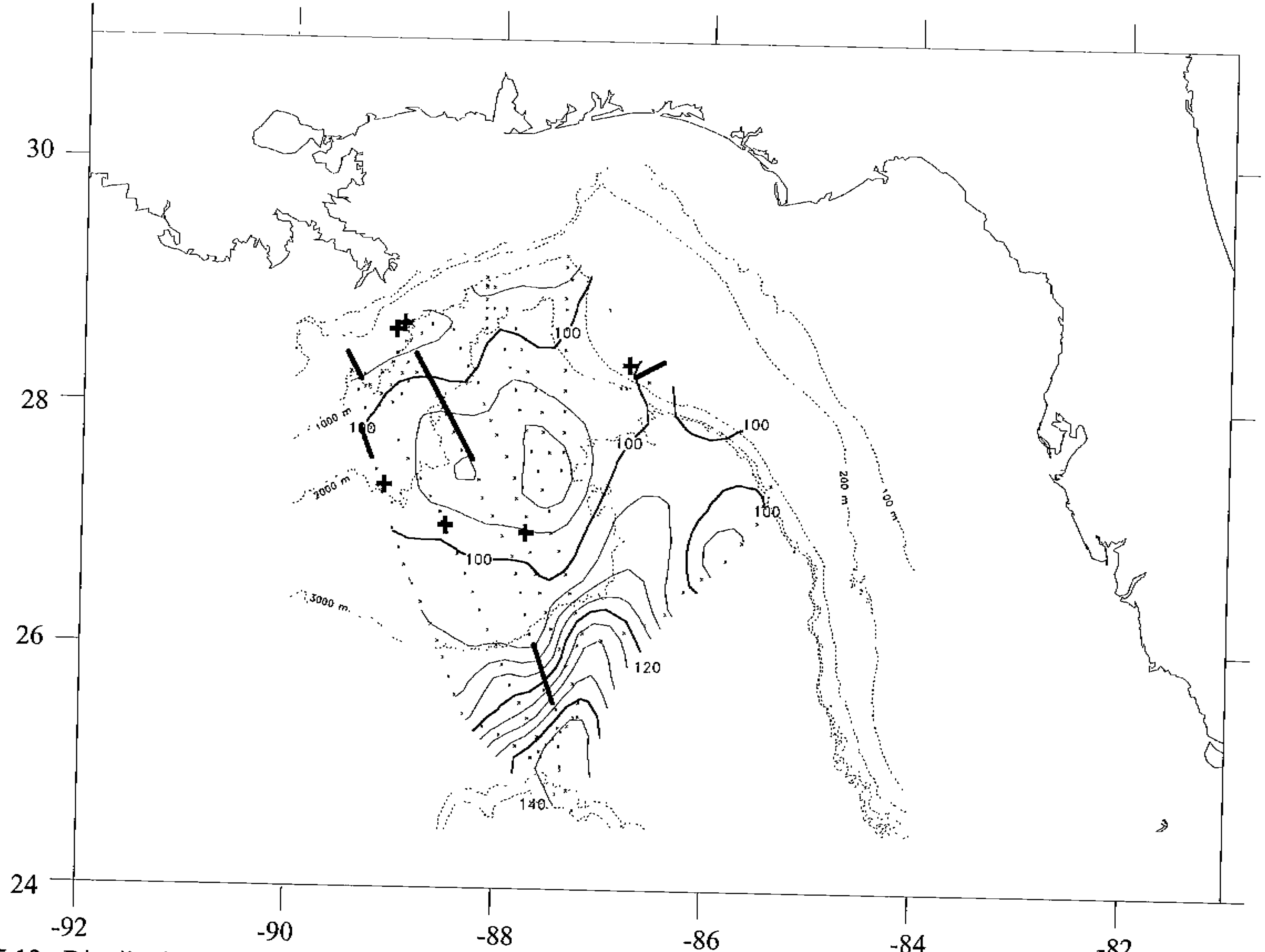

Figure 5.12. Distribution of sperm whales relative to hydrographic and bathygraphic data during the late summer 1996 cruise. Solid contour lines represent sea surface dynamic height in 5 cm intervals. The cyclone is between 88 and 100 cm, the confluence between 100 and 122 cm, and the anti-cyclone between 125 and 150 cm. Small crosses indicate the location of CTD and XBT stations along the cruise track.

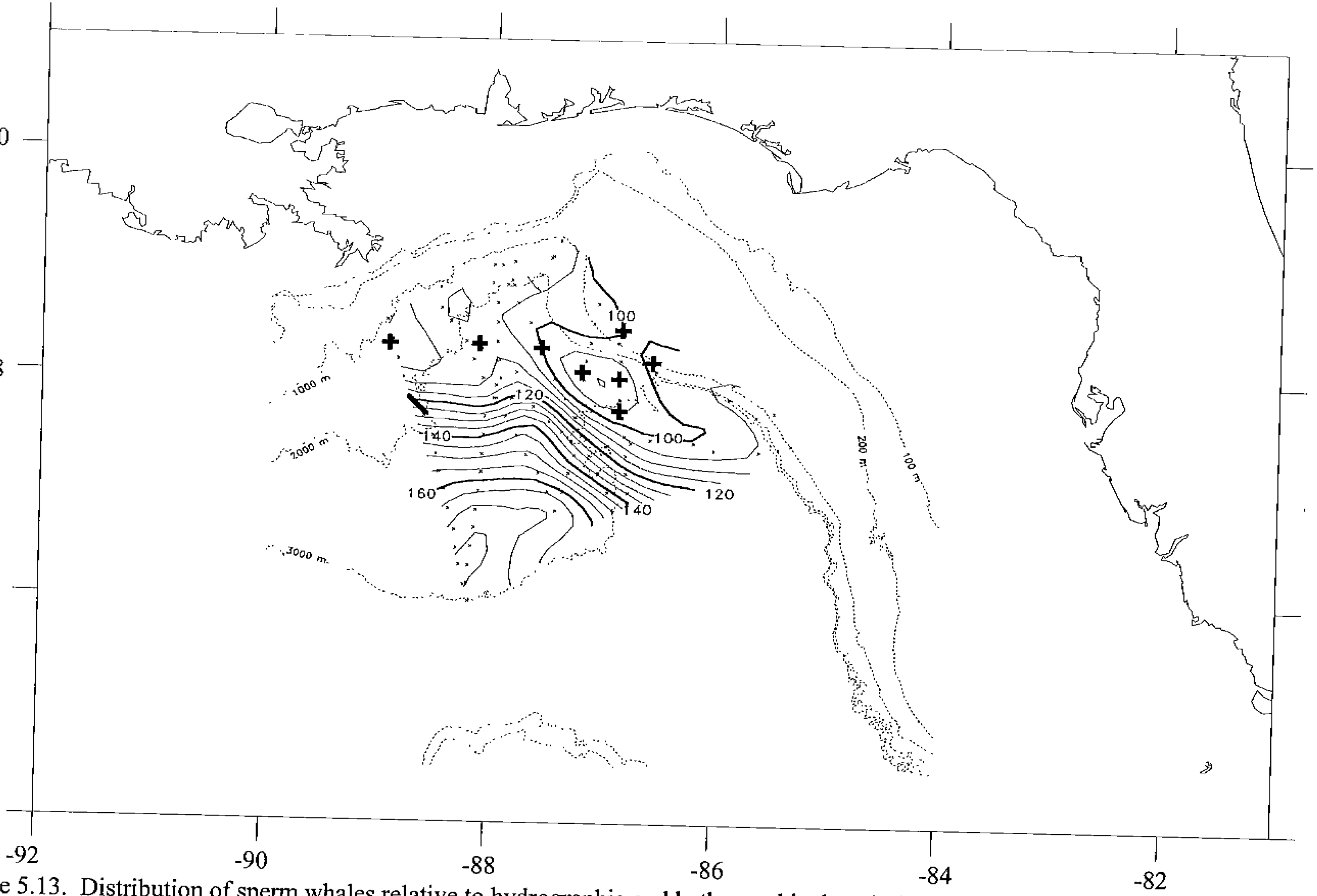

Figure 5.13. Distribution of sperm whales relative to hydrographic and bathygraphic data during the mid-summer 1997 cruise. Solid contour lines represent sea surface dynamic height in 5 cm intervals. The cyclone is between 92 and 105 cm, the confluence between 105 and 129 cm, and the anticyclone between 130 and 176 cm. Small crosses indicate the location of CTD and XBT stations along the cruise track.

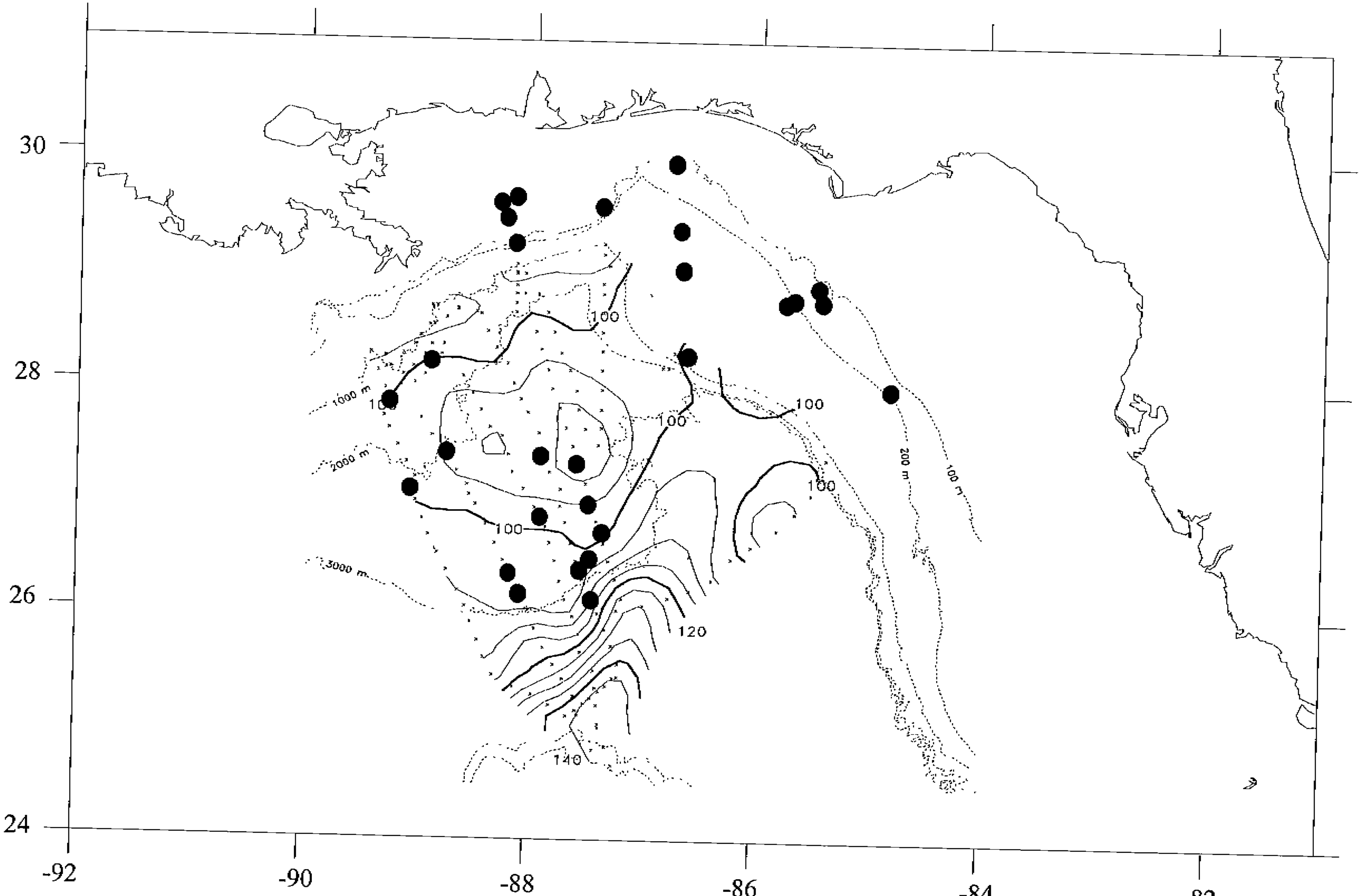

Figure 5.14. Distribution of all dolphin acoustic contacts relative to hydrographic and bathygraphic data during the 1996 late summer cruise. Solid contour lines represent Dynamic Sea Surface Height (SSH). Areas where SSH ≤ 100 dyn cm correspond to a cyclonic, cold core eddy, and areas where SSH ≥ 125 dyn cm correspond to an anti-cyclonic, warm core eddy. Small crosses indicate location of CTD and XBT stations along the cruise track.

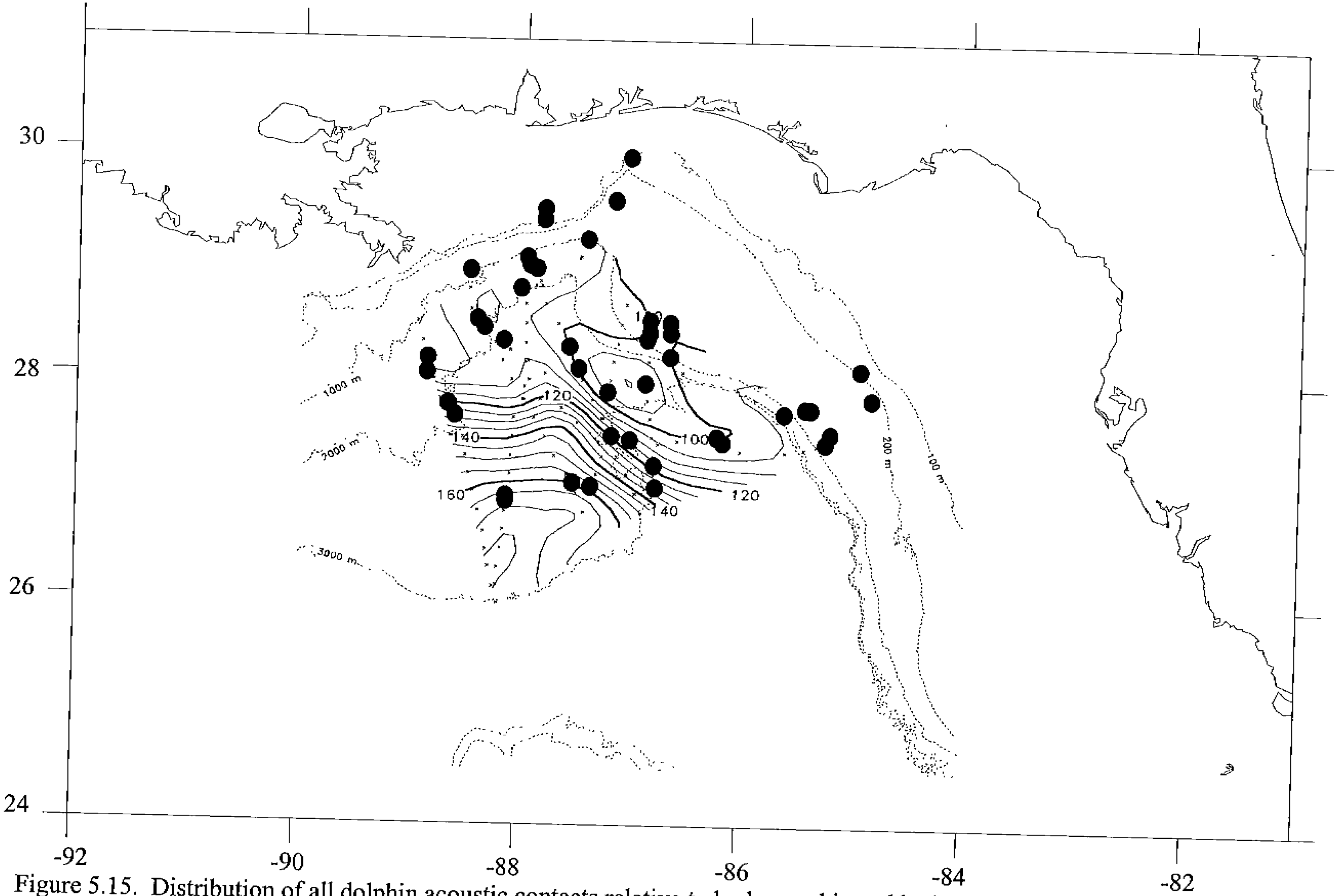

Figure 5.15. Distribution of all dolphin acoustic contacts relative to hydrographic and bathygraphic data during the 1997 mid-summer cruise. Solid contour lines represent Dynamic Sea Surface Height (SSH). Areas where SSH ≤ 105 dyn cm corresponds to a cyclonic, cold core eddy, and areas where SSH ≥ 130 dyn cm correspond to an anti-cyclonic, warm core eddy. Small crosses indicate location of CTD and XBT samples stations along the cruise track.

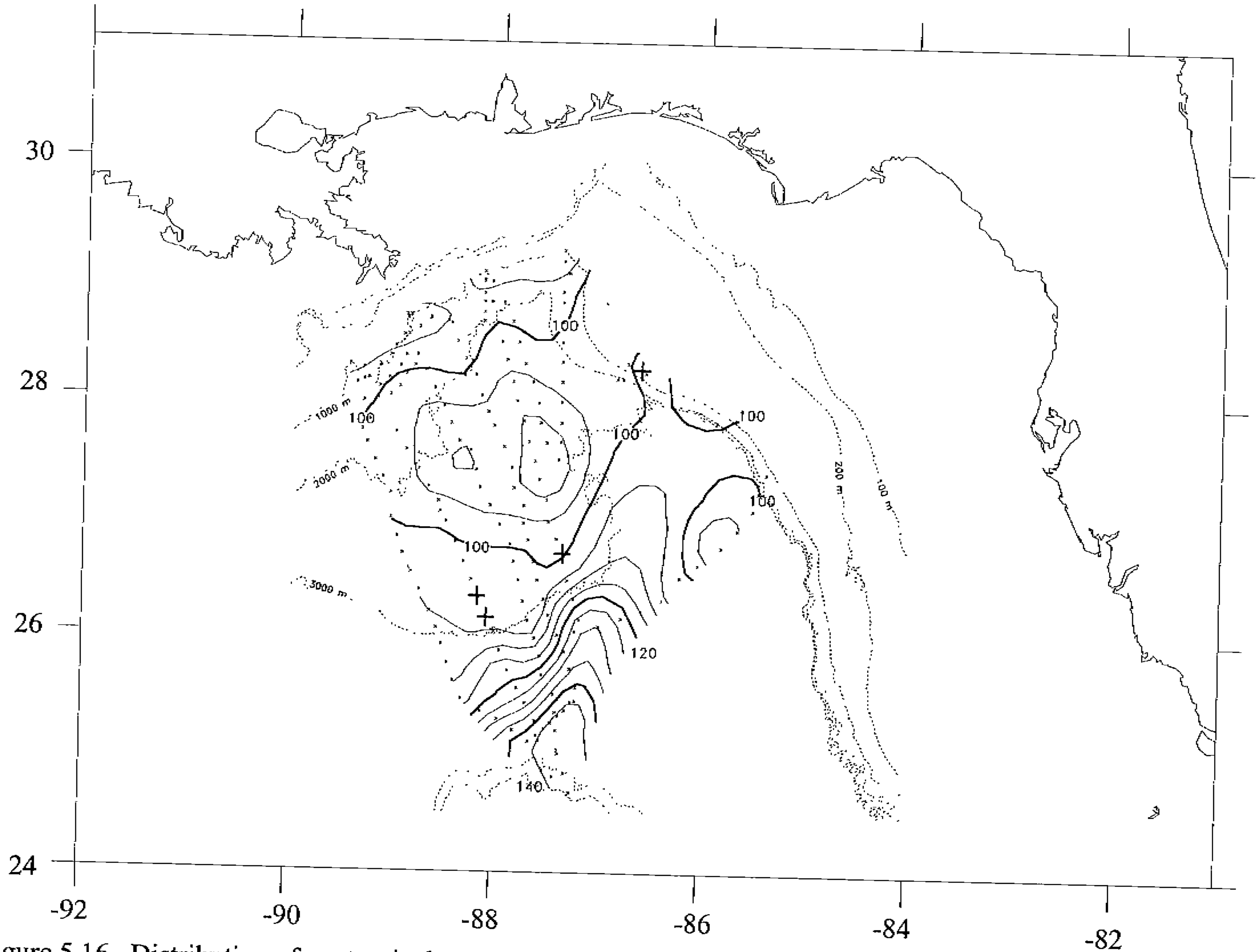

Figure 5.16. Distribution of pantropical spotted dolphins relative to hydrographic and bathygraphic data during the 1996 late summer cruise. Solid contour lines represent Dynamic Sea Surface Height (SSH). Areas where SSH ≤ 100 dyn cm correspond to a cyclonic, cold core eddy, and areas where SSH ≥ 125 dyn cm correspond to an anti-cyclonic, warm core eddy. Small crosses indicate location of CTD and XBT samples along the cruise track. Most of the contacts were in the convergence zone.

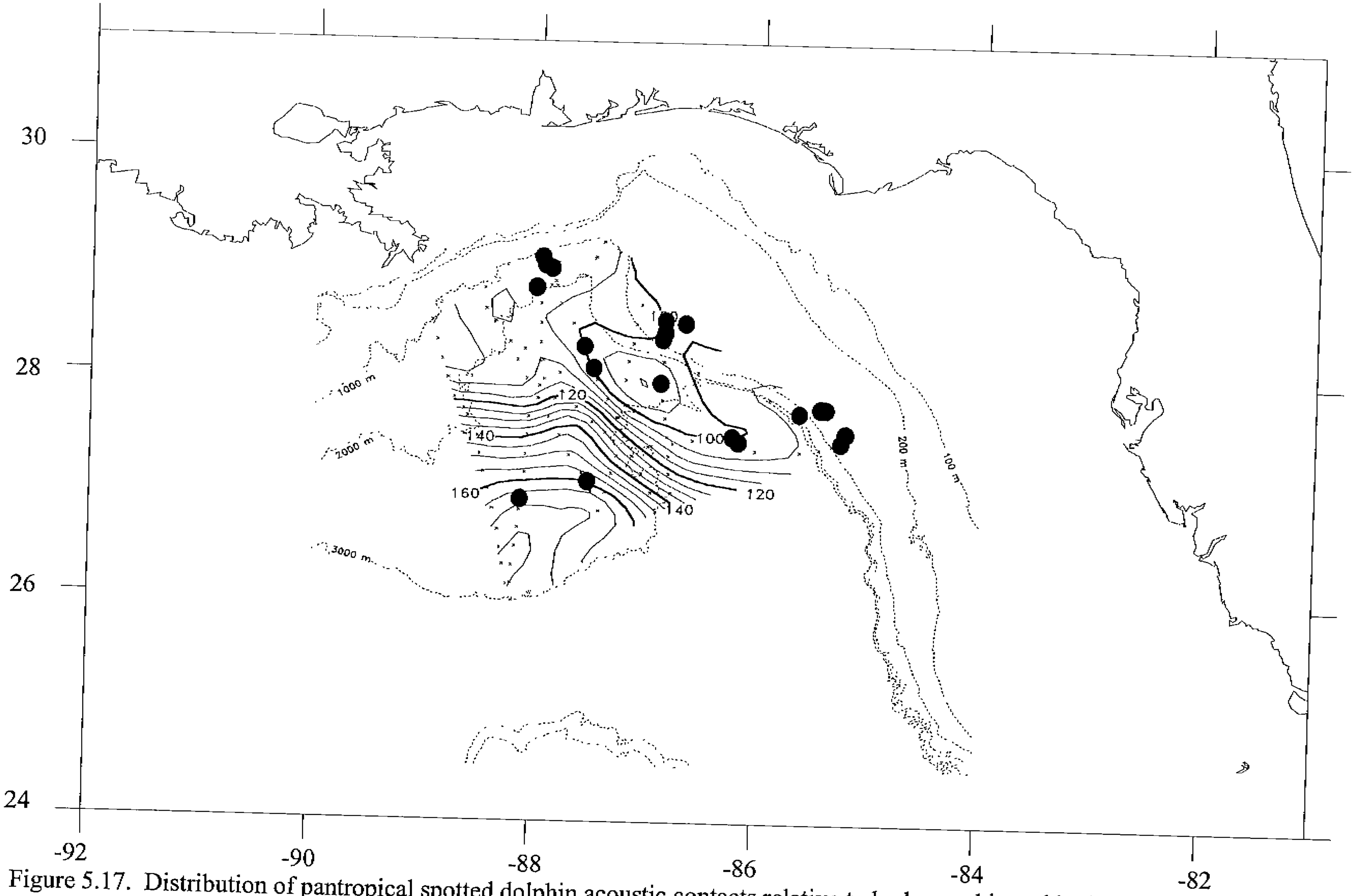

Figure 5.17. Distribution of pantropical spotted dolphin acoustic contacts relative to hydrographic and bathygraphic data during the 1997 mid-summer cruise. Solid contour lines represent sea surface dynamic height in 5 cm intervals. The cyclone is between 92 and 105 cm, the confluence between 105 and 129 cm, and the anticyclone between 130 and 176 cm. Small crosses indicate the location of CTD and XBT stations along the cruise track. Most of the contacts were associated with the periphery of the cyclone, as were the sperm whales during that year.

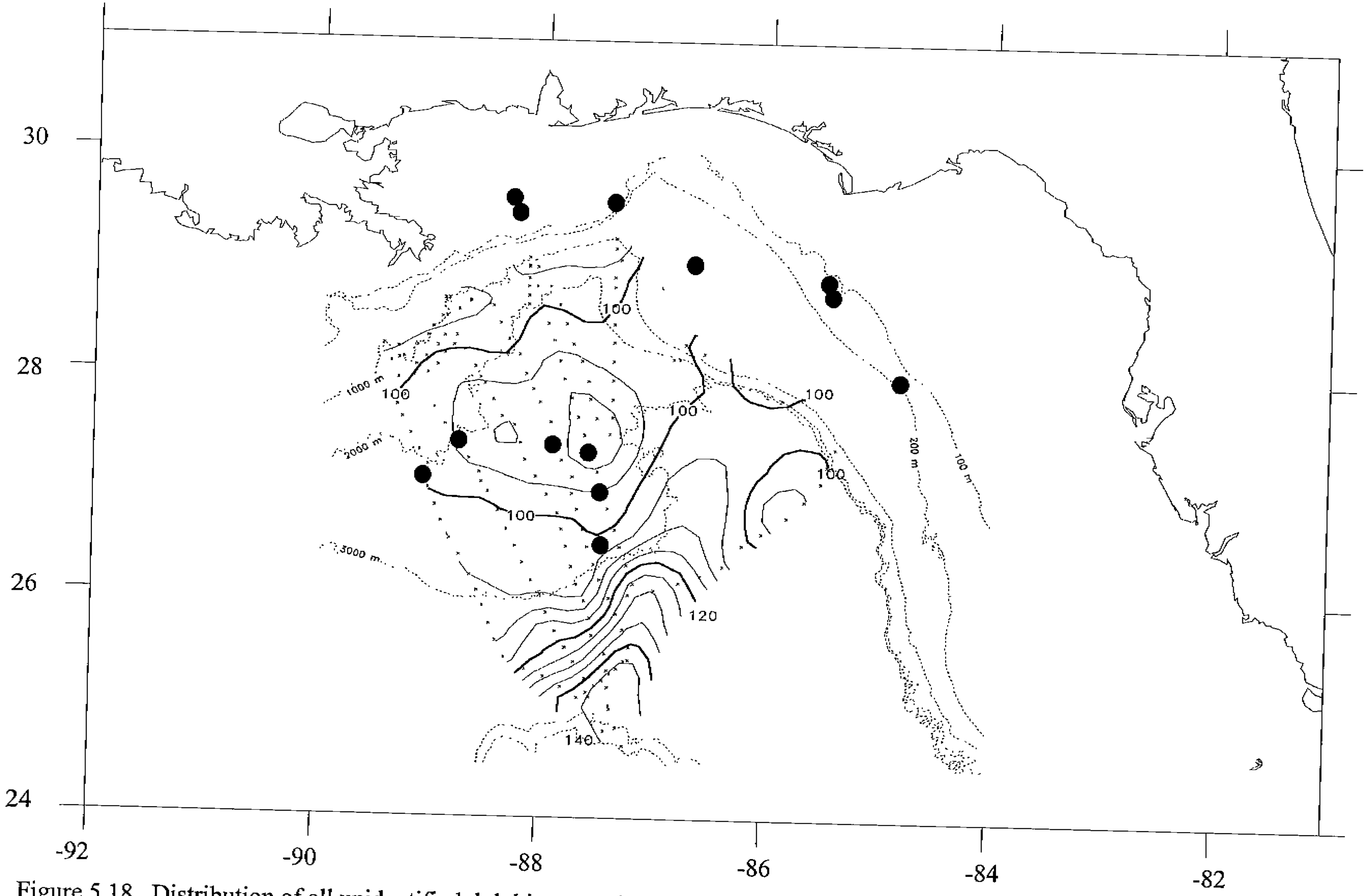

Figure 5.18. Distribution of all unidentified dolphin acoustic contacts relative to hydrographic and bathygraphic data during the 1996 late summer cruise. Solid contour lines represent Dynamic Sea Surface Height (SSH). Areas where SSH ≤ 100 dyn cm correspond to a cyclonic eddy, and areas where SSH ≥ 125 dyn cm corresponds to an anti-cyclonic eddy. Small crosses indicate location of CTD and XBT stations along the cruise track.

cyclone or in the confluence, including the northern edge where waters from the Mississippi River were entrained in the confluence zone (Figure 5.19). Two contacts occurred in the anticyclone.

5.4.5 Whistle Characterization and Identification

A total of 1,117 vocalizations from nine species were analyzed (Table 5.2). These nine species represent over 75% of the total estimated dolphin population in the northern Gulf of Mexico (Table 4.11). Three species alone, bottlenose dolphin, clymene dolphin, and pantropical spotted dolphin, represent over 70% of all the dolphins in the study area (Table 4.11).

The whistles were classified into six whistle types based on spectrograms. The most common was a concave whistle, and the constant frequency whistle was the least common (Table 5.2). There was inter-specific variability in whistle usage. This is best seen in the diversity indices for the nine species. The pantropical spotted dolphin had the most diverse whistle usage, indicating that it used all six whistle types and didn't emphasize one particular call. The Atlantic spotted dolphin had the least diverse whistle lexicon. Half of the lexicon of calls for both Atlantic spotted and striped dolphins were concave whistles. Additionally, Atlantic spotted dolphins did not use convex whistles, while Fraser's dolphin did not use constant frequency whistles. The five species in the genus Stenella used upsweep whistles three times as often as non-stenellids. Overall, the most commonly used vocalizations were upsweeps and concave whistles, each representing 25% of the overall lexicon. This difference in usage was one clue to species identification. Additionally, the acoustic characteristics of the whistles were highly variable and could be used for identification (Table 5.3). The parsing of this variability using discriminant function analysis permitted grouping by species. The final factor used for identification was ocean depth at the time of the recording. Two species, bottlenose and Atlantic spotted dolphin, were found primarily in shallow waters, with all other dolphin species in deeper waters. There was considerable inter-specific overlap in the mean values for the acoustic parameters for all identified dolphins (Table 5.3). This inter-specific overlap prevented satisfactory classification of the combined data set. The inability to classify these signals was expected, because initial comparisons were made between all whistles for all recorded species. There was greater intra-specific variability between different whistle types (e.g. pantropical spotted dolphin upsweeps versus downsweeps) than inter-specific variability within whistle types (e.g. pantropical spotted dolphin sine whistles vs. clymene dolphin sine whistles). By combining information about the lexicon, its physical context and the DFA characterizations, a contact identification decision tree was constructed (Figure 5.20).

We analyzed 60 whistles from 11 unidentified dolphin contacts that were recorded during the two summer cruises. The same DFA used on the identified contacts was applied to the unidentified signals, and the decision tree was used to identify four contacts. Unidentified contacts that were not whistles (i.e. dolphin pulses) could not be identified with this procedure. A scatter plot from the DFA of sine whistles from all species shows that two species, bottlenose dolphin and false killer whale, are separated from all of the other dolphin whistles (Figure 5.21). Sine whistles were the most common signal used by these two species. If the sine whistle was identified as coming from either a false killer whale or bottlenose dolphin, then the ocean depth

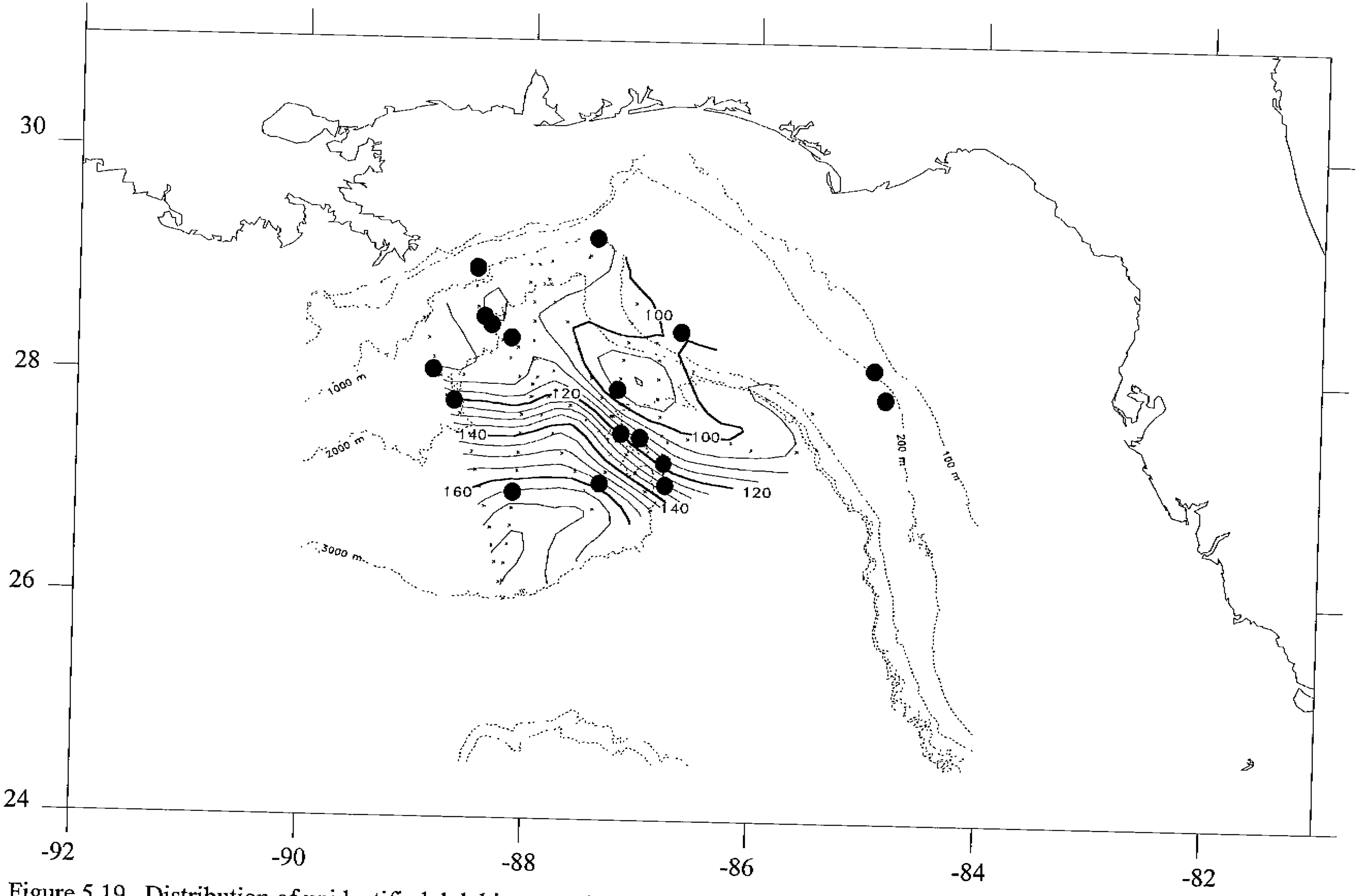

Figure 5.19. Distribution of unidentified dolphin acoustic contacts relative to hydrographic and bathygraphic data during the 1997 mid-summer cruise. Solid contour lines represent Dynamic Sea Surface Height (SSH). Areas where SSH ≤ 105 dyn cm correspond to a cyclonic, cold core edy, and areas where SSH ≥ 130 dyn cm correspond to an anti-cyclonic, warm-core rings. Small crosses indicate location of CTD and XBT stations along the cruise track.

Table 5.2. Number of whistles types by species and the Shannon-Weiner Index for whistle diversity for each species.

Species	Whistle Type Constant Freq.	Upsweeps	Downsweeps	Concave	Convex	Sine	Total	Diversity Index
Pantropical spotted dolphin	2	61	24	43	27	35	192	0.950
Atlantic spotted dolphin	5	7	1	21	0	8	42	0.566
Clymene dolphin	1	29	3	48	16	30	127	0.815
Striped dolphin	2	25	9	58	8	12	114	0.711
Spinner dolphin	36	89	24	24	22	34	229	0.806
Bottlenose dolphin	2	6	11	24	6	34	83	0.692
Rough-toothed dolphin	15	34	6	16	3	3	77	0.750
Fraser's dolphin	0	1	2	11	5	6	25	0.748
False killer whale	32	23	42	35	23	73	228	0.826
Total	95	275	122	280	110	235	1117	

Table 5.3. Means for acoustic parameters for all identified dolphins from all cruises. Duration is in msec, and all frequency parameters are in Hz.

Species	Acoustic Parameters Dur.	Beg. Freq.	End Freq.	Beg. - End Freq.	High Freq.	Low Freq.	High - Low Freq.	# of Inflection	# of Steps	N
Pantropical spotted dolphin	0.669	10036	12012	4300	14416	7739	6677	0.9	1.3	192
Atlantic spotted dolphin	0.390	10464	12076	2528	12698	6866	5832	1.0	0.2	42
Clymene dolphin	0.409	10766	12058	2790	13621	9245	4376	1.5	0.5	127
Striped dolphin	0.473	9845	10346	2220	11635	7824	3811	1.0	0.4	112
Spinner dolphin	0.743	9389	12216	4709	13741	7708	6033	0.7	0.7	232
Bottlenose dolphin	0.611	8836	7975	2902	10879	5738	5141	1.9	0.2	83
Rough-toothed dolphin	0.377	6945	8177	1554	8486	6377	2109	0.7	1.6	78
Fraser's dolphin	0.703	10735	10367	2253	12960	8684	4276	1.2	1.0	23
False killer whale	0.591	7138	6910	1492	8428	5706	2722	1.2	0.1	228
All species	0.585	9099	10252	3027	11913	7240	4673	1.1	0.6	112

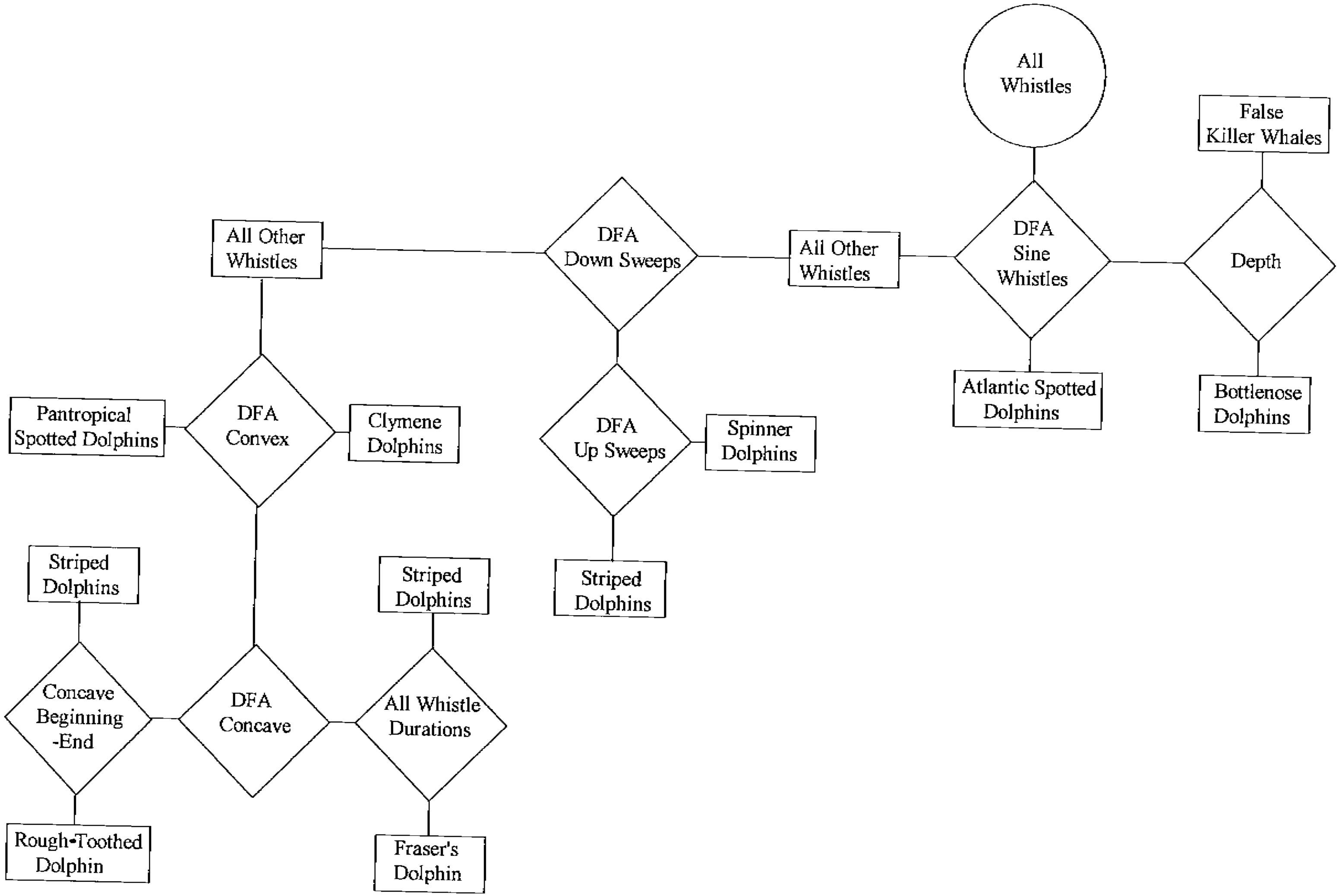

Figure 5.20. Decision tree for identifying unknown dolphin contacts. The factors used in these determinations are: 1) discriminant function analyses of acoustic parameters from specific whistle types (e.g. sine or convex whistles) from identified signals; 2) the ocean depth at the contact location; and 3) specific acoustic parameters such as mean whistle duration. The identity of a dolphin contact can be made by successively applying the decision rules to multiple whistles within a single contact.

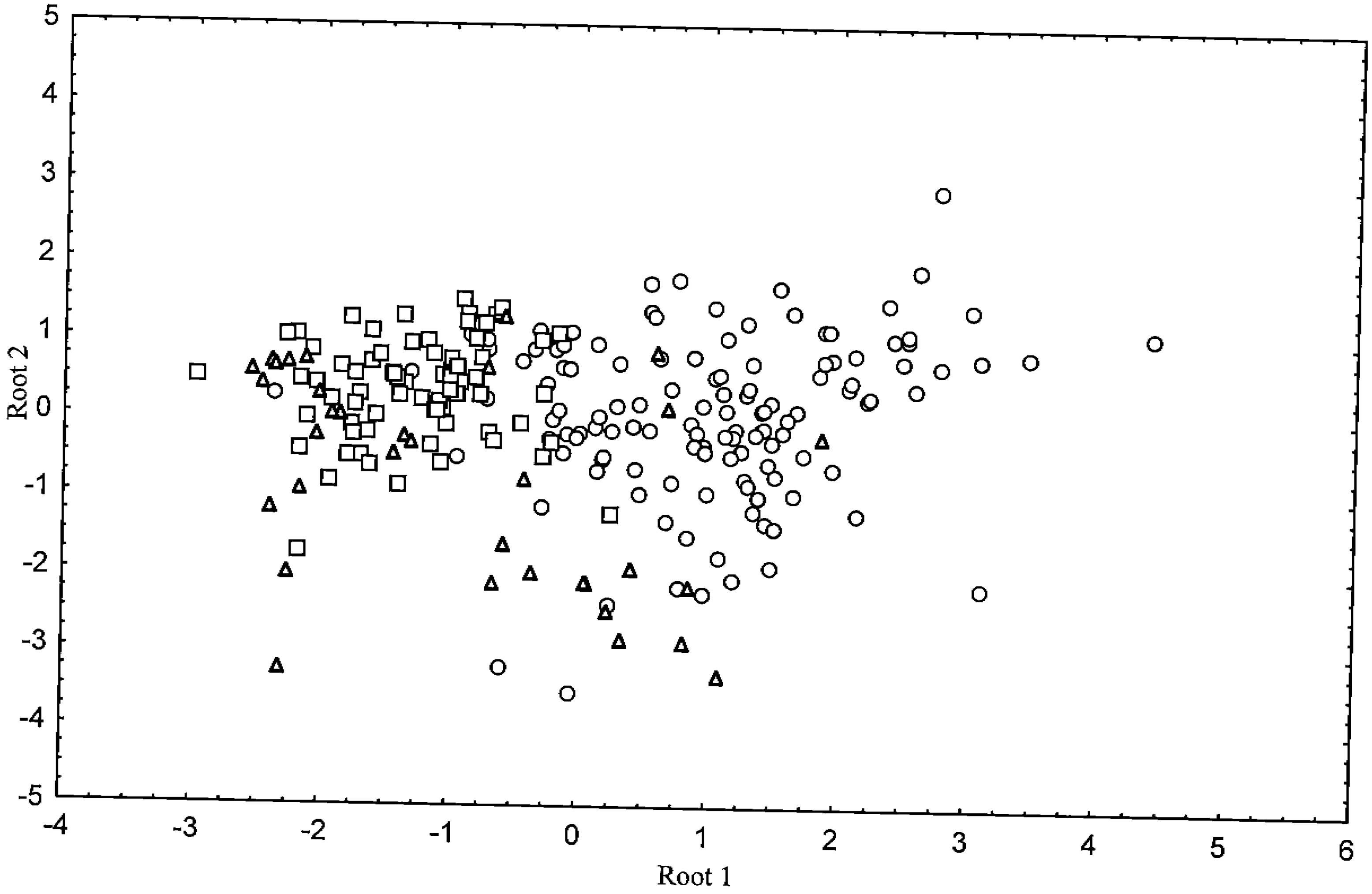

Figure 5.21. Scatter plot of discriminant function analysis of sine whistles from bottlenose dolphin (triangles), false killer whales (squares) and all other dolphins (circles). All other dolphins are reliably separated from the two other species, which can then be separated according to the ocean depth at the contact location.

at the contact location could distinguish the shallow water bottlenose dolphin from the deep water false killer whale. This same procedure was used for other whistle types

With a sufficiently large or distinctive repertoire within a contact, identification can be confidently made. For example, one contact was identified as coming from rough-toothed dolphins using the following reasoning. The contact was recorded in water depths of 1,500 m. This eliminates bottlenose and Atlantic spotted dolphins as likely sources. All five vocalizations were a specific type of upsweep whistle. Rough-toothed dolphins primarily (88%) use this call, whereas no other species uses it more than 34% of the time. Lastly, the sound of the signal, its spectrogram and the DFA analysis suggested it was from rough-toothed dolphins. Figure 5.22 illustrates the DFA scatterplot for the rough-toothed dolphin whistles, the five whistles from the unidentified contact, and all other dolphin whistles. The whistles from the unidentified contact are well matched to those from the rough-toothed dolphin. Similar analyses identified previously unknown contacts as being from pantropical spotted dolphins, Atlantic spotted dolphins and unidentified *Stenella* species.

5.4.6 Effects of Seismic Exploration on Cetaceans

In the nearly 17,000 km of acoustic monitoring in the Gulf of Mexico during GulfCet I and II, many forms of man-made sounds were recorded. These sounds could adversely affect animals by physically injuring their hearing, causing them to leave the area, or masking their own communication and food-finding signals (Richardson et al. 1995). The form of the signal, therefore, has an impact on whether it will affect an animal. A loud, pulsed explosion may deafen an animal, whereas a continuous signal (e.g. vessel noise) may result in the animal not hearing conspecifics calling, or interfere with reception of their own signals. Seismic signals are often described as being strictly low frequency signals, with energies only below 1 kHz . However, we recorded loud, pulsed signals associated with seismic exploration with center frequencies at 2.5 kHz, with little energy below 1 kHz (Figure 5.23). These signals are similar in frequency to sperm whale clicks, and are probably audible to the whales. Additionally, we recorded other signals, centered at 3.5 kHz that are used to locate the multiple hydrophone arrays relative to each other and the sound source (Figure 5.24). During the late summer 1996 cruise, we recorded a long series of these pulses (Figure 5.25) that were very similar to sperm whale signals.

Subsets of the acoustic and visual data were examined to determine if seismic signals affect cetacean distribution. Over 514 hours of "on effort" recordings covering approximately 6,819 km of survey effort were used. A total of 108 hours, or 21% of the total time, contained sounds associated with seismic exploration (Figure 5.26a). The percent time with seismic exploration sounds was 10.4% for GulfCet I (Figure 5.26b) and 34.1% (Figure 5.26c) for GulfCet II. The final cruise of GulfCet II had the greatest percentage of seismic exploration sounds, with pulses present 49.8% of the time. These sounds were not uniformly distributed, but were concentrated in the more shallow areas of the study area, the upper and mid-continental slope, and away from the deeper waters further to the south.

Signal to noise ratios were described to further understand the average distribution of seismic exploration signals. Measurements of 52 seismic exploration signals were analyzed for signal

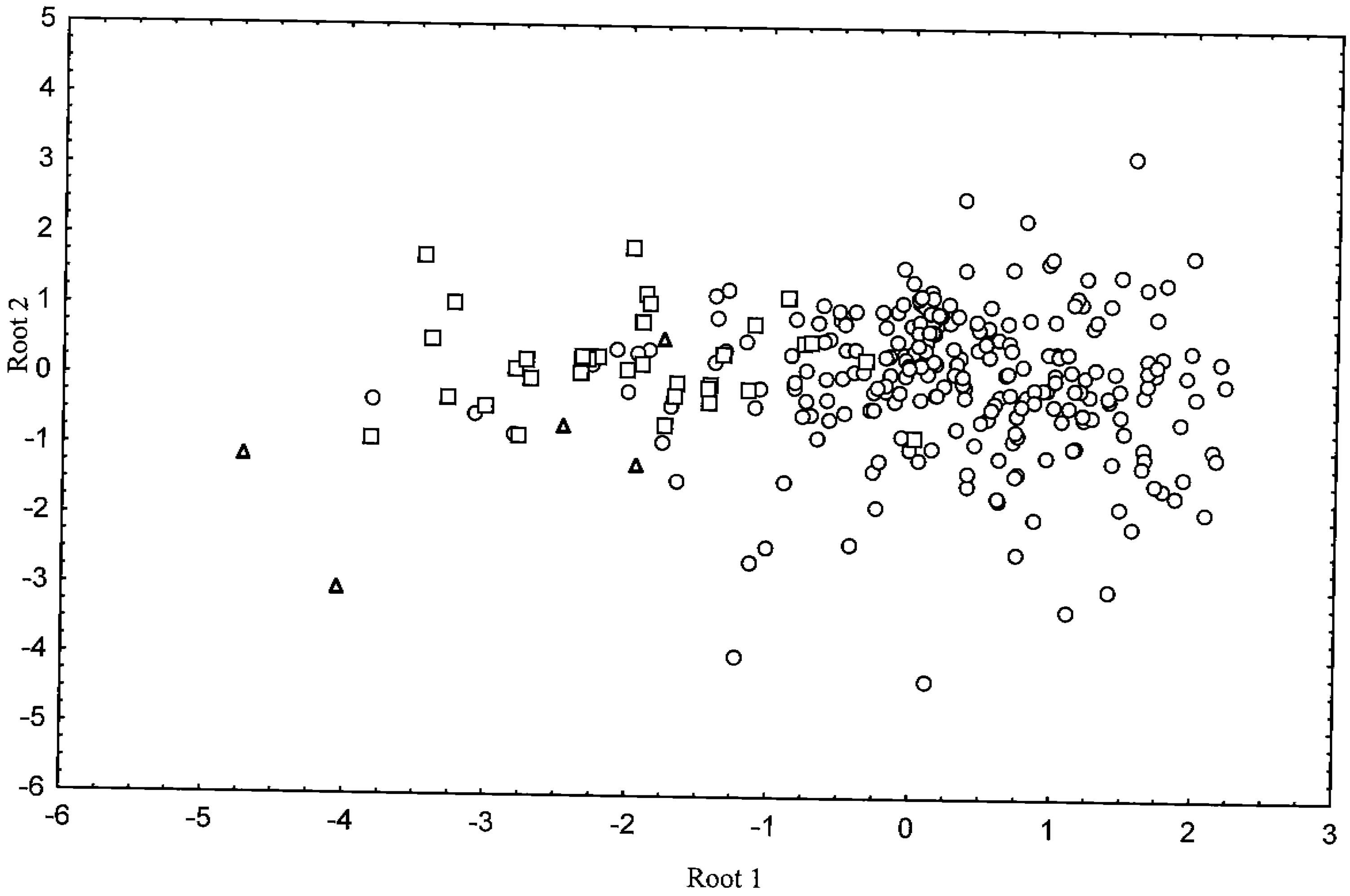

Figure 5.22. Scatter plot of the discriminant function analysis of upsweep whistles from rough-toothed dolphins (squares), the unidentified contact (triangles) and all other dolphins (circles) used to identify a particular contact .

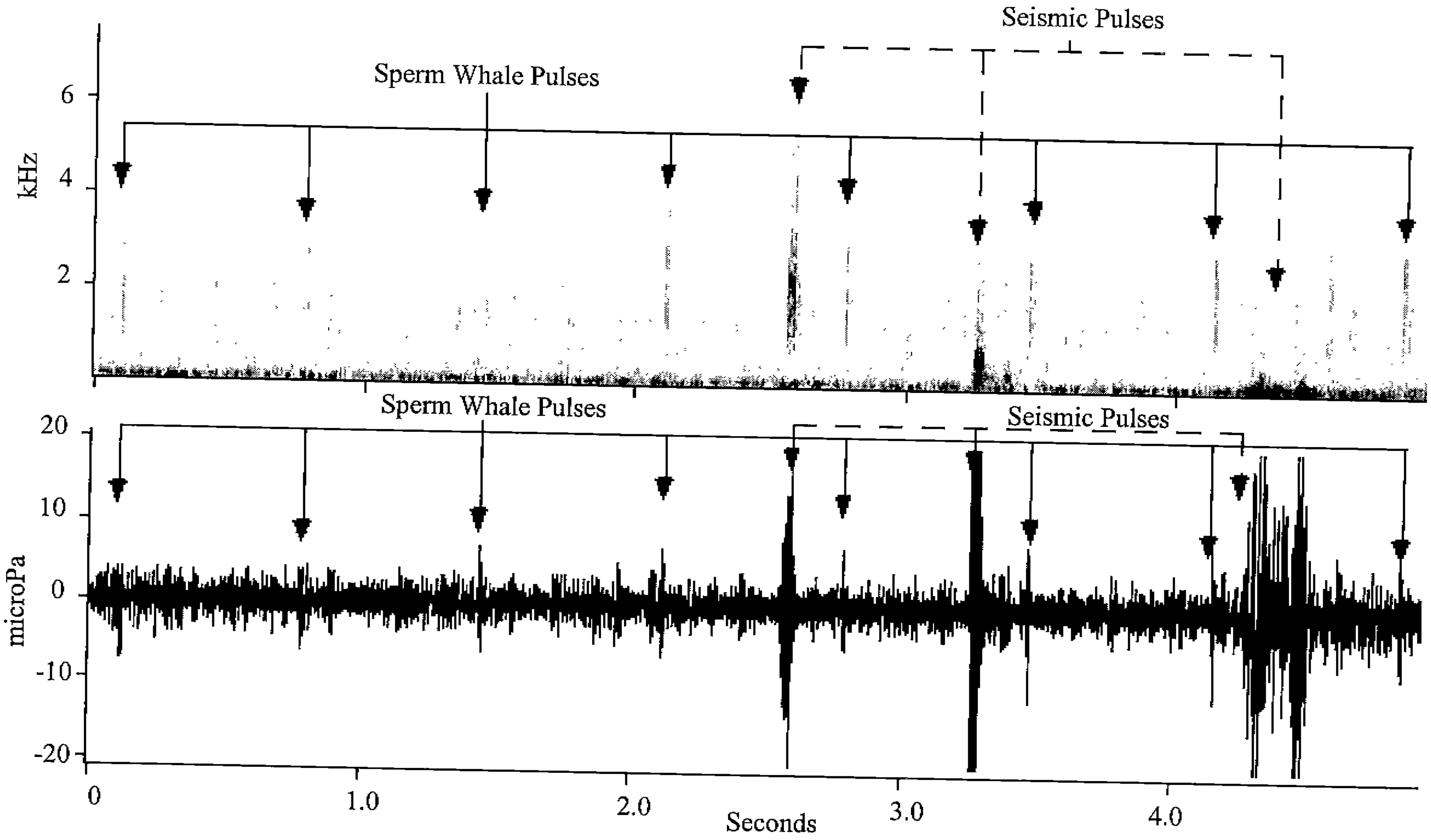

Figure 5.23. Spectrogram (top) and waveform (bottom) illustrating sperm whale pulses and two forms of seismic signals. The spectrogram displays frequency (y-axis) as a function of time (x-axis) with increased darkness indicating increased amplitude. The waveform displays amplitude over time. Eight sperm whale pulses are indicated, with center frequency at approximately 2.5 kHz. The first seismic pulse is also centered at 2.5 kHz, with little energy below 1 kHz. The second pulse is centered at 900 Hz. The final pulse, centered at less than 100 Hz, is an echo.

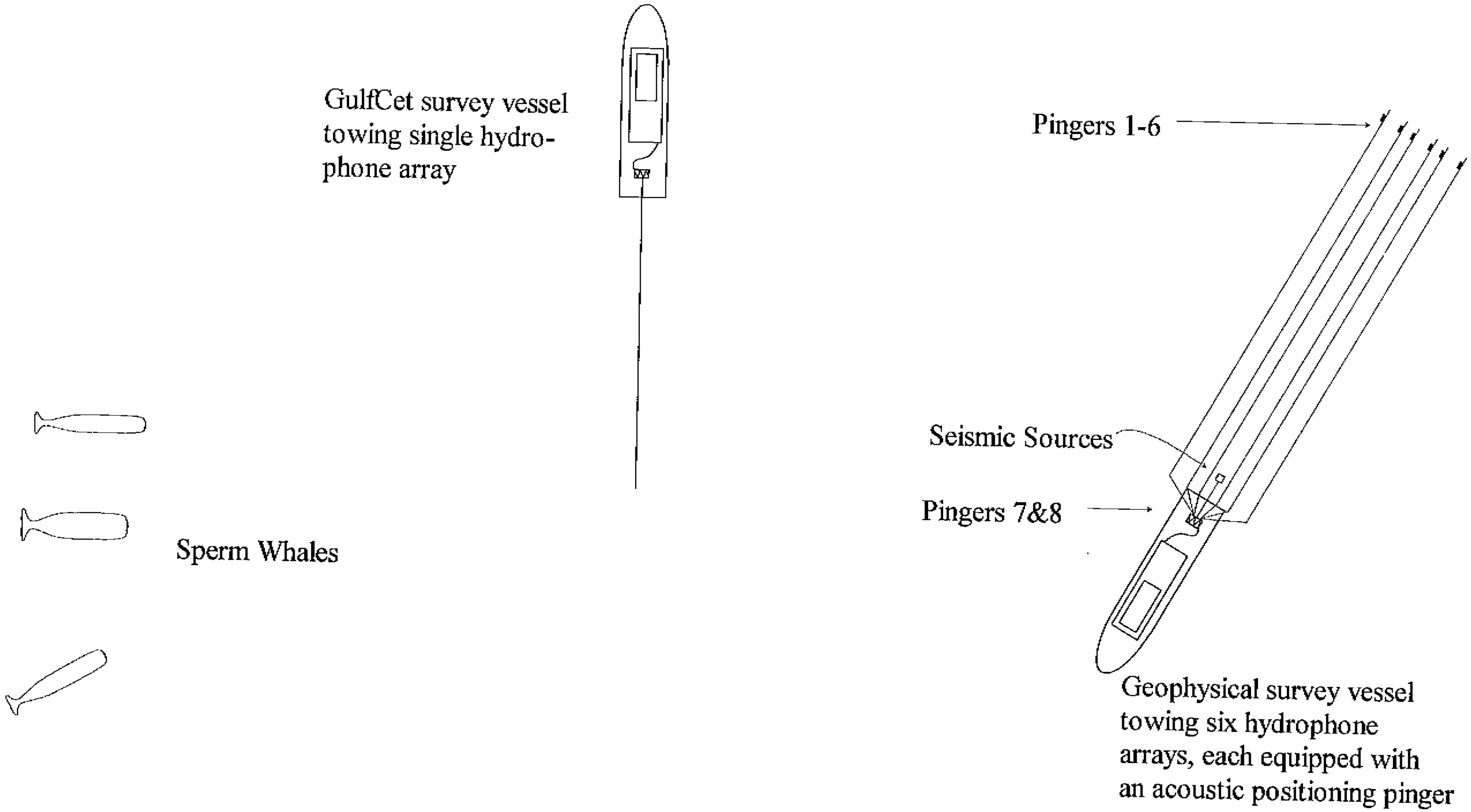

Figure 5.24. Schematic diagram, not to scale, of the seismic noise sources and receivers. The geophysical survey vessel produces pulses from three sources: pingers for the acoustic positioning system; one high frequency, high resolution seismic profiler; and a low frequency seismic profiler. For the acoustic positioning system, there are pingers on each of the six arrays, with a seventh pinger on a seismic profiling source, and the eighth pinger on the survey vessel. In this figure, there are sperm whales producing pulses. All of these signals are detected by the hydrophone array aboard the GulfCet survey vessel. In actuality, the geophysical survey vessel is 16 km from the GulfCet survey vessel. The geophysical arrays are probably five km long, while the GulfCet hydrophone array is 300 m long.

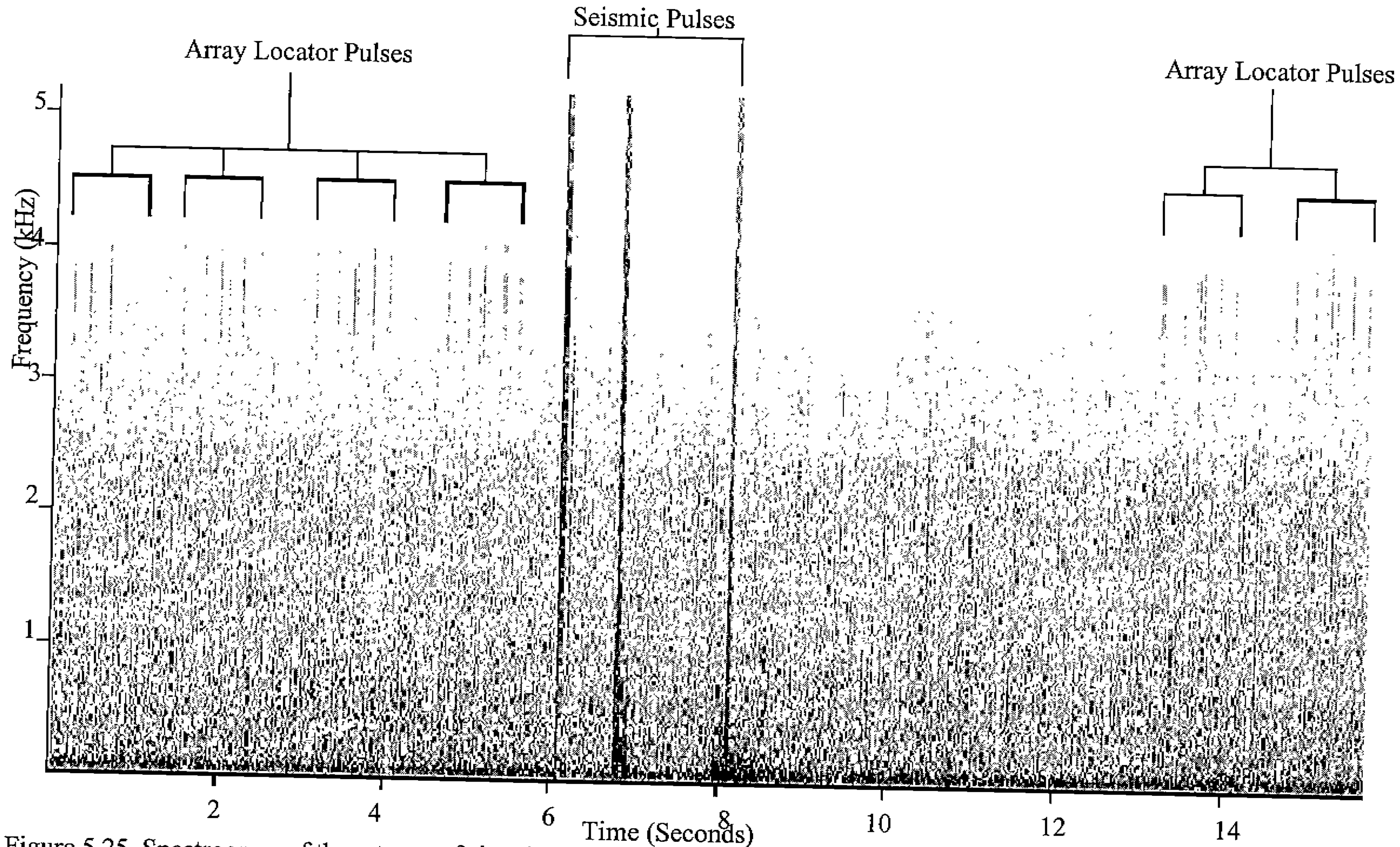

Figure 5.25. Spectrogram of three types of signals used in the seismic exploration industry. A spectrogram displays sound frequency (y-axis) as a function of time (x-axis), with relative darkness indicating amplitude. Four series of array locator pulses occur prior to the seismic pulses. The locator pulses are centered at 3.5 kHz, the first seismic pulse is centered at 2.5 kHz, with little energy below 1 kHz and above 5 kHz. The second seismic pulse is centered at 900 Hz, and its echo is centered below 100 Hz. Six seconds after the echo, the locator pulses restart.

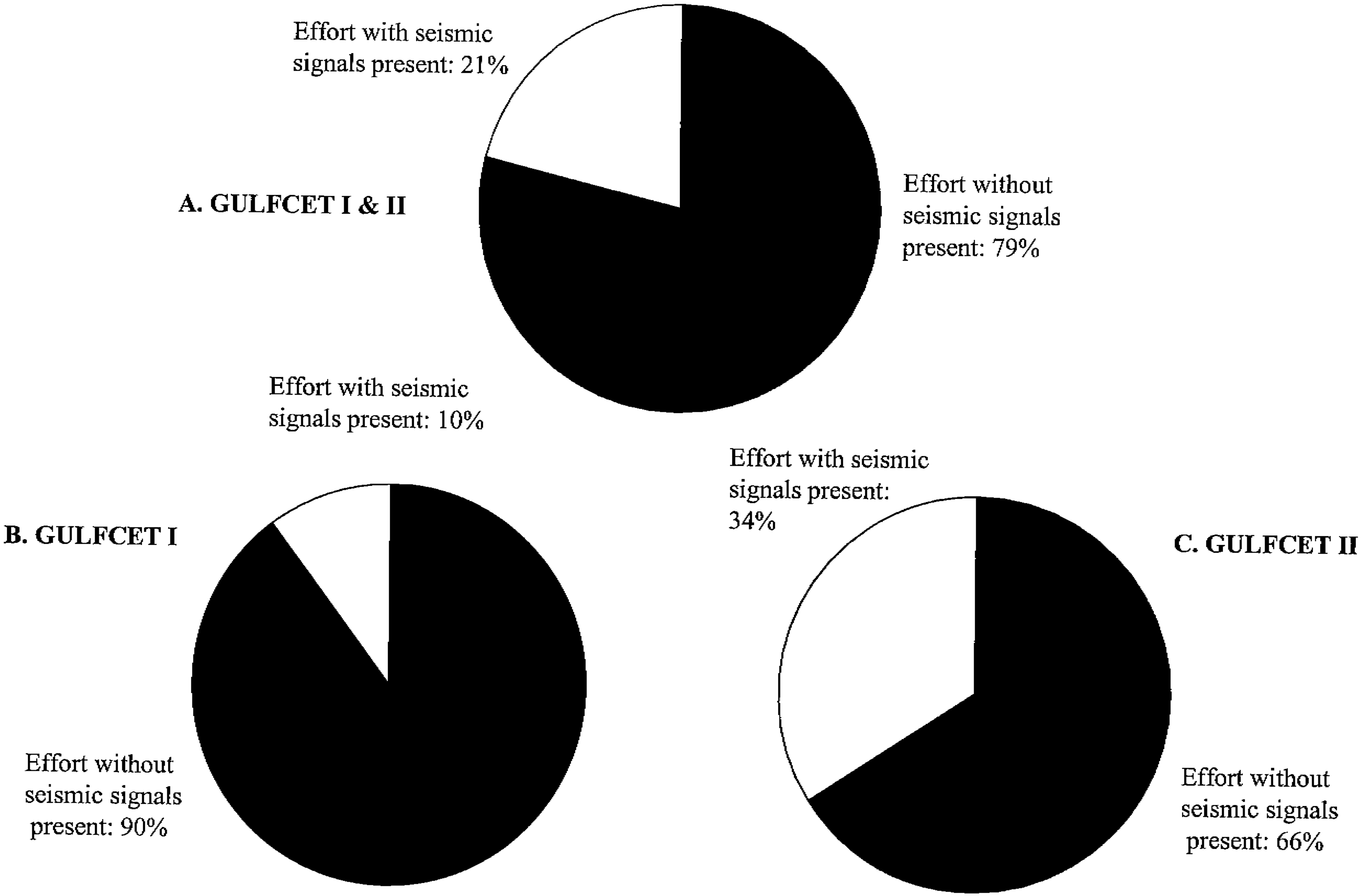

Figure 5.26. Percentage of effort with and without the presence of seismic exploration signals for (A) both GulfCet I & II (northern Gulf), (B) for seven GulfCet I cruises (western and central Gulf), and (C) three GulfCet II cruises (eastern and central Gulf).

characteristics. The overall average signal to noise ratio was 8.4 dB re 1 µPa , that is, on average a seismic exploration signal was 8.4 dB above the ambient noise recorded by the array as it was towed behind the survey vessel. The maximum signal to noise was 13.1 dB and a minimum of 4.3 dB. With regard to the spectral characteristics, the overall average maximum frequencies were 613.5 Hz , while the minimum was 26.7 Hz. The highest frequencies recorded from these signals were 2,426 Hz. The overall average peak frequency was 81.7 Hz, ranging from 35- 107 Hz.

Vocalizations of many cetaceans, as well as shrimp, were concurrently recorded with seismic exploration survey pulses. These included sperm whales, striped dolphins, Fraser's dolphin, pantropical spotted dolphins, clymene dolphins, spinner dolphins and rough-toothed dolphins. In addition, there were many unidentified cetacean vocalizations.

There was no significant difference between the overall sighting rate and the sound level when tested for each of the hydrographic regions. Distributions of two species, with sufficient number of sightings, were additionally examined. The sperm whale sighting rate did not differ significantly between the different sound levels for any of the hydrographic features. The sighting rate of the pantropical spotted dolphin was found to be significantly higher for the >12 dB areas within the hydrographic feature defined as "other" ($\chi^2 = 10.26$, p=.005). The sighting frequencies for the remaining hydrographic features did not differ significantly by sound level.

5.5 Discussion

5.5.1 Comparing Visual and Acoustic Surveys

There are a number of appropriate comparisons between the visual and acoustic survey methods used during GulfCet II. Contact rate is the number of contacts per unit effort distance. Acoustic and visual contact rate can be compared for area and species group. For all dolphin species (including unidentified species) along the continental slope, the visual survey had 66 contacts in 2,572 km of effort or 0.026 contacts/km. This compares to 17 contacts in 2,172 km or 0.0078 contacts/kilometer for acoustic effort. The visual survey contact rate was three times greater than the acoustic rate. In the oceanic northern Gulf, the visual survey had 97 contacts for all dolphins in 8,595 km of effort or 0.0113 contacts/km. This was similar to the acoustic survey, where there were 28 contacts in 2,812 km of effort or 0.0100 contacts/ km. For sperm whales throughout the study area, the visual survey had 29 contacts in 11,167 km of effort or 0.0026 contacts/km. The acoustic survey had 20 contacts in 4,984 km of effort or 0.0040 contacts/kilometer, which is 1.54 times greater than the visual rate. Easy recognition of vocalizations and greater detection range best explain the higher acoustic contact rate for sperm whales. Additionally, their long dive times reduce the likelihood that all animals will be seen. In some cases, acoustic contacts lasted for many hours, which couldn't occur for the visual survey. The smaller number of dolphin contacts for the acoustic survey is difficult to explain, but few animals were contacted during the late summer 1996 cruise. Neither visual nor acoustic surveys had many contacts during that cruise, which represented approximately half of the acoustic effort but less than a quarter of the visual effort .

There was general agreement on locations of sperm whales between acoustic and visual methods. During the late summer cruise, contacts by both methods were largely limited to the western side of the study area (Figures 6.3 and 5.12). However, animals were detected acoustically south of 27°N where none were visually detected. This probably resulted from the poor weather conditions that limited visual effort. During the mid-summer cruise, agreement between the two survey methods was also strong; most sperm whale contacts occurred around the cyclonic eddy (Figures 6.9 and 5.13).

In comparing dolphin contacts, there appeared to be important differences between visual and acoustic survey methods. During the late summer cruise, there were fewer acoustic than visual contacts on the continental shelf, but more acoustic than visual contacts at the confluence of the cyclone and anticyclone (Figures 6.2 and 5.14). There were also more acoustic contacts on the eastern slope of the study area. However, both methods showed dolphins farther south in the margin of the anticyclone. The agreement in contact location between methods was better in mid-summer 1997, with most dolphin contacts in or near the cyclonic eddy or at the confluence between the cyclone and anticyclone (Figures 6.8 and 5.15). In both cases, there were many contacts on the eastern edge of the study area, reflecting the strong eastern geostrophic flow created by the confluence zone (see Figure 2.09 and 2.11) and stronger shelf upwelling than in late summer 1996. In a similar fashion, there were a number of dolphin contacts to the west of the cyclone, due perhaps to fresh water from the MOM area that was entrained in the confluence zone and transported over the slope (Figure 2.11). There were five visual contacts farther south in the anticyclone that were not detected by the acoustic survey (Figures 6.8 and 5.15).

5.5.2 The Effects of Seismic Exploration on Cetaceans

The results show that the cetacean sighting rate did not change significantly between areas of low, moderate, or high intensity seismic exploration sounds. As described in the methods, these sound level categories were relative (i.e., signal-to-noise ratio) to the noise level at the hydrophone array. A major source of ambient noise during our recordings was the ship while traveling at nine knots. If a dolphin were to hear a seismic signal at a similar distance, the signal-to-noise ratio would be considerably higher than for our recordings because of the noise produced by the survey vessel towing our hydrophone array.

There were almost no instances where our survey vessel was within 5 km of a seismic vessel. All of the seismic exploration signals examined in this study appeared to come from distant vessels because they were relatively low intensity and low frequency in character (Rankin 1999). If we had been closer to the sound source, the signals would have been higher in intensity and contained higher frequencies. If seismic signals affect dolphins, it is probably due to the higher frequencies which they hear best.

Our analysis of the potential effects of seismic signals on cetaceans was unable to detect small-scale (i.e., < 100 km) changes in distribution. Finer resolution studies, similar to those conducted by Goold (1996) in the Irish Sea, and in closer proximity to the sound source are needed to determine the local impact of these signals. Three aspects of the cetacean community are relevant to the potential effects of seismic exploration in the Gulf: a large and diverse dolphin community, a large and stable sperm whale population, and very few baleen whales. Dolphins, which are the largest component of the cetacean community, are least sensitive to signals below 1 kHz (Richardson et al. 1995). It is therefore likely that their own hearing thresholds limit the impact of seismic signals. This would be true for nearly all encounters in this study, as the signals were from distant sources. The species likely to be most sensitive to low frequencies, Bryde's whale, regularly occurs in small numbers along the shelf break in the eastern Gulf. There appears to be site fidelity among some sperm whales in an area of intense oil industry activity near the MOM. Nevertheless, sperm whales continue to use this area of heavy seismic exploration. It is unclear whether the site fidelity is a consequence of low sensitivity to seismic noise or a high motivation to remain in the area. Townsend (1935) noted the presence of sperm whales in the north-central Gulf of Mexico as far back as the mid-1800's. This indicates that sperm whales have historically occupied this area and have been exposed to noise for many years. Their continued presence would appear to indicate either tolerance or insensitivity to this noise.

In explaining the possible responses of cetaceans to seismic signals, it is necessary to understand both how and why cetaceans might react. While the auditory thresholds of a few dolphin species are known, little is known about either sperm whale or baleen whale hearing. Because of their low-frequency vocalizations and auditory morphology, it is thought that baleen whales have good low frequency hearing. We suggest that sperm whales also have good low frequency hearing because of their large size and use of relatively low frequency pulsing. Both dolphins and sperm whales produce high amplitude, transient pulses. Like most animals, they have mechanisms to protect their hearing against loud sounds. If the rise time of a seismic pulse is slower than their own signals, it is likely that cetaceans can protect their hearing against loud pulses. There would still be a limit beyond which their hearing could still be damaged by sufficiently loud transients.

5.5.3 Sources of Variance in Acoustic Surveying

The sources of acoustic survey variability can be broadly divided into natural variation and sampling biases. Natural variability is a result of the distribution of the animals and the physical conditions in which they are found. Regardless of whether the distribution is random, clumped or correlated with some natural variable (e.g., food distribution), there will be variation in the number of contacts encountered per track line. There will also be variation in the detection distance, as a function of ambient noise, and variability in the transmission characteristics of the water mass. Additionally, there will be variation in the acoustic signal used to identify the presence of the animal. Signals will vary by frequency, duration, amplitude, the animals' behavioral state, and their relative distance from the hydrophones. Variation in these acoustic variables will affect the survey results to the degree that the hydrophone has the bandwidth and sensitivity to detect the signals. The ability to determine the temporal structure of the signal may also be affected by the transmission medium. For example, multiple transmission channels, as a result of temperature and salinity variations with depth, can produce multi-paths so that pulse configurations are altered.

Marsh and Sinclair (1989) described sources of bias in strip transect surveys. They suggested a method for describing these biases that has many parallels to problems that might occur with acoustic surveys. The authors described two general forms of bias: perception bias and availability bias.

Perception bias occurs where animals are present but not detected. In the acoustic domain, this occurs when an animal makes a sound that is not heard. Given the idiosyncrasies of each person's perceptual capabilities, perception bias can be considered observer bias. This bias may be due to a number of factors including the observer's lack of experience or knowledge of the pertinent sounds, or to inattention due to fatigue or lack of motivation.

Availability bias in the acoustic domain occurs when a sound is made but is undetectable to the observer. This may be due to masking by loud noise (i.e. the S/N ratio of the signal is below the detection threshold) or otherwise being imperceptible. The parallel condition in the visual domain occurs when an animal is unavailable to be seen because the water is turbid.

Variability can be reduced using two approaches: acoustic methods and data stratification. Acoustic methods improve the signal-to-noise ratio, which enhances sound detection. Data can be stratified by either noise conditions and/or by species. The signal-to-noise ratio can be improved by increasing the signal strength and using band pass filters. A 6 dB increase in signal-to-noise will result in a doubling of the detection distance and a four-fold increase in the overall strip width. This will increase the detection of acoustic contacts, which will decrease the variance and result in a more precise abundance estimate. We used 24 dB/octave filters to increase signal-to-noise.

Data stratification reduces variance by grouping data based on a similar parameter, such as signal amplitude, species or noise. Stratification requires a case-specific analysis of the pertinent data. For example, in visual surveys, data is stratified according to similar detection characteristics of the various species; those that are similarly visible have the same detection function. Likewise, acoustic data could be stratified according to the type of vocalization (e.g., whistles, echolocation pulses, sperm whale pulses). Stratification by noise level is based on the fact that, given equal signal amplitudes, noise limits our detection distance. Classifying data according to ambient noise conditions reduces the overall variance of the realized strip width.

5.6 Conclusions

The northern Gulf of Mexico has a large and diverse cetacean community, containing at least 19 species. The diversity of this community is comparable to the northeastern Atlantic and the eastern tropical Pacific (Hain et al. 1985, Wade and Gerrodette 1993). The acoustic survey had 73 dolphin and 20 sperm whale contacts during two cruises, with 29 dolphin and 11 sperm whale contacts during the late summer 1996 cruise and 44 dolphin and 9 sperm whale contacts during the mid-summer 1997 cruise. Recordings were made for sperm whales, pantropical spotted dolphins, clymene dolphins, spinner dolphins, striped dolphins, Atlantic spotted dolphins, false killer whales, bottlenose dolphins, rough-toothed dolphins and Fraser's dolphins. No recordings were made for any baleen or beaked whale.

The distribution of deep-water cetaceans appeared to be influenced by the cyclone and anticyclone pair in the eastern Gulf. Sperm whales in the Gulf of Mexico were more closely associated with the cyclone and the MOM and less with the confluence zones than some of the pelagic dolphin species. Almost half of the dolphin contacts in 1996 were in relatively shallow waters north of the influence of the cyclone and anticyclone. The more pelagic contacts were found considerably to the south in the confluence zone. In 1997, dolphins appeared to have three association patterns relative to the existing hydrographic features. Some northern contacts appeared to be influenced by the entrainment of Mississippi River outflow as it was brought seaward by the confluence zone; others were associated with the center of the cyclone; and finally others occurred within the confluence zone, in particular with the strong western current produced by the geostrophic flow. There were only two dolphins and a single sperm whale contact inside or near the northern periphery of the anticyclone. This distribution pattern suggests that anticyclones are not preferred areas for cetaceans in the Gulf of Mexico.

The whistles of nine dolphin species were characterized based on the analysis of 1,117 signals. There were species-specific patterns to whistle usage and acoustic structure. Based on these patterns, some unknown contacts were identified as coming from pantropical spotted dolphins, Atlantic spotted dolphins, rough-toothed dolphins and false killer whales.

A diversity of anthropogenic signals were recorded during nearly 17,000 km of acoustic effort during GulfCet I and II. Many of these were low frequency seismic exploration signals, but higher frequency seismic signals were also recorded. Bryde's and sperm whales can probably detect these signals. Cetaceans were exposed to a significant and increasing amount of noise, particularly off the MOM and in the eastern Gulf. Seismic exploration signals were detected during 21% of recordings, ranging from a low of 10% during the earlier GulfCet I project to more than half during the last GulfCet II cruise. There was no significant difference in the cetacean sighting frequency for low, medium, and high noise zones when controlling for differences in hydrographic conditions.

Chapter 6

Cetacean Habitat in the Northern Gulf of Mexico

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6.1 Introduction

There are many factors that influence the spatial and temporal distribution of cetaceans. These factors include physiographic and hydrographic characteristics, prey distribution, breeding and calving areas, and predation. Anthropogenic factors such as ship activity, oil and gas production, and seismic exploration (Richardson et al. 1995) may also influence whale and dolphin distribution. Previous studies (including the GulfCet I program) have demonstrated correlations of cetacean distribution with physiographic features such as ocean depth and seafloor slope (Evans 1975, Hui 1979, 1985, Selzer and Payne 1988, Sutcliffe and Brodie 1977, Payne et al. 1986, Whitehead et al. 1992, Jaquet and Whitehead 1996, Baumgartner 1997, Davis et al. 1998). Some studies have also demonstrated correlations between cetacean distribution and hydrographic characteristics that may secondarily affect prey availability (Reilly 1990, Reilly and Thayer 1990, Waring et al. 1993, Reilly and Fielder 1994, Jaquet et al. 1996, Jaquet and Whitehead 1996, Croll et al. 1998, Fiedler et al. 1998, Tynan 1997, Tynan 1998, Goold 1998, Griffin 1999). However, it was not possible during GulfCet I to correlate cetacean distribution with hydrographic variables in the northern Gulf of Mexico (Davis and Fargion 1996, Davis et al., 1998). This may have resulted from: (1) the small number of cetacean sightings with simultaneous hydrographic data, (2) the dynamic hydrography of the Gulf with periodic intrusion of the Loop Current and the formation of anticyclones (warm-core eddies) and cyclones (cold-core eddies) that move across the northern Gulf and (3) factors other than hydrographic features that influence the wide-ranging movements of cetaceans. Physiographic and hydrographic features alone may not fully explain cetacean distribution. Instead, the distribution of cetaceans may be better explained by prey availability, which is secondarily influenced by hydrographic features.

An objective of the GulfCet II program was to characterize cetacean habitat in the eastern Gulf of Mexico (Figure 1.4). Correlation of environmental features with sighting data may improve our understanding of cetacean ecology and indicate which, if any, physical and biological oceanographic variables influence cetacean distribution. During two of the four GulfCet II cruises, we conducted visual cetacean surveys and simultaneously collected data on the marine environment and zooplankton biomass. Cetacean-habitat associations were statistically analyzed for six physical and biological oceanographic variables. In addition, we retrospectively analyzed satellite remote sensing data for sea surface height (SSH) anomaly and shipboard cetacean sightings for the GulfCet I study area (Figure 1.2). These data were combined with the GulfCet II data to examine the relationship between cetacean distribution and hydrographic features for the entire oceanic northern Gulf (Figure 1.5). A similar analysis of seabird-habitat associations is presented in Chapter 8.

6.2 Methods

6.2.1 Cruise Data

To determine the relationship between cetacean distribution and habitat characteristics, two dedicated cruises aboard the R/V *Gyre* were conducted in the eastern Gulf of Mexico in late summer of 1996 (Gyre96G06) and mid-summer of 1997 (Gyre97G08) (Figure 1.4 and Table 6.1). Simultaneous data were collected on cetacean distribution, hydrography and zooplankton biomass. In addition, the *Gyre* received near real-time plots from the Colorado Center for Astrodynamic Research of SSH anomaly that identified hydrographic features such as anticyclones and cyclones. This enabled us to direct the ship's course into features that may have directly influenced the distribution of cetaceans or their prey.

In addition to the dedicated cruises described above, we used cetacean sighting data from 10 cruises in the north-central and western Gulf of Mexico collected from 1992-1994 during the GulfCet I Program (Davis and Fargion 1996, Davis et al. 1998) (Table 6.1). These data were combined with sighting data from all four cruises conducted in the northern Gulf during GulfCet II. The GulfCet I data were collected from a 154,621 km^2 area located between the 100 to 2,000 m isobaths west of 87.5°W (Figure 1.2). The GulfCet II data were collected from the oceanic northern Gulf of Mexico, an area of 396,960 km^2 located within the U.S. Economic Exclusive Zone (EEZ) in waters deeper than 100 m (Figure 1.5). This area included the GulfCet I study area, Eastern Planning Area and the focal study area for cetacean habitat surveys (Figures 1.2 and 1.4). Data from the GulfCet I study have been analyzed previously for cetacean-habitat associations using bathymetric and shipboard hydrographic data (Davis and Fargion 1996, Davis et al. 1998). For the current analysis, we retrospectively determined SSH anomaly from satellite remote sensing data for GulfCet I cetacean sightings and combined these data with comparable GulfCet II data for the northern Gulf. This large data set from 14 cruises was analyzed for correlations between cetacean distribution, ocean depth and hydrographic features.

6.2.2 Cetacean Sightings

During cruises, line transect data were collected by two teams of three observers during daylight hours, weather permitting (i.e., no rain, Beaufort sea state <4) using standard vessel survey data collection methods for cetaceans (Buckland et al. 1993) (see Chapter 4 for details). Each team had at least two members experienced in shipboard cetacean observation and identification techniques. Two observers searched for cetaceans using 25x binoculars mounted on the ship's flying bridge. The third observer maintained a search of the area near the ship using unaided eye or 7x hand-held binoculars, and recorded data. The observers rotated through each of these three stations every 30-40 minutes, and each team alternated two-hour watches while there was daylight. The vessel speed was usually 15 km/hr but varied with sea conditions. Sighting effort was interrupted to approach a group of animals to confirm identification, or due to weather conditions. On-effort transect segments located within a range of 5 km from each other were considered as the same segment.

Table 6.1. Cruises used in the habitat-association analysis.

	Vessel	Survey No.	Season	Project	Start date	End date
NMFS	*Oregon II*	199	Spring 92	GulfCet I	4/22/92	6/7/92
NMFS	*Oregon II*	203	Winter 93	GulfCet I	1/6/93	2/12/93
NMFS	*Oregon II*	204	Spring 93	GulfCet I	5/4/93	5/28/93
TAMU	*Longhorn*	1	Spring 92	GulfCet I	4/14/92	4/30/92
TAMU	*Pelican*	2	Summer 92	GulfCet I	8/10/92	8/24/92
TAMU	*Pelican*	3	Fall 92	GulfCet I	11/8/92	11/21/92
TAMU	*Pelican*	4	Winter 93	GulfCet I	2/12/93	2/25/93
TAMU	*Pelican*	5	Spring 93	GulfCet I	5/24/93	6/4/93
TAMU	*Pelican*	6	Summer 93	GulfCet I	8/27/93	9/7/93
TAMU	*Pelican*	7	Winter 93	GulfCet I	12/4/93	12/14/93
NMFS	*Oregon II*	220	Spring 96 & Early Summer	GulfCet II	4/16/96	6/9/96
NMFS	*Oregon II*	225	Spring 97 & Early Summer	GulfCet II	4/16/97	6/10/97
TAMU	*Gyre*	Gyre96G06	Late Summer 96	GulfCet II	10/11/96	10/19/96
TAMU	*Gyre*	Gyre97G08	Summer 97	GulfCet II	8/6/97	8/20/97

6.2.3 Hydrography and Satellite Remote Sensing of Sea Surface Height Anomaly

Hydrographic data collection during the late and mid-summer *Gyre* cruises is described in Chapter 2. Briefly, dynamic sea surface height anomaly (DHA), mixed layer depth (MLD) and 15°C depth were determined from CTD and XBT data. The *Gyre* was equipped with a through-the-hull pumped seawater system. Sea surface temperature (SST), conductivity (salinity) and fluorescence (a measure of chlorophyll concentration) were measured with a Sea-Bird Electronics Corporation in-line sensor and logged every two minutes with the ship's Serial ASCII Interface Loop (SAIL) system.

Hydrographic features for GulfCet I and II shipboard surveys were characterized using coincident altimetry from the TOPEX/POSEIDON and ERS-1&2 satellites. Daily fields of SSH topography on a 1/4 degree grid were estimated by adding the height anomaly fields, interpolated from the available along-track altimeter data, to a model mean surface. To quantify the relationship between sightings and the remotely sensed physical environment, the SSH anomaly was computed for each sighting location from the gridded height fields.

Ocean depths for cetacean sightings were determined from the Global Relief Data (National Geophysical Data Center, NOAA) that has a resolution of 5 min. Ocean depth gradient was calculated for each point in the bathymetric database to produce a seafloor slope in units of meters per km.

6.2.4 Predicted Mean Biomass (PMB) of Zooplankton in the MLD

A 153 kHz narrow-band Rowe Deines Instruments (RDI) Acoustic Doppler Current Profiler (ADCP) mounted on the *Gyre* was used to collect acoustic backscatter (S_v) data during the late summer (Gyre96G06) and mid-summer (Gyre97G08) cruises in the eastern Gulf of Mexico (see Chapter 3 for details). Acoustic data were used to make predictions about zooplankton and micronekton biomass in the water column. Biomass predictions were based on empirical calibration of the acoustic signal from the ADCP with samples of zooplankton and micronekton collected with a Multiple Opening and Closing Net and Environmental Sensing System (MOCNESS; 1 m^2 mouth area and 333 μm mesh) (Flagg and Smith 1989, Zhou et al. 1994, Ashjian et al. 1994, Ressler et al. 1998, Zimmerman and Biggs, 1999). For each MOCNESS tow, the mean S_v measured at a given depth during the tow was matched with the measured displacement volume biomass from the corresponding depth-discrete net sample. Linear regression of the $\log_{10}$ of MOCNESS displacement volume biomass ($cc{\cdot}m^{-3}$) as a function of mean S_v (in dB re m^{-1} $4\pi^{-1}$) was used as a first-order empirical model of predicted mean biomass (PMB; $cc{\cdot}m^{-3}$). PMB values (based on S_v data averaged every 300 seconds) had a horizontal resolution of 0.3-1.5 km, depending on ship speed, and a vertical resolution of 4 m. Depth discrete PMB estimates were vertically integrated from 10-50 m to give a summary PMB value ($cc{\cdot}m^{-2}$) within the MLD. MOCNESS samples were sorted for paralarval cephalopods and myctophids, and the numbers per square meter of sea surface was calculated. Cephalopod paralarvae were used as an indirect assessment of adult cephalopods (which are an important cetacean prey item) because the latter evade capture nets.

6.2.5 Statistical Methods

6.2.5.1 Cetacean Categories

Cetaceans were subdivided into five groups based on large body size and deep diving ability (sperm whales, Category 2), intermediate body size and dietary preference for squid (squid-eaters, Category 3), phylogenetic relationship and occurrence in deep water (> 200 m) habitats (oceanic stenellids, Category 4), or preference for shallow water (< 200 m) habitats (bottlenose and Atlantic spotted dolphin Category 5). However, some species belong to more than one category. For example, sperm whales and the oceanic stenellids (pantropical spotted dolphin, spinner dolphin, clymene dolphin and striped dolphin) are also squid-eaters (Perrin et al. 1973, Clarke 1996, Ridgway and Harrison 1994). Nevertheless, grouping was necessary to reduce the number of species and increase the sample size for modeling with physiographic and hydrographic variables. Cetacean sightings were grouped as follows:

1. Cetaceans (all species identified)
2. Sperm whales
3. Squid-eaters (except for sperm whales). Dwarf and pygmy sperm whales, false killer whales, melon-headed whales, pilot whales, pygmy killer whales, Risso's dolphins, rough-toothed dolphins and all the members of the Family Ziphiidae
4. Oceanic stenellids. Oceanic dolphins from the genus *Stenella*: clymene dolphins, pantropical spotted dolphins, spinner dolphins and striped dolphins but not Atlantic spotted dolphins

5. Bottlenose dolphins and Atlantic spotted dolphins

6.2.5.2 GulfCet II Data for the Eastern Gulf of Mexico

For the late and mid-summer *Gyre* cruises, where multiple environmental variables were collected, the presence of cetacean categories was modeled with logistic regression for each cruise (Hosmer and Lemeshow 1989). The environmental variables used were bottom depth (m), bottom depth gradient ($m \cdot km^{-1}$), sea surface salinity (SSS, psu), dynamic SSH anomaly (DHA, dyn cm), surface chlorophyll concentration ($\mu g \cdot L^{-1}$), and PMB ($cc \cdot m^{-2}$). Sea surface temperature was not used in the analysis because of the almost uniformly warm surface water in the Gulf during the summer. Step-wise logistic regression was run using S-plus 4.5 software (Mathsoft 1997). Only deepwater (depth >800 m) stations that had values for all environmental variables were used in the analysis. As a result, not all species or species categories had sufficiently large sample sizes for each cruise.

6.2.5.3 GulfCet I and II Data for the Oceanic Northern Gulf of Mexico

For the 14 cruises in the oceanic northern Gulf of Mexico, the presence of cetacean species or species groups was analyzed with a Chi-square test for independence. Freeman-Tukey deviates were calculated to determine the significant Chi-square contribution in each class. The environmental variables used in the analysis were ocean depth and hydrographic features. On-effort transects were divided into 18.5 km-long (10 nautical miles) segments. If a segment of on-effort transect were less than 9.25 km, it was added to the previous segment. If it were greater than 9.25 km, it was treated as a separate segment. A total of 2,351 transect segments were obtained from 14 cruises. The mean segment length was 16.6 km $\pm$ 5.61 S.D. Cetacean categories were matched to their respective transect segment.

The oceanic northern Gulf was divided into four ocean depth categories: continental shelf (< 200 m), upper continental slope (200-1,000 m), lower continental slope (1,000-2,000 m), and abyssal region (> 2,000 m). The study area was also divided into four hydrographic features based on DHA for GulfCet II data and SSH anomaly for GulfCet I data. The four features were: (1) anticyclone; (2) cyclone; (3) confluence; and (4) "other". Criteria to delineate hydrographic features varied for each cruise. For GulfCet I *Pelican* and *Longhorn* cruises in the north-central and western Gulf (Table 6.1), SSH anomaly ≥ 10 cm was considered an anticyclone; SSH anomaly ≤ -10 cm was considered a cyclone. SSH anomaly < 10 and > -10 cm was classified as "confluence" or "other" depending on its location relative to a cyclone-anticyclone pair. For the GulfCet I *Oregon II* cruises, hydrographic features were determined using SSH anomaly as well as depth of the 15°C isotherm obtained from CTD and XBT casts. This was necessary because some of these surveys were conducted in the northeastern Gulf where SSH anomaly was not as accurate as it is in the north-central and western Gulf. This reflects the fact that the Loop Current is temporally persistent but spatially variable in the location of its northern perimeter, which makes it difficult to establish a spatially accurate, model mean surface for the evaluation of SSH anomaly data from the northeastern Gulf. For bottlenose dolphins and Atlantic spotted dolphins (Category 5), the Chi-square test was run for the cyclone and "other" hydrographic features only, since anticyclones and confluence areas do not exist on the continental shelf where these species most often occur (Davis et al. 1998).

Hydrographic features for GulfCet II *Gyre* cruises were determined using DHA. For the 1996 late summer cruise, a cyclone was classified as any area with DHA 0 to -12 cm. An area with DHA 25 to 50 cm was classified as an anticyclone. An area of confluence (0 to 22 cm) occurred between cyclone-anticyclone pairs (from 26.2-26.6°N and 86.5-87.5°W). For the 1997 mid-summer *Gyre* cruise, a cyclone was defined as 0 to -13 cm and an anticyclone as 25 to 71 cm. A confluence area (0 to 24 cm) was observed from 26.9-27.9°N and 86.3-87.8°W. For the GulfCet II *Oregon II* cruises, we used SSH anomaly as described in the paragraph above to delineate the four hydrographic features because only partial CTD and XBT data were available.

6.3 Results

6.3.1 Hydrographic Features

Satellite remote sensing showed a broad area of temporally persistent but spatially variable cyclonic circulation in the northeastern Gulf throughout 1996 and 1997 (Figures 2.29 and 2.32 , see Chapter 2 for details). The MLD and 15°C depth were shallower in the cyclone than in the confluence or anticyclone during late summer 1996 and mid-summer 1997 (Tables 2.3 and 2.4). The Deep Chlorophyll Maximum (DCM) was located at or just above the depth at which nitrate was first detectable; this averaged 50 m below the surface in the cyclone and 100 m in the anticyclone. The cyclones were also distinguishable by sea surface temperature, salinity and chlorophyll. In late summer of 1996, surface waters of the cyclone averaged 1°C cooler and 1 psu less saline than surface waters of the anticyclone. Surface chlorophyll was lower than 0.05 $\mu g \cdot L^{-1}$ in the warm, nutrient-depleted surface waters of the anticyclone, while within the cyclone and over the rest of the continental margin, surface chlorophyll concentrations ranged 0.05-0.3 $\mu g \cdot L^{-1}$. The highest surface chlorophyll concentrations were encountered near the continental shelf in areas of greatest freshwater input from the Mississippi River. In mid-summer of 1997, surface temperatures over most of the continental margin were 30-31°C, while surface temperatures in the cyclone ranged from 29-30°C. Freshwater from the Mississippi River was entrained into the flow confluence between cyclone-anticyclone pair (Figure 2.33) and reached much farther offshore than in 1996. Surface chlorophyll concentrations in this river water reached 2.0 $\mu g \cdot L^{-1}$. In comparison, surface chlorophyll levels in the interior of the cyclone ranged 0.05-0.15 $\mu g \cdot L^{-1}$, while in interior of the anticyclone, surface chlorophyll concentrations were extremely low (<0.05 $\mu g \cdot L^{-1}$).

6.3.2 Predicted Mean Biomass (PMB) of Zooplankton

PMB during daytime was low throughout the study area, with values ranging from 0.2-1.2 $cc \cdot m^{-2}$ during late summer 1996 and 0.7-2.2 $cc \cdot m^{-2}$ during mid-summer 1997 (Figures 3.14, 3.18-19 and 3.24-25). It was lowest in the anticyclone (0.2-0.7 $cc \cdot m^{-2}$ and 0.7-1.2 $cc \cdot m^{-2}$ for late summer 1996 and mid-summer 1997, respectively) and in patches at the western and eastern edges of the cyclone during both cruises. PMB was highest (as high as 1.2 $cc \cdot m^{-2}$ and 2.2 $cc \cdot m^{-2}$ for late summer 1996 and mid-summer 1997, respectively) near the MOM along the continental slope, in the center of the cyclones, and throughout the confluence between the cyclone-anticyclone. At night, PMB was higher than during daytime (maximum = 3.2 $cc \cdot m^{-2}$ during both cruises) due to diel vertical migration of zooplankton and micronekton (Figures 3.14, 3.18, 3.20, 3.24 and 3.26). Nevertheless, PMB was still highest in the center of the cyclones, in areas along the continental slope and in the confluence zone; PMB was lowest in the anticyclones. Generally, PMB was higher during mid-summer 1997 than during late summer 1996.

Higher zooplankton and micronekton biomass may indicate richer concentrations of cetacean prey, since the number of cephalopod paralarvae per m^2 found in the MOCNESS samples was significantly correlated with integrated zooplankton and micronekton biomass in those samples ($r^2 = 0.73$, $p < 0.001$; see Chapter 3 for details). The five most abundant families of cephalopod paralarvae collected during GulfCet II were Enoploteuthidae, Ommastrephidae, Pyroteuthidae, Cranchiidae, and Onychoteuthidae. Previous studies have shown that each of these families is preyed on by cetaceans (Clarke 1996).

The number of trawls was too small to provide statistical information on the abundance of myctophids in different hydrographic features. The anticyclonic trawl contained the least number of myctophids per m^2 of sea surface (0.15 myctophids·m^{-2}), while both the confluence and cyclonic trawls contained much greater numbers (0.59 myctophids·m^{-2} and 0.81 myctophids·m^{-2}, respectively) (Figure 3.12, see Chapter 3 for details). The anticyclonic trawl was also the least diverse, with 8 genera represented, while the confluence trawl had 14 genera and the cyclonic trawl had 13 genera. Each of the genera found in the anticyclonic trawl was found in the confluence and cyclonic trawls, but the relative proportions of each genera changed for each trawl. (Figure 3.13).

6.3.3 GulfCet II Data: Eastern Gulf of Mexico (Logistic Regression Analysis)

Late summer 1996 Cruise

Visual survey effort, hydrographic features and bathymetry for the late summer *Gyre* cruise are illustrated in Figure 6.1. "On-effort" time covered all four hydrographic features. The presence of all cetaceans (Category 1) was related to depth, depth gradient, and chlorophyll, although the proportion of variance explained (0.127) was relatively low. Specifically, cetaceans were more likely to be present in areas where depth was shallower, depth gradient was less steep and chlorophyll concentrations were higher (Figure 6.2). Cetaceans were more likely to be seen in areas with a mean depth of 1,754 m (SE = 195, n = 23), a mean depth gradient of 13.2 m/km (SE = 2.2) and a mean chlorophyll concentration of 0.144 μg·L^{-1} (SE = 0.010). Cetaceans were less likely to be seen in areas with a mean depth of 2,170 m (SE = 84, n = 97), mean depth gradient of 16.6 m/km (SE = 1.8) and a mean chlorophyll concentration of 0.125 μg·L^{-1} (SE = 0.004). Note that only deepwater (depth >800 m) sightings were used in the analysis, although a number of shallow water sightings are also shown in Figure 6.2.

The presence of sperm whales (Category 2) was related to ocean depth, depth gradient, sea surface salinity, DHA and PMB (proportion variance explained = 0.350). Sperm whales were more likely to be seen in areas where depth was shallower, depth gradient was less steep, DHA was negative and PMB was higher (Figure 6.3). Specifically, sperm whales were more likely to be seen in areas with a mean depth of 1,581 m (SE = 227, n = 10), mean depth gradient of 12.8 m/km (SE = 0.5), DHA of -2.86 cm (SE = 1.79) and mean PMB of 0.86 cc·m^{-2} (SE = 0.08). The largest number of sightings occurred south of the MOM and extended southeast into the cyclone. Sperm whales were less likely to be seen in areas with a mean depth of 2,170 m (SE = 84, n =

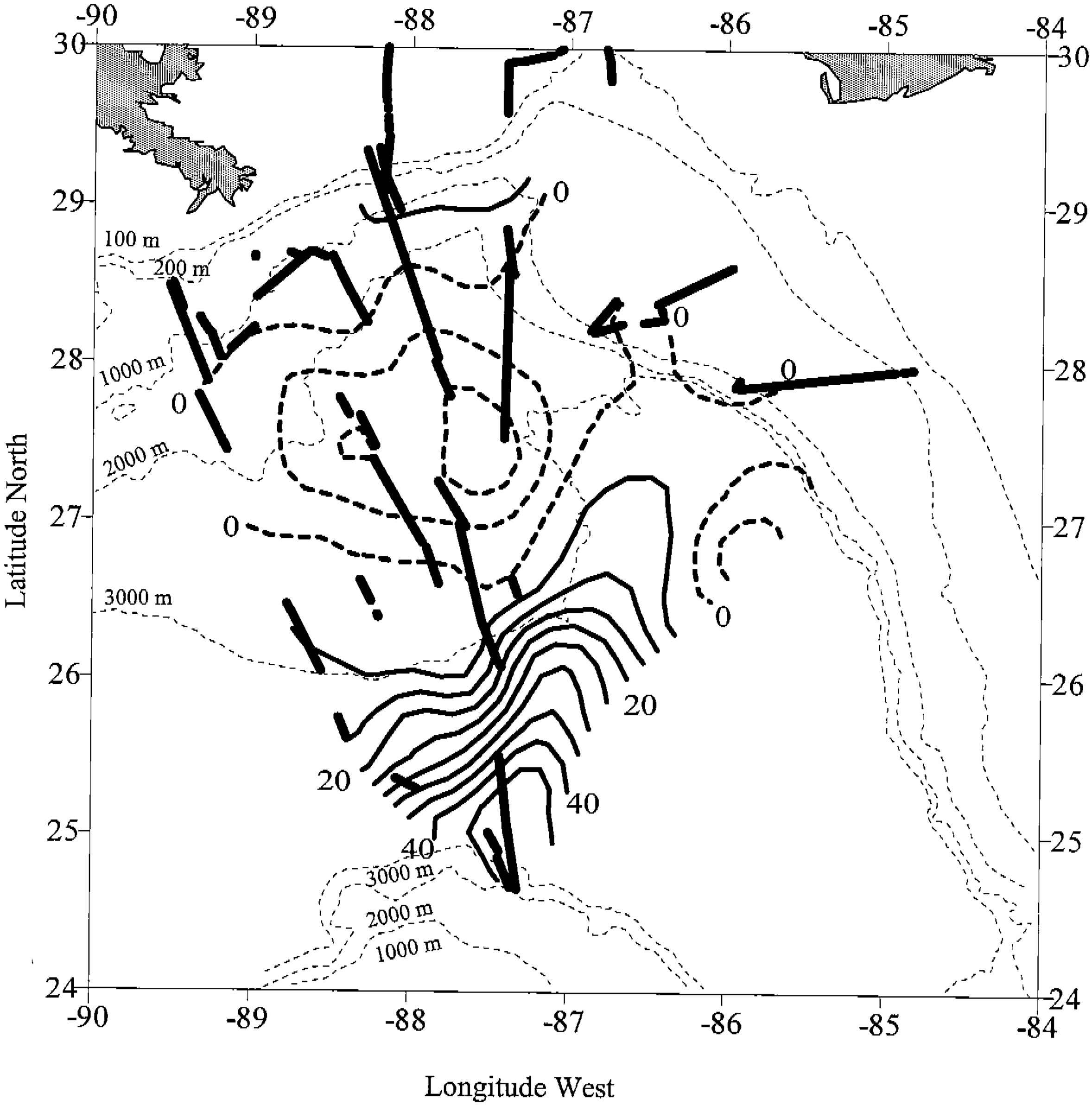

Figure 6.1. Visual survey effort (very bold lines) for the late summer 1996 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 100 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -12 cm, the confluence between 0 and 22 cm, and the anticyclone between 25 and 50 cm.

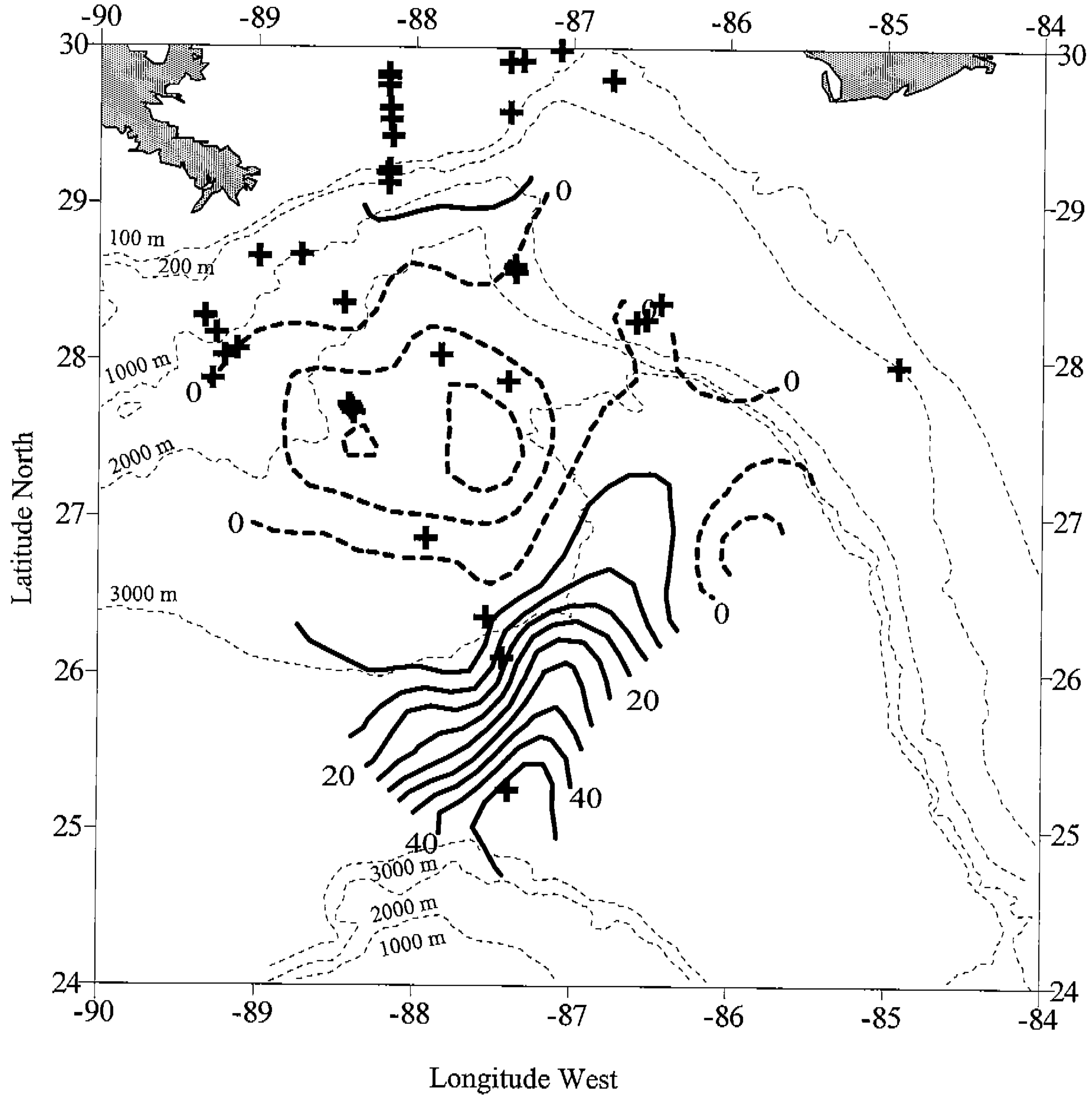

Figure 6.2. Cetacean (Category 1, all identified species) sightings (+) during the late summer 1996 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 100 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -12 cm, the confluence between 0 and 22 cm, and the anticyclone between 25 and 50 cm.

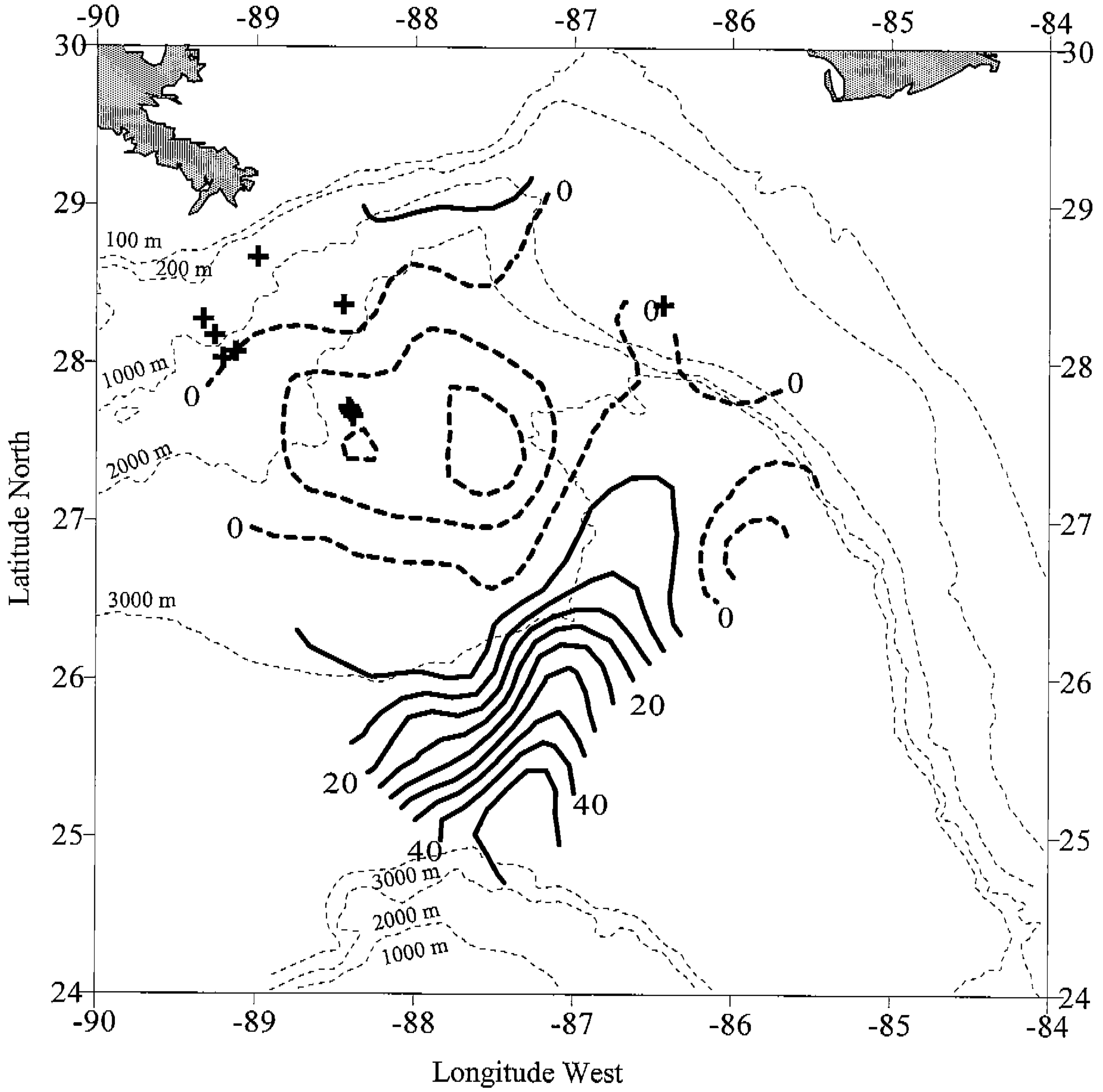

Figure 6.3. Sperm whale (Category 2) sightings (+) during the late summer 1996 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 100 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -12 cm, the confluence between 0 and 22 cm, and the anticyclone between 25 and 50 cm.

97), mean depth gradient of 16.6 m/km (SE = 1.7), mean DHA of 4.16 cm (SE = 1.37) and mean PMB of 0.73 cc·m^{-2} (SE = 0.02).

There were not enough sightings of squid eaters (Category 3) to analyze. The two sightings beyond the shelf break occurred along the lower slope and over abyssal depths, respectively, in a cyclone (Figure 6.4). There were seven sightings of Stenella (Category 4), but these sightings were not statistically explained by any of the environmental variables considered in the models. All were along the lower slope or over abyssal depths (Figure 6.5). Four sightings were within a cyclone, two in an area of confluence, and one in an anticyclone.

The presence of bottlenose dolphins and Atlantic spotted dolphins (Category 5) was not analyzed for these variables since some of them (e.g., cyclones and anticyclones) are not present on the continental shelf. All of the sightings were on the continental shelf or along the shelf break (Figure 6.6).

Mid-summer 1997 Cruise

Visual survey effort, hydrographic features and bathymetry for the mid-summer *Gyre* cruise are illustrated in Figure 6.7. "On-effort" time covered all four hydrographic features. The presence of all cetaceans (Category 1) was related to ocean depth, although the variance explained was extremely low (0.018). The presence of cetaceans may have been associated with shallower depths (mean = 1,863 m, SE = 124, n = 59) compared to areas where cetaceans were not seen (mean depth = 2,335 m, SE = 75, n = 83) (Figure 6.8). Sightings occurred in all four hydrographic features, although most sightings occurred in the cyclone, around the periphery of the cyclone and in confluence zone. Again, only deepwater (depth >800 m) sightings were used in the analysis although a number of shallow water sightings are also shown in Figure 6.8.

The presence of sperm whales (Category 2) was related to depth gradient. The proportion variance explained by the depth gradient model was 0.099. The presence of sperm whales may have been associated with steeper depth gradients (mean = 44.5 m/km, SE = 12.1, n = 12) compared to areas where sperm whales were not seen (mean = 16.3 m/km, SE = 2.6, n = 83) (Figure 6.9). This was probably due to a cluster of sightings during this cruise along the Florida escarpment, an area of steep depth gradient. Most of the sightings occurred along the lower slope and over abyssal depths less than 3,000 m in the cyclone or confluence zone; one sighting occurred in the anticyclone.

The presence of squid eaters (Category 3) was related to sea surface salinity, although the proportion of variance explained was extremely low (0.029). The presence of squid eaters may have been associated with higher salinity (mean = 35.653, SE = 0.437, n = 6) compared to areas where squid eaters were not seen (mean salinity = 33.992, SE = 0.249, n = 83) (Figure 6.10). Most sightings occurred along the lower slope and over abyssal depths on the periphery of the cyclone or in the confluence zone; one sighting occurred in the anticyclone.

The presence of oceanic stenellids (Category 4) was related to DHA, but the proportion of variance explained was only 0.096. The presence of oceanic stenellids was associated with areas of lower DHA (mean = 0.82 cm, SE = 2.62, n = 27) compared to areas where stenellids were not

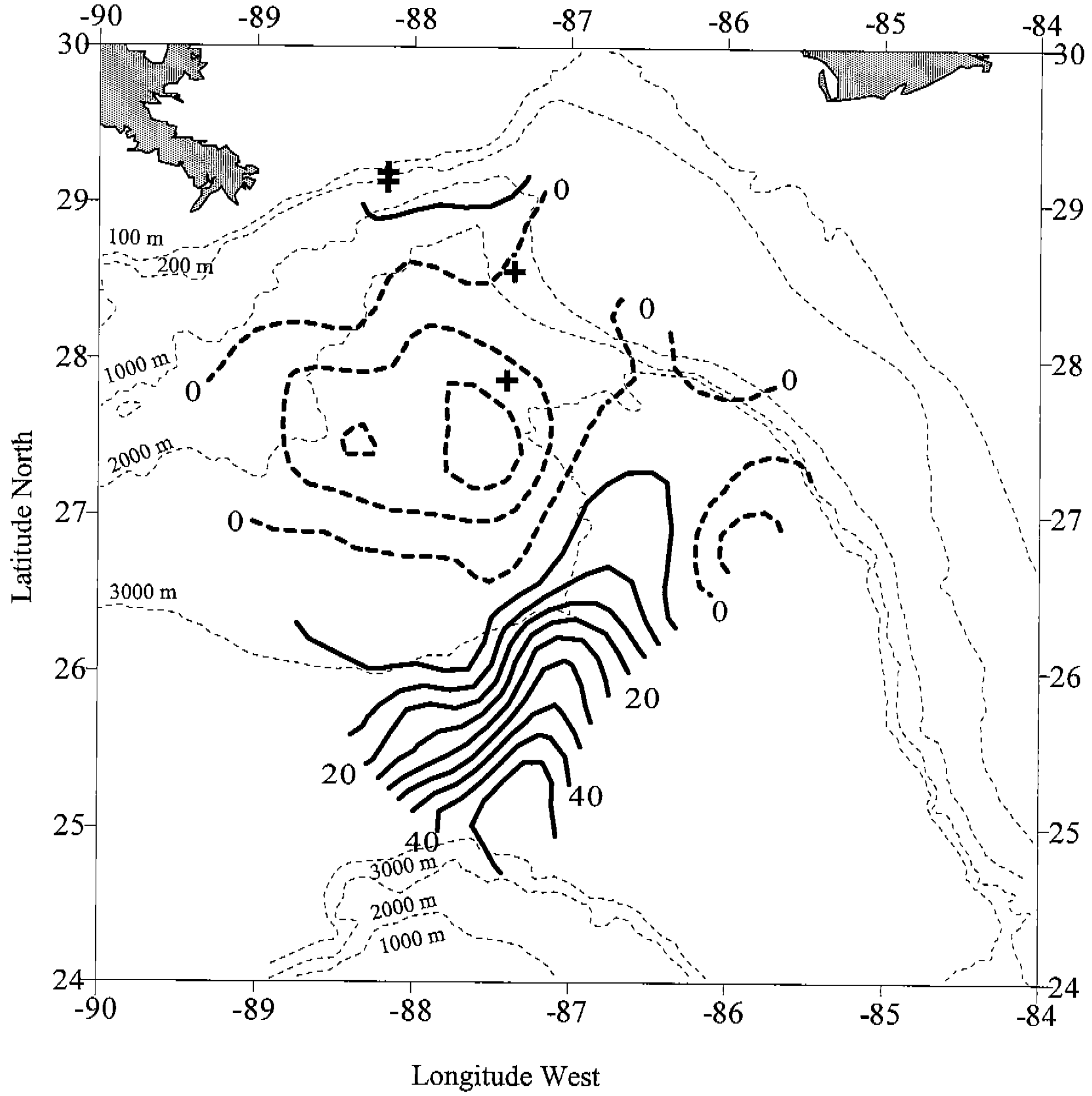

Figure 6.4. Squid-eater (Category 3, see text for list of species) sightings (+) during the late summer 1996 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 100 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -12 cm, the confluence between 0 and 22 cm, and the anticyclone between 25 and 50 cm.

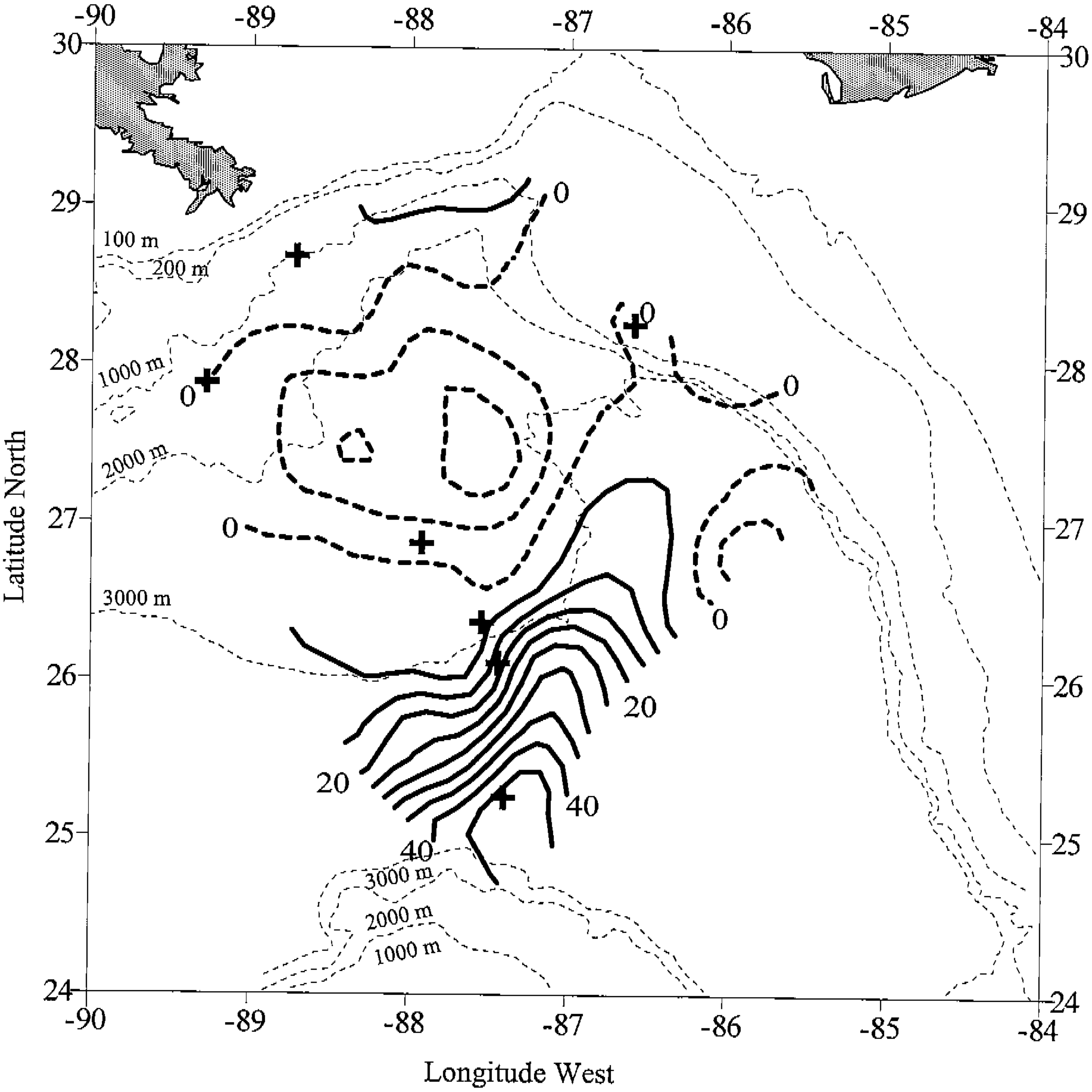

Figure 6.5. Stenellid (Category 4, see text for list of species) sightings (+) during the late summer 1996 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 100 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -12 cm, the confluence between 0 and 22 cm, and the anticyclone between 25 and 50 cm.

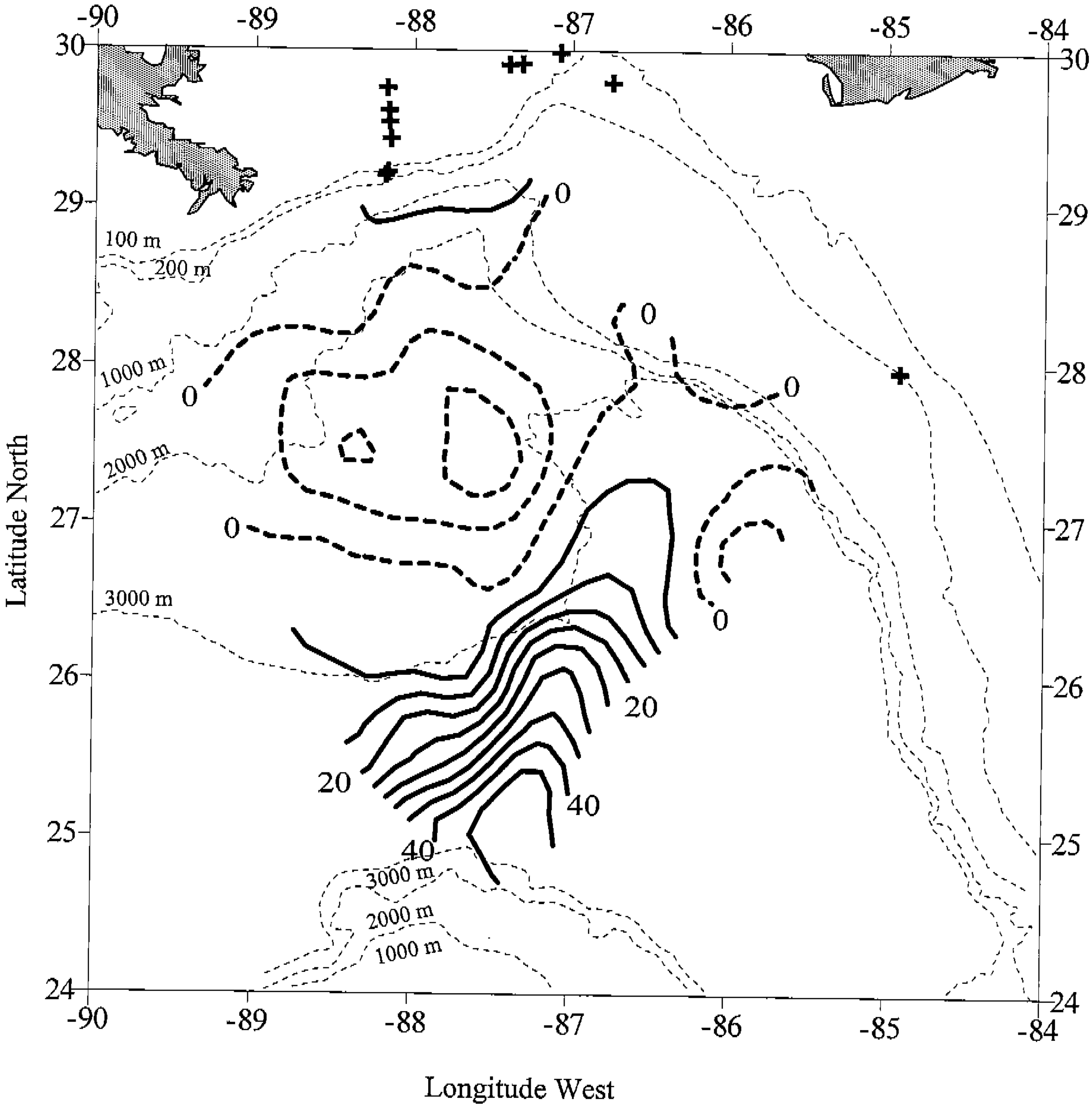

Figure 6.6. Bottlenose dolphin and Atlantic spotted dolphin (Category 5) sightings (+) during the late summer 1996 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 100 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -12 cm, the confluence between 0 and 22 cm, and the anticyclone between 25 and 50 cm.

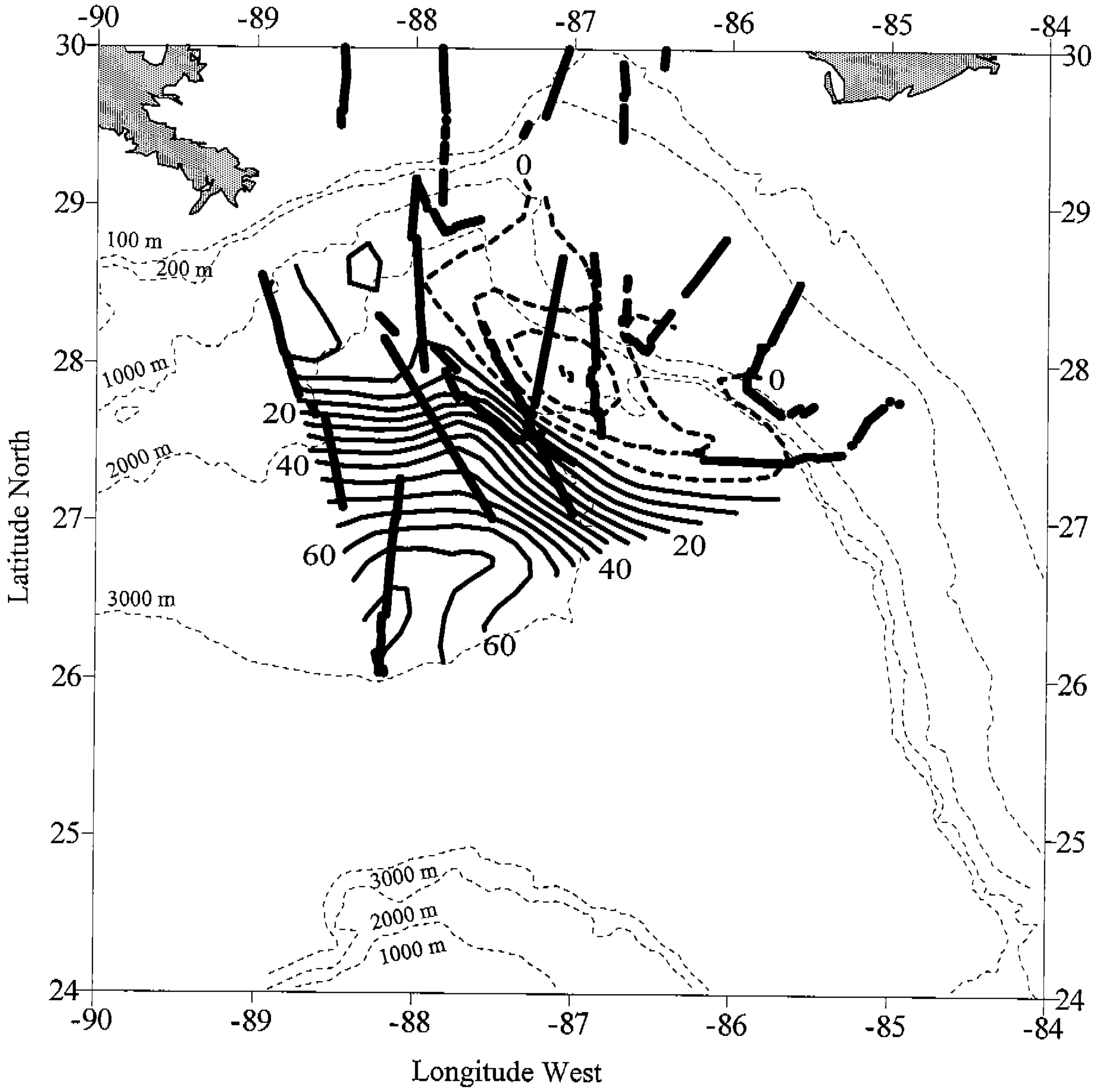

Figure 6.7. Visual survey effort (very bold lines) for the mid-summer 1997 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 105 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -13 cm, the confluence between 0 and 24 cm, and the anticyclone between 25 and 71 cm.

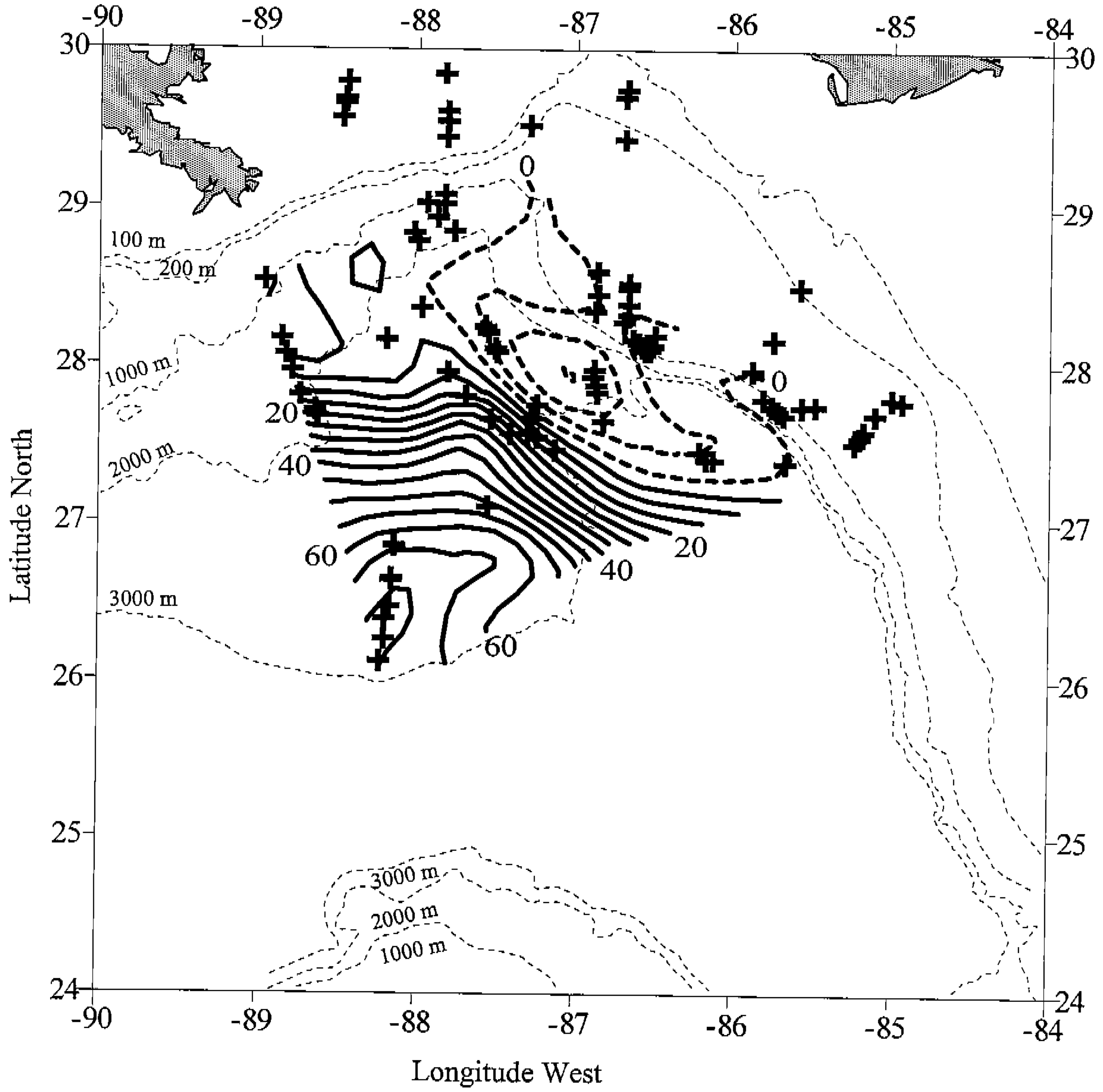

Figure 6.8. Cetacean (Category 1, all identified species) sightings (+) during the mid-summer 1997 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 105 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -13 cm, the confluence between 0 and 24 cm, and the anticyclone between 25 and 71 cm.

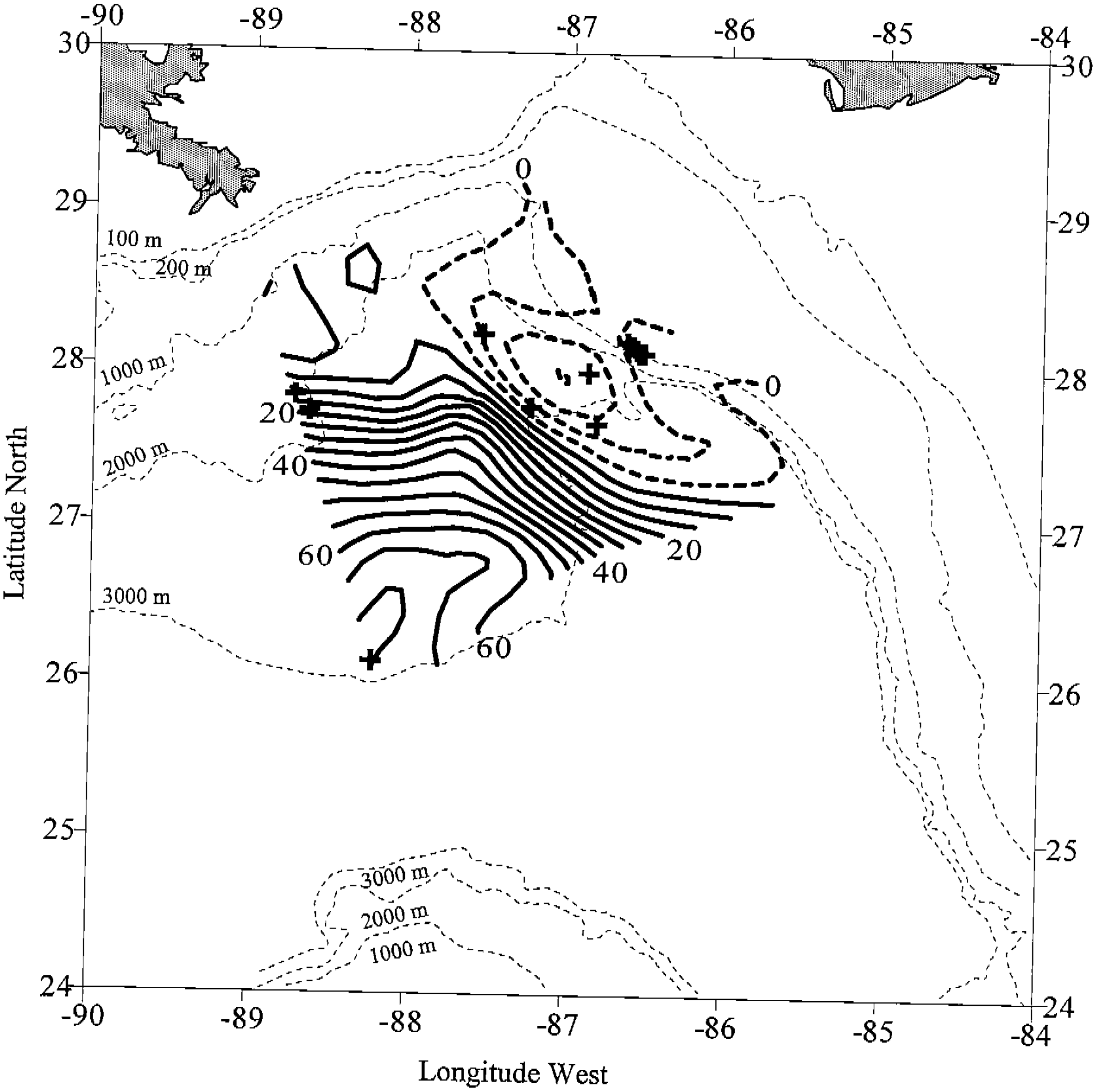

Figure 6.9. Sperm whale (Category 2) sightings (+) during the mid-summer 1997 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 105 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -13 cm, the confluence between 0 and 24 cm, and the anticyclone between 25 and 71 cm.

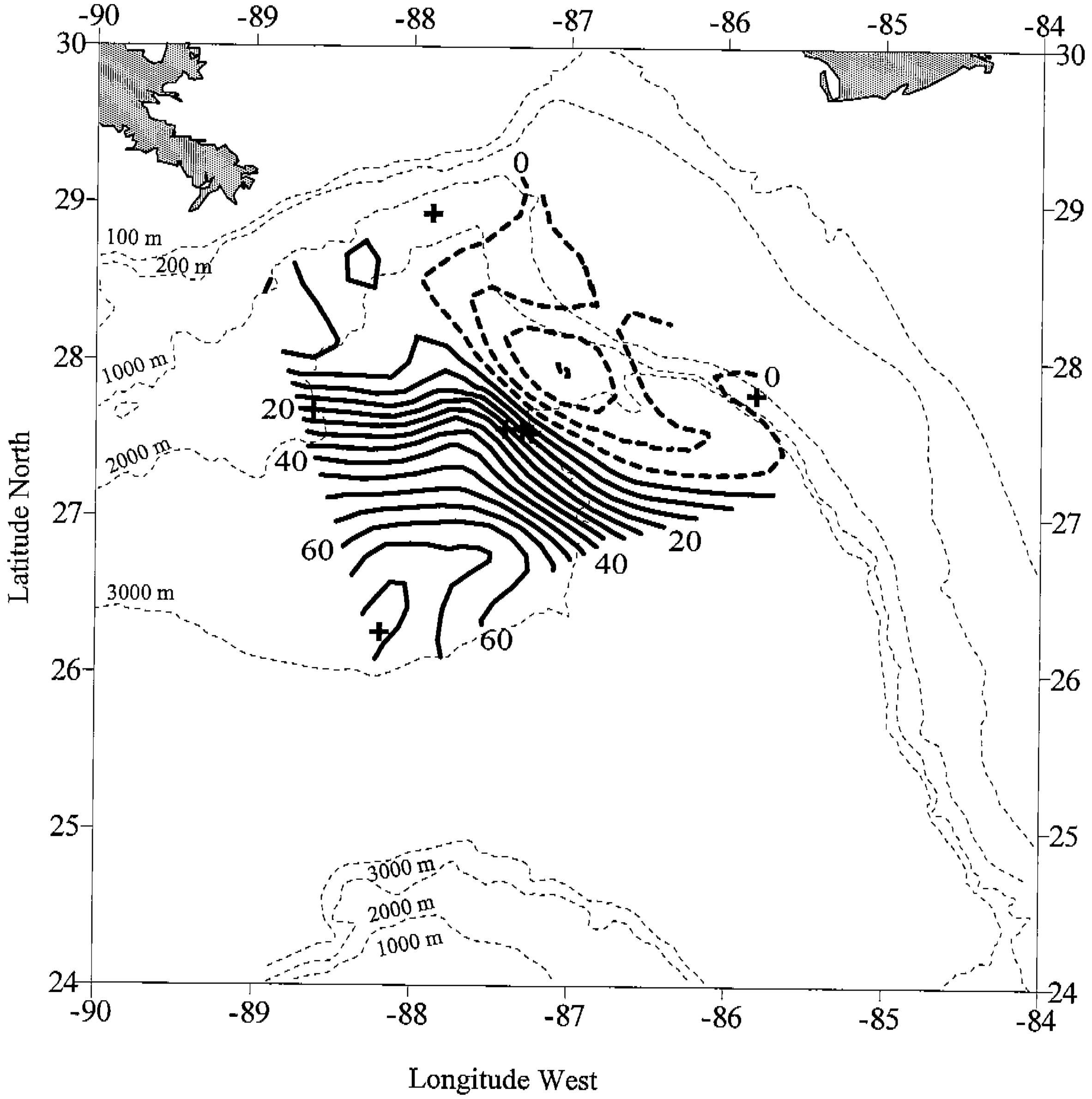

Figure 6.10. Squid-eater (Category 3, see text for list of species) sightings (+) during the mid-summer 1997 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 105 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -13 cm, the confluence between 0 and 24 cm, and the anticyclone between 25 and 71 cm.

seen (mean DHA = 16.34 cm (SE = 2.6, n = 83) (Figure 6.11). Oceanic stenellids were seen from the upper slope to abyssal depths; most occurred in the cyclone, on the periphery of the cyclone or in the confluence zone.

Again, the presence of bottlenose dolphins and Atlantic spotted dolphins (Category 5) was not analyzed for this group of variables. All sightings occurred on the continental shelf or along the shelf break (Figure 6.12).

6.3.4 GulfCet I and II Data: Oceanic Northern Gulf of Mexico (Chi-square Analysis)

Cetaceans (Category 1) in the oceanic northern Gulf were sighted differentially with respect to ocean depth (Table 6.2). Cetaceans were concentrated along the upper continental slope (200-1,000 m) and were sighted less frequently than expected over abyssal regions (>2,000 m). Sperm whales (Category 2) occurred more frequently along the lower slope (1,000-2,000 m) (Table 6.3), and the squid-eaters (Category 3) were concentrated along the upper slope (Table 6.4). However, commonly sighted species such as Risso's dolphin heavily influenced the preferred ocean depth range for squid-eaters and disguised the fact that some less frequently sighted species (e.g., *Mesoplodon* spp., Clarke 1996) occurred over the lower slope and abyssal areas (Figure 4.18). Oceanic stenellids (Category 4) occurred more frequently over the lower slope and in abyssal areas (Table 6.5). Bottlenose dolphins and Atlantic spotted dolphins (Category 5) occurred most frequently on the continental shelf (<200 m) and along the upper slope; they had a lower than expected occurrence along the lower slope and in abyssal areas (Table 6.6).

Cetaceans were sighted differentially with respect to hydrographic features (Table 6.7). Cetaceans in general (Category 1) and oceanic stenellids in particular (Category 4) were concentrated in cyclones and were less frequently observed in anticyclones (Tables 6.7 and 6.10). Similarly, the squid-eaters (Category 3) occurred less often than expected in anticyclones (Table 6.9). Sperm whales (Category 2) were infrequently seen near anticyclones when these nutrient-poor features were surveyed during GulfCet II. However, when sperm whale sightings from GulfCet I and II were combined, sperm whales in the oceanic northern Gulf were sighted in proportion to the survey effort expended in the four hydrographic features (Table 6.8). Bottlenose dolphins and Atlantic spotted dolphins (Category 5) occurred mostly in features other than cyclones, anticyclones and confluence areas, probably because they were concentrated along the continental shelf and upper slope where these features do not normally occur (Table 6.11).

6.4 Discussion

To characterize cetacean habitat, we used an integrated approach that included the analysis of hydrographic and bathymetric features. In addition to physical features, we measured zooplankton and micronekton biomass derived from both net and acoustic sampling to indicate the amount of potential food available for higher trophic level foragers. Although the diets of most cetaceans in the Gulf are poorly known, we hypothesized that hydrographic regimes in the study area have different levels of potential prey that influence cetacean distribution. We further hypothesized that these food stocks would be locally concentrated in nutrient-rich areas offshore

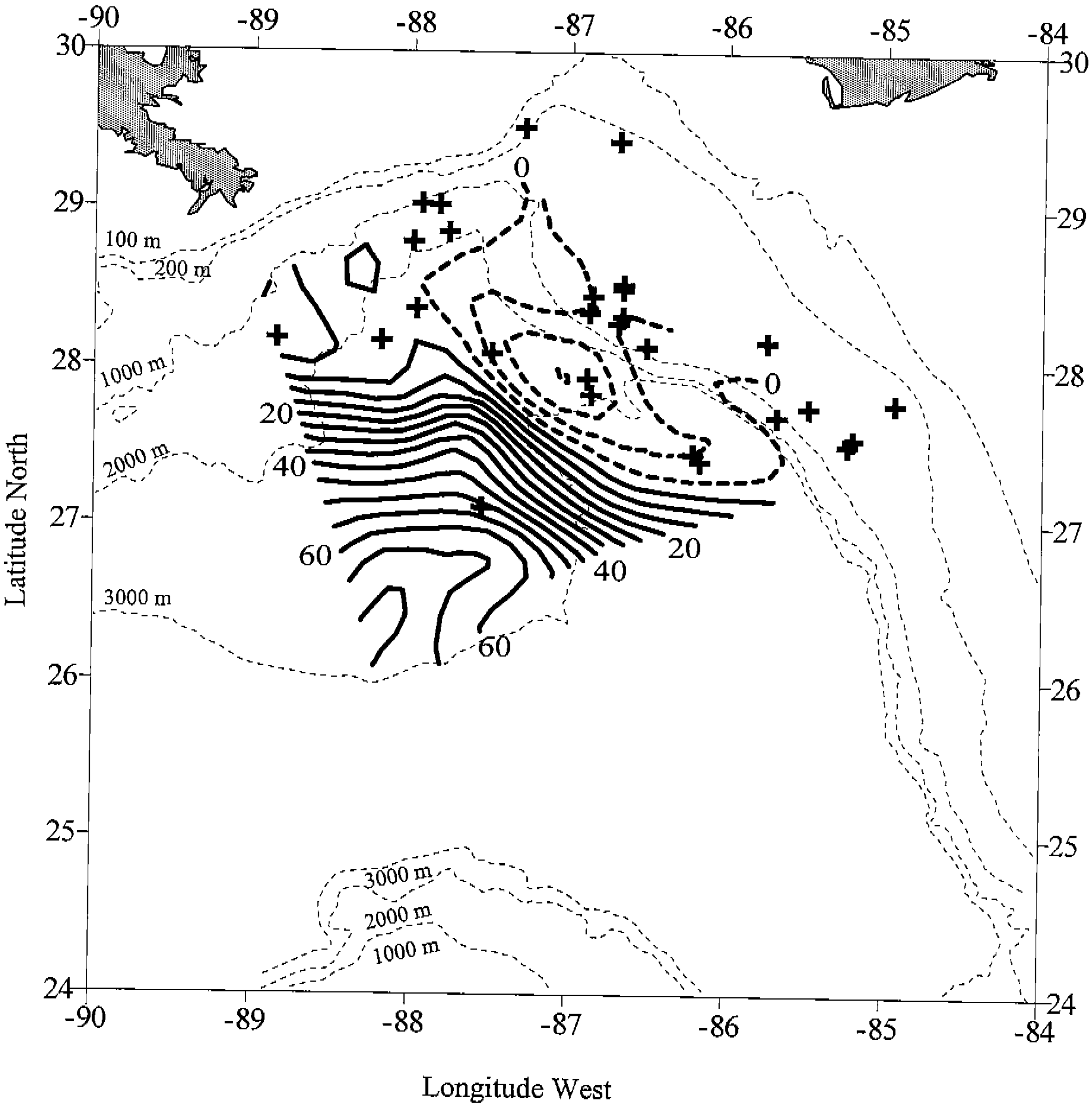

Figure 6.11. Stenellid (Category 4, see text for list of species) sightings (+) during the mid-summer 1997 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 105 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -13 cm, the confluence between 0 and 24 cm, and the anticyclone between 25 and 71 cm.

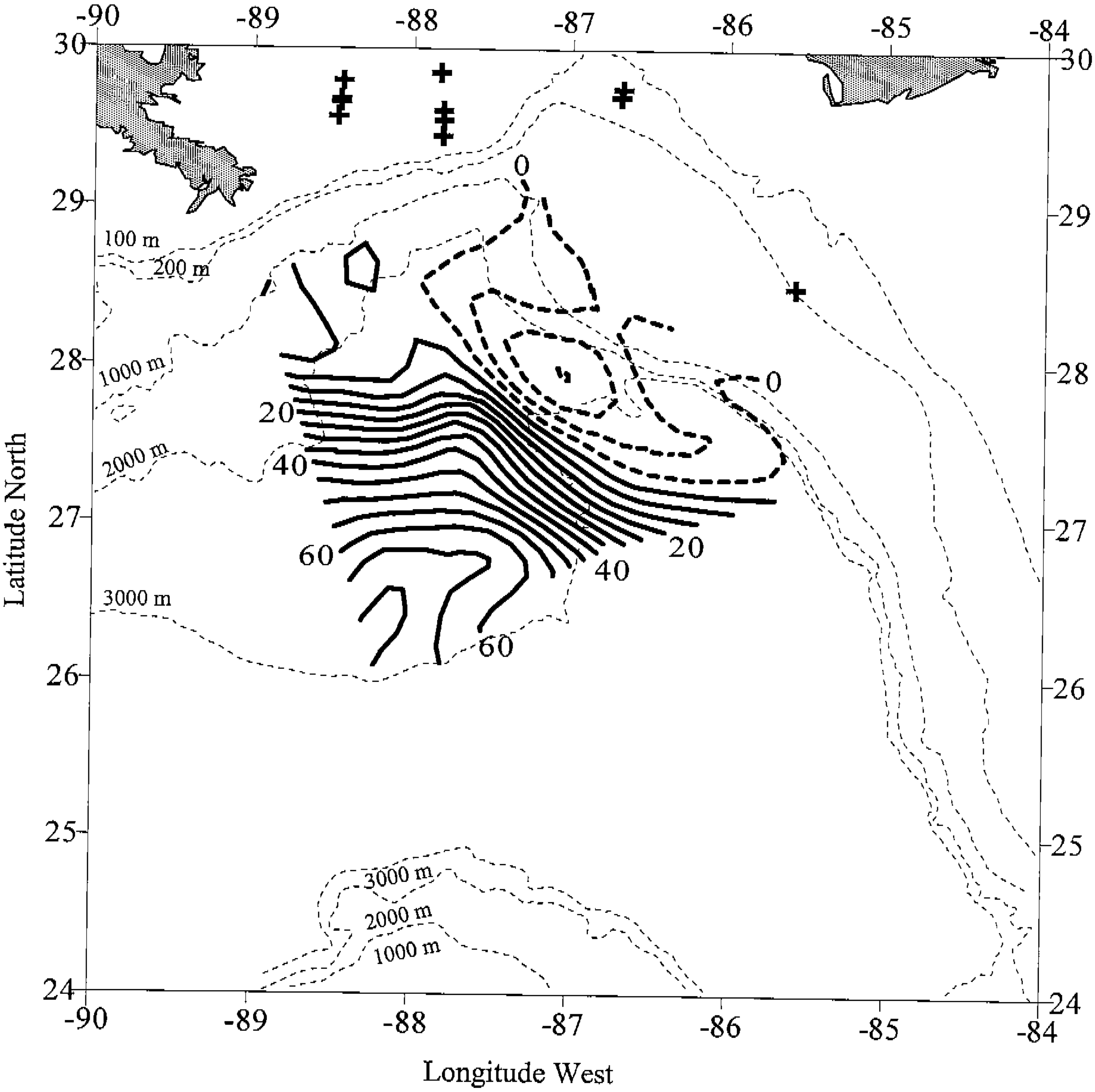

Figure 6.12. Bottlenose dolphin and Atlantic spotted dolphin (Category 5) sightings (+) during the mid-summer 1997 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 105 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -13 cm, the confluence between 0 and 24 cm, and the anticyclone between 25 and 71 cm.

Table 6.2. Contingency table of presence/absence of cetaceans (Category 1) in the on-effort transect segments with respect to ocean depth region. The depth range, number of effort segments analyzed for presence or absence of cetaceans (n), expected number of segments with presence or absence of cetaceans (E), X^2 contribution ($[E - n]^2 E^{-1}$), and Freeman-Tukey deviates in each class are reported. Freeman-Tukey deviates with absolute value >1.5 are significant for the X^2 (Chi-squared test of independence) result.

Class	Depth range (m)	Presence of cetaceans	n	E	$\frac{(E-n)^2}{E}$	Freeman-Tukey Deviate
Continental shelf	< 200	Absent	251	257.3	0.16	-0.38
		Present	115	108.6	0.37	0.62
Upper slope	200 – 1, 000	Absent	439	483.0	4.01	-2.04
		Present	248	203.9	9.51	2.95
Lower slope	1,000 – 2, 000	Absent	485	466.1	0.76	0.88
		Present	178	196.8	1.80	-1.36
Abyssal region	> 2,000	Absent	478	446.4	2.33	1.48
		Present	157	188.5	5.27	-2.38
		TOTAL	2351	2351	24.21	(df = 3, p<0.001)

Table 6.3. Contingency table of presence/absence of sperm whales (Category 2) in the on-effort transect segments with respect to ocean depth region. The depth range, number of effort segments analyzed for presence or absence of sperm whales (n), expected number of segments with presence or absence of cetaceans (E), X^2 contribution ($[E - n]^2E^{-1}$), and Freeman-Tukey deviates in each class are reported. Freeman-Tukey deviates with absolute value >1.5 are significant for the X^2 (Chi-squared test of independence) result.

Class	Depth range (m)	Presence of cetaceans	n	E	$\frac{(E-n)^2}{E}$	Freeman-Tukey Deviate
Continental shelf	< 200	Absent	365	352.4	0.45	0.68
		Present	1	13.5	11.62	-5.01
Upper slope	200 – 1, 000	Absent	657	661.5	0.03	-0.17
		Present	30	25.1	0.82	0.91
Lower slope	1,000 – 2, 000	Absent	631	638.4	0.09	-0.29
		Present	32	24.5	2.27	1.44
Abyssal region	$> 2,000$	Absent	611	611.5	0.00	-0.01
		Present	24	23.5	0.01	0.15
		TOTAL	2351	2351	15.29	(df = 3, p=0.0016)

Table 6.4. Contingency table of presence/absence of squid-eaters (Category 2) in the on-effort transect segments with respect to ocean depth region. The depth range, number of effort segments analyzed for presence or absence of squid-eaters (n), expected number of segments with presence or absence of cetaceans (E), X^2 contribution ($[E - n]^2 E^{-1}$), and Freeman-Tukey deviates in each class are reported. Freeman-Tukey deviates with absolute value >1.5 are significant for the X^2 (Chi-squared test of independence) result.

Class	Depth range (m)	Presence of cetaceans	n	E	$\frac{(E-n)^2}{E}$	Freeman-Tukey Deviate
Continental shelf	< 200	Absent	362	338.7	1.59	1.25
		Present	4	27.2	19.83	-6.25
Upper slope	200 – 1, 000	Absent	611	635.8	0.97	-0.99
		Present	76	51.1	12.09	3.16
Lower slope	1,000 – 2, 000	Absent	609	613.6	0.04	-0.18
		Present	54	49.3	0.44	0.68
Abyssal region	> 2,000	Absent	594	587.7	0.07	0.27
		Present	41	47.2	0.83	-0.90
		TOTAL	2351	2351	35.86	(df = 3, p<0.001)

Table 6.5. Contingency table of presence/absence of oceanic stenellids (Category 2) in the on-effort transect segments with respect to ocean depth region. The depth range, number of effort segments analyzed for presence or absence of oceanic stenellids (n), expected number of segments with presence or absence of cetaceans (E), X^2 contribution ($[E - n]^2E^{-1}$), and Freeman-Tukey deviates in each class are reported. Freeman-Tukey deviates with absolute value >1.5 are significant for the X^2 (Chi-squared test of independence) result.

Class	Depth range (m)	Presence of cetaceans	n	E	$\frac{(E-n)^2}{E}$	Freeman-Tukey Deviate
Continental shelf	< 200	Absent	364	330.5	3.39	1.81
		Present	2	35.4	31.61	-8.81
Upper slope	200 – 1, 000	Absent	620	620.3	0	-0.01
		Present	67	66.6	0	0.08
Lower slope	1,000 – 2, 000	Absent	581	598.7	0.52	-0.72
		Present	82	64.3	4.87	2.10
Abyssal region	> 2,000	Absent	558	573.4	0.41	-0.64
		Present	77	61.5	3.86	1.88
		TOTAL	2351	2351	44.66	(df = 3, p<0.001)

Table 6.6. Contingency table of presence/absence of bottlenose dolphins and Atlantic spotted dolphins (Category 2) in the on-effort transect segments with respect to ocean depth region. The depth range, number of effort segments analyzed for presence or absence of bottlenose dolphins and Atlantic spotted dolphins (*n*), expected number of segments with presence or absence of cetaceans (*E*), X^2 contribution ($[E-n]^2E^{-1}$), and Freeman-Tukey deviates in each class are reported. Freeman-Tukey deviates with absolute value >1.5 are significant for the X^2 (Chi-squared test of independence) result.

Class	Depth range (m)	Presence of cetaceans	*n*	*E*	$\frac{(E-n)^2}{E}$	Freeman-Tukey Deviate
Continental shelf	< 200	Absent	270	338.7	13.96	-3.93
		Present	96	27.2	173.52	9.16
Upper slope	200 – 1, 000	Absent	612	635.8	0.90	-0.95
		Present	75	51.1	11.13	3.04
Lower slope	1,000 – 2, 000	Absent	659	613.6	3.35	1.81
		Present	4	49.3	41.58	-9.85
Abyssal region	> 2,000	Absent	635	587.7	3.80	1.92
		Present	0	47.2	47.27	-12.79
		TOTAL	2351	2351	295.51	(df = 3, p<0.001)

Table 6.7. Contingency table of presence/absence of cetaceans (Category 1) in the on-effort transect segments with respect to hydrographic features. The number of effort segments with presence or absence of cetaceans (n), expected number of segments with presence or absence of cetaceans (E), X^2 contribution ($[E - n]^2E^{-1}$), and Freeman-Tukey deviates in each feature class are reported. Freeman-Tukey deviates with absolute value >1.5 are significant for the X^2 (Chi-squared test of independence) result.

Feature class	Presence of cetaceans	n	E	$\frac{(E-n)^2}{E}$	Freeman-Tukey Deviate
Anticyclone	Absent	288	258.5	3.37	1.80
	Present	78	107.5	8.09	-3.04
Confluence	Absent	37	38.8	0.09	-0.26
	Present	18	16.1	0.21	0.50
Cyclone	Absent	196	221.7	3.00	-1.77
	Present	118	92.2	7.21	2.54
Other	Absent	881	882.8	0	-0.05
	Present	369	367.1	0.01	0.11
	TOTAL	1985	1985	21.98	(df = 3, p<0.001)

Table 6.8. Contingency table of presence/absence of sperm whales (Category 2) in the on-effort transect segments with respect to hydrographic features. The number of effort segments with presence or absence of sperm whales (n), expected number of segments with presence or absence of cetaceans (E), X^2 contribution ($[E - n]^2E^{-1}$), and Freeman-Tukey deviates in each feature class are reported. Freeman-Tukey deviates with absolute value >1.5 are significant for the X^2 (Chi-squared test of independence) result.

Feature class	Presence of cetaceans	n	E	$\frac{(E-n)^2}{E}$	Freeman-Tukey Deviate
Anticyclone	Absent	348	350.1	0.01	-0.10
	Present	18	15.8	0.29	0.57
Confluence	Absent	53	52.6	0	0.09
	Present	2	2.3	0.06	-0.10
Cyclone	Absent	298	300.4	0.02	-0.12
	Present	16	13.6	0.42	0.68
Other	Absent	1200	1195.8	0.01	0.13
	Present	50	54.1	0.32	-0.54
	TOTAL	1985	1985	1.13	(df = 3, p=0.7671)

Table 6.9. Contingency table of presence/absence of squid-eaters (Category 3) in the on-effort transect segments with respect to hydrographic features. The number of effort segments with presence or absence of squid-eaters (*n*), expected number of segments with presence or absence of cetaceans (*E*), X^2 contribution ($[E - n]^2E^{-1}$), and Freeman-Tukey deviates in each feature class are reported. Freeman-Tukey deviates with absolute value >1.5 are significant for the X^2 (Chi-squared test of independence) result.

Feature class	Presence of cetaceans	n	E	$\frac{(E-n)^2}{E}$	Freeman-Tukey Deviate
Anticyclone	Absent	343	334.4	0.22	0.48
	Present	23	31.5	2.31	-1.58
Confluence	Absent	50	50.2	0	0
	Present	5	4.7	0.01	0.22
Cyclone	Absent	285	286.9	0.01	-0.10
	Present	29	27.0	0.14	0.41
Other	Absent	1136	1142.3	0.03	-0.18
	Present	114	107.6	0.37	0.62
	TOTAL	1985	1985	3.09	(df = 3, p=0.3764)

Table 6.10. Contingency table of presence/absence of oceanic stenellids (Category 4) in the on-effort transect segments with respect to hydrographic features. The number of effort segments with presence or absence of oceanic stenellids (*n*), expected number of segments with presence or absence of cetaceans (*E*), X^2 contribution ($[E - n]^2E^{-1}$), and Freeman-Tukey deviates in each feature class are reported. Freeman-Tukey deviates with absolute value >1.5 are significant for the X^2 (Chi-squared test of independence) result.

Feature class	Presence of cetaceans	n	E	$\frac{(E-n)^2}{E}$	Freeman-Tukey Deviate
Anticyclone	Absent	336	324.3	0.26	0.66
	Present	30	41.6	2.02	-1.90
Confluence	Absent	46	48.7	0.25	-0.36
	Present	9	6.2	1.96	1.06
Cyclone	Absent	254	278.2	2.00	-1.47
	Present	60	35.7	15.53	3.56
Other	Absent	1123	1107.6	0.43	0.47
	Present	127	142.3	3.36	-1.30
	TOTAL	1985	1985	25.81	(df = 3, p<0.0001)

Table 6.11. Contingency table of presence/absence of bottlenose dolphins and Atlantic spotted dolphins (Category 5) in the on-effort transect segments with respect to hydrographic features. The number of effort segments with presence or absence of bottlenose dolphins and Atlantic spotted dolphins (*n*), expected number of segments with presence or absence of cetaceans (*E*), X^2 contribution ($[E-n]^2E^{-1}$), and Freeman-Tukey deviates in each feature class are reported. Freeman-Tukey deviates with absolute value >1.5 are significant for the X^2 (Chi-squared test of independence) result.

Feature class	Presence of cetaceans	*n*	*E*	$\frac{(E-n)^2}{E}$	Freeman-Tukey Deviate
Cyclone	Absent	191	180.6	0.59	0.78
	Present	55	65.3	1.64	-1.30
Other	Absent	55	65.3	1.64	-1.30
	Present	34	23.6	4.54	1.97
	TOTAL	335	335	8.41	(df = 1, p<0.0037)

from the Mississippi River, within cyclonic, cold-core eddies, and along the high-shear edges of anticyclones (see Chapter 3 for additional detail). Although the results support these two hypotheses, the variance explained in many of the models was low. This may indicate seasonal, inter-annual and geographic variability in cetacean-habitat association.

Combining the results from the logistic regression and Chi-square analyses, cetaceans in general were concentrated along the continental slope in areas of cyclonic circulation where chlorophyll was elevated. They were less likely to occur over water deeper than 2,000 m and in anticyclones. Sperm whales tended to occur along the lower slope and, in some areas, in cyclonic eddies (i.e., low DHA) with elevated PMB. Squid-eaters occurred more frequently along the upper slope in areas outside of anticyclones. Oceanic stenellids occurred more often over the lower slope and abyssal regions in areas of cyclonic or confluence circulation. Finally, bottlenose dolphins and Atlantic spotted dolphins were seen most frequently on the continental shelf or along the upper slope, but outside of deepwater hydrographic features such as cyclones and anticyclones.

The physical forcing functions for ocean circulation in the north-central and eastern Gulf of Mexico are river discharge, wind stress, and the Loop Current (LC) (see Chapter 2). The major river system influencing this region is the Mississippi-Atchafalaya River, with most of the outflow transported west along the coast (Cochrane and Kelly 1986). Flow on the continental shelf is largely wind-driven, with buoyancy forcing effects from low-density river water. Beyond the shelf-break, the LC largely determines mesoscale circulation. Once or twice annually, the LC sheds anticyclones that migrate westward and spawn cyclones. The high concentration of nutrients in cyclones stimulates new biological production in the near-surface mixed layer (Biggs et al. 1988, Biggs 1992). In contrast, the LC and anticyclones are depleted of nutrients in the photic zone and have low biological productivity. In addition, frontal zones at the periphery of eddies can entrain low salinity, high-chlorophyll shelf water and transport it off the shelf (Biggs and Müller-Karger 1994). Frontal zones may also be created during periods of northern extension of the LC.

Recent studies have used acoustic techniques to assess zooplankton and micronekton biomass as a direct or indirect index of food resources for cetaceans (Croll et al. 1998, Macaulay et al. 1995, Beardsley et al. 1996, Fiedler et al. 1998). Although there was a pronounced diel fluctuation in the vertical migration of sound-scattering organisms during this study, integrated PMB was always greater in cyclones than in anticyclones (see Chapter 3). These former areas have a shallower MLD and lower dynamic SSH due to doming of cold, deep water. Our results show that cyclones and confluence zones are areas of locally concentrated zooplankton and micronekton, including cephalopod paralarvae and myctophids, that we suggest result from nutrient-rich water and locally high primary production in the mixed layer (Biggs et al. 1988, Chapter 3). Cetaceans were concentrated in these mesoscale features. This is illustrated in color composite plots for cetaceans (Category 1) and sperm whales (Category 2) that show the distribution of sightings, bathymetry, DHA and nighttime PMB for the late and mid-summer cruises (Figures 6.13-6.16). In the plots for sperm whales, we have included both sightings and acoustic contacts (see Chapter 5), most of which occurred in the cyclones, confluence zones or the MOM area where PMB was highest. A comparison of Figures 6.15 and 6.16 shows that, while sperm whales were seen in the MOM area in late summer 1996, more of them were seen

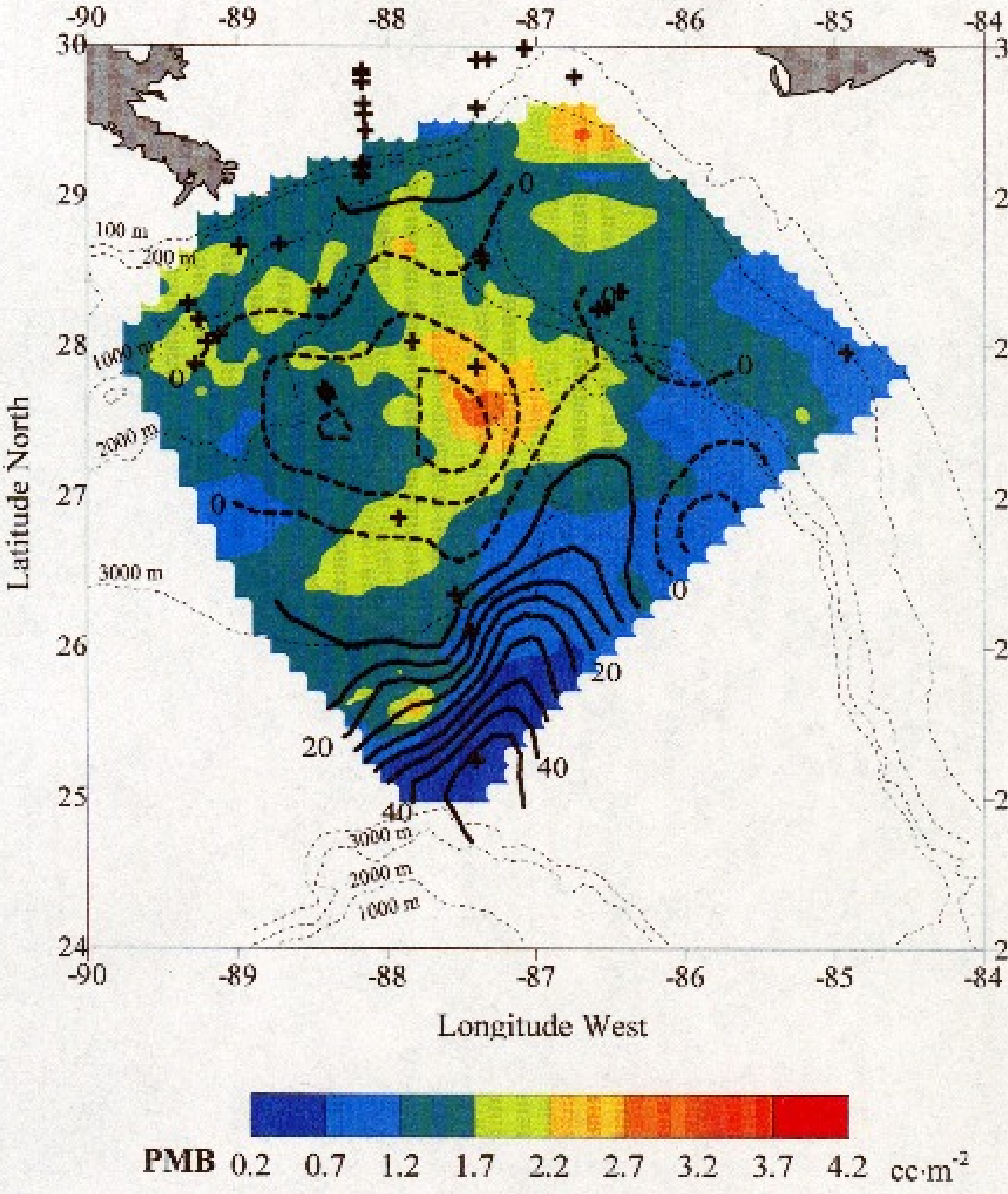

Figure 6.13. Cetacean (Category 1, all identified species) sightings (+) during the late summer 1996 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 100 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -12 cm, the confluence between 0 and 22 cm, and the anticyclone between 25 and 50 cm. The color contours indicate nighttime predicted mean biomass (PMB, cc·m^{-2}) in the interval 10-50 m.

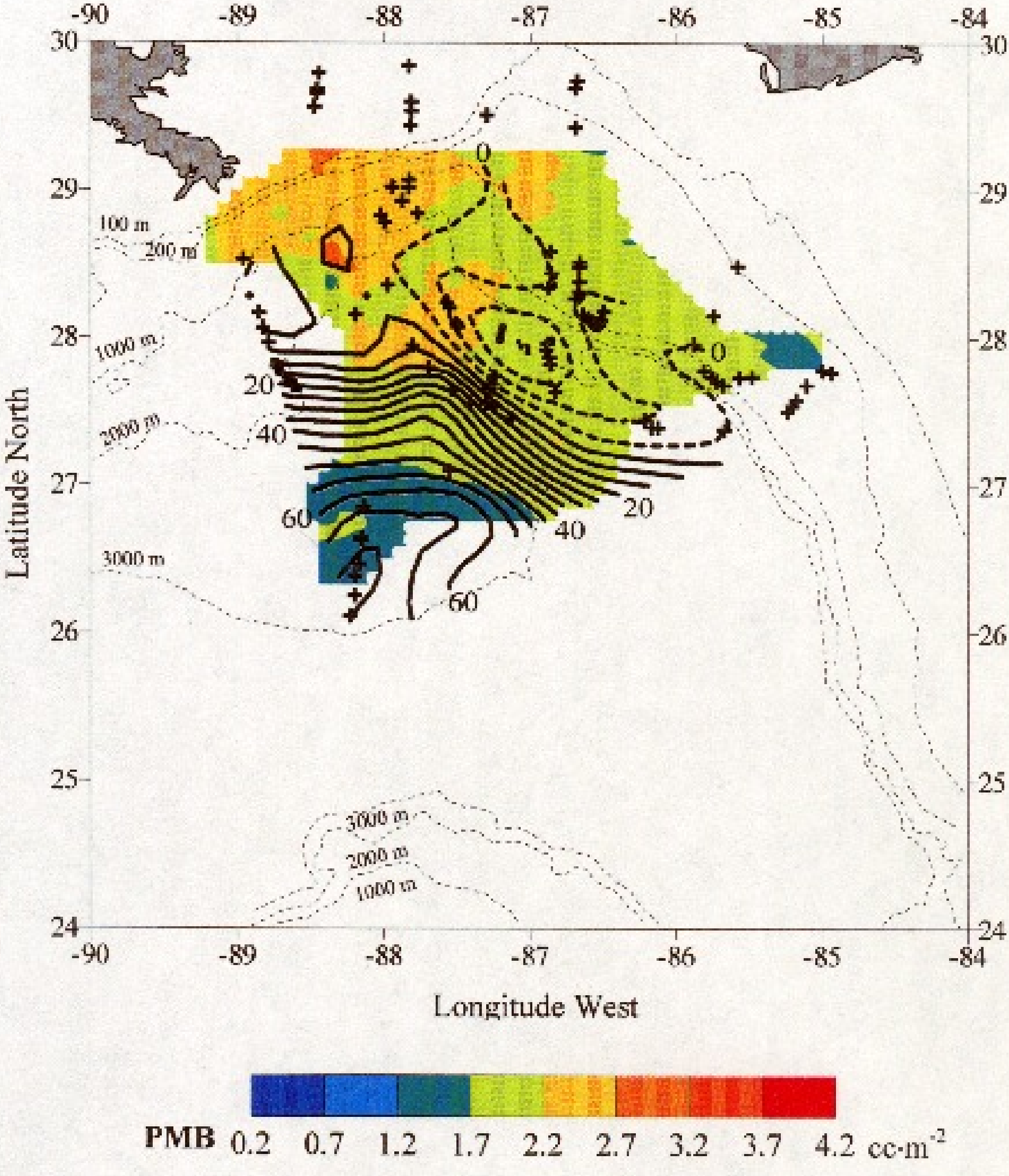

Figure 6.14. Cetacean (Category 1, all identified species) sightings (+) during the mid-summer 1997 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 105 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -13 cm, the confluence between 0 and 24 cm, and the anticyclone between 25 and 71 cm. The color contours indicate nighttime predicted mean biomass (PMB, $cc{\cdot}m^{-2}$) in the interval 10-50 m.

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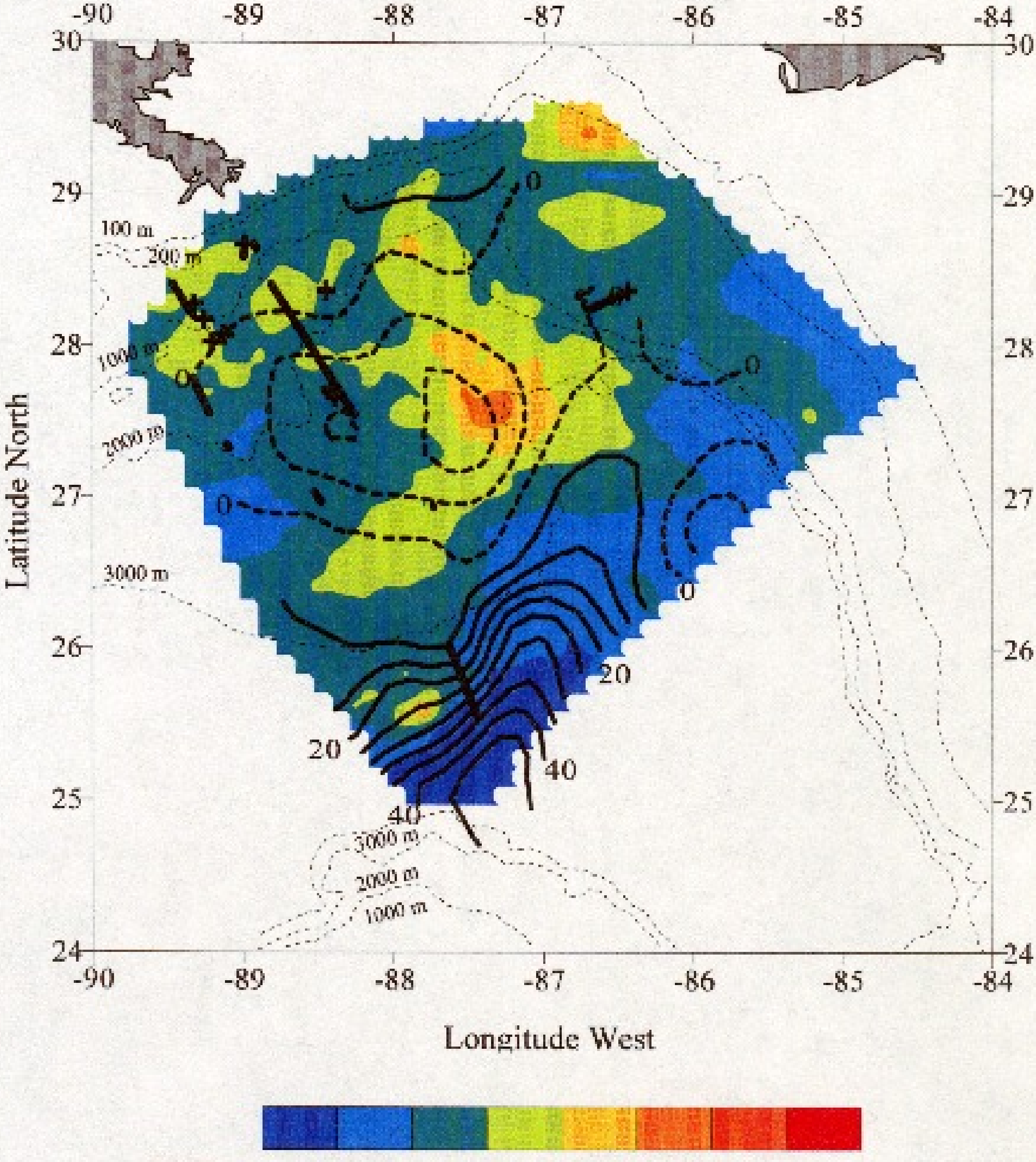

Figure 6.15. Sperm whale (Category 2) sightings (+) and acoustic contacts (very bold lines and dots) during the late summer 1996 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 100 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -12 cm, the confluence between 0 and 22 cm, and the anticyclone between 25 and 50 cm. The color contours indicate nighttime predicted mean biomass (PMB, cc·m^{-2}) in the interval 10-50 m.

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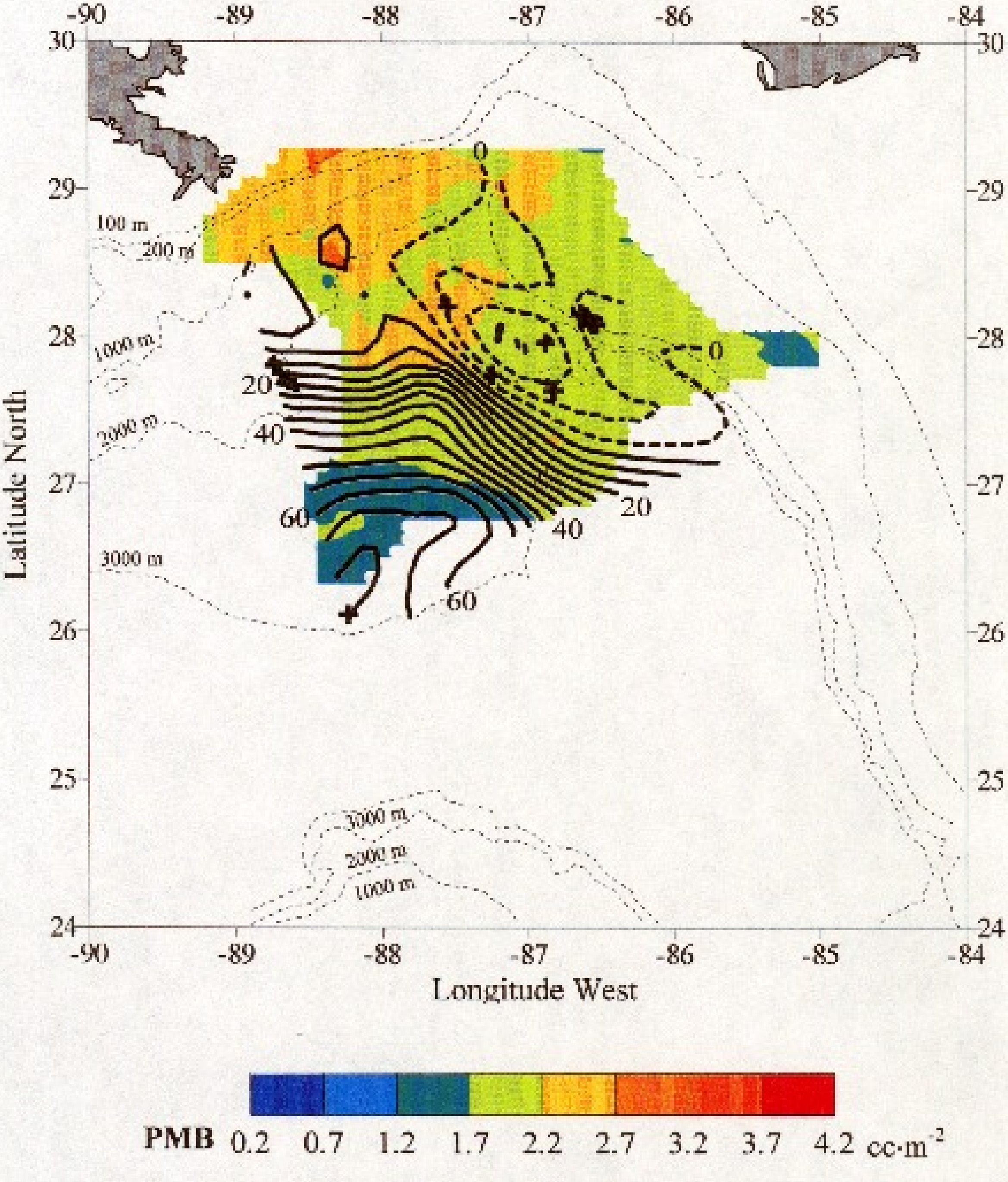

Figure 6.16. Sperm whale (Category 2) sightings (+) and acoustic contacts (very bold lines and dots) during the mid-summer 1997 cruise. Thin dashed lines represent isobaths. Bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (DHA, cm) relative to the 105 cm mean. Contour intervals are 5 cm. The cyclone is between 0 and -13 cm, the confluence between 0 and 24 cm, and the anticyclone between 25 and 71 cm. The color contours indicate nighttime predicted mean biomass (PMB, $cc \cdot m^{-2}$) in the interval 10-50 m.

100-200 km due east over the DeSoto Canyon in mid-summer 1997. In 1996, the MOM area was strongly cyclonic, but the next year the cyclone was centered farther east and sperm whale occurrence shifted similarly. Since cyclones in the northern Gulf are dynamic and usually associated with westward moving cyclone-anticyclone pairs, cetacean distribution will be dynamic. However, with near real-time satellite remote sensing of SSH anomaly, these features can be tracked and used to predict where cetaceans may be concentrated.

As mentioned in Chapter 3, 28 cephalopod families are eaten by cetaceans, and cephalopods are the main food constituent of 28 odontocetes (Clarke 1996). Of these cephalopod families, the ommastrephids, onychoteuthids, cranchiids and enoploteuthids are numerically important in the diets of sperm whales, members of the Family Ziphiidae, dwarf and pygmy sperm whales, false killer whales, melon-headed whales, pilot whales, Risso's dolphin, pantropical spotted dolphins, spinner dolphins and striped dolphins (Clarke 1996, Perrin et al. 1973, Wolff 1982). The paralarvae of all of these cephalopod families were found in GulfCet II trawl samples, although the family Enoploteuthidae was by far the most abundant. Although the number of trawls in this study was too small to detect a difference in squid paralarvae abundance in the different hydrographic features, a statistically significant relationship existed between integrated zooplankton biomass and integrated cephalopod paralarvae (a major component of cetacean prey) numbers (see Chapter 3 for details). This implies that higher zooplankton and micronekton biomass indicate richer concentrations of squid in the cyclones and confluence regions than in the anticyclones. In addition, the abundance and diversity of myctophids, a second important cetacean prey group, appear to be greater in the cyclones and confluence regions than in the anticyclones, although the sample size was too small to analyze statistically. These results suggest that the amount of prey for cetaceans (and seabirds) may be consistently greater in the cyclone and confluence areas (as opposed to anticyclones) making them preferential areas for foraging.

In addition to the presence of hydrographic features, ocean depth influences cetacean distribution in the northern Gulf. In earlier studies (Davis and Fargion 1996, Baumgartner 1997, Davis et al. 1998, Mullin et al. 1994c), the distribution of cetaceans in the north-central and western Gulf of Mexico in waters deeper than 100 m (i.e., the GulfCet I study area, Figure 1.2) was differentiated most clearly with ocean depth. Atlantic spotted dolphins were consistently found in the shallowest water on the continental shelf and along the shelf break. Bottlenose dolphins were found most commonly along the upper slope in water significantly deeper than that for Atlantic spotted dolphins. All the other species and species categories were found over deeper ocean depths; these were Risso's dolphins, short-finned pilot whales, pygmy/dwarf sperm whales, rough-toothed dolphins, spinner dolphins, sperm whales, striped dolphins, *Mesoplodon* spp., pantropical spotted dolphins, clymene dolphins and unidentified beaked whales (Ziphiidae). Risso's dolphins and short-finned pilot whales occurred along the upper slope and, as a subgroup, were significantly different from striped dolphins, *Mesoplodon* spp., pantropical spotted dolphins, clymene dolphins, and unidentified beaked whales, which occurred in the deepest water. Pygmy/dwarf sperm whales, rough-toothed dolphins, spinner dolphins, and sperm whales occurred at intermediate depths between these two subgroups and overlapped them. In terms of cetacean distribution based on ocean depth, our results for the combined GulfCet I and II data for the northern oceanic Gulf are consistent with these earlier results.

The enhanced presence of cetaceans along the slope instead of abyssal areas of the northern Gulf probably results from the collision of mesoscale eddies with the continental margin which enhances primary and secondary productivity, especially along the upper continental slope. Skipjack (*Katsuwonus pelamis*), blackfin tuna (*Thunnas atlanticus*), swordfish (*Xiphias gladius*), and blue marlin (*Makaira indica*) have been reported by fisherman to be locally abundant in these areas (Roffer's Ocean Fishing Forecasting Service, pers. com.). The presence of large, apex-predators such as tuna, billfish and cetaceans indicates reliable food resources along the continental slope.

In the north-central Gulf, an additional factor affecting cetacean distribution may be the narrow continental shelf south of the Mississippi River delta. Low salinity, nutrient-rich water may occur over the continental slope near the MOM or be entrained within the confluence of a cyclone-anticyclone eddy pair and transported beyond the continental slope. This creates a deep-water environment with locally enhanced primary and secondary productivity and may explain the presence of a resident population of endangered sperm whales within 50 km of the Mississippi River delta (Townsend 1935, Berzin 1972). Previous studies have shown that sperm whales in the north-central Gulf occur along the mid-to-lower slope (Collum and Fritts 1985, Davis et al. 1998). The results from the late and mid-summer cruises are in agreement with previous studies and show sperm whales inhabiting areas along the lower slope where DHA is low (i.e., within cyclones or confluence zones) and PMB is higher (Figures 6.15 and 6.16). Similar associations with cyclones and higher PMB were obtained for the squid-eaters and oceanic stenellids, although squid-eaters occurred along the upper slope and oceanic stenellids along the lower slope and in water greater than 2,000 m deep (Jennings 1982). Along the continental slope of Nova Scotia and the northeastern United States, sperm whales have been observed over similar ocean depths (200-1,500 m; Whitehead et al. 1992.) and in areas of increased productivity along frontal systems (Waring et al. 1993, Griffin 1999). In the South Pacific, sperm whales occur in areas with high secondary productivity and steep underwater topography (Jaquet and Whitehead 1996, Jaquet et al. 1996). However, it should be noted that the association of sperm whales with low DHA and elevated PMB was statistically significant only for the late summer cruise, although most of the sperm whale sightings during the mid-summer cruise also occurred in the cyclone and confluence zone. Sperm whale sightings for the entire oceanic northern Gulf (GulfCet I and II sightings combined) showed no significant relationship with hydrographic features. The inconsistent results for sperm whales indicate important problems with this type of analysis that may result from: 1) the difficulty in obtaining large numbers of sightings with simultaneous environmental data for some species, 2) combining sightings collected over large geographic and temporal scales in which important but subtle factors may be obscured, 3) the low resolution (>60 nm) of many environmental variables and 4) the lack of data on cetacean behavior (e.g., diving, social and sexual) and at-sea movements. We should also remember that the relationships between physical and biological processes are subtle and complex, and that factors other than hydrographic features and potential prey abundance may also influence the distribution of sperm whales and other cetaceans (Jaquet and Whitehead 1996, Jaquet et al. 1996). For example, the seasonal movements of sperm whales and other cetaceans may be affected by reproductive and migratory behavior, for which we currently have little information.

Unlike the other cetaceans, the distribution of bottlenose dolphins and Atlantic spotted dolphins was not correlated with the cyclones that occur in deeper waters beyond the shelf break. The preference of these two species for the shallow waters of the continental shelf and upper slope generally precludes them from feeding around cyclones and areas of confluence. The same appears to be true of Bryde's whale, which have been sighted in the northeastern Gulf in water 100 m deep (Davis et al. 1998, see also Chapter 4) and along the shelf break (Mullin et al. 1994c). We have little information on the environmental variables that influence the distribution of these species or their prey because hydrographic surveys have concentrated on deeper waters beyond the continental shelf.

6.5 Conclusions

Cetaceans in the northeastern and oceanic northern Gulf of Mexico were concentrated along the continental slope in or near cyclones. These eddies are mesoscale features with locally concentrated zooplankton and micronekton stocks that appear to develop in response to increased nutrient-rich water and primary production in the mixed layer. The exceptions were bottlenose dolphins, Atlantic spotted dolphins and possibly Bryde's whale that typically occur on the continental shelf or along the shelf break outside of major influences of eddies. Low salinity, nutrient-rich water from the Mississippi River, which may also contribute to enhanced primary and secondary productivity in the north-central Gulf, may explain the presence of a resident population of endangered sperm whales south of the delta. However, since cyclones in the northern Gulf are dynamic, cetacean distribution will undoubtedly change in response to the movement of prey associated with these hydrographic features.

Chapter 7

Behavior and Site Fidelity of Sperm Whales in the Northern Gulf of Mexico

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7.1 Background and Historical Overview in the Gulf

Sperm whales are the most common large whale in the northern Gulf of Mexico (Schmidly 1981, Mullin et al. 1994c, Davis and Fargion 1996, Jefferson 1996, Jefferson and Schiro 1997, Würsig et al. in press). The regular occurrence of sperm whales in the Gulf is known from whaling records of the mid-1700s to the early 1900s, and more recent aerial and ship-based census work (Townsend 1935, Collum and Fritts 1985, Mullin et al. 1994c, Jefferson 1996, Jefferson and Schiro 1997). Population estimates indicate a minimum of 300-530 sperm whales are likely to inhabit the northern Gulf (Davis and Fargion 1996, Jefferson 1996, Waring et al. 1997).

Sperm whales generally inhabit deep waters near oceanic islands, continental shelves and submarine ridges (Clarke 1956, Berzin 1972, Rice 1989). A similar pattern appears in the northern Gulf of Mexico, with a majority of sperm whale sightings in water depths from 104-2,742 m, with a mean bottom depth of 1,228 m (s.d. ± 617 m) (Collum and Fritts 1985). More recent studies found that sperm whales in the north-central Gulf of Mexico preferentially occur in water depths from 900-1,200 m, with most sightings along the 900 m isobath (Mullin et al. 1994c, Davis and Fargion 1996).

While general information regarding the occurrence and distribution of sperm whales in the Gulf has become increasingly available (Mullin et al. 1994c, Davis and Fargion 1996, Jefferson 1996), little is known about details of habitat use and behavior. For example, it is currently unknown if individuals or groups of sperm whales are resident in the Gulf year-round, are transient to the region, or undertake migrations to and from other oceanic basins such as the Atlantic or Caribbean.

Within the framework of Texas A&M University's GulfCet I & II Programs, the first preliminary information concerning occurrence patterns, habitat use, site fidelity, surface behaviors and some aspects of individual codas of sperm whales in the northern Gulf of Mexico has now been gathered. Results from this research are presented here.

7.2 Methods

The locations of sperm whale sightings during the late summer and mid-summer *Gyre* cruises (*Gyre*96G06 and *Gyre*97G08, respectively) were overlaid *a posteriori* with oceanographic characteristics that show the features of anticyclone, cyclone, confluence between the two, and "other" (See Chapter 6 for details of methods).

The GulfCet I & II Programs conducted two surveys and devoted significant effort to behavioral observations and photo-identification of sperm whales. The first sampling period was between 20-28 August 1994. The second sampling period was more limited in duration, and occurred on

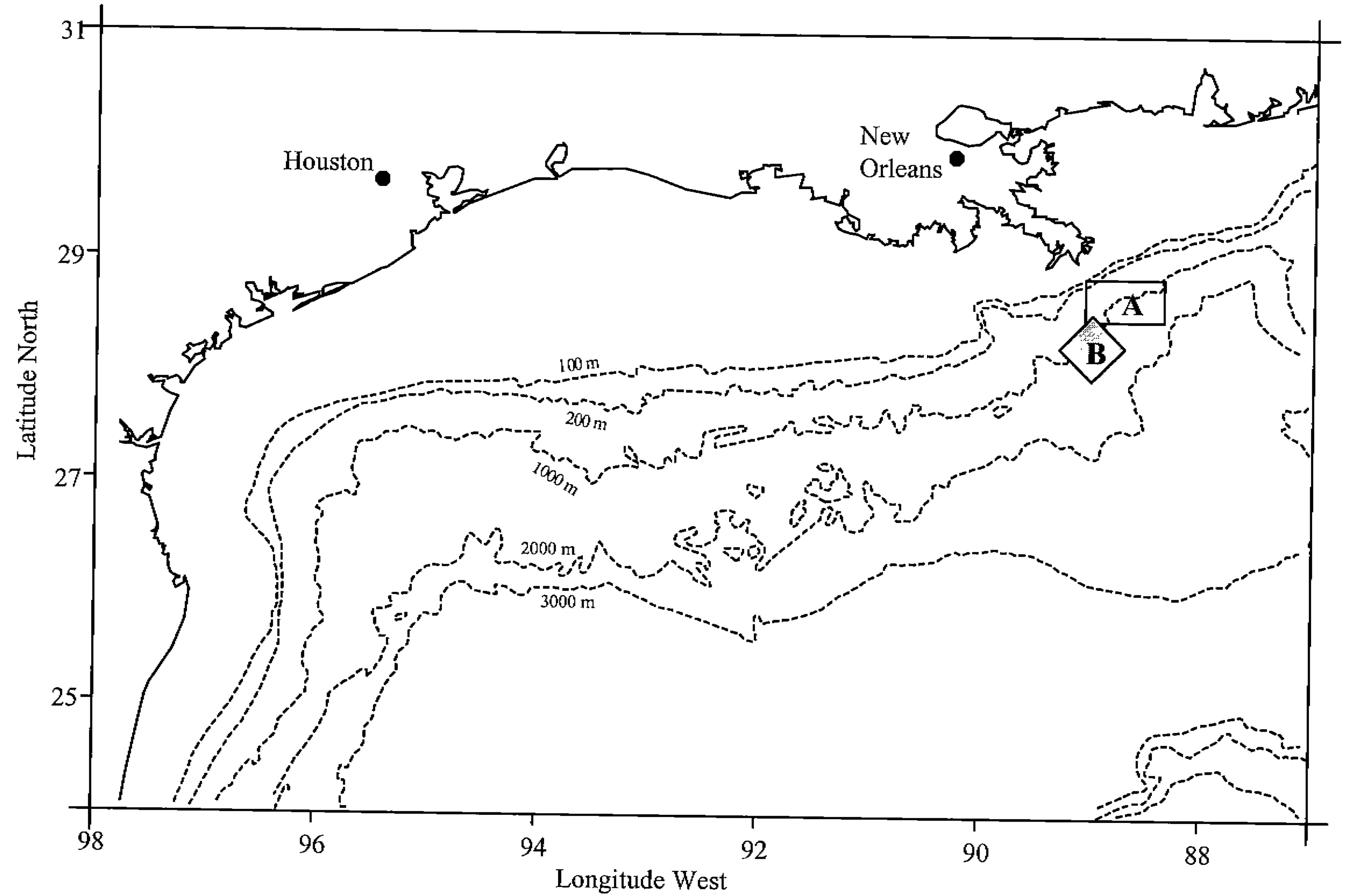

Figure 7.1. Map of the focal study areas: (A) denotes the GulfCet I TIO Cruise 8 study area, (B) denotes the GulfCet II *Gyre* Cruise 96G06 study area.

ship-based observers described the surface behavior of sperm whale groups generally within 2 km of the survey vessel. Data were collected mainly by use of 25 x 150 pedestal-mounted binoculars; however, smaller hand-held binoculars, video cameras and 35-mm cameras were also used. Following a pre-defined behavioral ethogram, group size, behavior, and respiration variables were recorded.

Three behavioral states were identified: (1) rafting -- whales essentially motionless at the surface with no observable behavior other than breathing; (2) travel -- whales moving in a discernible direction as indicated by forward movement; and (3) social -- whales in tight formation and in regular body contact with each other. The behavior of sperm whale groups was monitored over the course of each encounter and any changes were noted. Group size estimates represented a consensus of all trained observers involved in collecting data for a particular focal group.

The orientation of whales relative to the survey vessel was systematically monitored. In this procedure, observers noted whale orientation (relative to the ship) as determined by the point on a clock face in which whales would "see" the survey ship. For example, if the ship was directly abeam of a whale's left side, its view of the ship was 9 o'clock. Each hour on the clock face corresponded to 30° of arc. The clock face technique was easy and quick to use in the field but limited orientation estimates to 30° intervals. The distribution of whale orientations at the time of initial sighting was compared against a random (uniform) circular distribution with a chi-square test. The true orientation of whales (at time of first sighting) relative to North was determined and compared to swell direction with Moore's test for paired angular distance (Zar 1996). Whales with indiscernible or variable orientations were not included in the analysis.

Sperm whales displayed two dive types during our observations: fluke-up and slip-under dives. Fluke-up dives were presumably associated with deep vertical dives, and were characterized by the whale raising its caudal peduncle and flukes into the air prior to submergence. Slip-under dives consisted of a submergence without showing any portion of the flukes (or other behavioral dive indicator) being observed, and were presumably shallow horizontal dives. Frequency data were used to examine the percentage of each dive type as a function of daylight period.

Respiratory information was obtained from individual whales during focal observation sessions by recording the rate and timing of their blows. A Mann-Whitney U non-parametric analysis of variance was used to compare the amount of time between successive blows (inter-blow interval) as a function of surfacings which ended in either fluke-up or slip-under dives. Interpretation of these data warrant caution, however, as blow intervals may not have been entirely independent; that is, the same whale may have contributed to more than one observation session.

Group size estimates from the two GulfCet behavior study periods, different portions of the northern Gulf, and different observation platforms (aerial vs. ship-based) were compared using a Mann-Whitney U analysis and t-tests (Zar 1996). Analyses of sperm whale surface behavior were exploratory in nature. While significant alpha levels were taken to be $p < 0.05$, no corrections were made for experiment-wise error rate due to the increased alpha associated with multiple statistical tests.

An important part of sperm whale behavior is their vocal repertoire. Worthington and Schevill (1957) first described the characteristic "hammering" click produced by sperm whales (Figure

7.2). Unlike most other odontocetes, which can produce whistles and clicks, sperm whales are known to produce only the latter (Backus and Schevill 1966). Four main types of clicks have been categorized: usual clicks, slow clicks, creaks, and codas (Worthington and Schevill 1957, Backus and Schevill 1966, Watkins and Schevill 1977b, Weilgart and Whitehead 1988, Moore et al. 1993). Basic information on the coda patterns produced by sperm whales in the northern Gulf of Mexico is provided in this report for future comparisons within and outside of the Gulf.

During July and August 1995, a collaborative research effort was conducted between the National Geographic Society (NGS) and Texas A&M University (TAMU). The research objective of the NGS study was to attach an integrated video, audio, and dive-depth recorder, called "Crittercam," (Marshall 1998) to sperm whales in the north-central Gulf of Mexico, and thereby provide a unique opportunity for TAMU researchers to learn more of whale vocal and surface behavior. While not part of the GulfCet Program, findings from this research provide insight into the behavior of sperm whales in the Gulf, and are therefore included here. During the study, the research team was stationed at British Petroleum's MC-109-A, an oil production platform standing in approximately 300 m of water just east of the Mississippi River Canyon. Trips from the oil platform to regions identified as having high densities of sperm whales (Mullin et al. 1994c, Davis and Fargion 1996) were made on a daily basis, weather permitting. A 10-m sailing vessel and 5.4-m inflatable boat were used to find, tag and track sperm whale groups.

7.3 Results

7.3.1 Distribution

During the late summer and mid-summer cruises, sperm whales showed an apparent affinity for cyclonic (cold-core) eddies, confluence zones and the area south of the mouth of the Mississippi River (MOM), with only one whale group (during mid-summer) within an anticyclonic, or warm core eddy (See Chapter 6 for details). The line transect effort was 1613 km for late summer and 1695 km for mid-summer.

7.3.2 Group Size

Most sperm whale observations reported here were likely sub-groupings of larger schools. Mean sub-group size as determined from both the large and small vessels ranged from two to three individuals. No differences in group size were detected between the two GulfCet focal study periods ($p = 0.76$) or between aerial and ship-based surveys ($p = 0.30$). Similarly, no differences were found in group size by hour of the day ($p = 0.10$) during focal studies, or in the northern Gulf overall ($p = 0.80$). However, larger groups of sperm whales in the Gulf have been observed. For example, on 24 August 1994, when short-finned pilot whales and sperm whales were seen together during an apparent agonistic interaction (Weller et al. 1996), six sperm whales were initially sighted. After three hours, other sperm whales had joined and the total group size at the surface reached 12 animals.

7.3.3 Individual Recognition

A total of 37 individual whales were identified during 1994 and 1996. Initial sighting locations were mostly in waters from 700-1,100 m. Inter-sighting distances were calculated for within day

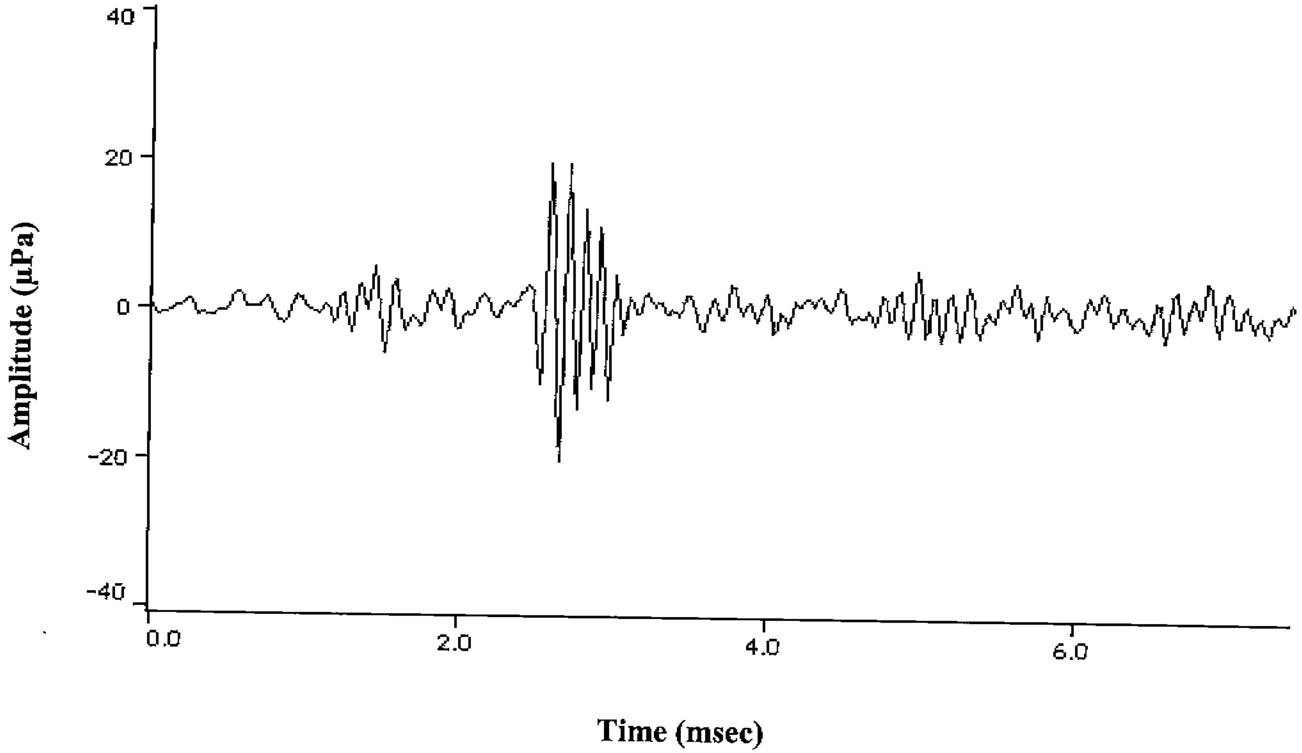

Figure 7.2. Waveform of a single sperm whale click.

periods (n = 9), between days (n = 4), and between years (n = 4) (Table 7.1). Four of the 37 whales identified were resighted on multiple days intra-annually, and four individuals were resighted inter-annually. The distance between resightings ranged from: 2.39-9.92 km on the same day: 17.30-24.31 km between days and 36.58-46.16 km inter-annually.

7.3.4 Photogrammetry

Photogrammetric work included calculation of the body sizes for five individuals. Body sizes ranged from 6.6-10.4 m (Table 7.2.), and were within typical size ranges for females and young (Best 1979). Due to the present incompleteness of testing accuracy and repeatability of measurements, further interpretation of these data warrant caution at this time.

7.3.5 Behavioral State Time Budgets

Rafting was the most frequently observed behavioral state, and accounted for 57.7% of behavior (Figure 7.3). Peaks in frequency of rafting and travel varied over the course of the day. In contrast, socializing was observed at a relatively constant but low level throughout the day. Interpretation of these data must be done with caution, as survey effort across days was not equal.

7.3.6 Orientation of Whales

When whales were first sighted, their orientation relative to the ship was non-random (p = 0.001). A histogram of orientation angles indicated that whales generally viewed the survey vessel at angles to their sides or behind, and less commonly in front of them (Figure 7.4.)

Angular differences between the true orientation of whales and the direction from which swells were coming are shown in Figure 7.5. Of all observations, 52.3% (n = 56) found whale orientations to be between 0° and 90°, while 47.7% (n = 51) were between 90° and 180°. The similar frequency of angular differences between 0-90° and 90-180° suggested that sperm whales may not have been orienting in a particular direction relative to the prevailing swell direction, and the statistical null hypothesis that whale orientation and swell direction were the same was rejected (p = 0.002).

7.3.7 Frequency of Dive Types

The proportion of fluke-up dives appeared to be higher than slip-under and unknown dives between 08:00 and 11:00 hr than at other time (Figure 7.6). In contrast, slip-under dives were proportionally higher than fluke-up dives between 12:00 and 13:00 hrs, but this pattern was again reversed starting at 14:00 hr.

7.3.8 Blow Intervals

Differences in mean blow intervals for fluke-up (mean = 13.4 sec, s.d. ± 5.38, n = 1018) and slip-under (mean = 15.6 sec, s.d. ± 7.77, n = 224) dive sequences were detected (p = 0.0004) (Figure 7.7 and Table 7.3). Intervals between blows were significantly longer for sequences culminating in slip-under dives than for those ending in fluke-up dives.

Table 7.1. Sperm whale sighting locations, dates and distances between resightings for photographically identified individuals.

Whale ID	Date	Lat. °N	Long. °W	Distance (km)
001	08/23/94	28.7388	88.7525	
001	08/23/94	28.7122	88.6553	9.92
001	08/25/94	28.7308	88.8680	20.83
002	08/22/94	28.7080	88.8550	
003	08/23/94	28.7120	88.7157	
003	08/23/94	28.7125	88.6557	5.85
004	08/23/94	28.7120	88.7157	
004	08/23/94	28.7125	88.6557	5.85
005	08/24/94	28.7405	88.8012	
005	08/28/94	28.5388	88.8977	24.31
005	10/20/96	28.9540	88.9150	46.16
006	08/23/94	28.7163	88.7382	
006	08/28/94	28.5743	88.9032	22.54
006	08/28/94	28.5447	88.8980	3.33
007	08/23/94	28.6973	88.6348	
008	08/28/94	28.5673	88.9023	
009	08/28/94	28.5447	88.8980	
009	10/20/96	28.9370	88.9190	43.64
010	08/23/94	28.7130	88.6917	
010	08/25/94	28.7308	88.8680	17.30
011	08/28/94	28.5743	88.9032	
012	08/25/94	28.7100	88.8605	
013	08/24/94	28.6828	88.8615	
014	08/23/94	28.7015	88.8058	
014	08/23/94	28.7087	88.7808	2.56
015	08/23/94	28.7015	88.8058	
015	08/23/94	28.7087	88.7808	2.56
015	08/23/94	28.7163	88.7382	4.24
016	08/28/94	28.5687	88.9020	
016	10/20/96	28.9150	88.9250	38.55
017	08/25/94	28.6568	88.8427	
018	08/22/94	28.7048	88.8367	
019	08/28/94	28.5610	88.9078	
020	08/23/94	28.7277	88.7568	
021	10/20/96	28.9540	88.9150	
022	10/28/96	28.0112	89.1528	
023	10/28/96	28.0291	89.1286	
024	10/28/96	28.0462	89.1244	
025	10/20/96	28.6610	89.0040	
026	10/20/96	28.6420	88.9910	
026	10/20/96	28.6250	89.0060	2.39
027	10/20/96	28.6250	89.0060	
028	10/20/96	28.6420	88.9910	
028	10/20/96	28.6250	89.0060	2.39
029	08/23/94	28.7363	88.6610	
029	10/20/96	28.6070	89.0060	36.58
030	10/20/96	28.8640	88.9770	
031	10/20/96	28.8910	88.9430	
032	08/26/96	28.7853	88.7542	
033	10/20/96	28.9150	88.9250	
034	10/28/96	28.0746	89.1713	
035	10/28/96	28.0462	89.1244	
036	08/23/94	28.7358	88.6575	
037	10/20/96	28.6610	89.0040	

Table 7.2. Size estimates for GOM sperm whales using Gordon (1990) photogrammetry techniques.

	Whale 1	Whale 2	Whale 3	Whale 4	Whale 5
Size (m)	10.4	9.4	6.6	10.3	8.3

Summary statistics for the five whales measured by photogrammetry.

Count	Min. Size	Max. Size	Mean	SEM	SD	Variance	Range
5	6.6	10.4	9.0	0.70	±1.58	2.51	3.8

Table 7.3. Descriptive statistics for categories of inter-blow intervals (IBI). Units are in seconds.

Category	N	Min. IBI (sec)	Max. IBI (sec)	Mean (sec)	SEM	SD	Skewness	Kurtosis
Fluke-up	1018	2	56	13.4	0.17	±5.38	2.08	9.54
Slip-under	224	1	50	15.6	0.53	±7.77	1.19	2.37

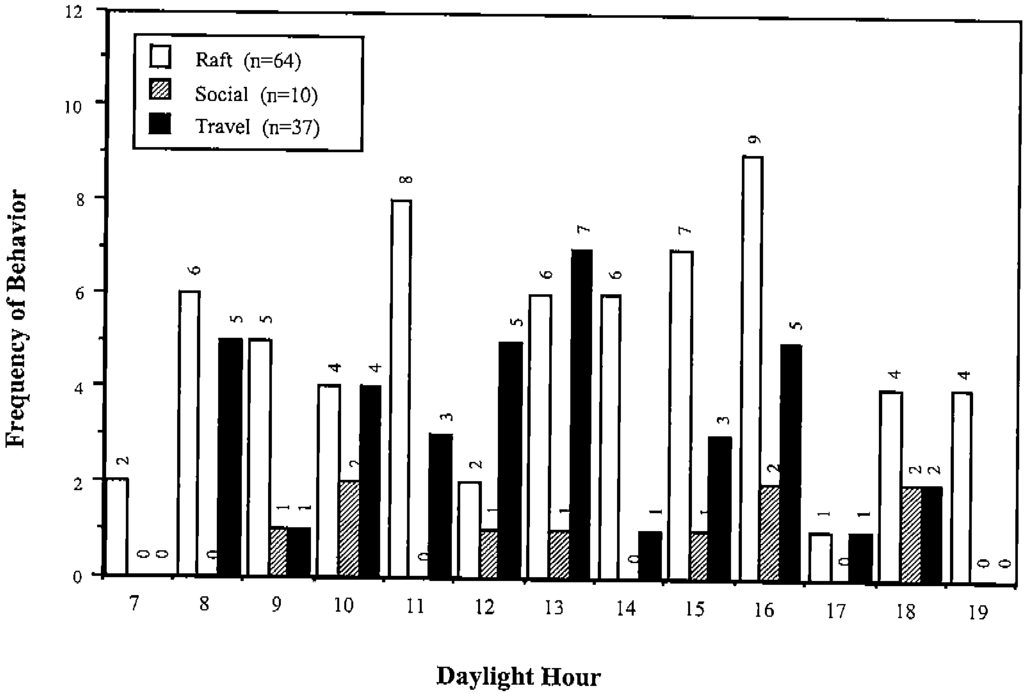

Figure 7.3. Frequencies of Raft, Social, and Travel behavior as a function of daylight hour.

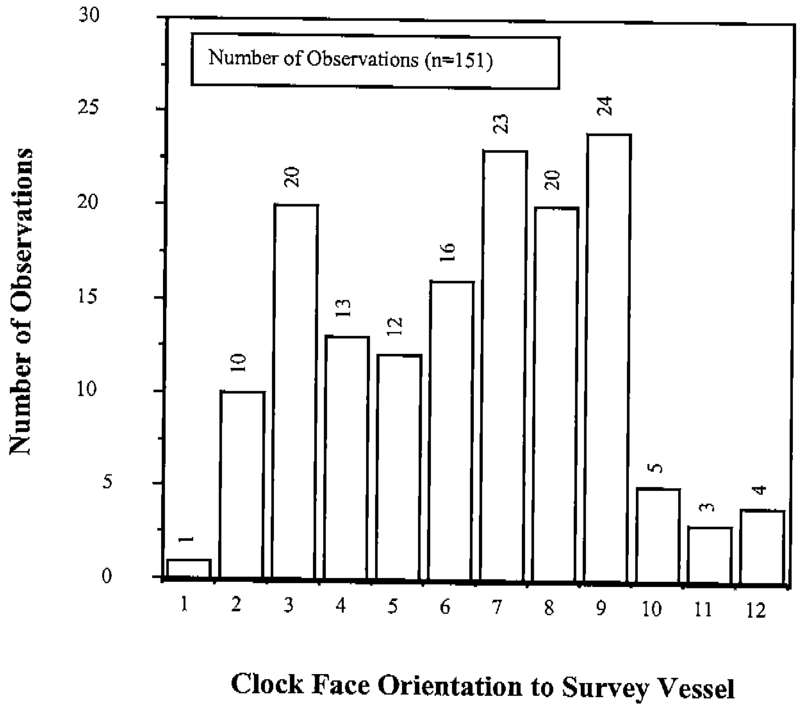

Figure 7.4. Whale orientation relative to survey vessel. For example, if the whale viewed the vessel directly to its left side, the view would be 9 o'clock.

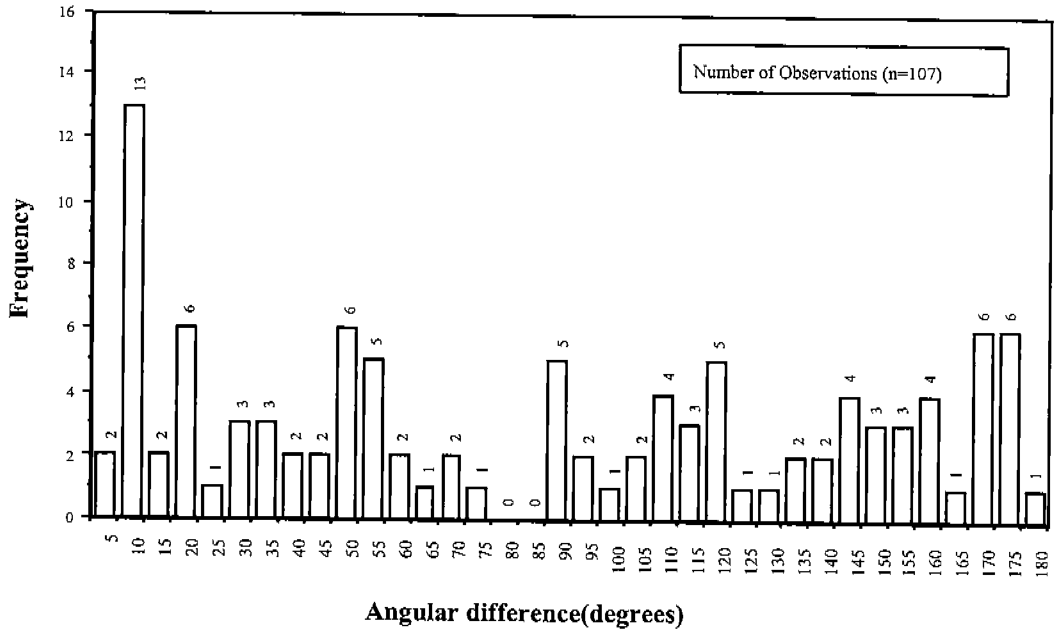

Figure 7.5. Frequency distribution of angular differences between whale orientation and swell direction. For example, orientations of 180° indicate whales swimming in the same direction as prevailing swell.

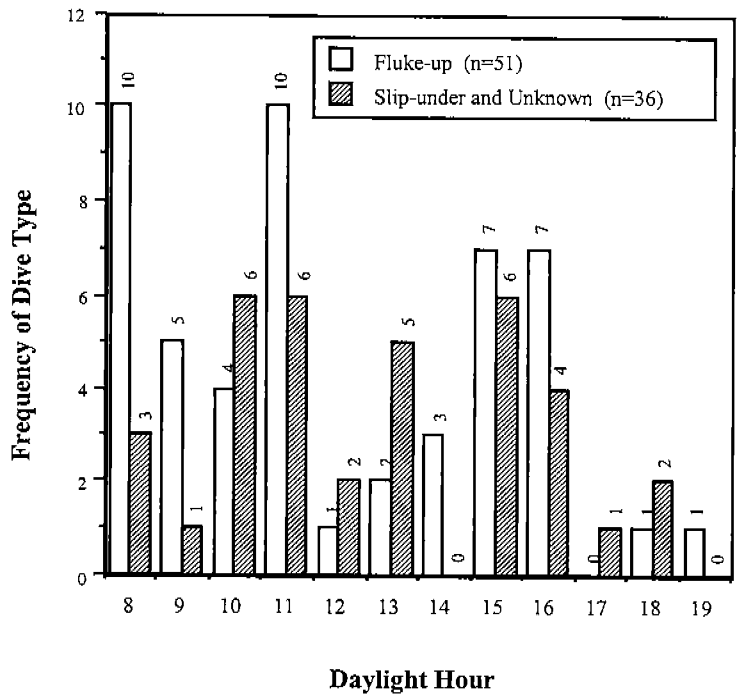

Figure 7.6. Frequency distribution of Slip-under and Unknown and Fluke-up dives as a function of daylight hour.

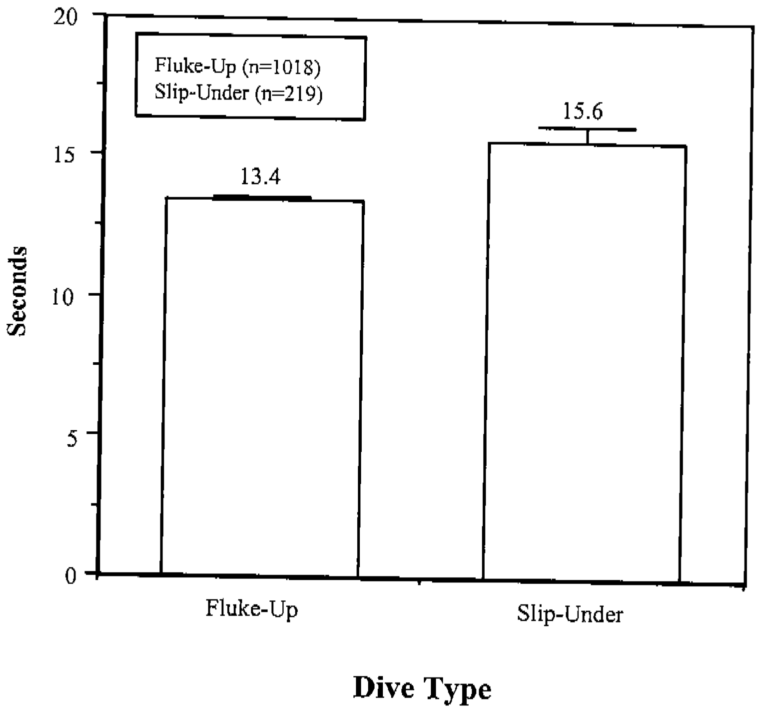

Figure 7.7. Mean inter-blow interval for Fluke-up and Slip-under dives. Error bars represent standard error of the mean.

7.3.9 Crittercam

A total of five distinct coda types was recorded from approximately six whales during two Crittercam sessions. Session one lasted 5.3 min and recorded vocal behavior from four whales. A four-click pattern accounted for 50.0% of the codas recorded, while seven-click and eight-click patterns accounted for 29.0% and 14.0%, respectively. In addition, six-click and nine-click codas accounted for the remaining 7.0%; however, these two coda patterns were viewed as variations of patterns previously identified (i.e., either adding or deleting one click from a coda). The four-click coda pattern was shared (e.g. more than one animal vocalizing with that coda at the same time) 10.0% of the recording time. An ANOVA followed by Fisher's *post hoc* comparisons test of the four-click inter-click-interval (ICI) indicated a significant difference between all ICI combinations ($p = 0.0001$).

Crittercam session three was approximately 9.0 min in duration and recorded two whales that dove to a depth of approximately 600 m. Upon tagging, the whale carrying the Crittercam began a steep dive and started producing a click train vocalization. Approximately 5 min into the dive, this whale started to produce an eight-click coda pattern. At this time, a second whale began vocalizing, producing a four-click coda pattern. The eight-click pattern represented 74.0% of the codas while the four-click pattern represented 24.0% of the total coda vocalizations during the session.

7.4 Discussion

7.4.1 Distribution

The distribution of sperm whales is treated with habitat descriptions of all cetaceans in the habitat association chapter of this report. For the presently-evaluated cruises (*Gyre*96G06 and *Gyre*97G08), there was a tendency for sperm whales to occur more frequently at the edges of, and closely associated with, cyclonic activity. However, for the overall sperm whale-oceanographic comparisons of 14 previous cruises, including the two mentioned here, there is a statistically significant trend showing whales to associate preferentially near the edges of anticyclonic activity. The apparent discrepancy may be as simple as the whales occurring at one or the other edge of the so-called confluence between anticyclonic and cyclonic features. This confluence is an active oceanographic area with potentially greater productivity due to upwelling at the point of divergence, particularly if the divergence originates near the continental shelf (Biggs and Müller-Karger 1994).

7.4.2 Group Size

The mean group size reported here closely follows previous results from the Gulf of Mexico. Mullin et al. (1994c) found that the average sperm whale group size was 2.1 animals (range = 1-11). The data of Collum and Fritts (1985) showed that sperm whale group size averaged 3.5 animals (range = 1-14). More recent aerial surveys documented a mean group size of 2.6, while shipboard visual surveys during the same period reported a mean group size of 2.0 (range = 1-12) (Davis and Fargion 1996). Mullin et al. (1994c) proposed that the small group sizes for the Gulf of Mexico might correspond to the whale "clusters" described by Whitehead and Arnbom (1987). Whitehead and Arnbom (1987) defined a cluster as whales swimming in a coordinated manner within 100 m of one another. Whitehead (1989) noted that mixed groups in the Galapagos formed one to four clusters while at the surface, with an average of 1.7 animals and a mean inter-cluster distance of 213 m. On average, social clusters formed once per day and had a range of 4-20 animals (Whitehead 1989). The average cluster size for sperm whales in Sri Lanka was 3.1 (Gordon 1987).

Davis and Fargion (1996) point out that if a cluster contains on average 1.7 animals and groups contain roughly 20 animals, then various members of a group may surface in 10-12 clusters over a period of 30-90 min. While this latter conclusion was not quantitatively substantiated by the work reported here, it was the behavioral observers' impression that once a group of sperm whales was detected, it was common to then begin sighting additional groups in the same general vicinity. Thus, the larger group of 12 animals that interacted with short-finned pilot whales on 24 August 1994 (Weller et al. 1996), probably represented most, if not all, subgroups of an entire school of sperm whales.

7.4.3 Individual Recognition

The occurrence patterns and movements of individually identified sperm whales reported here indicate that at least some whales maintain a level of intra- and inter-annual fidelity to the MOM region. These findings, when combined with historic whaling records (Townsend 1935) and results from ship and aerial surveys (Davis and Fargion 1996), suggest that the Mississippi River outflow, the narrow continental shelf and the close proximity of deep water to the MOM area plays an important role in the ecology of sperm whales in the northern Gulf of Mexico.

Schmidly and Shane (1978) suggested that a resident population of sperm whales might inhabit the Gulf. Preliminary findings presented here appear to support this hypothesis; however, additional data are needed to confirm year-round residency. The social structure and movement patterns of sperm whales in the Gulf are currently unknown. Based upon long-term studies of sperm whales off the Galapagos Islands (Whitehead and Arnbom 1987), we suggest the following scenarios for whales in the Gulf of Mexico: 1) female-based groups remain in the Gulf year-round and males "roam" into the area on a sporadic and occasional basis; 2) female-based groups immigrate to and emigrate from the Gulf to mix with other geographic populations; 3) males and females remain in the Gulf year-round. The last of these hypotheses is unlikely as the lack of adult male sightings during our studies remains a gap in our current data.

Only by continued behavioral studies in combination with other techniques such as genetic sampling and satellite tracking can questions regarding population size, structure, and movement patterns be better addressed. In light of the current expansion of oil and gas development activities into the offshore regions of the Gulf, more detailed information on both the basic behavioral ecology and potential industry-related disturbance are critical for deep water cetaceans such as the sperm whale.

7.4.4 Photogrammetry

The social organization of sperm whales in the Gulf of Mexico is presently unknown. World wide, however, sperm whales are categorized into three main group types: mixed, bachelor and solitary males (Caldwell et al. 1966, Best 1979, Whitehead and Arnbom 1987). Mixed groups consist of mature females with their dependent calves and sexually immature animals of both sexes (Best 1979). Body size estimates, obtained from the photogrammetric research presented here, fall within the typical range for mixed groups consisting of females, immature males and calves (Best 1979). Strong sexual dimorphism occurs in sperm whales (Leatherwood and Reeves 1983), with males growing to 16 m, while mature females generally achieve less than 11 m in length. No apparent observations of unusually large whales (as related to others within a group) were recorded during the GulfCet study, and this may suggest that large adult males are infrequent visitors to the northern Gulf.

7.4.5 Behavior, Dive Type and Respiration Information

The most frequently observed behavioral state during focal observation sessions was rafting. If rafting is indicative of both a physiological refractory period following a prolonged dive and, at the same time, a physiological preparatory period for a future dive, then the increase of this particular behavior may be related to periods of greater foraging. The trend for rafting to occur throughout the day may be suggestive of regular daylight foraging. However, rafting may alternately be indicative of rest or surface time unrelated to post-dive recovery. The trend for fluke-up dives to be more frequent at 8:00, 11:00, 15:00 and 16:00 hrs overlaps in time with an apparent increase of rafting behavior. Therefore, we suggest that rafting may indeed reflect periods of increased foraging.

The inter-blow interval for surface times followed by slip-under dives is significantly longer than the same parameter for surface bouts ending with fluke-up dives. A more rapid breathing sequence may, as is the case during fluke-up dives, suggest post-dive recovery and pre-dive preparation, and may help to explain the apparent association between fluke-up dives and rafting behavior. While interpretation of these data are preliminary and cannot be used conclusively, the hypotheses presented here may provide some information on the foraging ecology of this cetacean in the northern Gulf of Mexico.

7.4.6 Orientation of Whales

The angle at which whales viewed the ship when first detected by observers was not randomly distributed. Instead, the whales were directed away from or sideways relative to the ship when they were first seen. Although the ship tended not to approach whales head-on, initial orientations were expected to be uniformly random, and to change as the ship approached for behavioral observations. Two explanations for this behavior are possible: (1) whales may have reacted to the ship and reoriented before they were detected or (2) factors other than the ship (e.g., a physical or biological gradient, or environmental noise) may have been influencing the observed non-random orientation. One such environmental gradient could be swell direction. In rough seas, for instance, sperm whales may orient into or away from oncoming swells. The ambiguous findings regarding whale orientation with respect to swell direction reported here warrant more careful data collection. Improvements could be made in estimating both the "whale's view" of the ship and the swell direction. For example, the estimated swell direction often changed by 20° or more between successive observer evaluations over as little as one hour. It seems doubtful that actual swell direction was so variable.

Overall, we tend to favor the explanation that whales were oriented away from the vessel when first seen, possibly to reduce their perception of vessel noise. However, more data need to be gathered before this possibility can be accepted (or rejected) with certainty.

7.4.7 Crittercam

Codas are thought to occur mostly at the surface and in social contexts. They are rhythmic patterns of clicks (Watkins and Schevill 1977b, Whitehead and Weilgart 1990) usually consisting of 3-40 clicks with an average of 10 clicks/coda. Each coda may be repeated from 2-60 times (Watkins and Schevill 1977a, Watkins and Schevill 1977b). Watkins et al. (1985) proposed two types of codas: identity codas, and general use or shared codas. Identity codas are patterns that are unique to an individual for at least several hours. General use codas are vocalizations that are shared among groups of whales (Watkins and Schevill 1977b). Since codas were often heard at the surface and in conjunction with social interactions in the southeast Caribbean, Watkins and Schevill (1977b) believed that codas have a communicative function (Watkins 1980, Whitehead and Weilgart 1991). Mullins et al. (1988) noted that codas were only heard when more than one whale was present off the Scotian Shelf. There also appear to be geographical differences in spacing and composition of codas between the Galapagos (Weilgart 1990) and the southeast Caribbean (Moore et al. 1993).

Crittercam sessions of the present study revealed the use of codas for at least two individuals at a depth of 600 m. This finding provides new information on the apparent use of codas at depth. Future research employing these techniques may help to further elucidate the role of the coda. Vocal comparisons between the Gulf of Mexico and other regions may prove useful in determining stock structure and geographic isolation of sperm whale populations.

7.5 Conclusions

Behavioral observations showed variable, diel patterns in dive type, surface activity and respiratory parameters. We suggest that these trends may be related to foraging and food capture. The group composition and group size of sperm whales in the Gulf of Mexico resemble estimates for other populations. Body size measurements indicate that female-based groups are common, while the absence of sightings of large males remains a gap in our developing understanding of these whales. Previous studies have shown that sperm whales in the north-central Gulf occur along the mid-to-lower slope (Collum and Fritts 1985, Davis et al. 1998). The results from the late and mid-summer cruises are in agreement with previous studies and show sperm whales inhabiting areas along the lower slope within cyclones or confluence zones (see Chapter 6 for details). Results from this study indicate that the behavior of sperm whales in the northern Gulf of Mexico resembles that of populations in other geographic locations. The survey data (Chapter 4) and apparent inter- and intra-year site fidelity of numerous photo-identified individuals in the MOM area suggests that the north-central Gulf is essential habitat for a breeding population of sperm whales. However, critical uncertainties exist in our understanding of population structure, behavior and seasonal movements relative to mesoscale hydrographic features.

As well, there exist critical uncertainties in potential behavioral changes, vocal reactions, and overall habitat use changes of sperm whales relative to survey and industrial activities. It is hoped that future studies of sperm whale behavior allow for observational or experimental work on reaction to especially industrial seismic surveys, whose loud sounds travel long distances and therefore have the potential to affect sperm whales in short and long term.

Chapter 8

Seabird Ecology

Nancy A. Hess and Christine A. Ribic

8.1 Introduction

As part of the GulfCet II program, three seabird surveys were conducted during cruises in the northern Gulf of Mexico. These surveys occurred in different seasons. From 17 April to 9 June 1996, surveys were conducted aboard NOAA ship R/V *Oregon II* (NOAA Cruise 220). The northern slope and oceanic Gulf (Figure 4.4), and northeast Gulf shelf and slope waters (Figure 4.2) were surveyed during this spring and early summer cruise. From 10 to 29 October 1996 (late summer) and 5 to 21 August 1997 (mid-summer), surveys were conducted from the R/V *Gyre*. These cruises covered the central pelagic and northeastern continental shelf and slope regions of the Gulf (Figure 4.3). The spring *Oregon II* cruise was conducted at the same time of year as previous Gulf of Mexico surveys conducted by the National Marine Fisheries Service (Davis and Fargion 1996). The late summer survey was the first large-scale, shipboard seabird survey to take place in the Gulf of Mexico during the month of October, a time of seabird migration in this area. Previous late summer and autumn shipboard surveys occurred in late August to early September and November (Davis and Fargion 1996). Fritts and Reynolds (1981) conducted aerial surveys along coastal Texas and Florida areas during August and November. Southeast Texas, Louisiana and southwest Florida coastal waters were surveyed (via aircraft) by Fritts et al. (1983) every other month starting in February for a total of six surveys. However, little is known about seabird associations with physical features of the Gulf. Ribic et al. (1997a) identified possible associations with offshore eddies and indicated the need for further work on seabird/oceanic feature association to understand the distribution of seabirds in the Gulf.

8.2 Methods

8.2.1 Cruise Logistics

The spring cruise (*Oregon II* cruise 220) spanned 44 days and surveyed 6,401 km (see Chapter 4 for details; Mullin and Roden 1996). The cruise consisted of three legs targeting different regions of the Gulf. Two of the legs consisted of transects spaced evenly across the oceanic Gulf and continental shelf. The third leg, in early summer, focused on the northeastern continental slope and shelf water. During the late summer survey (*Gyre*96G06), there were 16 days of effort, covering approximately 2,015 km of the Gulf. This cruise surveyed two regions: an eddy pair in the north-central Gulf that contained a cyclonic eddy and an anticyclonic Loop Current eddy (LCE), and a northeastern region over the continental shelf and slope, in the Minerals Management Service's Eastern Planning Area (EPA). The mid-summer cruise (*Gyre*97G08) had 17 days of effort, resulting in approximately 2,500 km surveyed track line in the Gulf. The area surveyed covered an eddy pair in the north-central Gulf and the EPA. The *Oregon II* (spring cruise) and *Gyre* (mid-summer and late summer cruises) seabird surveys were conducted using different methodologies.

8.2.2 Spring Cruise Survey Methods

The spring visual survey recorded seabirds opportunistically and coincident with marine mammal sightings from the *Oregon II*. Two teams of three people alternated observation duties. When birds were seen during the survey, they were identified to the lowest taxonomic level possible, (dependent on the skill of the observer). Two of the observers used 25 x 150 "big eye" binoculars. The third observer recorded data and used hand-held binoculars or naked eye in this survey. Surveys were conducted during daylight hours in Beaufort Sea State 5 or less.

Only seabirds identified to the family/subfamily group were included in the analysis. Entries of "unidentified seabird" were not included in the total number of birds. Percent of total seabirds by group was the first index of relative abundance calculated. The second level of analysis addressed group composition. Within each group a breakdown by species (e.g., pomarine jaeger, parasitic jaeger, and long-tailed jaeger) and unidentified (e.g., jaeger spp.) was tallied. The data were compared to data from other NMFS cruises that occurred at the same time of the year using the same survey methods (Davis and Fargion 1996). The spring surveys of 1992, 1993, 1994 also used the methodology of opportunistically recording seabirds and other birds spotted during marine mammal surveys. Percentages of total birds in each group were compared between the different surveys.

8.2.3 Mid-summer and Late Summer Cruise Survey Methods

During the surveys from the *Gyre*, observations occurred by a three-person bird survey team during daylight hours. Observers rotated so that two observers surveyed simultaneously. Observers used hand-held 8x or 10x binoculars. Observations occurred from the flying bridge of the *Gyre* from sunrise to sunset, except during rain, Beaufort Sea State 6 or greater, and when the ship was stopped at hydrographic stations or for sperm whale observations. The *Gyre* seabird surveys consisted of continuous strip transects using the method of Tasker et al. (1984). The late summer survey used 300-m wide transects; the mid-summer seabird survey used 300 m and 600 m strip transects. The survey area was measured off one side of the ship, sweeping from the bow to 90° perpendicular to the ship. The side of the ship (port or starboard) containing the survey area was selected based on lowest amount of glare from the sea surface. A range finder as described by Heinemann (1981) was used to determine the limits of the 300 m and 600 m bands. Sightings of birds outside of the strip transect survey area were also recorded.

Only seabirds identified at least to the family/subfamily level were included in analysis. The total number of birds seen while "on effort," regardless of distance from ship, was used to assess presence and absence and relative numbers of species seen on the continental shelf compared to deeper water. Seabirds were tallied according to whether they were present on the continental shelf (< 200 m) or in deeper water (> 200 m depth). The total number of birds, seen at any distance from the ship, divided by the number of effort hours was used to compare the late summer and mid-summer cruise data to GulfCet I survey data (Davis and Fargion 1996).

Species abundance in the 300-m strip transect was categorized by hydrographic environment to assess species distributions, as well as species diversity, richness and evenness. The numbers of birds seen within the strip transect for both the late summer and mid-summer cruises were designated as occurring within one of six hydrographic environments as defined in Chapter 2.

The hydrographic environments were: the cyclone, Loop Current eddy (anticyclone), confluence, mouth of the Mississippi River (MOM), and other margin. The other margin was defined as regions with bottom depth greater than 200 m not directly associated with the eddy system. The sixth hydrographic environment was the continental shelf which was defined as regions in water less than 200 m deep.

Due to a relationship between kilometers of survey effort and species seen, diversity indices were calculated only for hydrographic environments with at least 200 km survey effort, the point where the relationship between species sighted and effort leveled off. The standardized Shannon Index for diversity was calculated and expressed as a ratio of observed diversity to maximum diversity possible for each hydrographic environment (or region) using:

$$-\Sigma(p_i)\log(p_i)/\log(S)$$

where $i = 1, 2, \ldots, S$, the number of species seen in the region and p_i equals the proportion of the i^{th} species out of the total number of birds (Magurran 1988). Standardization allows direct comparison of diversity between regions where different numbers of species were seen. Standardized diversity indices fall between zero and one. The Simpson Index was used as a measure of species dominance, or the probability that the next species seen is the same as the previous. It was calculated as:

$$\Sigma(p_i)^2$$

where $i = 1, 2, \ldots, S$, the number of species seen in the region and p_i is the proportion of the i^{th} species out of the total number of birds (Magurran 1988). This would indicate species prevalence in a hydrographic environment. A high Simpson Index value (close to one) suggested that one species was most abundant and most frequently seen.

To conduct habitat analyses, the continuous strip transect was split into approximately equal-length strip segments, with a target length of ca. 10 nautical miles to match the scale used in the marine mammal analysis. Ship turns, stops for hydrographic stations and marine mammal observations, and Beaufort Sea State > 5 were excluded from subsequent analysis. To match the marine mammal habitat analysis, we excluded transects with water depth less than 200 m, as well as one transect from the late summer survey with incomplete environmental data. For the late summer survey, a 300-m transect band width was used with a transect mean length of 7.63 nautical miles (SD = 2.02, n = 73). For the mid-summer survey, a 600-m transect band width was used with a mean transect length of 7.10 nautical miles (SD = 1.82, n = 103). For each transect, the presence or absence of seabirds was tallied for the most abundant species seen during the cruise. Analysis was conducted only for the species seen in at least 10% of the transects.

To test a species' affinity for a particular environmental feature, presence or absence was tabulated by hydrographic environment. Transects were assigned to one of the five hydrographic environments, excluding the continental shelf, by matching the transect midpoint to the nearest XBT or CDT station and categorizing the transect to the same environment as the closest station. A G-test of independence (Fienberg 1980) was conducted to determine if a significant relationship existed between the hydrographic environments and species presence. Standardized residuals (Fienberg 1980) were calculated to determine which hydrographic environments were associated with the presence of individual species. Significance was assessed at alpha = 0.05. Trends were assessed at alpha = 0.10. Analyses were conducted using SYSTAT®7.0 (SPSS 1997).

Several oceanographic variables were calculated to analyze the relationship of seabirds to the marine environment. Sea surface temperature and salinity were calculated for each transect by averaging values at the transect start and finish times from the *Gyre* SAIL system data (see Chapter 2 for details). Sea surface height and geostrophic flow were calculated by averaging the transect start and finish point values using remote sensing data processed at the University of Colorado Center for Astrodynamics Research (CCAR). Bottom-depth values for each transect were obtained from the ETOPO-5 database. A program written for the marine mammal data analysis (J. Ortega, TAMUG) was used to calculate bottom-depth gradient. Transect chlorophyll values were calculated by the same method as sea surface temperature and salinity using SAIL system data. Predicted mean biomass (PMB) was estimated by matching the midpoint of each transect to the closest position with predicted mean biomass integrated over a depth interval of 10-50 m (see Chapter 3).

A high degree of correlation occurred among the environmental variables. To decrease the amount of correlation between the predictor variables and to test competing hypotheses, four models were developed:

(1) Bathymetry, using bottom depth and slope of bottom depth as predictor variables of species presence or absence in transects;

(2) Surface physical properties, using sea surface salinity and temperature as predictor variables;

(3) Sea surface height, using sea-surface height and magnitude of geostrophic flow velocity as predictor variables; and

(4) Standing plankton stock, using PMB and surface chlorophyll as predictor variables

Generalized additive models, a nonparametric smoothing technique used in fishery science (Swartzman et al. 1995, Welch et al. 1995), were used. This technique analyzes nonmonotonic nonlinear relationships that are difficult to model with standard regression techniques. Analyses were done in S+4.5 (Statistical Sciences 1998). The "fit" of the different models, based on the proportion of variance explained, was compared. To illustrate model results (and infer what environments may be preferred), predictions for the best-fitting model were graphically presented.

8.2.4 Bias

Observation methods, bird behavior in response to the ship, and bird movement can result in biased estimates of both species composition and species numbers in a survey. The two different survey methods employed during the spring and summer cruises produced results that should not be used in direct comparison with each other. During the spring cruise, observers recorded seabirds opportunistically with marine mammal sightings using both handheld and 25x binoculars. As a result, sightings may have been biased toward more visible flocks of birds (Tasker et al. 1984).

Researchers have examined some of the sources of bias for transect survey methods of the type used during the summer cruises. Broni et al. (1985) found that the side of the ship chosen for observations did not affect survey results. The range finder we used to estimate distance was assessed by Briggs et al. (1985) to be accurate within 10%. The skill, experience and fatigue of an observer can affect survey results (Van der Meer and Camphuysen 1996). Therefore, two observers worked together during all survey effort. To minimize fatigue, a half-hour break was taken after surveying for one hour.

Since seabirds may have been attracted to the ship, precautions were taken to prevent double-counting the same bird. During the summer cruises, seabirds circling the ship were counted once. Additionally, observation effort made while the ship was turning or when ship speed was less than 4 knots was excluded from analysis to minimize the chance of seabirds being counted multiple times.

Seabird behavior can affect survey results. Seabirds in-flight may have a higher inclusion probability in a transect than stationary birds. Spear and Ainley (1997) found that seabird flight speed and direction varied with wind speed and direction. If a seabird is flying faster due to favorable wind conditions, it is more likely to be seen than a bird sitting on the water's surface. This bias varies by species, and information on flight speeds is needed to adjust the counts. These speeds are not available for all species in the Gulf of Mexico. Therefore, this chapter investigates only the presence and absence of species in transects rather than using seabird density.

8.3 Results

Latin names are listed in Table 8.1 for all species sighted on the three cruises. Common and Latin names were taken from American Ornithologists' Union (1998).

8.3.1 Overall Abundance

During the spring cruise, 5,918 seabirds were recorded during 334.8 effort-hours covering 6,401 km. Twenty-two seabird species were represented by eight groups (Table 8.2). Terns were the most abundant seabirds seen during the cruise; almost 70% of the total seabirds were terns. The next most abundant group of seabirds was storm-petrels (16.7% of the total seabirds), followed by gulls (7.4% of total birds). Shearwaters (3.0%) and jaegers (2.1%) were seen in lesser numbers. Sulids (gannets and boobies), frigatebirds, phalaropes, and tropicbirds combined amounted to just over 1% of the total seabirds.

Over one-third of the terns counted were not identified to the species level (Table 8.2). Unidentified terns comprised 28.1% of the total birds counted, and 40% of the total number of terns. The most abundant tern species was the sooty tern, accounting for one-fifth of the terns seen. Bridled/sooty terns, black terns and sandwich terns each comprised approximately one-

Table 8.1. Common and Latin names of seabirds seen during the spring, mid-summer and late summer cruises.

- Order Procellariiformes
    - Family Procellariidae
        - Audubon's shearwater (*Puffinus lherminieri*)
        - Cory's shearwater (*Calonectris diomedea*)
        - Greater shearwater (*Puffinus gravis*)
        - Manx shearwater (*Puffinus puffinus*)
        - Sooty shearwater (*Puffinus griseus*)
    - Family Hydrobatidae
        - Band-rumped storm-petrel (*Oceanodroma castro*)
        - Leach's storm-petrel (*Oceanodroma leucorhoa*)
        - Wilson's storm-petrel (*Oceanites oceanicus*)
- Order Pelecaniformes
    - Family Phaethontidae
        - Red-billed tropicbird (*Phaethon aethereus*)
        - White-tailed tropicbird (*Phaethon lepturus*)
    - Family Sulidae
        - Masked booby (*Sula dactylatra*)
        - Northern gannet (*Morus bassanus*)
    - Family Fregatidae
        - Magnificent frigatebird (*Fregata magnificens*)
- Order Charadriiformes
    - Family Laridae
        - Subfamily Stercorariinae
            - Long-tailed jaeger (*Stercorarius longicaudus*)
            - Parasitic jaeger (*Stercorarius parasiticus*)
            - Pomarine jaeger (*Stercorarius pomarinus*)
        - Subfamily Larinae
            - Herring gull (*Larus argentatus*)
            - Laughing gull (*Larus atricilla*)
        - Subfamily Sterninae
            - Arctic tern (*Sterna paradisaea*)
            - Black tern (*Chlidonias niger*)
            - Bridled tern (*Sterna anaethetus*)
            - Brown noddy (*Anous stolidus*)
            - Common tern (*Sterna hirundo*)
            - Least tern (*Sterna antillarum*)
            - Royal tern (*Sterna maxima*)
            - Sandwich tern (*Sterna sandvicensis*)
            - Sooty tern (*Sterna fuscata*)

Table 8.2. Number and percent of seabird species seen during the spring cruise.

	Number	Percent of total
Shearwaters		
Audubon's shearwater	164	2.8
Cory's shearwater	1	0.0 *
Unidentified shearwater	15	0.2
Total shearwaters	180	3.0
Storm-petrels		
Band-rumped storm-petrel	52	0.9
Wilson's storm-petrel	17	0.3
Leach's storm-petrel	2	0.0 *
Unidentified storm-petrel	916	15.5
Total storm-petrels	987	16.7
Tropicbirds		
White-tailed tropicbird	1	0.0 *
Unidentified tropicbird	2	0.0 *
Total tropicbirds	3	0.0 *
Sulids		
Northern gannet	37	0.6
Masked booby	2	0.0 *
Total sulids	39	0.7
Frigatebirds		
Magnificent frigatebird	7	0.1
Jaegers		
Pomarine jaeger	85	1.4
Parasitic jaeger	9	0.2
Long-tailed jaeger	1	0.0 *
Unidentified jaeger	27	0.5
Total jaegers	122	2.1
Gulls		
Laughing gull	428	7.3
Herring gull	1	0.0 *
Unidentified gull	8	0.1
Total gulls	437	7.4
Terns		
Sooty tern	834	14.1
Bridled/Sooty tern	533	9.0

(continued)

Table 8.2. Continued.

	Number	Percent of total
Sandwich tern	519	8.8
Black tern	494	8.3
Bridled tern	63	1.1
Royal tern	10	0.2
Common tern	7	0.1
Least tern	2	0.0 *
Brown noddy	1	0.0 *
Unidentified tern	1,664	28.1
Total terns	4,127	69.7
Phalaropes	16	0.3
Unidentified phalarope	16	0.3

* less than 0.1% of total seabirds seen.

Table 8.3. Percentages of taxonomic seabird groups for the spring cruises.

	1992	1993	1994	1996
Terns	66.2	72.9	64.0	69.9
Storm-petrels	17.1	12.7	22.8	16.7
Gulls	3.3	4.0	7.8	7.4
Shearwaters	0.8	2.7	2.4	3.0
Jaegers	9.2	6.2	1.8	2.1
Sulids	3.0	1.1	0.3	0.7
Frigatebirds	0.4	0.3	0.8	0.1
Tropicbirds	0.0	0.1	0.1	0.1

eighth of terns seen. Bridled terns, royal terns, common terns, least terns and brown noddies were also identified.

Over 90% of the storm-petrels seen were not identified to the species level. Of the storm-petrel species identified, band-rumped storm-petrels were the most abundant. Wilson's storm-petrel and Leach's storm-petrel were also seen during the cruise but accounted for less than 20 birds during the entire cruise. Most of the gulls seen were identified to species, with the majority of gulls being laughing gulls. One herring gull was seen, and eight gulls were not identified at the species level. Shearwaters were most frequently recorded as Audubon's shearwater. One Cory's shearwater was spotted, and 15 shearwaters were not identified to species level. About three-fourths of jaegers seen were pomarine jaegers. Nine parasitic jaegers and one long-tailed jaeger were also identified with the remaining jaegers not identified to species level. Sulids were comprised primarily of northern gannets, and two masked boobies were counted. The seven frigatebirds counted were magnificent frigatebirds. Three tropicbirds were counted, one of which was identified to the species level as a white-tailed tropicbird. Sixteen phalaropes were seen. Together, unidentified terns and storm-petrels represented almost one-half of all seabirds seen. The most abundant seabirds overall on a species level were sooty terns (14.1%), sandwich terns (8.8%), black terns (8.3%) and laughing gulls (7.3%).

The percentages of total seabirds in each group from the 1996 spring cruise were similar to percentages found in previous spring surveys conducted with the same survey methods (Davis and Fargion 1996) (Table 8.3). In each of the surveys, terns accounted for between 64.0% and 72.9% of total birds. Storm-petrels were the next most abundant genera in each of the four surveys, accounting for 12.7-22.8% of the total number of birds. Gulls ranged from 3.3-7.8% of the total. Shearwaters ranged from being the fourth most abundant group in 1996 (3.0% of the total birds), to being the sixth most abundant group (0.8%) in 1992. Percentages of jaegers fluctuated. During 1992 and 1993, 9.2% and 6.2% of total birds, respectively, were jaegers. However in 1994 and 1996, there were comparatively fewer jaegers; 1.8% and 2.1% of the total number of birds, respectively.

Sulids also decreased in relative abundance over the four-year period. Three percent of total birds in 1992 were gannets or boobies. In 1994 and 1996, less than one percent of seabirds were sulids. In any year, frigatebirds never comprised more than one percent of the total number of birds. Tropicbirds were rare in all four survey years. Only a few hundredths of a percent of total birds were tropicbirds.

During the late summer cruise, 279 seabirds were counted representing 14 species and eight family/subfamily groups (Table 8.4). Terns were the most common group, accounting for 46.1% of total birds. Gulls were the next most abundant group, totaling almost one-quarter of birds seen. Jaegers were the third most commonly seen birds (13.7% of total birds). Shearwaters accounted for 8.6% of total birds seen. Together, terns, gulls, jaegers and shearwaters comprised over 90% of the total. Frigatebirds (4.3%), tropicbirds (1.4%), sulids (1.4%), storm-petrels (1.1%) and phalaropes (<0.1%) were also seen. Many terns were not identified to species (55 out of 128 terns).

Table 8.4. Seabird numbers tallied by water depth seen while on-effort during the mid-summer and late summer cruises.

	Late summer			Mid-summer		
	Shallow[1]	Deep[2]	Total	Shallow[3]	Deep[4]	Total
Shearwaters						
Audubon's shearwater	2	9	11	0	154	154
Cory's shearwater	1	6	7	2	8	10
Greater shearwater	0	0	0	2	1	3
Manx shearwater	0	0	0	0	5	5
Sooty shearwater	0	0	0	0	1	1
Unidentified shearwater	2	4	6	1	20	21
Total shearwaters	5	19	24	5	189	194
Storm-petrels						
Band-rumped storm-petrel	0	2	2	1	249	250
Leach's storm-petrel	0	0	0	1	0	1
Wilson's storm-petrel	0	0	0	0	10	10
Unidentified storm-petrel	0	1	1	2	60	62
Total storm-petrels	0	3	3	4	319	323
Tropicbirds						
Red-billed tropicbird	0	2	2	0	2	2
Unidentified tropicbird	0	2	2	0	0	0
Total tropicbirds	0	4	4	0	2	2
Sulids						
Masked booby	0	4	4	0	4	4
Frigatebirds						
Magnificent frigatebird	6	6	12	4	0	4
Unidentified frigatebird	0	0	0	170	4	174
Total frigatebirds	6	6	12	174	4	178
Jaegers						
Long-tailed jaeger	0	0	0	1	1	2
Parasitic jaeger	0	0	0	0	1	1
Pomarine jaeger	1	24	25	1	13	14
Unidentified jaeger	2	11	13	0	1	1
Total jaegers	3	35	38	2	16	18
Gulls						
Laughing gull	44	11	55	21	17	38
Herring gull	5	2	7	0	0	0
Unidentified gull	3	0	3	0	2	2

(continued)

Table 8.4. Continued.

	Late summer			Mid-summer		
	Shallow[1]	Deep[2]	Total	Shallow[3]	Deep[4]	Total
Total gulls	52	13	65	21	19	40
Terns						
Arctic tern	0	0	0	0	2	2
Arctic/Common tern	0	2	2	2	1	3
Black tern	8	1	9	852	267	1,119
Bridled tern	1	5	6	0	70	70
Bridled/Sooty tern	0	5	5	6	67	73
Common tern	7	1	8	1	3	4
Least tern	0	0	0	0	1	1
Royal tern	17	19	36	14	5	19
Sandwich tern	0	0	0	21	3	24
Sooty tern	0	7	7	0	111	111
Unidentified tern	43	12	55	77	26	103
Total terns	76	52	128	973	556	1,529
Phalaropes	0	1	1	0	22	22
Unidentified phalarope	0	1	1	0	22	22

[1] Shallow water (<200 m depth) along the continental shelf. During the late summer cruise about 16.3% of effort occurred in shallow water.

[2] Deep water (>200 m depth) contained regions along the continental slope and deep water. About 83.7% of effort occurred in deep water.

[3] Shallow water (<200 m depth) along the continental shelf. During the mid-summer cruise about 13.5% of effort occurred in shallow water.

[4] Deep water (>200 m depth) contained regions along the continental slope and deep water. About 86.5% of effort occurred in deep water.

Over one-quarter of the total terns seen during the late summer cruise were royal terns (36 birds). Black terns (nine birds) and common terns (eight birds) were the next most abundant terns. Sooty terns, bridled terns, bridled/sooty terns and common/arctic terns accounted for the remaining 20 terns counted. The majority of gulls seen were laughing gulls (84.6%). Seven herring gulls were seen, and three gulls were not identified to species level. Out of the 38 jaegers seen, 25 were identified as pomarine jaegers; the rest were not identified. Audubon's shearwaters comprised almost half of the shearwaters seen (11 out of 24 birds). Seven Cory's shearwaters were spotted, and the remaining six shearwaters were not identified to the species level. All 12 frigatebirds were magnificent frigatebirds. Four tropicbirds were seen; two were red-billed tropicbirds and the other two were not identified to species. All four sulids seen were masked boobies. Three storm-petrels were seen, two of which were identified as band-rumped storm-petrels. One was not identified to the species level. Laughing gulls and unidentified terns each comprised about one-fifth of all seabirds seen during the late summer cruise. Royal terns were the next most abundant, accounting for 12.9% of the total number of birds. Pomarine jaegers and unidentified jaegers combined added up to 13.7% of the total birds. Magnificent frigatebirds and Audubon's shearwaters were the next most abundant species. Those seven groups totaled three-quarters of the seabirds seen.

The late summer cruise species' numbers tallied by water depth show species affinities for either shallow or deep water (Table 8.4). Shearwaters were more frequently encountered in deeper water regardless of species: only five out of the 24 shearwaters were seen on the continental shelf. Storm-petrels, tropicbirds and boobies were seen exclusively in water greater than 200 m deep. Half of the frigatebirds seen were detected on the shelf, and the other half in deeper water. The majority of jaegers (35 out of 38) were seen farther offshore. Both species of gulls were seen in greater numbers on the continental shelf. Terns were found both in shallow and deeper water depending on species. Black terns, common terns and terns not identified to species were found predominantly on the continental shelf. Royal terns were almost evenly split between the continental shelf and deeper water. Bridled terns and sooty terns were only seen in deeper water.

Shearwaters, frigatebirds, tropicbirds, jaegers and terns were detected in late summer (October) at rates between the August-September and November rates found during the GulfCet I cruises (Table 8.5). Storm-petrels were seen at rates less than August-September and November rates. Sulids were also seen at a rate less than the late summer and autumn rates from previous work. Gulls were seen at rates higher than the previously reported late summer and autumn values. During the mid-summer (August) cruise, over 2,100 seabirds were counted, representing 23 species from eight family/subfamily groups (Table 8.4). Two-thirds of the seabirds seen were terns, totaling 65.3% of total seabirds counted. Storm-petrels were the next most abundant group, accounting for 14.8% of total birds. Shearwaters comprised 8.9% of the seabirds counted, and frigatebirds accounted for 8.1% of total seabirds. Gulls (1.8%), jaegers (<1%), sulids (<1%) and tropicbirds (<1%) were also seen.

The majority of terns were black terns (73.2%), which accounted for half of all seabirds seen during the mid-summer cruise (Table 8.4). Sooty terns were the second most abundant tern species (7.3%). Bridled terns (4.6%) and either bridled or sooty terns (4.8%) were the next most represented terns. Twenty-four sandwich terns and 19 royal terns were seen. Two arctic terns,

Table 8.5. Cross-seasonal comparison of taxonomic group sightings per effort hour.

	February[1]	May-June[1]	August[2]	Aug-Sept[1]	October[2]	November[1]
Shearwaters	0.01	0.06	1.13	1.30	0.17	0.12
Storm-petrels	0.01	0.24	1.84	0.06	0.02	0.03
Frigatebirds	0.00	0.00	1.06	0.20	0.08	0.00
Sulids	0.60	0.02	0.03	0.13	0.03	0.12
Tropicbirds	0.00	0.00	0.01	0.03	0.03	0.00
Jaegers	1.05	0.08	0.11	0.00	0.26	1.08
Gulls	2.23	0.00	0.38	0.04	0.45	0.05
Terns	0.05	0.21	9.50	24.65	0.89	0.04
	3.95	0.61	14.06	26.41	1.93	1.44

[1] Davis and Fargion (1996)

[2] This study

four common terns, three common or arctic terns and one least tern were also encountered. One hundred and three terns were not identified to species.

The majority of storm-petrels seen were band-rumped storm-petrels (77.4%). Ten Wilson's storm-petrels and one Leach's storm-petrel were counted. Sixty-two storm-petrels were not identified to species. Five different species of shearwaters were encountered during the August cruise. The majority of shearwaters were Audubon's shearwater (79.4%). Ten Cory's shearwaters, five Manx shearwaters, three greater shearwaters and one sooty shearwater were seen. Twenty-one shearwaters were not identified to species. One hundred and seventy-eight frigatebirds were counted. No other frigatebird is known to be present in the Gulf (Harrison 1996).

All of the gulls identified to species in mid-summer were laughing gulls (95.0%); two gulls were unidentified. Three-fourths of the jaegers seen were pomarine jaegers (77.8%). Two long-tailed jaegers, one parasitic jaeger and one unidentified jaeger were counted. All four boobies seen were masked boobies. The two red-billed tropicbirds were seen.

A pattern of segregation by species in the two different depth categories was apparent for the mid-summer cruise (Table 8.4). Shearwaters were more frequently seen in deeper water (97.4%). However, the trend was not the same for all shearwaters; Audubon's, Manx and sooty shearwaters were seen exclusively in deep water. Two of the ten Cory's shearwaters and two of the three greater shearwaters were seen in shallow water. Although the one Leach's storm-petrel was seen in shallow water, the majority (98.8%) of storm-petrels were seen in deeper water. Tropicbirds and boobies were exclusively located in deeper water. Frigatebirds were predominantly located in shallow water; only four out of 178 frigatebirds were seen where water depths were greater than 200 m. Jaegers were primarily seen in deeper water. However one pomarine and one long-tailed jaeger were encountered in shallow water. Gulls, most of which were laughing gulls, were evenly split between shallow and deep water. Terns were seen in both shallow and deep water depending on species. Arctic terns, least terns and sooty terns were only seen in deeper water. Common, bridled and bridled/sooty terns were predominantly seen in deeper water. The majority of black terns, royal terns, sandwich terns and terns not identified to species were seen in shallow water.

A comparison of mid-summer sightings per hour with previous findings (Davis and Fargion 1996) indicates some seasonal patterns (Table 8.5). Shearwaters, storm-petrels and frigatebirds peaked in sighting rates in the mid-summer cruises (Figure 8.1a). Sulids, jaegers and gulls were seen more frequently during winter cruises (Figure 8.1b). Terns peaked in abundance during the mid-summer cruises; note that they were seen at a rate ten times higher than other taxonomic groups. Some differences in sighting frequencies are evident in two cruises that occurred at similar times of the year (summer). Storm-petrels, frigatebirds, jaegers and gulls were seen more frequently in August 1997 compared to August-September 1993. Either interannual variability or habitat differences could be responsible.

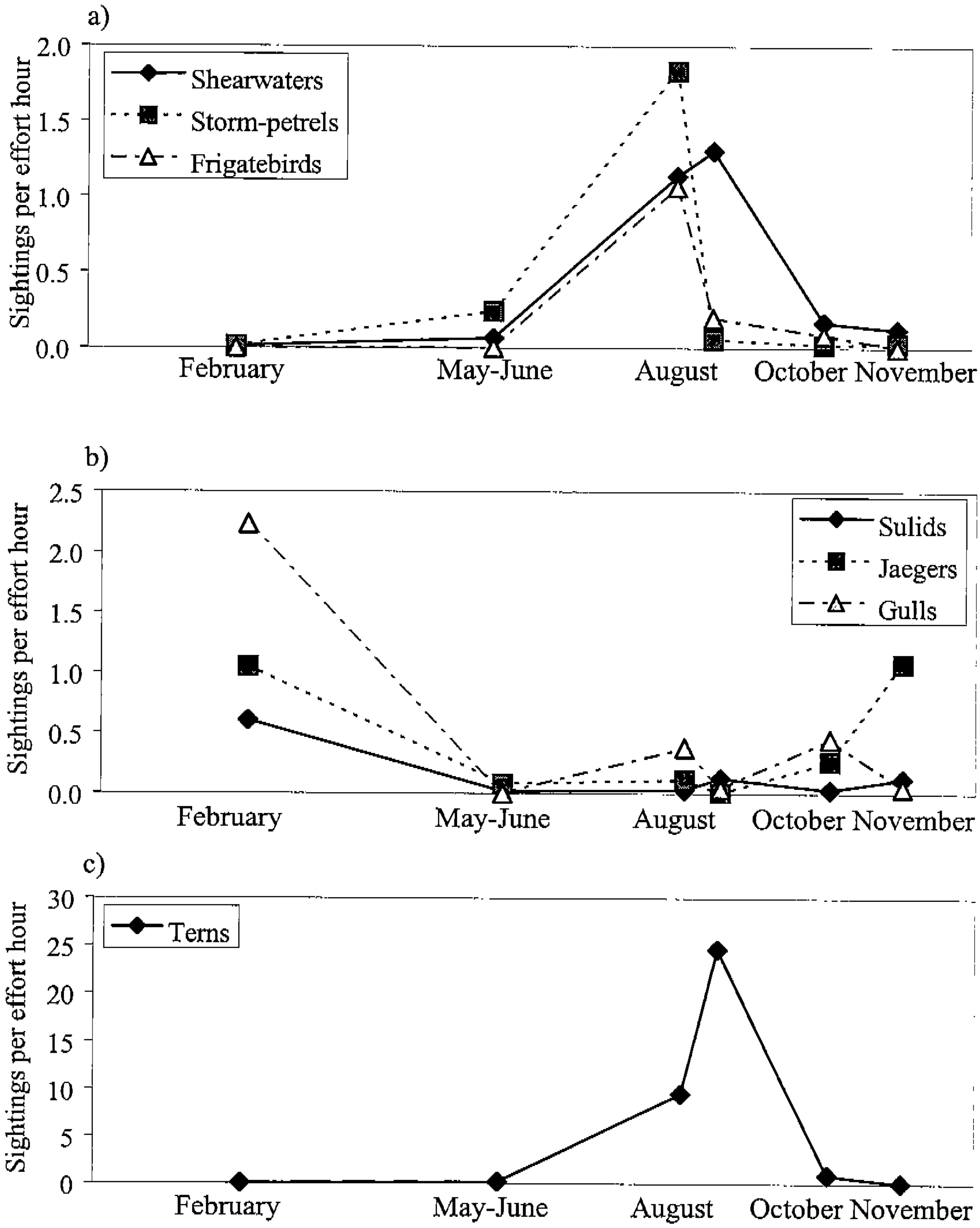

Figure 8.1. Cross-seasonal comparison of sightings per effort hour for (a) shearwaters, storm-petrels and frigatebirds, (b) sulids, jaegers and gulls, and (c) terns.

8.3.2 Species and Diversity by Hydrographic Environment

Of the birds seen within the 300 m strip transect during the late summer cruise, some species were seen in many of the six hydrographic environments, while some species were seen only in one or two hydrographic environments (Table 8.6). Laughing gulls were present in every region except for the confluence. Laughing gulls, however, were present in greatest numbers on the continental shelf. Pomarine jaegers were seen in every environment except for the continental shelf. Audubon's shearwaters were not seen in either the anticyclone or "other margin." Royal terns were seen in the MOM and "other margin." Cory's shearwater and masked boobies were seen only in the cyclone and in "other margin." Herring gulls and magnificent frigatebirds were seen in "other margin" and continental shelf; however, a herring gull was also present in the cyclone. Band-rumped storm-petrel, sooty tern, and red-billed tropicbird were seen inside the cyclone. A common tern was seen in "other margin."

Species richness or the number of seabird species seen in the 300 m continuous strip transects during the late summer cruise varied with hydrographic environment (Table 8.7). The most species (9) were seen in the cyclone. "Other margin" (regions with bottom depth greater than 200 m not directly associated with the eddy system) contained eight species, the next highest number in any hydrographic environment. The MOM area and continental shelf contained four species. The confluence and anticyclone contained two species, but these environments were covered with less effort than others.

During the late summer cruise the cyclone had a greater diversity of species compared to the "other margin" (Table 8.7). In the "other margin" regions, the majority of sightings were royal terns, which decreased species diversity. The continental shelf sightings were mainly laughing gulls, which was reflected in the lower Shannon Index and higher Simpson Index. The low Simpson Index values of the cyclone and the "other margin" regions indicate neither environment was dominated by one species.

During the mid-summer cruise, the distribution of species seen within the 300 m strip transect across the hydrographic environments was not uniform (Table 8.8). Frigatebirds were only seen on the continental shelf, as was the long-tailed jaeger. Royal terns, sandwich terns and black terns were seen predominantly on the continental shelf. The two masked boobies seen in the cyclone. Four of the five Manx shearwaters were also seen in the cyclone. Band-rumped storm-petrels were seen in all of the hydrographic environments except for the MOM area. A large number of band-rumped storm-petrels were seen in the "other margin" region in addition to the confluence and cyclone. Laughing gulls were found mainly on the continental shelf, but were present in every region but the MOM. Black terns, while predominantly found on the continental shelf, were also found in the confluence, MOM, cyclone and anticyclone. Audubon's shearwaters were found in the confluence, cyclone, anticyclone and "other margin." Bridled terns were seen predominantly in the cyclone, confluence and anticyclone. Sooty terns were also seen in the cyclone, confluence and anticyclone, but were seen in larger numbers in "other margin" regions.

The "other margin" and cyclone contained the greatest number of species during mid-summer (Table 8.7). Fewer species were found on the continental shelf, confluence and anticyclone.

Table 8.6. Species tallied by hydrographic environment within 300 m strip transect for the late summer cruise.

Hydrographic environment	MOM	Other Margin	Continental Shelf	Cyclone	Confluence	Anticyclone
Kilometers of effort	164	359	204	320	109	103
Audubon's shearwater	3	0	2	1	2	0
Band-rumped storm-petrel	0	0	0	2	0	0
Common tern	0	1	0	0	0	0
Cory's shearwater	0	1	0	1	0	0
Herring gull	0	1	3	1	0	0
Laughing gull	2	6	11	4	0	1
Magnificent frigatebird	0	3	1	0	0	0
Masked booby	0	1	0	1	0	0
Pomarine jaeger	6	2	0	2	4	2
Red-billed tropicbird	0	0	0	1	0	0
Royal tern	7	13	0	0	0	0
Sooty tern	0	0	0	1	0	0

Table 8.7. Species numbers and diversity for each hydrographic environment for sightings within the 300 m strip transect. Kilometers of effort refers to the length of effort in each region. Diversity indices were calculated only for regions with greater than 200 km effort.

Hydrographic environment	MOM	Other Margin	Continental Shelf	Cyclone	Confluence	Anticyclone
Late summer cruise						
Kilometers of effort	164	359	204	320	109	103
Number of species seen	4	8	4	9	2	2
Total seabirds seen	18	28	17	14	6	3
Scaled Shannon Index		0.77	0.73	0.93		
Simpson Index		0.28	0.47	0.15		
Mid-summer cruise						
Kilometers of effort	92	365	220	350	285	280
Number of species seen	5	12	9	12	8	7
Total seabirds seen	33	126	391	74	109	36
Scaled Shannon Index		0.56	0.25	0.83	0.73	0.77
Simpson Index		0.40	0.79	0.17	0.29	0.32

Table 8.8. Species tallied by hydrographic environment within 300 m strip transect for the mid-summer cruise.

Hydrographic environment	MOM	Other Margin	Continental Shelf	Cyclone	Confluence	Anticyclone
Kilometers of effort	92	365	220	350	285	280
Arctic tern	0	0	0	0	1	0
Audubon's shearwater	0	8	0	24	28	4
Band-rumped storm-petrel	0	77	1	11	12	6
Black tern	26	15	346	6	49	1
Bridled tern	0	1	0	12	6	19
Common tern	2	1	0	0	0	0
Cory's shearwater	0	1	1	0	0	0
Greater shearwater	0	0	2	1	0	0
Laughing gull	0	5	12	4	4	2
Long-tailed jaeger	0	0	1	0	0	0
Magnificent frigatebird	0	0	3	0	0	0
Manx shearwater	0	0	0	4	1	0
Masked booby	0	0	0	2	0	0
Pomarine jaeger	0	0	0	4	0	1
Red-billed tropicbird	0	1	0	0	0	0
Royal tern	2	1	11	1	0	0
Sandwich tern	2	1	14	0	0	0
Sooty tern	0	13	0	4	8	3
Wilson's storm-petrel	1	2	0	1	0	0

Only five species were encountered in the MOM region. However, MOM covered the least survey area. Diversity was the greatest in the cyclone followed by the anticyclone and confluence. The continental shelf had the lowest species diversity resulting from the large numbers of black terns. The Simpson Index was close to one for the continental shelf, indicating the predominance of black terns in that region.

8.3.3 Species' Affinities to Hydrographic Region

During the late summer cruise, laughing gulls (Figure 8.2) and pomarine jaegers (Figure 8.3) were the only species seen in at least 10% of the transects. Laughing gulls were seen most frequently in the "other margin" (four out of 24 transects), in two transects in the cyclone, and in one of the MOM transects (Table 8.9). There was no detectable difference in presence and absence of laughing gulls across the different hydrographic environments (G = 3.9, df = 4, p = 0.425). Pomarine jaegers were seen in transects across all hydrographic environments except for the anticyclone. However, they were encountered more frequently than expected in transects in the MOM area and confluence (G = 10.2, df = 4, p = 0.037).

Audubon's shearwaters (Figure 8.4) were seen in half of the transects in the cyclone during the mid-summer cruise and less frequently in the confluence, anticyclone and other margin (Table 8.9). The presence of Audubon's shearwaters was not independent of the features (G = 11.1, df = 4, p = 0.026). Residual analysis indicated more Audubon's shearwaters were encountered in the cyclone than expected, and less were in the MOM area than expected.

Band-rumped storm-petrels were also found in every deep water environment except for the MOM. Their distribution pattern was not uniform across the environments (G = 9.9, df = 4, p = 0.042). Band-rumped storm-petrels were more likely to be encountered in "other margin" regions (Figure 8.5).

Black terns (Figure 8.6) were seen in all environments, most notably near the MOM (Table 8.9). Black tern presence differed across hydrographic environments (G = 29.5, df = 4, p = 0.000). Specifically, more black terns were encountered near the MOM than expected, and less in the anticyclone and cyclone.

There was no statistically significant relationship with either bridled (Figure 8.7) or sooty terns (Figure 8.8) and the hydrographic environments (bridled tern: G = 4.7, df = 4, p = 0.324; sooty tern: G = 5.3, df = 4, p = 0.257). Both bridled and sooty terns were seen more frequently in the "other margin" and confluence (Table 8.9), areas where less saline water was entrained around the cyclone (see chapter 2). As with band-rumped storm-petrels and Audubon's shearwaters, neither bridled nor sooty terns were encountered near the MOM.

8.3.4 Seabird Habitat Preferences

During late summer, sea surface temperature and salinity explained the most variance of laughing gull presence or absence in transects off of the continental shelf (Table 8.10). The model predicted laughing gull presence in transects with sea surface temperatures ranging from 26.0°C to 26.5°C (Figure 8.9). The plankton-standing stock model also explained a similar

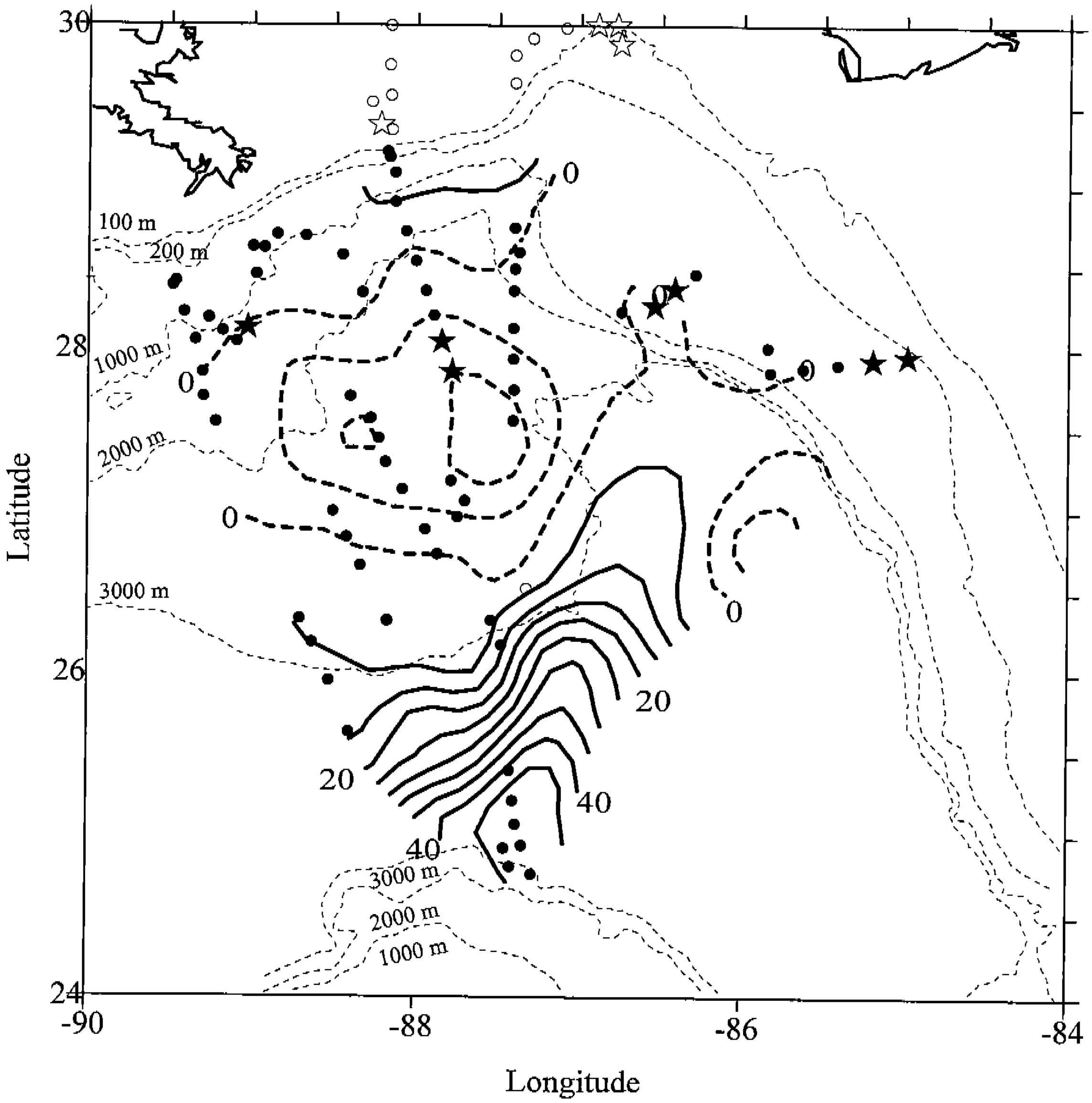

Figure 8.2. Distribution of laughing gulls (late summer cruise). Filled stars represent transects included in seabird-habitat analysis with laughing gulls present. Filled circles represent transects included in seabird-habitat analysis with laughing gulls absent. Empty stars represent transects not included in seabird-habitat analysis with laughing gulls present. Empty circles represent transects not included in seabird-habitat analysis with laughing gulls absent. Negative height (cyclone) is designated by heavy dashed lines; positive height (confluence and anticyclone) by heavy solid lines.

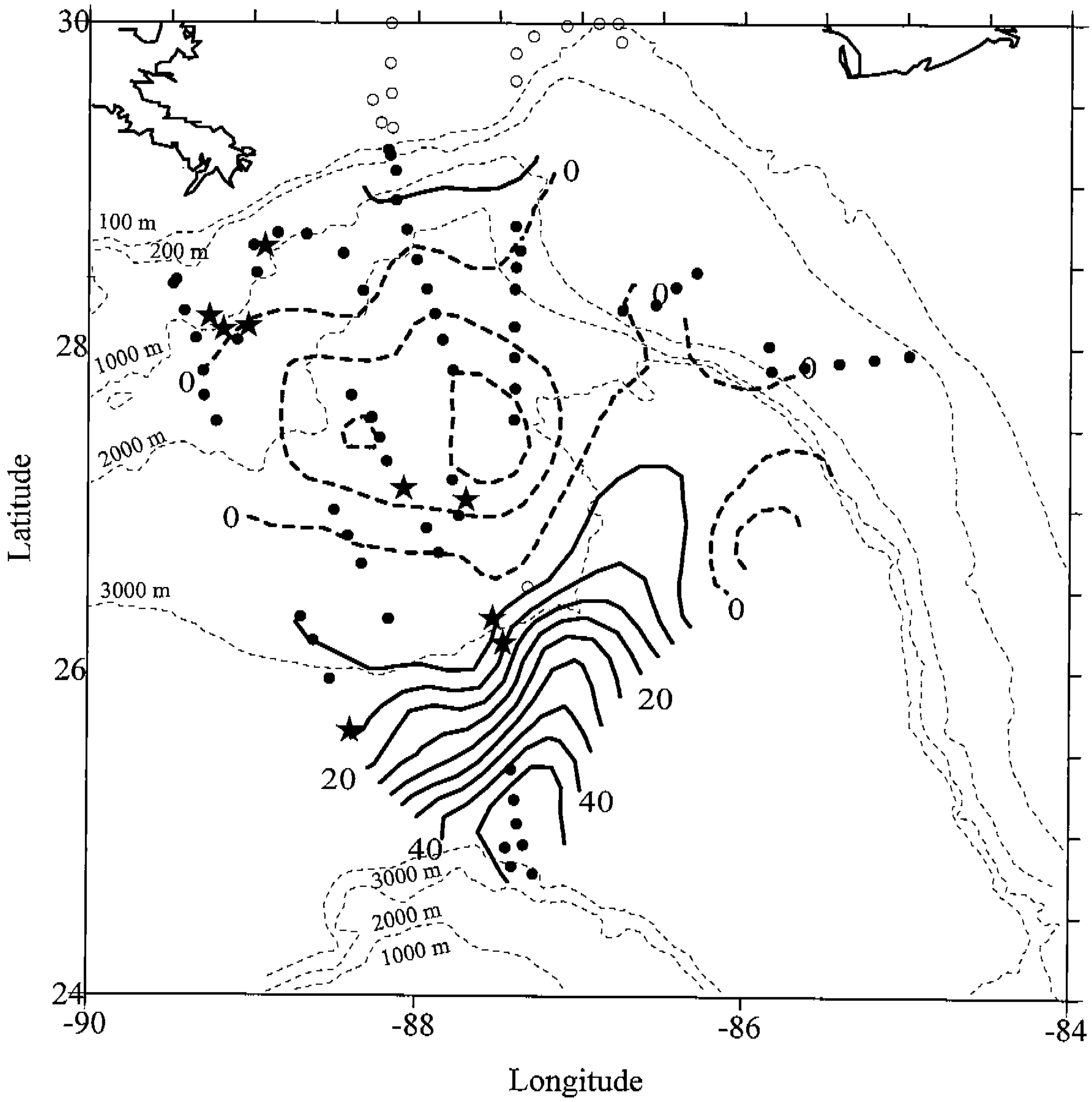

Figure 8.3. Distribution of pomarine jaegers (late summer cruise). Filled stars represent transects included in seabird-habitat analysis with pomarine jaegers present. Filled circles represent transects included in seabird-habitat analysis with pomarine jaegers absent. Empty circles represent transects not included in seabird-habitat analysis with pomarine jaegers absent. Negative height (cyclone) is designated by heavy dashed lines; positive height (confluence and anticyclone) by heavy solid lines.

Table 8.9. Number of transects containing species within hydrographic environments.

Hydrographic environment	MOM	Other Margin	Cyclone	Confluence	Anticyclone	Total
Late summer cruise total transects	11	24	25	6	7	73
Laughing gull	1	4	2	0	0	
Pomarine jaeger	4	1	2	2	0	
Mid-summer cruise total transects	7	29	26	22	19	103
Audubon's shearwater	0	7	13	10	7	
Band-rumped storm-petrel	0	13	7	6	3	
Black tern	7	11	2	5	2	
Bridled tern	0	7	3	4	2	
Sooty tern	0	9	5	5	3	

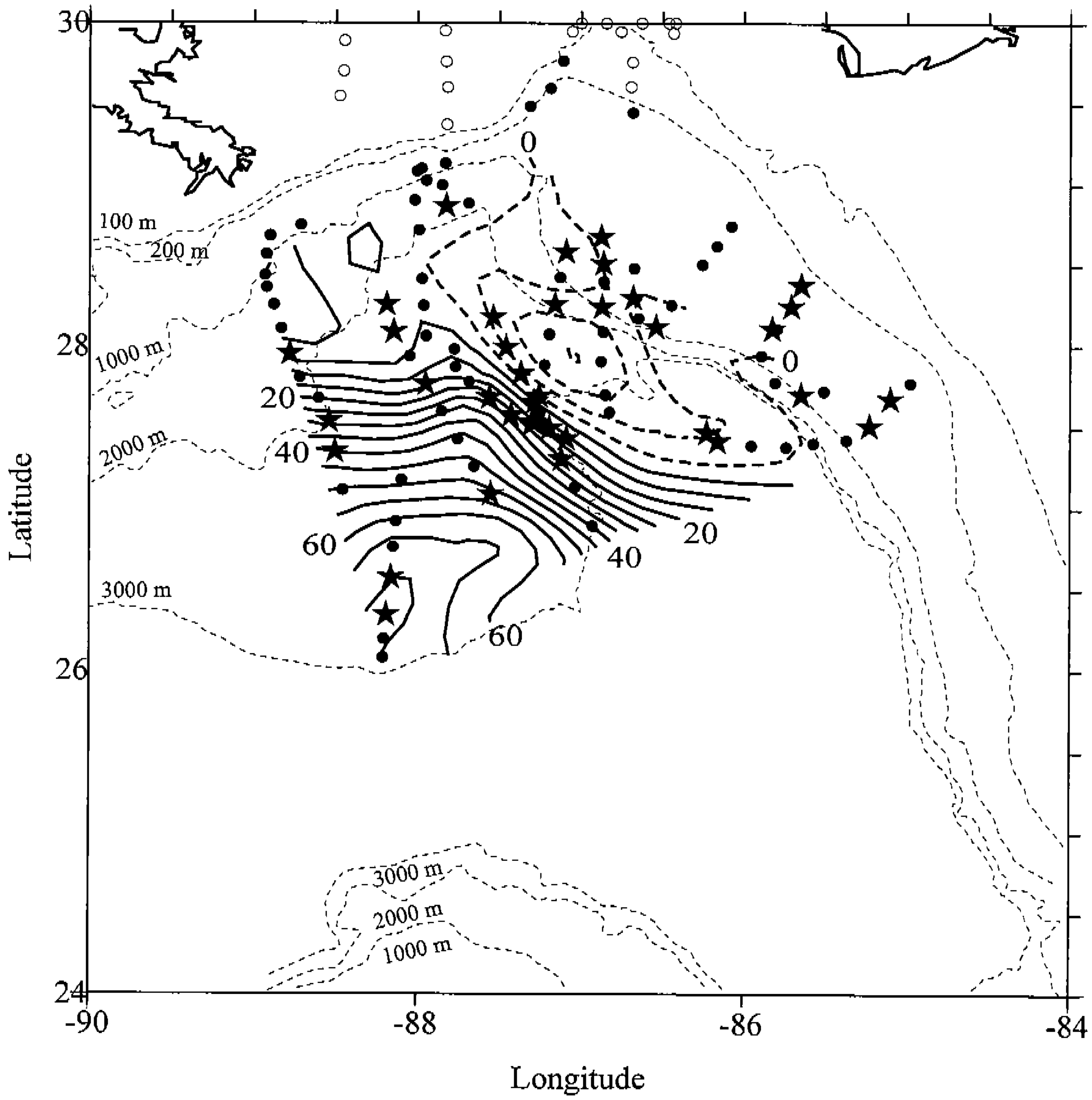

Figure 8.4. Distribution of Audubon's shearwaters (mid-summer cruise). Filled stars represent transects included in seabird-habitat analysis with Audubon's shearwaters present. Filled circles represent transects included in seabird-habitat analysis with Audubon's shearwaters absent. Empty circles represent transects not included in seabird-habitat analysis with Audubon's shearwaters absent. Negative height (cyclone) is designated by heavy dashed lines; positive height (confluence and anticyclone) by heavy solid lines.

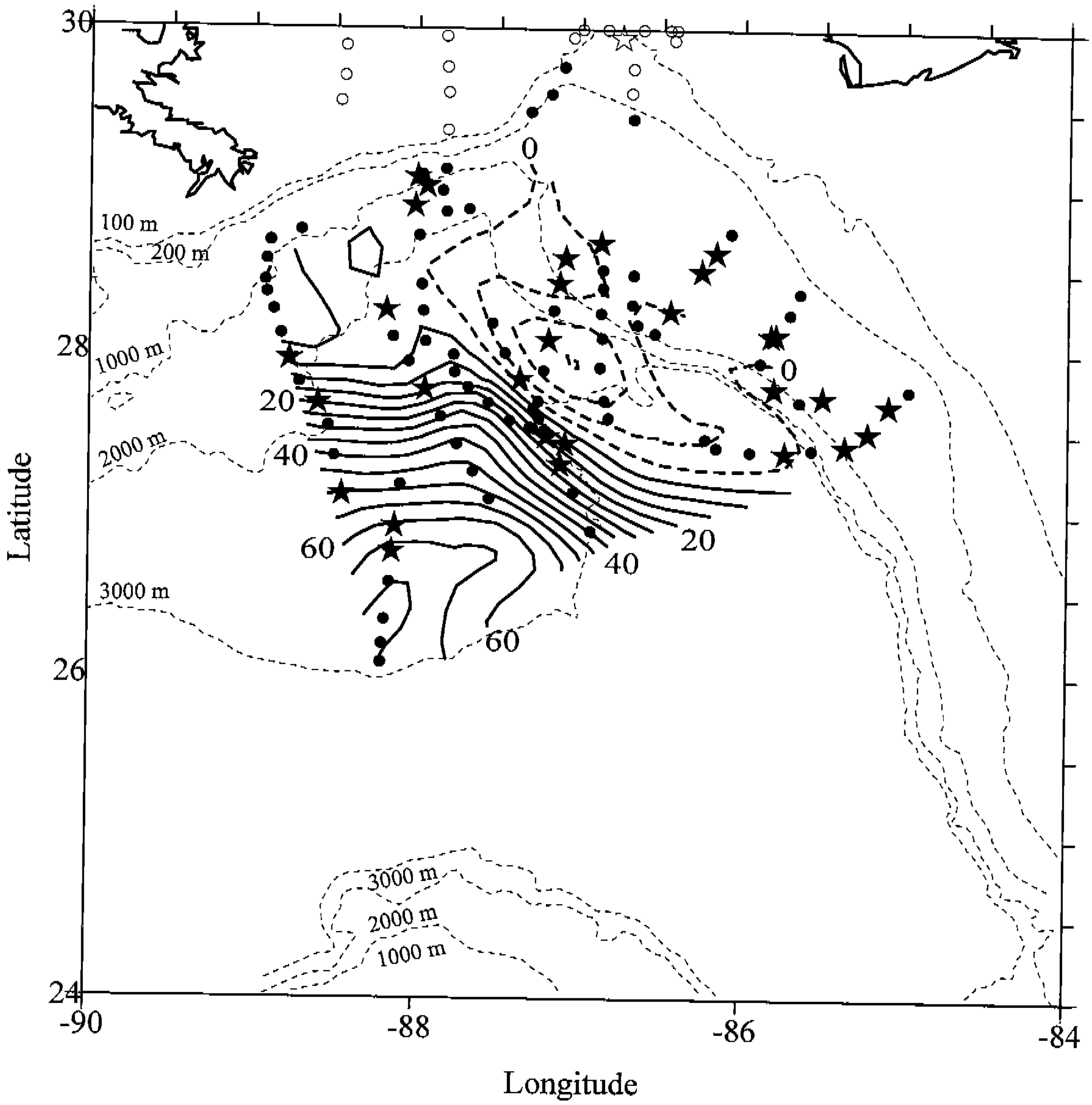

Figure 8.5. Distribution of band-rumped storm-petrels (mid-summer cruise). Filled stars represent transects included in seabird-habitat analysis with band-rumped storm-petrels present. Filled circles represent transects included in seabird-habitat analysis with band-rumped storm-petrels absent. Empty stars represent transects not included in seabird-habitat analysis with band-rumped storm-petrels present. Empty circles represent transects not included in seabird-habitat analysis with band-rumped storm-petrels absent. Negative height (cyclone) is designated by heavy dashed lines; positive height (confluence and anticyclone) by heavy solid lines.

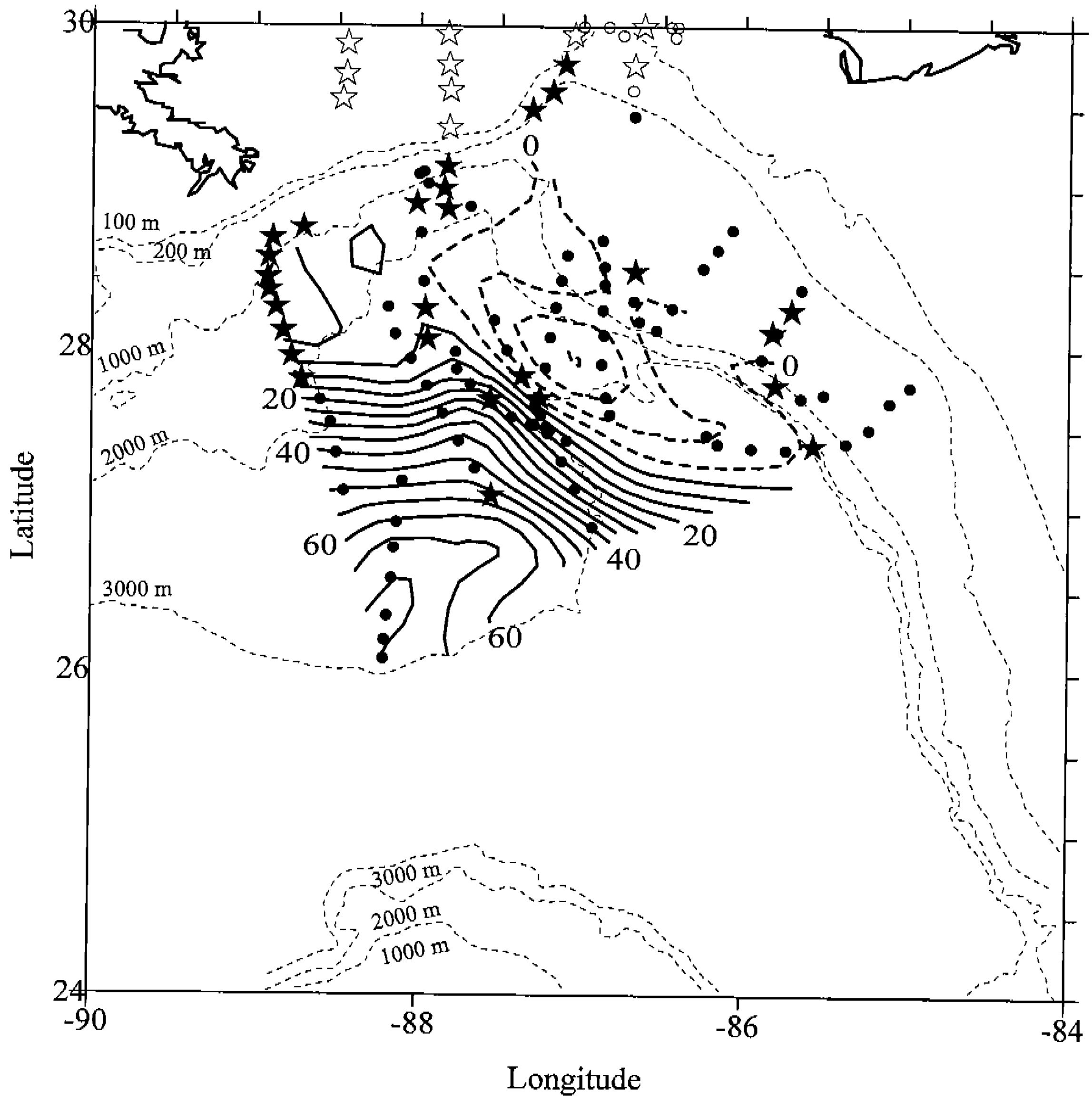

Figure 8.6. Distribution of black terns (mid-summer cruise). Filled stars represent transects included in seabird-habitat analysis with black terns present. Filled circles represent transects included in seabird-habitat analysis with black terns absent. Empty stars represent transects not included in seabird-habitat analysis with black terns present. Empty circles represent transects not included in seabird-habitat analysis with black terns absent. Negative height (cyclone) is designated by heavy dashed lines; positive height (confluence and anticyclone) by heavy solid lines.

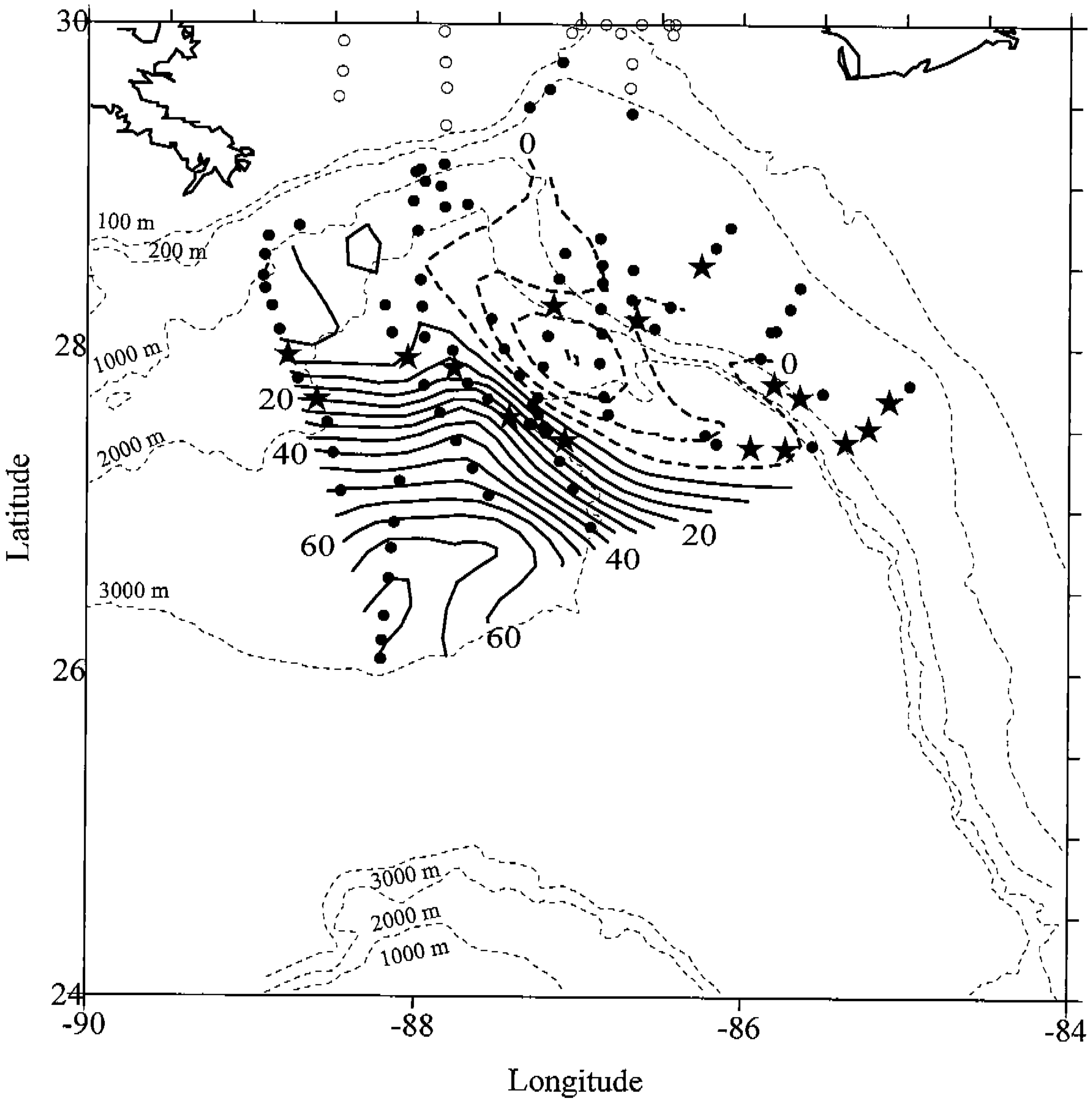

Figure 8.7. Distribution of bridled terns (mid-summer cruise). Filled stars represent transects included in seabird-habitat analysis with bridled terns present. Filled circles represent transects included in seabird-habitat analysis with bridled terns absent. Empty circles represent transects not included in seabird-habitat analysis with bridled terns absent. Negative height (cyclone) is designated by heavy dashed lines; positive height (confluence and anticyclone) by heavy solid lines.

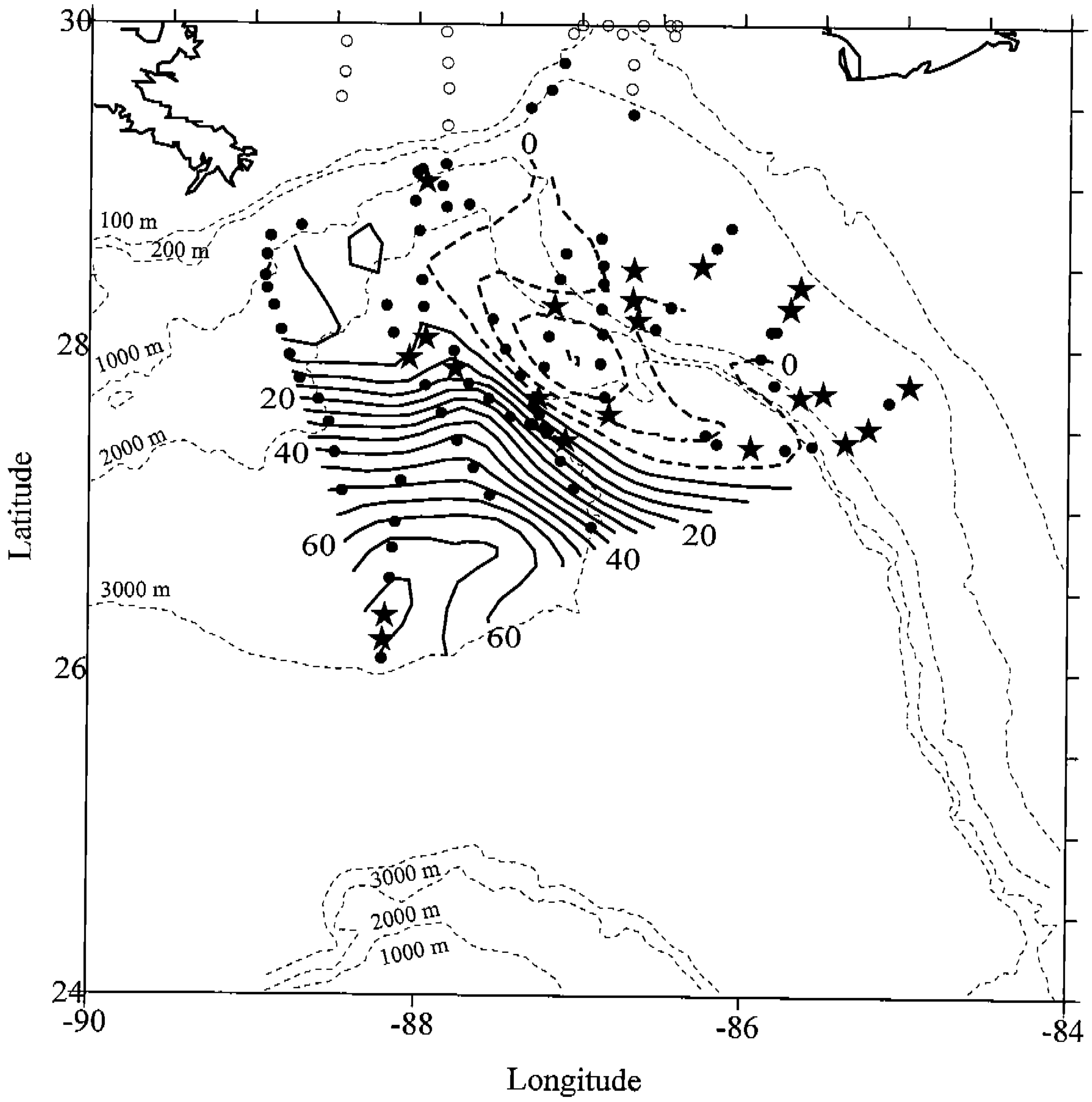

Figure 8.8. Distribution of sooty terns (mid-summer cruise). Filled stars represent transects included in seabird-habitat analysis with sooty terns present. Filled circles represent transects included in seabird-habitat analysis with sooty terns absent. Empty circles represent transects not included in seabird-habitat analysis with sooty terns absent. Negative height (cyclone) is designated by heavy dashed lines; positive height (confluence and anticyclone) by heavy solid lines.

Table 8.10. Percent of total variance in seabird presence or absence in transects explained using generalized additive models.

Model[a]	Bathymetry	Surface Properties	Sea Surface Height	Plankton Standing Stock
Late summer cruise				
Laughing gull	31.8%	45.5%	24.5%	45.3%
Pomarine jaeger	30.8%	12.1%	38.0%	34.5%
Mid-summer cruise				
Audubon's shearwater	13.0%	7.1%	7.4%	13.0%
Band-rumped storm-petrel	6.9%	7.0%	5.6%	18.3%
Black tern	13.5%	41.7%	22.3%	37.4%
Bridled tern	15.9%	10.3%	16.1%	17.1%
Sooty tern	12.2%	18.1%	10.1%	16.4%

[a] Variables used in each of the models are explained in section 8.2.3.

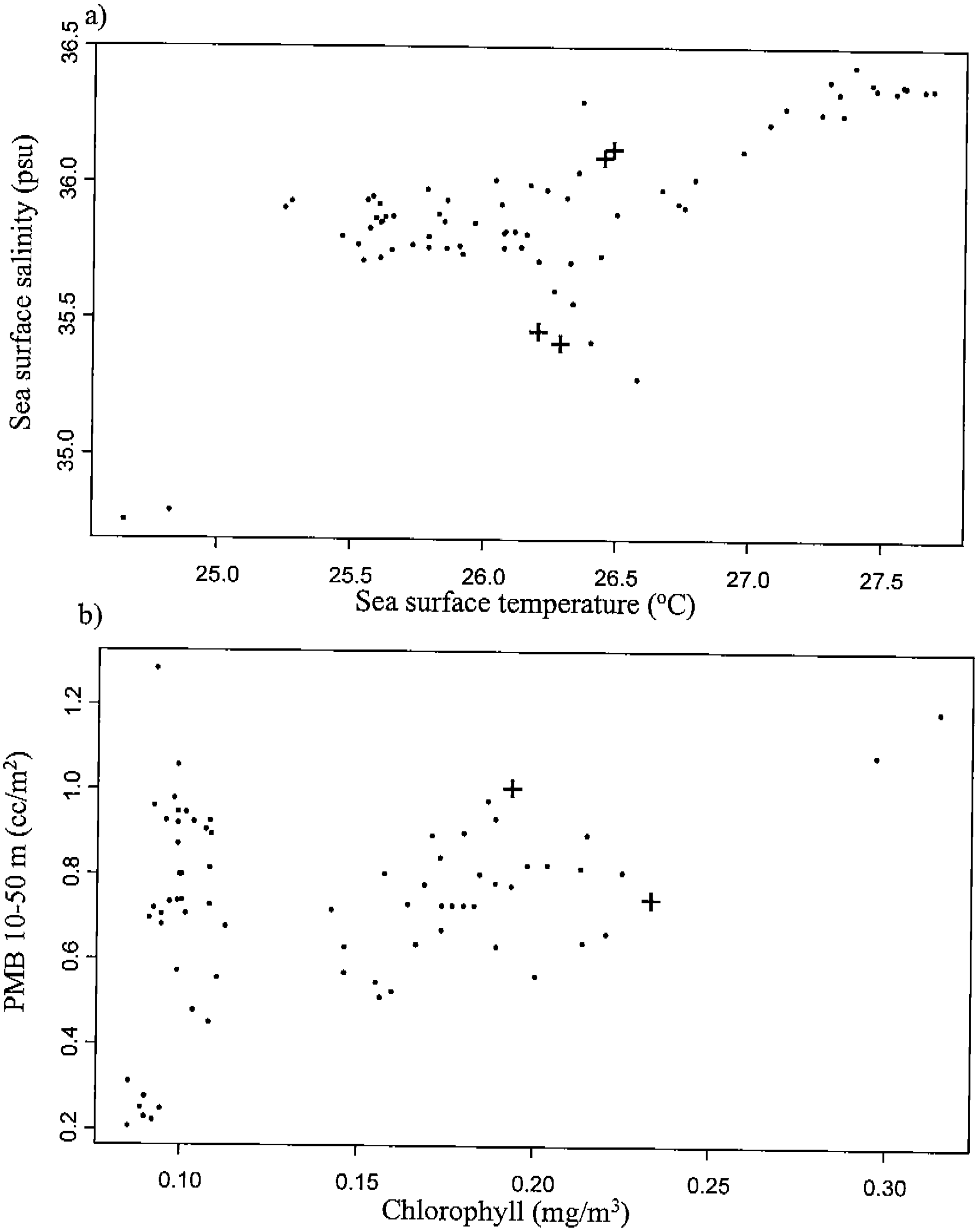

Figure 8.9. Presence of laughing gulls (late summer cruise) predicted by (a) sea surface properties model and (b) plankton standing stock model. Plus signs indicate presence in transects (as predicted by model). Dots represent absence in transects (as predicted by model).

amount of variance; laughing gulls occurred more frequently in areas with higher chlorophyll and PMB.

Pomarine jaeger presence and absence in transects was best explained by the model incorporating sea surface height and magnitude of geostrophic velocity (Table 8.10). Pomarine jaegers occurred in areas with a higher geostrophic velocity, but where the sea surface height was not as large as within the interior of the anticyclone (Figure 8.10). The plankton-standing stock model, using surface chlorophyll and PMB integrated from 10-50 m depth as predictor variables, also explained a large amount of variance in pomarine jaeger presence and absence. They were predicted to be seen in transects of low chlorophyll and high PMB.

The presence of Audubon's shearwater during mid-summer was best explained by the bathymetry model using depth and depth gradient as predictor variables, and the plankton-standing stock model, using surface chlorophyll and PMB as predictor variables (Table 8.10). However, neither model explained much of the variation. The bathymetry model predicted Audubon's shearwater in several combinations of bottom depth and slope of bottom depth (Figure 8.11a). The presence of Audubon's shearwater was predicted in two clusters in the plankton standing stock model: one transect with high chlorophyll (which was located in the confluence), and several transects with chlorophyll less than 0.20 mg/m^3 and PMB ranging from 1.4-1.8 cc/m^2 (Figure 8.11b).

The plankton-standing stock model best explained band-rumped storm-petrel presence (Table 8.10). This model predicted band-rumped storm-petrel presence in transects with 0.10-0.25 mg/m^3 chlorophyll and PMB (10-102 m) ranging from 1.0-1.4 cc/m^2 (Figure 8.12). Presence was also predicted in areas of high chlorophyll similar to Audubon's shearwater.

Sea surface temperature and salinity best explained the presence of black terns (Table 8.10). The model predicted that black terns would be present in areas where salinity was less than 32 psu, and temperature was less than 30.5°C (Figure 8.13). Additionally, black terns were predicted to be present in transects with high sea surface temperature if salinity was below 28 psu. Black terns were not predicted to be encountered in waters more saline than 32.5 psu regardless of sea surface temperature.

The plankton-standing stock model best explained bridled tern presence (Figure 8.14). However, this model predicted the presence of bridled terns in only one transect. It is noteworthy that this transect was the same confluence transect in which Audubon' shearwaters, band-rumped storm-petrels and black terns were predicted to be present.

Sea surface temperature and salinity best predicted sooty tern presence (Table 8.10). Specifically, the model predicted sooty tern presence in transects with a temperature between 30.5°C and 31.3°C and a salinity of approximately 32 psu (Figure 8.15).

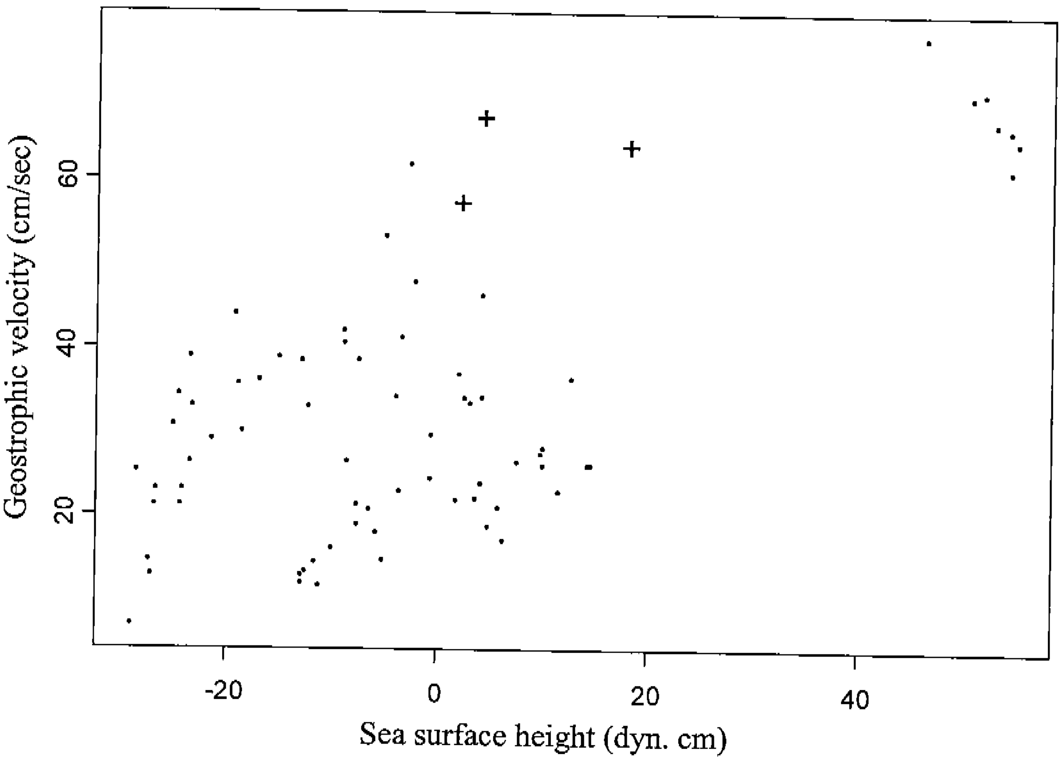

Figure 8.10. Presence of pomarine jaegers (late summer cruise) predicted by sea surface height model. Plus signs indicate presence in transects (as predicted by model). Dots represent absence in transects (as predicted by model).

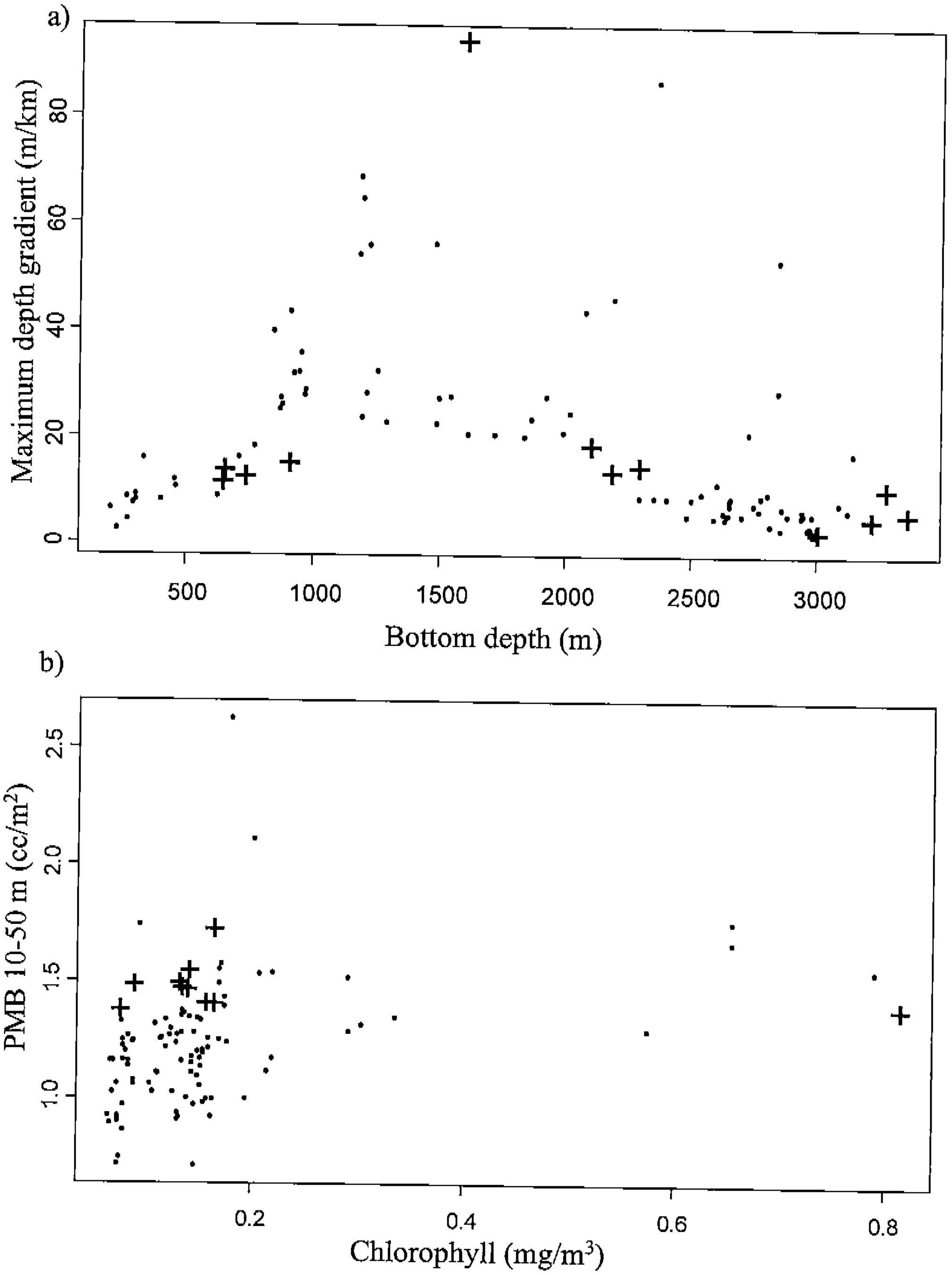

Figure 8.11. Presence of Audubon's shearwaters (mid-summer cruise) predicted by (a) bathymetry model and (b) plankton standing stock model. Plus signs indicate presence in transects (as predicted by model). Dots represent absence in transects (as predicted by model).

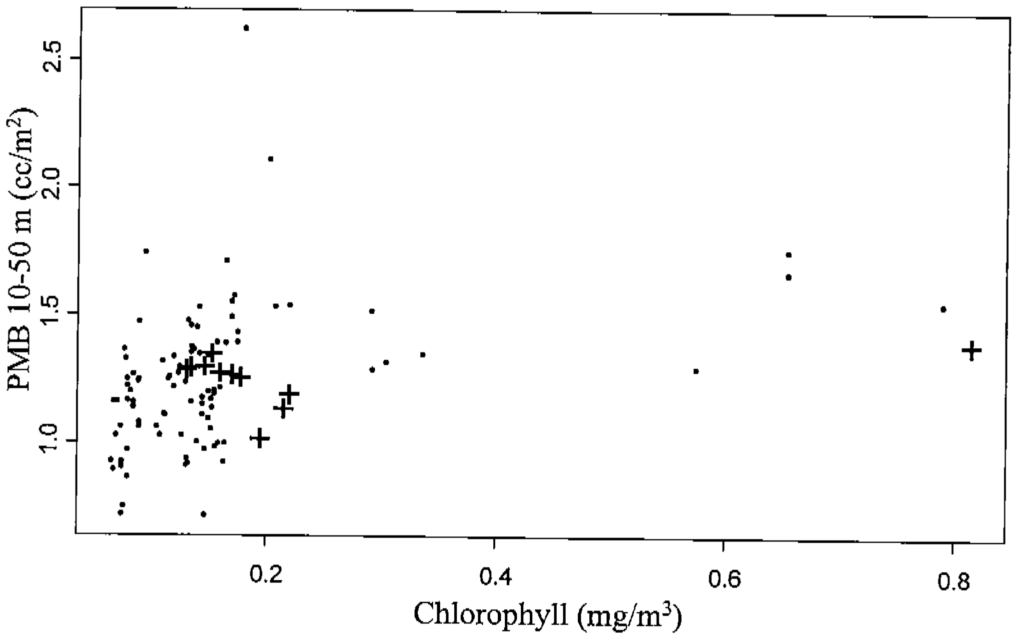

Figure 8.12. Presence of band-rumped storm-petrels (mid-summer cruise) predicted by plankton standing stock model. Plus signs indicate presence in transects (as predicted by model). Dots represent absence in transects (as predicted by model).

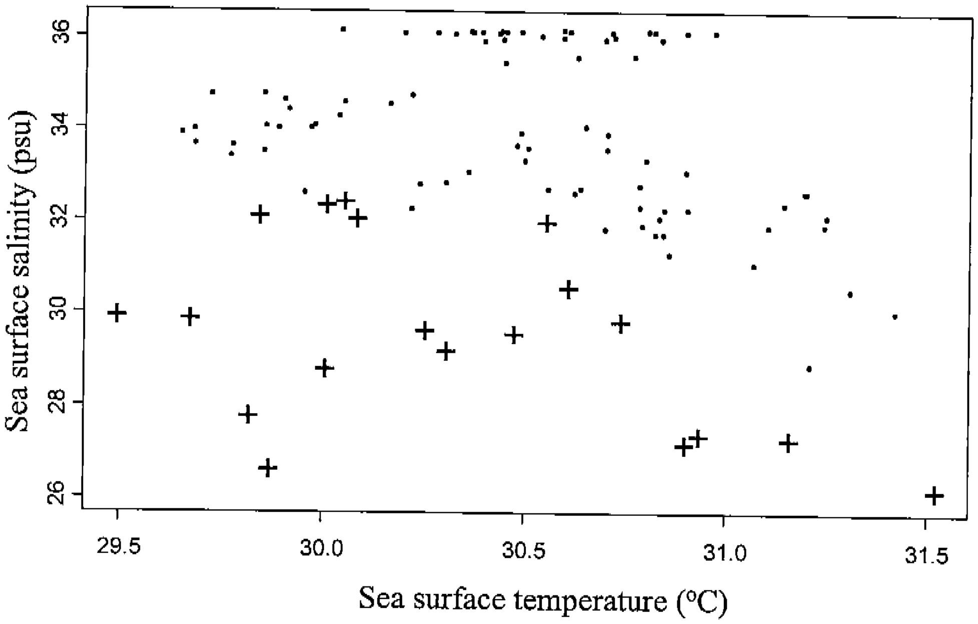

Figure 8.13. Presence of black terns (mid-summer cruise) predicted by sea surface properties model. Plus signs indicate presence in transects (as predicted by model). Dots represent absence in transects (as predicted by model).

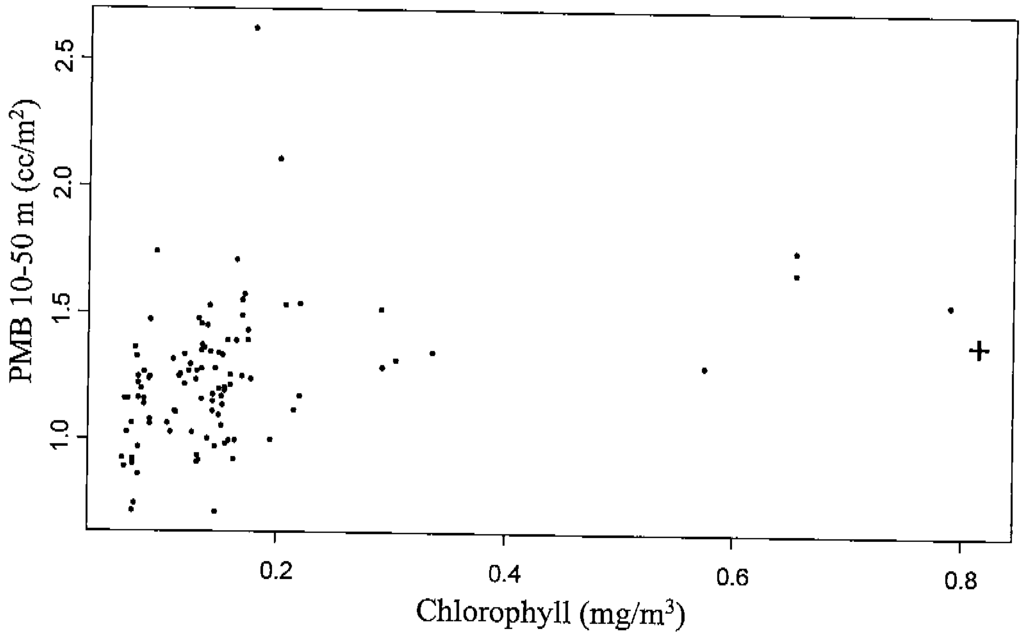

Figure 8.14. Presence of bridled terns (mid-summer cruise) predicted by plankton standing stock model. Plus signs indicate presence in transects (as predicted by model). Dots represent absence in transects (as predicted by model).

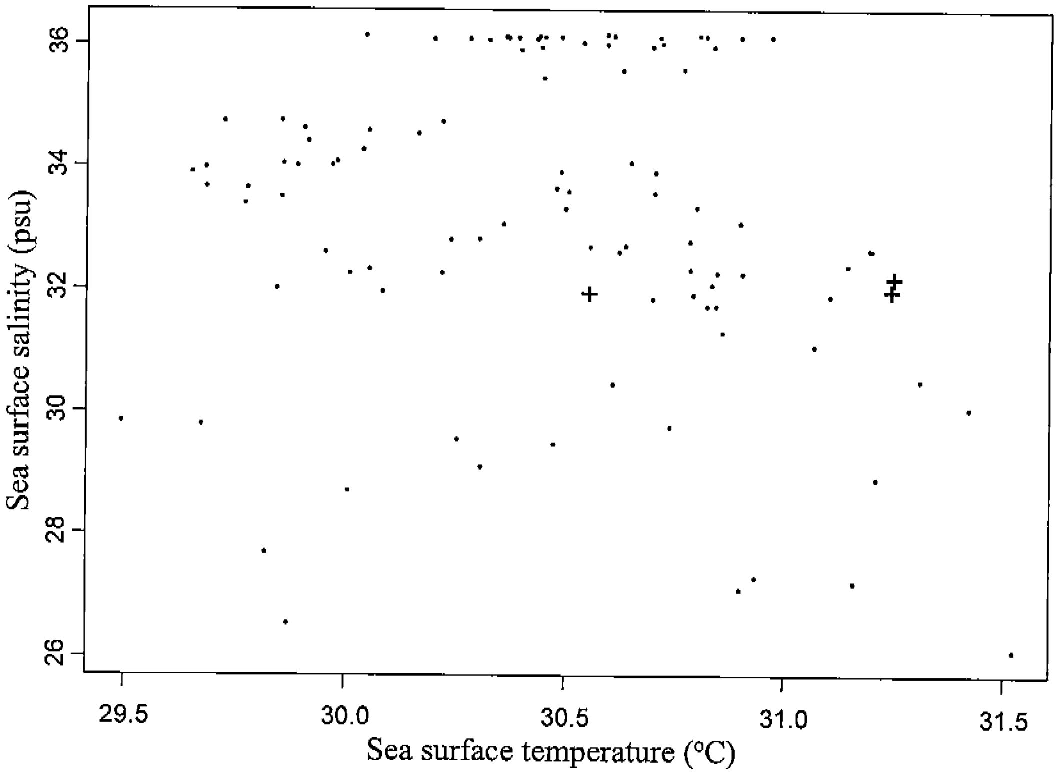

Figure 8.15. Presence of sooty terns (mid-summer cruise) predicted by sea surface properties model. Plus signs indicate presence in transects (as predicted by model). Dots represent absence in transects (as predicted by model).

8.4. Discussion

8.4.1 Overall Abundance

Seabird groups and species present in the Gulf of Mexico varied by season. These observations match expectations based on previous work detailing life histories of seabirds seen in the Gulf of Mexico. Fritts and Reynolds (1981) categorized birds as: summer migrant pelagic, summer resident, wintering marine, or permanent residents. Summer migrant pelagic species were defined as species that are present in the Gulf in the summer but breed primarily elsewhere. These include shearwaters, storm-petrels, boobies, tropicbirds, bridled terns and black terns. Examples of summer residents (seabirds that breed in the Gulf) are sooty terns, least terns and sandwich terns. Permanent residents are laughing gulls, royal terns and magnificent frigatebirds. Wintering marine birds are northern gannet, herring gulls and jaegers.

The spring cruise data suggest terns, storm-petrels and gulls were common in the Gulf during May and June. Jaegers and shearwaters were also present but in lower numbers. Tropicbirds, sulids and frigatebirds were rarely seen in the Gulf during the spring. The species composition of the late summer sightings was different from those of the spring cruise, as October is a period of migration and transition to winter distribution. Two of the three most commonly identified species (laughing gull and royal tern) were year-round residents of the Gulf. Pomarine jaegers, Gulf winter migrants, were the third most commonly identified bird. The mid-summer sightings included a large number of species. Black terns, the most abundant species during the mid-summer cruise, were summer migrant pelagic species. The four next most abundant species during the mid-summer cruise were: band-rumped storm-petrels (summer migrant pelagic), magnificent frigatebirds (permanent residents), Audubon's shearwaters (summer migrant pelagic) and sooty terns (summer residents).

Terns, which were the most abundant bird group during the spring cruise, are either year-round residents, summer residents or summer migrants; their presence during May/June would be expected. Storm-petrels were also frequently encountered during the spring cruise; this would be expected since they are summer migrants. Jaegers were not frequently seen in the Gulf during spring; this may be expected because they are primarily a winter species and may have left the Gulf region by May/June to return to their breeding grounds. Tropicbirds and sulids were not commonly encountered during the spring cruise; this may be expected as principally non-breeding birds would be present in the Gulf during the spring. Three of the four most frequently seen species (sooty tern, sandwich tern and black tern) were summer residents or summer migrants. Laughing gulls are year-round residents and were the fourth most frequently seen species.

Comparison of the late and mid-summer sighting rates to those from other shipboard surveys reveals a seasonal pattern of shifting species abundance. Although shearwaters, a summer migrant, are present year-round, they are most abundant during the summer and autumn. Storm-petrels are also present year-round, and previous data suggest a peak abundance during the spring (Davis and Fargion 1996). However, the mid-summer cruise had a sighting rate of 1.84 storm-petrels/effort hour, higher than the previously recorded spring sighting rate of 0.24 storm-petrels/effort hour.

While Fritts et al. (1983) consider magnificent frigatebirds to be a year-round species, our peak sightings during summer and early autumn suggest that frigatebirds may only be pelagic during part of the year. The mid-summer sighting rate of frigatebirds was higher than previously reported values, and the species was seen primarily in coastal waters. However, the frigatebirds seen during late summer were split evenly between shallow and deep water, suggesting that they may travel farther offshore after the breeding season.

Most tern species in the Gulf are summer residents or summer migrants, which was reflected in the large spike in tern sighting rates during August (Davis and Fargion 1996). However, in the mid-summer cruise, the sighting rate of terns was much lower than previously recorded. This difference may have resulted from the areas surveyed. Previous cruises focused on the shelf and slope region of the northern Gulf, whereas the mid-summer survey in this study was more pelagic. Between the late summer and mid-summer cruises, there was a different pattern of species presence and absence. During mid-summer, black terns were present in large numbers along the northern Gulf coast during migration. Sandwich terns were present only in mid-summer, primarily in coastal waters, but were not present in late summer. Bridled and sooty terns were present in increased numbers during mid-summer in deeper water. Royal terns, a year-round resident of the Gulf, were present during both mid- and late summer and seemed to prefer coastal habitats during mid-summer.

Gull abundance reflected two trends resulting from species with different life histories. While laughing gulls were present year-round, herring gulls, a wintering marine species, peaked in abundance in February (Davis and Fargion 1996). Laughing gulls exhibited a different pattern of distribution than other year-round species such as the magnificent frigatebird or royal tern. During mid-summer, laughing gulls were found evenly between shallow coastal water and deeper water. In late summer, laughing gulls were found in higher numbers in coastal water. Unlike the other year-round species, laughing gulls were found in higher proportions in coastal water during late summer (after the breeding season).

Sulid abundance increased during the winter (mainly northern gannets) and summer (mainly masked boobies), a trend also noted by Davis and Fargion (1996). The northern gannet being a wintering marine species could explain the difference in sulid abundance, while the masked booby is a summer resident in the Gulf.

Davis and Fargion (1996) described pomarine jaegers, considered uncommon in the Gulf by Duncan and Havard (1980), as a wintering marine species. They were seen during the late summer cruise at lower rates than winter, which may indicate that migrating jaegers were just beginning to arrive in the Gulf at that time. The mid-summer data show that jaegers are present in the summer at higher levels than previously reported (Davis and Fargion 1996) and may indicate some non-breeding jaegers remain in the Gulf.

8.4.2 Role of Hydrographic Environments

The results of both late summer and mid-summer cruises indicate the cyclone had the greatest species diversity of the hydrographic environments. Additionally, the confluence and Loop Current eddy during mid-summer had a greater species diversity than the continental shelf.

Species-specific habitat relationships with hydrographic environments were found for several species. Pomarine jaegers were more likely to be present near the MOM during late summer. Audubon's shearwaters during mid-summer were more likely to be seen inside the cyclone, while band-rumped storm-petrels were more likely to be present in the "other margin" areas. Black terns were encountered more frequently near the MOM. An interesting result was that while the MOM area had higher chlorophyll concentrations, many pelagic species (e.g., Audubon's shearwater, band-rumped storm-petrel, bridled tern and sooty tern) were not seen at all in this area.

8.4.3 Seabird Habitat

A generalized additive model, using indicators of plankton-standing stock (measured by surface chlorophyll and predicted mean biomass integrated from 10-50 m depth) best predicted (or was tied with another model) seabird presence for five of the seven species analyzed. A model incorporating sea-surface properties of temperature and salinity best predicted presence for black tern, sooty tern and laughing gull (tied with plankton-standing stock). The sea surface height and bathymetry models best explained pomarine jaeger and Audubon's shearwater (tied with plankton-standing stock) presence, respectively.

Sea surface salinity and temperature best predicted the presence of black tern and sooty tern. This was expected for black terns, which have been noted to follow the fresh water plume of the Mississippi River and coastal waters (Ribic et al. 1997a, Davis and Fargion 1996). Although sooty tern presence in transects was best explained by the same surface physical properties, the relationship was not the same as with black terns. Sooty terns were predicted to be present in salinity of about 32 psu, which is more saline than where black terns were found, but less saline than average values for the cyclone. This may reflect the affinity of sooty terns for lower salinity patches of water entrained around the cyclone (see Chapter 2). However, the percent of total variance explained by the model was low; there are probably other factors not considered that contribute to the distribution of sooty terns in the Gulf of Mexico. In the eastern tropical Pacific, sooty terns have been associated with more saline water than other seabird species (Ribic et al. 1997b).

Two competing models predicted laughing gull presence in late summer: plankton-standing stock and sea-surface properties. Laughing gulls were predicted in transects of increased PMB and increased concentrations of chlorophyll. The sea-surface properties model predicted laughing gulls in intermediate ranges of temperature. Ribic et al. (1997a) found laughing gulls in areas of low salinity and steep thermoclines. These findings are consistent. During late summer, there was an inverse relationship with salinity and chlorophyll concentration.

In late summer, pomarine jaegers were predicted to occur in areas with higher geostrophic flow and intermediate sea surface height. This suggests that pomarine jaegers may have been attracted to regions such as the confluence or the edge of the anticyclone. However, in the analysis of presence and absence in the hydrographic environments, pomarine jaegers were more likely to be encountered in the MOM area. This species may not be attracted to one particular environment during late summer.

Audubon's shearwater and band-rumped storm-petrel presence in mid-summer was best predicted by surface chlorophyll and PMB. Both species were predicted to be present at lower chlorophyll concentrations (generally less than 0.2 mg/m^3). This finding is consistent with the observation that neither species was present in transects in the MOM, which is where the majority of high chlorophyll transects occurred.

8.5 Conclusions

The three cruises provided more information on seasonal distribution and abundance of seabirds in the Gulf of Mexico. The relationship between hydrographic environment and species diversity was examined. We found the highest species diversity in the cyclone and lowest on the continental shelf. Several species exhibited affinities to specific hydrographic environments. Pomarine jaegers and black terns preferred the MOM area. Audubon's shearwaters were more likely to be present in the cyclone, and band-rumped storm-petrels in "other margin" areas. Species' presence was analyzed with models incorporating bottom depth, sea-surface properties, and plankton standing stocks using generalized additive models. Results suggest that the presence of laughing gull, Audubon's shearwater, band-rumped storm-petrel and bridled tern presence was best predicted by indicators of plankton-standing stock, using sea surface chlorophyll concentrations and PMB as predictor variables. For laughing gull, black tern and sooty tern, sea surface temperature and salinity best predicted presence. Models incorporating sea surface height and bathymetry predicted pomarine jaeger and Audubon's shearwater presence.

Chapter 9

Summary, Conclusions and Recommendations

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9.1 Objectives of the GulfCet Program

The Gulf of Mexico is a semi-enclosed, partially land-locked, intercontinental sea lying on the western margin of the Atlantic Ocean. It has been called the American Mediterranean Sea and has a total area of about 1.5 million square kilometers. As a large marine ecosystem, it has a unique bathymetry, hydrography and productivity. Cetaceans, sea turtles and seabirds are upper trophic level predators that play an important role in the pelagic marine ecosystem of the Gulf of Mexico. However, there was little information about the distribution, abundance and ecology of these marine vertebrates in the Gulf until surveys began in 1981 (Fritts et al. 1983, Mullin et al. 1991, Mullin et al. 1994c). These early studies eventually lead to the GulfCet I and II Programs in the 1990s, which were based on the most extensive surveys of cetaceans, sea turtles and seabirds ever conducted in the offshore waters of the northern Gulf of Mexico (Davis and Fargion 1996, Baumgartner 1997, Davis et al. 1998, this report). The objectives of the GulfCet II field studies (1996-97) were to: 1) expand the geographical coverage of ship and aerial surveys that were conducted previously during GulfCet I (1992-94), which surveyed the north-central and northwestern Gulf of Mexico, 2) estimate the minimum abundances of cetaceans and sea turtles in areas surveyed during 1996-97, 3) collect simultaneous hydrographic data and biological samples during the ship surveys to better define the habitat associations of cetaceans and seabirds, and 4) collect acoustic data on cetacean sounds and identify and record other natural and man-made underwater sounds to provide additional insights into cetacean distribution and behavior, particularly in relation to noise from seismic exploration vessels.

To accomplish these objectives, we used an integrated approach that included visual (aerial and shipboard) and acoustic (shipboard) surveys of the distribution of cetaceans, sea turtles and seabirds and simultaneous hydrographic measurements. We also used near real-time sea surface altimetry from the TOPEX/POSEIDON and ERS satellites to determine the location of hydrographic features (e.g., cyclones, anticyclones and confluence zones) during shipboard surveys. The sea surface altimetry maps enabled us to adjust the ship's course so that we could survey and sample hydrographic features that could influence the distribution of cetaceans and seabirds. Archival satellite sea surface altimetry data also allowed us to retrospectively determine the location of hydrographic features for analysis with GulfCet I cetacean sightings collected from 1992-94. In addition to characterizing hydrographic features during GulfCet II, we measured zooplankton and micronekton biomass derived from both net and acoustic sampling to indicate the amount of potential food available for higher trophic level foraging by cetaceans and seabirds. We hypothesized that hydrographic features in the study area had different levels of potential prey that influence cetacean and seabird distribution. We further hypothesized that these food stocks would be locally concentrated in nutrient-rich areas offshore from the Mississippi River, within cyclonic eddies, and along the high-shear edges of cyclonic eddies.

9.2 Cetaceans

Nineteen cetacean species were identified in the oceanic northern Gulf of Mexico (398,960 km^2, Figure 1.5) during GulfCet II surveys. Total abundance estimates ranged from 86,705 (based shipboard surveys) to 94,182 (based on highest estimate for each species from either shipboard or aerial surveys) animals (Table 9.1). Pantropical spotted dolphins were the most abundant species (an estimated 46,625 animals), followed by spinner dolphins (11,251) and clymene dolphins (10,093). Estimates for bottlenose dolphins, striped dolphins, melon-headed whales, Atlantic spotted dolphins, Risso's dolphins and short-finned pilot whales ranged from 5,618 to 1,471. Abundances of all other species were less than 1,000. Cetaceans were sighted throughout the study area, but fewer were sighted in the western Gulf. There are now sighting records during three or more seasons for at least 16 cetacean species. The seasonal abundance of several species (e.g., dwarf/pygmy sperm whale, Risso's dolphin, pantropical spotted dolphin) may vary regionally in continental slope waters. The distribution and abundance estimates of common cetacean species in both the oceanic northern Gulf (Figure 1.5) and GulfCet I study (Figure 1.2) areas were generally similar to previous estimates based on surveys conducted from 1992-94 (Mullin et al. 1994c, Davis and Fargion 1996).

Seventeen cetacean species were sighted in the Minerals Management Service's Eastern Planning Area (EPA, 70,470 km^2, Figure 1.4). The abundance estimate based on aerial surveys (which were more extensive than the ship surveys in the EPA) was 38,184 total animals. In general, cetaceans were found throughout the EPA each season. The most abundant species were pantropical spotted dolphins (13,649) and spinner dolphins (8,670). Other species with abundance estimates over 1,000 based on aerial surveys were bottlenose dolphins, Atlantic spotted dolphins, Risso's dolphins, striped dolphins and clymene dolphins. The seasonal abundance of some species may vary regionally in continental slope waters. For example, dwarf/pygmy sperm whales were 9-times more abundant in the summer than in the winter.

Cetaceans in the northeastern and oceanic northern Gulf of Mexico were concentrated along the continental slope in or near cyclones and the confluence of cyclone-anticyclone eddy pairs. Net tows and acoustic backscatter measurements with an Acoustic Doppler Current Profiler showed that cyclonic eddies and confluence areas are mesoscale features with locally concentrated zooplankton and micronekton stocks that appear to develop in response to increased nutrient-rich water and primary production in the mixed layer. A significant relationship existed between integrated zooplankton biomass and integrated cephalopod (a major component of cetacean prey) paralarvae numbers, indicating that higher zooplankton and micronekton biomass may correlate with higher concentrations of cetacean prey. In the north-central Gulf, an additional factor affecting cetacean distribution may be the narrow continental shelf south of the Mississippi River delta. Low salinity, nutrient-rich water may occur over the continental slope near the mouth of the Mississippi River (MOM) or be entrained within the confluence of a cyclone-anticyclone eddy pair and transported beyond the continental slope. This creates a deep-water environment with locally enhanced primary and secondary productivity and may explain the presence of a resident, breeding population (see Chapter 7) of endangered sperm whales within 50 km of the Mississippi River delta. Overall, the results suggest that the amount of prey for cetaceans (and seabirds) may be consistently greater in the cyclone, confluence areas, and south of the MOM, making them preferential areas for foraging (Figures 6.13-6.16). Since cyclones in the northern

Table 9.1 Cetaceans ranked by abundance with mean body mass, species-total biomass (percent of total biomass shown in parentheses) and minimum estimated food requirements for the oceanic northern Gulf of Mexico.

Species	Abundance[1]	Mean adult body mass (kg)[2]	Species-total biomass (kg)[3] (% of total)	Min. food requirement (tonnes·yr^{-1})[4]
Pantropical spotted dolphin	46,625	90	4,196,250 (17)	87,023
Spinner dolphin	11,251	50	562,550 (2)	13,513
Clymene dolphin	10,093	50	504,650 (2)	12,122
Bottlenose dolphin	5,618	150	842,700 (3)	15,381
Striped dolphin	4,858	90	437,220 (3)	9,067
Melon-headed whale	3,965	160	634,400 (3)	11,394
Atlantic spotted dolphin	3,213	100	321,300 (1)	6,490
Risso's dolphin	3,040	300	912,000 (4)	13,997
Short-finned pilot whale	1,471	2,000	2,942,000 (12)	28,101
Rough-toothed dolphin	852	100	85,200 (<1)	1,721
False killer whale	817	1,000	817,000 (3)	9,280
Dwarf/pygmy sperm whale	733	225	164,925 (1)	2,720
Sperm whale	530	20,000	10,600,000 (43)	56,935
Pygmy killer whale	518	110	56,980 (<1)	1,124
Killer whale	277	3,000	831,000 (3)	7,172
Cuvier's beaked whale	159	1,800	286,200 (1)	2,807
Fraser's dolphin	127	160	20,320 (<1)	365
Bryde's whale	35	12,000	420,000 (2)	2,563
Total	94,182		24,634,695	281,774

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[1] Minimum abundance estimates from GulfCet II visual survey data.

[2] Data published by Carwardine (1995).

[3] Total biomass was derived by multiplying the species abundance by the mean body mass.

[4] Estimated minimum food requirement (MFR, tonnes·yr^{-1}) for each species or species category was calculated as: MFR = $[(((A \times B \times C) / (D \times E)) / 10^6) \times 365]$, where A = annual species abundance in the study area; B = species resting metabolic rate (kcal/day,) equal to $70M^{0.75}$ (M = mass in kg); C = 2, the multiple of resting metabolic rate used to estimate the actual field metabolic rate (Hinga 1979); D = 0.8, the assimilation efficiency (Lockyer 1981); E = 1 kcal/g wet weight, the assumed caloric density of prey (Hinga 1979, Hain et. al. 1985); 10^6 is the conversion factor from grams to tonnes (10^6 g = 10^3 kg = 1 tonne); and 365 is the conversion factor from days to year.

Gulf are dynamic and usually associated with westward moving cyclone-anticyclone pairs, cetacean distribution will be dynamic. However, with near real-time satellite remote sensing of sea surface altimetry, these features can be tracked and used to predict where pelagic cetaceans may be concentrated. The exceptions are bottlenose dolphins, Atlantic spotted dolphins and possibly Bryde's whale that typically occur on the continental shelf or along the shelf break outside of major influences of eddies. We have little information on the environmental variables that influence the distribution of these three species or their prey because hydrographic surveys have concentrated on deeper waters beyond the continental shelf.

Although cetaceans were commonly observed throughout the GulfCet study area during all four seasons, we could not determine whether animals were in transit or resident in the study area for extended periods. It is possible that the oceanic northern Gulf encompasses only a portion of the home range for many of the species observed. For example, a radio-tagged pantropical spotted dolphin in the eastern tropical Pacific (ETP) moved over 500 km in 27 days (Perrin et al. 1979). Without additional information on daily movement patterns and feeding behavior, significant uncertainties remain in our understanding of cetacean association with mesoscale hydrographic features. The relationships between physical and biological processes are subtle and complex, and factors other than hydrographic features and potential prey abundance may influence the distribution of cetaceans. The seasonal movements of cetaceans may be affected by reproductive and migratory behavior, although we currently have little information on the behavior of pelagic species. The exception is sperm whales south of the MOM, which appear to reside along the lower slope throughout the year. We suggest that this area may be essential habitat for sperm whales in the northern Gulf, although additional information on population structure, seasonal movements and behavior is needed.

The diversity of cetaceans in the study area was comparable to that along the continental slope of the northeastern United States and in the eastern tropical Pacific (ETP) (Hain et al. 1985, Wade and Gerrodette 1993). However, the overall density of cetaceans (0.24 km^{-2}) in the oceanic northern Gulf of Mexico was only 29% and 45%, respectively, of the cetacean densities in the northeastern U.S. (0.80 km^{-2}) and the ETP (0.53 km^{-2}). Dolphins (Family Delphinidae) were the most common (>98%) cetaceans in all three areas. However, there were more than five times as many pilot whales along the northeastern U.S. than in the oceanic northern Gulf. Notable in their absence from the Gulf are common dolphins (*Delphinus delphis*). Baleen whales represented a large percentage (56%) of the total cetacean biomass along the northeastern U.S. (Hain et al. 1985), but were a negligible percentage (ca. 2%, primarily Bryde's whale) in the northern Gulf. The lower densities of cetaceans in the Gulf compared to the northeastern U.S. and the ETP could be related to more oligotrophic conditions and lower concentrations of prey. The estimated minimum biomass of cetaceans in the oceanic northern Gulf is 24,634,695 tonnes (Table 9.1). Of this biomass, sperm whales represent 43%. Together, pantropical spotted dolphins, sperm whales and short-finned pilot whales constitute 72% of the estimated cetacean biomass. The minimum food requirement for all cetaceans (assuming adult body masses for each species) in the oceanic northern Gulf is an estimated 281,774 tonnes per year, of which pantropical spotted dolphins, sperm whales and short-finned pilot whales consume 61% (Table 9.1). Dividing the minimum food requirement by the size of the study area (398,960 km^2) gives a cetacean food consumption rate of 0.71 tonnes$\cdot$km$^{-2}\cdot$yr^{-1}. This value is about 12% and 46% of the estimated annual food consumption for cetaceans living along the continental slope in the northeastern U.S. and the ETP, respectively, and it probably reflects the lower primary and secondary productivity in the Gulf (Hain et al. 1985, Wade and Gerrodette 1993).

To obtain a better understanding of the seasonal and annual distribution, abundance and habitat-associations of cetaceans, a survey of the entire Gulf with simultaneous satellite and conventional radio tracking and photo-identification of the predominant species (e.g., pantropical dolphins, sperm whales) is needed. Skin biopsies and skin swabbing (Harlin et al. 1999) for genetic analysis of population structure and blubber biopsies for assessing diet (based on fatty acid profiles that can be used to identify prey) should be taken. In addition to tracking the movements of cetaceans at sea, animal-borne satellite telemeters can record information on diving behavior. When combined with dietary information from blubber fatty acid profiles, diving behavior can provide new and much needed information on foraging areas, prey species and resource partitioning among cetaceans (Evans 1971, Tanaka 1987, Mate 1989, Merrick et al. 1994, Davis et al. 1996). We believe that the diet of many cetaceans found in the Gulf is dominated by cephalopods and mesopelagic fishes associated with the vertically migrating acoustic deep scattering layer (Perrin et al. 1973, Clarke 1996, Ridgway and Harrison 1994). However, there is little direct dietary information for pelagic cetaceans in the Gulf. Future studies should increase acoustic and net sampling of zooplankton and micronekton in different hydrographic features so that we can develop stronger statistical correlations between cetacean distribution and their potential prey. Behavioral data are also needed to determine whether animals use certain areas for specific activities, such as social/sexual behavior, foraging, resting, or transiting.

9.3 Sea Turtles

GulfCet II aerial surveys provided the first assessment of sea turtle abundance and distribution over a large area of the oceanic northeastern Gulf of Mexico. Three sea turtle species were sighted in the EPA study areas: loggerhead, Kemp's ridley and leatherback sea turtles. The leatherback and Kemp's ridley sea turtles are listed as endangered and the loggerhead is listed as threatened.

The overall density of loggerhead sea turtles in the EPA shelf was 20 times that of the EPA slope. The seasonal densities of loggerheads in the EPA shelf were similar. However, the majority of loggerheads in the EPA slope were sighted during winter. While many of the winter sightings were near the 100 m isobath, there were sightings of loggerheads over very deep water (i.e., >1000 m). It is not clear why adult loggerheads would occur in oceanic waters unless they were traveling between foraging sites or migrating to distant nesting areas. Adult loggerhead sea turtles forage primarily over continental shelves and in estuaries from the subtropics to warm temperate waters (National Research Council 1990). In the western North Atlantic, nesting occurs along the Atlantic coast of Florida, but significant nesting extends north to North Carolina and along the Gulf of Mexico coast of Florida. This region constitutes the second largest breeding aggregation of loggerhead nesting in the world. Elsewhere in the Gulf of Mexico, only a few sporadic nests occur in the northern Gulf west of Florida but significant nesting does occur in disjunct locations along and near the Yucatan Peninsula (Carr et al. 1982, National Research Council 1990).

Leatherbacks were sighted throughout the EPA slope and were about 12 times more abundant in the winter than summer. A small number also occurred in the EPA shelf during summer. The nearly disjunct summer and winter distributions of leatherbacks indicates that specific areas may be important to this species either seasonally or for short periods of time. Adult leatherback sea turtles forage from the tropics to subarctic waters (National Research Council 1990). While generally called a pelagic or oceanic species, in previous studies, leatherbacks have been routinely found in nearshore waters in the western Atlantic and Gulf of Mexico (CeTAP 1982, Fritts et al. 1983). In the western North Atlantic, they nest primarily in the southwestern Caribbean in Costa Rica and in the eastern Caribbean from the Dominican Republic to Trinidad. Low levels of leatherback nesting occur along the Atlantic coast of Florida. In the Gulf of Mexico, minimal nesting has been reported in the southwestern Gulf along the coast of Mexico (Carr et al. 1982). Adult leatherbacks feed primarily on jellyfish, often at great depths (e.g., 1,000 m), but also eat other coelenterates that are often concentrated near convergent zones and fronts (Bjorndal, 1997). Since these features are often dynamic and ephemeral, it may explain the irruptive distribution of leatherbacks in the Gulf of Mexico during both GulfCet I and II.

Kemp's ridley sea turtles were sighted only three times in EPA shelf waters, but many were probably missed due to their small adult size. Kemp's ridleys occur in the Gulf of Mexico and western North Atlantic. Adults forage throughout the northern Gulf of Mexico in shallow shelf waters but they concentrate off Louisiana, Mississippi and Alabama. The only significant nesting beach for this species is in western Gulf of Mexico at Rancho Neuvo, Mexico (Carr et al. 1982, National Research Council 1990).

9.4 Seabirds

Seabird species present in the Gulf of Mexico varied by season. The species composition of the sightings during late summer reflected a pattern of migration and transition to a winter distribution. Two of the three most commonly identified species (laughing gull and royal tern) in late summer were year-round residents in the Gulf. Pomarine jaegers, a wintering marine species in the Gulf, were the third most commonly identified species. During mid-summer, the black tern was the most abundant species, followed by band-rumped storm-petrels (summer migrant pelagic), frigatebirds (permanent resident), Audubon's shearwaters (summer migrant pelagic) and sooty terns (summer resident).

Cyclones had the greatest diversity of seabird species, although habitat use varied among species. Pomarine jaegers were more likely to be present in the MOM area during late summer. Audubon's shearwaters were more likely to be encountered inside a cyclone, while band-rumped storm-petrels were more likely to be present in the areas other than cyclones, anticyclones or confluence zones during mid-summer. Black terns were encountered more frequently in the MOM area during mid-summer. Generalized additive models incorporating indicators of plankton standing stock (surface chlorophyll and predicted mean biomass of zooplankton and micronekton) best-predicted seabird presence for five of the seven species analyzed. Other predictive models were: sea surface properties of temperature and salinity for black tern, sooty tern, and laughing gull; sea surface height for pomarine jaeger; and bathymetry for Audubon's shearwater. Seasonal surveys are needed to better assess community structure and seabird-habitat associations.

9.5 Potential Impacts of Oil and Gas Exploration and Production

Eighty-three percent of the crude oil and 99% of the gas production in United States federal waters occurs in the Gulf of Mexico, primarily along the Texas-Louisiana continental shelf and slope (Cranswick and Regg 1997). By 2003, oil production in the Gulf is projected to increase 43% (range = 23 to 63%), and gas production is projected to decrease by 9% (range = -23 to 18%) (Melancon and Baud 1999). Production from deepwater fields (depth >305 m) will account for about 59% of the daily oil production and 27% of the daily gas production in the Gulf. By the early 2000's, exploration wells may be drilled at 3,000-m depths at the very edge of the Exclusive Economic Zone, and production systems will be designed for depths of 1,800 m and greater (Cranswick and Regg 1997). The long-term forecast for petroleum transportation is for the total volume to increase into the next century. The projected number of service-vessel trips for lease sales in the central Gulf alone could exceed 700 trips per day or 260,000 trips annually (Marine Mammal Commission 1999). The cumulative impact of these and other human activities on cetaceans in the northern Gulf cannot be predicted with certainty (Marine Mammal Commission 1998, 1999). However, it can be anticipated that cetaceans along the continental slope will encounter increasing oil and gas exploration and production activities that include: surface and subsurface construction; FPSO (Floating Production, Storage and Offloading facilities) activities; waste discharge; service-vessel and aircraft traffic and noise; geophysical surveying; and oil spills (Cranswick and Regg 1997). One way to assess the long-term effects of these activities on cetacean distribution and abundance is through a monitoring program of indicator species (e.g., endangered sperm whales, pantropical spotted dolphins, clymene dolphins) that commences ahead of the widespread implementation of deepwater exploration and production. Such a monitoring program would involve traditional aerial and shipboard visual surveys, shipboard acoustic surveys, behavioral observations, and satellite and conventional radio telemetry studies of the predominant cetacean species that can provide an adequate sample size for statistical analysis. The shipboard acoustic surveys are particularly useful because they monitor the presence of vocalizing cetaceans as well as ambient noise levels. In addition, these kinds of data can be archived for later analysis as exploration and production activities develop and change over long periods of time. However, a monitoring program alone may not be able to determine whether population changes have resulted from oil and gas exploration and production activities, other anthropogenic causes (e.g., incidental take in fisheries, commercial shipping noise and collisions, plastics, river-borne contaminants), or natural changes in the marine environment. An assessment of the potential effects of oil and gas exploration and production activities must include experimental studies with testable hypotheses.

Sounds associated with offshore oil exploration in the Gulf of Mexico are becoming increasingly common. The peak intensity of seismic exploration pulses recorded during GulfCet II was found to be typically below 250 Hz, with an average peak intensity at 82 Hz. The average intensity of pulses was found to be 8.4 dB above ambient, more than double ambient levels. However, there was no significant difference in the sighting frequency between the different acoustic levels examined for GulfCet I and II, contrary to previous findings (Mate et al. 1994) suggesting that sperm whales may avoid seismic vessel noise. In addition, the observed distribution of cetaceans did not differ significantly with seismic sound intensity for different hydrographic regions. However, the present study did not examine smaller-scale behavioral impacts. While the GulfCet I and II programs offered an opportunity to examine the potential effects of human acoustic perturbation on the large-scale distribution of local cetacean populations, they lacked the ability to control for both the acoustic level and the hydrographic region. To better understand the potential impact of man-made noise on local cetacean populations, a systematic study is needed that can control for acoustic variation in different hydrographic features. Ideally, such a study would examine small-scale behavioral changes in addition to distribution.

The Gulf of Mexico is rich in species occurring throughout the food chain that are acoustically active. It is unfortunate that so little information is available on ambient noise levels, source levels from fish and dolphins, and especially accurate data on exposure levels as a function of frequency during geophysical surveys, explosive removal of platforms and other noise associated with oil and gas development. The northern Gulf of Mexico is ideal for using acoustic monitoring to study the potential effects of man-made noise on cetaceans. The sound reception and production capabilities of many families of cetaceans are well known (Richardson et al. 1995). Every group of cetaceans studied has been found to vocalize and to have broad-band hearing sensitivity. This includes all of the 19 species that regularly occur in the northern Gulf of Mexico, even though quantitative data on hearing exists for only five of these (i.e., bottlenose dolphins, false killer whales, killer whales, rough-toothed dolphins, and short-finned pilot whales). Lack of quantitative data on the responses of marine animals, especially cetaceans, to man-made noise emphasizes the concerns expressed by the Marine Mammal Commission (1999) about long-term, adverse effects. Better and precise measurements of the acoustic environment of cetaceans is needed along with acoustic monitoring. In addition to the comprehensive library of marine animal sounds that the GulfCet study has already archived, a great deal of data on ambient noise associated with shipping and oil and gas exploration has been recorded. These data await analysis and interpretation.

There are significant uncertainties in our understanding of short and long-term effects of seismic and other loud industrial sounds on the behavior and distribution of Gulf cetaceans. Potential impacts of seismic survey sounds include: 1) masking sounds made by cetaceans for communication, navigation, sensing their environment and prey capture, 2) causing animals to abandon or avoid important feeding and breeding areas, or altering migratory routes, 3) affecting the distribution, density and movements of important prey species, 4) causing physiological or psychological stress, and 5) causing temporary or permanent hearing loss (Richardson et al. 1995, Marine Mammal Commission 1999). Behavioral monitoring and *in situ* behavioral experiments, as have been conducted for gray (*Eschrichtius robustus*), bowhead (*Balaena mysticetus*), and humpback whales in other United States federal waters, are needed to improve our understanding of these potential impacts. Behavioral work should include assessments of respiration, diving, speed of travel, group size, and general behavior patterns relative to seismic survey sounds, their proximity to the animals, and their loudness at certain frequencies. It should also include, where possible, conventional and satellite radio tagging for large-scale (time and geography) movement information, and electronic recording or telemetering of depth of dive and heart rate. Observational and experimental work relative to assessments of disturbance need not be conducted on all species, but should target sperm whales and such potential dolphin "indicator species" as oceanic bottlenose dolphins, pantropical spotted dolphins, spinner dolphins or clymene dolphins. The methods for tagging and tracking these animals have been largely resolved, as have the behavioral data gathering protocols that have been so useful in helping the MMS in making management-related decisions in other federal waters. Without a monitoring program working in cooperation with the oil industry, it is impossible to make well-reasoned judgements on the potential impacts of geophysical survey activities on pelagic cetaceans.

The effects of oiling on cetaceans, sea turtles and seabirds have been reviewed (Clark and Gregory 1971, Hansen 1981, 1985, Geraci and St. Aubin 1982, 1985, 1988, 1990, Geraci et al. 1983, Clapp et al. 1983, Smith et al. 1983, Fry and Lowenstine 1985, Fry et al. 1985, St. Aubin et al. 1985, Lutz et al. 1986, Vargo et al. 1986, Butler et al. 1988, Lutz and Lutcavage 1989, Piatt et al. 1990, Hutchinson and Simmonds 1991). Although the immediate effects of oiling on cetaceans and sea turtles are considered less severe than for seabirds, chronic, sublethal effects are unknown. This is of special concern for the population of endangered sperm whales residing southeast of the Mississippi River delta in an area of active oil and gas production (Würsig 1990). Clapp et al. (1983) suggested that even a small spill could be harmful to seabirds if it occurred in an area where they aggregate. In the Gulf of Mexico, this could occur if oil were advected into the confluence region of a cyclone-anticyclone pair and transported offshore.

9.6 Recommendations for Future Research

In light of the current expansion of oil and gas activities into deep-water regions of the Gulf, more detailed information on the population biology, ecology, behavior and potential industry-related impacts is needed for cetaceans, sea turtles and seabirds. The following are research recommendations in approximate order of priority for the northern Gulf of Mexico:

1. Information is needed on the movements, diving behavior and site fidelity of endangered sperm whales along the continental slope southeast of the Mississippi River delta. Satellite telemeters should be attached to sperm whales to examine seasonal movements and diving behavior in relation to mesoscale hydrographic features and estimates of potential prey abundance. Skin biopsies and skin swabbing should be conducted to determine how closely related Gulf sperm whales are to those from the adjacent Atlantic Ocean and Caribbean Sea. Blubber biopsies should be taken to assess diet (based on fatty acid profiles that indicate dietary preferences). Finally, a photo-identification study in this region should be conducted to assess the site fidelity of individual whales.

2. Monitoring of cetacean and sea turtle distribution and abundance in the northern oceanic Gulf during the NMFS ichthyoplankton surveys should continue. These surveys can be conducted at relatively low cost because they occur simultaneously with ongoing cruises. Research on cetacean habitat-associations using satellite remote sensing and shipboard measurements should continue. Although progress was made during the GulfCet II study, much remains to be learned about cetacean habitat in the western and southern Gulf. If shifts in a species' distribution occur, a better understanding of habitat will be needed.

3. A GulfCet III Program for the southern Gulf of Mexico (south of the U.S. Economic Exclusive Zone including the Straits of Florida) should be initiated in cooperation with Mexico (this could be accomplished through U.S. and Mexico university cooperative research programs already in existence). Research objectives should be similar to those of GulfCet II (i.e., cetacean, sea turtle and seabird seasonal distribution and abundance surveys

and habitat studies). This would complement studies of northern Gulf waters where oil and gas activities already occur.

4. Conduct controlled experiments on the effects of seismic sounds on cetaceans. In addition, researchers should monitor the effects of seismic ship activity on the behavior and distribution of cetaceans. Potential changes in sperm whale vocalizations during geophysical exploration should be examined. Finally, a retrospective analysis should be conducted of GulfCet cetacean distribution data relative to seismic vessel location, signal characteristics, and source level. This research will require the cooperation of the geophysical survey industry. Specifically, we will need information on when and where seismic survey activities occur and the types of seismic signals produced. Observers should be placed on seismic vessels to monitor cetacean behavior.

5. Research on genetic stock structure should be given added emphasis. The Marine Mammal Protection Act mandates that stocks of cetaceans be protected. Stocks can be defined in a number of ways, but genetic analyses can provide the clearest indication of divisions. Questions of interest for each species include: (1) Should cetaceans in the Gulf of Mexico be considered as separate stocks from the adjacent Atlantic/Caribbean? (2) Is there more than one Gulf of Mexico stock? (3) Are there seasonal differences in occurrence patterns? Genetic analysis of skin samples collected during vessel surveys both in the Gulf and adjacent waters could begin to answer these questions. Of particular interest is Bryde's whale. Bryde's whales have displayed considerable local variation world-wide, and analysis of skin biopsy samples could determine whether the northern Gulf stock is restricted geographically and genetically isolated from animals in the Atlantic Ocean.

6. Seasonal seabird surveys should continue to better assess community patterns and understand how patterns change within a season in response to varied marine environments, such as the presence of eddies. In the present study, we found that seabirds responded to different conditions created by the outflow of the Mississippi River and hydrographically defined mesoscale features.

7. Taxonomic analyses of the Multiple Opening/Closing Net and Environmental Sampling System (MOCNESS) and Isaacs Kidd Midwater Trawl (IKMT) samples collected during the present study should continue. This will allow us to identify indicator species for the hydrographic features and extend the usefulness of the Acoustic Doppler Current Profiler (ADCP) data. In future studies, we should increase our sampling intensity in the major hydrographic features so that we can develop stronger statistical correlations.

In conclusion, the continental slope in the northern Gulf of Mexico is an area that supports a diverse cetacean community, but one whose density does not equal areas such as the continental slope in the northeastern United States and the ETP. We now have a better understanding of the mesoscale features that influence cetacean distribution, and the use of satellite remote sensing of sea surface altimetry is increasing our ability to predict where pelagic cetaceans may be concentrated. Against the background of growing oil and gas exploration and development, continued research and monitoring are needed to assess the potential impacts of these activities on pelagic cetaceans, sea turtles and seabirds in the Gulf of Mexico. The GulfCet Program has demonstrated that any future monitoring programs should be long-term, with intensive sampling effort to detect significant changes in the density and distribution of these upper trophic level marine predators.

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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.

USGS
science for a changing world

The Biological Resources Division Mission

The mission of the Biological Resources Division (BRD) of the U.S. Geological Survey (USGS) is to work with others to provide the scientific understanding and technologies needed to support the sound management and conservation of our Nation's biological resources.

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 **Royalty Management Program** 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.