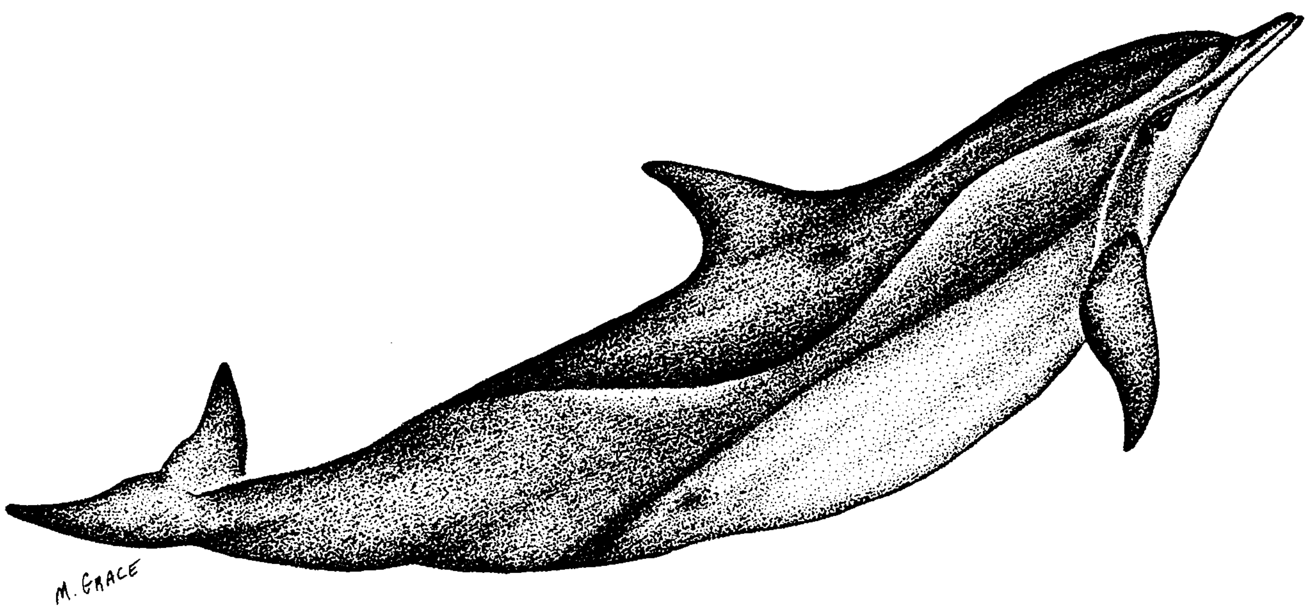
OCS Study
MMS 96-0027

Distribution and Abundance of Cetaceans in the North-Central and Western Gulf of Mexico, Final Report

Volume II: Technical Report



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

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Distribution and Abundance of Cetaceans in the North-Central and Western Gulf of Mexico, Final Report

Volume II: Technical Report

Editors

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ABOUT THE COVER

The cover art depicts a clymene dolphin and is the work of Mark Grace, an employee of the National Marine Fisheries Service Laboratory at Pascagoula, MS.

ABSTRACT

The purpose of this study (hereafter referred to as the GulfCet Program) was to determine the distribution and abundance of cetaceans (whales and dolphins) in areas potentially affected by future oil and gas activities along the continental slope in the north-central and western Gulf of Mexico. This 3.75 year project commenced on 1 October 1991 and concluded on 15 July 1995. The study area was bounded by the Florida-Alabama border, the Texas-Mexico border, and the 100 m and 2,000 m isobaths. The distribution and abundance of cetaceans were determined from seasonal aerial and shipboard visual surveys and shipboard acoustic surveys. In addition, hydrographic data were collected *in situ* and by satellite remote sensing to characterize the habitats of cetaceans in the study area. Finally, tagging and tracking of sperm whales using satellite telemetry was attempted.

Cetaceans were observed throughout the study area during all four seasons. Nineteen species were identified, including two species (melon-headed whales and Fraser's dolphins) that were previously thought to be rare in the Gulf. Pantropical spotted dolphins, bottlenose dolphins, clymene dolphins, striped dolphins, Atlantic spotted dolphins, and melon-headed whales were the most common small cetaceans. The most common large cetacean was the sperm whale. Only one species of baleen whale, the Bryde's whale, was sighted, and the estimated abundance of this species was very low. The mean annual abundance for all cetaceans was estimated to be 19,198 animals.

The oceanography in the study area was complex and dynamic, with mesoscale features that showed large annual and interannual variability. Warm- and cold-core rings (eddies) and the fresh water effluent from the Mississippi River were the most distinctive hydrographic features observed in the study area. The marine habitat for this area can be characterized as tropical to subtropical with a mixed layer that is seasonally deepest in the winter.

With the exception of bottom depth, there was no significant correlation of cetacean distribution with any of the hydrographic variables examined. Cetaceans could be divided into three groups relative to bottom depth. The first group, which occurred on the continental shelf or along the shelf break, consisted of Atlantic spotted dolphins and bottlenose dolphins. The second group consisted only of Risso's dolphin and occurred along the mid-to-upper slope. The third group included sperm whales, pygmy/dwarf sperm whales, pantropical spotted dolphins, striped dolphins, and *Mesoplodon* spp. This third or deep-water group typically occurred along the mid-to-lower slope in water over 1,000 m deep. There was some indication that sperm whales may be found in conjunction with the edge of warm-core rings, where upwelling events may enhance productivity and prey abundance.

The potential effects of oil and gas exploration and production activity on cetaceans along the continental slope cannot be predicted with certainty. However, it can be anticipated that cetaceans will encounter construction activity, ship traffic, seismic exploration, and underwater noise as the oil and gas industry moves into yet deeper water. The GulfCet Program has demonstrated that any future monitoring programs would need to be long-

term, with relatively intensive sampling effort in order to detect significant changes in the abundance and distribution of most cetaceans.

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LIST OF ABBREVIATIONS AND ACRONYMS

The following acronyms and abbreviations are used throughout this report:

AAIW	Antarctic Intermediate Water
AGIS	Advanced Geographical Information System
AVHRR	Advanced Very High Resolution Radiometer
CETAP	Cetacean and Turtle Assessment Program
CI	Confidence Interval
CTD	Conductivity, Temperature, and Depth Profiler
CV	Coefficient of Variation
CZCS	Coastal Zone Color Scanner
DB	Decibars
DBDB5	Digital Bathymetric Database-5 Minute Resolution
dB rel µP	Decibels Relative to 1 micro Pascal
DDS	Delta Data Systems, Inc.
DMA	Defense Mapping Agency
Dyn Ht	Dynamic Height
ESA	Endangered Species Act
ESW	Effective Strip Width
ETP	Eastern Tropical Pacific
GCW	Gulf Common Water
GIS	Geographic Information System
GPS	Global Positioning System
GMMI	Gulf of Mexico Master Image
GulfCet	MMS North-central and Western Gulf of Mexico Cetacean Study (this study)
HPLC	High Pressure Liquid Chromatography
HMSC	Hatfield Marine Science Center, OSU
IMLS	Institute of Marine Life Sciences, TAMUG
IO	Independent Observer
IPS	Inches Per Second
K-S	Kolmogorov-Smirnov Two-Sample Statistical Test
LATEX-A	Louisiana and Texas Shelf Circulation and Transport Process Study
LATEX-B	Louisiana and Texas Mississippi River Plume Study
LATEX-C	Louisiana and Texas Eddy Circulation Study
LUMCON	Louisiana Universities Marine Consortium
MIDAS	Multiple Interface Data Acquisition System
MMPA	Marine Mammal Protection Act
MMRP	Marine Mammal Research Program, TAMUG
MMS	Minerals Management Service
NADW	North Atlantic Deep Water
NAVOCEANO	U.S. Naval Oceanographic Office
NESDIS	National Environmental Satellite, Data, and Information Service
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NOS	National Ocean Survey

LIST OF ABBREVIATIONS AND ACRONYMS (continued)

OCS	Outer Continental Shelf
ONR	Office of Naval Research
OSU	Oregon State University
PC	Personal Computer
PSS 78	The Practical Salinity Scale 1978
PSD	Perpendicular Sighting Distance
PSU	Practical Salinity Units
RTS	Real Time Spectrograms
PTT	Platform Transmitter Terminals
SAS	Statistical Analysis System
SBE	Sea-Bird Electronics, Inc.
SD	Standard Deviation
SE	Standard Error
SEAMAP	Southeast Area Monitoring and Assessment Program
SEFSC	Southeast Fisheries Science Center, NMFS
SGI	Silicon Graphics, Inc.
SIO	Scripps Institution of Oceanography
SLDR	Satellite-linked Depth Recorder
SPL	Sound Pressure Level
SRB	Scientific Review Board
SSC	Stennis Space Center
SST	Sea Surface Temperature
STI	Sea Tech, Inc.
SUW	Subtropical Underwater
SVA	Specific Volume Anomaly
TAMU	Texas A&M University (College Station)
TAMUG	Texas A&M University at Galveston
TAMUS	Texas A&M University System
TIO	Texas Institute of Oceanography
TL	Transmission Loss
T-S	Temperature-salinity Relationship
USGS	United States Geological Survey
VIM	Vibration Isolating Mechanisms
WMO	World Meteorological Organization
XBT	Expendable Bathythermograph

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I. INTRODUCTION

R.W. Davis

1.1 Background and Objectives

The Minerals Management Service (MMS) is responsible for assuring that the exploration and production of oil and gas reserves located more than three miles offshore and within the U.S. Exclusive Economic Zone are conducted in a manner that reduces risks to the marine environment. To meet their responsibilities under the Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973, the MMS must understand the effects of oil and gas operations on marine mammals. As the oil and gas industry moves into deeper water along the continental slope in their continuing search for extractable reserves, information is needed on the distribution, abundance, behavior, and habitat of cetaceans, especially large and deep-water species in the Gulf of Mexico (Table 1.1). This study, hereafter called the GulfCet Program, was designed to help the MMS assess the potential effects of deepwater oil and gas exploration and production on marine mammals in the Gulf of Mexico.

The purpose of this study was to determine the distribution and abundance of cetaceans along the continental slope in the north-central and western Gulf of Mexico. The study was restricted to an area bounded by the Florida-Alabama border, the Texas-Mexico border, and the 100 m and 2,000 m isobaths (Figure 1.1). This 3.75 year project commenced on 1 October 1991 and concluded on 15 July 1995. In addition to conducting aerial visual, shipboard visual, and shipboard acoustic marine mammal surveys, the GulfCet Program collected hydrographic data *in situ* and by remote sensing to characterize the marine habitat of cetaceans in the study area (Table 1.2). An attempt was also made to tag sperm whales and track their movements using satellite telemetry.

1.2 Program Participants

The GulfCet Program was administered by the Texas Institute of Oceanography (TIO), which is part of the Texas A&M University System (TAMUS). Researchers at Texas A&M University Campuses at Galveston (TAMUG) and College Station (TAMU) provided expertise in marine mammal biology, bioacoustics, and oceanography. Expertise in aerial and shipboard surveys of marine mammals, satellite remote sensing, and Geographical Information Systems (GIS) was provided by the National Marine Fisheries Service (NMFS) at the Southeast Fisheries Science Centers (SEFSC). The SEFSC that participated in this study were the Miami Laboratory and the Mississippi Laboratories, with facilities at Pascagoula and Stennis Space Center. This part of the project was contracted under a separate Interagency Agreement between the MMS and the NMFS. Finally, the program included scientists from the Hatfield Marine Science Center at Oregon State University, who have developed techniques to tag and track whales using satellite telemetry. A list of the program's participants is shown in Table 1.3.

Table 1.1. Cetaceans of the Gulf of Mexico

Balaenidae	
Northern right whale	*Eubalaena glacialis*
Balaenopteridae	
Blue whale	*Balaenoptera musculus*
Fin whale	*Balaenoptera physalus*
Sei whale	*Balaenoptera borealis*
Bryde's whale	*Balaenoptera edeni*
Minke whale	*Balaenoptera acutorostrata*
Humpback whale	*Megaptera novaeangliae*
Physeteridae	
Sperm whale	*Physeter macrocephalus*
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	*Stenella coeruleoalba*
Spinner dolphin	*Stenella longirostris*
Clymene dolphin	*Stenella clymene*

Adapted from Mullin et al. 1991.

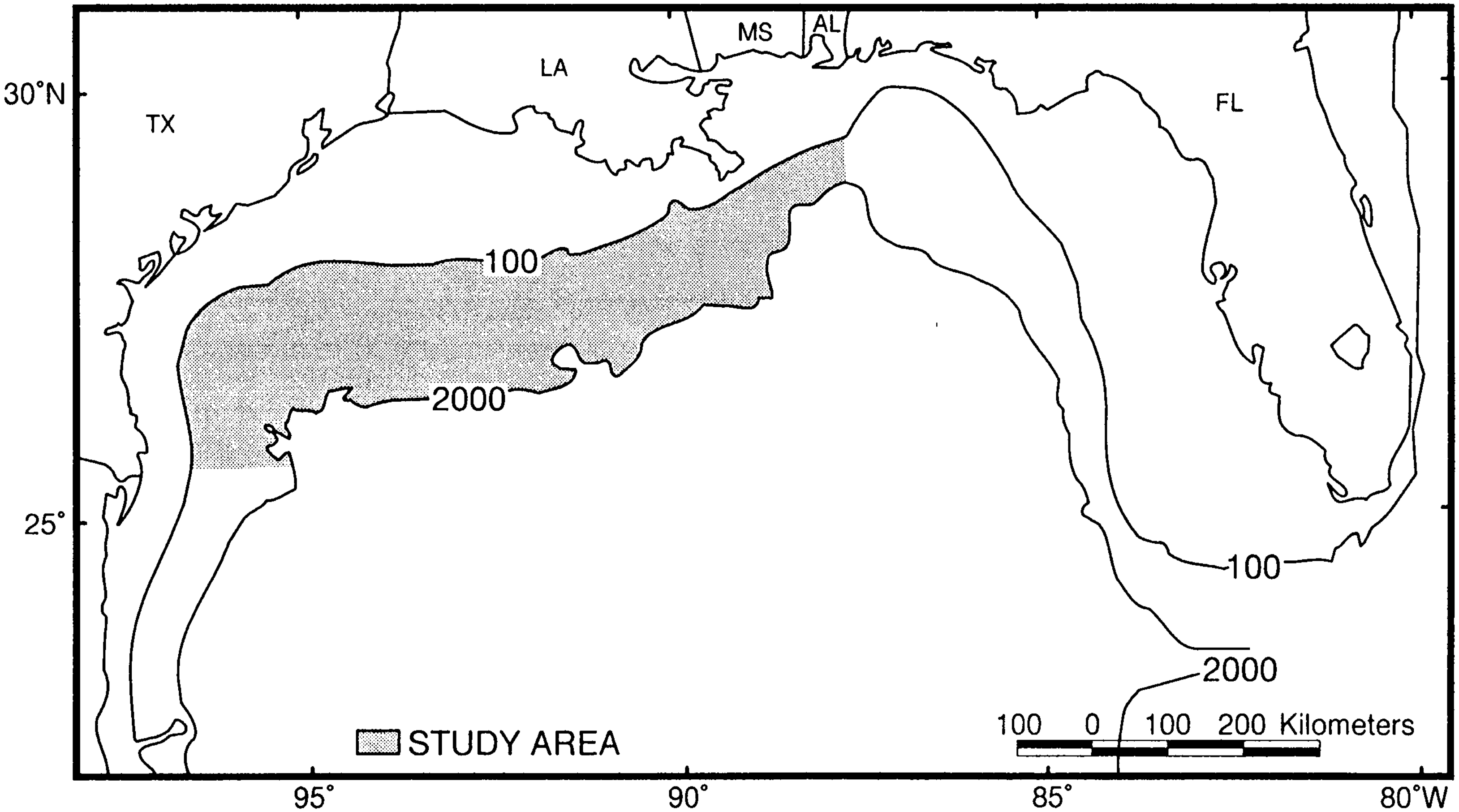

Figure 1.1. Study area between the 100 and 2,000 m isobaths, extending as far east as the Florida-Alabama border, and as far southwest as the Texas-Mexico border.

Table 1.2. Types of data collected by season and survey.

			Marine Mammal Surveys		Hydrographic Surveys					
Survey		Dates	Visual	Acoustic	CTD	XBT	Chlorophyll	Salinity	Nutrients	Remotely sensed SST
Spring 1992										
R/V *Longhorn*	Cruise 1	15 Apr-1 May 1992	✔	✔	✔	✔	✔	✔		✔
NOAA Ship *Oregon II*	Cruise 199									
	Leg 1	17 Apr-4 May 1992	✔		✔	✔	✔	✔		✔
	Leg 2	6-25 May 1992	✔		✔	✔	✔	✔		✔
	Leg 3	26 May-8 Jun 1992	✔		✔	✔	✔	✔		
Summer 1992										
R/V *Pelican*	Cruise 2	10-24 Aug 1992	✔	✔	✔	✔	✔	✔		✔
Aerial 1		10 Aug-19 Sep 1992	✔							✔
Fall 1992										
Aerial 2		3 Nov-16 Dec 1992	✔							✔
R/V *Pelican*	Cruise 3	8-22 Nov 1992	✔	✔	✔	✔	✔	✔		✔
Winter 1993										
NOAA Ship *Oregon II*	Cruise 203									
	Leg 1	5-17 Jan 1993	✔		✔	✔	✔	✔		✔
	Leg 2	18-30 Jan 1993	✔		✔	✔	✔	✔		✔
	Leg 3	1-14 Feb 1993	✔		✔	✔	✔	✔		✔
Aerial 3		1 Feb-22 Mar 1993	✔							✔
R/V *Pelican*	Cruise 4	12-27 Feb 1993	✔	✔	✔	✔	✔	✔		✔
Spring 1993										
Aerial 4		25 Apr-1 Jun 1993	✔							✔
NOAA Ship *Oregon II*	Cruise 204									
	Leg 1	3-17 May 1993	✔		✔	✔	✔	✔		✔
	Leg 2	18 May-2 Jun 1993	✔		✔	✔	✔	✔		✔
	Leg 3	4-15 Jun 1993	✔		✔	✔	✔	✔		✔
R/V *Pelican*	Cruise 5	23 May-5 Jun 1993	✔	✔	✔	✔	✔	✔		✔

Table 1.2. Types of data collected by season and survey. (continued)

Survey		Dates	Marine Mammal Surveys		Hydrographic Surveys					
			Visual	Acoustic	CTD	XBT	Chlorophyll	Salinity	Nutrients	Remotely sensed SST
Summer 1993										
Aerial 5		1-21 Aug 1993	✔							✔
R/V *Pelican*	Cruise 6	28 Aug-5 Sep 1993	✔	✔	✔	✔	✔	✔	✔	
Fall 1993										
Aerial 6		31 Oct-16 Dec 1993	✔							✔
R/V *Pelican*	Cruise 7	3-14 Dec 1993	✔	✔	✔	✔	✔	✔		✔
Winter 1994										
Aerial 7		31 Jan-15 Mar 1994	✔							✔
Spring 1994										
NOAA Ship *Oregon II*	Cruise 209									
	Leg 1	15-24 Apr 1994	✔		✔	✔		✔		✔
	Leg 2	27 Apr-18 May 1994	✔		✔	✔		✔		✔
	Leg 3	20-29 May 1994			✔	✔		✔		✔
	Leg 4	30 May-10 Jun 1994	✔		✔	✔		✔		✔
Aerial 8		2 May-2 Jun 1994	✔							✔
Summer 1994										
R/V *Pelican*	Cruise 8	20-28 Aug 1993	✔	✔		✔				

Table 1.3. **GulfCet management structure, principal investigators, and their affiliations.**

Randall Davis	Program Manager, Principal Investigator	TIO, TAMUG
Bernd Würsig	Deputy Program Manager, Principal Investigator	TIO, TAMUG
Gerald Scott	Program Manager for SEFSC	NMFS, SEFSC, Miami Laboratory
William Evans	Principal Investigator, TIO President	TIO, TAMUG
Giulietta Fargion	Data Manager, Principal Investigator	TIO, TAMUG
Robert Benson	Principal Investigator	TIO, TAMU
Larry Hansen	Principal Investigator	NMFS, SEFSC, Miami Laboratory
Thomas Leming	Principal Investigator	NMFS, SEFSC, Stennis Space Center
Bruce Mate	Principal Investigator	OSU, HMSC
Nelson May	Principal Investigator	NMFS, SEFSC, Stennis Space Center
Keith Mullin	Principal Investigator	NMFS, SEFSC, Pascagoula Laboratory

TIO= Texas Institute of Oceanography
TAMUG= Texas A&M University, Galveston
TAMU= Texas A&M University, College Station
NMFS= National Marine Fisheries Service
SEFSC= Southeast Fisheries Science Center
OSU= Oregon State University
HMSC= Hatfield Marine Science Center

The GulfCet Program had a Scientific Review Board (SRB) composed of five scientists who reviewed and commented on the project's goals, methodologies, results, analyses, and conclusions. The SRB members were:

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Dr. N. Bray of the Scripps Institution of Oceanography, La Jolla, California, was a previous SRB member who was replaced by Dr. J. Cochrane in September 1993.

1.3 Report Organization

This report is organized like a book, with an introduction and separate chapters covering the major parts of the study. Based on their respective areas of expertise, each author contributed to their individual chapters and to Chapters 9 (Habitat) and 10 (Conclusions and Recommendations).

The Introduction, Chapter 1, describes the purpose of this study, the program objectives, and the program participants. In Chapter 2, Davis and May provide a geographical overview of the Gulf of Mexico. Fargion and Leming then describe the general oceanography of the region. A historical overview of the abundance and distribution of cetaceans is provided by Jefferson. In Chapter 3, Hansen and Mullin present the results of the aerial and shipboard visual surveys of cetaceans and sea turtles. This was one of the largest parts of the GulfCet program, and this chapter forms the core of the species abundance estimates, seasonal distribution, and estimates of group sizes in the study area. Evans, Benson, Norris, and Sparks present the results of the ship-board acoustic surveys in Chapter 4. The use of towed acoustic hydrophone arrays is a relatively new technique for censusing marine mammals, and it proved very useful for detecting many species of cetaceans and, in the case of sperm whales, estimating abundance. The behavioral reaction of cetaceans to the aerial and shipboard survey platforms is presented by Würsig, Lynn, and Mullin in Chapter 5. Their results show how cetacean behavior towards a survey platform may influence abundance and distribution estimates. Fargion presents the results of the oceanographic surveys in Chapter 6. The GulfCet program conducted an extensive survey of the marine environment concurrently with the visual and acoustic surveys of cetaceans. These results were then used in an analysis of habitat. Although not part of the original scope of work, an ornithological survey was conducted by Peake and members of the National Marine Fisheries Service during cetacean surveys. The results are presented in Chapter 7. Chapter 8 presents data collected during the sperm whale focal cruise (TIO Cruise 8), and, although no data was obtained, Mate describes the attempts to attach satellite telemeters to sperm whales during dedicated cruises in order to track their movements at sea and record their diving behavior. He also discusses the technical problems that were experienced. There has been increasing interest in habitat partitioning among cetaceans, although acquiring the simultaneous data on cetacean distribution and environmental characteristics has been difficult. In Chapter 9, Davis, May, Fargion, and Evans analyze the data from Chapters 3 and 6 to develop an environmental profile for cetaceans living in the study area. Some evidence is provided for habitat partitioning. In the final Chapter, Davis, Mullin, Fargion, May, and Evans draw the final conclusions and make recommendations for future research.

1.4 Literature Cited

Mullin, K., W. Hoggard, C. Roden, R. Lohoefener, and C. Rogers, and B. Taggart. 1991. Cetaceans on the upper continental slope in the north-central Gulf of Mexico. OCS Study MMS 91-0027. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, LA. 108 pp.

II. OVERVIEW OF THE GULF OF MEXICO

R.W. Davis, B. Würsig, G.S. Fargion, T.A. Jefferson, and C. Schroeder

This section of the report will acquaint readers with the general geography, climatology and oceanography of the northern Gulf of Mexico. In addition, we review historical data on the distribution and abundance of cetaceans in offshore waters of the Gulf. We hope that this brief introduction will assist the reader in understanding the results and conclusions in the chapters that follow.

2.1 Geographic Overview

The region encompassing the Gulf of Mexico and Caribbean Sea have been termed the "American Mediterranean" since both are isolated and semi-enclosed basins (Sverdrup et al. 1949). The Gulf basin encompasses an area of about 1.5 million km^2 and is bounded by the United States, Mexico, and Cuba. The basin consists of sialic basement materials, and in the east and southeast, the carbonate structures of the Florida-Bahama Platform and Campeche-Yucatan Bank, respectively (Brooks 1973). The Gulf is connected to the Caribbean Sea via the Yucatan Straits, a relatively deep (2,000 m) channel, and to the Atlantic Ocean through the Florida Straits, a silled channel with a depth of about 860 m (Jones 1973). Based on tabulations from Herring's (1993) bathymetric data, continental shelf waters less than 180 m deep cover about 35.4% of the total area of the Gulf. The continental shelf varies greatly in width. Along the Florida west coast, the southern coast of Texas, and the northern coast of the Yucatan Peninsula, the continental shelf is 160-240 km wide. In contrast, it is only 32-48 km wide at the mouth of the Mississippi River and along certain coastal areas of the Bay of Campeche, Mexico. The continental slope, defined as bottom depths between 180 and 3,000 m, covers about 39.2% of the total area and contains steep escarpments and numerous submarine canyons. The areas located in depths greater than 3,000 m (i.e., Sigsbee Plain and sections of the Lower Mississippi Fan) make up the remaining 25.4% of the total area. At its deepest point, on the Sigsbee Plain, the Gulf is 3,700 m deep. The bathymetry and principal physiographic features are shown in Figure 2.1. Whereas the continental shelf is a smooth, gently sloping plain, the upper continental slope in the north-central and western Gulf is characterized by complex hill and basin topography. The average gradient in the study area is less steep than the average gradient for the entire Gulf of Mexico (Figure 2.2).

The formation of the Gulf basin apparently began during the late Paleozoic to early Mesozoic eras (Kennett 1982). The evolutionary history of the Gulf has been characterized by significant physiographic changes in the region due to global climate changes, sea level oscillations, sediment deposition, erosion, and subsidence. The veneer of sediments which covers the region can be classified into two categories: those of terrigenous origin, consisting of quartz sand, clay, and silts eroded from the continental land masses; and calcareous sediments originating from marine flora and fauna. The sediment map of the

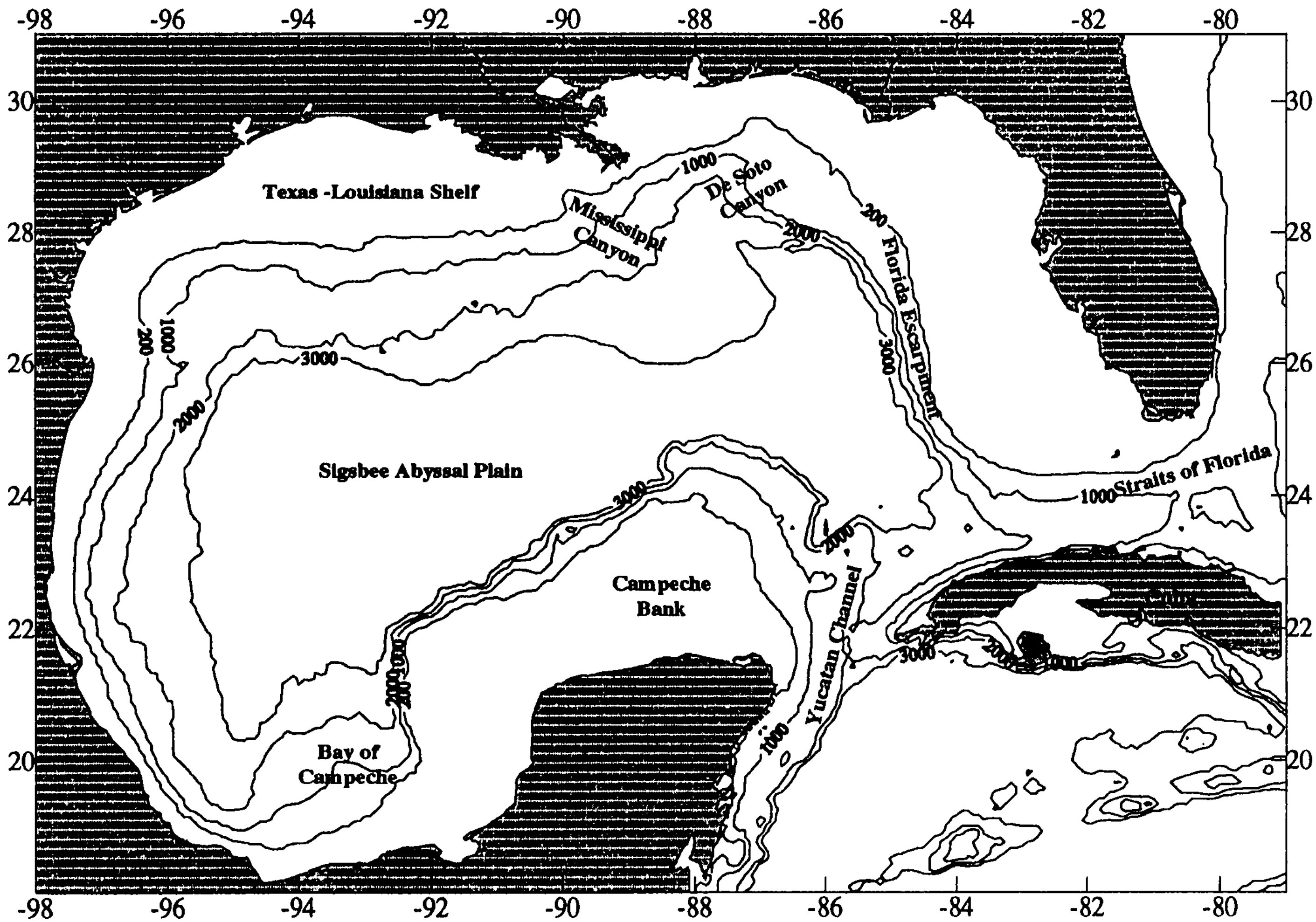

Figure 2.1. Bathymetry and major physiographic features of the Gulf of Mexico.

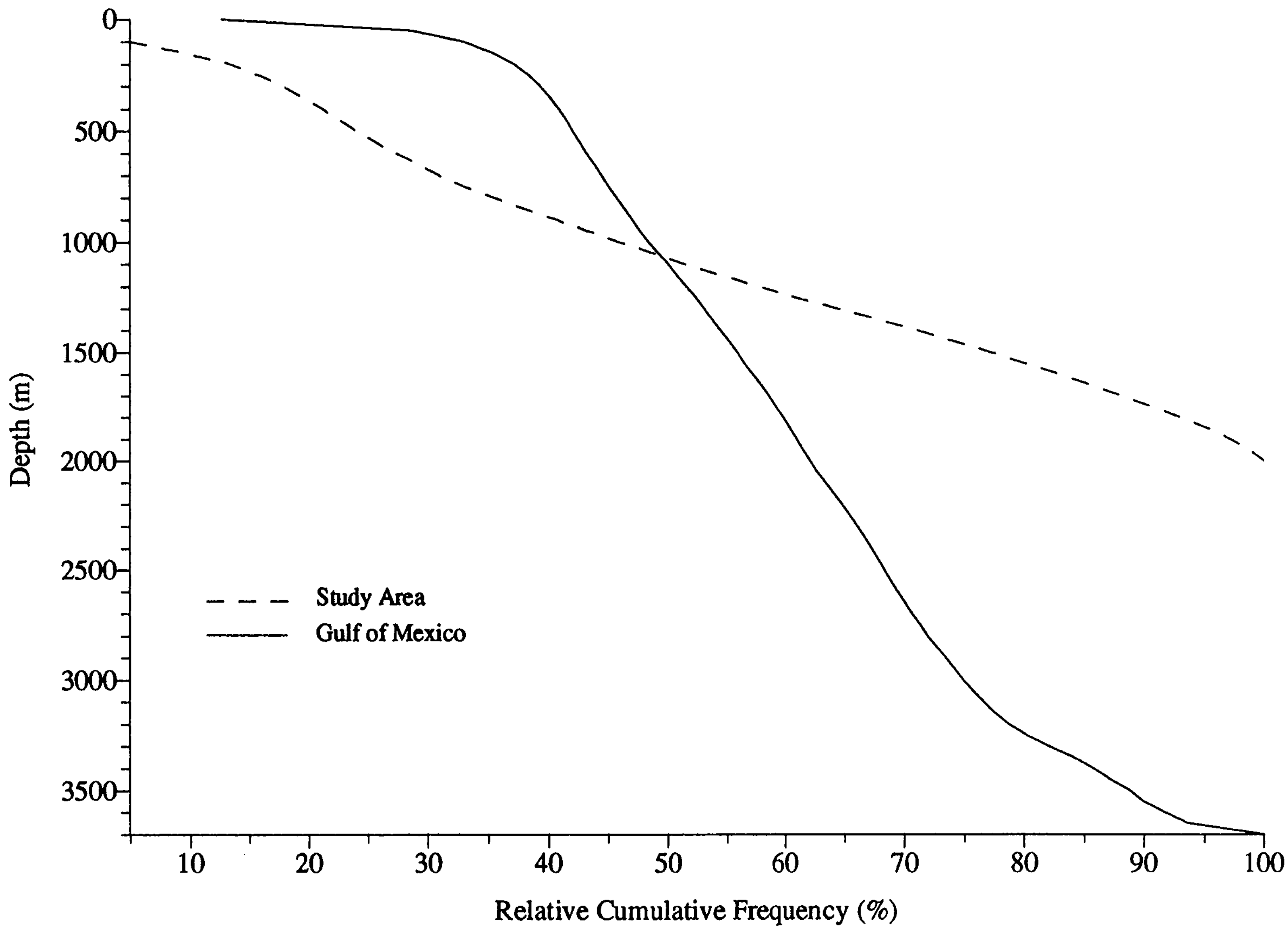

Figure 2.2. Bottom depth profiles of the Gulf of Mexico and GulfCet study area tabulated from Herring's (1993) bathymetric data set showing the percentage of each region which is less than a given depth.

Gulf from Uchupi and Emery (1968) indicates that the two sediment classes vary both spatially and in composition across the region. Terrigenous sediments are present in bands adjacent to land along the continental shelf, with the exception of the Yucutan-Campeche Shelf, and in the northern and western Gulf along the continental slope. Calcareous sediments are evident in the deeper areas of the Sigsbee Plain and Lower Mississippi Fan, along the Yucutan-Campeche Shelf, and the outer continental shelf off the Florida west coast.

The climatology of the central and western Gulf, which includes the GulfCet study area, is influenced by two seasonal weather patterns with well-defined transitional periods (Florida A&M University 1988). During the summer and early fall months (May to October), moist maritime tropical air dominates, with a mean air temperature of approximately 26° C. During the winter and early spring months (December to March), the mid-latitude polar jet stream pushes southward and displaces the maritime tropical air with cold, dry continental air. The mean air temperature during the two transitional months of April and November is about 20° C. Winds are typically influenced by tropical air masses arriving from the south and southeast in spring and summer, and by cold air fronts moving southward in the autumn and winter. Mean winter air temperature is around 13° C. Severe hurricanes frequently enter the Gulf from the mid-Atlantic Ocean, especially during the summer months. Wind and fresh water discharge from the Mississippi/Atchafalaya River system are the dominant factors controlling hydrographic conditions and variability on the inner portions of the Texas-Louisiana shelf (Kelly 1988). The Mississippi/Atchafalaya River system contributes about 73% of the fresh water entering the northern Gulf. About 20% is contributed by precipitation, and the remaining 7% comes from smaller rivers and streams (Darnell and Phillips 1988).

Tides in the Gulf are usually diurnal (one high and one low tide per lunar day of 24.84 hours) with a small, semidiurnal component (Marmer 1954). The relative magnitudes of the diurnal and semidiurnal components result in mixed tides off the Calcasieu Pass, Louisiana area and primarily diurnal tides from the Mississippi Delta eastward and to the west of Galveston, Texas (Kelly 1988). The tidal range averages about 60 cm throughout the Gulf.

2.2 General Oceanography of the Region

2.2.1 *Circulation Patterns*

The Gulf of Mexico is a semi-enclosed basin with only two openings, the Yucatan Channel and the Straits of Florida. Water flow through the two openings is further restricted to the upper portion of the water column by sills that are 1900 m and 800 m deep, respectively. The circulation of the eastern Gulf is governed by the Yucatan Current and the Florida Current. The Yucatan Current flows into the Gulf through the Yucatan Channel, and the Florida Current flows out of the Gulf through the Straits of Florida. The subsequent clockwise flow of water thus created extends northward into the Gulf and unites the two currents. This circulatory feature is referred to as the Loop Current.

The Gulf is dominated by two major circulation features: the Loop Current system in the eastern Gulf, which sheds eddies as a result of instability processes, and an anticyclonic cell (warm-core eddy) of circulation in the western Gulf (Nowlin and McLellan 1967, Behringer et al. 1977, Merrell and Vazquez 1983). The Loop Current enters the Gulf in a nearly annual cycle. The extent of its intrusion into the Gulf varies with season, but reaches a maximum in the summer, at which time an anticyclonic eddy usually separates from the Loop and drifts westward (Hofmann and Worley 1986, Merrell and Vazquez 1983). The eddy can and often does reattach itself to the Loop Current. High fluctuations in the frequency of eddy formation ranging from 8 to 17 months have been reported by Behringer et al. (1977). Advanced Very High Resolution Radiometer (AVHRR) data from NOAA satellites have produced maps that show Gulf warm-core eddies originating as pinched-off, northward penetrations of Loop current meanders. After their separation from the Loop Current, these anticyclonic rings drift westward until their progress is eventually constrained by shoaling topography that leaves them in a "graveyard" over the northwestern continental slope of the Gulf (Vukovich and Hamilton 1989). These warm eddies interact with the steep topography of the Mexican and Texan continental slope and generate secondary cyclonic (cold-core) eddies. These warm-core and cold-core eddies remain in the region, slowly decaying or coalescing with another approaching eddy.

The ability to locate Gulf warm-core rings by their sea surface temperature (SST) anomaly is usually limited seasonally to the period. November through May. For the remainder of the year, the sea surface temperature for the entire Gulf is uniform, and so eddies cannot be distinguished by temperature. During the summer months, clouds and water vapor further limit the detection of eddies by making clear satellite images of the Gulf difficult to obtain.

Vukovich and Hamilton (1989), using infrared satellite data (1976-1980), showed that the Loop Current covers more than 50% of the oceanic area of the Gulf east of 90°W over 50% of the time. They also found that the highest probability for warm rings occurred at about 25°N and 92°W. Warm rings are also common in the southwestern Gulf, but are not easily detected by satellites because of the rapid warming of the region in the spring and the effects of cloud cover.

Vidal et al. (1992) have shown that the weakening of the western Gulf's anticyclonic rings' relative vorticity is due to their collision against the western Gulf of Mexico's continental slope. Hence, anticyclonic ring interactions with the western Gulf boundary give rise to cyclonic-anticyclonic ring pairs. Recent field work has shown that when an anticyclonic (warm-core) eddy is present in the northwestern corner of the Gulf, there are often one or more regions of local, cold cyclonic circulation about its perimeter (Biggs et al. 1988, Vidal et al. 1990 and 1992). In addition, recent studies have described different types of rings or eddies, including anticyclonic eddies, cyclonic eddies, cyclonic-anticyclonic eddy pairs (Merrell and Morrison 1981, Brooks and Legeckis 1982), and cyclonic-anticyclonic-cyclonic triads (Vidal et al. 1994, Jockens et al. 1994).

Less is known about the circulation in the western Gulf relative to the eastern Gulf (Merrell and Morrison 1981). In general, the large-scale circulation consists of a clockwise (anticyclonic) gyre which is most prominent in the upper 500 m of the Gulf (Hofmann and Worley 1986). Eastward to westward transport associated with the gyre is approximately equal to 5 x 10^6 $m^3 \cdot s^{-1}$. Variations to this flow are created by the Loop Current in the eastern Gulf and a cyclonic eddy in the northwestern Gulf. Two primary mechanisms for maintaining the western Gulf anticyclonic gyre have been suggested. The first mechanism is thought to maintain the gyre by separated Loop Current eddies which have drifted to the west (Ichiye 1967, Schroeder et al. 1974). The second mechanism postulates that the gyre is driven by a curl of wind stress and thus is analogous to the world's major ocean gyres (Sturges and Blaha 1976). The relative contribution of each mechanism may vary greatly from year to year. An equal contribution of both mechanisms has been suggested by Merrell and Morrison (1981). Figure 2.3 shows a schematic of the Loop Current and warm-core eddies pinching off the Loop Current.

2.2.2 *Water Temperature and Salinity*

In 1916, Helland-Hansen (Sverdrup et al. 1949) introduced the study of temperature-salinity (T-S) diagrams for analyzing and identifying a complex system of water masses. The first attempt to establish a T-S characteristic for the Gulf was made by Parr (1935) using the *Mabel Taylor* winter cruise data. Parr was able to recognize two separate water masses within the Gulf: that derived from the Caribbean and Gulf water. Maximum sampling depth for these data was 200 m, so the distinction of these water masses was confined to the this portion of the water column. The first complete coverage of the Gulf was with the R/V *Hidalgo* survey (winter 1962). Nowlin and McLellan (1967) analyzed these data and for the first time, constructed T-S diagrams below 1500 m.

A temperature-salinity diagram constructed for the Gulf reveals a distinct maximum (36.60 to 36.70 psu with a temperature of 22.5°C) and minimum (34.84 to 34.88 psu) salinity. These salinity signatures are characteristic of Subtropical Underwater (SUW) and Antarctic Intermediate Water (AAIW), respectively. Each of these water masses is found in the adjacent Cayman Sea and enters the Gulf through the Yucatan Channel (Nowlin and McLellan 1967). Usually the SUW salinity maximum is centered at about 200 m. The AAIW salinity minimum in the eastern Gulf occurs between depths of 800 to 1,000 m (shallower in the western Gulf). Waters below the AAIW are isosaline at 34.97 psu. This salinity concentration is consistent with that found in the flow of North Atlantic Deep Water (NADW) over the Yucatan sill into the Gulf (Nowlin and McLellan 1967, Morrison et al. 1983). Hofmann and Worley (1986) used these three water masses as a basis for a three-layer system to investigate the circulation of the Gulf.

The SUW is found in the region of the Loop Current and the rings derived from the current. These rings constitute the principal mechanism by which Caribbean Sea water enters the central and western Gulf (Elliot 1982). Thus the SUW can be used as a tracer to identify the presence of anticyclonic rings within the Gulf. The collision of Loop Current anticyclonic rings against the western continental slope of the Gulf constitutes the principal mechanism responsible for the dilution of SUW core water and its conversion to Gulf

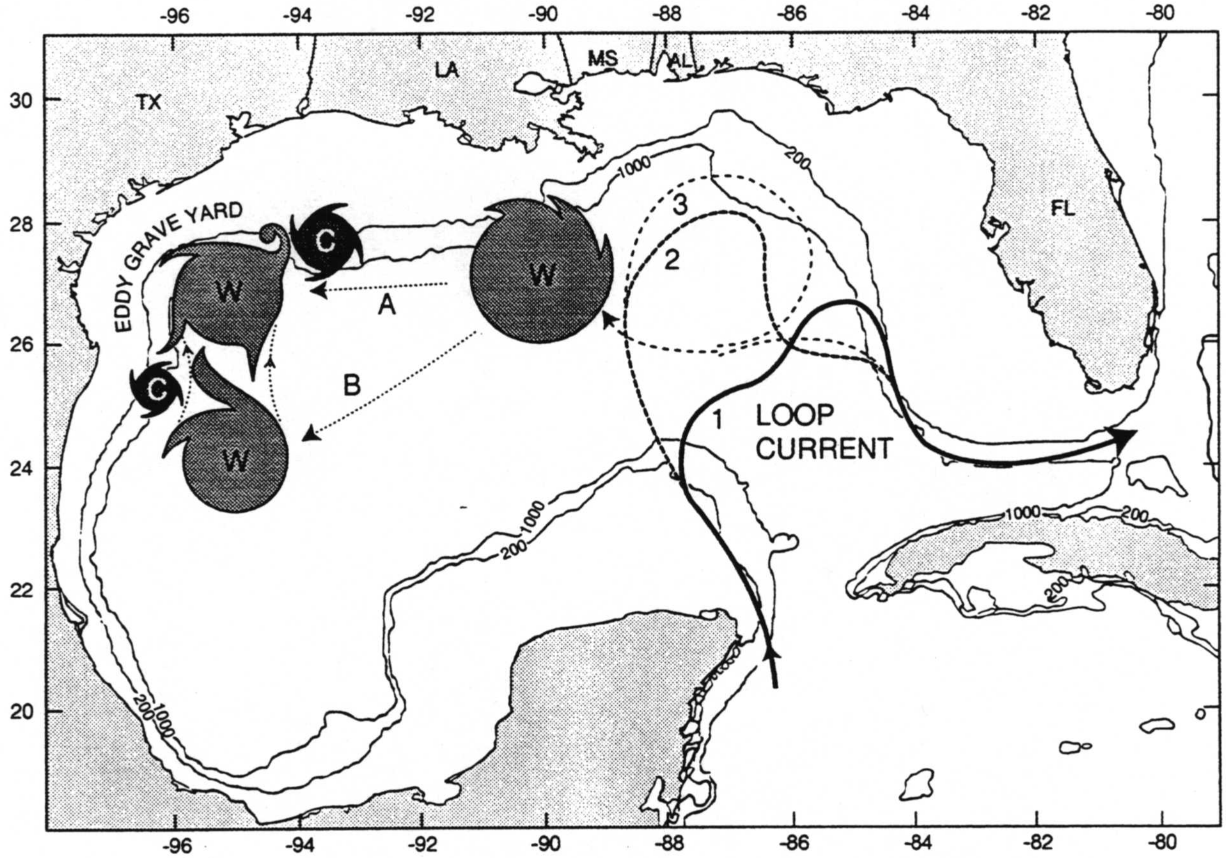

Figure 2.3. Schematic of the life-cycle of a Loop Current anticyclonic or warm-core eddy (W) as it is pinched off or separated from the Loop Current, and its possible paths through the western Gulf of Mexico. A time series representation of the Loop Current shows it in three possible positions (1-3). The third position represents the most northerly intrusion into the Gulf (this event usually occurs in summer), at which time an anticyclonic eddy may pinch off from the Loop Current. After its formation, the warm-core eddy may follow one of two paths: a westerly (A) or southwesterly (B) path. Cyclonic or cold-core eddies (C) are frequently associated with a warm-core eddy. Regardless of whether an eddy follows path A or B, anticyclonic eddies spin down or fade away in an area of the NW Gulf known as the eddy graveyard. This is due to loss of vorticity from collision with the continental margin.

Common Water (GCW). GCW is also formed during the winter by intense vertical mixing in the upper 200 to 300 m of the water column. Water in the upper 250 m of the western Gulf is then characterized by salinity concentrations of 36.4 to 36.5 psu and are then designated as GCW (Morrison et al. 1983).

2.2.3 *Mississippi River Influence*

The Mississippi River is the largest river in North America and the sixth largest worldwide in terms of discharge (Milliam and Meade 1983). The Mississippi River discharges into the northern Gulf through the Balize and Atchafalaya delta regions. Approximately 30% of the Mississippi River flow enters the northern Gulf through the Atchafalaya, and the remaining 70% goes through the Balize bird-foot delta. The fresh water influence of this river has been observed as far away as 800 km from its source, near Port Aransas, Texas (Smith, 1980). In the summer of 1993, the fresh water flow reached the Straits of Florida and the east coast of the U.S. (Walker et al. 1994).

Nearly two-thirds of the U.S. mainland and half the area of Mexico drains into the Gulf (Weber et al. 1990). 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. Walker and Rouse (1993) utilized four years of AVHRR data (1989-1992) to quantify which areas of the continental shelf and slope of the Gulf are most influenced by the river. The eighty-three satellite images revealed that the Mississippi River plume area varied from 450 km^2 to 7,700 km^2. Under medium discharge conditions (10,001 to 20,000 $m^3 \cdot s^{-1}$) the mean extent of the river plume covered 2,200 km^2 and exhibited a southwest-northeast orientation following the 200 m isobath. Under maximum discharge (20,001 to 35,000 $m^3 \cdot s^{-1}$), the river's plume covered an extensive area of the continental shelf-slope (13,207 km^2) and extended from 88°20'W to 90°50'W and offshore to the 1,000 m isobath.

Walker and Rouse (1993) identified wind as a major force for sediment transport. Under the influence of strong northeasterly winds, shelf water can be rapidly forced away from the delta and onto the continental slope. The Mississippi River plume is then subject to oceanic forcing by eddies and filaments detached from the Loop Current. Walker and Rouse also documented large, persistent anticyclonic-cyclonic Loop Current eddies east of the delta. The current associated with these eddies can augment the off-shore movement of water from the continental slope.

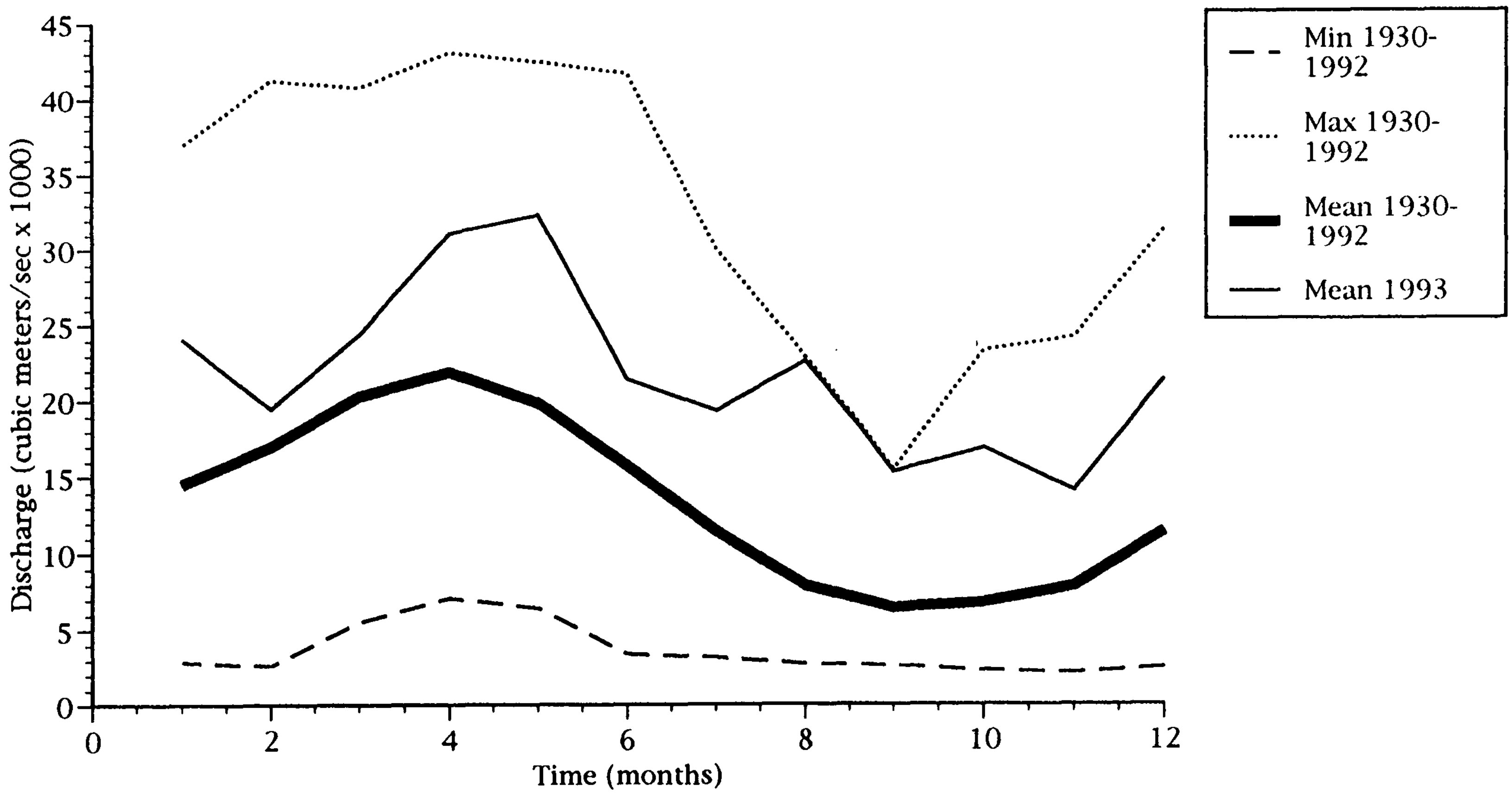

Figure 2.4. Comparison of 1993 total Mississippi River discharge volume to that of the minimum, maximum, and mean river discharge volumes (in cubic meters/second x 1,000) for 1930-1992 (data courtesy of the LATEX-A program).

The 1992-1993 Mississippi River flow was anomalous in its seasonality and flow (USGS 1992 and 1993 a and b). High rainfall during the spring of 1993 caused the ground to become saturated, so that when the rainfall continued to be unusually high throughout the summer, extreme flooding occurred along the Mississippi River valley in the late summer of 1993. The result was that the highest rainfall and therefore outflow from the Mississippi and its tributaries occurred unseasonably in August of 1993. GulfCet's Cruise 6 (R/V *Pelican*) took place during August-September of 1993, and very high fresh water concentrations were found from the surface to a depth of three meters on the easternmost track-line. The seasonality of the Mississippi River is shown in Figure 2.4. This shows the total discharge volume of the river using daily data from 1932 to 1992. Figures 2.5 and 2.6 show the flow of the river from November 1979 to June 1986 with a time series of chlorophyll pigments from the Coastal Zone Color Scanner (CZCS) satellite. The data clearly indicate a positive correlation between the Mississippi River flow and the interannual variations in chlorophyll concentration, which in turn influence the development of high primary productivity in the Gulf.

Another consequence of the fresh water influence in the Gulf is the hypoxic condition (i.e., oxygen concentrations below 2 mg/l) of waters found along the Louisiana coastline west of the Mississippi delta (Rabalais et al. 1991). Two events have been suggested to cause this condition. The first event may be initiated by an increase in phytoplankton biomass during the summer (a bloom), which is fueled by the high nutrient content of the fresh water. The sinking and subsequent degradation of this increased biomass causes the hypoxia. The second scenario may occur when the river's widespread low-salinity plume is rapidly heated by solar radiation, resulting in a very stable, stratified water mass on the continental shelf. Mixing of the water column is prevented by this stratification and leads to stagnant, hypoxic conditions in the lower portion of the water column. The effect of this hypoxic condition certainly impacts the benthic community, but its affect on the fish community has not yet been determined (Rabalais et al. 1991).

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 shelf-slope and into the northern Gulf. The fresh water of the Mississippi affects the spatial and temporal distribution of areas of higher primary production which may also influence the distribution of cetaceans in the Gulf of Mexico.

2.2.4 *Summary*

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 Gulf. In the western Gulf, a warm water anticyclonic eddy with associated cold water cyclones is the primary circulatory feature. Temperature-salinity diagrams demonstrate the complexity of the Gulf of Mexico. Waters of the Gulf of Mexico are derived from three water masses: Subtropical Underwater, Antarctic Intermediate Water, and North Atlantic Deep Water. Each of these water masses

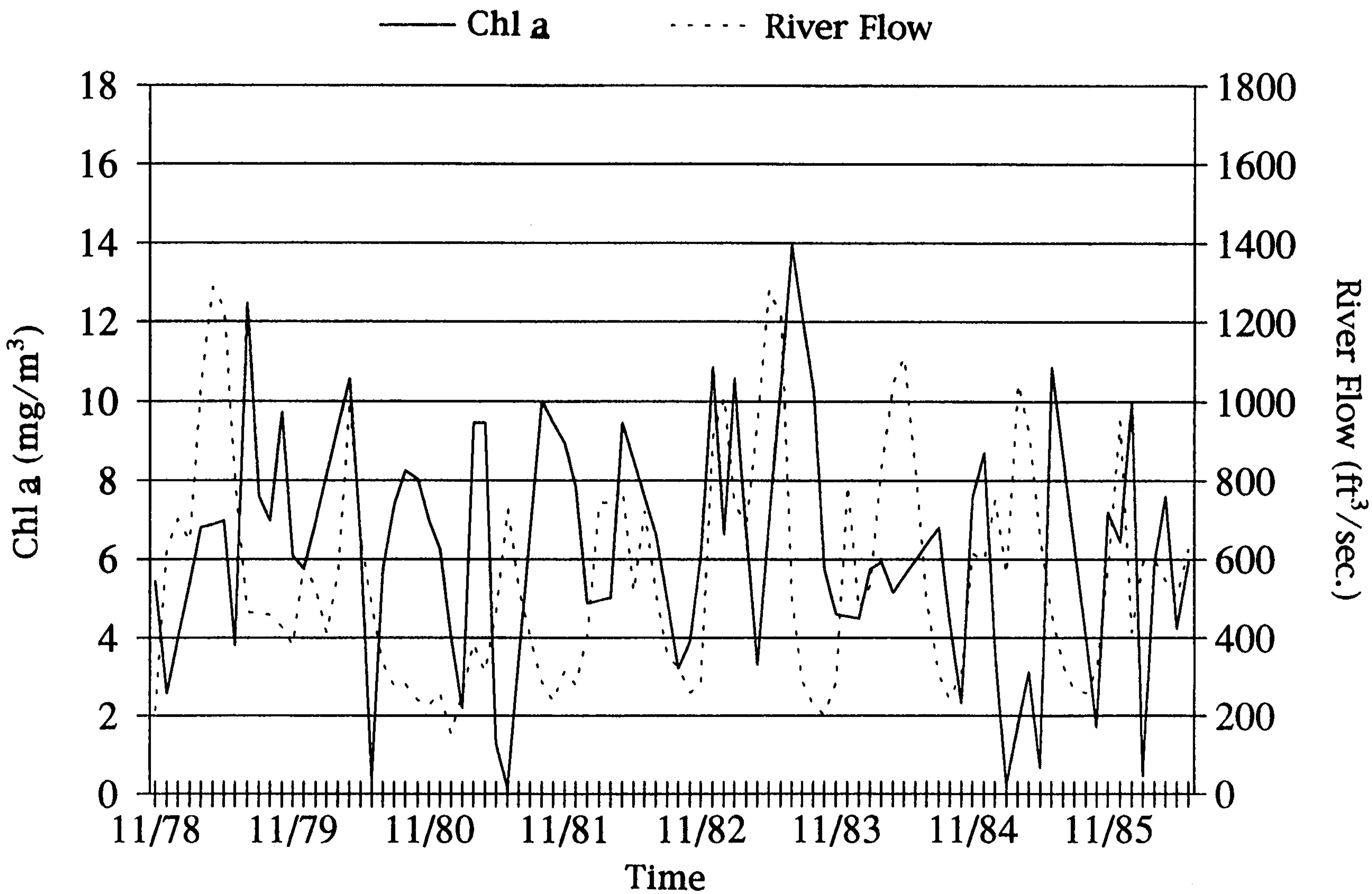

Figure 2.5. Time series 1979-1986 of Mississippi River flow and chlorophyll pigment data from CZCS (data in close proximity to *Pelican/Longhorn* station 12-125).

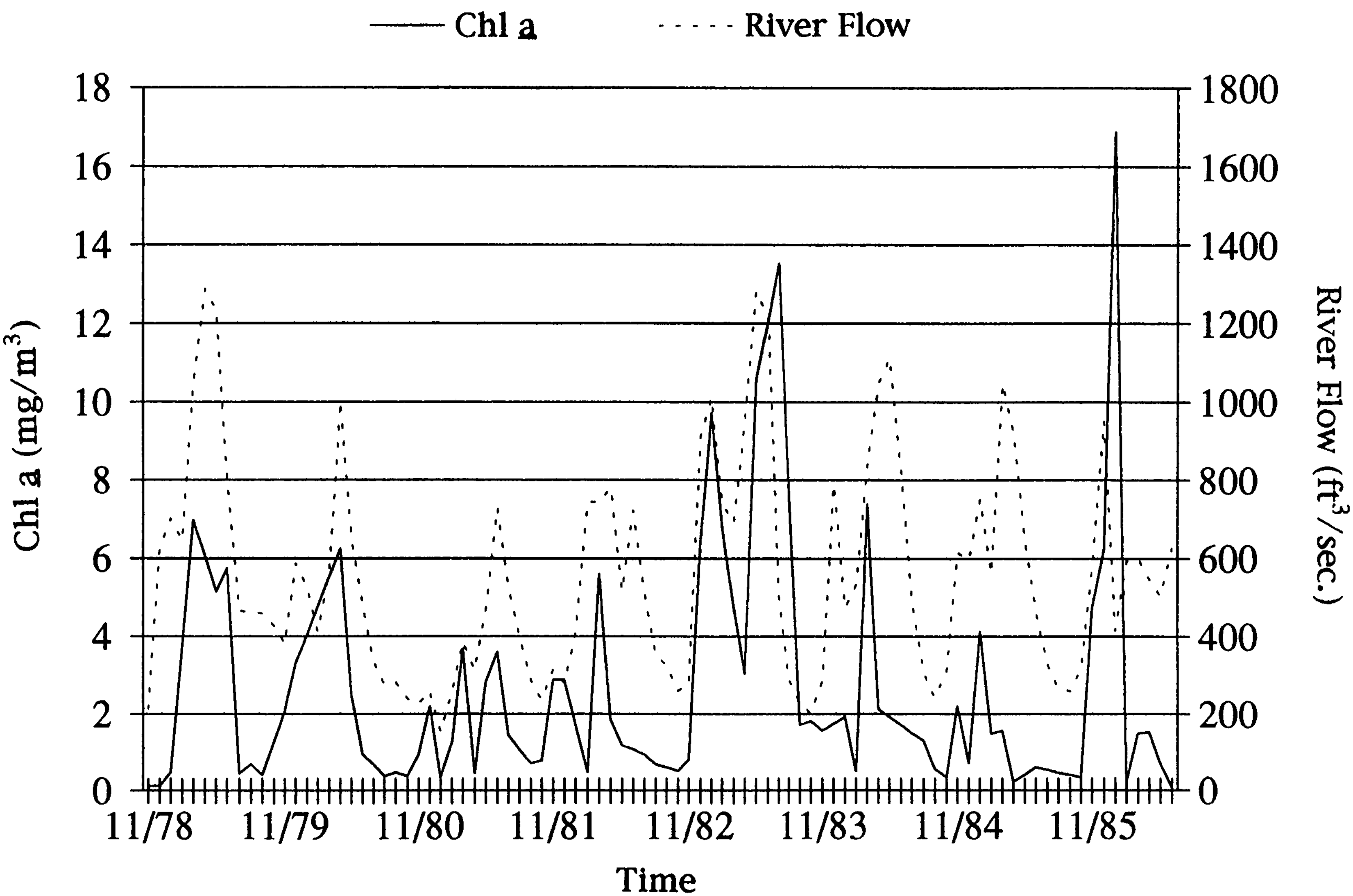

Figure 2.6. Time series 1979-1986 of Mississippi River flow & chlorophyll pigment data from CZCS (data in close proximity to *Pelican/Longhorn* station 11-106).

has its own characteristic temperature and salinity range. These characteristics allow the identification and tracking of these water masses in the Gulf. As mixing and dilution of these water masses occurs, the conversion to Gulf Common Water takes place. Gulf Common Water is identified by a salinity of 36.4-36.5 psu. The dynamics of the Gulf are made more complex by the large fresh water inflow. Nearly two-thirds of the continental U.S. and half of Mexico's land area drains into the Gulf. The associated nutrient input from this fresh water inflow increases the level of primary production with a subsequent increase in secondary production as well. The overall resulting circulation of the Gulf of Mexico is remarkable because of its interannual variability and intensity.

2.3 Historical Overview of the Distribution of Cetaceans in the Offshore Gulf of Mexico

2.3.1 *Introduction*

This section provides an overview of previous knowledge about the status of marine mammals in the north-central and western Gulf of Mexico. This overview serves as a bench mark for present and future studies and provides information Gulf-wide instead of only in the northern part of the Gulf.

Many types of marine mammal distribution records were reviewed and analyzed for this section of the report. It is important to remember that what a particular record indicates about the distribution of a species depends on the record type. Sightings (with very few exceptions) can be assumed to indicate the true location and movement of the animals. The animals are at a specific location because they swam there of their own volition. Not all sightings are indicative of the normal range of the species, however, as animals may get lost or occasionally venture to areas outside their normal range during unusual circumstances.

Similarly, most direct captures (reports of incidental captures in fishing gear are rare in the Gulf) first involve a sighting of a group of animals and can generally be assumed to represent a true location. The major exception to this generalization involves some of the Gulf records where an animal was captured outside its normal habitat, usually very near to shore, possibly in the process of stranding.

Finally, strandings should not be assumed to indicate anything more than a very general region of occurrence (and nothing at all of the habitat preference of a species). Reasons for this assumption are that strandings often involve sick or injured animals that are behaving abnormally, swimming or being carried (sometimes after death) by currents many hundreds of kilometers from their normal range. One need only look at the numerous stranding records for offshore species, such as sperm whales and beaked whales, to understand the significance of this.

Strandings involve at least one other major bias: they are highly dependent on physical features that bring the animals to shore. Currents and weather patterns will affect when and where (and even if) an animal strands. In the Gulf, for instance, a dolphin that dies off the coast of Louisiana may wash up on a beach in southern Texas due to the current system in that part of the Gulf. There are also many reports of cetacean strandings in the Gulf of Mexico coinciding with the passage of hurricanes or other large oceanic storms (Lowery 1943, 1974, Gunter 1955, Waldo 1957, Caldwell and Caldwell 1969, Schmidly et al. 1972a, Schmidly and Melcher 1974, Schmidly and Shane 1978, Davis 1978, Gruber 1981, Harris 1986). Thus, it should not be assumed that the stranding of a cetacean in a certain area at a certain time means that the species naturally occurs in that area at that time.

There have been few systematic surveys of marine mammals in the Gulf of Mexico, especially in the offshore areas. For species other than the bottlenose dolphin, what is known of their natural history in the Gulf comes mostly from occasional strandings or opportunistic sightings, and for at least one species, old whaling records. The first large-scale vessel surveys to assess marine mammal distribution and abundance in the Gulf of Mexico began in 1990.

Two reports have previously summarized information on historical cetacean records for the Gulf of Mexico. Schmidly (1981) presented distribution maps for all species of cetaceans known to occur in the Gulf of Mexico. This analysis has continued to be useful, but it is now out-of-date. In addition, because Schmidly was not able to verify species identification for many records, there were many mistaken identifications. Recently, Jefferson et al. (1992) updated Schmidly's maps for a cetacean field guide of the Gulf of Mexico. This guide provided more recent information, but suffered from similar verification problems with some of the historical records. It is thus suggested that the maps of Schmidly and Jefferson et al. not be cited, but that those included in this section be used instead.

This section reviews and summarizes what is known of the historical distribution and seasonal occurrence of offshore cetaceans in the Gulf of Mexico. Offshore cetaceans are defined here to include all those members of the order Cetacea found in the Gulf, with the exception of the bottlenose dolphin. This species was not included because it has primarily been recognized as a coastal species, and its distribution in the Gulf has been comparatively well studied (Leatherwood et al. 1978, Barham et al. 1980, Odell and Reynolds 1980, Leatherwood and Reeves 1983, Scott et al. 1989, Mullin et al. 1990). However, the GulfCet program has found what may be a larger form of bottlenose dolphin which is present quite commonly in the offshore waters of the Gulf, and more detailed information may be found in Appendix A sighting records as well as in Chapter 3. The analyses in this section are based on all available records, published and unpublished, except those resulting from the GulfCet program (except where these have already been published: Leatherwood et al. 1993, Mullin et al. 1994a, and Mullin et al. 1994b). The GulfCet records form a continuous, homogeneous database, based on systematic surveys.

2.3.2 *Data Acquisition*

2.3.2.1 *Area of Coverage*

For the purposes of this section, the Gulf of Mexico study area was demarcated in the east by a line from the southern tip of Florida to the Cuban coast, running along longitude 80°30'W, and in the southeast by the shortest line from the northeastern tip of the Yucatan Peninsula to Cabo San Antonio (or western), Cuba (refer to Figure 2.7).

2.3.2.2 *Sources of Data*

All available cetacean records of strandings, sightings, and captures from the waters of the Gulf of Mexico were compiled. A total of 1,223 records were available for this analysis. These records came from the following sources:

Published and unpublished literature - There is a moderate amount of Gulf of Mexico cetacean literature available. Most of the published papers report strandings or opportunistic sightings, but there are a few reports of live-captures, specimens collected for research, and whaling catches (e.g., Cuni 1918, Moore 1953, Layne 1965, Lowery 1974, Schmidly and Melcher 1974, Schmidly and Shane 1978). In recent years, there have also been several research projects that conducted systematic visual surveys of cetaceans in offshore waters of the Gulf (Fritts and Reynolds 1981, Fritts et al. 1983, Mullin et al. 1991 - see Figure 2.7 for locations of survey blocks). Identifications were verified whenever possible.

Southeastern United States Marine Mammal Stranding Network (SEUS MMSN) Database - The Southeastern U.S. Stranding Network maintains a database of reported strandings from Gulf coast states (Texas, Louisiana, Mississippi, Alabama, and Florida) (see Odell 1991). Most records in this database are unpublished, and although species identifications were not always confirmed, most of the data were collected by experienced marine mammal biologists and are considered accurate. Data for the years 1977 to 1991 were available courtesy of D.K. Odell and N.B. Barros, both of Sea World of Florida.

Texas Marine Mammal Stranding Network (TMMSN) Database - The marine mammal stranding network in Texas (Tarpley 1987) has records from the inception of the program in 1981 through 1994. These records were made available courtesy of G.A.J. Worthy and E. Haubold, each of whom is affiliated with Texas A&M University at Galveston (TAMUG). Most records in this database are also in the SEUS MMSN database, and it was possible to verify species identification for many records by examining TMMSN data and photographic files.

J.G. Mead's Stranding and Historical Record Database - J.G. Mead, of the National Museum of Natural History, Smithsonian Institution, maintained a database through 1977 of marine mammal records from the U.S. East and Gulf coasts. The majority of records in the database are of strandings, and most are from the published literature (see Mead 1975). Not all identifications in this database have been verified.

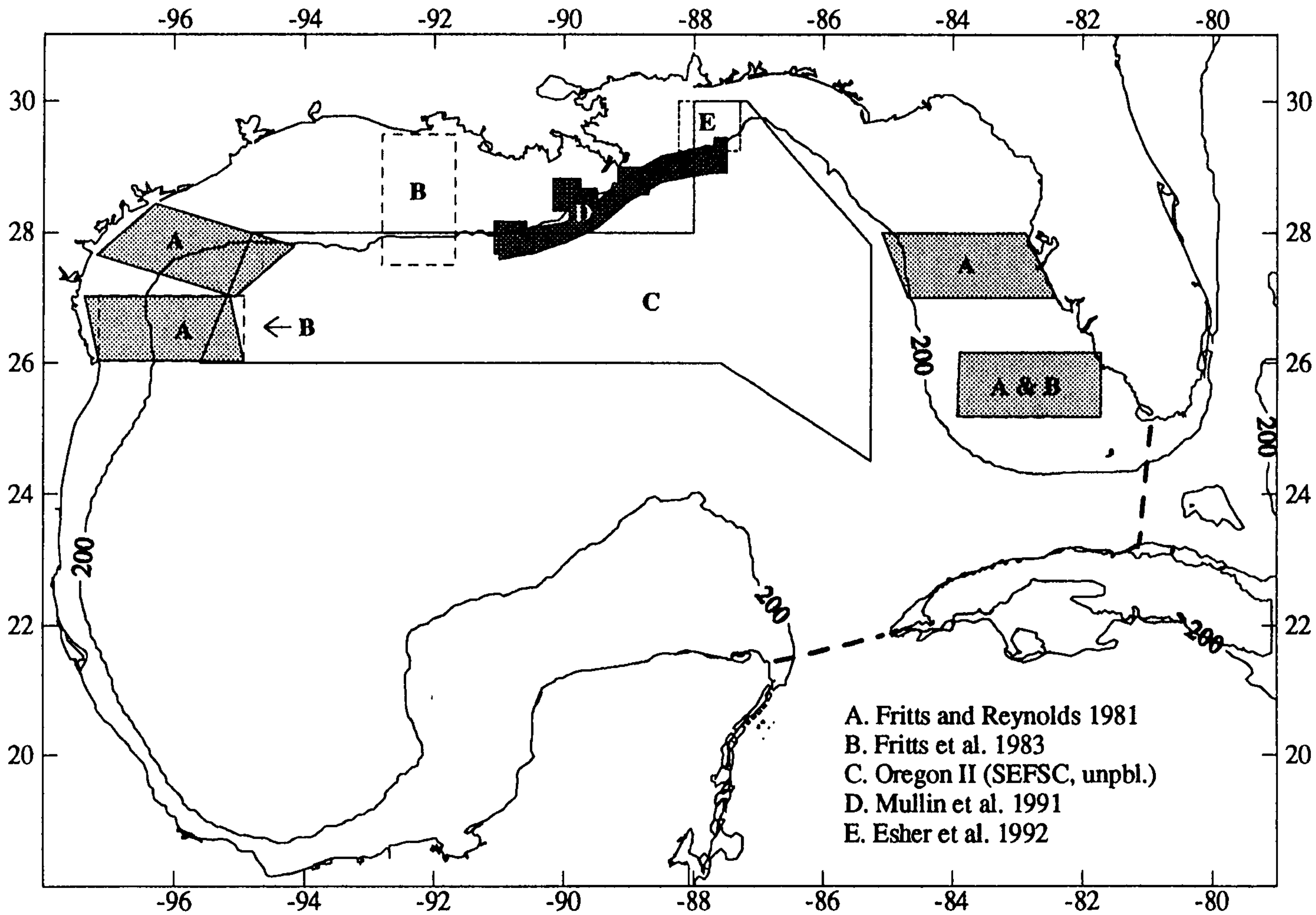

Figure 2.7. Map of the study area showing locations of survey blocks from previous studies. The bold dashed lines demarcate the easterly and southeasterly boundaries of the area used in this overview.

D.J. Schmidly's Gulf of Mexico marine mammal files - Files compiled by D.J. Schmidly of TAMUG, primarily during the preparation of his 1981 report (Schmidly 1981), were searched and reviewed. Information principally consisted of newspaper clippings and previously unpublished stranding records. Often photos or other information were available to verify species identifications.

W.F. Perrin's compilation files of data on dolphins of the genus Stenella - Several binders of data on dolphins of the genus *Stenella*, collected by D.K. and M.C. Caldwell, G.H. Lowery, and D.J. Schmidly, are in the possession of W.F. Perrin, Southwest Fisheries Science Center, NMFS. These binders were searched for records of dolphins in the Gulf of Mexico. Examination of photos, drawings, or skeletal material allowed verification of most of these records.

Museum holdings - Gulf of Mexico specimens from several museums were examined. The entire cetacean osteological collections of the following museums were examined by T.A. Jefferson: the Texas Cooperative Wildlife Collection (TCWC), Houston Museum of Natural Science (HMNS), University of Southwestern Louisiana (USWL), and Louisiana State University Museum of Zoology (LSUMZ). A portion, primarily *Stenella* specimens, of the Florida Museum of Natural History (UF), and National Museum of Natural History (USNM) collections were also examined.

National Oceanic and Atmospheric Administration (NOAA) Vessel Bridge logs - NOAA vessels stationed at the SEFSC, Pascagoula laboratory (*Oregon, Oregon II, Researcher*, and *Chapman*) often kept logs of opportunistic sightings of marine mammals in the Gulf of Mexico during cruises dedicated to other types of research. These data were provided courtesy of K.D. Mullin, K. Rademacher, and W.L. Perryman; some records from the *Oregon* and *Oregon II* were previously plotted in Lowery (1974). These records cover the years 1950-1992. The data were collected by many different people, with widely different abilities to identify marine mammals. Many of the identifications could not be verified and were not used.

Oregon II marine mammal surveys - Prior to the present GulfCet study, two marine mammal surveys were conducted by the SEFSC using the NOAA Ship *Oregon II* during the spring seasons of 1990 and 1991 (see Figure 2.6). These marine mammal surveys had a systematic sighting effort and used highly trained observers (thus all identifications are verified). Unpublished data from these surveys were provided by K.D. Mullin and L.J. Hansen (SEFSC, unpubl.).

Several marine mammal surveys, which provided almost no data that could be used in this section, have been conducted in the Gulf of Mexico. Esher et al. (1992) sighted several large herds of dolphins that were identified as either Atlantic spotted dolphins or pantropical spotted dolphins, and groups of unidentified whales and dolphins (see Figure 2.7 for survey blocks). It was also stated in this report that sperm whales, pilot whales, and common dolphins were detected by acoustic methods (sonobuoy drops from the survey aircraft), but except for sperm whales, these detections were rejected as unreliable because of the lack of visual confirmation. The sperm whale detections were accepted as verified records because of the unique species-specific characteristics of their vocalizations. However, they were not plotted or used in the present analyses, because Esher et al. (1992) did not provide positions for these records.

Scott et al. (1989) surveyed out to 9.3 km beyond the 183 m contour. However, very few animals other than bottlenose dolphins were sighted, and data on these other species were not presented in the report. Similarly, Mullin et al. (1990) surveyed coastal and offshore waters (within 37 km of shore), but reported no sightings other than bottlenose dolphins. There have been several other surveys for bottlenose dolphins in coastal waters, but they have provided no data on offshore species of cetaceans (Leatherwood et al. 1978, Barham et al. 1980, Odell and Reynolds 1980, Leatherwood and Reeves 1983, Mullin et al. 1990).

Finally, the Galveston laboratory of the NMFS maintains a database of marine mammal sightings by observers from their Oil Platform Removal Observer Program. These unpublished data, mostly collected over the continental shelf, were provided by E. Klima, SEFSC. The database was checked, but since the observers were not trained in marine mammal identification, species identification was not available (although the vast majority of sightings were apparently of bottlenose dolphins).

2.3.2.3 *Verification of Species Identification*

There are many errors in species identification for the older records, and even some for recent records from stranding network data. In addition, the taxonomy of some groups (such as *Kogia* and *Stenella*) has only recently been clarified. Thus, for each record, the species identification was questioned and an attempt made to verify it. Verification was done in one of several ways: review of photographs, drawings, or detailed descriptions of the animals demonstrating diagnostic features; examination of voucher materials, such as skulls collected from specimens stranded or captured; identifications made by highly trained observers; or identifications made by relatively inexperienced observers, but of highly distinctive species (such as sperm whales or killer whales). The ease of identifying each species was kept in mind when judging the extent of an observer's identification experience.

For many records, it was not possible to verify the species identification. Unless there was strong reason to believe that the identification was in error, these records were included in plots, using a unique symbol (X) indicating questionable accuracy. For many other records, the genus could be verified, but not the species. Such records were not plotted. Despite this treatment of the data, there may still be some errors in a few of the records that have been considered verified. These are pointed-out in the text where applicable. Of the 1,223 records, 1,044 were considered to be verified, 104 were questionable, and 75 could only be identified to genus.

2.3.2.4 *Plotting of Distribution Maps*

After species verification, records were plotted for each species represented by at least two verified records. It should be mentioned that it was not always possible to obtain an exact position for each record. In cases where the position could be localized to a small area (such as a county or a region of less than about 50 x 50 km), a position in the middle of that area was chosen for plotting. Thus, a small number of records on the maps may appear some distance from their true location. For records in which only a very general region (such as "the northwestern Gulf of Mexico") was available, the record was not plotted. A bar graph of the seasonal distribution of the verified records has been overlaid onto each species map. Questionable records were not included in these graphs. Distribution maps which are not provided as figures in the following section are provided in Appendix A.

2.3.3 *Species Distribution*

2.3.3.1 *Sighting and Stranding Records*

Northern Right Whale

There were only two confirmed records of northern right whales in the Gulf of Mexico, a spring sighting off Florida (Moore and Clark 1963) and a winter stranding in Texas (Schmidly et al. 1972b). In addition, there were three questionable records. Townsend (1935), in his report on nineteenth century whaling grounds and whaling catch records, did not show any catches in the Gulf of Mexico. Clark (1884), however, did identify the central Gulf as a whaling ground for right whales, but did not present any specific records of their occurrence there, and we know of no other information that documents whaling of this species in the Gulf.

From the above information, it is concluded that the northern right whale is not a normal inhabitant of the Gulf of Mexico. Existing records probably represent extralimital strays from the wintering grounds of this species off the southeastern U.S. coast from Georgia to northeastern Florida (see Kraus et al. 1987).

Rorquals

There are five species in the genus *Balaenoptera*, and they are all cosmopolitan, occurring in all oceans and major seas. All five have been reported from the Gulf of Mexico. In addition to the records summarized below, which were considered to be at least tentatively identified to species, there were 14 others that were not supported by enough evidence, or were collected by inexperienced observers, and thus could not be confidently assigned to any particular species.

There were only two reliable records of blue whales in the Gulf, both of strandings (Lowery 1974, Mead unpubl.), and two additional questionable reports. Possibly, some records of unidentified balaenopterids were of this species, but there appears to be little justification for considering the blue whale to be a regular inhabitant of the Gulf of Mexico.

Seven reports of fin whales in the Gulf of Mexico, from Louisiana to Florida, were considered reliable, but four others were of questionable accuracy. Apparently fin whales are not abundant in the Gulf of Mexico, but it is possible that the Gulf represents a portion of the range of a low latitude western

Atlantic population (or a sub-area of it). Alternatively, the more likely consideration is that the fin whale records may be extralimital. All records of fin whale occurrence in the Gulf were from summer, fall, and winter.

Sei whales occur primarily in temperate waters, with lower densities in the tropics and near the poles (see Gambell 1985). They were represented in the Gulf by only four reliable records, near Louisiana, and one questionable one. This species should be considered most likely to be of accidental occurrence in the Gulf, although it is worth noting that three of the four reliable records were from strandings in eastern Louisiana.

The Bryde's whale was represented by more records than any other species of baleen whale (15 verified records in the northern Gulf, and three questionable). The frequency with which Bryde's whales have been identified in recent years suggests that many of the older records of unidentified balaenopterids may be of this species. It is interesting that all the sightings were from the shelf edge near the De Soto Canyon. Bryde's whales are known to be year-round inhabitants of tropical and subtropical waters (see Cummings 1985). Stranding records for the Gulf of Mexico were scattered throughout the year, with the three spring sightings all resulting from the *Oregon II* surveys. It is likely that the Gulf of Mexico represents at least a portion of the range of a dispersed, resident population of Bryde's whales. This appears to be the most common species of baleen whale in Gulf waters.

There were 10 reliable and two questionable records of minke whales in the Gulf of Mexico, from Texas to Florida, all were of strandings. Seven out of eight records for which the season was known were from winter or spring. It is suggested that either minke whales migrate into the Gulf regularly in winter, but in small numbers, or that these records represent strays from low-latitude breeding grounds elsewhere in the western North Atlantic. The latter explanation was proposed by Mitchell (1991), and it is considered the more likely of the two.

Humpback Whale

Seven records of humpback whales, from Texas to Florida, were considered reliable either because they were supported by photographic or written evidence, or because sightings were made by observers with enough experience to recognize this highly distinctive species. Two records were questionable. The records were all sightings, several of which have been noted to be of small animals (see Weller et al. in press). All except one (Aguayo 1954) of these sightings were in shallow, nearshore waters.

The West Indies breeding grounds of the western North Atlantic stock of humpbacks is well-known (Katona and Beard 1991). Although most of the winter population is located at the Silver and Navidad banks north of the Dominican Republic, some whales venture as far south of the normal breeding grounds as the coast of Venezuela (Katona and Beard 1991). It seems likely that some humpbacks stray into the Gulf of Mexico during the breeding season or on their return migration northward. This hypothesis is supported by the time of year in which the sightings occurred (all six in winter and spring), and the small size of the animals involved in many sightings (most likely inexperienced yearlings on their first return migration). This is similar to the occurrence of gray whales in the northern Gulf of California, reported by Tershy and Breese (1991), except that gray whales' use of the Gulf of California may be a more regular occurrence.

Sperm Whale

Sperm whales have an extensive deep water distribution, ranging from the tropics to the Arctic ice edges in both hemispheres (Rice 1989). There were numerous records of sperm whales in the Gulf of Mexico (189 reliable records and two questionable ones), more than for any other species of offshore cetacean, except the Atlantic spotted dolphin (Figure 2.8). Townsend (1935) identified the Gulf of Mexico as a significant sperm whaling ground for nineteenth century Yankee whalers. Although the exact dates were not reported by Townsend, most of the catches occurred from spring to summer in the area between the Straits of Florida and the Mississippi River delta. The historical records show no strong seasonal pattern (see Figure 2.8). The low number of sightings in winter probably resulted from decreased offshore human activity and poorer sighting conditions during that time of year. Sperm whales were found primarily in deep waters beyond the edge of the continental shelf (although there are a few records from over the shelf). In the Gulf of Mexico, this generally puts their distribution offshore several tens-to-hundreds of kilometers. However, in areas where the continental shelf is very narrow (such as off the Mississippi River delta), sperm whales may be seen close to shore.

It appears likely that there is a resident population of sperm whales in the Gulf of Mexico, but only identification and or long-term tracking of individual whales will tell us how much interchange there may be with populations in the Atlantic Ocean. There is no doubt, however, that sperm whales are the most common large whales in the Gulf of Mexico, and that they can be found there at any time of year.

Pygmy and Dwarf Sperm Whale

Two species of *Kogia* are currently known, although it was not until Handley's (1966) study that the dwarf sperm whale classification was widely recognized as valid. Due to the taxonomic problems and the continuing difficulty in distinguishing these animals by many observers (especially in sightings at sea), there were many (48) records that could not be confidently assigned to either species. In addition, it is likely that a few of the records assigned to one or the other species were, in fact, misidentifications.

Historical records of pygmy sperm whales in the Gulf of Mexico were exclusively of strandings or presumed strandings from Texas to Florida (61 reliable records and two questionable ones). This species was previously considered to be rare (see Schmidly 1981), but the number of records would indicate otherwise. Alternatively, it may be due to an increased tendency to strand or increased mortality in colder months. Whatever the case, these data do not indicate that this species is rare in the Gulf. The absence of sightings

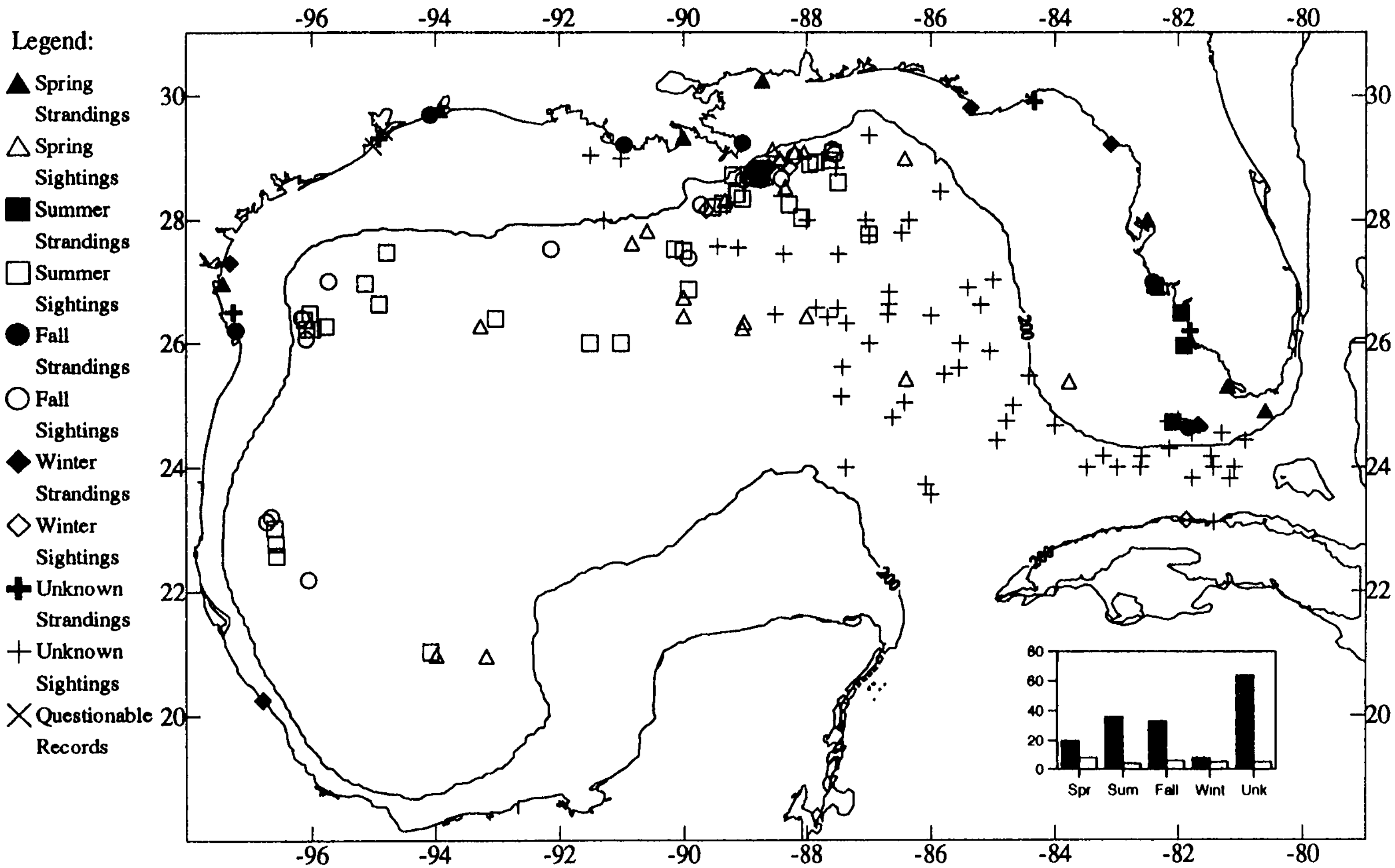

Figure 2.8. Records of sperm whales in the Gulf of Mexico. Seasonality is represented by the bar graph in the lower right hand corner, where sightings are indicated by shaded bars and strandings are unshaded bars.

probably has to do with the cryptic behavior and difficulty in positively identifying this species at sea. Many of the sighting records identified as *Kogia* sp. on recent shipboard and aerial surveys were probably of this species.

The dwarf sperm whale, like its congener, was previously thought to be rare in the Gulf of Mexico. However, there are numerous records (39 reliable ones) from this body of water, many of them strandings. In recent years, the first reliable sightings at sea of this species in the Gulf have been reported. There are stranding records from all four seasons.

Cuvier's Beaked Whale

Cuvier's beaked whale is the most cosmopolitan of all the beaked whales (Heyning 1989). It was reported at least 24 times from the Gulf of Mexico (with one additional questionable record), and may be the most common beaked whale in these waters. Most of the records are of strandings and are scattered more-or-less equally throughout the four seasons.

Mesoplodonts

Three of the 13 species in the genus *Mesoplodon* have been reported from the Gulf of Mexico. This is a problematic group because the taxonomy is still in a state of flux, and because identification presents major challenges due to poor documentation of diagnostic characteristics. One species was first described in 1991 (Reyes et al. 1991). Only rarely have at-sea sightings been identified to species (although the frequency of such identifications is increasing as our knowledge grows), and even specimens "in hand" often can not be identified without museum preparation. Because of these difficulties, any assessments of mesoplodont distribution in the Gulf must be considered highly tentative. Other species, such as True's beaked whale, which has not yet been recorded in the Gulf of Mexico but is known from the nearby Bahamas (Mead 1989), may be shown to occur in the Gulf in the future.

There were only three confirmed records of Blainville's beaked whale from the Gulf, plus one questionable record. This species has the widest distribution of all the mesoplodonts (Mead 1989). All of the Gulf records were of strandings, and all the reliable records were from December and January.

Sowerby's beaked whale was represented in the Gulf of Mexico by only one record, a stranding in Florida (Bonde and O'Shea 1989). This species normally occurs much further north in cool temperate waters (Mead 1989), and this record was thus considered extralimital.

Gervais' beaked whale is the most common mesoplodont stranded along the Atlantic coast of the United States, and most records of its occurrence are from the western North Atlantic (Mead 1989). There were more records for Gervais' beaked whale in the Gulf of Mexico than for any other species of *Mesoplodon*. There were 16 reliable records (all strandings), plus another questionable one. This species is probably the most common mesoplodont in these waters. However, this conclusion must be considered tentative, as the sample sizes are still small and many *Mesoplodon* records remain unidentified to species.

Melon-headed Whale

Melon-headed whales occur throughout the tropical and subtropical waters of the world (Perryman et al. 1994). The first records of this species from the Gulf of Mexico were obtained only recently. These consisted of two strandings, one in Texas in 1990, the other in Louisiana in 1991 (Barron and Jefferson 1993). There have been a number of recent sightings, all associated with the GulfCet program, (Mullin et al. 1994b), bringing the total number of reliable Gulf records to 12. Most of the sightings have been in deep waters, well beyond the edge of the continental shelf. Records exist for all seasons except fall.

Pygmy Killer Whale

Pygmy killer whales occur around the world in tropical and subtropical waters (Ross and Leatherwood 1994). These animals do not appear to be very common in the Gulf of Mexico; there were only 19 reliable records, most of them strandings. Records were found for all four seasons.

False Killer Whale

False killer whales are found in tropical to warm temperate waters of the world (Stacey et al. 1994). There were 27 reliable records from the Gulf of Mexico. Several sightings have occurred over the continental shelf, although the majority appeared to be in oceanic waters. Stacey et al. (1994) mentioned that inshore movements associated with movements of prey and warm-water currents have been documented. Strandings have occurred in all four seasons.

Killer Whale

Killer whales are found in all oceans and seas and probably have the most extensive distribution of any cetacean (see Heyning and Dahlheim 1988). There were 15 reliable records of killer whales in the Gulf of Mexico (plus two others that were questionable), mostly of sightings at sea. There were records for all four seasons. In recent years (since 1989) there have been at least nine sightings (mostly resulting from GulfCet cruises and aerial surveys and thus not summarized in this section), and some have involved resightings of previously seen pods or individuals (Roden et al. 1993). Most of these sightings have been in oceanic waters greater than 200 m deep (Roden et al. 1993), although there were other sightings from over the continental shelf.

Katona et al. (1988) located records of only four sightings, four strandings, and two fishery catches from the Gulf of Mexico. This report stated that killer whale use of the Gulf was unclear, but considered killer whales uncommon in the Gulf. On the basis of the gathered data in this report, it seems likely that there are a small number of pods that use the offshore waters of the Gulf of Mexico as all or part of their normal range.

Short-finned Pilot Whale

Two species of pilot whales are currently recognized, the long-finned pilot whale and the short-finned pilot whale. The taxonomy of this genus is still somewhat controversial, and in this section, all of the pilot whale records from the Gulf are assumed to be the short-finned pilot whale, the more tropical of the two species. This assumption is based on the currently known distributions of the two species and their habitat preferences (see Bernard and Reilly in press). However, it should be kept in mind that the identifications of many specimen records and most or all sightings have not been unequivocally shown to be of the short-finned species.

Based on historical records (mostly strandings), the short-finned pilot whale would be considered to be one of the most common offshore cetaceans in the Gulf of Mexico, with more records than any species except the sperm whale, and Risso's, pantropical spotted, and Atlantic spotted dolphins. A total of 64 records were accepted as reliable, and an additional 17 were considered questionable. However, recent aerial and shipboard surveys in the northern Gulf of Mexico have not borne out the conclusion that pilot whales are common in the Gulf, as they have only been occasionally sighted. This is evidence that strandings are not necessarily a good indicator of a species' relative abundance. Since pilot whales tend to strand in mass, they are more likely to be discovered and reported, and so may be disproportionately represented in stranding records.

One potential explanation for the preponderance of pilot whales in the older records and their surprising rarity in recent surveys is that many of the old records were misidentifications of other "blackfish" (i.e., pilot, killer, false killer, pygmy killer, or melon-headed whales, or sometimes Risso's dolphins), most likely false killer whales. This is a possibility, but many of the older records are supported by photographs or voucher specimens (skulls) that were collected from stranding sites.

Rough-toothed Dolphin

Rough-toothed dolphins are found in tropical to warm temperate waters of the world (Miyazaki and Perrin 1994). Although not very common, the historical records nonetheless indicate that the rough-toothed dolphin occurs in the Gulf of Mexico throughout the year. The 21 verified records (plus one additional questionable record) were from all four seasons. The apparent peak in spring sightings most likely results from the effort associated with the *Oregon II* surveys.

Fraser's Dolphin

This is a tropical species, found worldwide on the high seas and nearshore in some areas where deep water approaches the coast (Perrin et al. 1994b). There are very few records from the Atlantic Ocean (see Leatherwood et al. 1993). Until 1992, there was only a single record from the Gulf of Mexico, a mass stranding in the Florida keys (Hersh and Odell 1986). The first sightings in the Gulf were made in 1992, and since then there have been a number of others, mostly associated with the GulfCet program (Leatherwood et al. 1993). The seven verified records come from all four seasons. The recent spring and summer sightings reflect the bias in sighting effort during this time of year, and the three strandings occurred one each in spring, fall, and winter.

Risso's Dolphin

This species is found in all major oceans in tropical to warm temperate waters (Kruse et al. in press). Although the first record for this species in the Gulf of Mexico was only documented in 1966 (Paul 1968), and Risso's dolphins were previously considered to be rare in the Gulf, there are now numerous records (Figure 2.9). A total of 97 reliable records were located, the vast majority of them sightings, and most of these from Mullin et al. (1991). There is a large peak in sightings during the spring months, and this may be indicative of increased abundance on the upper continental slope in this season.

Atlantic Spotted Dolphin

Atlantic spotted dolphins are endemic to the tropical to warm temperate Atlantic Ocean (Perrin et al. 1987, 1994a). Although Atlantic spotted dolphins have been recorded near oceanic islands and far offshore, they occur in the Gulf of Mexico almost exclusively over the continental shelf and the shelf edge (Figure 2.10). The animals from offshore and around oceanic islands are smaller and more lightly spotted, and may represent a different form than the coastal animals (Perrin et al. 1994a). There are more Gulf records of Atlantic spotted dolphins than there are for any other species of offshore cetacean. There were 194 records that were considered reliable and an additional seven that were questionable. This is the only species, other than the bottlenose dolphin, that commonly occurs over the continental shelf. It is also the only species for which there is adequate information to assess its occurrence in Mexican waters, which is also primarily over the continental shelf. The apparent peak in sightings for the spring months may be real, as sightings per unit effort also increase in the spring (Mills et al. 1993). However, sighting rate is not necessarily a good indicator, because it does not account for bias due to seasonal effects on sightability. One interesting aspect of this species' distribution was the low number of strandings; almost all records were of sightings or captures. It is unclear why a species as common as this one appears to be is so poorly represented in the stranding record, but apparently they seldom strand.

Pantropical Spotted Dolphin

This is a tropical species, known from the Pacific, Indian, and Atlantic oceans (Perrin and Hohn 1994). Most historical and recent evidence indicates that this species is the most common and abundant delphinid in the oceanic (deeper than 200 m) waters of the Gulf of Mexico (Figure 2.11) (Johnson et al. 1991, Jefferson and Lynn 1994). A total of 112 records have been located, mostly of sightings. Many of these sightings were the result of recent deep-water surveys in the northern Gulf (Mullin et al. 1991, SEFSC unpublished). The previous conclusion that this species was uncommon (see Schmidly 1981) was probably the result of this species' confused taxonomic status. Many older records of *Stenella* that could not be identified to species were probably pantropical spotted dolphins. Since its re-description (Perrin et al. 1987), there have been numerous reports of this species in the Gulf.

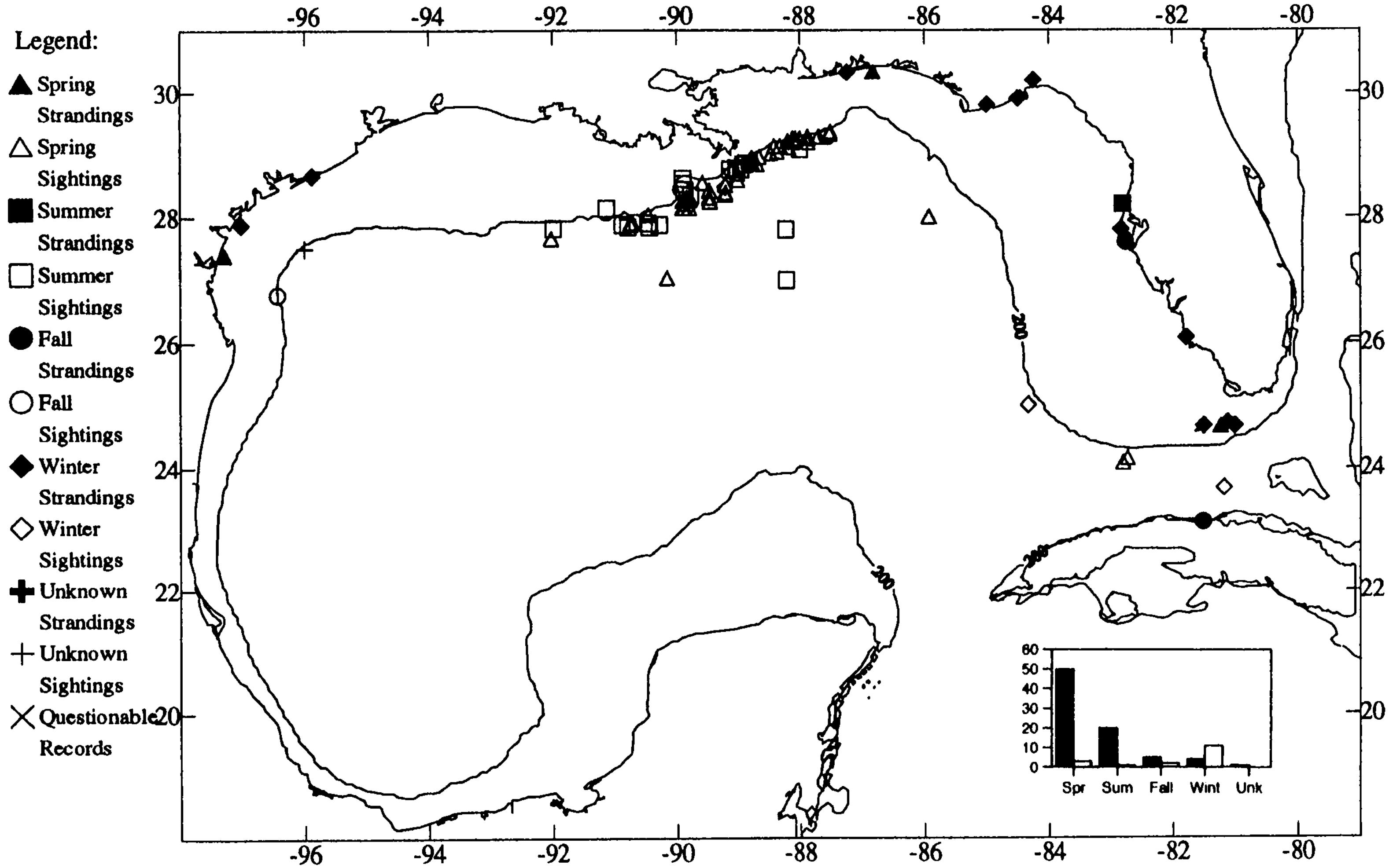

Figure 2.9. Records of Risso's dolphins in the Gulf of Mexico. Seasonality is represented by the bar graph in the lower right hand corner, where sightings are indicated by shaded bars and strandings are unshaded bars.

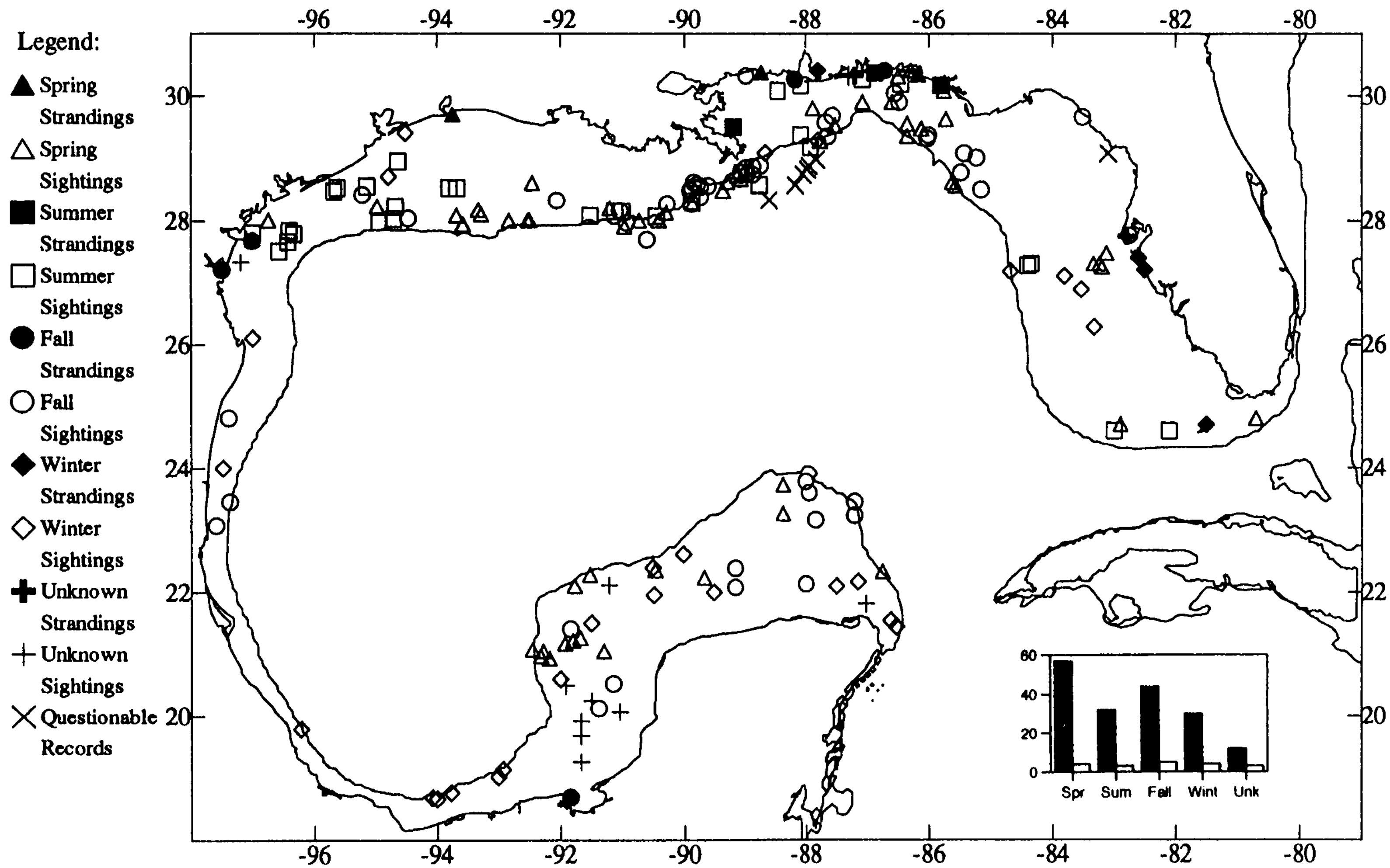

Figure 2.10. Records of Atlantic spotted dolphins in the Gulf of Mexico. Seasonality is represented by the bar graph in the lower right hand corner, where sightings are indicated by shaded bars and strandings are unshaded bars.

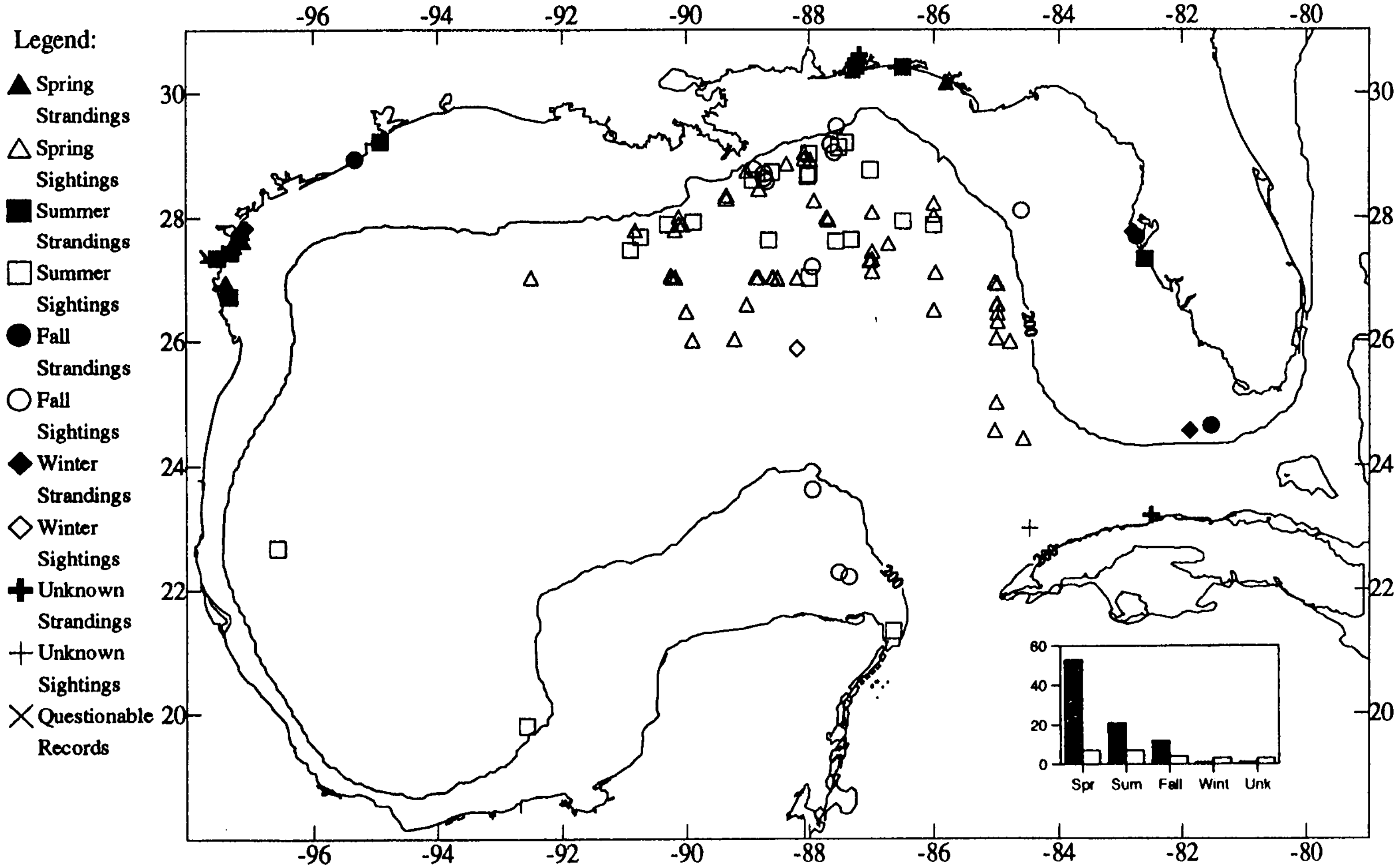

Figure 2.11. Records of pantropical spotted dolphins in the Gulf of Mexico. Seasonality is represented by the bar graph in the lower right hand corner, where sightings are indicated by shaded bars and strandings are unshaded bars.

The sightings reported from the mid-continental shelf area off the Yucatan Peninsula by Fuentes et al. (1986) do not agree with what is known of the preferred oceanic habitat of the pantropical spotted dolphin. These sightings may be misidentifications of Atlantic spotted dolphins.

Striped Dolphin

Striped dolphins occur from tropical to warm temperate waters in all three major ocean basins (Perrin et al. 1994c). There were relatively few verified records (27), but many questionable ones (41) (Figure 2.12). Many of the questionable records were from aerial surveys by Fritts et al. (1983). There were records from all seasons.

In most areas of the world, the primary habitat of striped dolphins appears to be deep water. Thus, there is reason to question the accuracy of the many sightings reported from the west Florida shelf by Fritts et al. (1983). These were made from aircraft, in which species identification can be difficult (as described by Mullin et al. 1991). It is possible that many, if not all, of these sightings were misidentifications of Atlantic spotted dolphins. Groups of young spotted dolphins, which are not heavily spotted, may be easily mistaken for striped dolphins (especially from the air), since both have prominent spinal blazes.

Spinner Dolphin

Spinner dolphins are pantropical animals (Perrin and Gilpatrick 1994). In the Gulf of Mexico, only 19 verified and 10 questionable records were found. This is fewer than for any other species of *Stenella*. There were records from all four seasons.

The distribution of this species in the tropical Atlantic appears to be primarily oceanic, with the exception of movements into shallow, nearshore waters, such as around the island of Fernando de Norohna off Brazil (Lodi and Fiori 1987). Thus, some of the continental shelf sightings reported for the west coast of Florida (Fritts et al. 1983) and the Campeche Bank, northwest of the Yucatan Peninsula (Urbañ-Ramirez and Aguayo-Lobo 1983) may be misidentifications.

Clymene Dolphin

The clymene dolphin is an Atlantic endemic, found in tropical and subtropical waters (Perrin et al. 1981, Perrin and Mead 1994). There were 50 verified records for the Gulf of Mexico (plus one questionable one from the southern Gulf), indicating that this species is not rare in this body of water (Figure 2.13). The rarity of clymene dolphin records in the past (see Schmidly 1981) was probably only a result of its recently clarified taxonomic status and the tendency of observers to confuse it with other species (see Perrin et al. 1981). Records were from all seasons of the year. The large spring sighting peak is probably due to the seasonal bias in survey effort of the *Oregon II* and in the present study (Mullin et al. 1994a).

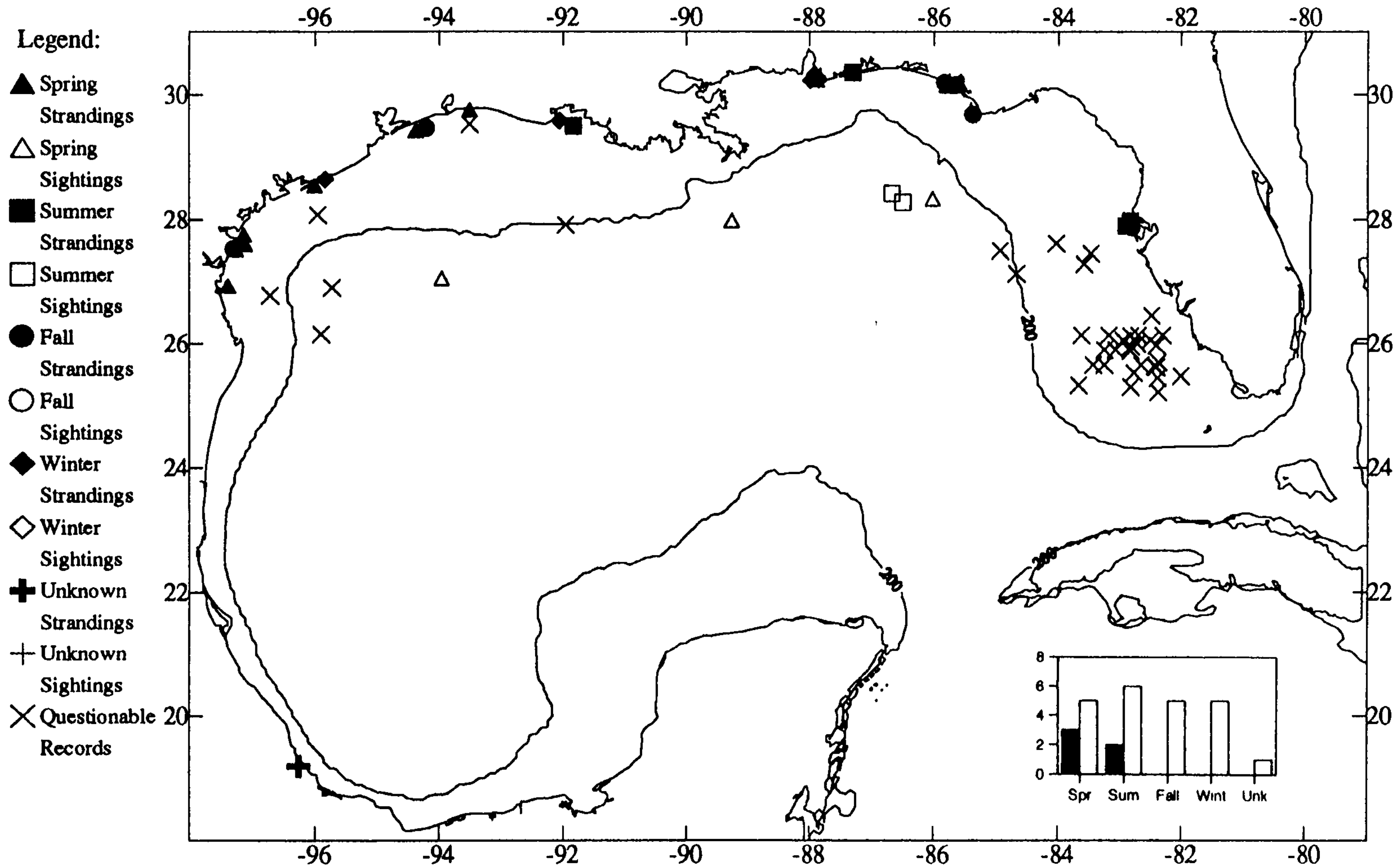

Figure 2.12. Records of striped dolphins in the Gulf of Mexico. Seasonality is represented by the bar graph in the lower right hand corner, where sightings are indicated by shaded bars and strandings are unshaded bars.

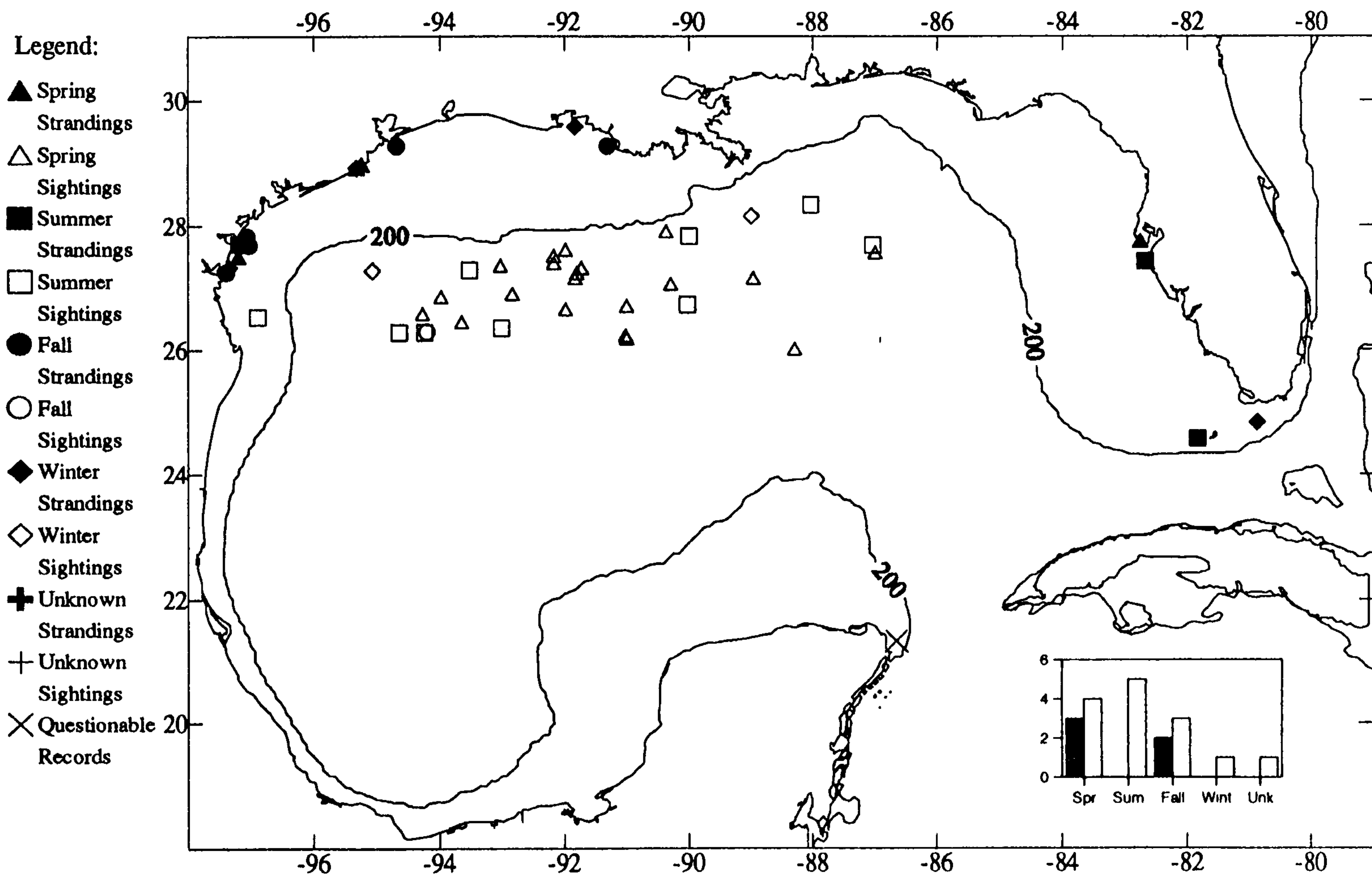

Figure 2.13. Records of clymene dolphins in the Gulf of Mexico. Seasonality is represented by the bar graph in the lower right hand corner, where sightings are indicated by shaded bars and strandings are unshaded bars.

Common Dolphin

Common dolphins occur in tropical to warm temperate waters of all three major oceans (Evans 1994). Although long-beaked and short-beaked varieties of common dolphins have long been recognized, until recently they were classified as one species by most biologists. However, Heyning and Perrin (1994) have discovered that the two types represent separate species in the eastern North Pacific. These are the short-beaked common dolphin and the long-beaked common dolphin. These differences appear to apply to other ocean basins as well. Short-beaked common dolphins are known from the east coast of Florida, while the nearest occurrence of the long-beaked species is from Venezuelan waters (Heyning and Perrin 1994).

Only three alleged specimen records of common dolphins from the Gulf of Mexico were located. These consist of a live-capture of two specimens from near St. Petersburg, Florida in the spring of 1965 (R-G-1-SLS), which was mentioned by Caldwell and Caldwell (1973). These animals were later re-identified as "short snouted spinner dolphins" (Caldwell and Caldwell 1975), and photographs published therein leave no doubt that these animals were indeed clymene dolphins. A stranding at Sabine Pass, Texas, on 16 May 1974 (TCWC 28286) was identified at the time as a common dolphin, but was later re-identified as a spinner dolphin by Schmidly and Shane (1978). Finally, a live-stranding of a common dolphin in Galveston, Texas on 30 March 1979 (TCWC 50849), was briefly mentioned in Schmidly (1981). The skulls of the latter two specimens have been examined by T.A. Jefferson and the identifications were confirmed as spinner dolphin (TCWC 28286) and clymene dolphin (TCWC 50849), respectively (see Jefferson et al. 1995). Thus, there are no valid specimen records of the genus *Delphinus* from the Gulf of Mexico.

There have also been several reported sightings of common dolphins in Gulf of Mexico waters (Cuni 1918, Caldwell 1955, Caldwell and Caldwell 1973, Lowery 1974, Fritts and Reynolds 1981, and Dorf 1982). However, none of these was accompanied by photographs, sketches, or detailed descriptions of diagnostic characteristics used in identification. Most of the reports were made by untrained observers and were made at a time when the taxonomy and diagnostic features of the long-snouted tropical dolphins were poorly known. All of these sightings occurred prior to 1981, when the re-description of the similar-appearing clymene dolphin was published (Perrin et al. 1981). Further, the sightings by Fritts and Reynolds (1981) and Dorf (1982) were made from aircraft, a platform from which identification can be difficult (see Mullin et al. 1991).

In conclusion, all reported records of common dolphins from the Gulf of Mexico are rejected as either incorrect or questionable. Common dolphins should not, at this time, be considered a species known to occur in the Gulf of Mexico. This conclusion is supported by the results of the GulfCet surveys.

2.3.4 *Summary and Conclusions*

There are often strong geographic and seasonal biases in sighting and stranding recovery efforts. For essentially all types of records, almost none were available for the southern Gulf of Mexico. Thus, distribution maps showing records primarily from the northern Gulf of Mexico do not, in any way, imply that these species do not occur in the southern Gulf. On the contrary, there is no reason to believe that any species known from the northern Gulf does not also occur in the southern part of the Gulf of Mexico. Areas of the northern Gulf coast with low human population density also show a conspicuous lack of strandings.

Likewise, seasonal graphs must be viewed with several important biases kept in mind. For the most part, effort to document strandings since the inception of the Southeastern U.S. Marine Mammal Stranding Network in 1977, has been relatively even throughout the year. However, since stranding recoveries depend heavily on reports from the general public, the summer season (when more people are at the beach) would be expected to produce more stranding records than other seasons. This is probably even more true of older stranding records from a time prior to the establishment of systematic data collection, and for species, such as pilot whales, which mass strand and were therefore more likely to be discovered and reported. Finally, opportunistic sightings tend to be biased towards the time of year when the weather is good and more people are venturing offshore (primarily summer). In addition, one of the major sources of high-quality data for this analysis, the *Oregon II* surveys (SEFSC unpubl.), have occurred almost exclusively in the spring. Thus, the apparent spring and or summer peaks in sightings for many species may only be artifacts of seasonal biases in survey effort. In addition, seasonality of strandings is not necessarily directly related to population abundance. It may, instead, reflect seasonality in mortality patterns.

The apparent absence of common dolphins in the Gulf of Mexico is interesting and worthy of examination. Schmidly and Scarbrough (1990) noted that common dolphins had not been documented from the Gulf in the past decade, but apparently did not doubt the accuracy of the older records. Common dolphins occur in most tropical to warm temperate waters of the world (Evans 1994, Heyning and Perrin 1994). Their status in northeastern Florida (the nearest area to the Gulf with confirmed records) was discussed by Caldwell and Caldwell (1978). Common dolphins were once abundant in northeastern Florida, but in the past few decades have disappeared from those waters. The last known sightings and strandings were in 1958 and 1960, respectively (Caldwell and Caldwell 1978). The disappearance of common dolphins from northeastern Florida may be the result of natural fluctuations in numbers or distribution (possibly associated with oceanographic changes), since there have been no known fishery interactions or other human-caused mortality events involving common dolphins from the southeastern United States.

There are other potential historical data sources that have not been examined in this section. Some of the most valuable sources are old, nineteenth century whaling logbook records. Townsend (1935) has extracted entries of the large whale target species (sperm, humpback, and right whales) from many logbooks of Yankee whalers. There are undoubtedly many more logbooks that have not yet been examined, and it is likely that other information may also be available from those Townsend did examine. For instance, other large whales that were too quick to be primary targets of whalers (balaenopterids), and other species of small cetaceans were often mentioned in old whaler's logbooks. Although species identification would be very difficult to verify for many of these records, there may be a number of records of highly distinctive species (such as killer whales) that could be extracted. Thus, these whaling logbooks represent a potentially valuable untapped source of data for analyses such as this.

Understanding of the marine mammal fauna of the Gulf of Mexico is still incomplete. It is probable that there are still undocumented species that may occur in the Gulf; beaked whales are the most likely candidates. Although knowledge of Gulf marine mammals is still in a rudimentary stage, a great deal has been learned in the past decade, and the pace at which this knowledge is acquired continues to increase. This has come about only through the hard work and dedication of a small group of interested individuals. Recent studies, such as the GulfCet program described in the remainder of this report, have added greatly to the efforts of those early workers who painstakingly documented strandings and occasional sightings of these relatively poorly known animals.

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III. VISUAL SURVEYS ABOARD SHIPS AND AIRCRAFT

L.J. Hansen, K.D. Mullin, T.A. Jefferson, and G.P. Scott

3.1 Introduction

Studies of continental slope waters of the northern Gulf of Mexico (Fritts et al. 1983, Mullin et al. 1994c) indicated that cetaceans were diverse (at least 18 species) and that some species (e.g., sperm whale, Risso's dolphin, pantropical spotted dolphin), at least seasonally, were relatively abundant. However, these studies were restricted to relatively small geographic areas and the results could not be meaningfully extrapolated to a broader region of the Gulf of Mexico. Therefore, information on the seasonal abundance and distribution of cetaceans in the slope waters of the entire north-central and western Gulf of Mexico (i.e., the GulfCet study area) was not available to the MMS. In order to meet these information needs, seasonal line transect surveys of the GulfCet study area from ship and aircraft platforms were conducted. Line transect surveys are the established and standard method for assessing cetacean density and abundance over large geographic areas (Buckland et al. 1993). Ships were used to survey the entire GulfCet study area. Aircraft were used to provide faster but more fine-scale seasonal surveys of a subregion of the study area. The primary objectives of the GulfCet visual aerial and ship surveys were: 1) to obtain data on the cetacean species composition in the GulfCet study area, 2) to obtain a minimum population estimate of each cetacean species encountered in order to establish a baseline for monitoring trends in abundance over time, 3) to study the seasonal abundance and distribution patterns of each species, and 4) to collect location data for use in cetacean habitat studies. The surveys were conducted for two years as a first step in studying interannual and intraseasonal variation in the diversity, abundance, and distribution of cetaceans in the north-central and western Gulf. Additionally, line transect data from each sea turtle species sighted during the aerial surveys were used to estimate sea turtle abundance.

3.2 Methods

3.2.1 *Data Acquisition*

3.2.1.1 *Ship Surveys*

Shipboard surveys were conducted seasonally, lasting from 10 to 55 days per survey. Seasons were defined as follows for both the ship and aerial surveys: summer, July-September; fall, October-December; winter, January-March; and spring, April-June. The survey tracks followed one of three designs that sampled the entire GulfCet study area. The TIO surveys followed fixed north-south track-lines that were designed to accommodate oceanographic sampling as well as visual and acoustic sampling of marine mammals (Figure 3.1). The ship transited the track once each survey for 24 hours a day, and visual sampling occured during daylight hours on the north-south track-lines or on transit between the track-lines. The SEFSC surveys followed two transect line

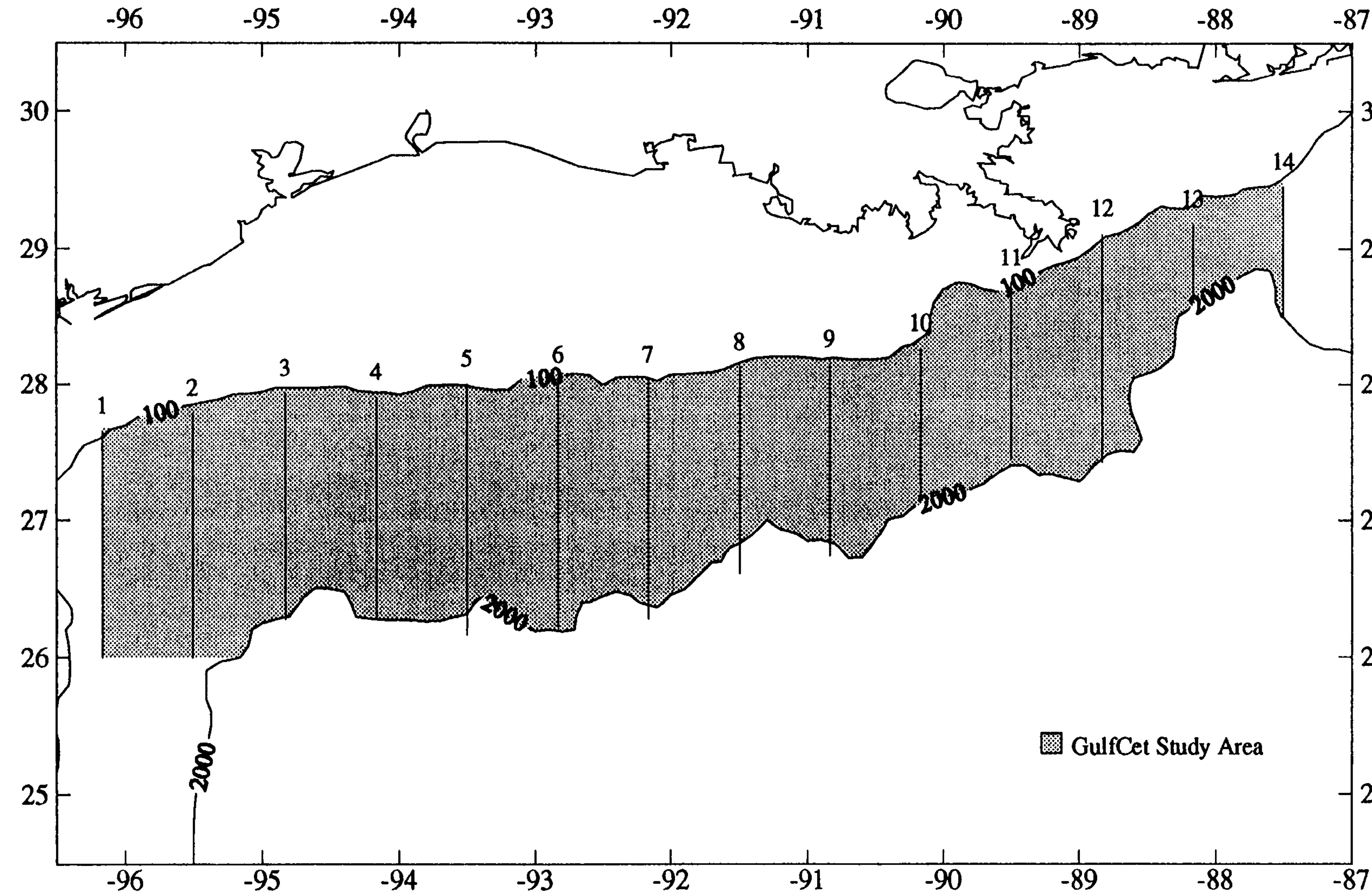

Figure 3.1. R/V *Longhorn* and R/V *Pelican* marine mammal visual and acoustic track-lines. This transect was completely or partially surveyed during spring, summer, and fall of 1992, and the winter, spring, summer, and fall of 1993. The 100 and 2,000 m isobaths define the northern and southern borders of the study area.

designs, sampling the study area three times each survey period. The spring SEFSC surveys consisted of one or two transits of equidistant north-south tracks (surveyed during daylight hours) with a random start (Figure 3.2), and one or two transits of a predetermined track for sampling ichthyoplankton stations, which were transited 24 hours a day (Figure 3.3). The winter SEFSC survey transited the north-south tracks three times. Visual sampling of the ichthyoplankton track could be latitudinal or longitudinal, or a combination of both. The SEFSC north-south tracks were designed specifically for visual sampling of marine mammals along transects perpendicular to the depth gradient.

Visual sampling methods of the TIO and SEFSC surveys were similar except for the slower vessel speed on the TIO surveys (varying from 9.3-17 km/hr) than the SEFSC surveys (18 km/hr). Marine mammal sighting data were collected by two teams of three observers during daylight hours, weather permitting (i.e., no rain, Beaufort sea state <6), using standard vessel survey data collection methods for cetaceans developed by the Southwest Fisheries Science Center (NMFS) (Holt and Sexton 1987). Each team had at least two members trained and experienced in shipboard marine mammal observation and identification techniques. Two observers searched for marine mammals using high-power (25X), large format "Big Eye" binoculars mounted on the ship's flying bridge. The third observer maintained a search of the area near the track-line either without visual aids or with handheld 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.

Sighting data were recorded on a computer interfaced with either a global positioning system (GPS) or LORAN-C navigation receiver via a data acquisition program during the SEFSC surveys. On TIO surveys data were recorded on standard marine mammal visual sampling forms developed by NMFS (see Hill et al. 1991). Data collected included species, group size, bearing and reticle (a measure of radial distance) of a sighting, and data on environmental conditions (e.g., Beaufort sea state, sun position, etc.) which 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 track-line was measured using a 360° graduated scale attached to the base of the binoculars (Figure 3.4). Ancillary data were also collected and included, but were not limited to, time of day, latitude and longitude, behavior, and associated animals. Typically, on the SEFSC surveys, the vessel was diverted from the track-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 and entered in a personal notebook.

During both the ship and aerial surveys, cetaceans were identified to the lowest taxonomic level possible based on descriptions in field guides and scientific literature (e.g., Leatherwood et al. 1976, Leatherwood and Reeves 1983, Perrin et al. 1987). The ability to make an identification was dependent on water clarity, sea state, and animal behavior. Identifications to species were not possible for some genera or groups of species. In some cases, cetaceans could only be identified as large whales (>7 m long), small whales (non-dolphin, <7 m), dolphins, or odontocetes.

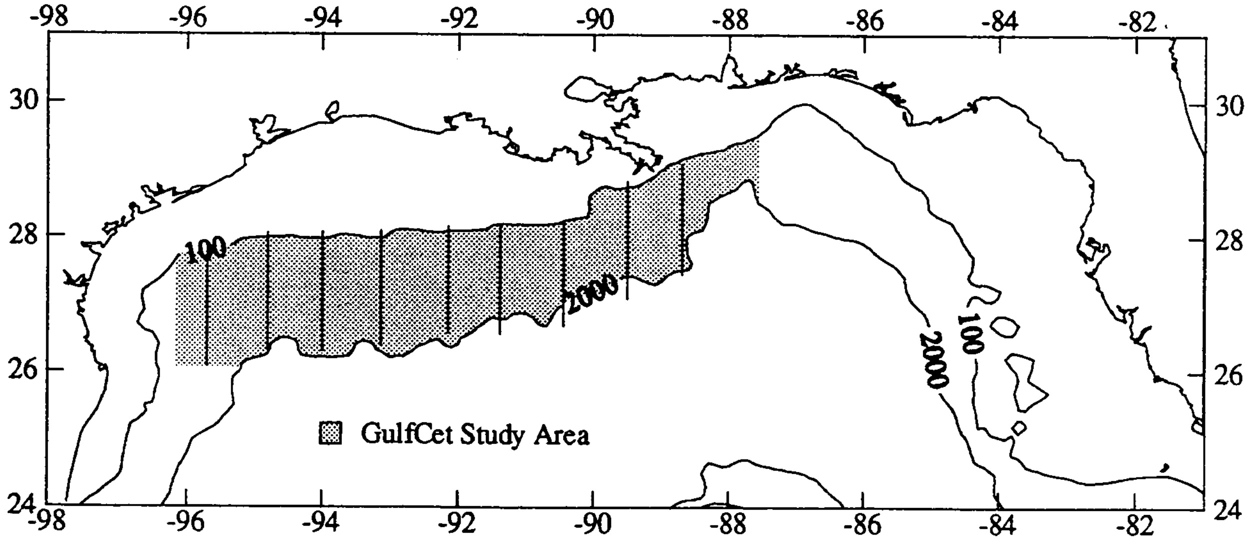

Figure 3.2. Representative NOAA Ship *Oregon II* marine mammal cruise track. A systematic set of lines from a random start similar to this track was completely or partially surveyed three times during winter 1993, and one time each during spring 1992-1994. The 100 and 2,000 m isobaths define the northern and southern borders of the GulfCet study area.

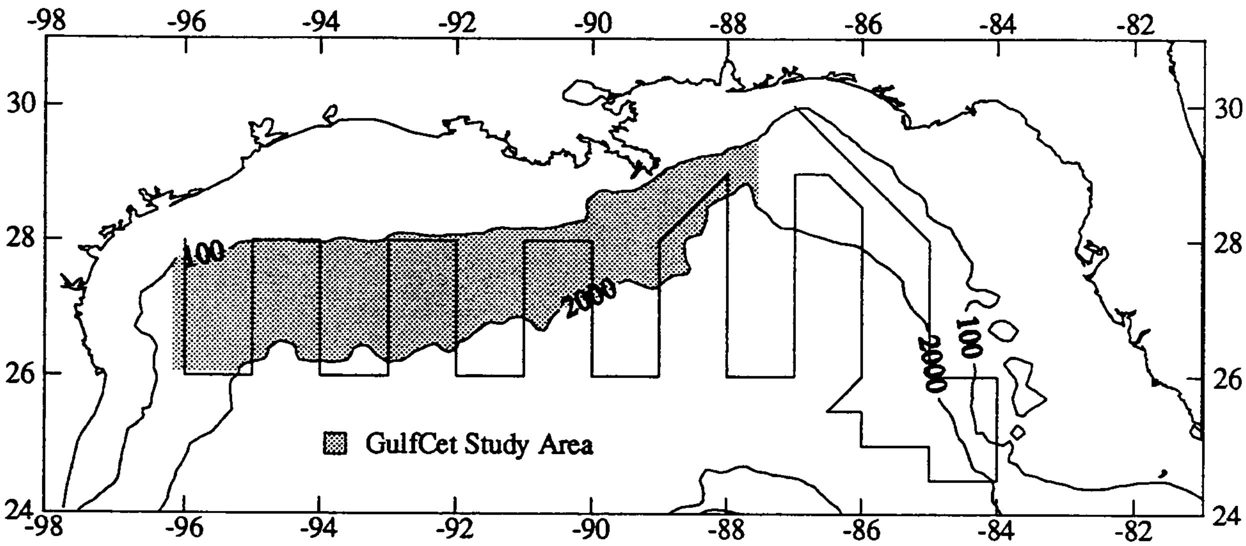

Figure 3.3. NOAA Ship *Oregon II* standard ichthyoplankton/marine mammal cruise track. This track was completely or partially surveyed two times each spring from 1992-1994. The 100 and 2000 m isobaths define the northern and southern borders, respectively, of the GulfCet study area.

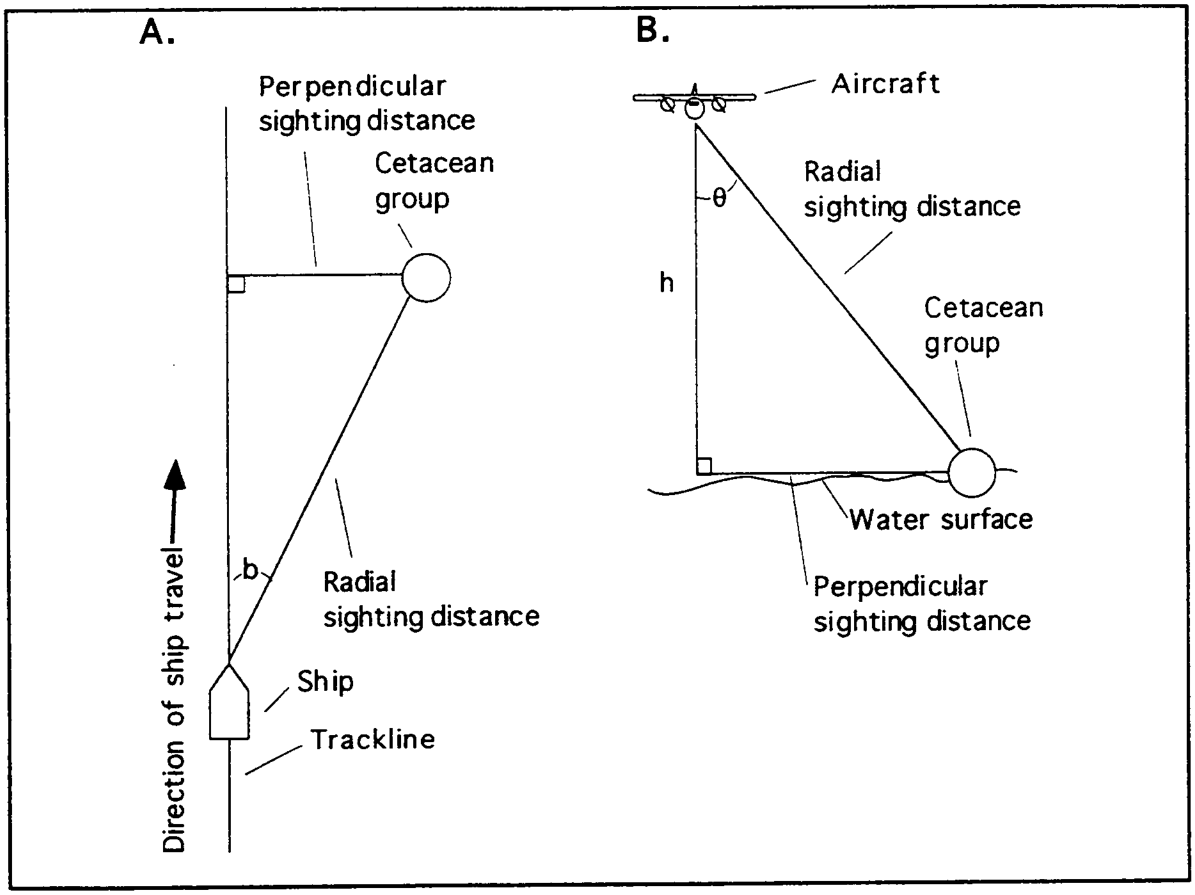

Figure 3.4. Diagram of perpendicular sighting distance (PSD) and other sighting parameters for shipboard (A) and aerial (B) surveys (b and θ = angle between track-line and cetacean group, h = altitude).

The SEFSC data were error-checked daily with programs designed to detect inappropriate entries in each data field. The original data file was copied, and corrections were made on the copy only. The TIO data were checked by hand, and corrections were noted on the original data sheets.

The sighting and effort data were summarized by survey for the line transect distance sampling analysis. The sample unit for analyses was one day's survey effort. The length of track-line sampled was determined using LORAN or GPS positions (latitude and longitude) collected at regular intervals (usually every two minutes during the SEFSC surveys, and every 30 minutes during the TIO surveys) along the transect. In some cases, the positions were known to be in error and effort was determined using the elapsed time and average vessel speed. Effort and sighting data were pooled across environmental conditions that may have had different sighting rates due to effects on observers' abilities to sight animals (i.e., sighting rates tended to decrease as wind and wave height increased).

3.2.1.2 *Aerial Surveys*

Based on several considerations, including projected availability of acceptable survey conditions, available funding, and flight times to the study area, the aerial surveys were designed to survey track-lines totaling about 6,400 km each season. Given this constraint and the width of both the continental shelf and slope in the northwestern Gulf, it would have been logistically difficult to uniformly cover the entire GulfCet study area and keep the distance between transects small for both efficient use of flight-time and finer scale coverage. Therefore, the aerial surveys did not sample the entire GulfCet study area. The aerial survey study area (85,815 km^2) only included waters from 100-1,000 m deep west of 90°00.0'W. However, the entire continental slope was surveyed east of 90°00.0'W because: (1) it was logistically more feasible (i.e., both the slope and shelf are narrow); (2) the area was of special interest because previous aerial surveys of the area (Mullin et al. 1994c) indicated that cetacean diversity, distribution, and abundance in this area were seasonally variable; and (3) this area is oceanographically and physiographically complex (e.g., Mississippi Canyon, DeSoto Canyon, Mississippi River Delta, and the Loop Current).

Aerial surveys were conducted once each season for two years, from summer 1992 through spring 1994 (eight seasonal surveys). During each season, the aerial survey study area was covered uniformly by flying 74 track-lines placed equidistantly apart from a random start. Track-lines were oriented perpendicular to the bathymetry and consisted of 60 north-south track-lines off the Alabama coast, west, through northern Texas, and 14 east-west track-lines off of southern Texas (Figure 3.5). Track-lines were 13.5 km apart. A window of 45-days and about 100 flight hours was allocated for each seasonal survey. Survey flights were conducted only on days with good visibility (i.e., no rain or fog) and when there were no or few whitecaps (Beaufort Sea State 0-3).

The survey platform was a NOAA-operated DeHavilland Twin Otter (twin-engine turbo-prop) aircraft modified with a large bubble window on each side. These windows provided observers with track-line visibility. This aircraft was used in previous aerial surveys of the Gulf of Mexico in 1989-90 (Mullin et al. 1994c). Because a NOAA Twin Otter was not available for the first survey (summer 1992), a similarly modified Partenavia aircraft was used. This aircraft had a flight time of only 4.5 hours. As the transit time to the study area was about one hour, this limited the amount of survey time per flight. The Twin Otter, with a flight time of 6.5 hours, was used for the fall 1992 and all subsequent GulfCet aerial surveys.

Survey flights typically began at 0800 hours and were 4.5-6.5 hours in duration. Surveys were conducted from an altitude of 229 m (750 feet) and at a speed of 204 km/hour (110 knots). A pilot, co-pilot, and three observers participated in each flight. At least two observers on each flight were trained and experienced in aerial survey techniques for marine mammals. 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 track-line and scanned periodically out to the horizon. Only sightings made

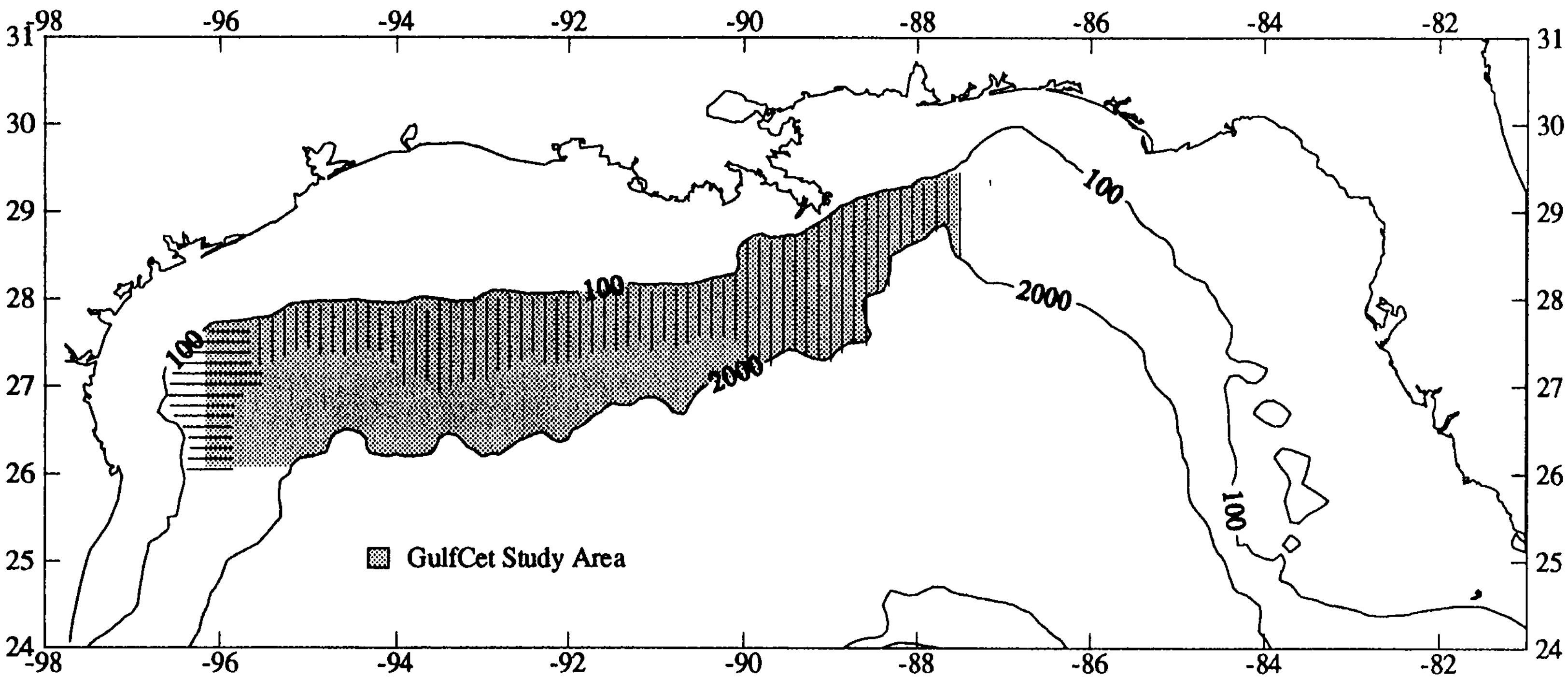

Figure 3.5. GulfCet aerial survey track-lines. A systematic set of lines from a random start similar to this track was completely or partially surveyed seasonally from summer 1992 through spring 1994.

from the bubble window stations 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 via a data acquisition program. Sighting data included species, group size, and sighting angle or interval (for estimating perpendicular sighting distance). A suite of data characterizing survey conditions (e.g., sea state, weather, visibility, water color), effort status, and observer positions 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 the group and the track-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 >70° corresponding to interval endpoints with perpendicular sighting distances (PSD) equal to 40, 83, 132, 192, 273, 397, and 629 or >629 m (see Figure 3.4). If the inclinometer malfunctioned or the sighting angle was greater than 60°, the interval was recorded.

When a cetacean group was sighted, 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.

3.2.2 *Data Analysis Techniques*

Line transect methods (Buckland et al. 1993), implemented with the program DISTANCE™ (Laake et al. 1993), were used to make two independent sets of abundance estimates; one set based on the aerial surveys and the other based on the ship surveys. For aerial surveys, estimates were made for the following species and temporal strata: (1) each species for the entire study (i.e., all eight seasonal surveys combined); (2) all species combined for each year of the study (Year 1= 8/92-4/93, Year 2= 8/93-5/94), each seasonal survey (e.g., winter 1993), and each season (e.g., summer 1992 and summer 1993 combined); and (3) each species with 20 or more on-effort sightings for each year of the study and for each season. For the ship surveys, estimates were made for each species by season and overall (all seasons combined).

The formula used to estimate density (D) was:

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

where n= number of on-effort group sightings
S= mean group size or expected group size
f(0)= sighting probability density function at 0 perpendicular distance
L = length of track-lines sampled within a stratum.

Abundance was estimated as the density multiplied by the size of the area surveyed (ship survey area = 154,621 km^2, aerial survey area = 85,815 km^2). The log-normal 95% confidence intervals were computed for each abundance estimate.

The parameter f(0) was estimated using a hazard-rate model and a half-normal model (Buckland 1985, Buckland et al. 1993). 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

3.2.2.1 *Estimation of Perpendicular Sighting Distance and f(0)*

Ship Surveys

The perpendicular sighting distance (PSD) was estimated using bearing and reticle measurements. 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). 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. This was done to reduce the potential for artificial grouping of sighting distances due to rounding of measurements by observers.

The smeared reticle readings were converted to radial sighting distances (R) using a model which was derived from empirical data (Hansen et al. 1995). Perpendicular sighting distances (PSD) were calculated as (Figure 3.4):

$$PSD = R \cdot \sin(b)$$

where b = smeared angle between sighting and trackline.

An exploratory analysis indicated that sightings made at small radial distances (generally < 0.46 km) resulted in a poor fit of the sighting probability density function. Exclusion of these sightings resulted in better fits and more precise estimates of f(0). Most of these sightings were probably of animals that were attracted to the vessel 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 bias due to attraction to the vessel, only sightings made at radial distances of ≥ 0.46 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). Sightings of species with similar sighting characteristics (i.e., body size, group size, behavior) were pooled to estimate f(0). (Table 3.1). For example, f(0). for Cuvier's beaked whale was estimated by pooling with sightings of Blainville's beaked whale, unidentified beaked whales (family Ziphiidae), and dwarf and pygmy sperm whales of group sizes less than five. Seven species did have sufficient sightings (30 or more, including non-GulfCet study area sightings) to estimate species f(0) without pooling; these were the sperm whale, dwarf sperm whale, bottlenose dolphin, Risso's dolphin, Atlantic spotted dolphin, pantropical spotted dolphin, and striped dolphin. The estimated values of f(0) and associated statistics are listed in Table 3.2.

Aerial Surveys

The perpendicular sighting distance (PSD, Figure 3.4) from the track-line to the group was calculated as:

$$PSD = h \cdot \tan(\theta)$$

Table 3.1. Pooling categories for estimating f(0). "X" indicates sightings pooled (all sightings used). "<#" and ">#" indicate the group sizes of sightings used. Abbreviations: Bede=Bryde's whale, Pmac=Sperm whale, Kbre=pygmy sperm whale, Ksim=dwarf sperm whale, KsKb=*Kogia* spp., Zcav=Cuvier's beaked whale, Ziph=Unidentified Ziphiidae, Pele=melon-headed whale, Fatt=pygmy killer whale, FaPe=pygmy killer/melon-headed whale, Pcra=false killer whale, Oorc=killer whale, Gmac=short-finned pilot whale, Sbre=rough-toothed dolphin, Lhos=Fraser's dolphin, Ttru=bottlenose dolphin, Ggri=Risso's dolphin, Sfro=Atlantic spotted dolphin, TtSf=bottlenose/Atlantic spotted dolphin, Satt=pantropical spotted dolphin, Scoe=striped dolphin, Slon=spinner dolphin, Scly=clymene dolphin, Ular=unidentified large whale, Usml=unidentified small whale.

	Bede	Pmac	Kbre	Ksim	KsKb	Zcav	Ziph	Pele	Fatt	Pcra	Oorc	Gmac	Sbre	Lhos	Ttru	Ggri	Sfro	Satt	Scoe	Slon	Scly
Bede																					
Pmac	X																				
Kbre					X	<5	<5														
Ksim			X		X	<5	<5														
KsKb			X			<5	<5														
Zcav							X														
Ziph						X															
Pele														> 29							
Fatt																					
FaPe								> 29	< 30												
Pcra											< 16	X									
Oorc										X		X									
Gmac									< 30	X	< 16										
Sbre																					
Lhos								> 29													
Ttru									>9<30				< 21								
Ggri									>9<30	X	< 16	>6<30									
Sfro													< 21								
TtSf													< 21								
Satt								> 29						> 29						X	X
Scoe								> 29						> 29						X	X
Slon								> 29						> 29							X
Scly								> 29						> 29						X	
Ular	X																				
Usml						<5	<5														

Table 3.2. The estimated value of f(0) and associated statistics. CV = coefficient of variation, n(f(0)) = number of sightings used to estimate f(0) (* indicates species which required pooling with other species to estimate f(0)), n(D) = number of sightings used for estimating density and abundance, n(ALL) = total number of on effort sightings, and ANIMALS = total estimated number of individuals sighted.

Species	f(0) (km^{-1})	CV (f(0))	n(f(0))	n(D)	n(ALL)	ANIMALS
Bryde's whale	0.470	0.20	86*	1	1	2
Sperm whale	0.435	0.15	108	73	73	201
Pygmy sperm whale	0.480	0.12	65*	9	9	11
Dwarf sperm whale	0.525	0.13	36*	22	22	47
Dwarf/pygmy sperm whale	0.493	0.13	65*	15	16	34
Cuvier's beaked whale	0.567	0.07	78*	6	6	7
Unidentified Ziphiidae	0.493	0.08	86*	15	16	35
Melon-headed whale	0.411	0.10	184*	10	10	1407
Pygmy killer whale	0.433	0.14	104*	2	2	23
False killer whale	0.419	0.13	108*	2	3	9
Killer whale	0.439	0.14	83*	4	4	45
Short-finned pilot whale	0.519	0.17	74*	9	9	138
Rough-toothed dolphin	0.602	0.07	284*	8	8	106
Fraser's dolphin	0.411	0.10	183*	1	2	64
Bottlenose dolphin	0.760	0.11	206	83	97	999
Risso's dolphin	0.448	0.14	89	44	46	411
Atlantic spotted dolphin	0.786	0.22	80	18	25	472
Pantropical spotted dolphin	0.537	0.11	191	80	98	4998
Striped dolphin	0.751	0.42	37	21	22	782
Spinner dolphin	0.500	0.10	260*	10	10	470
Clymene dolphin	0.492	0.10	263*	23	25	1310

where θ = angle between the track-line and the group
h = altitude, always 229 m.

Due to inclinometer malfunction, no angle was recorded for 26 groups sighted from 0-60°. For these and sightings from 60-70°, the midpoint of the interval was used as the PSD and was treated as an exact distance. Sightings at angles > 70° were bounded by the horizon. However, we assumed they occurred at less than 1,300 m (about 80°), and the midpoint of the interval 70°-80° was used. In trial runs, the value of the midpoint made little difference in estimates of D or f(0), and therefore these sightings were used because they constituted a significant portion of the data (9%).

All analyses were made with the data left truncated at 50 m. The frequency distribution of PSD of all sightings peaked near PSD = 50 m and decreased as the PSD approached 0 m, whereas the expected distributions showed no such peaks. This deviation from the expected distributions may have been a result of better sighting conditions at PSD = 50 than at PSD = 0, due to glare or other conditions. Including the sightings between 0-50 m could have resulted in negatively biased abundance estimates (see Alldredge and Gates 1985). The 45 sightings with a PSD < 50 m were excluded from analyses and the left-truncation option was implemented on DISTANCE™.

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 (i.e., body size and surface behavior) were pooled into four categories (Table 3.3) and an estimate of f(0) was made for each category (Table 3.4). For each species, the value of f(0) for the category to which it belonged and its associated variance were used in abundance estimates. 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 X^2 value and decreased CV[f(0)]). For each estimate, except those involving species from Category 4, a model was fit to PSD data grouped into intervals: 50-150, 151-250, 251-400, 401-630, and 631-1,300 m. PSD intervals for Category 4 were: 50-200, 201-400, 401-630, and 631-1,300 m.

3.2.2.2 *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 (Weber et al. 1992). 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 for sea turtles were essentially the same as those for cetaceans except that sea turtles were not circled. All sea turtle sightings were pooled in order to estimate a common f(0) which was then applied to each species. Analyses methods were the same as those for cetaceans with the following exceptions: (1) data were not left-truncated (a left-truncated estimate of f(0) at 50 m was made, but since both estimates of f(0) were similar the non-left-truncated estimates were used in order to maintain as large a sample size as possible) (2) data were

Table 3.3. Categories of cetaceans with similar sighting characteristics for which sightings were pooled to estimate the parameter f(0) for aerial surveys.

Category 1: Inactive at the surface and <7 m in length

Pygmy/dwarf sperm whale	Unidentified dolphin
Cuvier's beaked whale	Unidentified ziphiid
Unidentified small whale	Unidentified odontocete

Category 2: Active at the surface and <7 m in length

False killer whale	Risso's dolphin
Short-finned pilot whale	Atlantic spotted dolphin
Rough-toothed dolphin	Bottlenose/Atlantic spotted dolphin
Bottlenose dolphin	

Category 3: Very active at the surface and <7 m in length

Melon-headed whale	Spinner dolphin
Pantropical spotted dolphin	Clymene dolphin
Striped dolphin	*Stenella* spp.

Category 4: Large whales, >7 m in length

Bryde's/sei whale	Unidentified large whale
Sperm whale	

right-truncated at 629 m, and (3) exact distances were used instead of intervals. Sea turtles do not occur in social groups as cetaceans do, and 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, there is no variance in group size.

Table 3.4. Estimate of f(0) for each category of cetaceans with similar sighting characteristics (n = number of sightings, P = number of parameters in the model, CV = coefficient of variation).

	n	Model	P	f(0) (km^{-1})	CV[f(0)]
Category 1	69	Hazard Rate	2	4.365	0.24
Category 2	141	Hazard Rate	3	3.538	0.09
Category 3	80	Half-normal	2	2.753	0.09
Category 4	30	Half-normal	1	1.986	0.15
All cetaceans	310	Half-normal	2	3.390	0.05

3.3 Results

3.3.1 *Cetacean Abundance from Ship Surveys*

A total of 21,350 km of transect was visually sampled during the GulfCet ship surveys (Table 3.5). The transect kilometers sampled during each survey varied from 418-4,217 km. The cumulative survey effort each season was: spring - 13,507 km, summer - 2,085 km, fall - 1,275 km, and winter - 4,483 km. Overall, 19 cetacean species were identified in 683 sightings made on-effort (Table 3.6). All sightings are listed in Appendix A. The number of on-effort sightings each season ranged from 509 during spring to 14 during fall (Tables 3.7-3.10). Most of the survey effort occurred during the spring, with the least effort in the fall. The survey effort by cruise and season are also listed in Table 3.5.

Sighting rates of cetacean groups were consistent during the spring surveys, averaging about 4.0 groups/100 km (range = 3.3-4.7) (Table 3.5). The summer sighting rates were 2.7 and 7.6 groups/100 km. The fall sighting rates were 0.8

Table 3.5. Shipboard visual survey effort and cetacean groups sighted by vessel and season. Sighting rate = groups/100 km effort.

Vessel	Dates	Effort (km)	#Groups sighted on effort	Sighting rate
Spring				
R/V *Longhorn*	15 Apr-1 May 1992	418	17	4.1
NOAA Ship *Oregon II*	17 Apr-8 Jun 1992	4,217	170	4.0
NOAA Ship *Oregon II*	3 May-15 Jun 1993	4,102	137	3.3
R/V *Pelican*	23 May-5 Jun 1993	957	45	4.7
NOAA Ship *Oregon II*	15 Apr-10 Jun 1994	3,813	140	3.7
Total		13,507	509	3.8
Summer				
R/V *Pelican*	10 Aug-28 Aug 1992	1,037	28	2.7
R/V *Pelican*	25 Aug-5 Sep 1993	1,048	80	7.6
Total		2,085	108	5.2
Fall				
R/V *Pelican*	8 Nov- 22 Nov 1992	536	4	0.8
R/V *Pelican*	3 Dec-14 Dec 1993	739	10	1.4
Total		1,275	14	1.1
Winter				
NOAA Ship *Oregon II*	5 Jan-14 Feb 1993	3,964	43	1.1
R/V *Pelican*	12 Feb-27 Feb 1993	529	9	1.7
Total		4,493	52	1.2
Total		21,360	683	3.2

Table 3.6. Overall sighting and group-size statistics used for estimating cetacean abundances from shipboard surveys (n = number of sightings, n/L = groups encountered per 1,000 km [survey effort = 21,588], G = mean group size, S = size-bias adjusted group size [group sizes denoted with an * indicate which size estimate was used in density calculations], CV = coefficient of variation, N = abundance estimate, D = density estimate per 1,000 km^2, LCI = lower log-normal 95% confidence interval, UCI = upper 95% confidence interval. The size-bias adjusted group size was used in the density calculations if it was significantly different from the mean size at $p < 0.15$.

OVERALL Species	n	n/L	CV n/L	G	S	CV group size	N	D	CV	LCI	UCI
Bryde's whale	1	0.05	0.78	2*	-	-	**3**	0.02	0.81	1	14
Sperm whale	73	3.38	0.19	2.7*	3.1	0.14	**313**	2.02	0.25	192	508
Pygmy sperm whale	9	0.42	0.36	1.2*	1.3	0.12	**19**	0.12	0.40	9	40
Dwarf sperm whale	22	1.02	0.27	2.1*	1.9	0.17	**88**	0.57	0.34	46	170
Pygmy/dwarf sperm whale	15	0.69	0.33	2.0*	1.7	0.15	**53**	0.34	0.39	25	111
Cuvier's beaked whale	6	0.28	0.38	1.17*	1.25	0.14	**14**	0.09	0.41	7	31
Unidentified Ziphiidae	26	1.20	0.25	2.4*	2.2	0.13	**124**	0.81	0.29	71	218
Melon-headed whale	10	0.46	0.26	140.7*	167.7	0.19	**2,067**	13.38	0.34	1,071	3,988
Pygmy killer whale	2	0.09	0.61	11.5*	11.5	0.13	**36**	0.23	0.64	11	113
False killer whale	2	0.09	0.60	3.5*	3.5	0.14	**10**	0.07	0.63	3	33
Killer whale	4	0.19	0.43	11.2*	11.0	0.04	**71**	0.46	0.46	30	167
Short-finned pilot whale	9	0.42	0.34	15.3	13.7*	0.33	**215**	1.39	0.50	82	563
Rough-toothed dolphin	8	0.37	0.29	13.2	10.3*	0.18	**177**	1.14	0.35	89	351
Fraser's dolphin	1	0.05	1.16	44.0*	-	-	**65**	0.42	1.17	10	400
Bottlenose dolphin	83	3.84	0.20	11.2*	11.2	0.12	**2,538**	16.43	0.26	1,543	4,174
Risso's dolphin	44	2.04	0.17	9.2	7.5*	0.14	**529**	3.42	0.26	317	881
Atlantic spotted dolphin	18	0.83	0.26	22.6*	19.5	0.15	**1,145**	7.41	0.37	562	2,332
Pantropical spotted dolphin	80	3.71	0.15	59.8	46.2*	0.11	**7,105**	45.99	0.22	4,661	10,831
Striped dolphin	21	0.97	0.27	37.0*	49.2	0.14	**2,091**	13.53	0.52	788	5,544
Spinner dolphin	10	0.46	0.43	47.0*	52.0	0.41	**840**	5.44	0.60	274	2,580
Clymene dolphin	23	1.07	0.22	54.3	41.8*	0.28	**1,695**	10.97	0.37	827	3,474
ALL[1]	-	-	-	-	-	-	**19,198**	124.26	0.12	10,619	36,523

[1] (The CV of ALL (ΣN) was estimated as: $CV(\Sigma N) = \sqrt{\Sigma (CVN)^2} / \Sigma N$)

Table 3.7. Summer sighting and group-size statistics used for estimating cetacean abundances from shipboard surveys (n = number of sightings, n/L = groups encountered per 1,000 km [survey effort = 2,251], G = mean group size, S = size-bias adjusted group size [group sizes denoted with an * indicate which size estimate was used in density calculations], CV = coefficient of variation, N = abundance estimate, D = density estimate per 1,000 km^2, LCI = lower log-normal 95% confidence interval, UCI = upper 95% confidence interval. The size-bias adjusted group size was used in the density calculations if it was significantly different from the mean size at $p < 0.15$.

Season: SUMMER Species	n	n/L	CV n/L	G	S	CV group size	N	D	CV	LCI	UCI
Bryde's whale	0	-	-	-	-	-	-	-	-	-	-
Sperm whale	20	8.88	0.36	3.0*	4.3	0.16	**880**	5.70	0.42	391	1,984
Pygmy sperm whale	1	0.44	0.86	2.0*	-	-	**33**	0.21	0.87	7	156
Dwarf sperm whale	2	0.89	0.74	5.5*	-	0.27	**198**	1.28	0.80	46	855
Pygmy/dwarf sperm whale	2	0.89	0.83	1.0*	-	0.00	**34**	0.22	0.84	7	153
Cuvier's beaked whale	0	-	-	-	-	-	-	-	-	-	-
Unidentified Ziphiidae	8	3.55	0.48	2.8*	2.9	0.16	**579**	3.68	0.46	231	1,397
Melon-headed whale	1	0.44	0.85	250.0*	-	-	**3,522**	22.79	0.86	756	16,407
Pygmy killer whale	0	-	-	-	-	-	-	-	-	-	-
False killer whale	0	-	-	-	-	-	-	-	-	-	-
Killer whale	0	-	-	-	-	-	-	-	-	-	-
Short-finned pilot whale	0	-	-	-	-	-	-	-	-	-	-
Rough-toothed dolphin	1	0.44	0.83	14.0*	-	-	**289**	1.87	0.84	63	1,318
Fraser's dolphin	0	-	-	-	-	-	-	-	-	-	-
Bottlenose dolphin	16	7.11	0.47	8.2	7.5*	0.19	**3,131**	20.26	0.52	1,161	8,444
Risso's dolphin	2	0.89	0.76	22.0*	-	0.59	**677**	4.38	0.98	98	4,681
Atlantic spotted dolphin	1	0.44	0.76	55.0*	-	-	**1,484**	9.61	0.79	351	6,270
Pantropical spotted dolphin	3	1.33	0.58	39.3*	61	0.46	**2,175**	14.08	0.74	504	9,378
Striped dolphin	2	0.89	0.76	37.5*	-	0.87	**1,933**	12.51	1.23	135	27,594
Spinner dolphin	1	0.44	1.15	9.0*	-	-	**154**	1.00	1.16	23	1,048
Clymene dolphin	1	0.44	1.28	85.0*	-	-	**1,436**	9.29	1.28	185	11,131
ALL[1]	-	-	-	-	-	-	**16,515**	106.89	0.31	3,958	90,816

[1] (The CV of ALL (ΣN) was estimated as: $CV(\Sigma N) = \sqrt{\Sigma (CVN)^2} / \Sigma N$)

Table 3.8. Fall sighting and group-size statistics used for estimating cetacean abundances from shipboard surveys (n = number of sightings, n/L = groups encountered per 1,000 km [survey effort = 1,247], G = mean group size, S = size-bias adjusted group size [group sizes denoted with an * indicate which size estimate was used in density calculations], CV = coefficient of variation, N = abundance estimate, D = density estimate per 1,000 km^2, LCI = lower log-normal 95% confidence interval, UCI = upper 95% confidence interval. The size-bias adjusted group size was used in the density calculations if it was significantly different from the mean size at $p < 0.15$.

Season: FALL Species	n	n/L	CV n/L	G	S	CV group size	N	D	CV	LCI	UCI
Bryde's whale	0	-	-	-	-	-	-	-	-	-	-
Sperm whale	5	0.40	0.64	3.2	1.7*	0.25	**224**	1.45	0.70	60	842
Pygmy sperm whale	0	-	-	-	-	-	-	-	-	-	-
Dwarf sperm whale	0	-	-	-	-	-	-	-	-	-	-
Pygmy/dwarf sperm whale	0	-	-	-	-	-	-	-	-	-	-
Cuvier's beaked whale	0	-	-	-	-	-	-	-	-	-	-
Unidentified Ziphiidae	2	1.60	0.51	1.0*	-	0.00	**68**	0.44	0.52	24	192
Melon-headed whale	0	-	-	-	-	-	-	-	-	-	-
Pygmy killer whale	0	-	-	-	-	-	-	-	-	-	-
False killer whale	0	-	-	-	-	-	-	-	-	-	-
Killer whale	0	-	-	-	-	-	-	-	-	-	-
Short-finned pilot whale	2	1.60	0.56	11.0*	-	0.82	**667**	4.32	1.00	19	23,960
Rough-toothed dolphin	0	-	-	-	-	-	-	-	-	-	-
Fraser's dolphin	0	-	-	-	-	-	-	-	-	-	-
Bottlenose dolphin	1	0.80	2.02	15.0*	-	-	**706**	4.6	2.02	47	10,726
Risso's dolphin	0	-	-	-	-	-	-	-	-	-	-
Atlantic spotted dolphin	0	-	-	-	-	-	-	-	-	-	-
Pantropical spotted dolphin	0	-	-	-	-	-	-	-	-	-	-
Striped dolphin	0	-	-	-	-	-	-	-	-	-	-
Spinner dolphin	0	-	-	-	-	-	-	-	-	-	-
Clymene dolphin	0	-	-	-	-	-	-	-	-	-	-
ALL[1]	-	-	-	-	-	-	**1,665**	10.78	0.95	150	35,720

[1] (The CV of ALL (ΣN) was estimated as: $CV(\Sigma N) = \sqrt{\Sigma(CVN)^2} / \Sigma N$)

Table 3.9. Winter sighting and group-size statistics used for estimating cetacean abundances from shipboard surveys (n = number of sightings, n/L = groups encountered per 1,000 km [survey effort = 4,548], G = mean group size, S = size-bias adjusted group size [group sizes denoted with an * indicate which size estimate was used in density calculations], CV = coefficient of variation, N = abundance estimate, D = density estimate per 1,000 km^2, LCI = lower log-normal 95% confidence interval, UCI = upper 95% confidence interval. The size-bias adjusted group size was used in the density calculations if it was significantly different from the mean size at $p < 0.15$.

Season: WINTER Species	n	n/L	CV n/L	G	S	CV group size	N	D	CV	LCI	UCI
Bryde's whale	0	-	-	-	-	-	-	-	-	-	-
Sperm whale	9	1.98	0.56	2.9*	3.5	0.16	**192**	1.24	0.60	63	582
Pygmy sperm whale	3	0.66	0.75	1.0*	1.0	0.00	**24**	0.16	0.76	6	95
Dwarf sperm whale	0	-	-	-	-	-	-	-	-	-	-
Pygmy/dwarf sperm whale	0	-	-	-	-	-	-	-	-	-	-
Cuvier's beaked whale	0	-	-	-	-	-	-	-	-	-	-
Unidentified Ziphiidae	0	-	-	-	-	-	-	-	-	-	-
Melon-headed whale	1	0.22	0.85	60.0*	-	-	**418**	2.71	0.85	94	1,866
Pygmy killer whale	0	-	-	-	-	-	-	-	-	-	-
False killer whale	0	-	-	-	-	-	-	-	-	-	-
Killer whale	0	-	-	-	-	-	-	-	-	-	-
Short-finned pilot whale	2	0.44	0.88	16.5*	-	0.03	**274**	1.78	0.90	58	1,298
Rough-toothed dolphin	0	-	-	-	-	-	-	-	-	-	-
Fraser's dolphin	0	-	-	-	-	-	-	-	-	-	-
Bottlenose dolphin	5	1.10	0.44	5.8*	480.8	0.27	**374**	2.42	0.53	136	1,032
Risso's dolphin	0	-	-	-	-	-	-	-	-	-	-
Atlantic spotted dolphin	3	0.66	0.47	9.3*	22.1	0.31	**374**	2.42	0.60	118	1,186
Pantropical spotted dolphin	4	0.88	0.62	28.0*	30.4	0.09	**1,022**	6.61	0.64	315	3,316
Striped dolphin	1	0.22	1.08	28.0*	-	-	**357**	2.31	1.16	56	2,284
Spinner dolphin	0	-	-	-	-	-	-	-	-	-	-
Clymene dolphin	2	0.44	0.82	6.5*	-	0.23	**109**	0.70	0.85	24	487
ALL[1]	-	-	-	-	-	-	**3,144**	20.36	0.30	870	12,146

[1] (The CV of ALL (ΣN) was estimated as: $cv(\Sigma N) = \sqrt{\Sigma (cvN)^2} / \Sigma N$)

Table 3.10. Spring sighting and group-size statistics used for estimating cetacean abundances from shipboard surveys (n = number of sightings, n/L = groups encountered per 1,000 km [survey effort = 13,723], G = mean group size, S = size-bias adjusted group size [group sizes denoted with an * indicate which size estimate was used in density calculations], CV = coefficient of variation, N = abundance estimate, D = density estimate per 1,000 km^2, LCI = lower log-normal 95% confidence interval, UCI = upper 95% confidence interval. The size-bias adjusted group size was used in the density calculations if it was significantly different from the mean size at $p < 0.15$.

Season: SPRING Species	n	n/L	CV n/L	G	S	CV group size	N	D	CV	LCI	UCI
Bryde's whale	1	0.73	0.83	2.0*	-	-	**5**	0.03	0.85	1	23
Sperm whale	39	2.84	0.24	2.6*	2.9	0.11	**248**	1.60	0.30	139	444
Pygmy sperm whale	5	0.36	0.45	1.2*	1.3	0.17	**16**	0.11	0.50	6	42
Dwarf sperm whale	20	1.46	0.30	1.8	1.6*	0.14	**93**	0.60	0.35	47	183
Pygmy/dwarf sperm whale	13	0.95	0.38	2.2*	2.0	0.16	**79**	0.51	0.43	35	76
Cuvier's beaked whale	6	0.44	0.39	1.2*	1.3	0.14	**23**	0.15	0.43	10	51
Unidentified Ziphiidae	5	0.36	0.43	1.4*	1.6	0.17	**98**	0.63	0.37	48	200
Melon-headed whale	8	0.58	0.30	147.6*	137.1	0.20	**2,569**	16.63	0.38	1,230	5,363
Pygmy killer whale	2	0.15	0.65	11.5*	-	-	**57**	0.37	0.68	17	192
False killer whale	2	0.15	0.64	3.5*	-	-	**17**	0.11	0.67	5	56
Killer whale	4	0.29	0.45	11.3*	11.0	0.04	**113**	0.73	0.48	46	275
Short-finned pilot whale	5	0.36	0.43	16.6*	17.2	0.22	**232**	1.50	0.51	88	607
Rough-toothed dolphin	7	0.51	0.32	13.1	9.2*	0.19	**221**	1.43	0.39	105	467
Fraser's dolphin	1	0.07	1.23	44.0*	-	-	**103**	0.67	1.24	15	699
Bottlenose dolphin	61	4.45	0.24	12.5	12.6*	0.14	**3,335**	21.58	0.30	1,877	5,925
Risso's dolphin	42	3.06	0.18	8.6	7.5*	0.14	**803**	5.20	0.27	478	1,349
Atlantic spotted dolphin	14	1.02	0.34	23.1*	23.7	0.13	**1453**	9.05	0.42	653	3,232
Pantropical spotted dolphin	73	5.32	0.16	62.4	45.6*	0.11	**10,191**	65.96	0.23	6,553	15,850
Striped dolphin	18	1.31	0.31	37.5*	60.9	0.15	**2,891**	18.72	0.54	1,049	7,968
Spinner dolphin	9	0.66	0.48	51.2*	64.8	0.41	**1,314**	8.50	0.64	403	4,286
Clymene dolphin	20	1.46	0.24	57.6	52.1*	0.28	**2,924**	18.93	0.38	1,398	6,119
ALL[1]	-	-	-	-	-	-	**26,785**	173.02	0.13	14,203	53,407

[1] (The CV of ALL (ΣN) was estimated as: $cv(\Sigma N) = \sqrt{\Sigma(cvN)^2} / \Sigma N$)

and 1.4 groups/100 km. The winter sighting rates were similar to fall, and were 1.1 and 1.7 groups/100 km. However, the shipboard survey effort was not designed to provide information on seasonal occurrence of cetaceans. More than 50% of the total effort and 75% of all sightings occurred during the spring. The relatively small amount of effort and the resulting small number of sightings collected during the other seasons preclude valid comparisons between seasons; any variation in species distribution and abundance between seasons relative to the ship surveys may be a result of the inconsistent seasonal survey effort.

The sperm whale, bottlenose dolphin, and pantropical spotted dolphin were the most commonly sighted species during ship surveys. Each species was sighted more than 70 times (Table 3.6). Dwarf sperm whale, unidentified ziphiid, Risso's dolphin, striped dolphin, and clymene dolphin were each sighted 21-44 times, with the other species sighted fewer than 20 times. Average group sizes ranged from 1.2 for pygmy sperm whale and Cuvier's beaked whale to 140.7 for melon-headed whale (Table 3.6).

The overall estimate of cetacean abundance (with CV in parentheses) in the GulfCet study area was 19,198 (0.12) animals (Table 3.6). The most common species was the pantropical spotted dolphin with an estimated overall abundance of 7,105 (0.22) animals. The bottlenose dolphin was the next most common species with 2,538 (0.26) animals and was followed by the striped dolphin and the melon-headed whale, with 2,091 (0.52) and 2,067 (0.34) animals, respectively. The clymene dolphin and Atlantic spotted dolphin estimates were 1,695 (0.37) and 1,145 (0.37) animals, respectively, and were the only other species with estimates of over 1,000 animals. Relatively precise estimates were achieved for the sperm whale with 313 (0.25) animals and Risso's dolphin with 519 (0.26) animals. The only other species with estimates of more than 200 animals were the spinner dolphin and the short-finned pilot whale with estimates of 840 (0.60) and 215 (0.50) animals, respectively.

3.3.2 *Cetacean Abundance from Aerial Surveys*

A total of 49,960 km of transect was visually sampled during the eight GulfCet aerial surveys (Tables 3.11 and 3.12). Except for fall 1992, all of the proposed aerial track-lines were completed each survey. During fall 1992, high winds and rain persisted throughout most of the survey window and only 80% of the proposed survey effort was completed (eight track-lines between 89°47'W and 90°44'W were not surveyed) For the entire GulfCet study, 97% of the proposed aerial survey effort was completed. The transect kilometers sampled each survey ranged from 5,330-6,592 km, and each season, from 11,756-12,942 km.

In total, 351 cetacean groups were sighted on-effort during aerial surveys (Tables 3.11 and 3.12). The number of sightings per survey ranged from 24 to 61, and the number of sightings per season ranged from 49 to 109. Except for fall, group sighting rates were generally similar each season and ranged from 0.73-0.86 groups/100 km. During fall, the group sighting rate was lower (0.42 groups/100 km). The animal sighting rates were much more variable and ranged from 5.1 to 23.1 animals/100 km for fall and winter, respectively.

Table 3.11. Summary of the on-effort results of each GulfCet aerial survey.

	Summer 1992	Fall 1992	Winter 1993	Spring 1993	Summer 1993	Fall 1993	Winter 1994	Spring 1994
Starting date	11 Aug	3 Nov	1 Feb	25 Apr	1 Aug	31 Oct	31 Jan	2 May
Ending date	18 Sep	16 Dec	22 Mar	1 Jun	21 Aug	16 Dec	16 Mar	2 Jun
Days in window	40	44	50	38	21	47	45	32
survey	15	10	12	16	14	12	12	13
weather	17	31	28	17	1	30	29	13
travel/transit	6	3	6	4	4	4	4	5
mechanical	1	0	3	0	1	1	0	1
rest	0	0	0	1	1	0	0	0
other	1	0	1	0	0	0	0	0
Flight hours	97	80	90	100	92	88	96	89
Percent completed	100	80	100	100	100	100	100	100
Transect kilometers	6,592	5,330	6,184	6,264	6,350	6,426	6,433	6,381
Transects	77	66	74	74	74	74	74	74
Mean Beaufort Sea State	1.5	2.4	1.8	1.5	1.3	2.1	1.5	1.2
Number of sightings	50	24	37	51	45	25	61	58
Number of animals	905	226	912	1,159	749	372	712	1768
Group sighting rate (groups/100 km)	0.76	0.45	0.59	0.81	0.71	0.39	0.95	0.91
Animal sighting rate (animals/100 km)	13.7	4.2	14.7	18.5	11.8	5.8	26.6	27.7
Mean group size	17.4	9.4	24.6	20.7	16.3	14.3	26.8	30.0
Off-effort sightings	7	1	4	6	7	0	6	9
Number of species	10	9	10	12	12	8	14	11

Table 3.12. Summary of on-effort seasonal results of GulfCet aerial surveys.

	Summer	Fall	Winter	Spring	Total
Percent completed	100	90	100	100	97
Transect kilometers	12,942	11,756	12,616	12,645	49,960
Transects	151	140	148	148	587
Average Beaufort Sea State	1.4	2.3	1.7	1.3	1.5
Number of sightings	95	49	98	109	351
Number of animals	1,654	59	2,624	2,927	7,803
Group sighting rate (groups/100 km)	0.73	0.42	0.78	0.86	0.70
Animal sighting rate (animals/100 km)	12.8	5.1	20.8	23.1	15.6
Average group size	17.4	12.2	26.7	26.8	22.2
Off-effort sightings	14	1	10	15	40
Number of species	12	10	14	13	16

At least 17 cetacean species were identified during GulfCet aerial surveys (Table 3.13). The only sighting of killer whales during aerial surveys was off-effort. Aerial sightings are listed in Appendix A. All species sighted during aerial surveys also sighted during ship surveys. Seasonally, the number of species sighted ranged from 11 in fall to 15 in winter. Eight species were identified in all four seasons, two in three seasons, four in two seasons and four in only one season (Table 3.13). Five species that were each sighted 20 or more times accounted for 71% of the identified sightings: sperm whales, pygmy/dwarf sperm whales, bottlenose dolphins, Risso's dolphins, and pantropical spotted dolphins.

Overall, there were an estimated 16,986 (CV = 0.14) cetaceans in the GulfCet aerial survey study area (Tables 3.14 and 3.15). There were an estimated 12,690 (0.23) cetaceans the first year and 20,669 (0.18) the second. Most of the difference between years was a consequence of the two winter and the two spring estimates. In both cases, the point estimates were about two times as large the second year compared to the first. Seasonally, the overall cetacean abundance was about the same in winter (21,894 [0.27]) and spring (19,215 [0.25]), a little less in summer (14,959 [0.24]), but two-three times lower in the fall (6,051 [0.32]).

Overall, the pantropical spotted dolphin was the most abundant species in the aerial survey study area (5,251 [0.22]) followed by the melon-headed whale (2980 [0.60]), bottlenose dolphin (2,890 [0.20]), and Risso's dolphin (1,214 [0.24]) (Tables 3.16 and 3.17). The overall sperm whale population was estimated to be 87 whales (0.27) and pygmy/dwarf sperm whales, 176 (0.31). All the other delphinid species were represented by less than 1,000 individuals each, and

Table 3.13. Number of on-effort sightings of cetacean species during aerial surveys by temporal strata (Year 1 = summer 1992 to spring 1993, Year 2 = summer 1993 to spring 1994, T = total of 1 & 2, S = number of surveys/number of seasons a sighting was made).

Species	Summer			Fall			Winter			Spring			Years			S
	1	2	T	1	2	T	1	2	T	1	2	T	1	2	T	
Bryde's/sei whale	0	0	0	0	0	0	1	0	1	0	0	0	1	0	1	1/1
Sperm whale	2	4	6	1	6	7	0	6	6	7	2	9	15	18	28	7/4
Pygmy/dwarf sperm whale	7	7	14	1	1	2	3	3	6	7	8	15	18	19	37	8/4
Cuvier's beaked whale	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1/1
Unidentified ziphiid	1	1	2	2	2	4	0	3	3	3	0	3	6	6	12	4/4
Melon-headed whale	0	0	0	0	0	0	0	1	1	2	1	3	2	2	4	3/2
Melon-headed/pygmy killer whale	1	0	1	0	2	2	0	2	2	0	0	0	1	4	5	3/3
False killer whale	1	1	2	0	0	0	0	0	0	0	0	0	1	1	2	2/1
Short-finned pilot whale	2	1	3	2	1	3	1	2	3	2	0	2	7	4	11	7/4
Rough-toothed dolphin	2	0	2	1	0	1	0	1	1	2	3	5	5	4	9	5/4
Fraser's dolphin	0	0	0	0	0	0	0	1	1	1	0	1	1	1	2	2/2
Bottlenose dolphin	9	18	27	4	4	8	11	13	24	10	14	24	34	49	83	8/4
Risso's dolphin	2	2	4	2	1	3	5	11	16	7	9	16	16	23	39	8/4
Atlantic spotted dolphin	2	1	3	1	0	1	3	2	5	3	0	3	9	3	12	6/4
Bottlenose/Atlantic spotted dolphin	0	1	1	0	0	0	1	2	3	3	0	3	4	3	7	6/3
Pantropical spotted dolphin	11	4	15	1	3	4	4	8	12	4	12	16	21	26	47	8/4
Striped dolphin	0	0	0	0	2	2	1	3	4	0	2	2	1	7	8	4/3
Spinner dolphin	0	1	1	0	0	0	1	2	3	0	0	0	1	3	4	3/2
Clymene dolphin	0	1	1	0	0	0	1	1	2	2	2	4	3	4	7	5/3
Stenella spp.	2	1	3	1	0	1	2	1	3	0	3	3	5	5	10	6/4
Unidentified dolphin	4	0	4	3	1	4	1	0	3	2	0	2	12	1	13	6/4
Unidentified small whale	5	0	5	1	1	2	0	0	0	2	1	3	8	2	10	5/4
Unidentified large whale	1	1	2	0	1	1	0	1	1	0	0	0	1	3	4	4/3
Unidentified odontocete	0	2	2	4	1	5	0	1	1	0	1	1	4	5	9	5/4
Total sightings	52	46	98	24	26	50	37	64	101	57	59	116	170	195	365	
Species sighted	10	12	12	9	8	10	10	14	14	12	11	13	15	15	16	

Table 3.14. Estimates of the parameters used to estimate the abundance of all cetaceans combined in the aerial survey study area. Year 1 = Aug 1992-May 1993, Year 2 = Aug 1993-Jun 1994, n = groups sighted, n/L = group sighting rate per 1,000 km, S = size-bias adjusted group size, G = average group size, CV = coefficient of variation, P = probability that group size vs. PSD regression was significant.

Stratum	n	n/L	CV(n/L)	S	CV(S)	G	CV(G)	P
Years 1 & 2	310	6.20	0.07	18.8	0.12	20.9	0.11	0.08
Year 1	145	5.95	0.10	14.0	0.17	20.2	0.18	0.02
Year 2	165	6.45	0.09	24.1	0.16	21.4	0.14	0.54
Summer 1 & 2	85	6.57	0.12	15.7	0.20	17.2	0.13	0.07
Summer 1	44	6.68	0.18	13.2	0.29	17.8	0.18	0.04
Summer 2	41	6.46	0.15	19.5	0.30	16.6	0.18	0.42
Fall 1 & 2	40	3.40	0.21	22.6	0.29	12.2	0.24	0.99
Fall 1	19	3.56	0.33	20.2	0.45	10.7	0.29	0.92
Fall 2	21	3.27	0.27	33.7	0.45	13.6	0.36	0.97
Winter 1 & 2	88	6.98	0.12	21.6	0.24	26.8	0.19	0.07
Winter 1	33	5.34	0.17	18.5	0.38	26.1	0.30	0.08
Winter 2	55	8.55	0.16	26.4	0.32	27.2	0.26	0.23
Spring 1 & 2	97	7.67	0.12	17.2	0.21	22.3	0.23	0.10
Spring 1	49	7.82	0.19	11.9	0.30	22.2	0.40	0.05
Spring 2	48	7.52	0.16	24.6	0.30	22.4	0.23	0.38

Table 3.15. Density (D = animals/1,000 km^2) and abundance (N) estimates of all cetacean species combined in the aerial survey study area. CV = coefficient of variation of D and N, CI = confidence interval, Year 1 = Aug 1992-May 1993, Year 2 = Aug 1993-Jun 1994.

Stratum	D	N	CV	Log-normal 95% CI
Years 1 & 2	197.95	16,986	0.14	12,869-22,419
Year 1	147.88	12,690	0.23	8,081-19,929
Year 2	240.87	20,669	0.18	14,650-29,161
Summer 1 & 2	174.33	14,959	0.24	9,390-23,830
Summer 1	149.83	12,857	0.35	6,541-25,271
Summer 2	181.52	15,576	0.24	9,747-24,890
Fall 1 & 2	70.51	6,051	0.32	3,265-11,215
Fall 1	64.88	5,567	0.43	2,444-12,682
Fall 2	75.18	6,451	0.46	2,683-15,510
Winter 1 & 2	255.14	21,894	0.27	13,023-36,805
Winter 1	167.11	14,340	0.42	6,362-32,320
Winter 2	393.96	33,806	0.31	18,621-61,374
Spring 1 & 2	223.93	19,215	0.25	11,935-30,936
Spring 1	157.83	13,544	0.37	6,818-26,906
Spring 2	285.32	24,483	0.30	14,218-42,161

balaenopterids and ziphiids, less than 100 individuals each. Mean group sizes ranged from 315 for melon-headed whales to less than four for sperm whales, pygmy/dwarf sperm whales, and ziphiids (Table 3.16).

3.3.3 *Cetacean Distribution*

Cetaceans were found throughout the GulfCet study area (Figures 3.6 and 3.7). While the perception from the distribution of all cetaceans from ship surveys is that of a marked reduction in sightings in the extreme western part of the study area (Figure 3.6), ship survey effort was not uniformly distributed. However, aerial survey effort was uniformly distributed and, while not as marked, fewer sightings were made in the extreme west (Figure 3.7).

Seasonally (based on aerial surveys only), except for one sighting, no cetacean groups were sighted in the extreme eastern portion (DeSoto Canyon) of the study area during summer and fall (Figures 3.8-3.11). Very few cetacean groups were sighted in the western portion during spring. Cetacean groups were sighted throughout the study area during winter.

Table 3.16. Estimates of the parameters used to estimate the abundance of cetaceans in the aerial survey study area for the entire study (n = groups sighted, n/L = group sighting rate, S = size-bias adjusted group size, G = average group size, CV = coefficient of variation, P = probability that group size vs PSD regression was significant).

Species	n	n/L	CV(n/L)	S	CV(S)	G	CV(G)	P
Bryde's/sei whale	1	0.00002	1.07	-	-	1.0	1.00	-
Sperm whale	25	0.00050	0.19	2.1	0.13	2.0	0.12	0.52
Pygmy/dwarf sperm whale	33	0.00066	0.18	1.4	0.08	1.4	0.09	0.47
Cuvier's beaked whale	1	0.00002	0.67	-	-	3.0	0.58	-
Unidentified ziphiid	11	0.00022	0.46	3.2	0.19	3.1	0.11	0.43
Melon-headed whale	3	0.00006	0.70	526.0	0.98	311.7	0.22	0.43
Melon-headed/pygmy killer whale	2	0.00004	0.72	-	-	14.5	0.72	-
False killer whale	2	0.00004	0.66	-	-	27.5	0.27	-
Short-finned pilot whale	10	0.00020	0.43	23.8	0.21	22.5	0.17	0.50
Rough-toothed dolphin	7	0.00014	0.38	11.2	0.44	15.0	0.39	0.11
Fraser's dolphin	2	0.00004	0.88	-	-	31.0	0.45	-
Bottlenose dolphin	70	0.00140	0.14	13.7	0.16	13.6	0.12	0.25
Risso's dolphin	34	0.00068	0.18	11.7	0.14	12.0	0.19	0.55
Atlantic spotted dolphin	11	0.00022	0.32	17.4	0.30	17.8	0.21	0.31
Bottlenose/Atlantic spotted dolphin	5	0.00010	0.41	9.7	0.77	8.2	0.52	0.34
Pantropical spotted dolphin	43	0.00086	0.16	43.3	0.15	50.2	0.11	0.07
Striped dolphin	6	0.00012	0.45	62.7	0.67	52.5	0.39	0.37
Spinner dolphin	4	0.00008	0.50	250.1	0.74	91.3	0.40	0.71
Clymene dolphin	5	0.00010	0.36	29.7	0.46	35.0	0.21	0.20
Unidentified stenellid	8	0.00016	0.40	53.3	0.45	28.5	0.31	0.88
Unidentified dolphin	10	0.00020	0.33	6.0	0.44	5.0	0.36	0.56
Unidentified small whale	6	0.00012	0.41	3.9	0.18	2.2	0.18	0.96
Unidentified large whale	4	0.00008	0.47	1.5	0.27	1.3	0.19	0.41
Unidentified odontocete	8	0.00016	0.35	2.2	0.59	3.0	0.57	0.25

Table 3.17. Overall density (D = animals/1,000 km²) and abundance (N) estimates of cetacean species in the aerial survey study area for all seasons combined (CV = coefficient of variation of D and N, CI = confidence interval).

Species	D	N	CV	Log-normal 95% CI
Bryde's/sei whale	0.02	2	1.08	0-10
Sperm whale	1.01	87	0.27	52-146
Pygmy/dwarf sperm whale	2.04	176	0.31	97-317
Cuvier's beaked whale	0.13	11	0.71	3-40
Unidentified ziphiid	1.44	123	0.37	43-162
Melon-headed whale	29.84	2,561	0.74	698-9,396
Melon-headed/pygmy killer whale	1.02	88	1.03	8-925
False killer whale	1.94	167	0.72	45-614
Short-finned pilot whale	7.96	684	0.48	284-1656
Rough-toothed dolphin	2.76	237	0.59	74-758
Fraser's dolphin	1.69	146	1.00	26-810
Bottlenose dolphin	33.67	2,890	0.20	1,955-4,270
Risso's dolphin	14.41	1,237	0.28	727-2,102
Atlantic spotted dolphin	6.94	596	0.38	288-1,233
Bottlenose/Atlantic spotted dolphin	1.45	125	0.67	32-478
Pantropical spotted dolphin	59.40	5,097	0.24	3,207-8,100
Striped dolphin	10.05	863	0.60	276-2,699
Spinner dolphin	11.65	1,000	0.65	291-3,433
Clymene dolphin	5.59	479	0.43	209-1,101
Unidentified stenellid	7.28	624	0.52	235-1,660
Unidentified dolphin	2.18	187	0.55	67-526
Unidentified small whale	0.56	49	0.51	19-124
Unidentified large whale	0.10	9	0.53	3-23
Unidentified odontocete	1.05	90	0.71	23-350

The distribution of species are summarized below. The distribution of most species in the GulfCet study area had a depth component. That is, some were generally found only in the more shallow portions of the study area near the continental shelf break (100 m isobath) and others were usually only found well past the 100 m isobath. In addition to this depth component, some species were concentrated in different broad regions of the study area (e.g., central, western, or eastern). There was no evidence that any species shifted distribution seasonally within the aerial survey study area (see below).

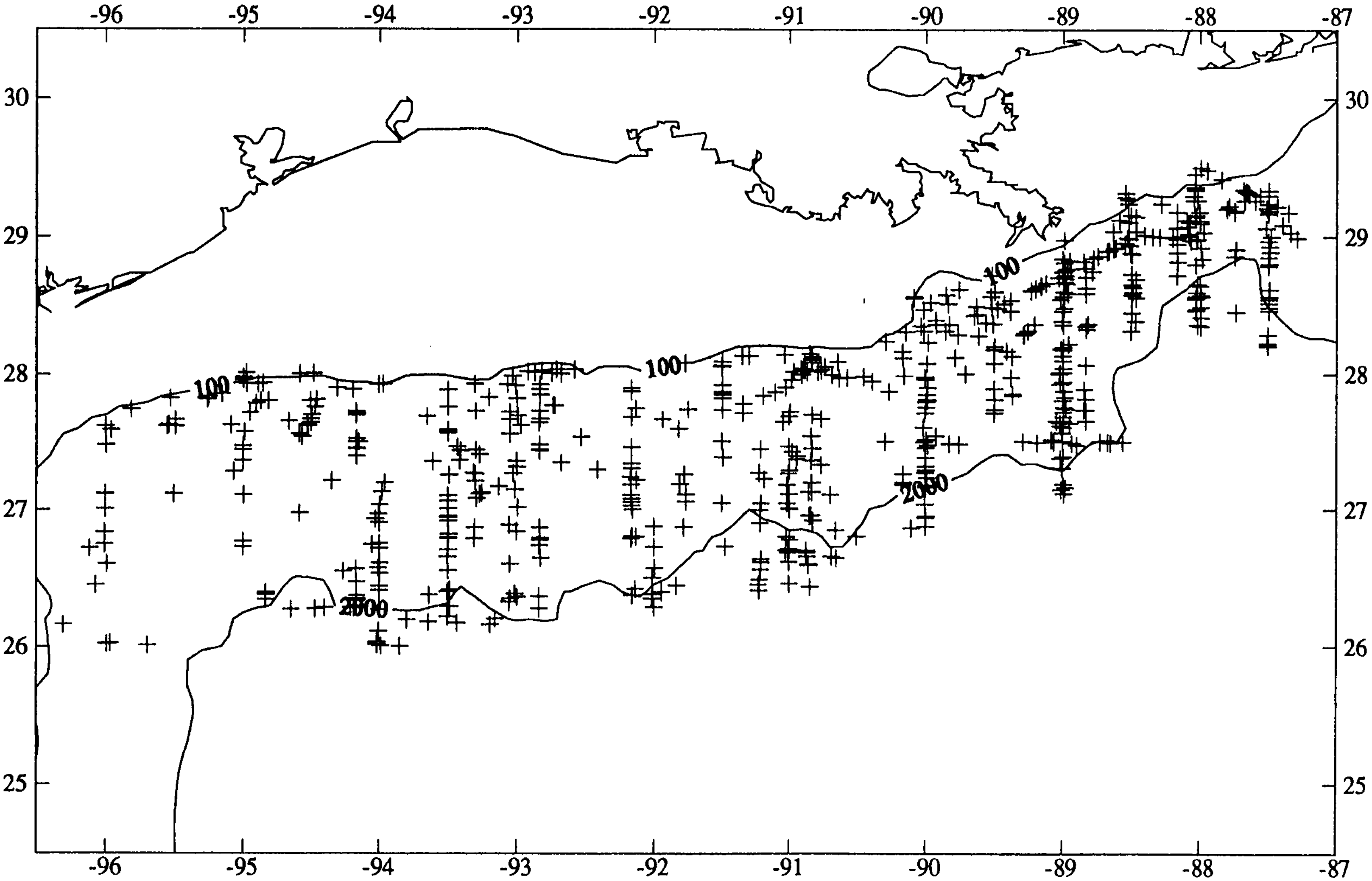

Figure 3.6. The locations of all cetacean groups sighted during GulfCet ship surveys.

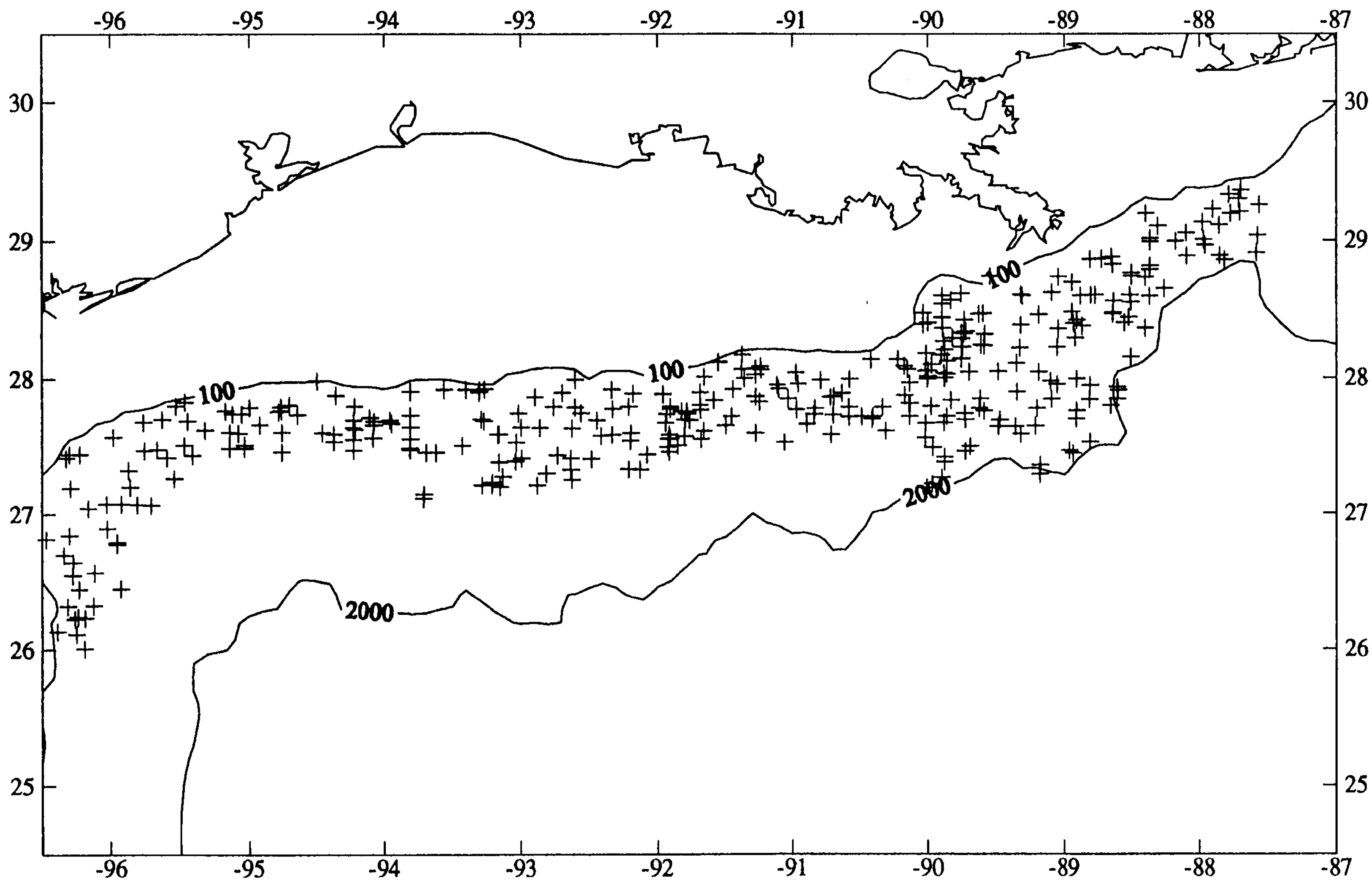

Figure 3.7. The locations of all cetacean groups sighted during GulfCet aerial surveys.

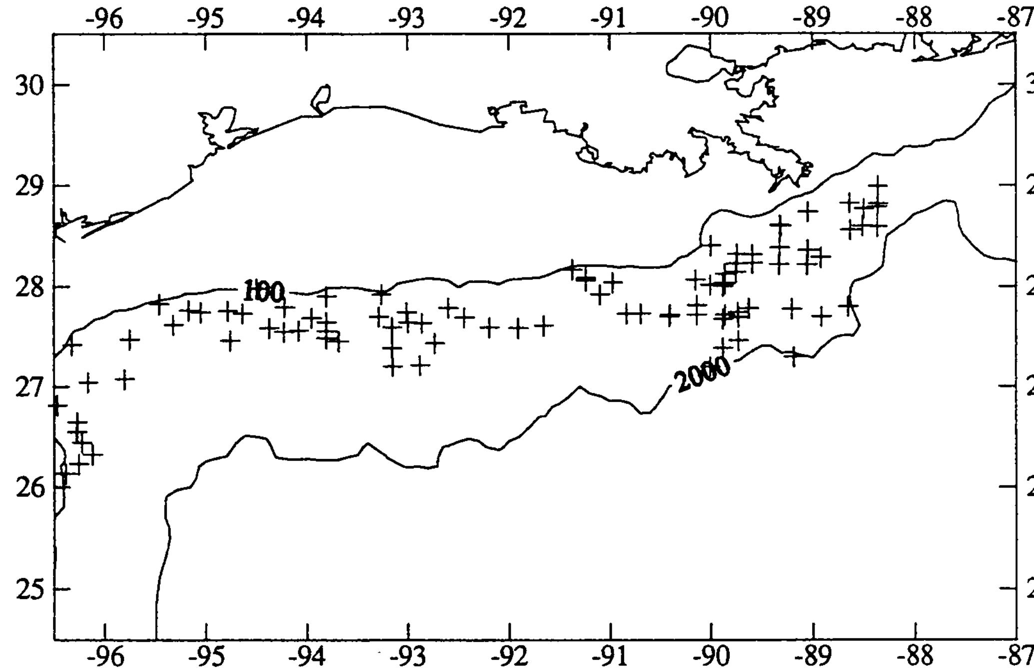

Figure 3.8. The locations of all cetacean groups sighted during GulfCet summer aerial surveys.

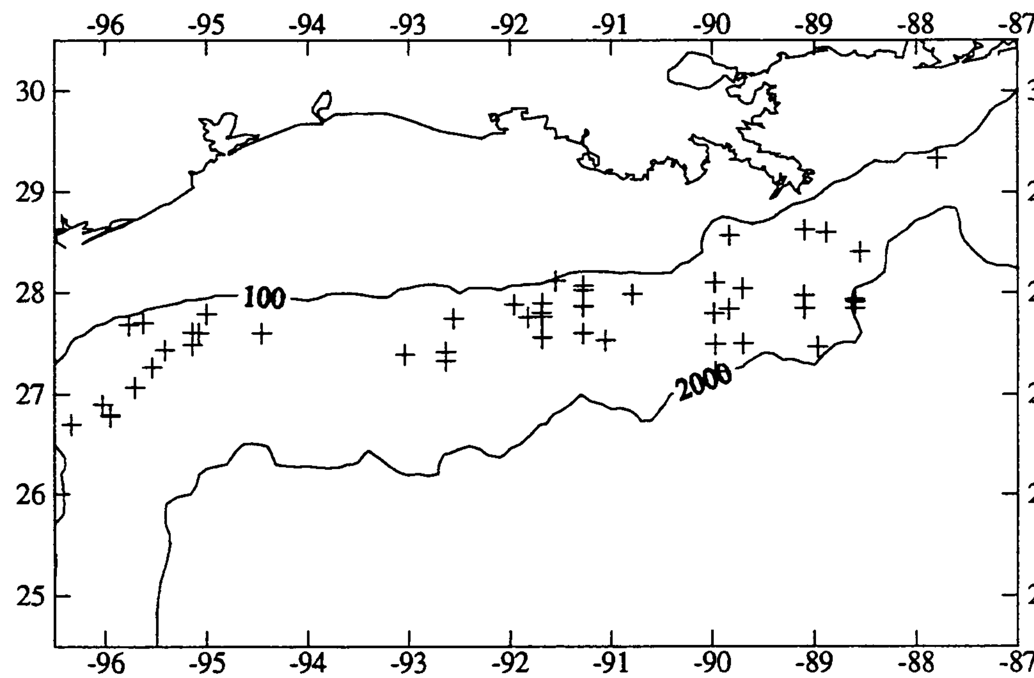

Figure 3.9. The locations of all cetacean groups sighted during GulfCet fall aerial surveys.

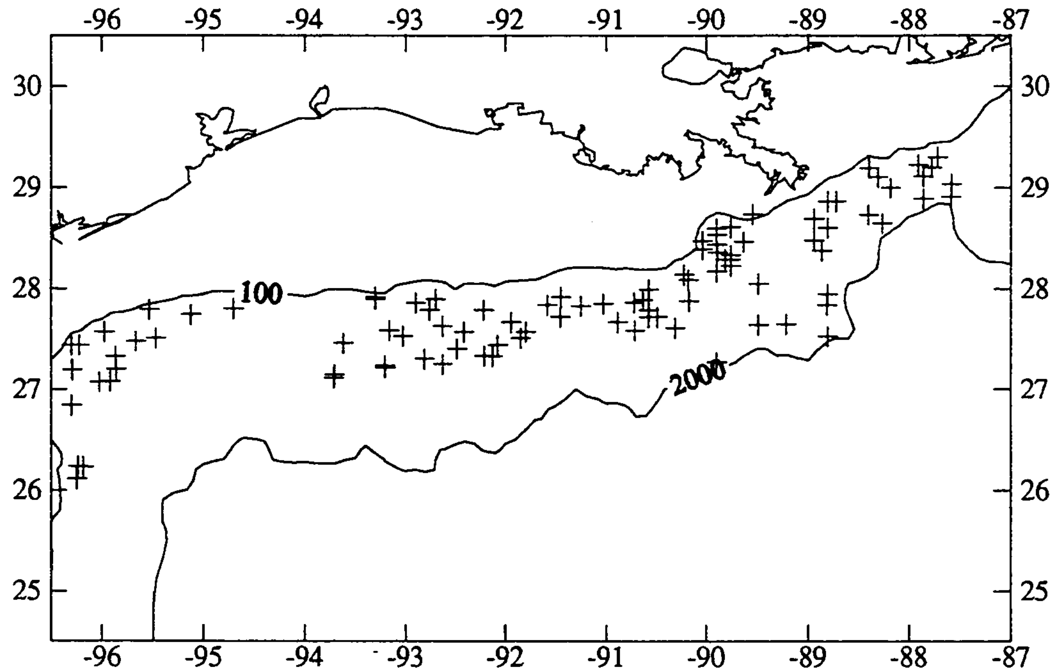

Figure 3.10. The locations of all cetacean groups sighted during GulfCet winter aerial surveys.

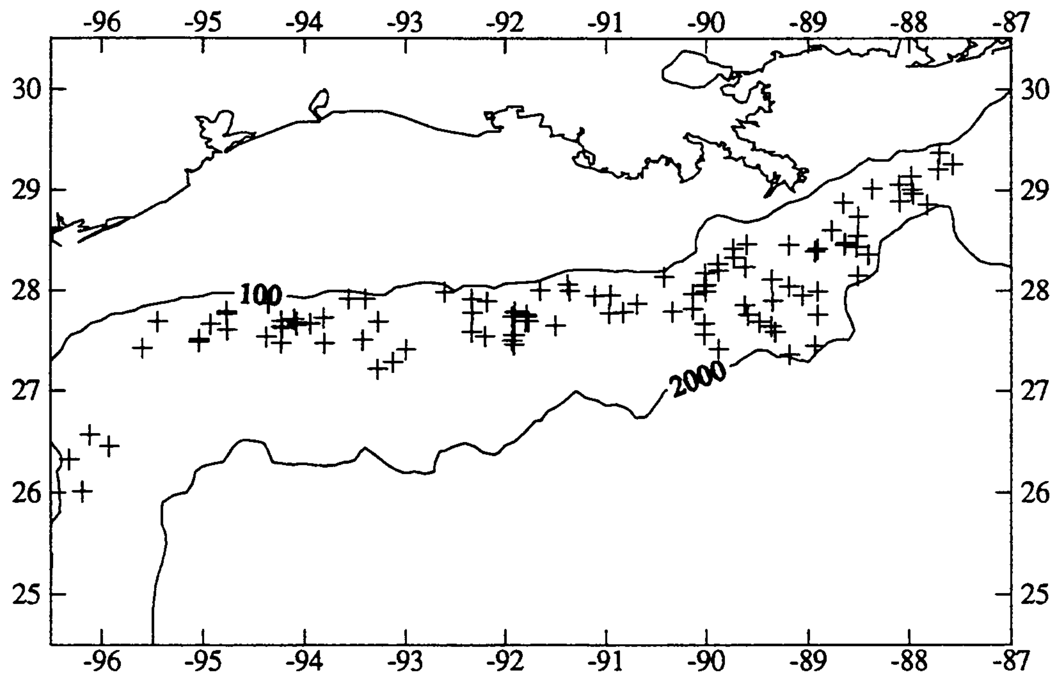

Figure 3.11. The locations of all cetacean groups sighted during GulfCet spring aerial surveys.

3.3.4 *Species Accounts*

In order to quickly access abundance and distribution information for each species from both ship and aerial surveys, summaries are provided below. Each summary includes: (1) the number of on-effort sightings (Tables 3.6 and 3.13), (2) estimates of overall mean group size (Tables 3.6 and 3.16), and (3) estimates of overall animal density from both ship and aerial surveys (Tables 3.6 and 3.17); (4) the range of group sizes; (5) where applicable, seasonal density estimates (Tables 3.18 and 3.19); and for the entire GulfCet study area, (6) an estimate of overall abundance (Table 3.6), and (7) a summary of distribution (Figures 3.12-3.50). As stated earlier, aerial surveys were designed to provide information on seasonal densities whereas ship surveys were not. However, seasonal density estimates were only made for those species sighted 20 or more times during aerial surveys. Although some of the seasonal density estimates are variable, they generally are not significantly different ($p < 0.05$). Since aerial surveys only sampled about 56% of the GulfCet study area, and because abundance estimates are the product of density and size of the area sampled, overall abundance estimates are from the overall ship surveys which sampled the entire study area. Comments on the distribution of each species are based on distribution maps from all aerial and ship surveys.

Balaenopterid whales

Balaenopterid whales were sighted on two occasions. Two Bryde's whales were sighted together from a ship during spring. A whale that was either a Bryde's whale or a sei whale was sighted from the aircraft during winter. The density estimates (animals/1,000 km^2 (CV)) were 0.02 (0.81) and 0.02 (1.08) for overall ship and overall aerial surveys, respectively. Bryde's whale abundance was estimated to be three animals (95% CI = 1-14, where CI = confidence interval). Both sightings were made near the 100 m isobath in the west-central part of the study area (Figures 3.12 and 3.13).

Sperm whale

Sperm whales were sighted during all seasons, 73 times during ship surveys and 28 times during aerial surveys. Group sizes averaged 2.7 (0.14) and 2.0 (0.12) animals as estimated from ship and aerial platforms, respectively, and ranged from 1-12 animals. The density estimates (animals/1,000 km^2 (CV))were 2.02 (0.25) and 1.01 (0.27) for overall ship and overall aerial surveys, respectively. The annual densities of sperm whales were similar, 0.85 (0.33) and 1.16 (0.33), for Year 1 and Year 2, respectively. Seasonally, the fall and spring densities were similar, 1.26 (0.43) and 1.41 (0.43), respectively. Summer density was intermediate 0.84 (0.52) and winter density was the lowest 0.55 (0.54). Sperm whale abundance was estimated to be 313 animals (95% CI = 192-508). Sperm whales were sighted throughout the study area (Figures 3.14 and 3.15). However, concentrations occurred near the 1,000 m isobath in the vicinity of the Mississippi River delta and on the central slope in the west-central part of the study area.

Table 3.18. Estimates of the parameters used to estimate the abundance of all cetaceans sighted 20 or more times in the aerial survey study area by year and season. Year 1 = Aug 1992-May 1993, Year 2 = Aug 1993-Jun 1994, n = groups sighted, n/L = group sighting rate per 1,000 km, S = size-bias adjusted group size, G = average group size, CV = coefficient of variation, P = probability that group size vs. PSD regression was significant.

Species	Stratum	n	n/L	CV(n/L)	S	CV(S)	G	CV(G)	P
Sperm whale	Years 1 & 2	25	0.50	0.19	2.1	0.13	2.0	0.12	0.52
	Year 1	10	0.41	0.30	2.0	0.24	2.1	0.19	0.25
	Year 2	15	0.59	0.24	2.4	0.18	2.0	0.16	0.75
	Summer	5	0.39	0.42	2.2	0.39	2.2	0.26	0.26
	Fall	7	0.60	0.31	3.0	0.33	2.1	0.26	0.76
	Winter	5	0.40	0.49	1.5	0.32	1.4	0.17	0.46
	Spring	8	0.63	0.34	2.2	0.31	2.3	0.21	0.28
Pygmy/dwarf sperm whale	Years 1 & 2	33	0.66	0.18	1.4	0.08	1.4	0.09	0.47
	Year 1	17	0.70	0.24	1.3	0.11	1.4	0.12	0.34
	Year 2	16	0.63	0.25	1.6	0.11	1.5	0.11	0.57
	Summer	13	1.00	0.27	1.7	0.16	1.8	0.13	0.34
	Fall	2	0.17	0.80	-	-	1.5	0.33	-
	Winter	5	0.40	0.50	1.7	0.18	1.2	0.17	0.89
	Spring	13	1.03	0.27	1.2	0.11	1.3	0.10	0.22
Bottlenose dolphin	Years 1 & 2	70	1.40	0.14	13.7	0.16	13.6	0.12	0.25
	Year 1	30	1.23	0.23	11.6	0.22	14.0	0.17	0.08
	Year 2	40	1.56	0.16	16.8	0.23	13.3	0.16	0.68
	Summer	24	1.85	0.21	21.5	0.30	18.2	0.19	0.45
	Fall	6	0.51	0.63	31.1	0.70	18.2	0.32	0.56
	Winter	20	1.59	0.22	9.1	0.29	9.0	0.16	0.25
	Spring	20	1.58	0.28	12.3	0.30	11.3	0.22	0.36

Table 3.18. Estimates of the parameters used to estimate the abundance of all cetaceans sighted 20 or more times in the aerial survey study area by year and season. Year 1 = Aug 1992-May 1993, Year 2 = Aug 1993-Jun 1994, n = groups sighted, n/L = group sighting rate per 1,000 km, S = size-bias adjusted group size, G = average group size, CV = coefficient of variation, P = probability that group size vs. PSD regression was significant. (continued)

Species	Stratum	n	n/L	CV(n/L)	S	CV(S)	G	CV(G)	P
Risso's dolphin	Years 1 & 2	34	0.68	0.18	11.7	0.14	12.0	0.19	0.55
	Year 1	12	0.49	0.35	10.0	0.20	10.4	0.20	0.33
	Year 2	22	0.86	0.20	13.4	0.19	12.8	0.30	0.66
	Summer	3	0.23	0.58	325.4	1.60	30.7	0.77	0.80
	Fall	2	0.17	0.70	-	-	9.0	0.22	-
	Winter	14	1.11	0.26	9.8	0.19	11.1	0.17	0.18
	Spring	15	1.19	0.29	9.9	0.19	9.4	0.17	0.53
Pantropical spotted dolphin	Years 1 & 2	43	0.86	0.16	43.3	0.15	50.2	0.11	0.07
	Year 1	19	0.78	0.23	30.3	0.26	40.2	0.17	0.08
	Year 2	24	0.94	0.21	52.4	0.16	58.1	0.14	0.16
	Summer	14	1.08	0.26	34.8	0.26	35.1	0.17	0.34
	Fall	4	0.34	0.42	41.1	0.25	54.3	0.24	0.13
	Winter	10	0.79	0.35	41.5	0.32	63.7	0.13	0.07
	Spring	15	1.19	0.26	66.5	0.32	55.1	0.24	0.54

Table 3.19. Density (D = animals/1,000 km^2) and abundance (N) estimates of cetacean species sighted 20 or more times by year and season in the aerial survey study area. CV = coefficient of variation of D and N, CI = confidence interval, Year 1 = Aug 1992-May 1993, Year 2 = Aug 1993-Jun 1994.

Species	Stratum	D	N	CV	Log-normal 95% CI
Sperm whale	Year 1 & 2	1.01	87	0.27	52-146
	Year 1	0.85	73	0.33	35-153
	Year 2	1.16	100	0.33	54-186
	Summer	0.84	72	0.51	27-192
	Fall	1.26	109	0.43	47-250
	Winter	0.55	47	0.52	18-127
	Spring	1.41	121	0.43	54-274
Pygmy/dwarf sperm whale	Year 1 & 2	2.04	176	0.31	97-317
	Year 1	1.96	168	0.36	85-334
	Year 2	2.04	176	0.37	88-352
	Summer	3.87	333	0.38	161-688
	Fall	0.55	48	0.90	10-227
	Winter	1.03	89	0.58	31-255
	Spring	2.71	233	0.39	114-478
Bottlenose dolphin	Year 1 & 2	33.67	2,890	0.20	1955-4270
	Year 1	25.15	2,158	0.33	1141-4081
	Year 2	36.70	3,150	0.25	1959-5064
	Summer	59.73	5,126	0.30	2867-9163
	Fall	16.40	1,407	0.71	395-5011
	Winter	25.09	2,154	0.29	1241-3737
	Spring	31.61	2,713	0.36	1356-5428
Risso's dolphin	Year 1 & 2	14.41	1,237	0.28	727-2102
	Year 1	9.07	779	0.41	359-1689
	Year 2	19.49	1,673	0.34	861-3249
	Summer	12.57	1,079	0.97	133-8777
	Fall	2.70	232	0.74	62-872
	Winter	21.87	1,877	0.32	1019-3459
	Spring	19.72	1,693	0.35	874-3279
Pantropical spotted dolphin	Year 1 & 2	59.40	5,097	0.24	3207-8100
	Year 1	37.67	3,233	0.37	1586-6590
	Year 2	86.86	7,453	0.27	4413-12587
	Summer	58.89	5,053	0.33	2674-9549
	Fall	22.32	1,915	0.50	726-5050
	Winter	52.49	4,504	0.49	1766-11486
	Spring	104.16	8,938	0.37	4383-18224

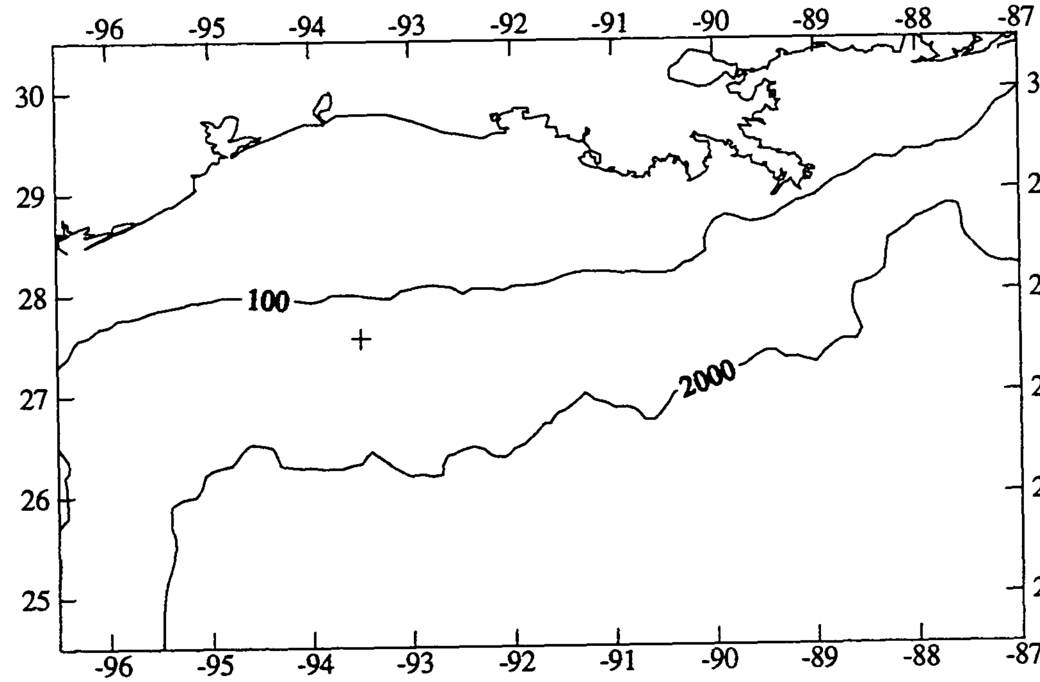

Figure 3.12. The location of the Bryde's/sei whale sighted during GulfCet ship surveys.

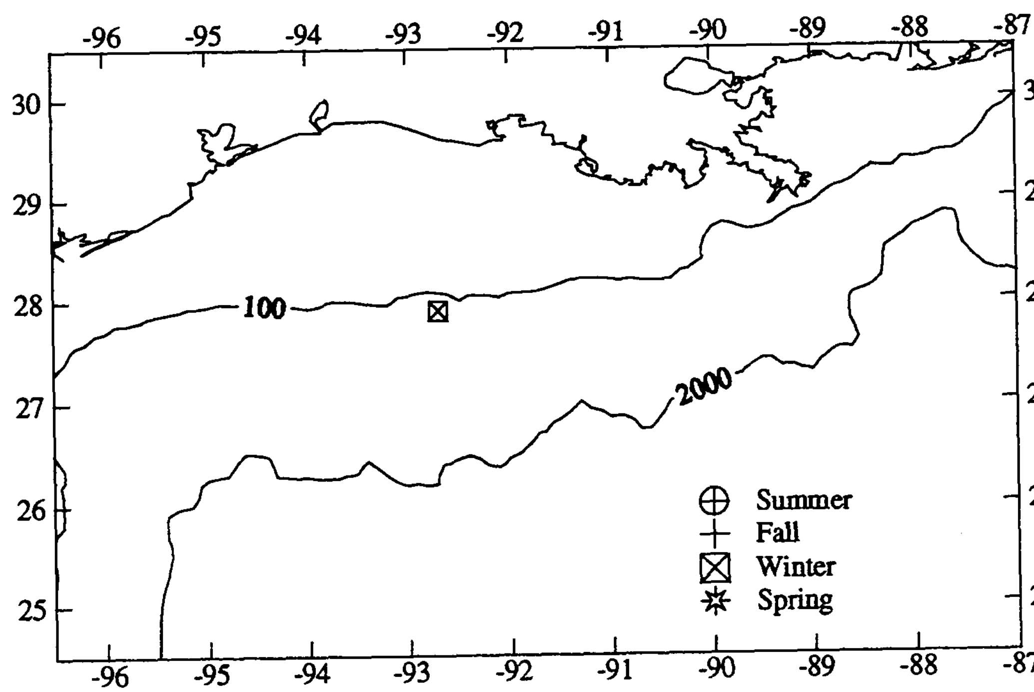

Figure 3.13. The locations of the Bryde's/sei whale sighted during GulfCet aerial surveys.

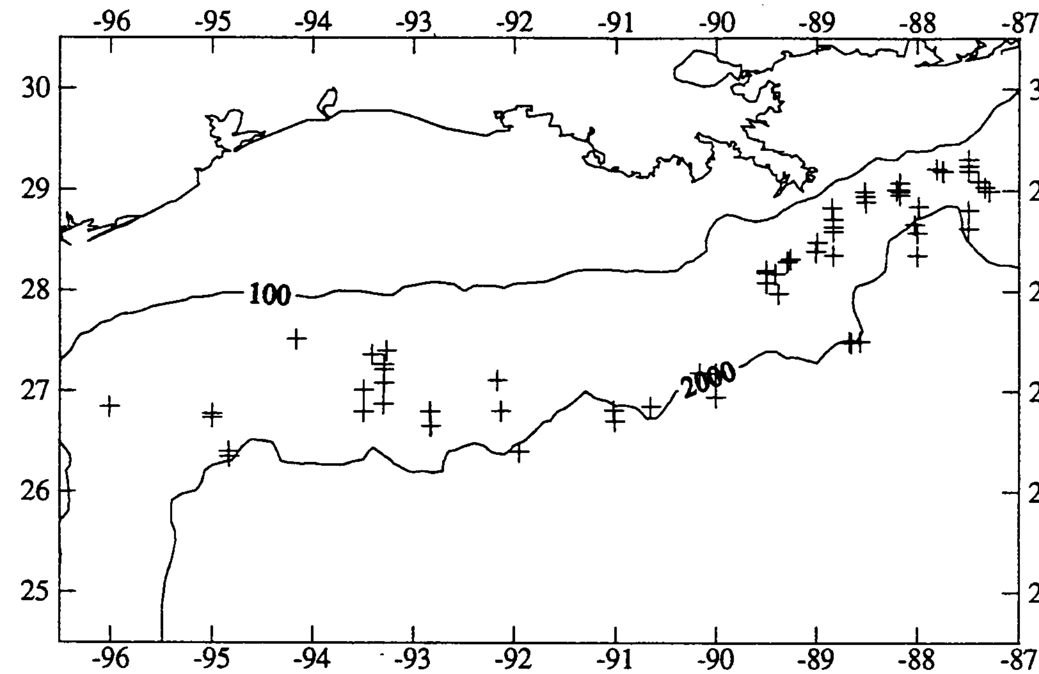

Figure 3.14. The locations of all sperm whales sighted during GulfCet ship surveys.

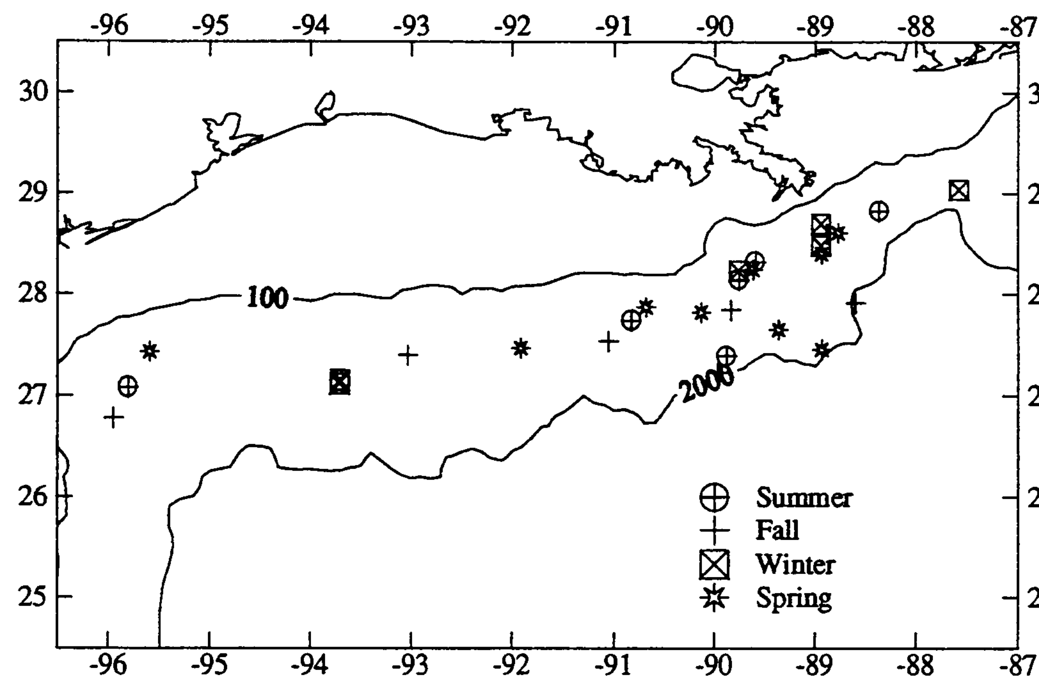

Figure 3.15. The locations of all sperm whales sighted during GulfCet aerial surveys.

Pygmy sperm whale

Pygmy sperm whales were sighted during all seasons except fall, a total of nine times from ship platforms. (Pygmy sperm whales could not be distinguished from dwarf sperm whales from aircraft. See below.) Group sizes averaged 1.2 (0.12) animals and ranged from 1-2 animals. The density estimate (animals/1,000 km^2 (CV)) was 0.12 (0.40) for overall ship surveys. Pygmy sperm whale abundance was estimated to be 19 animals (95% CI = 9-40). Pygmy sperm whales were sighted in the central part of the study area. No sightings occurred in the extreme eastern or western portions of the study area (Figure 3.16).

Dwarf sperm whale

Dwarf sperm whales were sighted during spring and summer, a total of 22 times from ship platforms. (Dwarf sperm whales could not be distinguished from pygmy sperm whales from aircraft. See below.) Groups sizes averaged 2.1 (0.17) animals and ranged from 1-7 animals. The density estimate (animals/1,000 km^2 (CV))was 0.57 (0.34) for overall ship surveys. Dwarf sperm whale abundance was estimated to be 88 animals (95% CI = 46-170). Dwarf sperm whales were sighted throughout the study area with most sightings occurring in the eastern portion of the study area (Figure 3.17).

Pygmy/dwarf sperm whales

Pygmy/dwarf sperm whales were sighted in all seasons, 15 times during ship surveys and 37 times during aerial surveys. Group sizes averaged 2.0 (0.15) and 1.4 (0.09) animals as estimated from ship and aircraft platforms, respectively, and ranged from 1-4 animals. The density estimates (animals/1,000 km^2 (CV)) were 0.34 (0.39) and 2.04 (0.31) for overall ship and overall aerial surveys, respectively. The sum of the overall ship densities of dwarf, pygmy, and pygmy/dwarf sperm whales was 1.13. The densities from Year 1 and Year 2 were similar, 1.96 (0.36) and 2.04 (0.37), respectively. Seasonally, densities peaked during summer (3.87 [0.38]) and spring (2.71 [0.38]), and were much lower during fall (0.55 [0.90]) and winter (1.03 [0.58]). Pygmy/dwarf sperm whale abundance was estimated to be 53 animals (95% CI = 25-111). Pygmy/dwarf sperm whales were sighted throughout the study area (Figures 3.18 and 3.19).

Cuvier's beaked whale

Cuvier's beaked whales were sighted six times during ship surveys and once during aerial surveys. All of the sightings were made during spring. The group sizes averaged 1.2 (0.14) animals from ship sightings with a range of 1-2 animals, and the aircraft sighting consisted of one whale. The density estimates (animals/1,000 km^2 (CV)) were 0.09 (0.41) and 0.13 (0.71) for overall ship and overall aerial surveys, respectively. Cuvier's beaked whale abundance was estimated to be 14 animals (95% CI = 7-31). Cuvier's beaked whale sightings were distributed throughout the deepest part of the study area near the 2,000 m isobath (Figures 3.20 and 3.21).

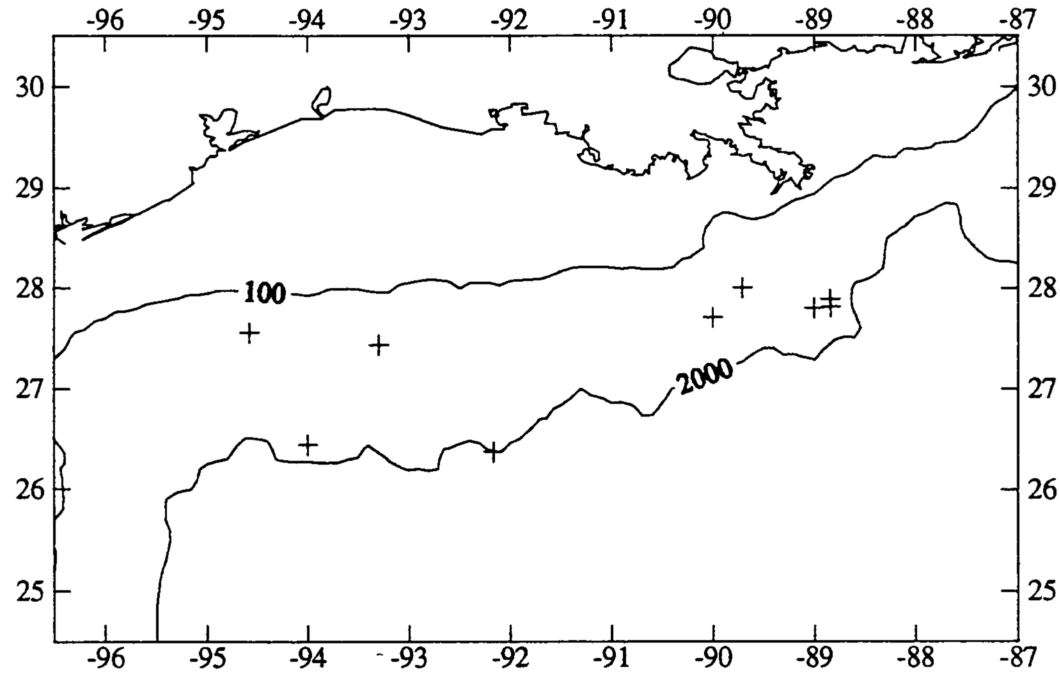

Figure 3.16. The locations of all pygmy sperm whales sighted during GulfCet ship surveys.

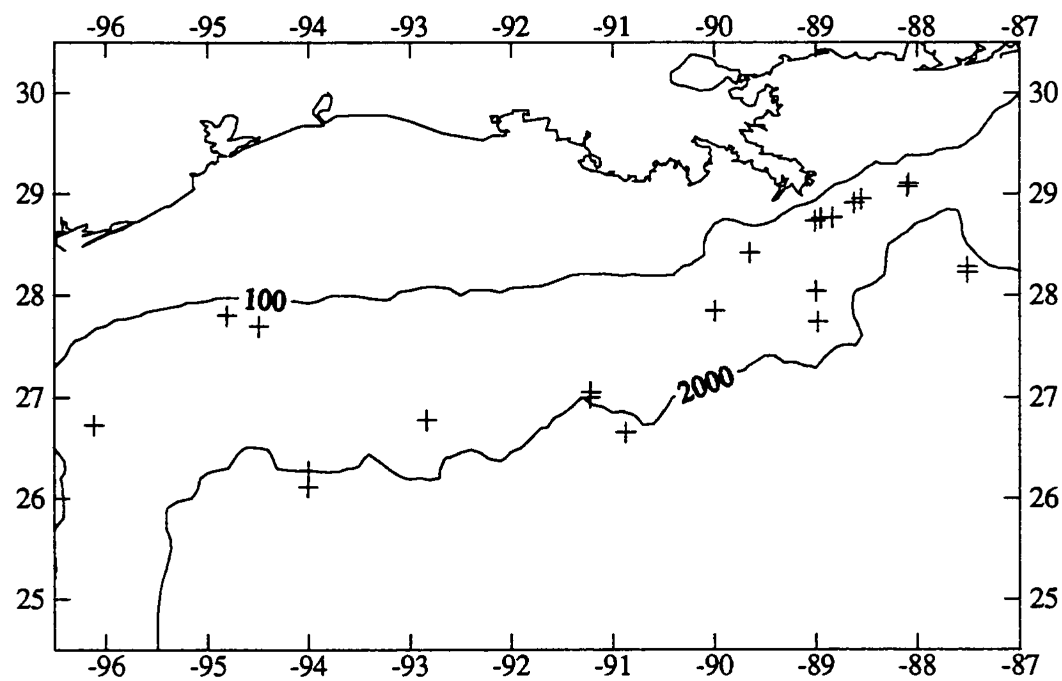

Figure 3.17. The locations of all dwarf sperm whales sighted during GulfCet ship surveys.

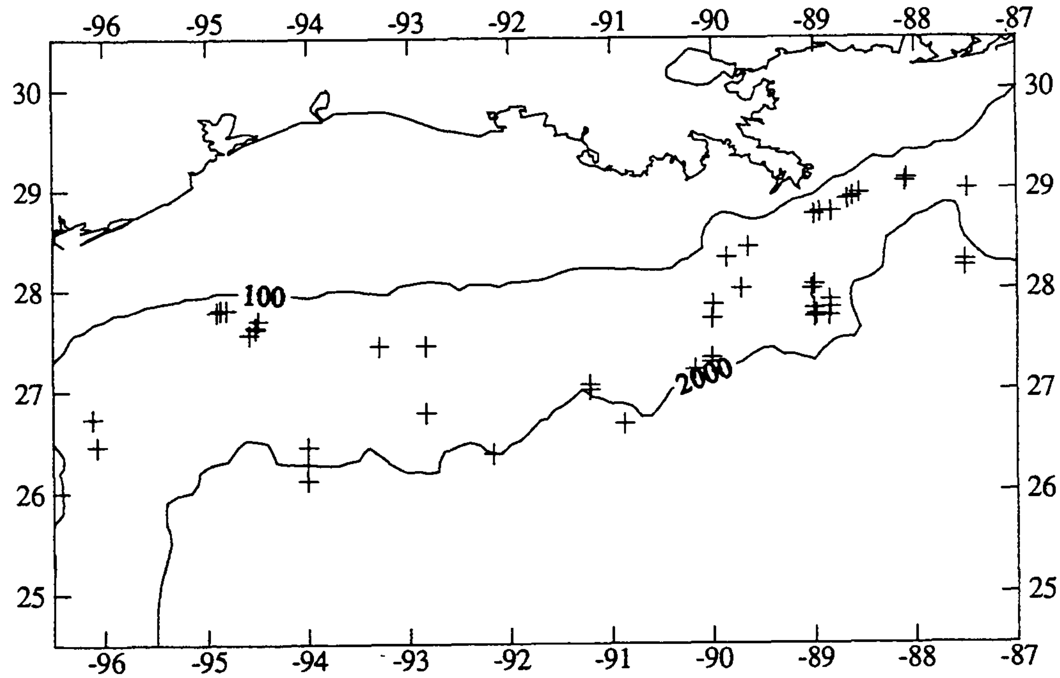

Figure 3.18. The locations of all pygmy/dwarf sperm whales sighted during GulfCet ship surveys.

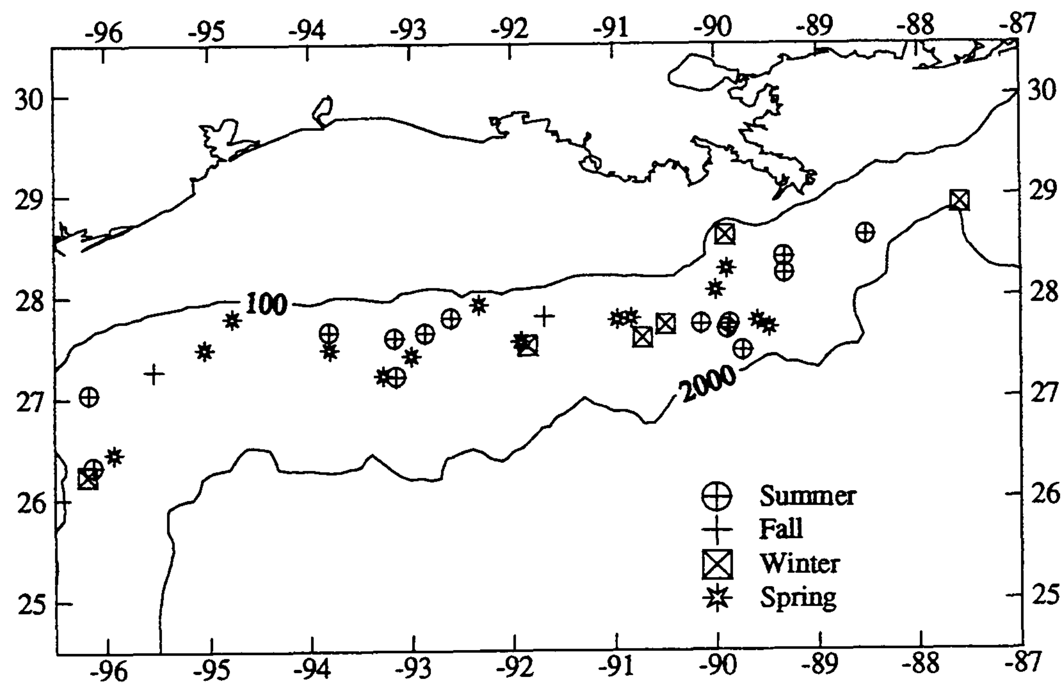

Figure 3.19. The locations of all pygmy/dwarf sperm whales sighted during GulfCet aerial surveys.

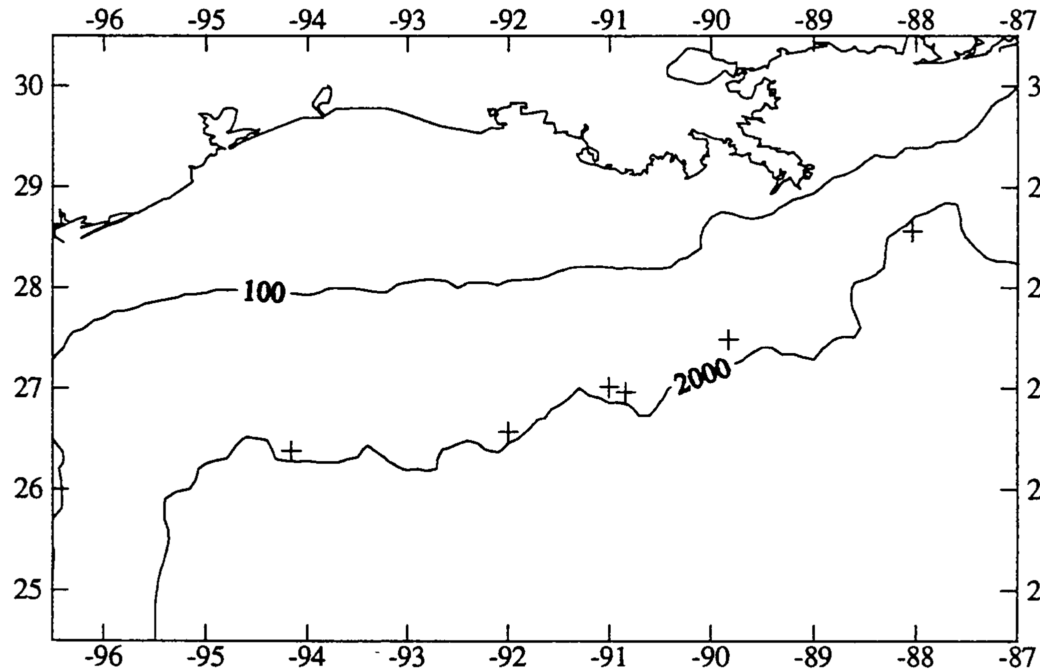

Figure 3.20. The locations of all Cuvier's beaked whales sighted during GulfCet ship surveys.

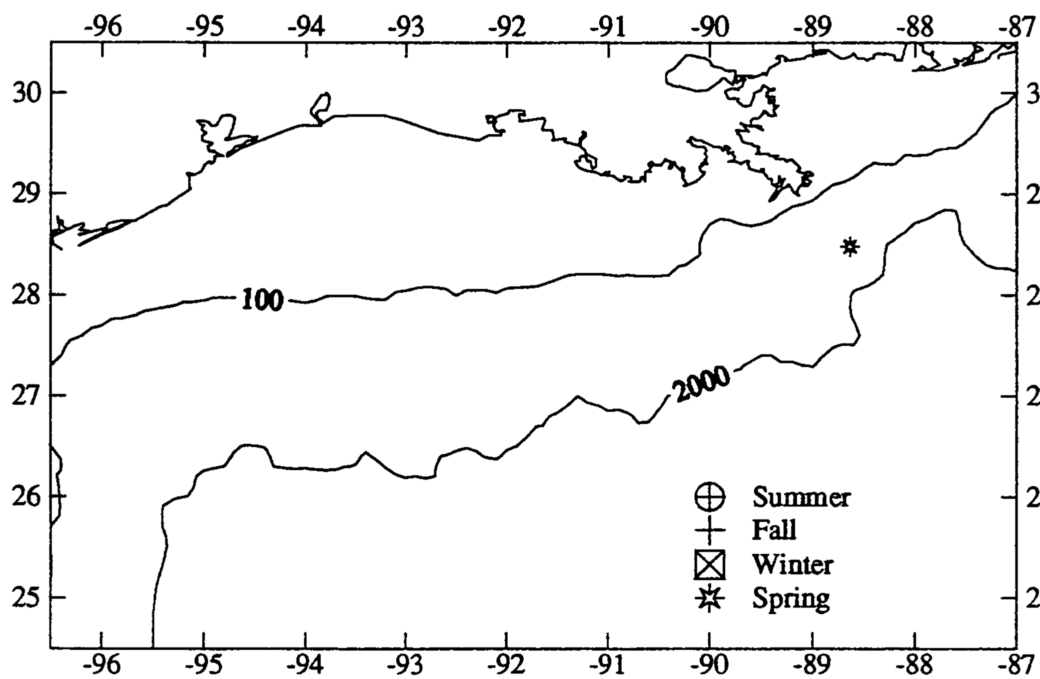

Figure 3.21. The locations of all Cuvier's beaked whales sighted during GulfCet aerial surveys.

Unidentified ziphiid whales

Unidentified ziphiid whales were sighted in all seasons, 15 times during ship surveys and 12 times during aerial surveys. Group sizes averaged 2.4 (0.13) and 3.2 (0.19) animals as estimated from ship and aircraft platforms, respectively, and ranged from 1-7 animals. The density estimates (animals/1,000 km^2 (CV)) were 0.80 (0.38) and 1.44 (0.37) for overall ship and overall aerial surveys, respectively. During aerial surveys, five sightings occurred in Year 1, three in Year 2, and two or more sightings were made in each season except summer. Unidentified ziphiid whale abundance was estimated to be 124 animals (95% CI = 71-218). Unidentified ziphiid whales were sighted throughout the study area, generally well away from the 100 m isobath (Figures 3.22 and 3.23).

Melon-headed whale

Melon-headed whales were sighted during all seasons except fall, 10 times during ship surveys and four times during aerial surveys. Melon-headed whales were not always distinguished from pygmy killer whales from aircraft. Identification of melon-headed whales from aircraft was based on large group size (>100 animals) and the presence of Fraser's dolphins (see Mullin et al. (1994a) and the Pygmy killer/melon-headed whales account, below). Group sizes averaged 140.7 (0.19) and 311.7 (0.22) animals as estimated from ship and aircraft platforms, respectively, and ranged from 30-400 animals. The density estimates (animals/1,000 km^2 (CV)) were 13.38 (0.34) and 29.84 (0.74) for overall ship and overall aerial surveys, respectively. During aerial surveys, two groups were sighted in both Year 1 and Year 2 and three sightings were made in the spring. Melon-headed whale abundance was estimated to be 2,067 animals (95% CI = 1,071-3,988). Melon-headed whales were sighted in the west-central portion of the study area, well past the 100 m isobath (Figures 3.24 and 3.25).

Pygmy killer whale

Pygmy killer whales were sighted from ship two times during spring. Pygmy killer whales and melon-headed whales could not be distinguished from the aircraft (see Pygmy killer/melon-headed whale account, below). Group sizes were 10 and 13 animals. The density estimate (animals/1,000 km^2 (CV)) was 0.23 (0.64). Pygmy killer whale abundance was estimated to be 36 animals (95% CI = 11-113). The pygmy killer whale sightings were in the west-central portion of the study area well past the 100 m isobath (Figure 3.26).

Pygmy killer/melon-headed whale

Pygmy killer/melon-headed whales were sighted from aircraft during all seasons except spring (Figure 3.27). These two species were always distinguished from each other during ship surveys (see species accounts above). The five sightings averaged 14.5 (0.72) animals and ranged from 3-25 animals. The density estimate (animals/1,000 km^2 (CV)) was 1.02 (1.03). Four of the sightings were made in Year 2. Two sightings were made in fall, two in

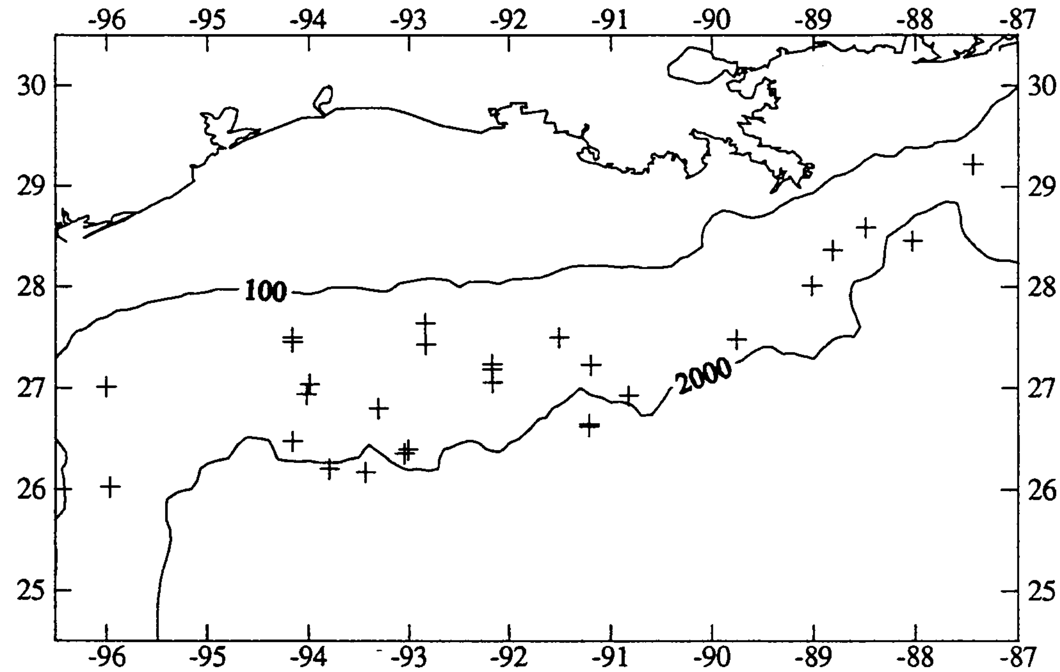

Figure 3.22. The locations of all unidentified Ziphiids sighted during GulfCet ship surveys.

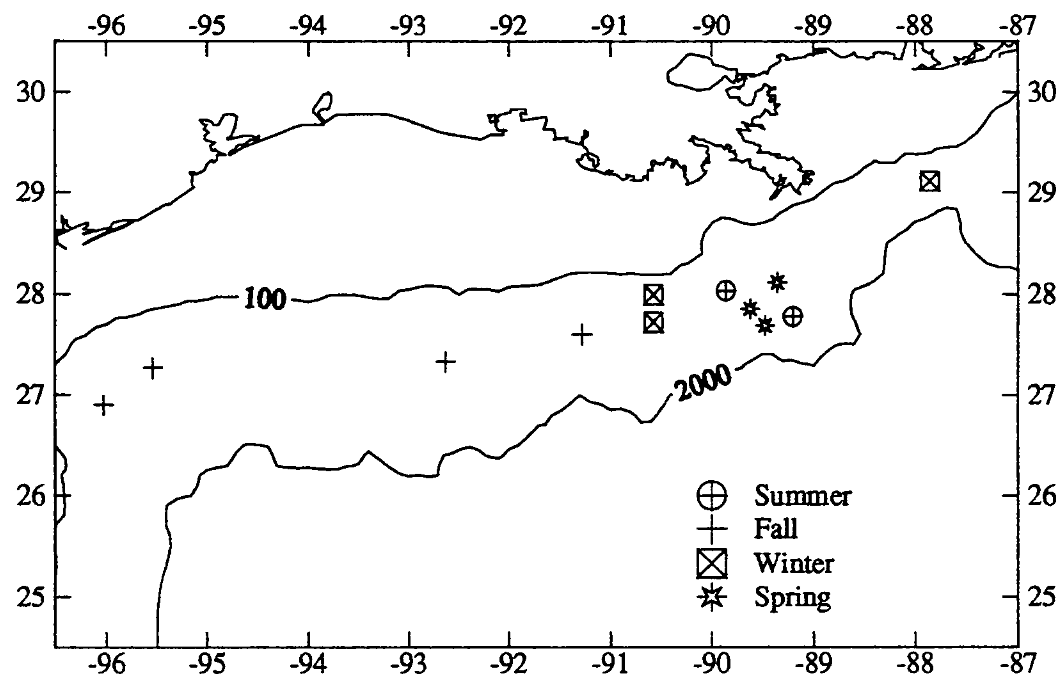

Figure 3.23. The locations of all unidentified Ziphiids sighted during GulfCet aerial surveys.

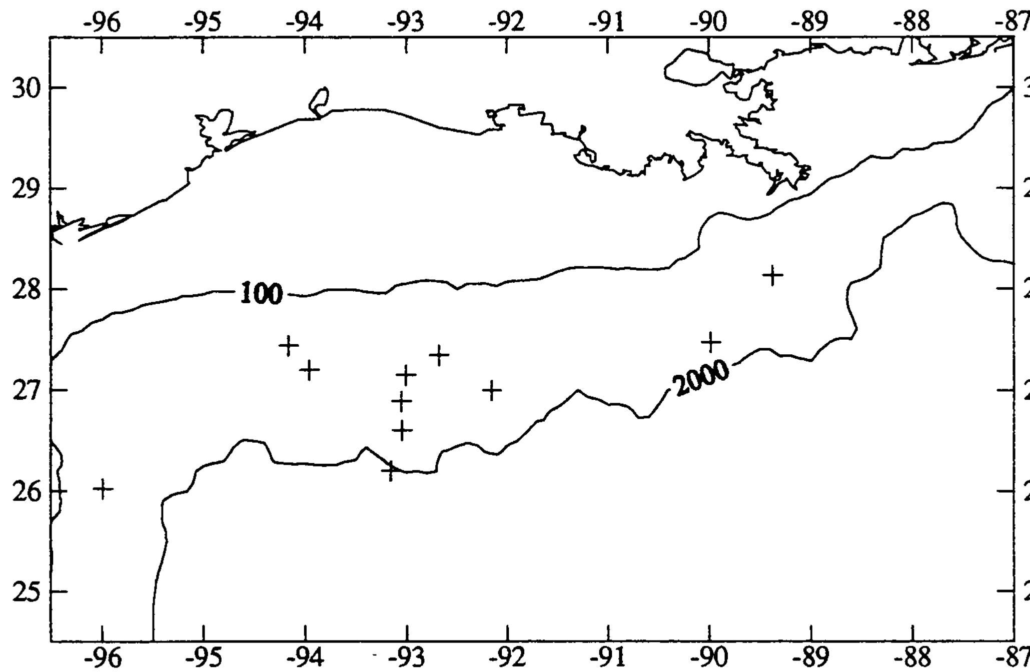

Figure 3.24. The locations of all melon-headed whales sighted during GulfCet ship surveys.

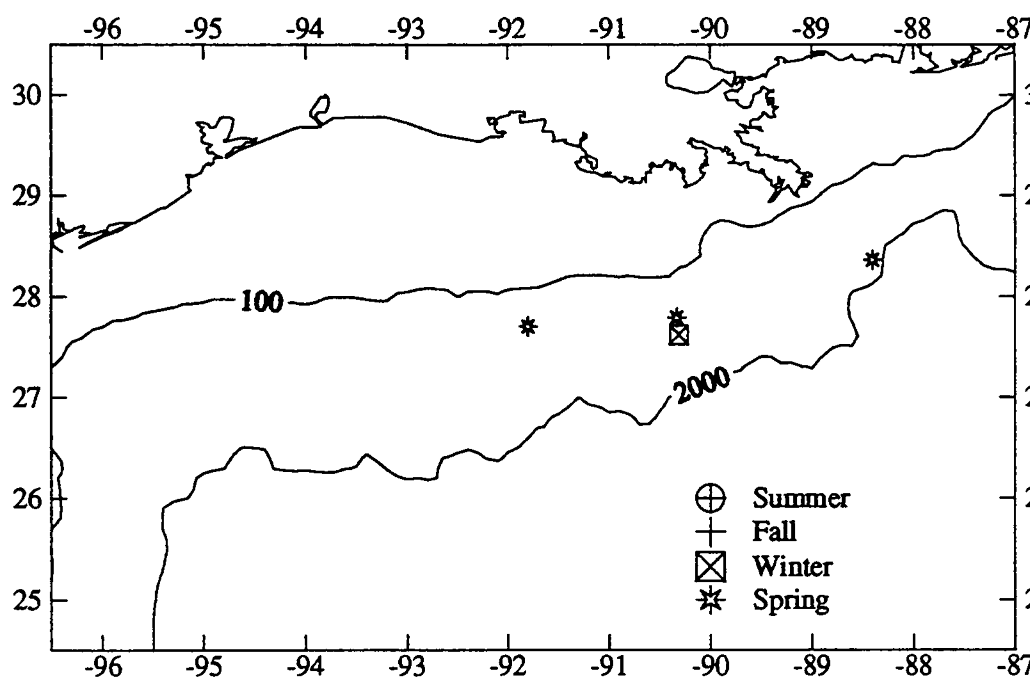

Figure 3.25. The locations of all melon-headed whales sighted during GulfCet aerial surveys.

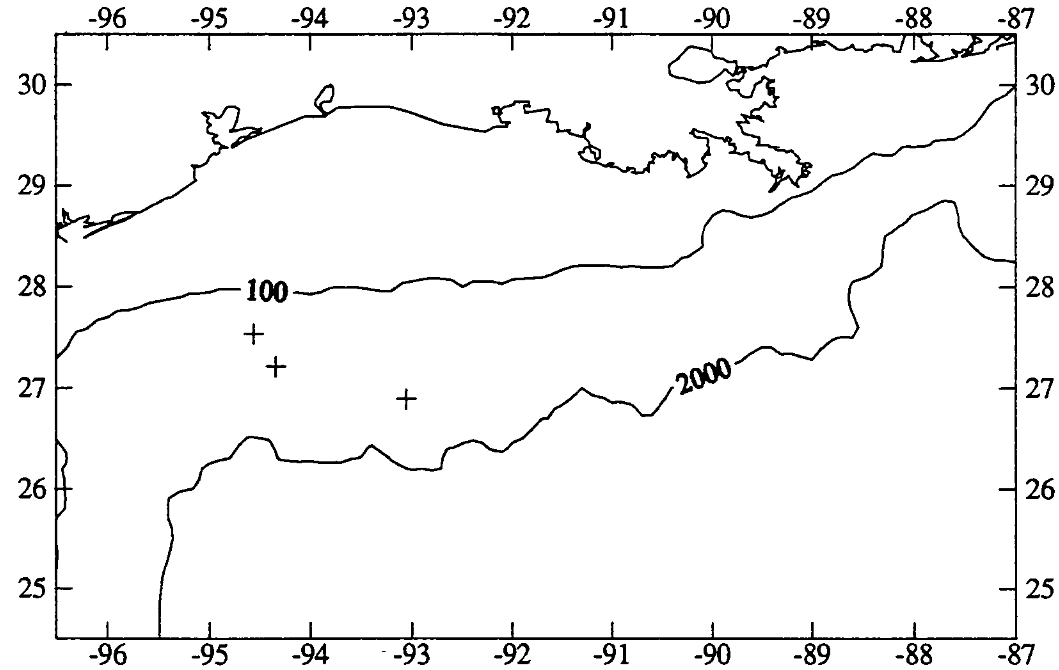

Figure 3.26. The locations of all pygmy killer whales sighted during GulfCet ship surveys.

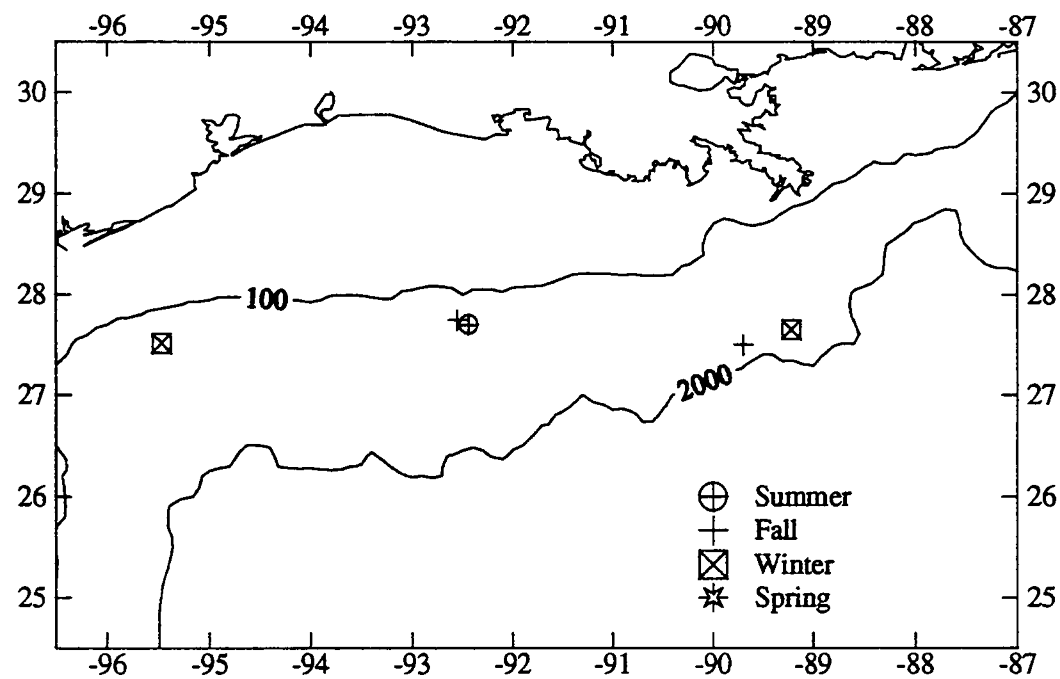

Figure 3.27. The locations of all pygmy killer/melon-headed whales sighted during GulfCet aerial surveys.

winter, and one was made in summer. Most pygmy killer/melon-headed whales were sighted throughout the central portion of the study area well away from the 100 m isobath.

False killer whale

False killer whales were sighted in spring and summer, twice during ship surveys and twice during aerial surveys. Group sizes averaged 3.5 (0.14) and 27.5 (0.27) animals as estimated from the ship and aerial platforms, respectively, and ranged from 2-35 animals. The density estimates [animals/1,000 km^2 (CV)] were 0.07 (0.63) and 1.94 (0.72) for overall ship and overall aerial surveys, respectively. False killer whale abundance was estimated to be 10 animals (3-33). False killer whale sightings were not concentrated in any particular portion of the study area (Figures 3.28 and 3.29).

Killer whale

Killer whales were sighted in spring and summer, four times during ship surveys and one time (off-effort) during aerial surveys. Group sizes averaged 11.2 (0.04) as estimated from the ship platforms and ranged from 10-12 animals. The group sighted from the aircraft consisted of 10 animals. The density estimate (animals/1,000 km^2 (CV)) was 0.46 (0.46) for overall ship surveys. Killer whale abundance was estimated to be 71 animals (95% CI = 30-167). Killer whales sightings were confined to an relatively small area well past the 100 m isobath south and southwest of the Mississippi River delta (Figure 3.30). The off-effort aircraft sighting was near the 1,000 m isobath south of the delta.

Short-finned pilot whale

Short-finned pilot whales were sighted in all seasons, nine times during ship surveys and 11 times during aerial surveys. Group sizes averaged 13.7 (0.33) and 22.5 (0.18) animals as estimated from ship and aircraft platforms, respectively, and ranged from 2-50 animals. The density estimates (animals/1,000 km^2 (CV)) were 1.39 (0.50) and 7.96 (0.48) for overall ship and overall aerial surveys, respectively. During aerial surveys, seven and four groups were sighted during Year 1 and Year 2, respectively, and sightings were almost evenly distributed throughout the seasons. Short-finned pilot whale abundance was estimated to be 215 animals (95% CI = 82-563). Short-finned pilot whales were sighted primarily in the west and central portion of the study area (Figures 3.31 and 3.32).

Rough-toothed dolphin

Rough-toothed dolphins were sighted in every season, eight times during ship surveys and nine times during aerial surveys. Group sizes averaged 10.3 (0.18) and 11.2 (0.44) animals as estimated from ship and aircraft platforms, respectively, and ranged from 3-48 animals. The density estimates (animals/1,000 km^2 (CV)) were 1.14 (0.35) and 2.76 (0.59) for overall ship and

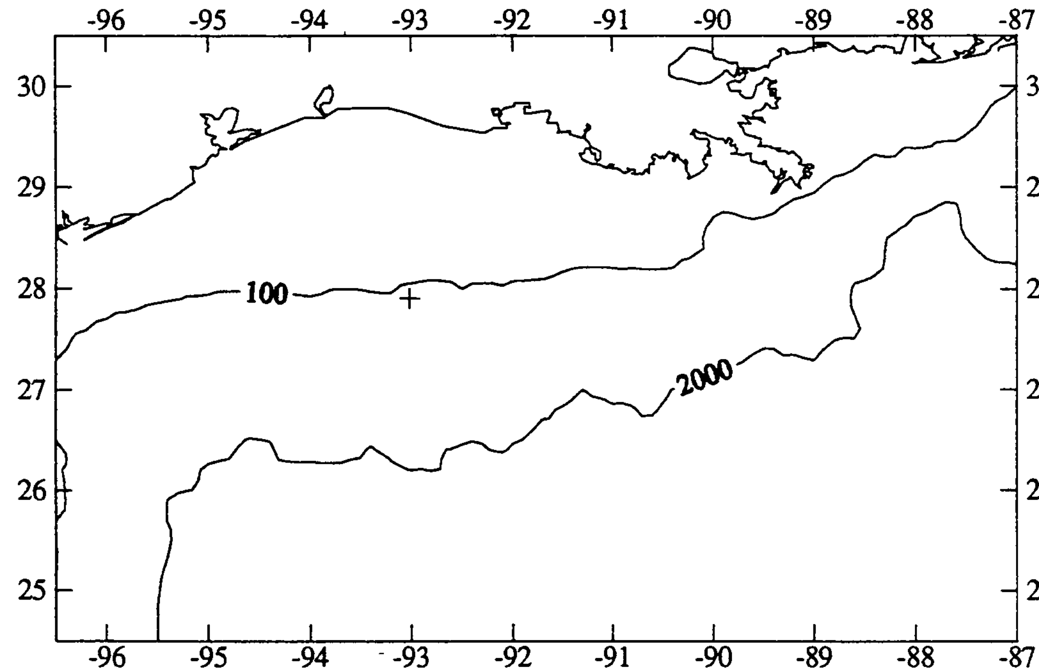

Figure 3.28. The locations of all false killer whales sighted during GulfCet ship surveys.

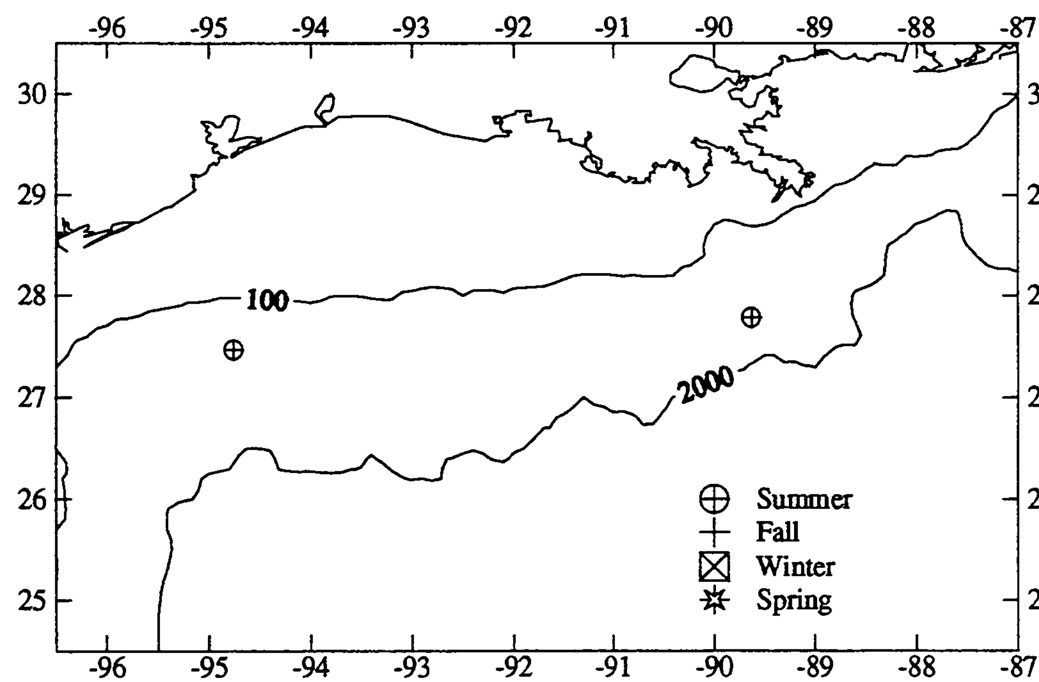

Figure 3.29. The locations of all false killer whales sighted during GulfCet aerial surveys.

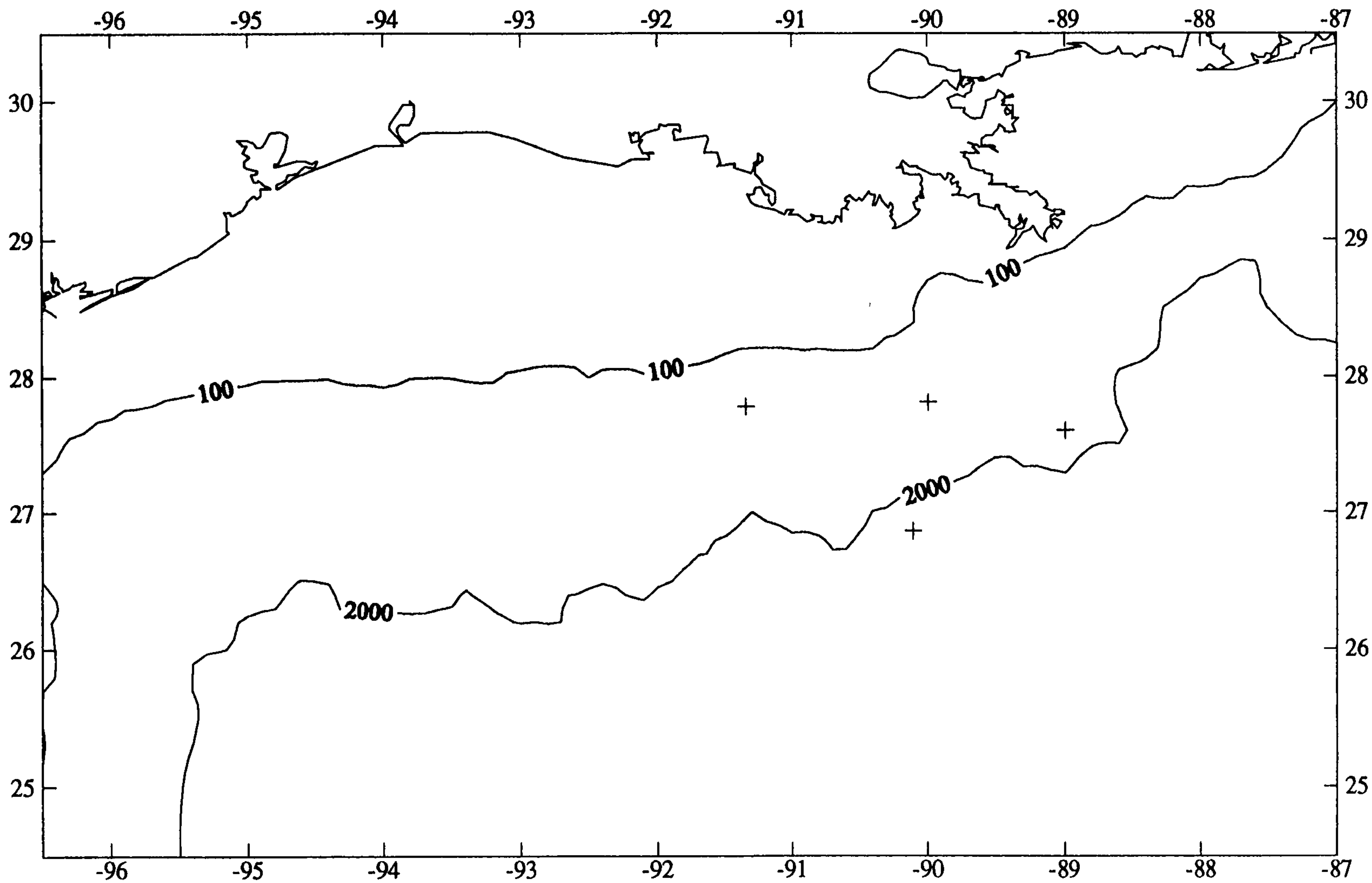

Figure 3.30. The locations of all killer whales sighted during GulfCet ship surveys.

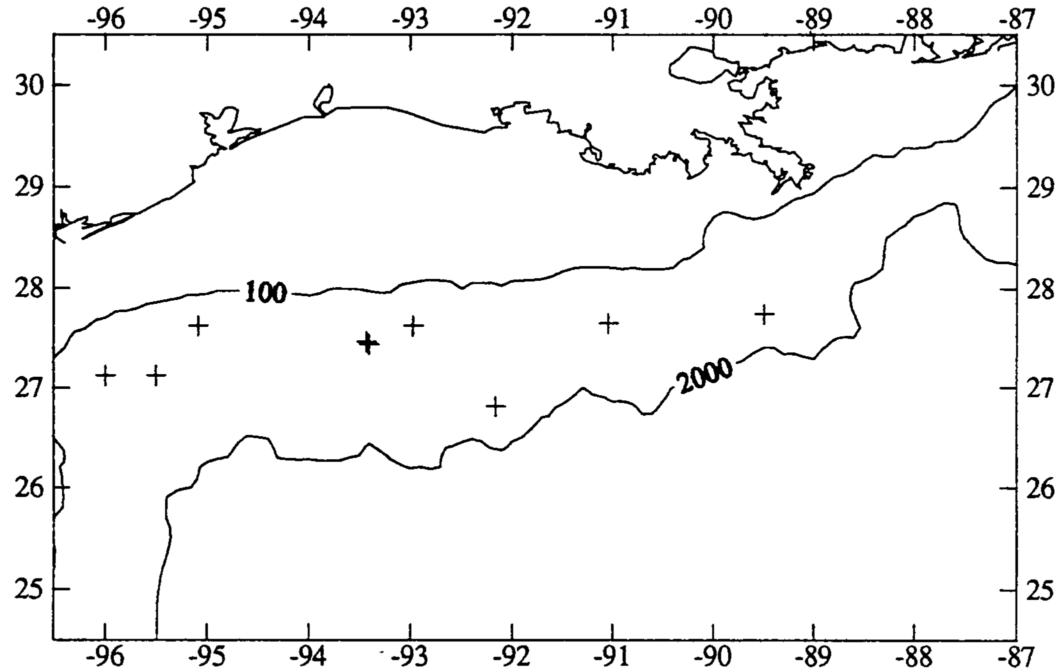

Figure 3.31. The locations of all short-finned pilot whales sighted during GulfCet ship surveys.

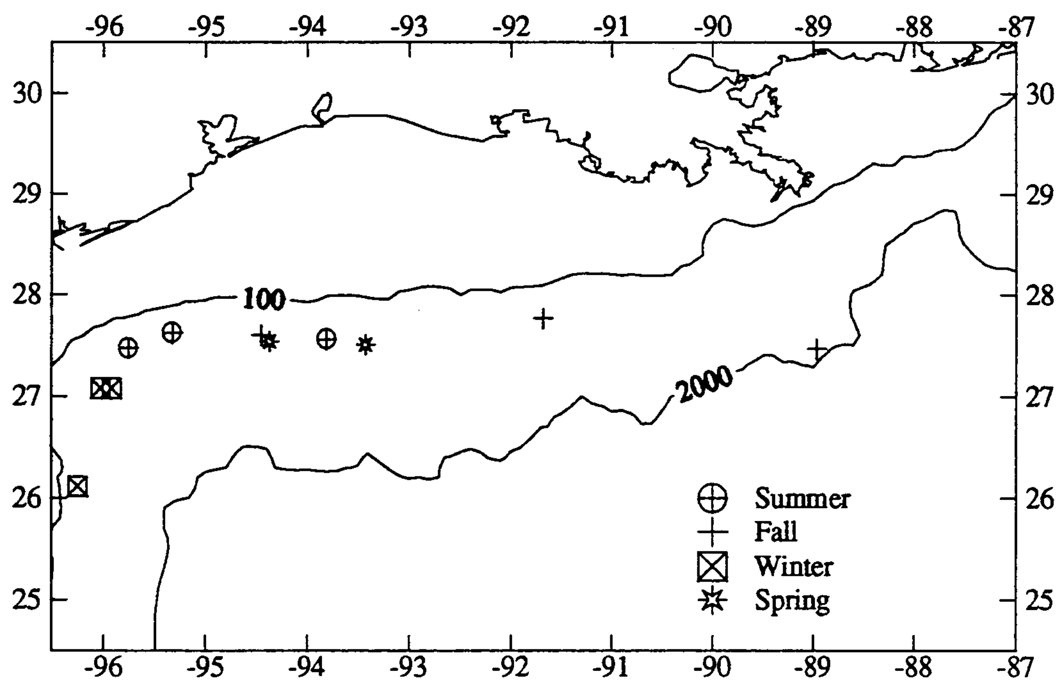

Figure 3.32. The locations of all short-finned pilot whales sighted during GulfCet aerial surveys.

overall aerial surveys, respectively. During aerial surveys, five and four sightings were made during Year 1 and Year 2, respectively, and five sightings occurred during spring. Rough-toothed dolphin abundance was estimated to be 177 animals (95% CI = 89-351). Rough-toothed dolphins were not sighted in the extreme eastern portion of the study area (Figures 3.33 and 3.34).

Fraser's dolphin

Fraser's dolphins were sighted in winter and spring, twice during ship surveys and twice during aerial surveys. Group sizes were 22 and 44 (ship), and 17 and 45 (aerial) animals. Fraser's dolphins were associated with melon-headed whales in all four sightings. The density estimates (animals/1,000 km^2 (CV)) were 0.42 (1.17) and 1.69 (1.00) for overall ship and overall aerial surveys, respectively. Fraser's dolphin abundance was estimated to be 65 animals (95% CI = 10-400). Fraser's dolphins were sighted in the central portion of the study area. Two of the four sightings occurred in different seasons and were within a radius of 50 km (Figures 3.35 and 3.36).

Bottlenose dolphin

Bottlenose dolphins were sighted in all seasons, 83 times during ship surveys and 83 times during aerial surveys. Group sizes averaged 11.2 (0.12) and 13.6 (0.12) animals as estimated from ship and aircraft platforms, respectively, and ranged from 1-90 animals. The density estimates (animals/1,000 km^2 (CV)) were 16.43 (0.26) and 33.67 (0.20) for overall ship and overall aerial surveys, respectively. The densities from Year 1 and Year 2 were 25.15 (0.33) and 36.70 (0.25), respectively. Seasonally, densities peaked during summer (59.73 [0.30]), were similar during winter and spring (25.09 [0.29], 31.61 [0.37]) and were much lower during winter (16.40 [0.71]). Bottlenose dolphin abundance was estimated to be 2,538 animals (95% CI = 1,543-4,174). Bottlenose dolphins were sighted throughout the study area almost exclusively at depths less than 1,000 m (Figures 3.37 and 3.38).

Risso's dolphin

Risso's dolphins were sighted in all seasons, 44 times during ship surveys and 39 times during aerial surveys. Group sizes averaged 7.5 (0.14) and 12.0 (0.19) animals as estimated from ship and aircraft platforms, respectively, and ranged from 1-78 animals. The density estimates (animals/1,000 km^2 (CV)) were 3.42 (0.26) and 14.41 (0.28) for overall ship and overall aerial surveys, respectively. The density from Year 1 was less than one-half that of Year 2, 9.07 (0.41) and 19.49 (0.34), respectively. Seasonally, densities were similar during winter and spring (21.87 [0.32], 19.72 [0.35]), somewhat lower during summer (12.57 [0.97]), and were much lower during fall (2.70 [0.76]). Risso's dolphin abundance was estimated to be 529 animals (95% CI = 317-881). Risso's dolphins were sighted throughout the study area. Many sightings occurred from the Mississippi Canyon, east (Figure 3.39 and 3.40).

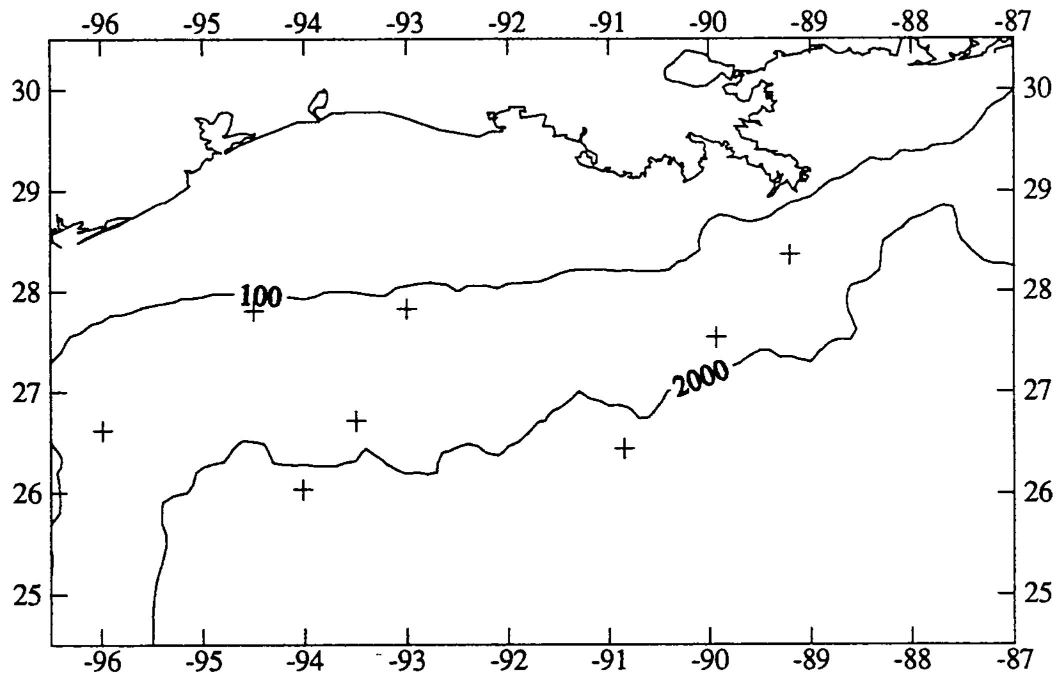

Figure 3.33. The locations of all rough-toothed dolphins sighted during GulfCet ship surveys.

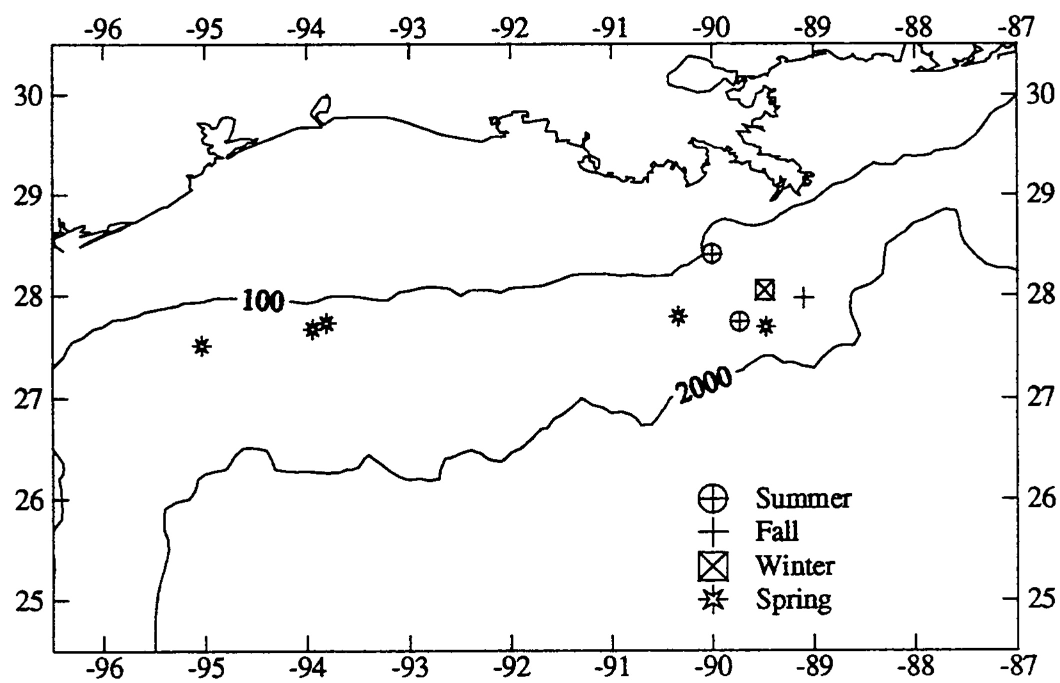

Figure 3.34. The locations of all rough-toothed dolphins sighted during GulfCet aerial surveys.

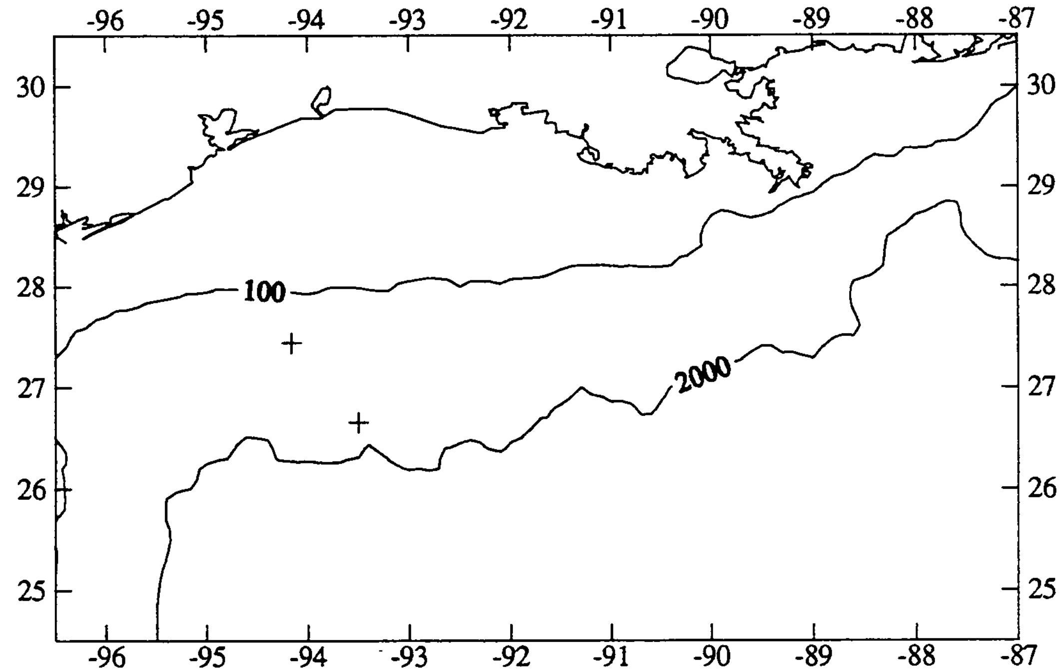

Figure 3.35. The locations of all Fraser's dolphins sighted during GulfCet ship surveys.

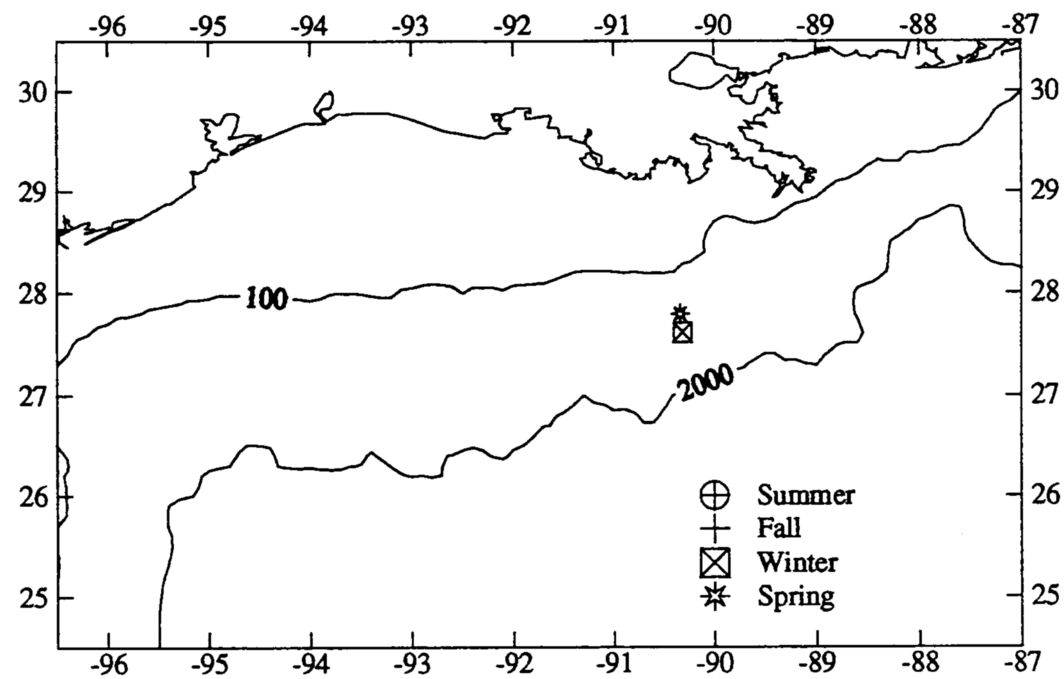

Figure 3.36. The locations of all Fraser's dolphins sighted during GulfCet aerial surveys.

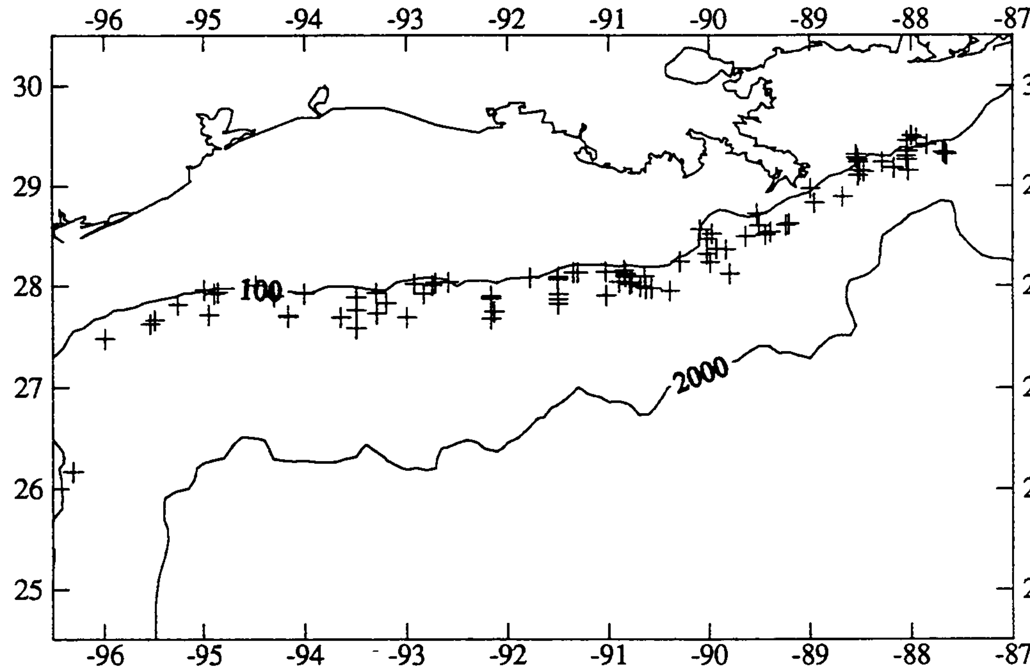

Figure 3.37. The locations of all bottlenose dolphins sighted during GulfCet ship surveys.

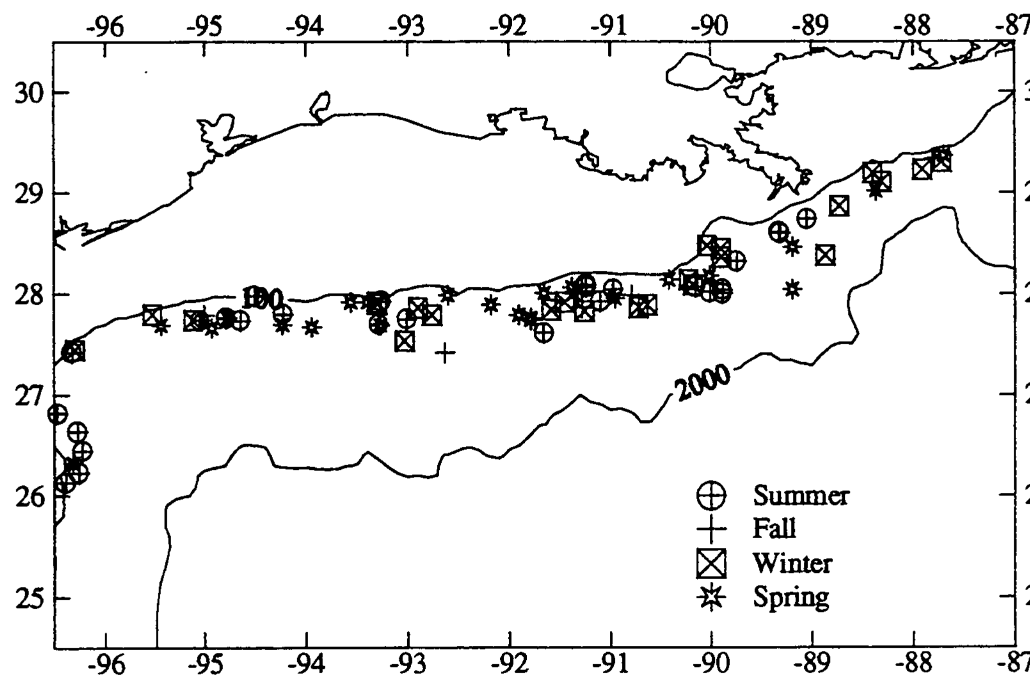

Figure 3.38. The locations of all bottlenose dolphins sighted during GulfCet aerial surveys.

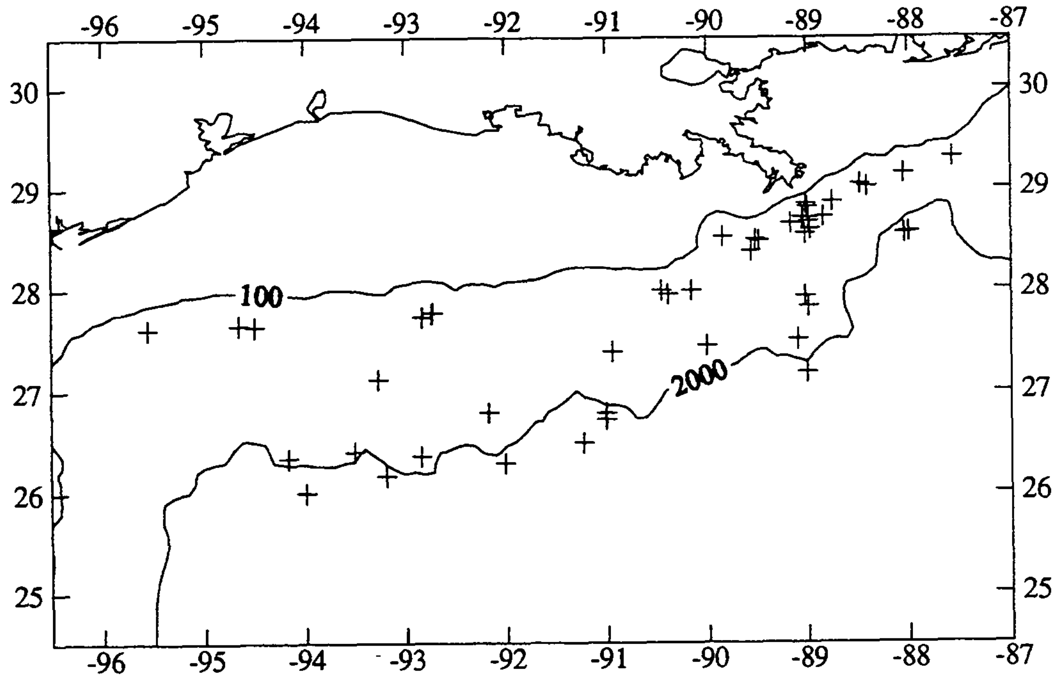

Figure 3.39. The locations of all Risso's dolphins sighted during GulfCet ship surveys.

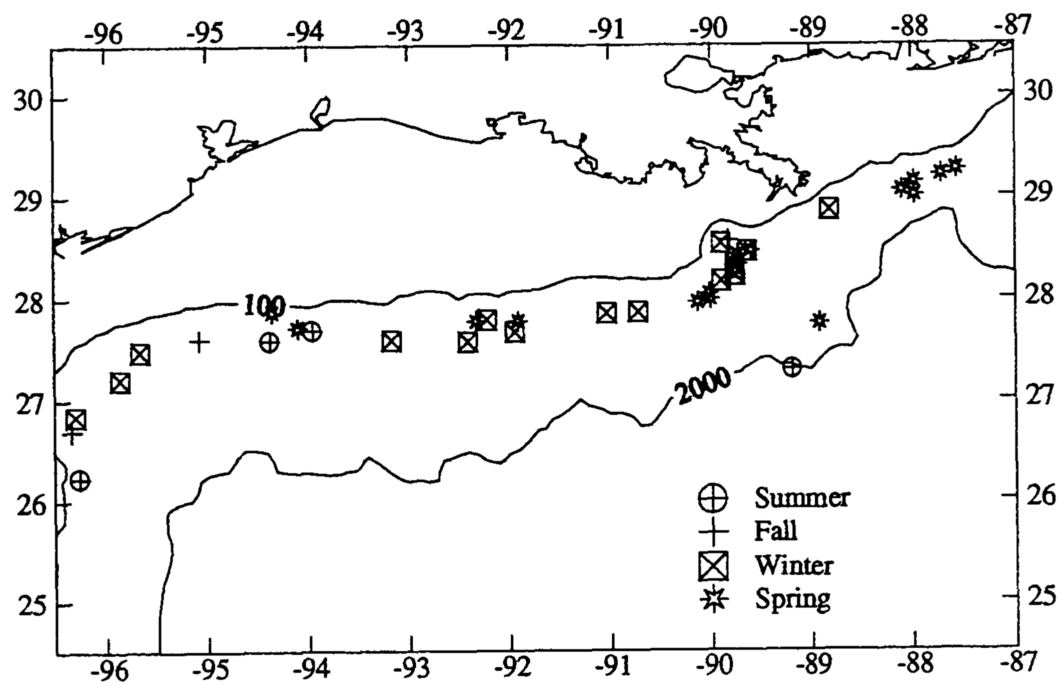

Figure 3.40. The locations of all Risso's dolphins sighted during GulfCet aerial surveys.

Atlantic spotted dolphin

Atlantic spotted dolphins were sighted in all seasons, 18 times during ship surveys and 12 times during aerial surveys. Group sizes averaged 22.6 (0.15) and 17.8 (0.21) animals as estimated from ship and aircraft platforms, respectively, and ranged from 3-55 animals. The density estimates (animals/1,000 km^2 (CV)) were 7.41 (0.37) and 6.94 (0.39) for overall ship and overall aerial surveys, respectively. Atlantic spotted dolphin abundance was estimated to be 1,145 animals (95% CI = 562-2,332). Atlantic spotted dolphins were generally sighted throughout the length of the study area but almost exclusively near the 100 m isobath. None were sighted in the extreme eastern or southwestern portions of the study area (Figures 3.41 and 3.42).

Pantropical spotted dolphin

Pantropical spotted dolphins were sighted in all seasons, 80 times during ship surveys, and 47 times during aerial surveys. Group sizes averaged 46.2 (0.11) and 55.1 (0.24) animals as estimated from ship and aircraft platforms, respectively, and ranged from 3-225 animals. The density estimates (animals/1,000 km^2 (CV)) were 45.99 (0.22) and 59.40 (0.24) for overall ship and overall aerial surveys, respectively. The Year 1 density (37.67 [0.37]) was less than one-half of the Year 2 density (86.86 [0.27]). Seasonally, pantropical spotted dolphin densities were similar during summer and winter (58.89 [0.33], 52.49 [0.49]), peaked during spring (104.16 [0.37]), were at a low during fall (22.32 [0.50]). Pantropical spotted dolphin abundance was estimated to be 7,105 animals (95% CI = 4,661-10,831). Pantropical spotted dolphins were sighted throughout the study area generally well past the 100 m isobath. However, very few of the sightings occurred in the extreme western part of the study area (Figures 3.43 and 3.44).

Striped dolphin

Striped dolphins were sighted in every season, 21 times during ship surveys and eight times during aerial surveys. Group sizes averaged 37.0 (0.14) and 52.5 (0.39) animals as estimated from ship and aircraft platforms, respectively, and ranged from 4-150 animals. The density estimates (animals/1,000 km^2 (CV)) were 13.53 (0.52) and 10.05 (0.60) for overall ship and overall aerial surveys, respectively. During aerial surveys, seven of the eight sightings occurred in Year 2 of the study. Striped dolphin abundance was estimated to be 2,091 animals (95% CI = 788-5,544). Striped dolphins were sighted throughout the study area and were generally well past the 100 m isobath. Ten of the 21 ship sightings occurred in the extreme east (DeSoto Canyon) portion of the study area (Figures 3.45 and 3.46).

Spinner dolphin

Spinner dolphins were sighted in every season except fall, 10 times during ship surveys and four times during aerial surveys. Group sizes averaged 47.0 (0.41) and 91.3 (0.40) animals as estimated from ship and aircraft platforms,

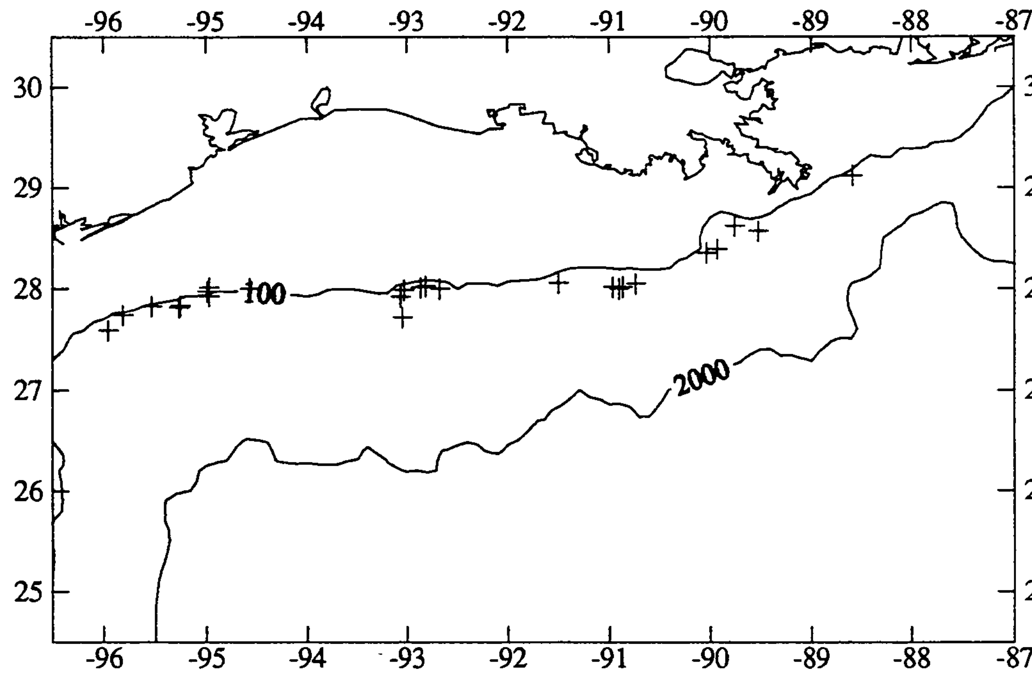

Figure 3.41. The locations of all Atlantic spotted dolphins sighted during GulfCet ship surveys.

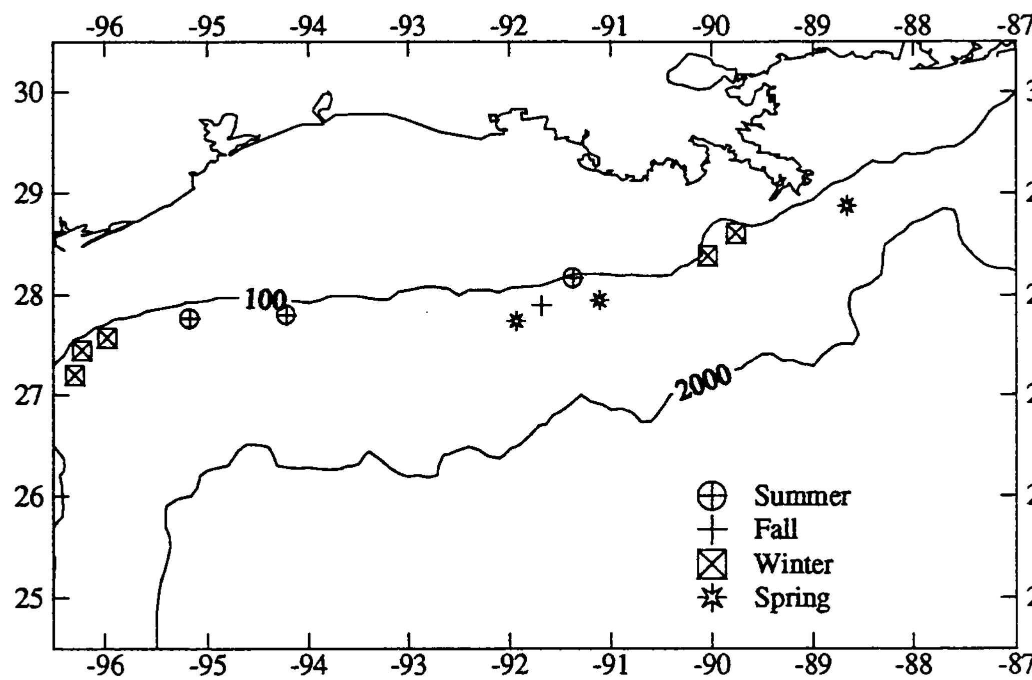

Figure 3.42. The locations of all Atlantic spotted dolphins sighted during GulfCet aerial surveys.

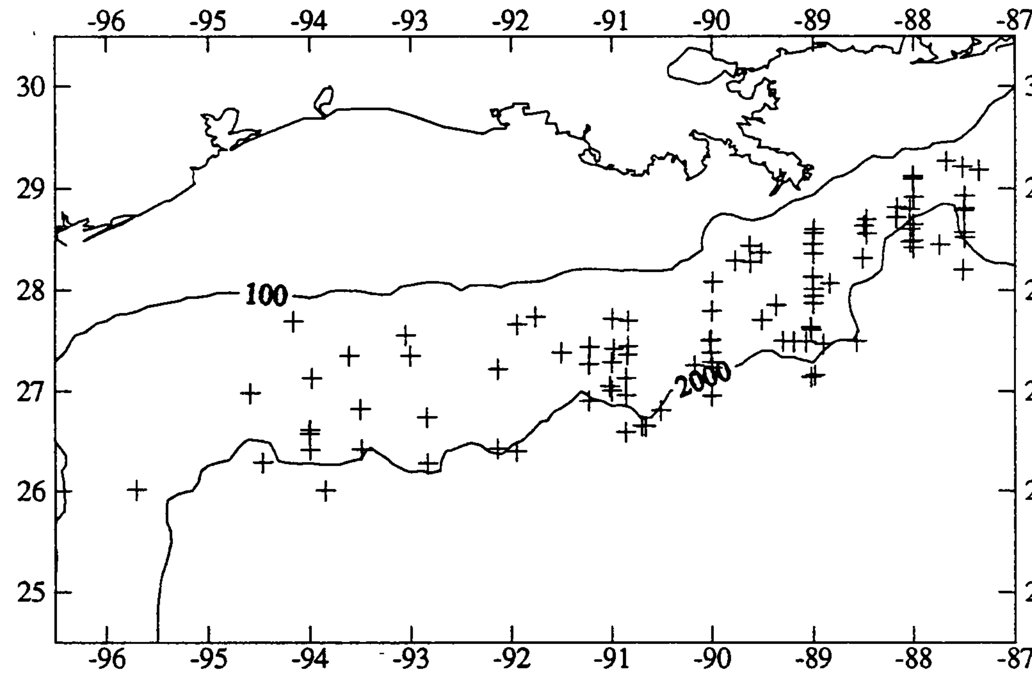

Figure 3.43. The locations of all pantropical spotted dolphins sighted during GulfCet ship surveys.

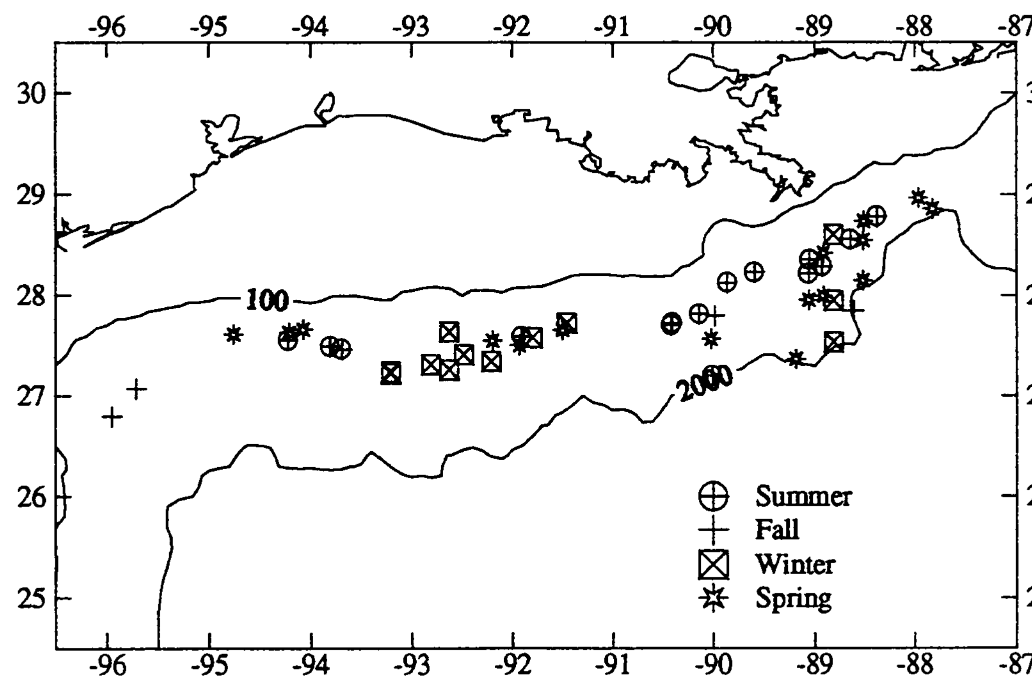

Figure 3.44. The locations of all pantropical spotted dolphins sighted during GulfCet aerial surveys.

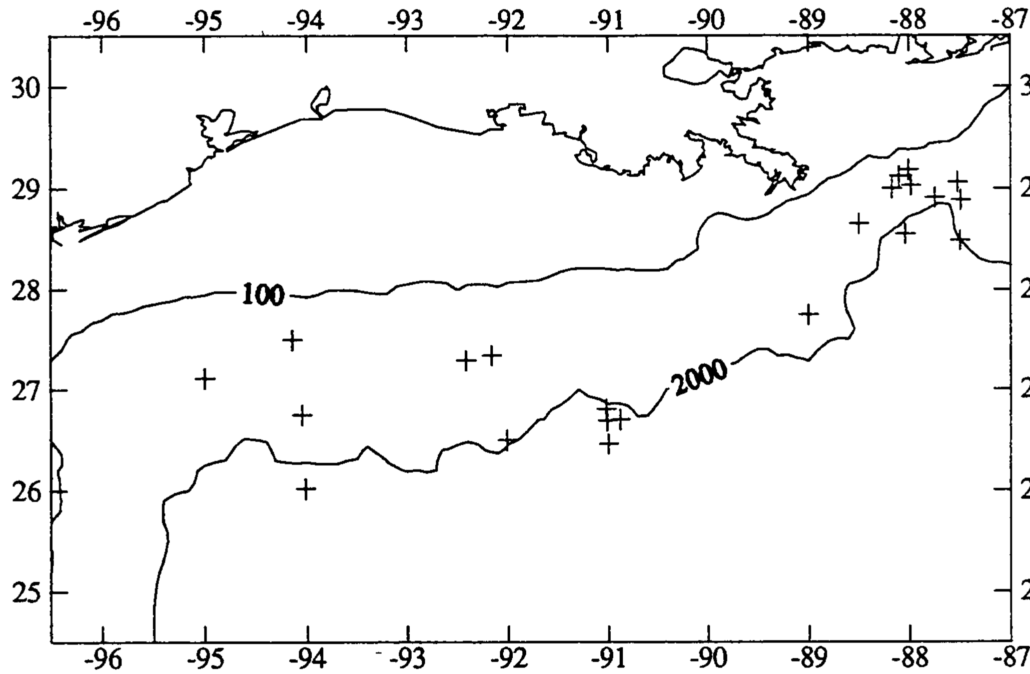

Figure 3.45. The locations of all striped dolphins sighted during GulfCet ship surveys.

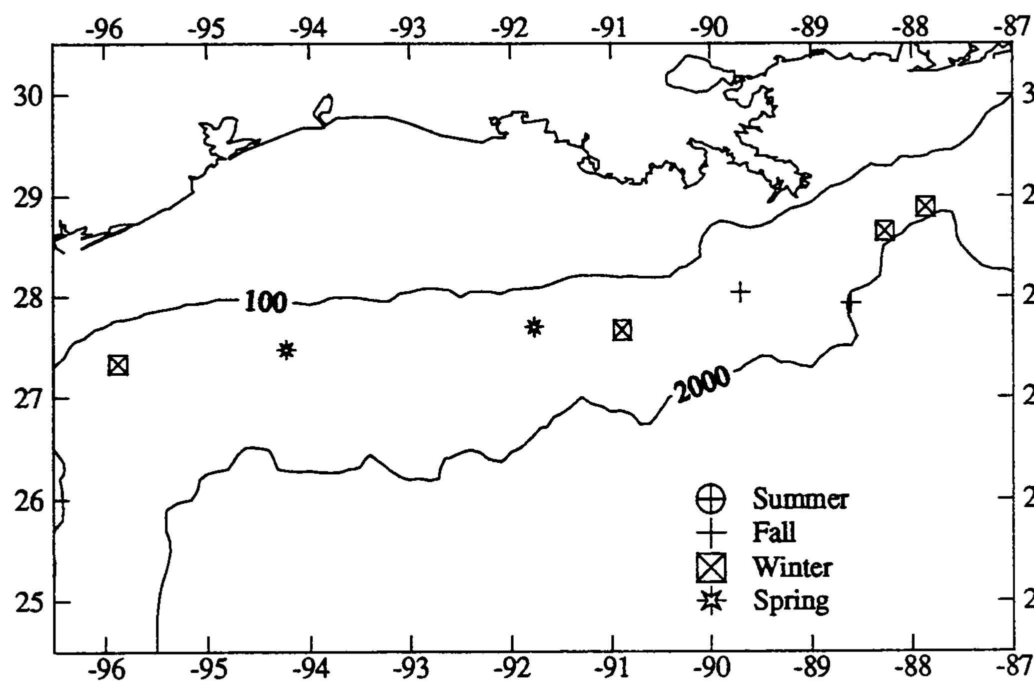

Figure 3.46. The locations of all striped dolphins sighted during GulfCet aerial surveys.

respectively, and ranged from 9-215 animals. The density estimates [animals/1,000 km^2 (CV)] were 5.44 (0.60) and 11.65 (0.65) for overall ship and overall aerial surveys, respectively. During aerial surveys, three of four sightings occurred in Year 2 of the study and three sightings occurred during winter. Spinner dolphin abundance was estimated to be 840 animals (95% CI = 274-2,580). Spinner dolphins were generally sighted in the eastern one-half of study area usually well away from the 100 m isobath (Figures 3.47 and 3.48).

Clymene dolphin

Clymene dolphins were sighted in every season except fall, 23 times during ship surveys and seven times during aerial surveys. Group sizes averaged 41.8 (0.28) and 35.0 (0.21) animals as estimated from ship and aircraft platforms, respectively, and ranged from 2-200 animals. The density estimates (animals/1,000 km^2 (CV)) were 10.97 (0.37) and 5.59 (0.44) for overall ship and overall aerial surveys, respectively. During aerial surveys, six of seven sightings occurred during winter and spring. Clymene dolphin abundance was estimated to be 1,695 animals (95% CI = 827-3,474). Clymene dolphin sightings occurred almost exclusively in a central portion of the study area well past the 100 m isobath (Figures 3.49 and 3.50).

3.3.5 *Distribution, Density, and Abundance of Sea Turtles*

Three species of sea turtles were sighted: 50 leatherbacks, 13 loggerhead, and two Kemp's ridley sea turtles. Twelve unidentified chelonid sea turtles were also recorded. Overall, annual, seasonal, and by-survey estimates of leatherback abundance were made. However, because of small sample sizes, estimates of abundance for the other species were limited to an overall estimate (Table 3.20).

Leatherback sea turtles were the most abundant sea turtle in the aerial survey area with an overall density estimate (CV in parentheses) of 1.79 turtles/1,000 km^2 (0.19) and an abundance estimate of 153 (0.19) turtles. Leatherback sea turtle abundances were similar during Year 1 and Year 2 with 160 (0.29) and 139 (0.22) turtles, respectively, and during each season where estimates ranged from 135 (0.28) to 171 (0.43) turtles. However, by survey, estimates were much more variable. Estimates for the two summer surveys ranged from 0 to 336 (0.43) turtles and for the two spring surveys, from 54 (0.63) to 213 (0.31) turtles.

Leatherback sea turtles were sighted throughout the aerial survey study area. However, the majority of the sightings (34/50) occurred in the eastern part of the study area from Mississippi Canyon east to DeSoto Canyon. Eight of these sightings were made on one day during the first summer survey; seven of the eight, on one track-line.

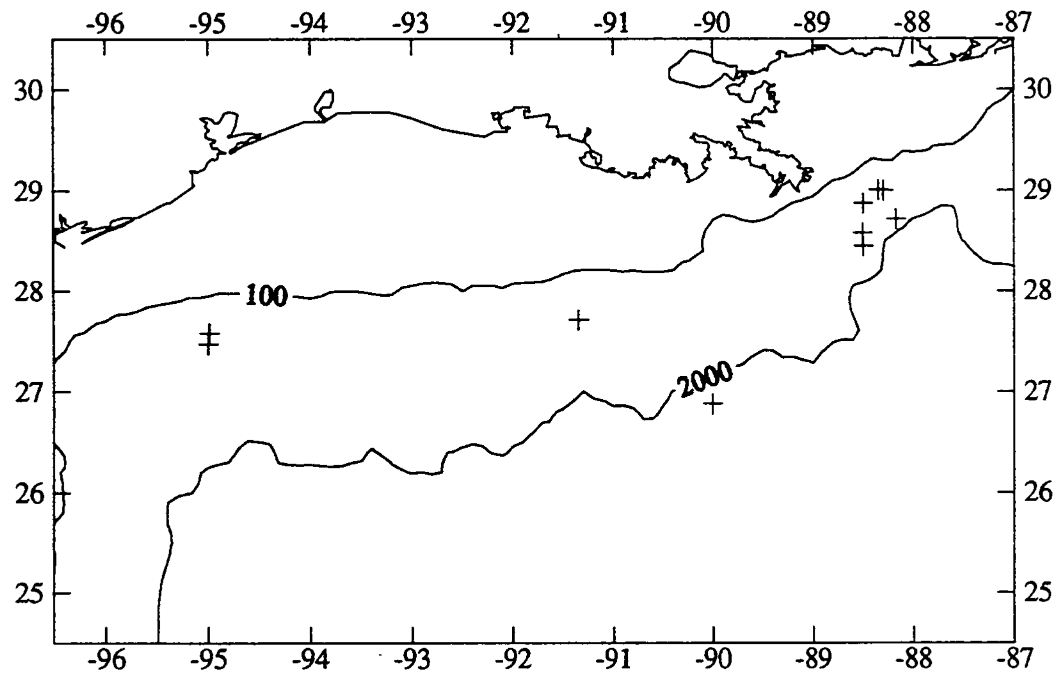

Figure 3.47. The locations of all spinner dolphins sighted during GulfCet ship surveys.

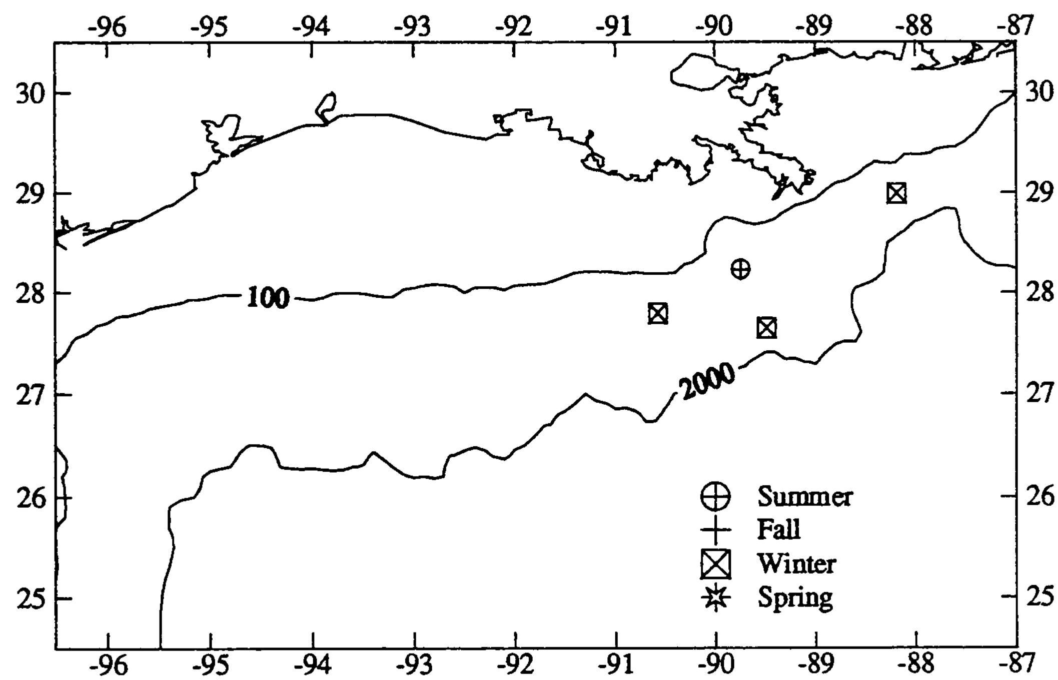

Figure 3.48. The locations of all spinner dolphins sighted during GulfCet aerial surveys.

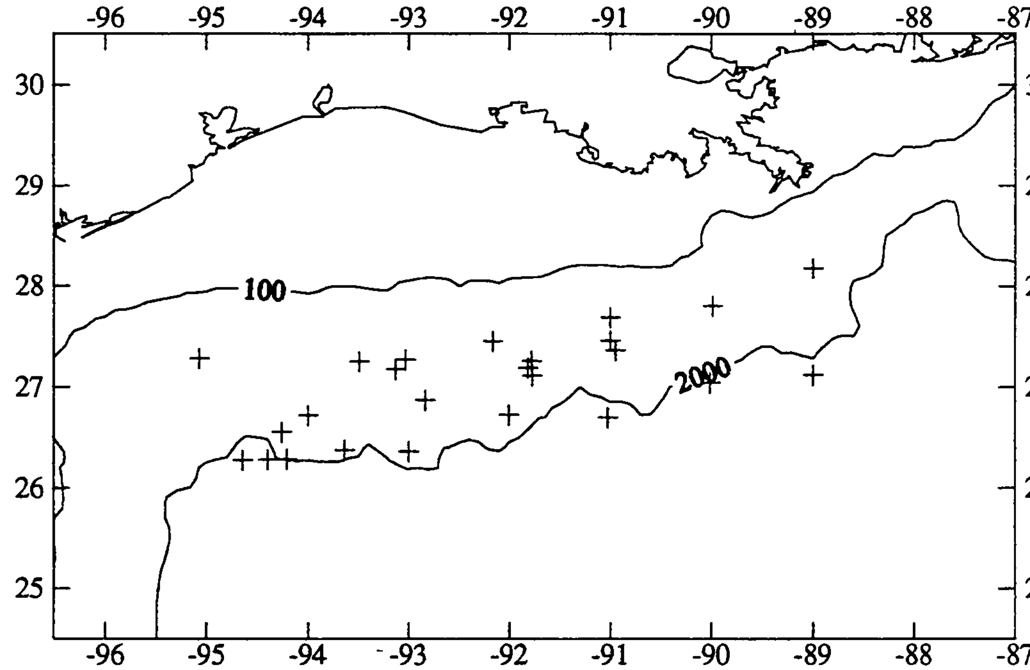

Figure 3.49. The locations of all clymene dolphins sighted during GulfCet ship surveys.

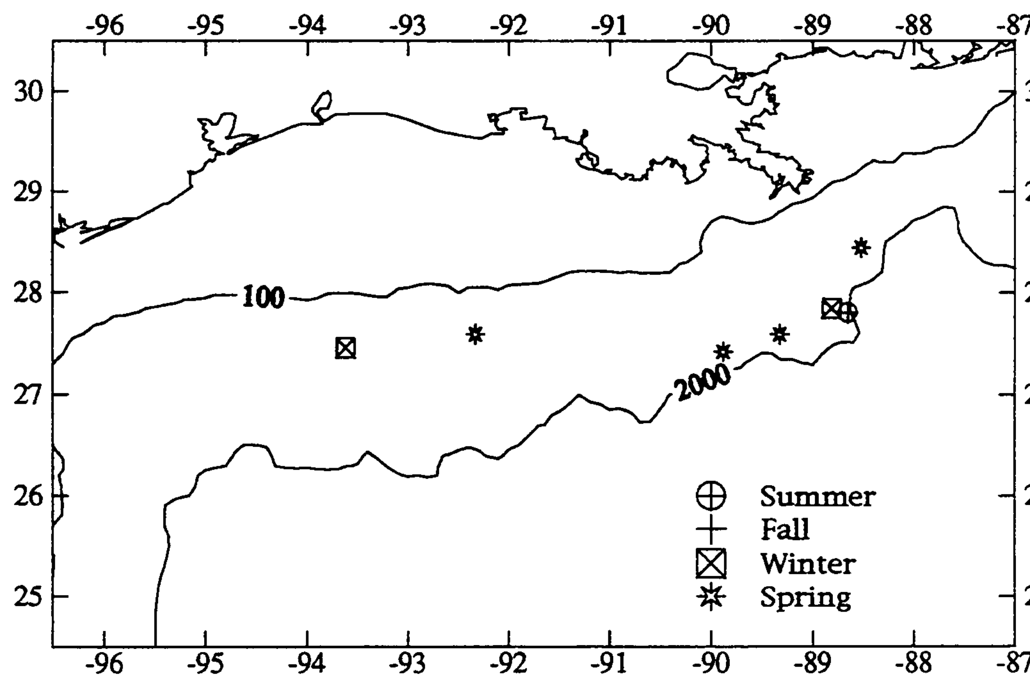

Figure 3.50. The locations of all clymene dolphins sighted during GulfCet aerial surveys.

Table 3.20. Abundance estimates and related statistics of sea turtle species in the aerial survey study area. Estimates for years and seasons are for leatherbacks. Year 1 = Aug 1992-May 1993, Year 2 = Aug 1993-Jun 1994, n = number turtles sighted, n/L = number turtles per 1,000 km, D = number turtles/1000 km^2, N = number of turtles, CV = coefficient of variation, CI = confidence interval.

Species	Stratum	n	n/L	CV(n/L)	D	N	CV(N)	Log-normal 95% CI
Loggerhead		12	0.24	0.28	0.48	41	0.29	23-71
Kemp's ridley		2	0.04	0.71	0.08	7	0.71	2-24
Unid. chelonid		12	0.24	0.32	0.48	41	0.33	22-77
Leatherback								
	Years 1 & 2	45	0.90	0.18	1.79	153	0.19	105-223
	Year 1	23	0.94	0.29	1.87	160	0.29	91-282
	Year 2	22	0.82	0.20	1.62	139	0.22	91-214
	Summer 1 & 2	13	1.00	0.42	1.99	171	0.43	76-385
	Summer 1	13	1.97	0.42	3.91	336	0.42	149-754
	Summer 2	0	0	-	0	0	-	-
	Fall 1 & 2	11	0.94	0.32	1.86	159	0.33	85-300
	Fall 1	4	0.75	0.67	1.49	128	0.68	37-435
	Fall 2	7	1.09	0.32	2.16	185	0.33	97-355
	Winter 1 & 2	11	0.87	0.31	1.73	148	0.32	80-276
	Winter 1	4	0.65	0.51	1.28	110	0.51	42-289
	Winter 2	7	1.09	0.40	2.16	185	0.41	84-407
	Spring 1 & 2	10	0.79	0.27	1.57	135	0.28	78-231
	Spring 1	2	0.32	0.63	0.63	54	0.63	17-172
	Spring 2	8	1.25	0.30	2.48	213	0.31	118-387

Another aggregation of 10-12 sightings occurred in the central part of the study area; five of these made on one day (Figure 3.51).

Estimates of abundance for loggerhead and Kemp's ridley sea turtles were 41 (0.29) and 7 (0.71) turtles, respectively. There were an estimated 41 (0.33) unidentified chelonids (most probably loggerheads). Although loggerhead turtles were sighted in all seasons, 10 of 13 sightings occurred in the winter and spring. Sightings of Kemp's ridley, loggerhead, and unidentified chelonid sea turtles occurred throughout the study area. However, very few sighting were made in the DeSoto Canyon area (Figure 3.52).

3.4 Discussion

3.4.1 *Comparison of Ship and Aircraft Surveys*

The use of line transect theory to assess the density and abundance of cetaceans has been developing over the past two decades (Buckland et al. 1993). Aerial, ship and land-based platforms have been effectively used. Some of the first extensive surveys, both aerial and ship, were conducted in the Eastern Tropical Pacific (ETP) in conjunction with the involvement of small cetaceans in the yellowfin tuna purse seine fishery (Smith 1983, Holt and Sexton 1990). The refinement of survey design, equipment, and analysis techniques for both platforms has improved the reliability of population estimates for cetaceans (e.g., Wade and Gerrodette 1993).

Ship-based and aerial surveys are the standard techniques used for cetacean density and abundance estimates. A ship allows for the identification of more cetacean species and for the collection of a more complete suite of hydrographic data than do aircraft surveys. Ship-based surveys are, however, labor intensive and take considerable time to cover large areas. Aircraft can cover large areas in a matter of days rather than weeks and provide a time efficient method for monitoring and periodically verifying population numbers and distribution. However, depending on the type of aircraft, range offshore can limit aerial surveys. Both of these visual methods are limited to daylight hours and sea states that are generally less than Beaufort 6 (for ship surveys) and less than Beaufort 4 (for aerial surveys). Rain and reduced visibility conditions are also limiting.

The density estimates of cetacean species were generally similar between the aerial and ship survey platforms (Table 3.21). Except for false killer whales, all of the differences in density estimates were less than an order of magnitude. Due to the small sample size (total of four sightings), any difference in the false killer whale estimates is probably not significant. For most species, the estimate from one platform was less than twice the size of the estimate from the other platform. Neither platform provided consistently higher or lower estimates of density. However, these comparisons are confounded by the differences in habitat surveyed from the aircraft and ship. The density estimates for short-finned pilot whale, bottlenose dolphin, and Risso's dolphin were significantly different ($p < 0.05$), using the criteria of non-overlap of 85% confidence interval. These were probably due to differences in the proportion of habitats sampled from each platform.

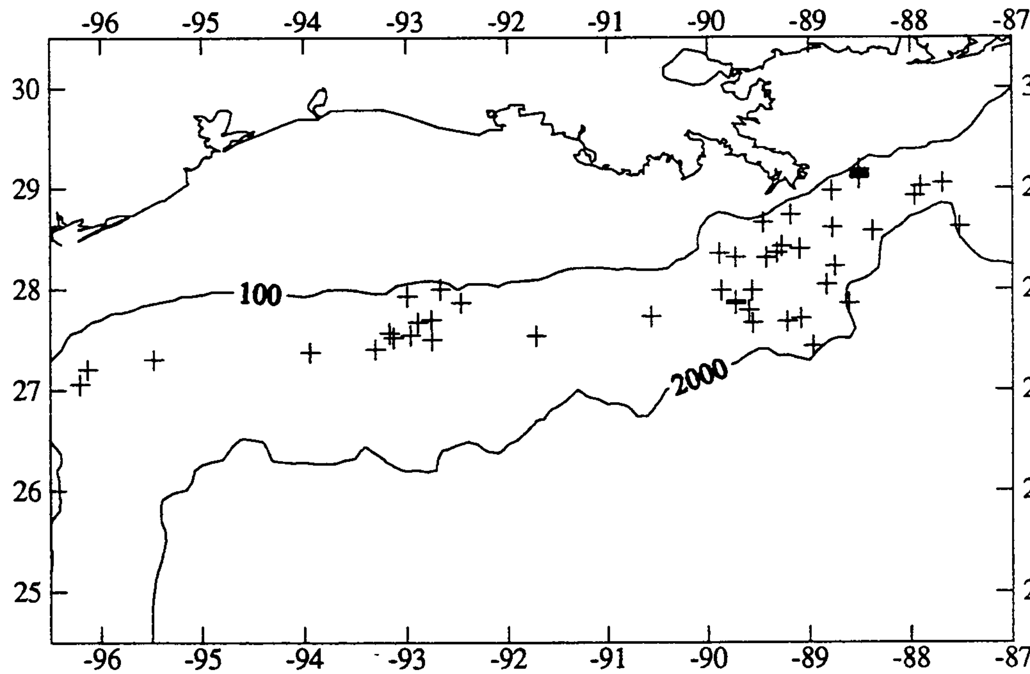

Figure 3.51. The locations of leatherback sea turtles sighted during all GulfCet aerial surveys.

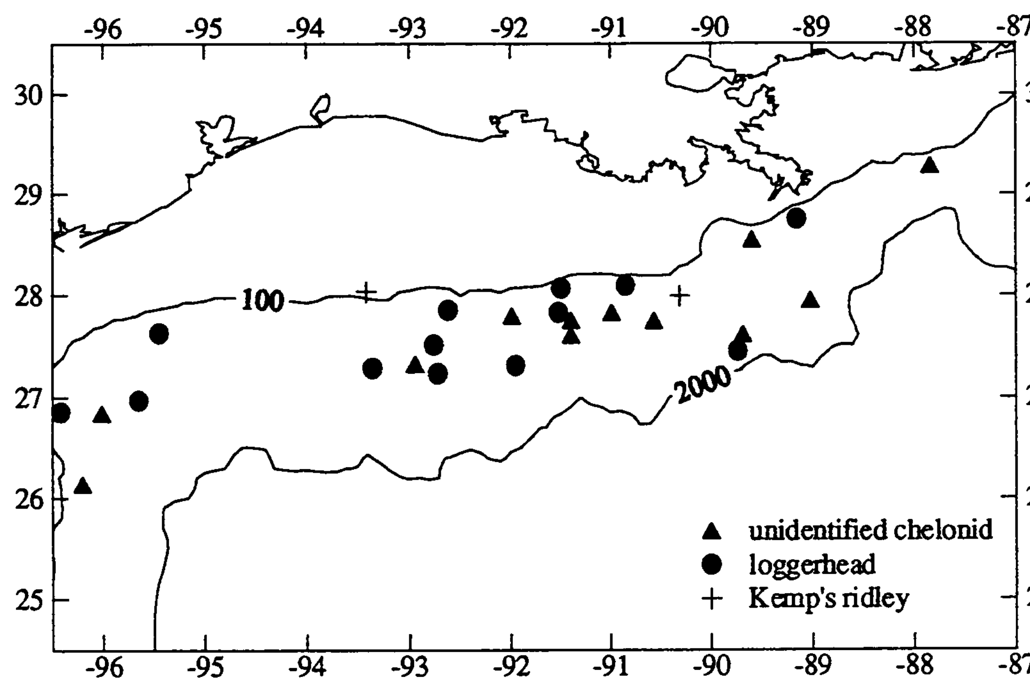

Figure 3.52. The locations of Kemp's ridley, loggerhead, and unidentified chelonid sea turtles sighted during all GulfCet aerial surveys.

Table 3.21. Comparisons of overall density estimates from aerial and ship surveys, by species.

Species	Density per 1,000 km² Visual Aerial	Visual Shipboard	Acoustic
Bryde's whale	0.02	0.02	
Sperm whale	1.01	2.02	2.04
Pygmy/dwarf sperm whale	2.04	1.03	
Cuvier's beaked whale	0.13	0.09	
Unidentified ziphiids	0.61	0.80	
Pygmy killer whale/Melon-headed whale	30.86	13.60	
False killer whale	1.94	0.07	
Killer whale	-	0.46	
Short-finned pilot whale	7.96	1.39	
Rough-toothed dolphin	2.76	1.14	
Fraser's dolphin	1.69	0.41	
Bottlenose dolphin	33.67	16.43	
Risso's dolphin	14.41	3.42	
Atlantic spotted dolphin	6.94	7.41	
Pantropical spotted dolphin	59.40	45.99	
Striped dolphin	10.05	13.53	
Spinner dolphin	11.65	5.44	
Clymene dolphin	5.59	10.97	
All dolphins	186.92	124.26	229.00

The proportion of habitats sampled by aircraft and ships differed because the aerial and shipboard visual survey areas were not equal in size. The aerial survey covered about 56% of the total study area, with most of the aerial effort in waters from 100 to 1,000 m deep. In contrast, the shipboard visual survey effort occurred throughout the entire study area (i.e., 100 to 2,000 m). Ship-based density estimates for species whose primary habitat includes waters beyond the 1,000 m isobath could be larger than the aerial-based estimates, because most of the aerial survey sampling occurred inside the 1,000 m isobath. In contrast, aerial-based density estimates for those species whose primary habitat includes waters inside the 1,000 m isobath could be larger than the ship-based estimates, for the same reason. For example, bottlenose dolphins were sighted almost exclusively in waters less than 1,000 m deep (see Figures 3.49 and 3.50) while clymene dolphins were sighted almost exclusively in waters greater than 1,000 m deep (refer to Figures 3.32 and 3.33). The density estimate of bottlenose dolphins from the aerial survey was larger than the ship-based estimate (33.7 versus 16.4 animals/1,000 km^2), and the density estimate of clymene dolphins from the ship surveys was larger than the aerial-based estimate (11.0 versus 5.6 animals/1,000 km^2). For some species this pattern in density estimates did not appear to hold, and of these, most were based on small sample sizes. Sample sizes for several species, however, were judged adequate. Atlantic spotted dolphins, for example, were sighted relatively frequently and almost exclusively within the 1,000 m isobath (see Figure 3.24 and 3.25), and the ship estimate was similar to that of the aerial estimate (7.4 versus 6.9 animals/1,000 km^2).

3.4.2 *Cetacean Distribution*

3.4.2.1 *Temporal Distribution*

Assessments of seasonal variation in density estimates were based on the aerial surveys since they were designed to provide equal seasonal sampling. Seasonal density estimates were made for all cetaceans combined, and for the four species and one genus sighted a total of 20 or more times. Seasonal densities were lowest during the fall for all categories (Table 3.19) except sperm whales, which had the lowest densities in the summer and winter. Most of the seasonal estimates were not significantly different ($p < 0.05$) using the criteria of non-overlap of 85% CI. There were, however, several significantly different seasonal estimates and all of them involved a fall estimate. The fall density estimate for all cetaceans combined was significantly less than those for the other seasons. Significantly different seasonal estimates occurred as follows: pygmy/dwarf sperm whales, fall less than summer; bottlenose dolphin, fall less than summer; Risso's dolphin, fall less than winter and spring; and pantropical spotted dolphin, fall less than spring. These differences suggest that the GulfCet study area was less heavily utilized by cetaceans during fall.

Although the ship surveys were not designed to provide equal seasonal coverage (the SEFSC cruises occurred primarily in the spring), seasonal density estimates were made for several species (Tables 3.7-3.10). Interestingly, the spring and winter ship-based visual density estimates of pantropical spotted dolphins were significantly different, with the spring estimate being about 10 times larger than the winter estimate. This contrasts with the aerial pantropical spotted dolphin estimates which were lowest in the fall. The ship-based winter estimate was based mainly on one year of sampling, whereas the aerial estimate was based on two years of sampling. In addition, there were twice as many sightings during the first year of the shipboard survey. This may indicate significant interannual variability which could obscure long-term trends in seasonal patterns.

3.4.2.2 *Spatial Distribution*

With the exception of the clymene dolphin, groups of oceanic dolphins (i.e., pantropical spotted, spinner, and striped dolphins) were generally sighted more frequently in the eastern part of the GulfCet study area. Common dolphins were never sighted and are not known to occur in the Gulf of Mexico. Atlantic spotted dolphins, which occur in all but the very nearshore habitats on the continental shelf in the Gulf, were only sighted near the 100 m isobath during these surveys. Bottlenose dolphins were most commonly sighted in association with the continental shelf edge.

Clymene dolphins, short-finned pilot whales, melon-headed whales, and pygmy killer whales were found primarily in the central to western region of the GulfCet study area. The distributions of melon-headed whales and clymene dolphins throughout the entire northern Gulf of Mexico (Mullin et al. 1994a and 1994b) suggests that the GulfCet study area may make up a significant portion of the range of both of these species. However, short-finned pilot whales were sighted by Mullin et al. (1994c) during one survey day near the Mississippi River Delta and were observed opportunistically in this same area (see Chapter 8). It is important to remember that while melon-headed whale sightings were relatively uncommon, because of their very large group sizes (up to 400) they were the fourth most abundant species in the study area.

The distribution of Risso's dolphin was concentrated along the upper continental slope near the Mississippi River but sightings were made throughout the remainder of the study area. Groups of Risso's dolphins were the most common species sighted by Mullin et al. (1994c) during surveys near the Mississippi River Delta.

Killer whales were found in a broad, but distinct region just southwest of the Mississippi River Delta. Opportunistic sightings of killer whales in the Gulf support this distribution. However, two sightings have also occurred off the Texas coast (O'Sullivan and Mullin in prep.). Killer whales were observed killing a pantropical spotted dolphin from the NOAA Ship *Oregon II* in this area (O'Sullivan and Mase in prep.). However, pantropical spotted dolphins are much more widely distributed in the study area than killer whales.

3.4.3 *Cetacean Abundance and Group Size*

This project was the first attempt to estimate the abundance of all cetaceans along the continental slope in the north-central and northwestern Gulf of Mexico. As a result, good historical comparisons are not available. However, abundance estimates from small sections of the GulfCet study area (Fritts et al. 1983, Mullin et al. 1994c) and qualitative indices of abundance based primarily on stranding data and sightings (Schmidly and Scarbrough 1990, see Chapter 2 of this report) do provide a basis for comparison with the results from this study.

The precision of abundance estimates depends in part on the number of sightings for each species. As a result, abundance estimates of rarely sighted species had very large coefficients of variation (CV). Only four species (pantropical spotted dolphins, bottlenose dolphins, Risso's dolphins, and sperm whales) had relatively precise estimates (CV of 30% or less) and eight species had a CV of 40% or less (Table 3.22). Some estimates, such as for Fraser's dolphin and Bryde's whale were very imprecise (CVs of 123.8% and 85.3%, respectively) which should be considered when comparing the abundance estimates. Due to the relatively low number of shipboard seasonal sightings and the high CVs, distinguishing seasonal patterns in abundance was not appropriate.

Pantropical spotted dolphins occur around the world in tropical waters (Perrin and Hohn 1994). This species was the most abundant cetacean in the study area, and was three times more abundant than the next most abundant species, the bottlenose dolphin (Table 3.22). Although this species was thought to be rare

Table 3.22. Ranked abundances (N) and mean group sizes (G) of cetaceans from all ship surveys. CV = coefficient of variation.

Species	N	CV(N)	G	CV(G)
1. Pantropical spotted dolphin	7,105	0.22	46.2	0.41
2. Bottlenose dolphin	2,538	0.26	11.2	0.12
3. Striped dolphin	2,091	0.52	37.0	0.14
4. Melon-headed whale	2,067	0.34	140.7	0.19
5. Clymene dolphin	1,695	0.37	41.8	0.28
6. Atlantic spotted dolphin	1,145	0.37	22.6	0.15
7. Spinner dolphin	840	0.60	47.0	0.41
8. Risso's dolphin	529	0.26	7.5	0.14
9. Sperm whale	313	0.25	2.7	0.14
10. Short-finned pilot whale	215	0.50	13.7	0.33
11. Rough-toothed dolphin	177	0.35	10.3	0.18
12. Unidentified ziphiids	124	0.29	2.4	0.13
13. Dwarf sperm whale	88	0.34	2.1	0.17
14. Killer whale	71	0.46	11.2	0.4
15. Fraser's dolphin	65	1.17	44.0	-
16. Pygmy killer whale	36	0.64	11.5	0.13
17. Pygmy sperm whale	19	0.40	1.2	0.12
18. Cuvier's beaked whale	14	0.41	1.2	0.14
19. False killer whale	10	0.63	3.5	0.14
20. Bryde's whale	3	0.81	2.0	-

in the northern Gulf of Mexico (Schmidly and Scarbrough 1990), a reevaluation of the historical data (see Chapter 2) and recent surveys by Mullin et al. (1994c) indicated that pantropical spotted dolphins were common in deeper waters beyond the continental shelf. The results of this study confirm that this species is very abundant along the continental slope in the north-central and western Gulf of Mexico. The mean group size of 45.6 (Table 2.23) was within the range reported by Mullin et al. (1994c), but smaller than the range of means (75-149) reported for this species in the ETP (Wade and Gerrodette 1993).

Bottlenose dolphins are the most abundant inshore dolphin species on the U.S. continental shelf in the Gulf of Mexico. The bottlenose dolphin is especially abundant in shallow bays and estuaries along the mainland and barrier islands (Scott et al. 1989, Blaylock and Hoggard 1994). This was the second most abundant species in the study area, although they were mostly confined to waters along the continental shelf break and upper continental slope. The results from Mullin et al. (1994c) were similar to those of this study. Mean group size was 12.6 animals, which is similar to that reported by Mullin et al. (1994c). The mean group size (22.7) for bottlenose dolphins in the ETP (Wade and Gerrodette 1993) was larger than that of the present study.

Table 3.23. Comparison of mean group size estimates from ship and aerial surveys, by species.

Species	Mean group size	
	Shipboard	Aerial
Bryde's whale	-	1
Sperm whale	2.6	2.0
Pygmy/dwarf sperm whale	2.2	1.4
Cuvier's beaked whale	1.2	3.0
Unidentified mesoplodont	1.4	3.5
Melon-headed whale	147.6	311.7
False killer whale	3.5	27.5
Killer whale	11.3	10.0
Short-finned pilot whale	16.6	22.5
Rough-toothed dolphin	9.2	11.2
Fraser's dolphin	44.0	31.0
Bottlenose dolphin	12.6	13.6
Risso's dolphin	7.5	12.0
Atlantic spotted dolphin	23.1	17.8
Pantropical spotted dolphin	45.6	43.8
Striped dolphin	37.5	52.5
Spinner dolphin	51.2	91.3
Clymene dolphin	52.1	35.0

Striped dolphins, melon-headed whales, and clymene dolphins were the next most abundant species, respectively, in the GulfCet study area. Clymene dolphins are known only from the tropical and subtropical Atlantic (Perrin and Mead 1994), whereas striped dolphins inhabit tropical and warm-temperate waters around the world (Perrin et al. 1994b). Melon-headed whales are found throughout the world in tropical and subtropical waters (Perryman et al. 1994). As pointed out by Mullin et al. (1994b), the earlier belief that the clymene dolphin was uncommon in the Gulf of Mexico may have resulted from confusion with other species (e.g., spinner and common dolphins) until its taxonomic status was clarified by Perrin et al. (1981). No previous estimates of abundance are available for clymene dolphins. The abundance of striped dolphins in this study is consistent with earlier reports indicating that they are common in the northern Gulf of Mexico (Schmidly and Scarbrough 1990). More surprising was the relatively high abundance of melon-headed whales, which prior to this study were thought to be rare in the Gulf of Mexico (Schmidly and Scarbrough 1990, Mullin et al. 1994a). Prior to the GulfCet study, there were only two stranding records and no confirmed sightings from the Gulf of Mexico (Barron and Jefferson 1993). Mean group sizes for clymene (52.1) and striped dolphins (37.5) were similar to that of pantropical spotted dolphins (45.6), but less than one-third the average group size (147.6) for the gregarious melon-headed whales. Group size for melon-headed whales varied greatly (30-400 animals), and this species was frequently observed in association with Fraser's dolphin and rough-toothed dolphins (Mullin et al.

1994a). The mean group sizes for striped dolphins (60.9) and melon-headed whales (199.1) reported for the ETP (Wade and Gerrodette 1993) were comparable to those for this study.

Atlantic spotted dolphins and spinner dolphins were the sixth and seventh most abundant species in the GulfCet study area. Atlantic spotted dolphins are endemic to the tropical and warm, temperate Atlantic Ocean (Perrin et al. 1994a), while spinner dolphins occur in tropical waters around the globe (Perrin and Gilpatrick 1994). The former was thought to be common in the northern Gulf of Mexico, while the latter was considered rare or could not be distinguished from other species (Schmidly and Scarbrough 1990, Mullin et al. 1994c). The average group size of Atlantic spotted dolphins (23.1) was about half that of spinner dolphins (51.2). Average group size for spinner dolphins in the ETP was much larger and ranged from 111.7-134.1 (Wade and Gerrodette 1993).

Schmidly and Scarbrough (1990) considered Risso's dolphin to be uncommon in the Gulf of Mexico, although Mullin et al. (1994c) found this to be the most common species in the offshore waters of Louisiana out to the 1,000 m isobath. This species is found world-wide in tropical and warm-temperate waters (Jefferson et al. 1993). In the present study, Risso's dolphins were not the most abundant species, but they were common along the continental slope. Average group size was 7.5 individuals, similar to that reported by Mullin et al. (1994c) for the offshore waters along the Louisiana coast and by Wade and Gerrodette (1993) for the ETP.

Sperm whales are found throughout all deep oceans of the world from the tropics to the polar pack ice (Rice 1989). This species was the most abundant large cetacean in the study area with an estimated total of about 313 animals. Schmidly and Scarbrough (1990) considered sperm whales to be common in the Gulf of Mexico. Fritts et al. (1983) and Mullin et al. (1994c) also found sperm whales to be the most abundant large cetacean in the northern Gulf of Mexico. Average group size based on the shipboard visual surveys was 2.6 individuals which is similar to that reported by Fritts et al. (1983) and Mullin et al. (1994c) for the northern Gulf of Mexico, but smaller than the 7.9 animals per group reported for the ETP (Wade and Gerrodette 1993).

Short-finned pilot whales are found around the world in tropical and warm-temperate waters (Jefferson et al. 1993). The abundance of short-finned pilot whales was similar to that of sperm whales in the GulfCet study area, but they occurred in larger groups averaging 16.6 animals. Schmidly and Scarbrough (1990) considered pilot whales to be common in the northern Gulf of Mexico. Although Fritts et al. (1983) and Mullin et al. (1994c) did not report large numbers of sightings, group size was large (18-52). Mean group size for this genus in the ETP was 18.3, comparable to that reported in this study. At this time, pilot whales appear to be less abundant than the melon-headed whales, which were once thought to be extremely rare in the northern Gulf of Mexico.

Rough-toothed dolphins are found in tropical and warm-temperate seas around the world (Miyazaki and Perrin 1994). This species, which was previously thought to be rare in the Gulf of Mexico (Schmidly and Scarbrough 1990, Mullin et al. 1994c), appears to be at least as common as sperm whales and pilot whales in the northern Gulf of Mexico. Average group size appears to range from 4 (Mullin et al. 1994c) to 9.2 (GulfCet). This is slightly smaller than mean group size of 14.7 animals observed in the ETP (Wade and Gerrodette 1993).

Dwarf sperm whales, killer whales, Fraser's dolphins, and pygmy killer whales were the next most abundant species, with very different group sizes. Killer whales are found world-wide in both coastal and pelagic waters (Jefferson et al. 1993). Fraser's dolphin is found in tropical waters around the world (Perrin et al. 1994c). The distribution of dwarf sperm whales is not well established, but they may be expected in temperate, warm-temperate, and tropical waters around the world (Caldwell and Caldwell 1989). Pygmy killer whales occur in tropical waters world-wide (Jefferson et al. 1993). Schmidly and Scarbrough (1990) considered these four species to be uncommon or rare (Fraser's dolphin had never been seen) in the Gulf of Mexico. However, historical evidence exists (Chapter 2) indicating that killer whales and pygmy killer whales did occur regularly and that dwarf sperm whales could be common. This view was consistent with sightings by Mullin et al. (1994c) in offshore waters along the Louisiana coast. Fraser's dolphin was thought to be uncommon in the Atlantic Ocean and Gulf of Mexico. Sightings from this study now indicate that this species occurs in the Gulf of Mexico. Whereas Fraser's dolphin occurred in large groups averaging 44 individuals, average group sizes for killer whales, pygmy killer whales, and dwarf sperm whales were smaller at 11.3, 11.5, and 1.6 animals, respectively. In the ETP, the mean group sizes for Fraser's dolphin (394.9) and pygmy killer whales (27.9) were larger than in the northern Gulf of Mexico, but comparable in size for killer whales (5.4) and dwarf sperm whales (1.6).

Pygmy sperm whales, Cuvier's beaked whales, *Mesoplodon* spp., false killer whales, and Bryde's whales were infrequently sighted and typically occurred in groups of less than four individuals. It is interesting to note that, based on stranding data, pygmy sperm whales were thought to be more common than dwarf sperm whales (Schmidly and Scarbrough 1990). However, the shipboard visual surveys in the GulfCet study area now indicate the opposite. Bryde's whale was the only baleen whale sighted in the study area, with an estimated abundance of only three animals. The results from this study are consistent with those of Mullin et al. (1994c).

A total of 20 species or genera were sighted in the GulfCet study area, which is comparable in diversity to that reported for the ETP where 19 species or genera were reported (Wade and Gerrodette 1993). The estimated abundance of all cetaceans sighted in the GulfCet study area was 19,198 animals. With a total area of 154,621 km^2, the cetacean density was 0.12 animals/km^2. This is about one-fourth the estimated density (0.52 animals/km^2) for cetaceans in the ETP (Wade and Gerrodette 1993). It appears that the GulfCet study area is as species rich as the ETP, but supports a lower density of cetaceans. This may be due to the more oligotrophic conditions in the Gulf. One striking difference between these two areas was that common dolphins were the most numerous species in the ETP, but appear to be completely absent from the northern and possibly the entire Gulf of Mexico. Common dolphins have a world-wide distribution from 40° N latitude to 40° S latitude, including the east coasts of North and South America (Evans 1994). Why they have not entered the Gulf of Mexico is unknown, but one possible explanation is the absence of large areas of cold, upwelling-modified waters typically associated with this species (Reilly 1990).

3.4.4 *Distribution and Abundance of Sea Turtles*

All five species of sea turtles that occur in the Gulf of Mexico are protected under the Endangered Species Act of 1973. The leatherback, Kemp's ridley, and hawksbill sea turtles are listed as endangered and the loggerhead and green sea turtles are listed as threatened. The hawksbill is usually associated with reefs or similar habitats in tropical and subtropical waters and is thought to be rare in the northwestern 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). It is not clear why adults of either species would occur in oceanic waters, unless they were transiting to and from foraging sites on distant and disjunct areas of the continental shelf.

The leatherback, which feeds primarily on jellyfish, is the most oceanic of the sea turtles. However, its distribution is not entirely oceanic, as was previously thought, and it is commonly found in relatively shallow continental shelf waters along the Atlantic coast of the United States (Hoffman and Fritts 1982). Leatherbacks also occur on the continental shelf in the northwestern Gulf of Mexico (Fritts et al. 1983, Lohoefener et al. 1988, 1990). This study suggests that in the northwestern Gulf the primary habitat of the leatherback sea turtle is oceanic (> 200 m). The sighting rate of leatherback sea turtles on the continental shelf in the north-central Gulf was 0.4 turtles/100 km whereas the sighting rates from the upper continental slope in the north-central Gulf were 2.0 turtles/100 km, almost five times greater (Lohoefener et al. 1990). Also, comparatively few leatherbacks were sighted during fall SEFSC surveys of the entire continental shelf in the northern Gulf of Mexico. However, the majority of the sightings occurred just north of DeSoto Canyon (NMFS, SEFSC-Miami unpublished data). Sighting rates of leatherback sea turtles from the GulfCet study were 1.0 turtles/100 km for the entire aerial survey study area. However, the sighting rate of leatherbacks from Mississippi Canyon to DeSoto Canyon (i.e., the north-central Gulf) was 1.8 turtles/100 km.

With the two years of turtle data combined by season, leatherbacks were found to occur in similar numbers throughout the GulfCet study area in all seasons (Table 3.20). However, specific locations could be very important to leatherbacks, at least for brief periods of time. Lohoefener et al. (1990) sighted eleven turtles during one day in August 1989 just south of the Mississippi River delta and 14 on one day during October 1989 in DeSoto Canyon. During GulfCet flights, eight were sighted on 30 August 1992 in DeSoto Canyon. It is important to remember that these numbers of leatherbacks were sighted while surveying a relatively narrow and straight corridor (maximum width for sighting leatherbacks, about 1 km) and that true size of an aggregation was probably not assessed. An estimated 100 leatherbacks were sighted just offshore of Texas in 1956 in association with jellyfish (Leary 1957).

In summary, the GulfCet aerial surveys provided the first assessment of sea turtle abundance and distribution over a large area of the oceanic Gulf of Mexico. Three sea turtle species occurred in the study area: loggerhead, Kemp's ridley, and leatherback. The significance of the oceanic Gulf to loggerheads and Kemp's ridley is not clear. However, the leatherback sea turtle, an endangered species, occurred in significant numbers, and the study area was inhabited by them during all seasons the year. A portion of the study area, particularly the region from Mississippi Canyon to DeSoto Canyon, appears to be an important habitat for leatherbacks.

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IV. ACOUSTIC SURVEYS

J.C. Norris, W.E. Evans, R. Benson, and T.D. Sparks

4.1 Introduction

It has been known for several decades that cetaceans produce a variety of vocalizations. Acoustic communication is favored because of the excellent transmission characteristics of water, and most marine vertebrates, including cetaceans, make extensive use of that transmission channel. It was evident during WWII that cetaceans were a significant interference to Navy Antisubmarine Warfare (ASW) use of passive (listening) sonars for submarine detection. This resulted in extensive research on cetacean vocalizations and the development of increasingly sophisticated systems for detection and identification of biological noise sources (e.g., Levenson 1974).

In the late 1960's and early 1970's, the U.S. Navy began to address the problem of tracking mobile underwater targets that make noise in order to identify them and determine their abundance and distribution as a function of time. The Navy benefited from a transfer of the towed acoustic array technology from the oil and gas exploration industry. This technology, coupled with rapidly improving computer data analysis capability, produced a sensitive, mobile, range detection and tracking passive sonar. With 15 years of Navy experience, the stage was set to use this capability for the detection, location, and assessment of biological targets.

In 1980, a towed linear acoustic array specially tuned to optimize the reception of biological signals was designed by the Hubbs/Sea World Research Institute (Thomas et al. 1986). This new system was initially tested in the eastern tropical Pacific Ocean (ETP) for detecting cetaceans associated with the yellowfin tuna purse seine fishery by scientists from Hubbs/Sea World Research Institute and the National Marine Fisheries Service Southwest Fisheries Center. The tests demonstrated that a properly designed system could detect and classify various species of cetaceans, in many cases well beyond visual detection range. Tests also showed that acoustic censusing was not limited by sea state, weather, or lighting conditions, and that large herds of dolphins and in some cases large whales could be detected as well as tracked (Thomas et al. 1986).

The array described above had several distinct advantages over other systems that have been used in the past to detect and record vocalizations. Hydrophone groups were arranged for improved reception of specific frequency bands to optimize detection of certain species. Array depth could be adjusted to enhance sound reception as a function of target depth and ambient oceanographic conditions. The directional sensitivity of the array was used to minimize ship self-noise. The array could be modified to electronically form narrow beams that facilitate the tracking operation of specific targets. In addition, the array proved to be easily transported, adaptable for use on a variety of boats and ships, and easy to repair at sea. These initial trials demonstrated that passive-acoustic analysis techniques coupled with acoustic array technology had significant potential for advances in bio-acoustic research and could possibly improve the assessment of fisheries resources, including cetaceans.

There have been several acoustic surveys of marine mammals. Bowhead whales were censused 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). Later projects used concurrent visual and acoustic censusing methods (Zeh et al. 1988). There have also been two attempts to devise acoustic surveying techniques to census sperm whales. Investigators have used multiple hydrophones in an attempt to determine three-dimensional locations of vocalizing sperm whales (Watkins and Schevill 1977, Leaper et al. 1992). The latter study used paired arrays to determine sperm whale locations, but found that determining the location of one array relative to the other was difficult. Whitehead and Weilgart (1990) attempted to determine the density of sperm whales around the Galapagos Islands using click rates.

The purpose of this chapter is to describe the techniques and results of an acoustic survey of cetaceans in the GulfCet study area. The towed linear hydrophone array was the same one developed by the Hubbs/Sea World Research Institute. It was towed behind the survey vessel during each of the shipboard visual surveys conducted by Texas A&M University. The technology proved to be a valuable adjunct to visual surveys for detecting and estimating the abundance of cetaceans.

4.2 Methods

4.2.1 *Data Acquisition*

4.2.1.1 *Equipment*

Hydrophone Array and Associated Equipment

A linear hydrophone array was towed behind the vessel during *Longhorn/Pelican* Cruises 1-7 to record the distinctive underwater vocalizations of cetaceans. The 525 m array consisted of two sections: a 290 m tow cable and a 235 m wet section that contained the active hydrophone groups (Figure 4.1). A 30 m deck cable connected the shipboard electronics to the array via the tow cable. The tow cable both pulled the array and provided negative buoyancy which allowed depth control over the positively buoyant array. The wet section of the array consisted of four sections: 1) a "dead" section, 2) a fore and aft vibration isolating mechanism (VIM) section, 3) a fore and aft high frequency hydrophone section, each with depth and temperature sensors, and 4) a middle low frequency hydrophone section. The dead section contained no hydrophones or VIM elements and functioned as a spacer between the tow cable and the remainder of the array. The VIMs were elastic sections used to reduce low frequency, self-induced vibration.

Within the active section of the array, there were 195 hydrophones in 16 groups. The low frequency sections used Teledyne T-1 low frequency hydrophones. The high frequency groups used Benthos AQ 20 hydrophones with a frequency sensitivity from 0.5 Hz to 30 kHz. These 16 groups were tuned

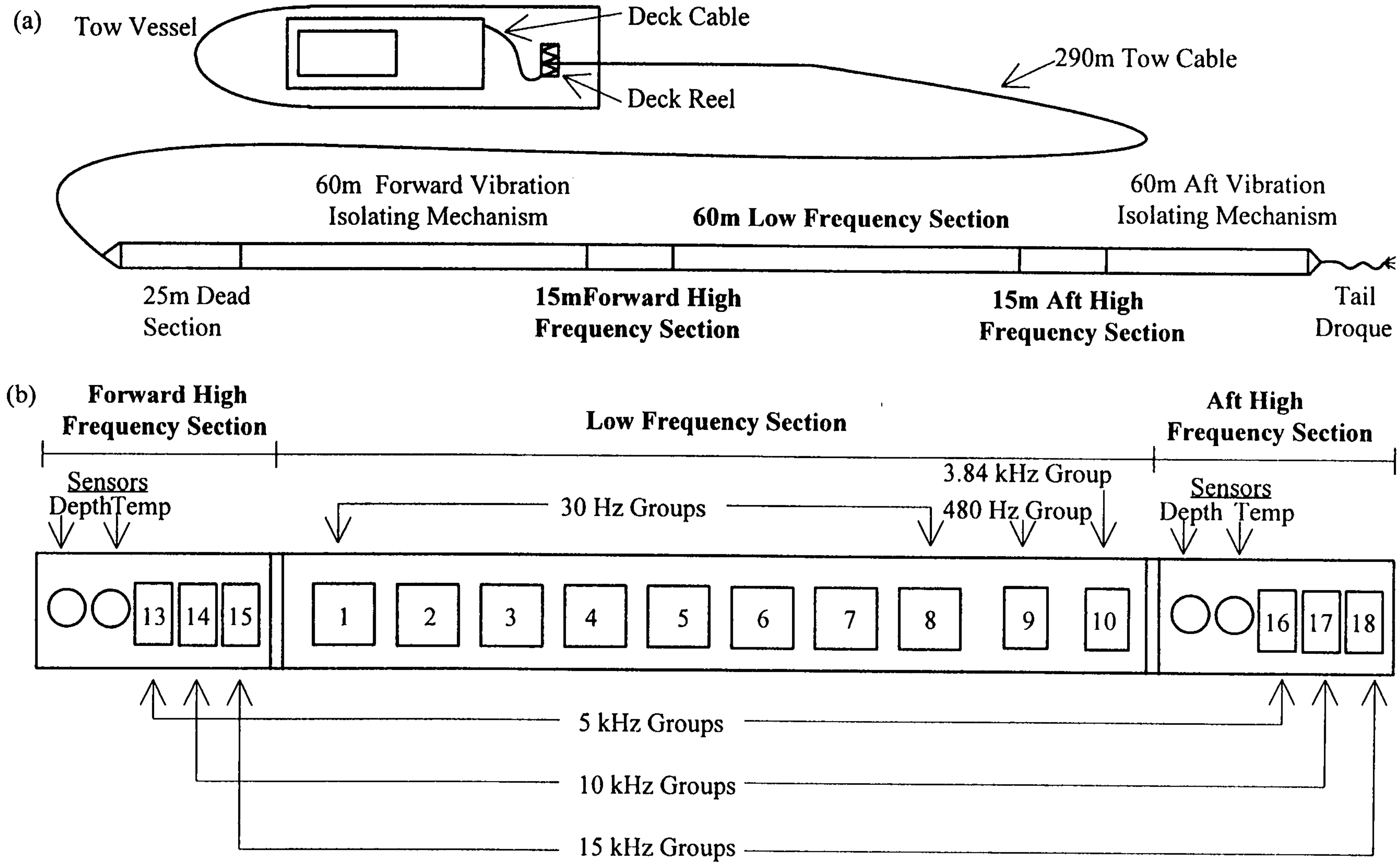

Figure 4.1. Diagram of (a) the 525 m linear acoustic array illustrating its various components (including the deck capble, deck reel, tow cable, dead section, vibration isolating mechanisms, hydrophone groups, and tail torque) and (b) a detailed diagram of the active section, illustrating the placement of depth and temperature sensors, and the various hydrophone groups listed by their respective tuning frequencies.

to six different frequency bands. In the low frequency section, hydrophone groups were tuned to three frequency bands: eight hydrophone groups tuned to 30 Hz, one group tuned to 480 Hz, and one group tuned to 3.84 kHz. In each fore and aft high frequency section, there were groups tuned to 5, 10, and 15 kHz (Figure 4.2). Each hydrophone group was designed to maximize sensitivity and directivity at a particular frequency. To increase directivity, each group was optimized to receive signals at four-times the wavelength of the frequency of interest. For the 5 kHz hydrophone group, for example, the wavelength of 5,000 Hz is 0.3072 m. Four-times 0.3072 m is 1.229 m. To increase phase and frequency resolution, 20 hydrophones were used in the 5 kHz group, therefore each hydrophone was separated by 0.061 m (1.229/20). The 10 kHz groups contained 10 hydrophones, and the 15 kHz groups contained six hydrophones. All hydrophones were acceleration canceling and side-mounted. The array's area of maximum sensitivity was located in a torus pattern perpendicular to the long axis of the array (Figure 4.3). The array possessed little sensitivity to the front and rear of this area (shadow zones) and, as a result, received little ship generated noise.

Signal Amplifier and Recording Equipment

The amplifier was a SIE, Inc. portable Geophysical Amplifier (model RA-44A) with 16 channels, each with its own gain and variable cut-off filters for the high frequency channel (Figure 4.4). An eight channel Racal V-Store analog tape recorder was used to record the acoustic data. This recorder had seven recording speeds, ranging from 15/32 to 30 inches per second (ips) and three bandwidth settings for each channel. The 3-3/4 ips recording speed produced a 2.5 kHz bandwidth for the low frequency hydrophone groups and a 12.5 kHz bandwidth for the high frequency hydrophone groups. At this recording speed, approximately 40 minutes of recording time were possible on a T-120 VHS tape. The 3-3/4 ips recording speed was used to minimize the number of tapes used per cruise, while a 7-1/2 ips recording speed was often used when good signal-to-noise ratios were available. The 7-1/2 ips recording speed had a 5 kHz bandwidth for the low frequency and 25 kHz bandwidth for the high frequency hydrophone groups.

Monitoring and Analytical Equipment

While at sea, acoustic signal processing was conducted with an AST 386 microcomputer utilizing SIGNAL™ software. The software contained a subroutine providing real-time spectrograms displayed on the computer screen. The signals were auditorially monitored with either speakers or headphones concurrently with the spectrogram display. The acoustic operator detected and logged all acoustic events via these aural and visual outputs.

The primary analytical tool was a Kay Elemetrics (model 5500) dual channel, real-time spectrograph. This instrument produced the spectrograms (frequency versus time displays with relative amplitude signified by shades of gray), oscillograms (time versus amplitude), and spectra (frequency versus amplitude) used to analyze the tapes. The dolphin whistle classification work used SIGNAL™ and Canary™ sound analysis software programs.

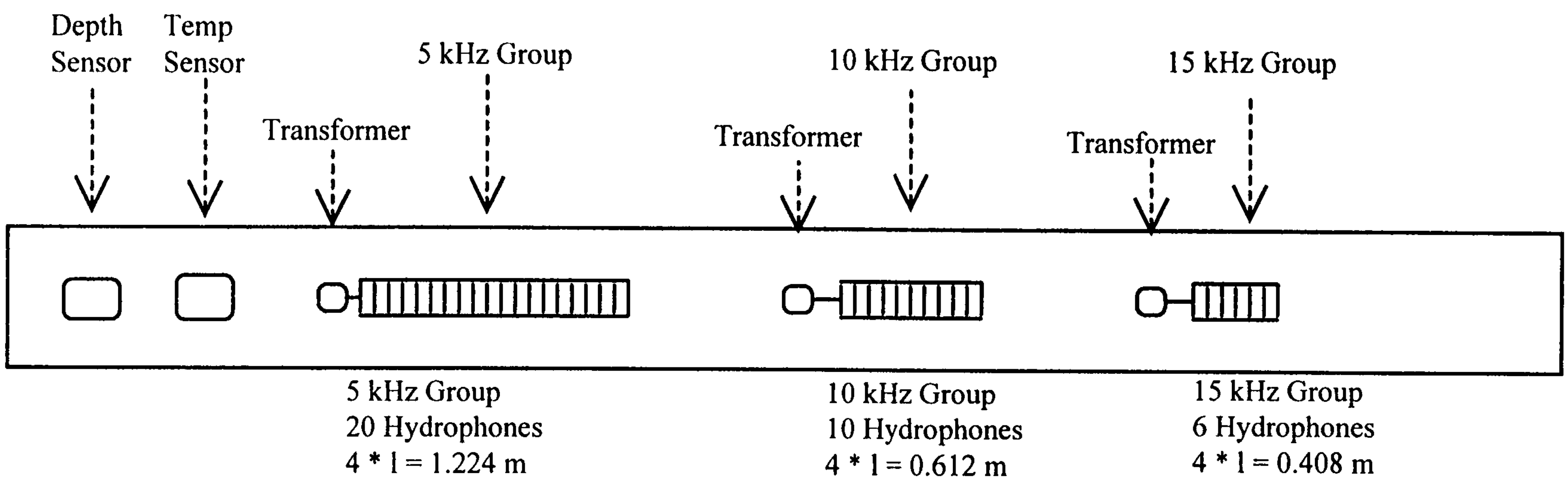

Figure 4.2. Illustration of the high frequency section of the hydrophone array indicating sensors, transformers, and frequency groups with their respective number of hydrophones and their spacing.

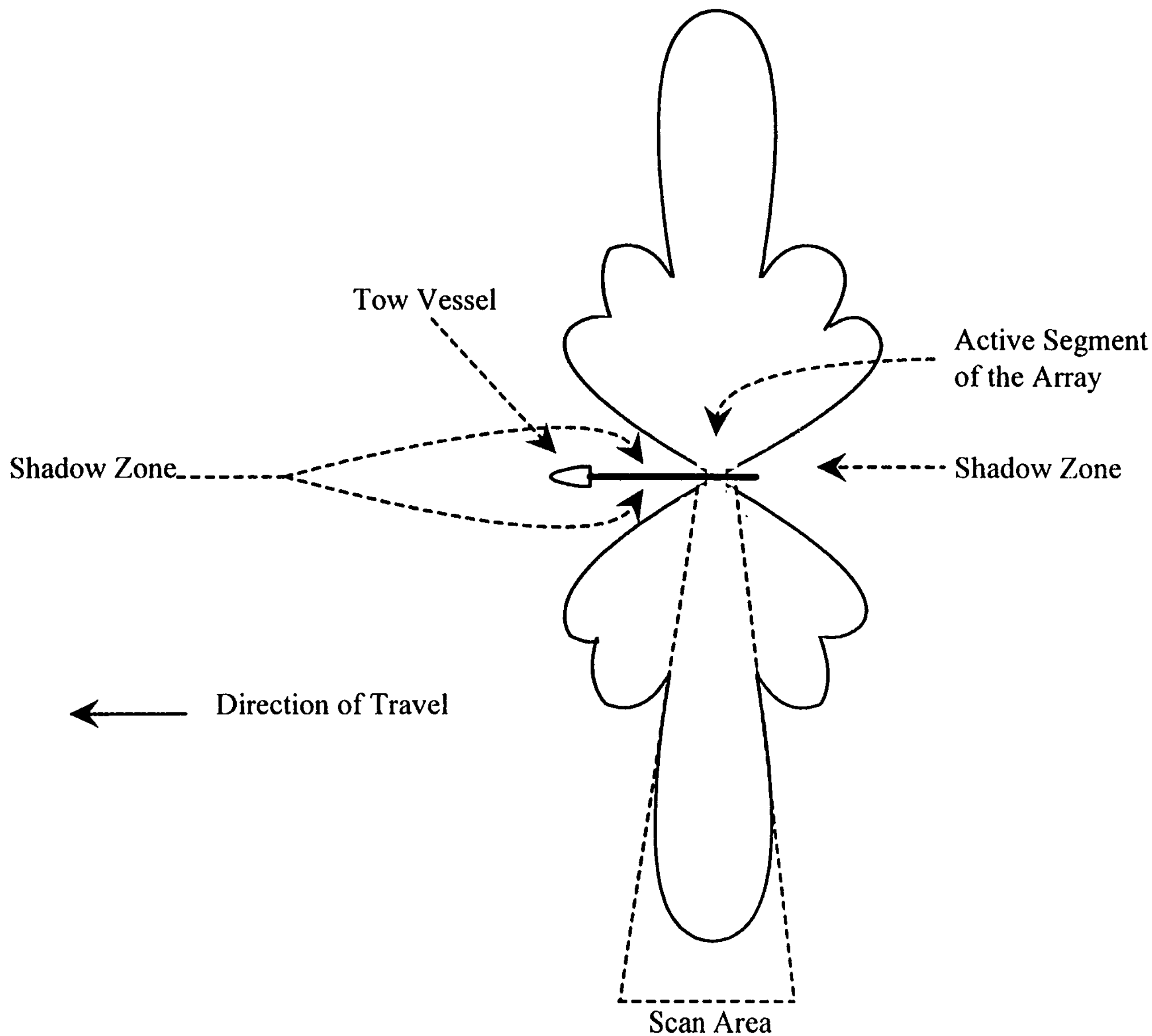

Figure 4.3. The directivity pattern of the hydrophone array.

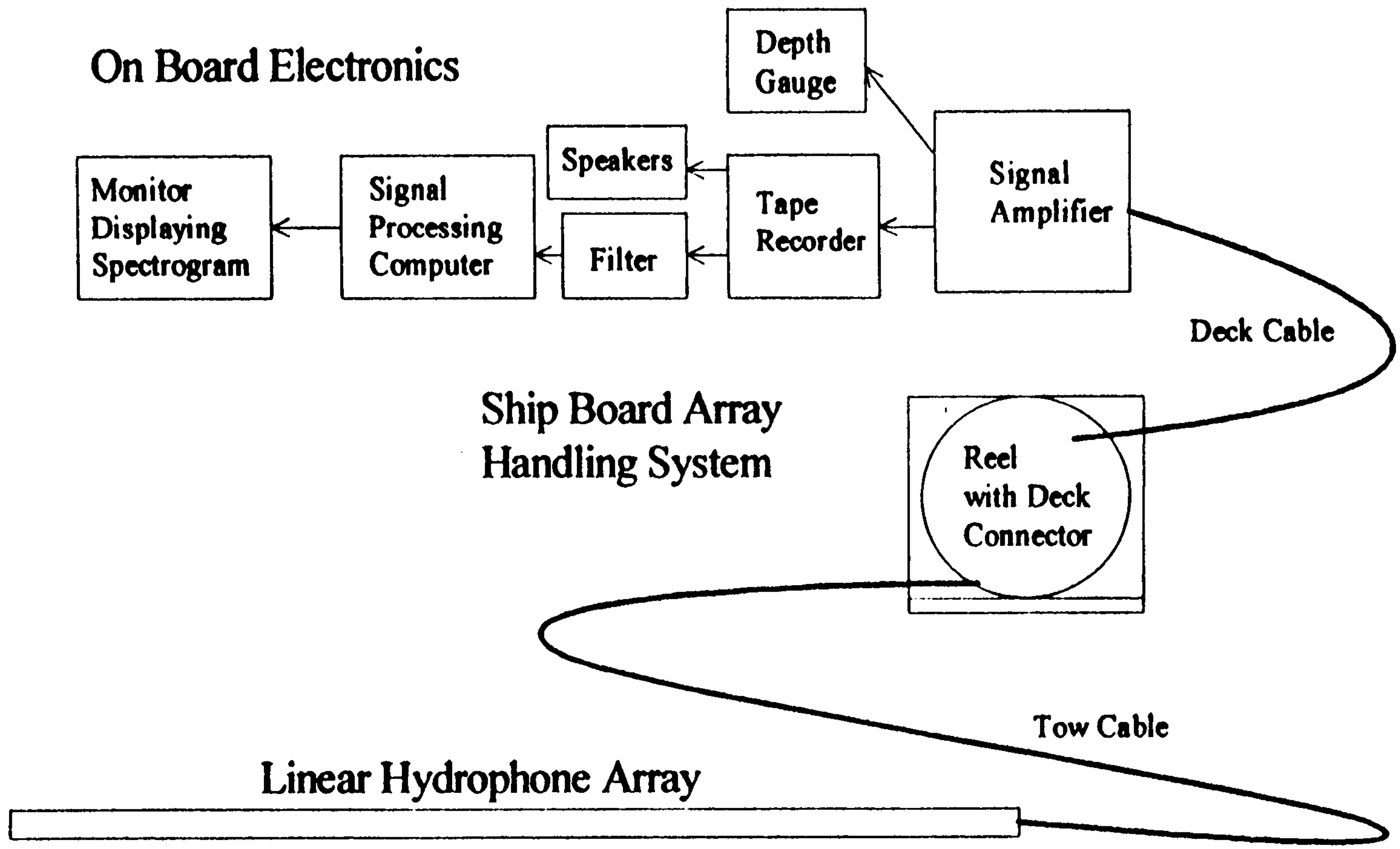

Figure 4.4. The configuration of the on-board electronics, array handling system, and the array.

4.2.1.2 *Array Operation and Recording Procedures*

Array Operation

The array was deployed while the survey vessel was on a track-line. The towing speed ranged from 9.3-12.4 km/hr for the seven cruises. The speed of the vessel and the length of the tow cable determined the depth of the array. This placed the array above the thermocline most of the time. The forward section of the array traveled significantly deeper than the aft section at any given tow speed ($t = 43.8$, $p < 0.001$), with a mean difference of 2.28 m.

The array was retrieved when the vessel was to be stopped, such as at a CTD hydrographic stations. Retrieval took approximately 12 minutes, deployment 10 minutes. Both retrieval and deployment required three people: one to operate the winch, one to guide the array on or off the reel, and a third to guide the array on or off the stern.

Recording methods

Eight channels on the Racal recorder were used to record the output from the array: the fore and aft 5, 10, and 15 kHz, as well as two 30 Hz groups. Information on the array trace number, tape recorder channel number, amplifier gain, and tape recorder attenuation was necessary for later determination of equipment sensitivity. These hardware settings, as well as the date, time, ship's location, track-line number, recording tape speed, and ship's speed were written on the data sheet at the beginning of each VHS tape. Whenever a signal was perceived, the tape revolutions, time, location, and any appropriate comments were noted. While all recorded tapes were archived, this written record was used for subsequent acoustic contact analysis.

4.2.1.3 *Data Processing*

Cataloging

The first step in post-cruise data processing was to catalog the recorded tapes. Based on the written record made at sea, a tape with a signal of interest was located. Information on the recording time, and vessel speed and position were entered as a file header into a data management program. Once this header information was entered, the tape was forwarded to the signal's location. Each acoustic event that had been noted at sea was then analyzed. The tape revolution, source identity when known, and any pertinent comments were listed for each signal. The data management program calculated the time and the ship's location for each acoustic event. This data record contained the location and identity of every recorded acoustic event. Each acoustic contact often consisted of multiple acoustic events. For example, a single sperm whale contact typically consisted of a multiple series of clicks, often with many entries per minute. A second data set was generated by importing the Multiple Interface Data Acquisition System (MIDAS) location data into the acoustic contact database to provide GPS locations for all acoustic contacts at a one minute time resolution. All subsequent analyses were performed on this data set. Only MIDAS locations were used in the analyses reported here.

MIDAS Location Data

Cruises 2-7 were conducted aboard Louisiana Universities Marine Consortium's (LUMCON) R/V *Pelican*. The ship's GPS location and speed were recorded every 10 seconds using LUMCON's proprietary data collection system, MIDAS (Walser et al. 1992). The R/V *Longhorn*, used on Cruise 1 only, did not have such an automated system. Therefore, only location and speed information that had been recorded on the data sheets while at sea could be used for subsequent analysis of Cruise 1.

Acoustic Effort

Acoustic effort was defined as occurring when the survey vessel was traversing a track-line while recording. Off-effort events occurred when recording off the track-line. For example, at the request of the visual survey team, the ship would occasionally leave the transect-line to verify the identification of animals. Effort also stopped for CTD hydrographic stations and high noise conditions caused by ship traffic or heavy rain. Acoustic effort differed from shipboard visual effort in that it did not include the time spent traveling between track-lines but did include track-lines traversed at night, and during all Beaufort sea states.

4.2.2 *Data Analysis Techniques*

4.2.2.1 *Species Identification*

Schevill and Lawrence (1949) were among the first investigators to note that there is considerable difference between the sounds of different cetacean species. Their report also proposed that underwater vocalizations might be helpful in distinguishing species at sea. Schevill (1964) suggested that sounds of cetaceans might be used as taxonomic aids, if and when a sufficient data base was available.

Since the 1960's, the number of recorded vocalizations of whales, dolphins, and porpoises has greatly increased (Watkins et al. 1991, Evans 1967). In the case of the great whales, the underwater vocalizations are distinctive enough to allow a high probability of correct identification (Thompson et al. 1979, Cummings et al. 1986, Clark 1995). Bowhead and gray whale vocalizations are well studied. Underwater vocalizations of bowhead whales have been used to estimate the Bering Sea population of this endangered species (Clark et al. 1986, Clark and Ellison 1988). The rorquals have also been the subject of extensive acoustic research. This is true especially for the humpback whale, where populations have been differentiated using vocalizations (Winn et al. 1981). The most vocally distinctive of the great whales, the sperm whale, has been studied in detail (Berzin 1971, Watkins and Schevill 1977, Watkins et al. 1985, Weilgart and Whitehead 1988, Whitehead and Weilgart 1990). Sperm whale pulses are distinguished from other species by their bandwidth, duration, and rhythmic nature. While limited knowledge exists about the vocalizations of the two *Kogia* species, their vocalizations differ from those of sperm whales by being of a higher frequency and shorter duration (Norris, personal observation). There is little data on ziphiid pulses; there is no indication that they use the rhythmic patterns that are commonly used by sperm whales. The bandwidth of delphinid pulses are much wider and pulse repetition rates are higher (Au 1993).

Based on the historical records of cetacean occurrence and distribution in the Gulf of Mexico (see Chapter 2 of this report), the decision was made to concentrate acoustic effort on those species that had a high probability of accurate identification from underwater vocalizations without visual verification. Sperm whales were the main focus of the acoustic effort reported here..

Dolphin vocalizations have been extensively studied, but because of their variability they have been difficult to quickly and accurately identify to species (Wang Ding 1993, Fristrup and Watkins 1992). The most common dolphin vocalization, whistles, although different from species to species, are difficult to identify to the species level without considerable analysis. Evans (1967) noted that most of the smaller pelagic species, including the common dolphin and the pantropical spotted dolphin, are distinctive from bottlenose dolphins and other larger species because their whistles are of higher frequencies. This was verified by Wang Ding (1993) who found a 0.931 correlation between maximum frequency of vocalization and body length for nine species of dolphin. Hauser (1993) found a similar frequency-to-body size relationship among primates. The first comprehensive quantitative study of whistles of different dolphin species was done by Steiner (1980, 1981). Using multivariate discriminant analysis, he compared the whistle structures of five western north Atlantic dolphin species. He measured six variables for each whistle: beginning frequency, end frequency, minimum frequency, maximum frequency, duration, and number of inflection points. The results indicated that the whistles from the five species studied had consistent species-specific characteristics. The relative degrees of species distinctiveness were broadly correlated with taxonomic and zoogeographic relations. The greater the taxonomic differences between species the greater the difference between whistle vocalizations. Differences were generally greater between sympatric species than between allopatric species.

Wang Ding (1993) conducted a detailed comparison of the whistles of six dolphin species. He found that whistle structures of dolphins were associated with taxonomic relations, body size, habitat, and oceanographic conditions in a complex way. The major difference between Wang Ding's and Steiner's (1981) studies was that Wang Ding considered habitat. Pelagic species usually emitted whistles in a higher frequency range with greater frequency modulation than coastal species. Because of the large number of dolphin species recorded without visual identification to species and listed as unidentified dolphins, Wang Ding's (1993) method was used to differentiate the coastal species and pelagic species encountered during the GulfCet cruises. Whistles from bottlenose dolphins, clymene dolphins, pantropical spotted dolphins, and striped dolphins, recorded during *Pelican/Longhorn* Cruises 1-3, were compared.

In this study, signal spectral analysis and statistical analysis procedures were the same as those used by Wang Ding (1993). All recordings were analyzed with SIGNAL™ software and the analysis frequency range was 0-20 kHz. All signals with suitable signal-to-noise ratios were analyzed. The sonograms had a frequency resolution of 98 Hz when the analysis bandwidth was 20 kHz. Ten variables were measured for whistles from the four species: beginning frequency, end frequency, minimum frequency, maximum frequency, duration, number of inflection points (a change in the slope of the frequency contour from negative to positive or vice versa), beginning frequency sweep and end frequency sweep (up or down), harmonics, and contour break. Multivariate discriminant analysis was used to compare overall whistle structures to determine if any significant variations existed between the species being studied. The SAS-PROC CANDISC™ program was used to compute Mahalanobis distance-squared statistic (D^2), F-statistic, and canonical variable values. The Mahalanobis D^2 statistic is a relatively simple size-independent measure of the differences between overall whistle structure as determined by the distance between species mean vectors in multivariate space; the greater the D^2 statistic the greater the differences between species.

Canonical variables, which are computed from the linear combination of quantitative variables entered into the discriminant function, are a multivariate measure of the differences in overall whistle structures between different species. Each canonical variable is a linear combination of a subset of the acoustic variables, with each canonical variable minimizing the variance within its particular subset of variables. When the first two canonical variables of each species are plotted on an X-Y coordinate plot, the relative distance between the positions of each species is proportional to the relative differences between their whistles.

For the purposes of describing distributions and determining number of acoustic contacts, species identity was determined by two means. With all species except sperm whales, acoustic contact identity was made when an animal was concurrently recorded with an identified visual contact. In those cases where recordings were made from schools containing more than a single species, the contacts were listed as unidentified dolphins. For sperm whales, identification was made as described above using acoustic cues such as bandwidth, duration, and the rhythmic nature of their pulses.

4.2.2.2 *Abundance and Density Estimation Techniques*

Detection Distance

Standard line transect methods for estimating abundance require the measurement of perpendicular distances (or angles and radial distances) from the track-line to the position of the target animal. Using the array configuration described, perpendicular distances to vocalizing sperm whales could not be determined with sufficient accuracy. Consequently, an alternative method, a detection function modified strip transect method, was developed to estimate the sperm whale population density in the study area.

To use this method, it was necessary to determine the distance from which sperm whales could be detected. The hydrophone array was calibrated by projecting three signals (sperm whale pulses, rough-toothed dolphin whistles, and a 5 kHz pure tone) from measured distances perpendicular to the array. Distances between the array and the signal projector were determined using two GPS receivers; one at the projector and one aboard the *Pelican*. The projector was a calibrated F56 transducer leased from the Naval Research Laboratory. The source level of the projected signal was measured using a Brüel and Kjær (B&K) SPL meter. The source level of sperm whale pulses has been estimated as being from 165-185 dB re. 1 μP at 1 m (Watkins 1977, Watkins and Schevill 1977, and Watkins et al. 1988). Corcella and Green (1968) reported a source level of 136 dB re 1mP at 1 m. Dunn (1969) reported a mean source level of 173.9 dB re 1mP at 1 m (n = 148, SD = 3.51 dB). Levenson (1974) reported a mean source level of 171.2 dB re 1μP at 1 m (n = 13, SD = 2.9 dB, range = 165.5-175.3 dB). We chose to broadcast the pulses at the source level reported by Levenson (1974). The projected signals were then recorded at the array from a known distance. Subsequently, 63 random samples of background noise from Cruises 2-7 were measured to adjust the transmission loss model to the average noise level during the cruises. It was determined that a sperm whale signal of at least 67 dB re 1μP must be present at the array in order for the signal to be detected. A transmission loss (TL) model was used with the form:

$$TL = 20 \log r + ar$$

where r = source range, and a = an attenuation coefficient. Based on the transmission loss model, the average maximum detection range for sperm whales producing 171 dB signals was 11.1 km.

Detection Threshold

The detection function describes how many sperm whale contacts should be detected as a function of distance from the vessel. Earlier it was established that signals up to 11.1 km away from the vessel were detectable. Signals may, however, go undetected for reasons associated with the psychoacoustics of listening. This is analogous to the problem of determining the visual detection function for standard line transect. A proportion of otherwise detectable signals are lost due to human factors concerning attentiveness to low amplitude signals mixed with background noise. The detection function determines the proportion of missed signals so that the density calculations can be adjusted.

An audio recording was made to simulate the experience of listening to the hydrophone array at sea. Forty-three minutes of background noise, without detectable sperm whale signals, were transferred from a recording made during a GulfCet cruise. The sound pressure level of this background noise was equilibrated to the average sound pressure level based on the mean dB level from 63 segments taken from Cruises 2-7. Thirty-four sequences of sperm whale clicks were then digitally mixed into this background noise at random intervals. The sperm whale click amplitude levels were adjusted to simulate a random distribution of animals around a simulated transect line. A data acquisition program was written to record the elapsed time, allowing us to grade the ability of each listener to detect a signal. Based on their performance, a detection threshold representing the probability density function for detecting signals was generated.

Each listener was trained using two tapes. The first tape contained a series of sperm whale pulses that familiarized the listeners with these signals. The second tape familiarized them with the test paradigm (Atkinson 1988). Twenty-four participants listened to the 43-minute test tape. From their responses (Figure 4.5), a model for the psychoacoustic sperm whale detection function was developed. The data was standardized so that there were no responses at 11.1 km. Participants had little trouble detecting clicks in marginal or higher signal-to-noise ratios. A rapid drop off in the ability to detect clicks occurred only after the signal-to-noise ratio became very low. This suggested that very few actual sperm whale contacts were missed, even out to the maximum detection range of 11.1 km. Based on this model, we predicted that only 3.8% of the sperm whale clicks within 11.1 km of the array were missed and that the unadjusted density estimate should be multiplied by a correction factor of 1.038.

Sperm Whale Group Size

Central to the accurate estimation of sperm whale numbers is the size of the enumerated population unit. The results of the density estimates are given in number of groups/km^2. A problem arises when translating this density number to the number of animals in the study area: How many animals are in a group? This question arises because sperm whales have a hierarchical social system containing varying numbers of whales over space and time (Whitehead and Kahn 1992). What was the detected population unit - a group or a cluster of sperm whales? It is likely that the various survey teams (shipboard visual and acoustic, and aerial visual) counted different social units. Clearly, for the results to be comparable, each census team must use the appropriate group definition and number of animals per group.

Based on association patterns between repeatedly identified animals within mixed age/sex groups in the Galapagos, Whitehead and coworkers described a hierarchical system for sperm whale social organization as including units, groups, and aggregations (Whitehead 1987, Whitehead and Arnbom 1987, Whitehead and Waters 1990, Whitehead et al. 1991, Whitehead et al. 1992a, Whitehead et al. 1992b, Whitehead and Kahn 1992). They found that each individual was a member of a "unit" consisting of approximately 13 whales. Individuals within units associated with one another for periods of several years. The associations may be permanent, lasting the entire lifetime of some animals. An average of about two of these units were together at any time, forming groups of roughly 20 individuals as noted in the earlier studies (Whitehead and Kahn 1992). These associations integrated their behavior for a period of several days, splitting on average after 6.5 days. Aggregations were temporary associations of multiple groups, often consisting of two groups, although aggregations could also consist of a single group.

The term "cluster" was used by Whitehead (1989) in describing an association of foraging sperm whales. His analysis did not include association patterns of identified animals. Foraging sperm whales, while at the surface, were seen in clusters, with one to four individuals coordinating their movements within 100 m of each other. Clusters contained a mean of 1.7 whales (Whitehead 1989). Multiple clusters occurred in the same area, with a mean distance of 200 m

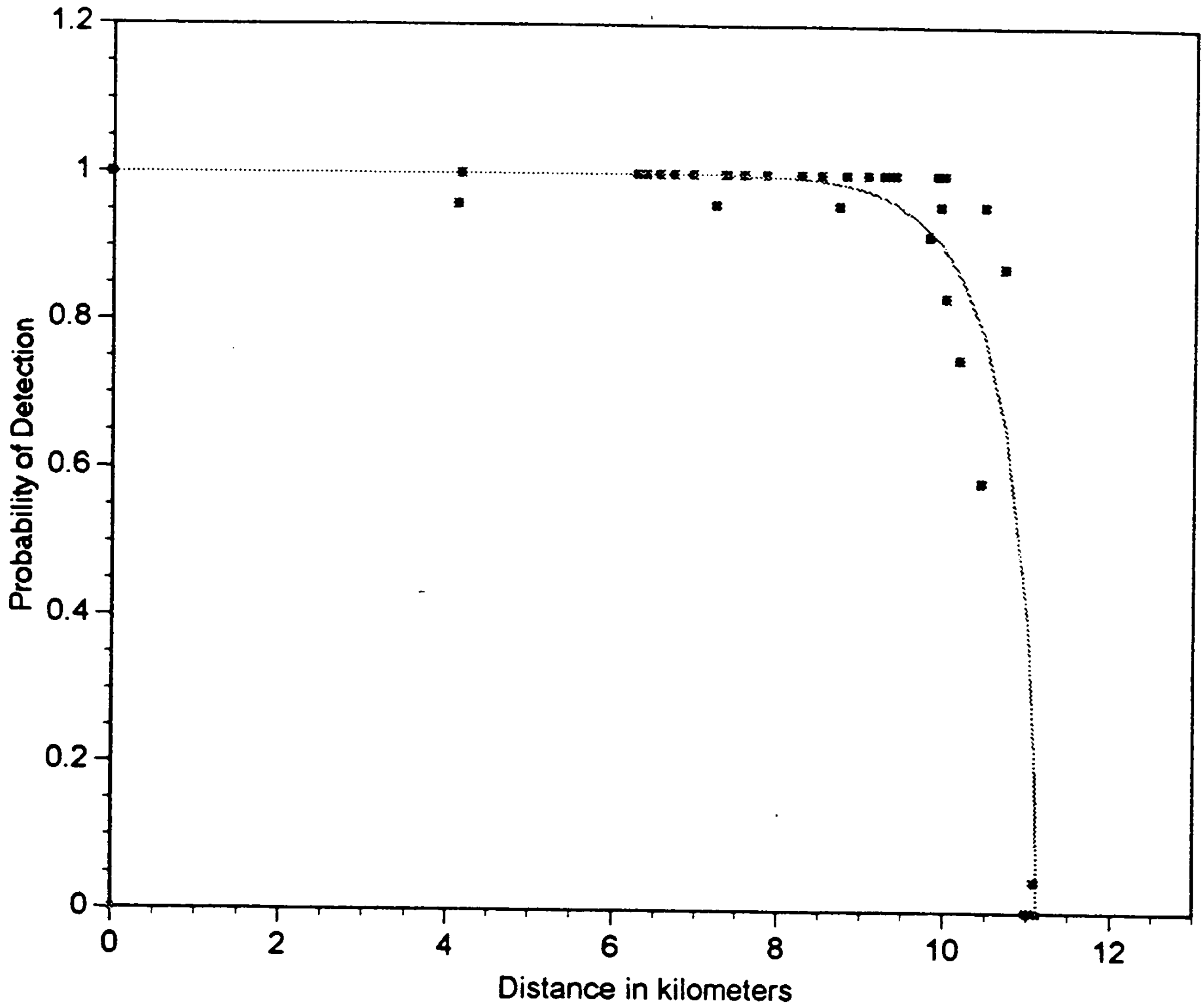

Figure 4.5. The detection function for sperm whales using the acoustic array.

between clusters (Whitehead 1989). If a cluster contained on average 1.7 animals and groups contained roughly 20 animals, then the various members of a group may surface in 10-12 clusters over a period of 30-90 minutes. This organizational structure is complicated by the fact that, when socializing, entire groups may come together at the surface such that the entire group of 10-20 animals may be visible at once.

Geographic scale is a criterion in determining whether the observed animals are in a cluster, group, or aggregation. If animals are sighted together in a small area, then it is likely they are a cluster. If they are spread over a larger area, on the order of kilometers, they are probably a group. For example, a sighting of two to four animals in one location followed by another sighting of two to four animals within a few kilometers is likely to be one group of four to eight animals consisting of two clusters.

The size of sperm whale social structures is relatively uniform throughout the world. Mean group sizes were 22 in the Galapagos (Whitehead 1989), 20 in Sri Lanka (Gordon 1987), and 25 in New Zealand (Gordon et al. 1992). Similarly, mean cluster sizes were consistent worldwide: 1.7 in Galapagos (Whitehead 1989), 2.1-3.5 in the Gulf of Mexico (Mullin et al. 1994, Collum and Fritts 1985), and 3.1 in Sri Lanka (Gordon 1987). Mullin et al. (1994) noted that the small group size, 2.1, reported for the Gulf of Mexico may correspond to the clusters given by Whitehead and Arnbom (1987). All-male clusters off Nova Scotia averaged 1.1 animals; these clusters rarely formed groups unless joining mixed age/sex groups. Whitehead (1989) found that mixed groups in the Galapagos Islands consisted of one to four clusters with an average of 3.4 animals per cluster and a mean inter-cluster distance of 213 m.

The methodology of visual censusing requires that all sightings be independent events (Buckland et al. 1993). In practice, if several animals surface at some distance to port, then five minutes later animals surface to starboard, they are counted as separate sightings. Using the nomenclature described above, what was counted during visual surveys were almost certainly clusters. The geographic pattern of sperm whale acoustic contacts was analyzed, comparing visual and acoustic results to determine if acoustic surveys enumerated clusters or groups.

Dolphin Group Size

The group size used in the dolphin abundance calculations was a weighted mean taken from the visual shipboard data. The weighting was calculated by taking the sum of the individual densities for each of the 14 species (see Chapter 3, Table 3.6) and dividing that value by the sum of the group densities for those same species. This takes into account the number of contacts for each species, such that those species that were seen more often were weighted more heavily than less frequently observed species.

Abundance Estimates

The estimated mean contact density ($\overline{D}$) was calculated, using a detection function-modified strip transect method as follows:

$$\overline{D} = f(d_{max})\left[\left(\sum_{L=1}^{k}\frac{n_L}{A_L}\right)k^{-1}\right]$$

where $\overline{D}$ = corrected mean contact density for transect lines 1 to k,
$f(d_{max})$ = correction factor resulting from detection function,
k = number of transect lines,
n_L = number of contacts on transect line L, and
A_L = area of census effort on transect line L.

The estimated abundance, N, in the study area was calculated as follows:

$$N = AS\overline{D}$$

where N = estimated sperm whale or dolphin abundance,
A = total census area,
S = sperm whale or dolphin group size, and
$\overline{D}$ = mean density.

The log-normal 95% confidence intervals for population estimates were calculated using the following equations:

$$\text{Lower 95\% CI} = \frac{N}{\exp\left[\sqrt{1.96 \cdot \left(\ln\left(1 + (CVN)2\right)\right)}\right]}$$

$$\text{Upper 95\% CI} = N \cdot \exp\left[\sqrt{1.96 \cdot \left(\ln\left(1 + (CVN)2\right)\right)}\right]$$

where CVN = coefficient of variation of N.

Statistical Methods for Cetacean Distribution Analysis

A contour index (CI) was calculated to determine the effect of sea-floor topography on sperm whale distribution. The study area was divided into roughly equal blocks approximately 160 NM^2 centered around CTD positions (see Chapter 6). A CI reflects the percent change in depth of a given block and was calculated for each block using the following equation:

$$CI = \frac{M - m}{M} \cdot 100$$

where M represents the maximum depth and m represents the minimum depth of a given block; however, m was restricted to depths ≥ 100 m because blocks in the northern study area extended into very shallow areas (e.g., block 125 encompasses part of the Mississippi River delta). Following the conventions set forth in Mullin et al. (1991), each block was subsequently assigned to one of four CI categories: 20-39, 40-59, 60-79, or 80-99. The null hypothesis tested was that sperm whale acoustic contacts were randomly distributed across all CI categories. The test statistic was a Chi-square comparing the expected sperm whale contacts to the observed sperm whale contacts based on the level of effort (in km) for each block. The expected number of sperm whale contacts (E_i) was determined using the following equation:

$$E_i = O_t (L_i / L_t)$$

where O_t represents the total number of sperm whale contacts, L_i represents the kilometers of effort in CI-category$_i$, and L_t represents the total kilometers of effort.

Sperm whale and dolphin contacts by cruise and season were examined, as were sperm whale contacts by contact duration and water depths. The null hypothesis was that the observed distributions or values were randomly distributed relative to the expected value based on observer effort. Chi-square analyses were used to compare observed versus expected values. As stated above, the expected value was derived from effort (during the parameter of interest) divided by the total effort, with that ratio then multiplied by the total for all cruises for that parameter. In all cases, $\alpha < 0.05$ or 0.1 as indicated.

A Kruskall-Wallis test was used to compare lengths of sperm whale contacts by cruise and season, the water depths for sperm whale contacts, and both sperm whale and dolphin densities by season and region. Where statistical significance was indicated with the Kruskall-Wallis test, multiple paired-comparisons were conducted using a Mann-Whitney U test.

The above analyses describe the distribution and abundance of cetaceans in the study area using data similar to that available to the other survey techniques (i.e., the number of contacts and their modal, or initial location). The acoustic data, however, permitted further analyses because acoustic contacts had a greater temporal and spatial extent than the visual methods. This was largely due to cetaceans being vocal animals that spend most of their time below the surface. Acoustic contact with the animals was longer, which permitted description of differences in the duration and length of contacts relative to seasonal and daily patterns. Time series analyses were used to determine if there were temporal patterns to the starting time of sperm whale contacts and to effort. Spectral analyses identified the correlation of different frequencies with the observed data. They indicated, for example, whether there was a cyclical pattern to when sperm whale contacts began. An autocorrelation analysis of the data was also conducted. This analysis showed whether a particular time lag was present in the data, such that, given that time lag the data were highly correlated. This tool was used to determine whether the pattern of sperm whale contacts correlated at a particular time lag (i.e., whether the pattern of contact initiation was similar at sunrise and sunset, indicating that the animals had a repetitive, crepuscular behavior pattern).

4.3 Results

4.3.1 *Acoustic Effort*

A total of 12,219 km and 1,055 hours of acoustic effort was completed. On-effort acoustic sampling occurred 95% of the available time for *Pelican* Cruises 2-7 (Figures 4.6-4.12). Gaps in effort during Cruises 3 and 7 occurred when the ship returned to port because of poor weather or illness. There were two cruises for each season, except winter, which had one (see Chapter 1, Table 1.3). The four spring and summer cruises had approximately the same effort, whereas the two fall cruises were shorter.

The mean hourly duration of effort was 42.08 hr (SD = 5.27, range 32.2-51.7 hr, n = 24) (e.g., between 0000-0059 hr there were 45.1 hours of effort over the seven cruises). The duration of effort by time of day was relatively constant (Figure 4.13). A time series analysis of this data suggested that the only periodicity was a 24-hour cycle, about the time it took to transit one track-line and cross to the next in the western half of the study area.

4.3.2 *Species Recorded*

A total of 487 acoustic contacts were recorded (Table 4.1). Of that number, 124 contacts were from 12 identified species (see Appendix A for the location and time of all acoustic contacts). The sperm whale was the most commonly recorded species, accounting for 56% of identified contacts. The most commonly recorded small cetacean was the pantropical spotted dolphin, with 22 contacts. A single recording of an unidentified baleen whale was made, probably a sei or Bryde's whale based on its spectral configuration. An additional 331 contacts were of unidentified dolphins. These were signals recorded during sightings of unidentified dolphins, or at times when there was no visual effort, such as during poor weather and at night. There were 30 contacts with unidentified cetaceans. These were typically pulsed signals that did not sound like sperm whales or dolphins, and were possibly either dwarf/pygmy sperm whales or beaked whales. Also recorded were 19 unidentified biological contacts, probably shrimp. Approximately half of the species expected to occur in the Gulf as determined by Jefferson et al. (1992) were recorded, including the rarely recorded clymene and rough-toothed dolphins as well as the first recording ever of Fraser's dolphin.

Noteworthy in their absence were many baleen whale signals. The expectation had been to record at least minke, Bryde's, and humpback whales. No identified recordings were made of beaked whales, though they were seen on several occasions. Only a single identified recording was made from either pygmy or dwarf sperm whales. Of the expected dolphin species, only killer and pygmy killer whales were not recorded.

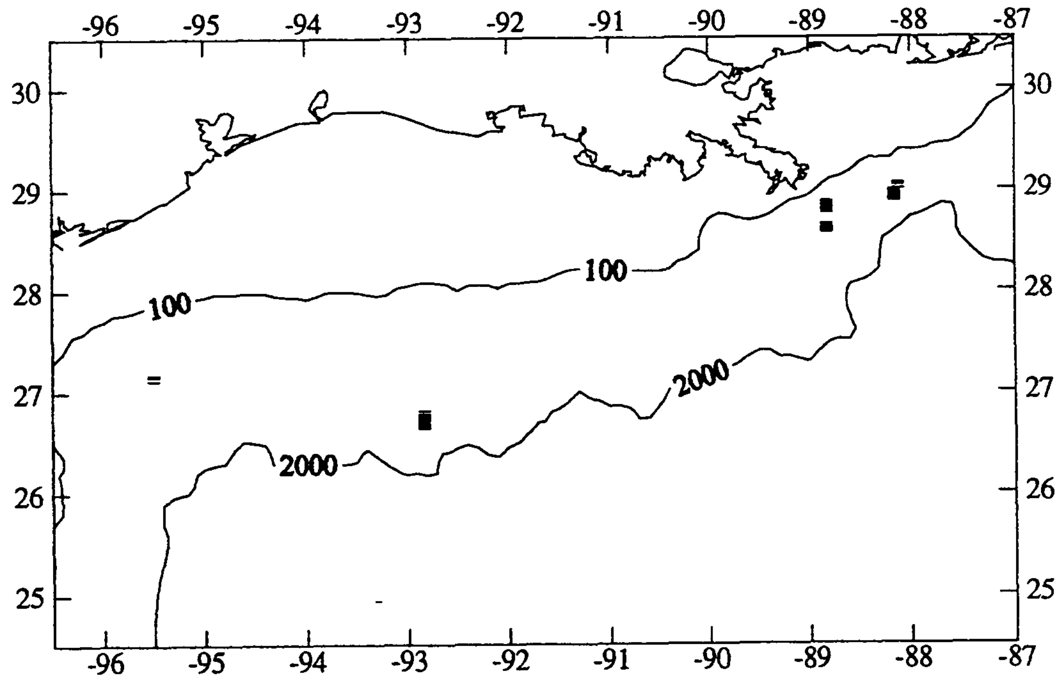

Figure 4.6. Distribution of sperm whale contacts on R/V *Longhorn* Cruise 1 (first spring cruise). Horizontal lines indicate the location of a single signal.

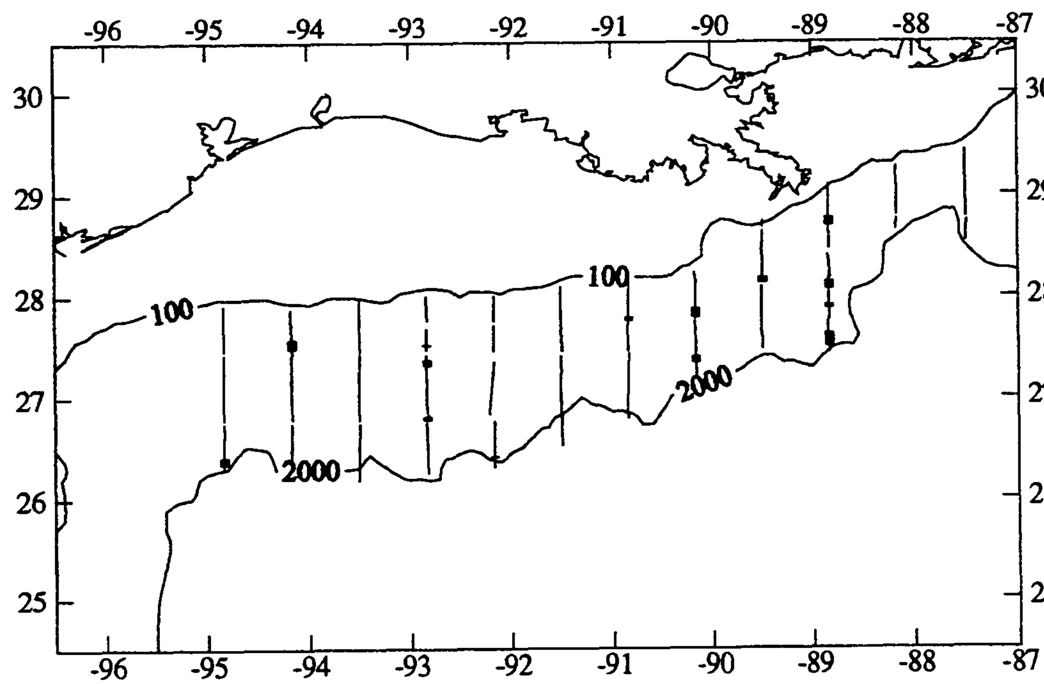

Figure 4.7. Distribution of sperm whale contacts on R/V *Pelican* Cruise 5 (second spring cruise). Horizontal lines indicate the location of a single signal. Effort is shown as the solid line along each track-line.

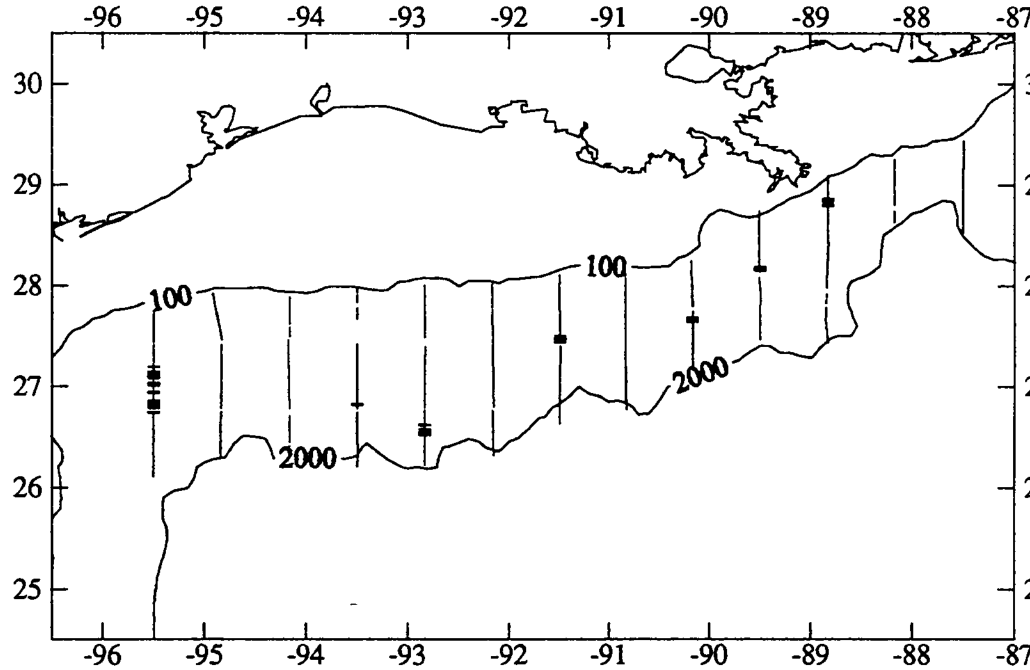

Figure 4.8. Distribution of sperm whale contacts on R/V *Pelican* Cruise 2 (first summer cruise). Horizontal lines indicate the location of a single signal. Effort is shown as the solid line along each track-line.

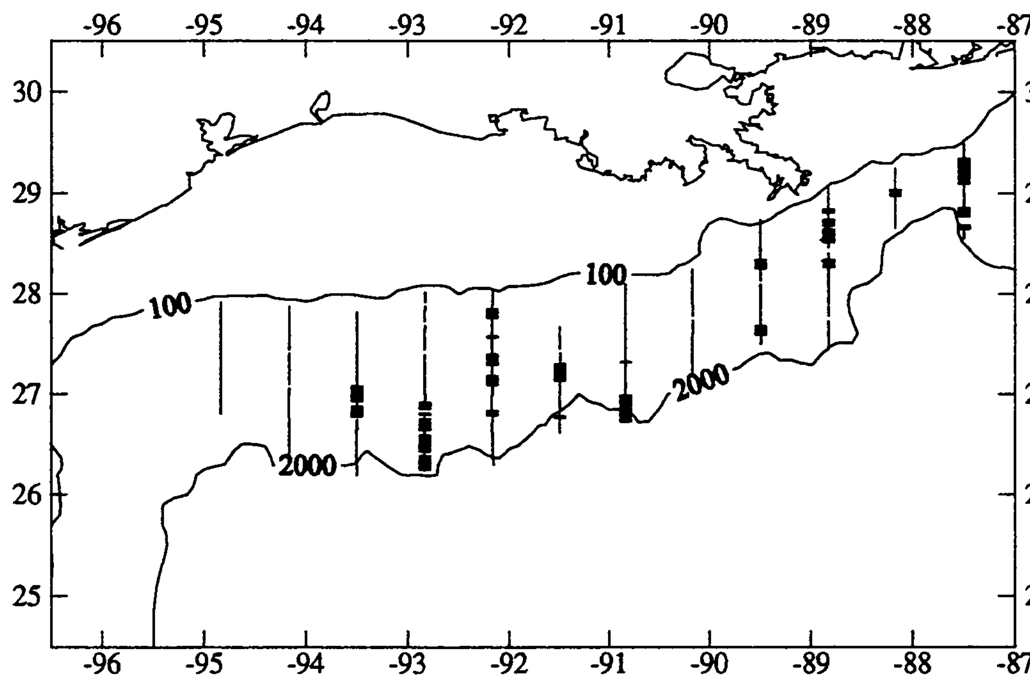

Figure 4.9. Distribution of sperm whale contacts on R/V *Pelican* Cruise 6 (second summer cruise). Horizontal lines indicate the location of a single signal. Effort is shown as the solid line along each track-line.

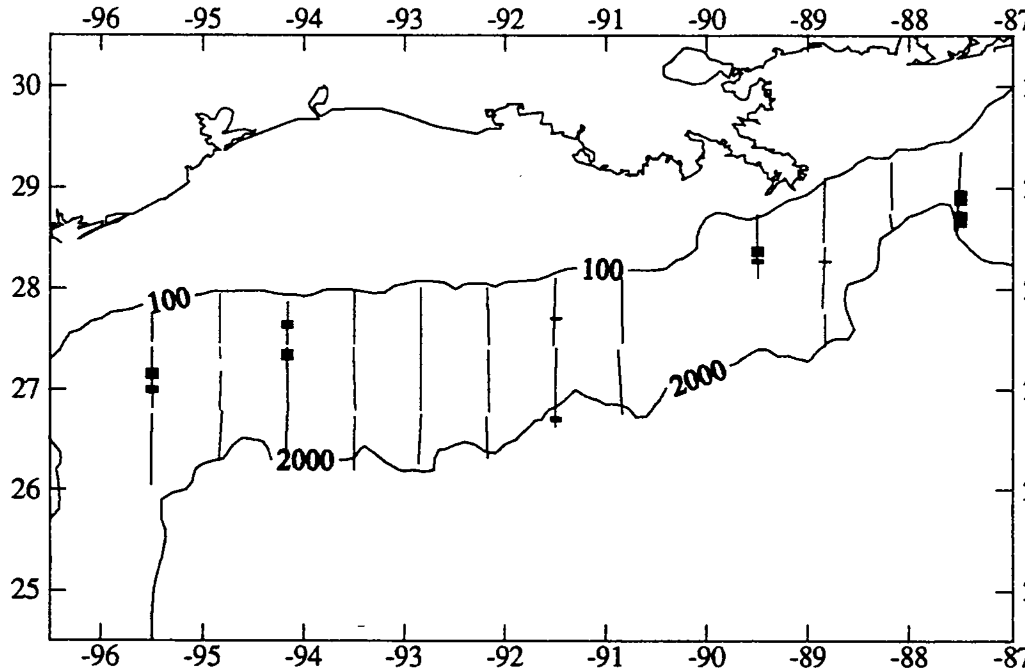

Figure 4.10. Distribution of sperm whale contacts on R/V *Pelican* Cruise 3 (first fall cruise). Horizontal lines indicate the location of a single signal. Effort is shown as the solid line along each trackline.

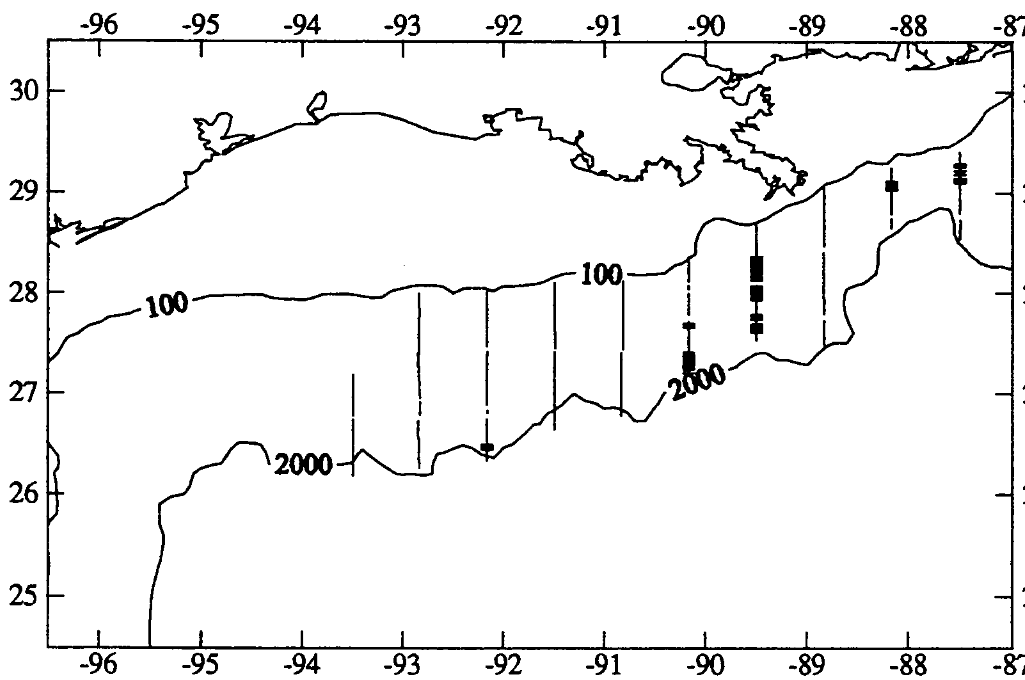

Figure 4.11. Distribution of sperm whale contacts on R/V *Pelican* Cruise 7 (second fall cruise). Horizontal lines indicate the location of a single signal. Effort is shown as the solid line along each trackline.

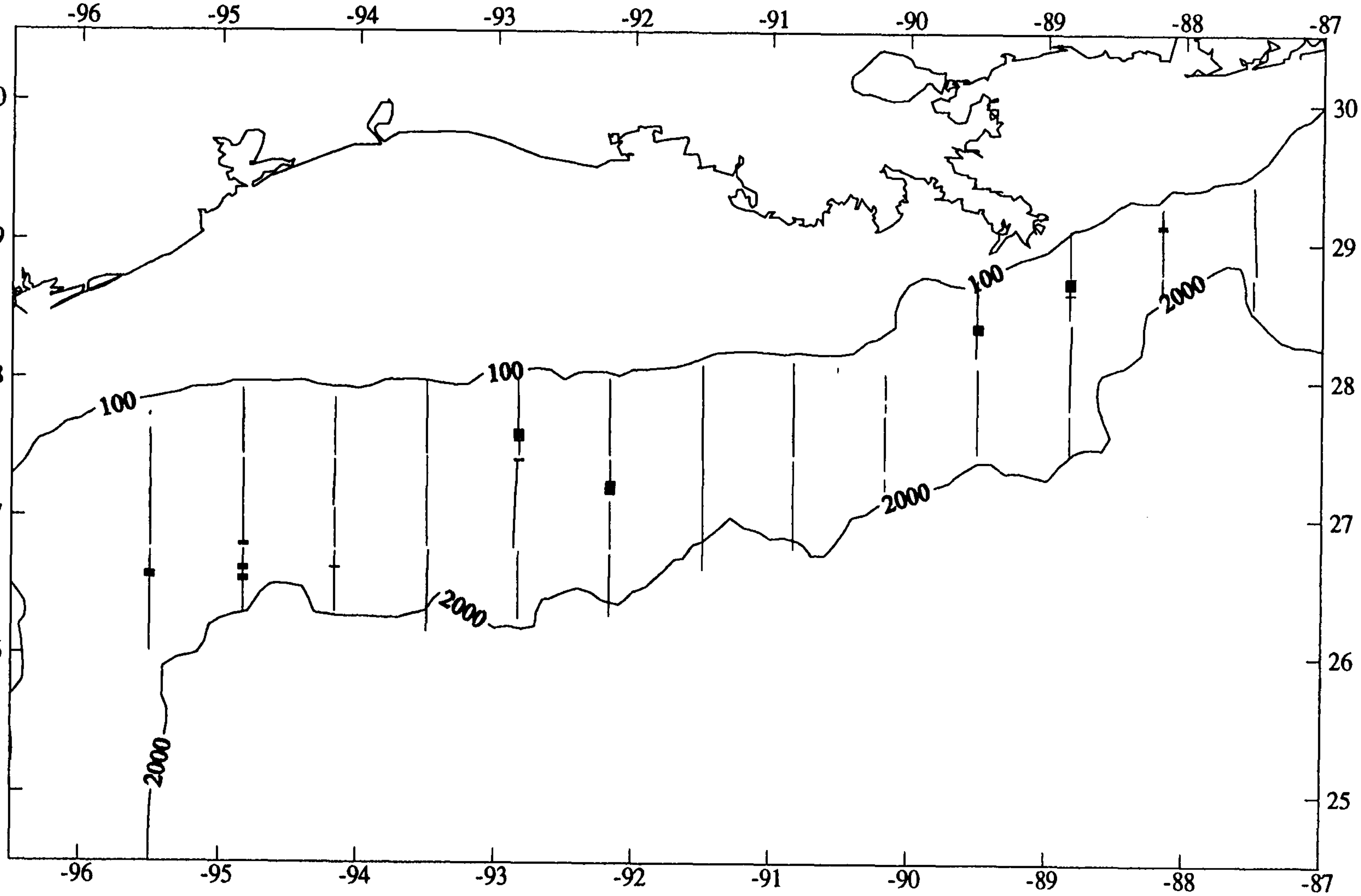

Figure 4.12. Distribution of sperm whale contacts on R/V *Pelican* Cruise 4 (winter cruise). Horizontal lines indicate the location of a single signal. Effort is shown as the solid line along each track-line.

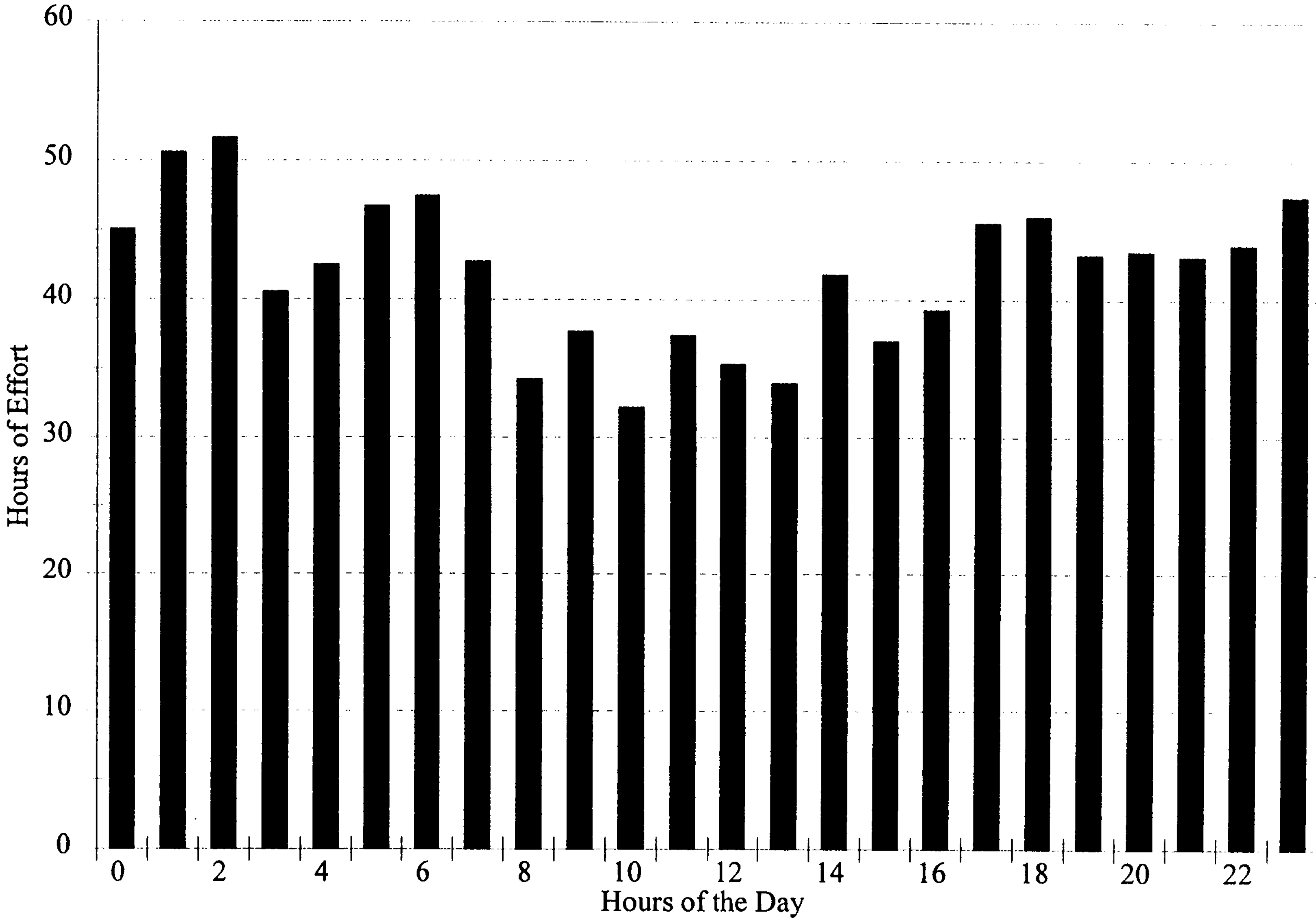

Figure 4.13. Hours of effort by time of day for *Pelican/Longhorn* Cruises 1-7.

Table 4.1. Number of on-effort acoustic contacts by cruise and species.

Species	*Pelican/Longhorn* Cruise Number							Total
	1	2	3	4	5	6	7	
Unidentified cetacean	4	7	7	3	4	2	3	30
Unidentified baleen whale					1			1
Sperm whale	4	7	8	10	14	17	7	67
Dwarf sperm whale						1		1
Melon-headed whale					1			1
False killer whale					2	1		3
Short-finned pilot whale					1		2	3
Rough-toothed dolphin			1			1		2
Fraser's dolphin						1		1
Bottlenose dolphin	7	3	2	0	1	2	0	15
Risso's dolphin					2	1		3
Atlantic spotted dolphin		1						1
Pantropical dolphin	3	1	6	7	1	2	2	22
Striped dolphin		1			1			2
Clymene dolphin	1				3			4
Unidentified dolphin	30	65	26	60	64	47	39	331
Total Contacts	49	85	50	80	95	75	53	487

4.3.3 Distribution of Cetaceans by Species

4.3.3.1 *Sperm Whales*

Analysis By Cruise

Sperm whales were encountered on all cruises and along all track-lines. The number of contacts ranged from five on Cruise 1 to 18 on Cruise 6 (Table 4.2). These data were analyzed to determine whether certain cruises had more contacts than expected by correcting for effort and conducting a Chi-squared test. The observed number of contacts by cruise was significantly different from expected ($X^2 = 16.1897$, $p = 0.01297$, $df = 6$). There were fewer observed contacts during the early cruises and more than expected during the later cruises. These differences are examined in greater detail below.

Sperm whales were detected throughout the study area (Figures 4.6 to 4.12). There were, however, certain areas where sperm whales were encountered each time we surveyed that location, in particular, along track-lines 2, 6, 11, and 12. For example, we encountered sperm whales six times within an average of 7.6 km (SD = 8.52) of a point 38 km south of the north end of track-line 12. This point is 57 km SE of the Southwest Pass of the mouth of the Mississippi River.

Table 4.2. Analysis of sperm whale contacts by cruise. The number of contacts includes two off-effort contacts.

Pelican/ Longhorn Cruise	Number of Contacts	Total length of Contacts (km)	Effort (km)
1	5	68.34	2105.6
2	7	90.56	1867.8
3	8	98.32	1727.5
4	10	59.97	1888.1
5	14	77.78	1733.5
6	18	311.88	1603.6
7	7	130.71	1292.6

Sperm whales not only were found repetitively at particular locations, but groups were also spread over differing amounts of area. The average length of a sperm whale contact was 12.13 km (SD = 13.26). For the first five cruises, there were few very long contacts. During the last two cruises, however, there were several long contacts, with the longest lasting 74.15 km. A comparison of the lengths of sperm whale contacts for all cruises indicated that they were significantly different (Kruskal-Wallis, $H = 12.669$, $p = 0.0486$, $n = 69$). A multiple paired comparison by cruises indicated that Cruises 4 and 5 were each statistically different from Cruises 1, 6, and 7 ($p < 0.055$) (Table 4.3). In each case, contact lengths were less for Cruises 4 and 5 than their ordered pairs.

There was a highly significant difference between the observed versus expected length of contacts ($X^2 = 496.915$, $p < 0.01$, df = 6) (Figure 4.14). This resulted from the long contacts during Cruise 6, when the observed contact length was 2.84 times the expected. Additionally, contact length was much less than expected on Cruises 4 and 5. Since the distance censused on each cruise was not normally distributed, parametric regression methods were not applicable. A Kendall rank correlation between length of contact and level of effort resulted in a negative, though low correlation ($r = -0.7143$, $p = 0.0243$), suggesting that only half of the variability in contact length was explained by level of effort.

In May 1992, the R/V *Gyre* sailed south along *Pelican/Longhorn* track-line 4 and then further south into Mexican waters in the western and west-central Gulf of Mexico. Marine mammals were surveyed using the same acoustic and visual methods as used on *Pelican/Longhorn* cruises. Of the six cetacean visual and acoustic contacts, no sperm whales were detected on that cruise.

Table 4.3. **Matrix of pair-wise comparisons of the lengths of all sperm whale contacts by cruise. The p-value is the two-tailed probability of equaling or exceeding the Mann Whitney U value for each comparison. * indicates significance at $p < 0.055$.**

Cruise #	Season	Cruise 1	Cruise 2	Cruise 3	Cruise 4	Cruise 5	Cruise 6	Cruise 7
Cruise 1	spring	-	p = 0.167	p = 0.464	p = 0.0373*	p = 0.012*	p = 0.881	p = 0.570
Cruise 2	summer	-	-	p = 0.908	p = 0.558	p = 0.371	p = 0.304	p = 0.277
Cruise 3	fall	-	-	-	p = 0.424	p = 0.339	p = 0.405	p = 0.298
Cruise 4	winter	-	-	-	-	p = 0.815	p = 0.055*	p = 0.032*
Cruise 5	spring	-	-	-	-	-	p = 0.008*	p = 0.025*
Cruise 6	summer	-	-	-	-	-	-	p = 0.762
Cruise 7	fall	-	-	-	-	-	-	-

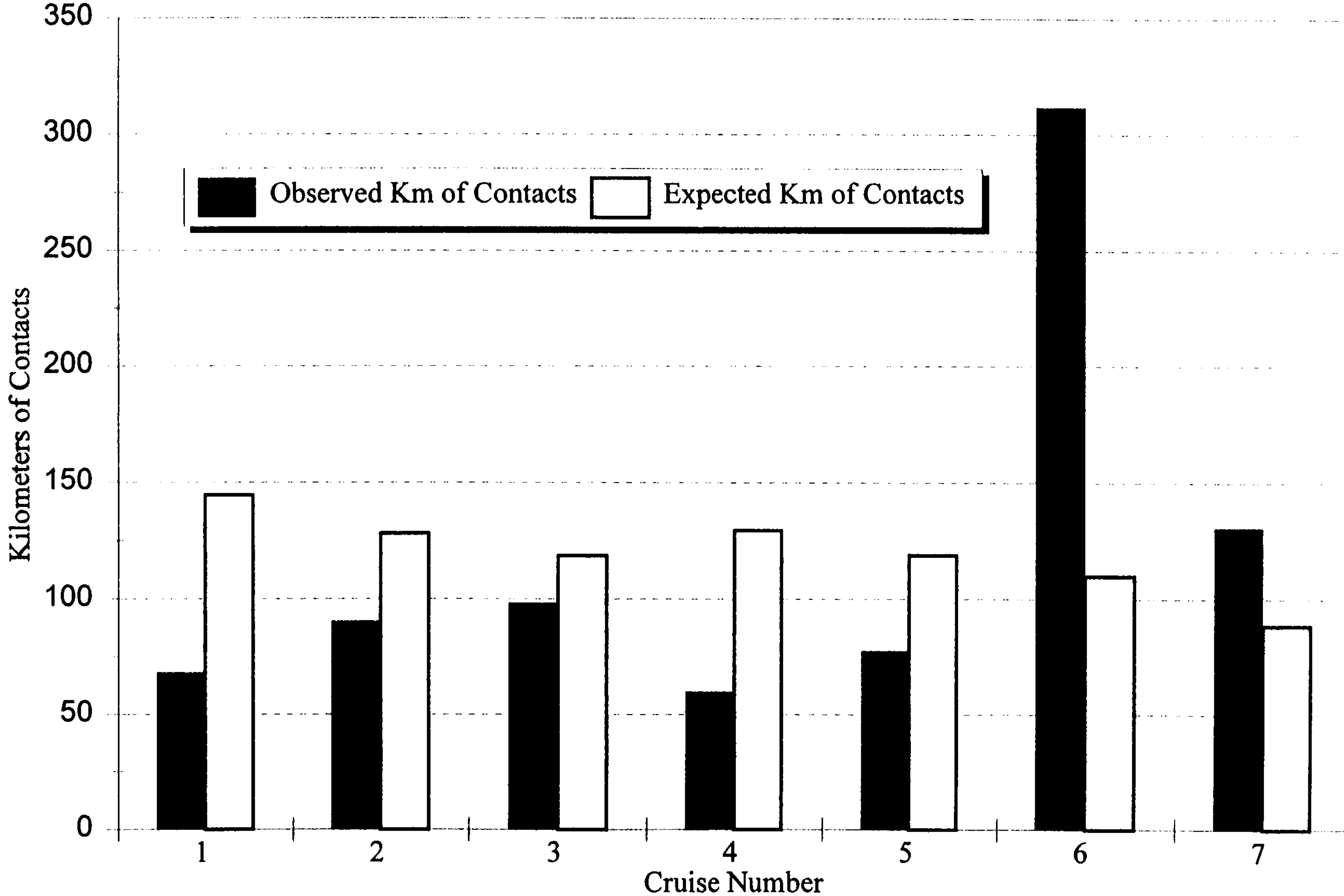

Figure 4.14. **Kilometers of sperm whale contacts for** ***Pelican/Longhorn*** Cruises 1-7.

Analysis By Season

There was no significant seasonal difference between observed and expected number of contacts ($X^2 = 2.106$, $p = 0.5507$, $df = 3$) (Table 4.4). There was no apparent pattern to seasonal changes in sperm whale distribution. Similarly, there was also no apparent change in distribution between cruises during the same season. On many occasions, however, there were contacts on the same track-line during separate cruises. Occasionally, contacts were in virtually the same location during separate cruises:

- Spring cruises: two sets of contacts near the same location on track-lines 12 and 6.
- Summer cruises: three sets of contacts near the same location on track-lines 12, 6, and 5.
- Fall cruises: a single set of contacts near the same location on track-line 11.
- Summer and spring cruises combined: two sets of contacts near the same location on track-lines 12 and 6.

Table 4.4. Number and length of sperm whale contacts by seasons.

Season	Number of contacts	Length of contacts (km)	Effort (km)
Summer	25	402.44	3471.4
Fall	15	229.04	3020.1
Winter	10	59.97	1888.1
Spring	19	146.12	3839.1

There was a significant seasonal difference in the lengths of sperm whales contacts. A comparison of the observed versus expected lengths of contacts indicated there was a highly significant difference ($X^2 = 204.303$, $p < 0.0001$, $df = 3$). A Kruskal-Wallis test indicated a significant seasonal difference between the length of sperm whale contacts ($H = 9.332$, $p = 0.0252$, $n = 69$). Table 4.5 presents a multiple paired comparison between seasons. Conclusions from statistical tests were:

- Spring cruises: The contact lengths for the spring cruises were shorter than expected and significantly different from the summer cruises. The Spring contact lengths were less than the contact lengths noted on the summer cruises.

Table 4.5. **Matrix of pair-wise comparisons of the lengths of all sperm whale contacts by season. The p-value is the two-tailed probability of equaling or exceeding the Mann-Whitney U value for each comparison. * indicates significance at $\alpha = 0.1$.**

Season	Summer	Fall	Winter	Spring
Summer	-	p = 0.944	p = 0.093*	p = 0.093*
Fall	-	-	p = 0.086*	p = 0.140
Winter	-	-	-	p < 0.0001*
Spring	-	-	-	-

- Summer cruises: The contacts lengths were longer than expected, and were significantly different from both winter and fall cruises.
- Fall cruises: The contact lengths were greater than during winter.
- Winter cruise: The contact lengths were shorter than expected and significantly different from both the summer and fall cruises. Winter contact lengths were less than either summer or fall.

These differences indicated that within groups, animals were more widely dispersed in the summer than during other seasons. During the winter and spring, groups were concentrated into smaller areas. During fall, contacts were randomly distributed.

Diel Patterns

There were no significant differences in the number of contacts by time of day (in four-hour intervals), or by track-line ($p > 0.5$, Kruskal-Wallis). In addition, we found no significant differences between observed and expected duration of contacts analyzed at hourly intervals, corrected for effort ($X^2 = 7.46$, $p = 0.589$). The general pattern was for duration of contacts to increase through the day, with peaks at 1000, 1600, 1900, and 2100 hours (Figure 4.15).

Contact duration was examined by using spectral analyses to determine whether there was a cycle to the daily pattern of hours of sperm whale contacts. The spectral analysis suggested a pattern to the contacts at periods of three and six hours. For example, there were long duration contacts at six hour

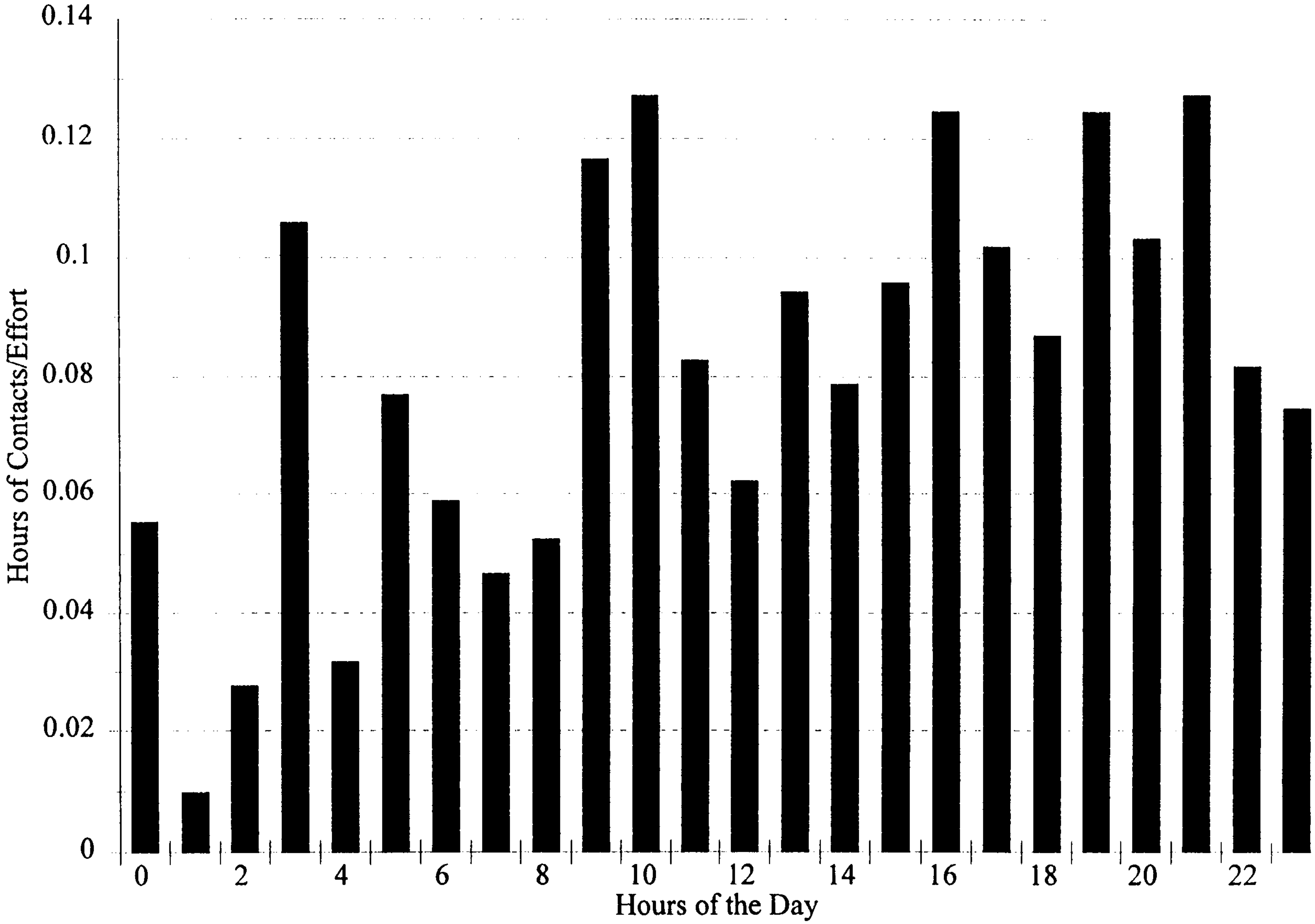

Figure 4.15. The daily pattern of hours of sperm whale contacts per hours of effort.

intervals beginning two hours before sunrise (at 0400 hr) and 0-3 hours after sunset, depending on the time of the year. These peaks in contact duration were followed within three hours by periods of shorter contact duration.

The analysis above pooled all contacts by time of day. A single long contact was spread over the hours in which it occurred. This blurred the difference between a single, long duration contact and multiple, short duration contacts. The pattern of long and short duration contacts became more evident when analyzed by their start time. In this data set, the number of minutes for each contact was allotted to the time in which it began. For example, for a 325 minute contact beginning at 0800 hours, all 325 minutes were allotted to 0800 hr.

The diel pattern of contact duration by start time was highly variable relative to sunrise (Figure 4.16). Sunrise was used as the coordinating point because of light's overriding influence on the vertical migration of organisms that may be important to sperm whales. Two families of squid, both found in sperm whale stomachs, migrate to the surface at night after spending the day at approximately 600 m (Clarke et al. 1993, Martin and Clarke 1986). No contacts started at sunrise, sunrise + 4 hr. (1100 hr), or sunrise + 7 hr (1400 hr). On the other hand, there were more than 500 minutes of contacts which started at sunrise + 1 hr (0800 hr) and sunrise + 12 hr (1900 hr). When effort was factored in, the pattern remains variable (i.e., high effort with no contact initiation at sunrise and low effort but many contacts at sunrise + 1 hr).

A spectral analysis of the contact duration pattern was conducted. The goal of this analysis was to locate diel patterns in the time series of contacts. The spectral analysis suggested several important patterns. There was a major peak at approximately three hours but also a secondary peak at 12 hours. The three-hour pattern may be the result of the short-term behavior of sperm whales, in which animals have a cyclic pattern of deep dives during which they vocalize followed by silent periods at the surface, a pattern repeated every three hours. The longer pattern appears related to the pattern beginning at sunrise + 2 hours and sunrise + 14 hours. Note that this is not the timing of the contact duration maxima at sunrise and sunset, when the longest duration contacts occurred.

Figure 4.17 presents an autocorrelation of sperm whale contact duration by time of day. It shows that the highest positive correlation was at an 11 hour time lag. This corresponded to the pattern of contact maxima at sunrise + 1 hr (0800 hours) and sunrise + 12 hours (1900 hours) (e.g., sunrise and sunset).

Overall, there was a strong diel pattern to sperm whale contacts. In particular, there was a high correlation to their sunrise and sunset behavior as well as an overriding three hour cycle to their behavior. The crepuscular behavior pattern suggested that their behavior was associated with foraging, while the three-hour cycle may be related to the pattern of long dives.

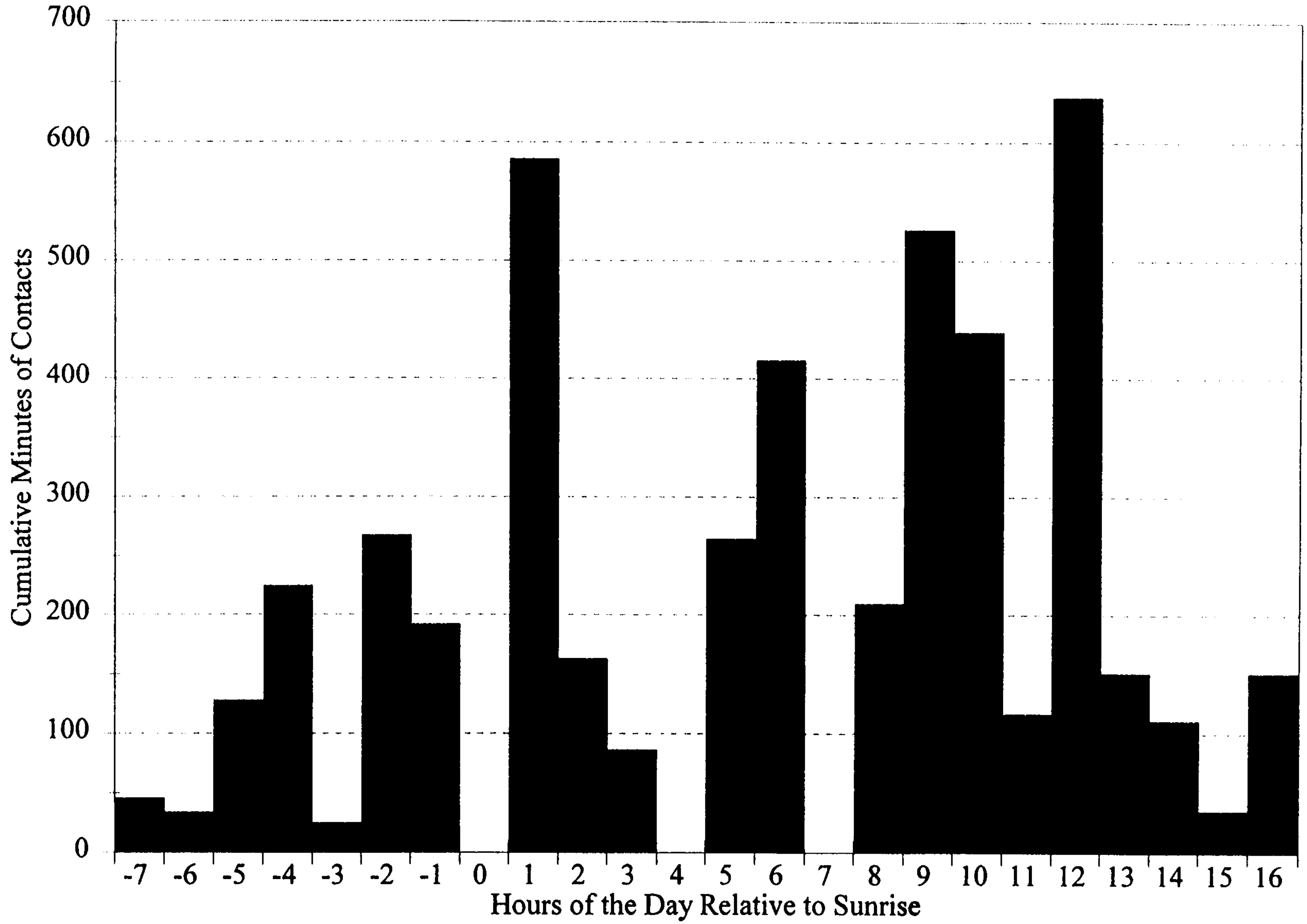

Figure 4.16. Duration of contacts by hour of the day during which they started relative to sunrise.

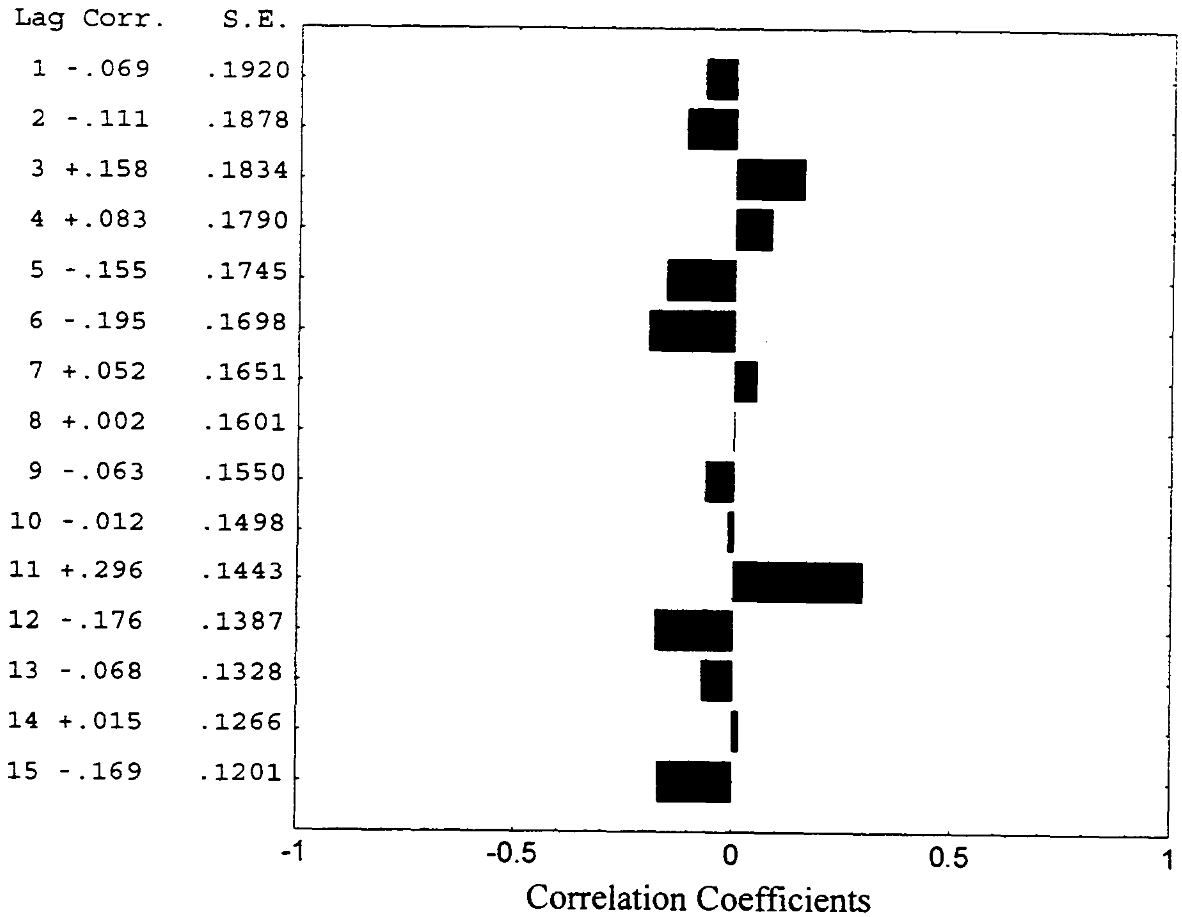

Figure 4.17. Autocorrelation of duration of sperm whale contacts by time of day. The autocorrelation is the correlation of the contact duration time series with itself, shifted successively by 1 hr increments out to 15 hr lags. The correlation coefficient and standard error for each time lag is also provided.

Contacts Relative to Bottom Depth

The GulfCet study area varied in depth from 100-2,000 m. Determining the average water depth of sperm whale contacts required defining the area in which each contact occurred. This was defined as a rectangle 22 km wide by the length of the contact. The depth of that rectangle was randomly sampled 100 times to compute an average depth.

The mean water depth for all contacts was 1,244 m (SD = 413, range: 407-2,011 m). Depth categories were selected to minimize the number of times a contact crossed from one depth category to the next, in order to have sufficient data to permit the chi-squared analysis. The resulting depth categories were 300-710 m, 711-1,190 m, 1,191-1,800 m, and > 1,801 m. The water depth at first contact was then compared among these depth categories. There was a significant difference between observed and expected water depths, corrected for effort (X^2 = 10.243, p = 0.017) (Figure 4.18). In particular, there were many more observed contacts in the 711-1,190 m depth category than expected (24 versus 16.3). These data suggest that the sperm whales observed in the study area preferred intermediate water depths.

An analysis of sperm whale contacts relative to the contour index showed that there was no significant difference between observed versus expected values (X^2= 3.42, p = 0.33, df = 3). Upon further examination of the eastern third of the study area which encompasses the Mississippi River Canyon (track-lines 11-14), there was still no significant difference in the number of sperm contacts (n = 24) across CI categories (X^2 = 2.0, p = 0.53).

The contact water depths were not significantly different between seasons (Kruskal-Wallis, H = 2.406, p = 0.4925, n = 69). There was no significant correlation between water depth and length of contacts (r = - 0.1244, r^2 = 0.0155, p = 0.3084). Less than 2% of the variance in contact length was explained by variance in contact water depth. This showed that there was little relationship between the length of a contact and the water depth in which it occurred. In summary:

- There was no significant difference between water depth at beginning and end of contact.
- The mean water depth for acoustic contacts was 1,244 m.

4.3.3.2 *Distribution of Dolphins and Other Cetaceans*

Dolphins and other small cetaceans were detected on all cruises and on all track-lines (Table 4.1). Combining all dolphin contacts together, including unidentified dolphins, there was a significant difference between observed versus expected numbers of contacts by cruise (X^2 = 44.25, p < 0.0001, df = 6) (Figure 4.19). The significant difference was due to the greater number of observed versus expected contacts on *Pelican* Cruise 5 and fewer observed than expected on *Longhorn* Cruises 1 and *Pelican* Cruise 3.

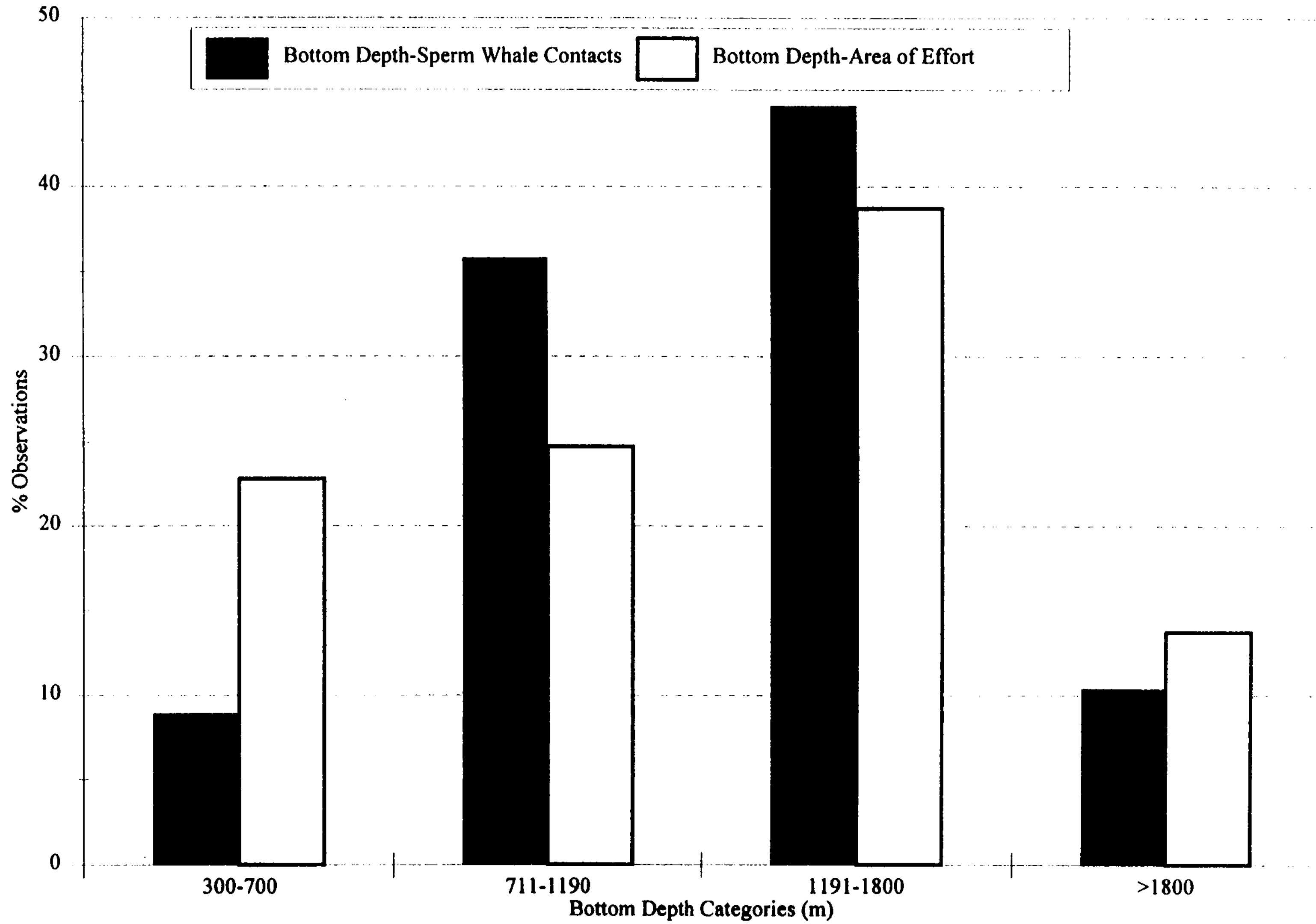

Figure 4.18. Sperm whale contacts divided into four water depth categories and distribution of water depth in the study area. Depths are from the ETOPO-5 dataset (Herring 1993).

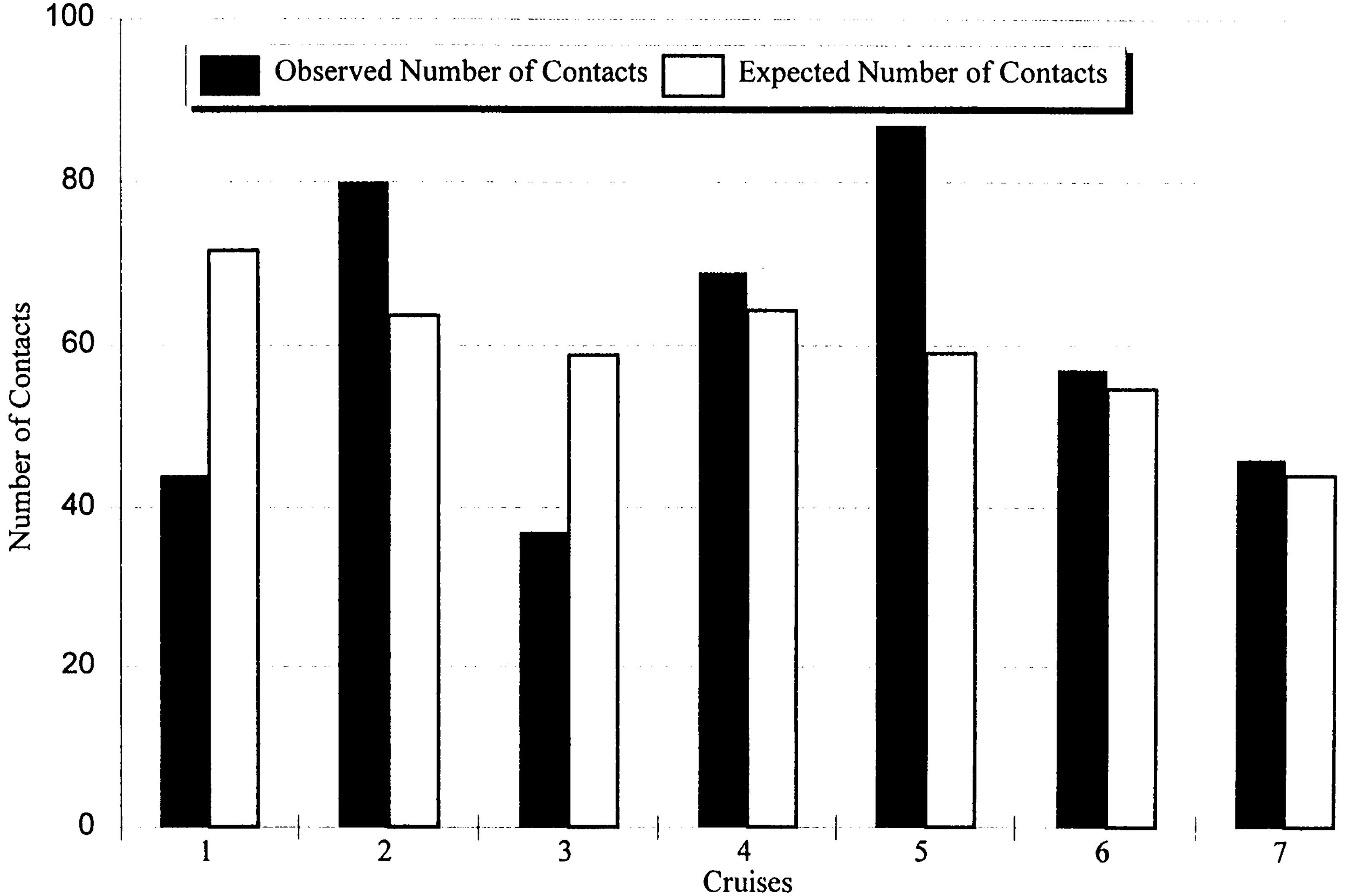

Figure 4.19. Number of acoustic contacts for all species except sperm whales for *Pelican/Longhorn* Cruises 1-7, including expected number of contacts based on effort.

The acoustic contacts were fairly uniformly distributed throughout the study area in waters deeper than 200 m, where 95% (365/385) of all dolphin contacts were made (Figures 4.20 to 4.26). There was a significant difference ($X^2 = 6.842$, $p = 0.0771$) between the observed and expected number of contacts by season (Figure 4.27). This was due to fewer than expected dolphin contacts in the fall and more than expected during the summer cruises.

There was a strong diel pattern to dolphin acoustic contacts. Although acoustic effort was split evenly between day and night, 65% of all dolphin contacts occurred at night and 35% occurred during the day. This suggested that some dolphin species were more active at night.

Four cetacean species were observed during the R/V *Gyre* cruise into Mexican waters, including the spinner dolphin, rough-toothed dolphin, bottlenose dolphin, and the first Gulf of Mexico sighting and tape recording of Fraser's dolphin.

4.3.4 *Dolphin Acoustics*

A total of 191 whistle samples were used in the analysis: 89 from bottlenose dolphins, 20 from clymene dolphins, 48 from pantropical spotted dolphins, and 34 from striped dolphins. Analysis of these whistles, based on frequency and duration, using D^2 canonical correlation tests, significantly separated all four species. The relationship, however, between the clymene dolphin and pantropical spotted dolphin was closer than for the other two species. Since this test is independent of sample size, the results are probably more reliable than the F-statistic which was also significant but is sample size dependent.

All F-values for all pairwise comparisons were significant at $p < 0.0001$ level except for the comparison between clymene dolphins and striped dolphins, for which $p < 0.06$. This indicated that the multivariate mean vectors of the whistles were statistically different between different species. All Mahalanobis D^2 values were relatively large, and all percent correct classification scores (74-89) were relatively higher than the random chance level (50). For the four-way comparison, the F-value was significant at $p < 0.0001$ level and the percent correct classification score (57) was also relatively higher than the random chance level of 25. All frequency and duration comparisons between bottlenose dolphins and the three stenellid species showed significant differences. None of the three comparisons between the three species of stenellids showed great differences. Among stenellid species, there was only one frequency parameter for each pair-wise comparison that showed a significant difference. For clymene dolphin versus pantropical spotted dolphin, it was minimum frequency, while for clymene dolphin versus striped dolphin, it was maximum frequency. For pantropical spotted dolphin versus striped dolphin, it was beginning frequency. There was no significant difference between the whistle durations. The spatial plot of the first two canonical variables, which were computed from the linear combination of quantitative variables entered into the discriminant function, is shown in Figure 4.28. This figure shows that the whistles of the bottlenose dolphins, which are more coastal in their distribution, were significantly

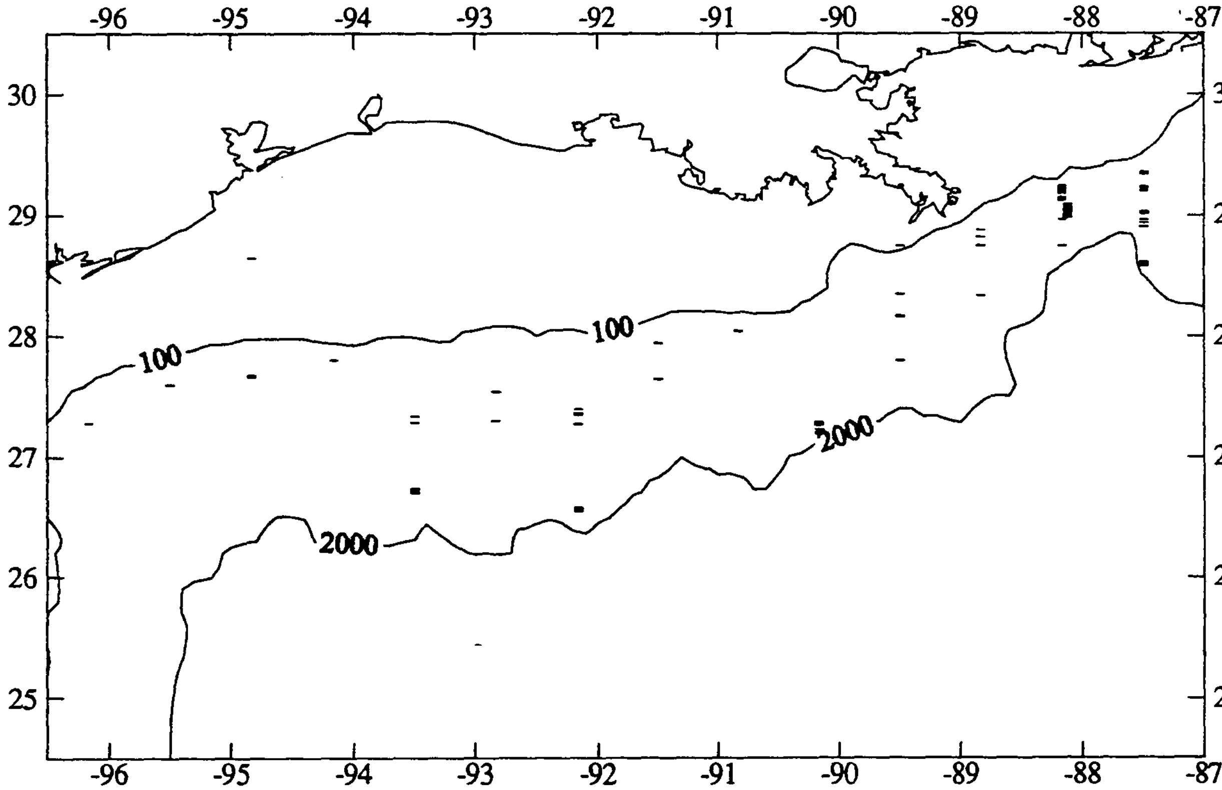

Figure 4.20. *Longhorn* Cruise 1 acoustic contacts, except sperm whales.

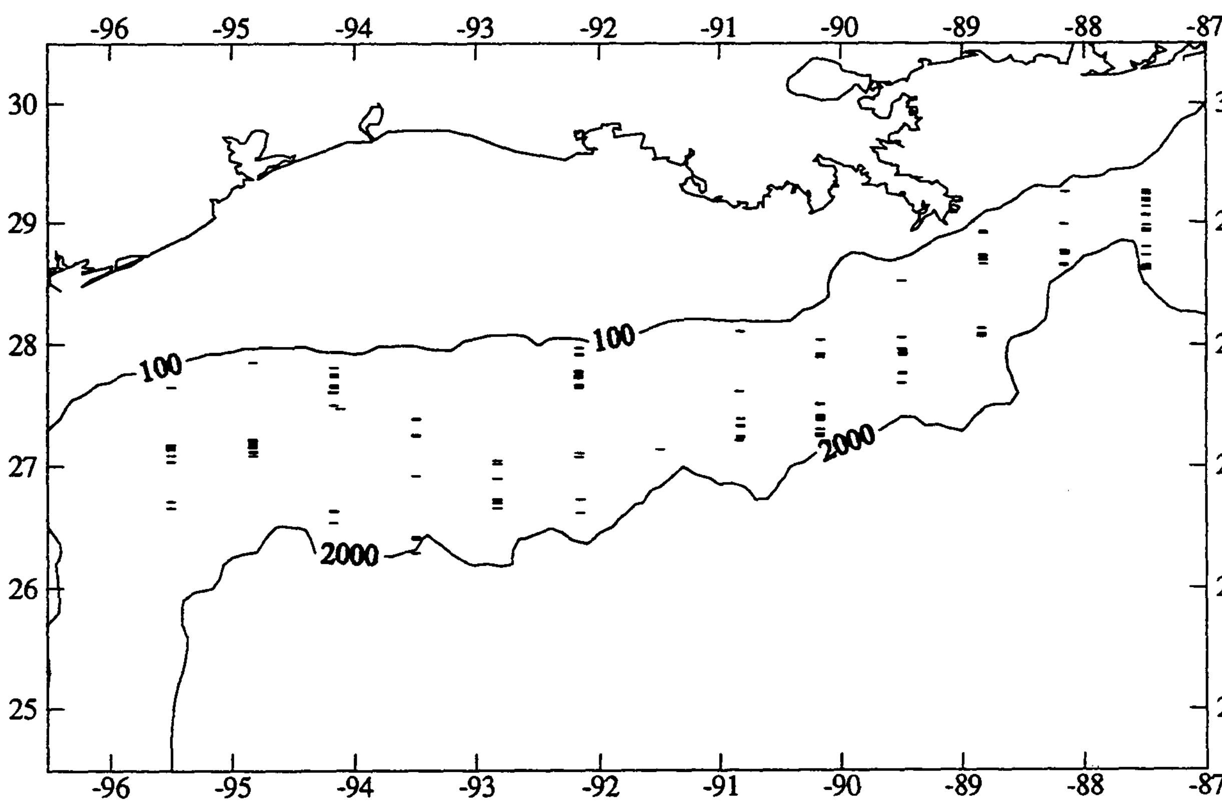

Figure 4.21. *Pelican* Cruise 2 acoustic contacts, except sperm whales.

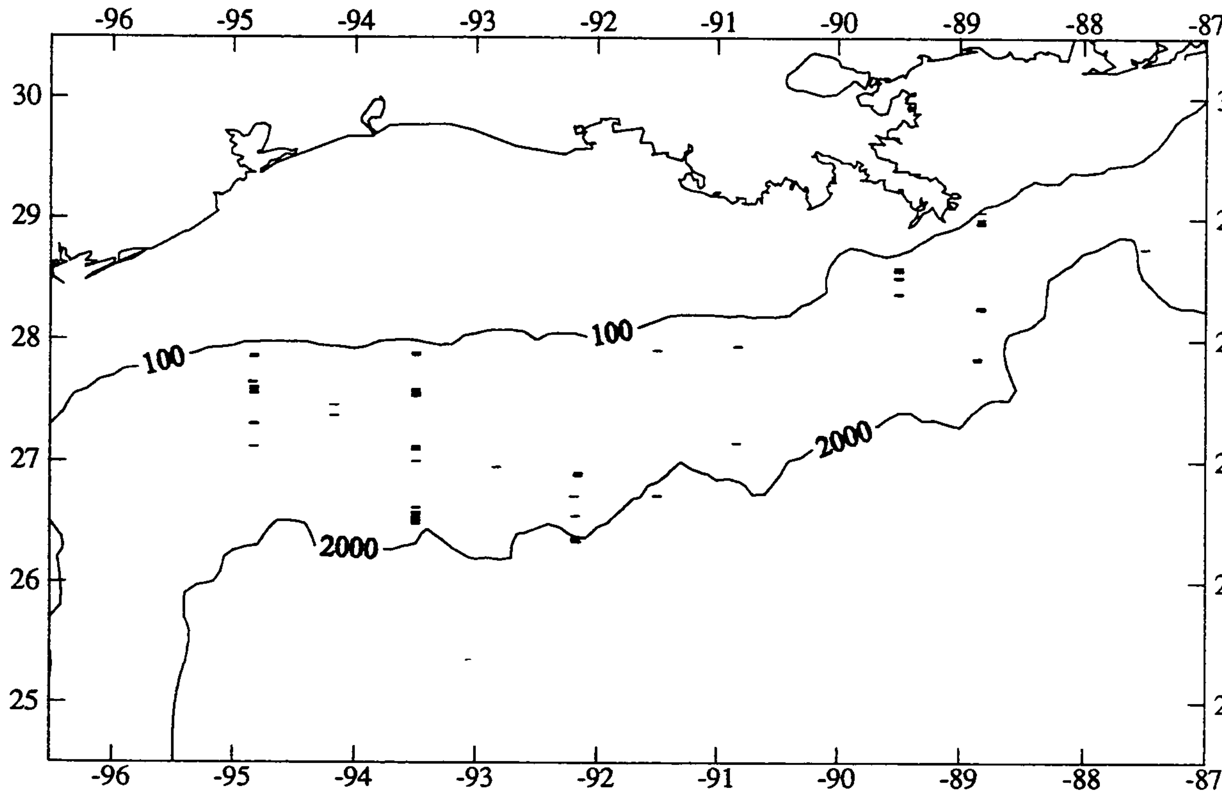

Figure 4.22. *Pelican* Cruise 3 acoustic contacts, except sperm whales.

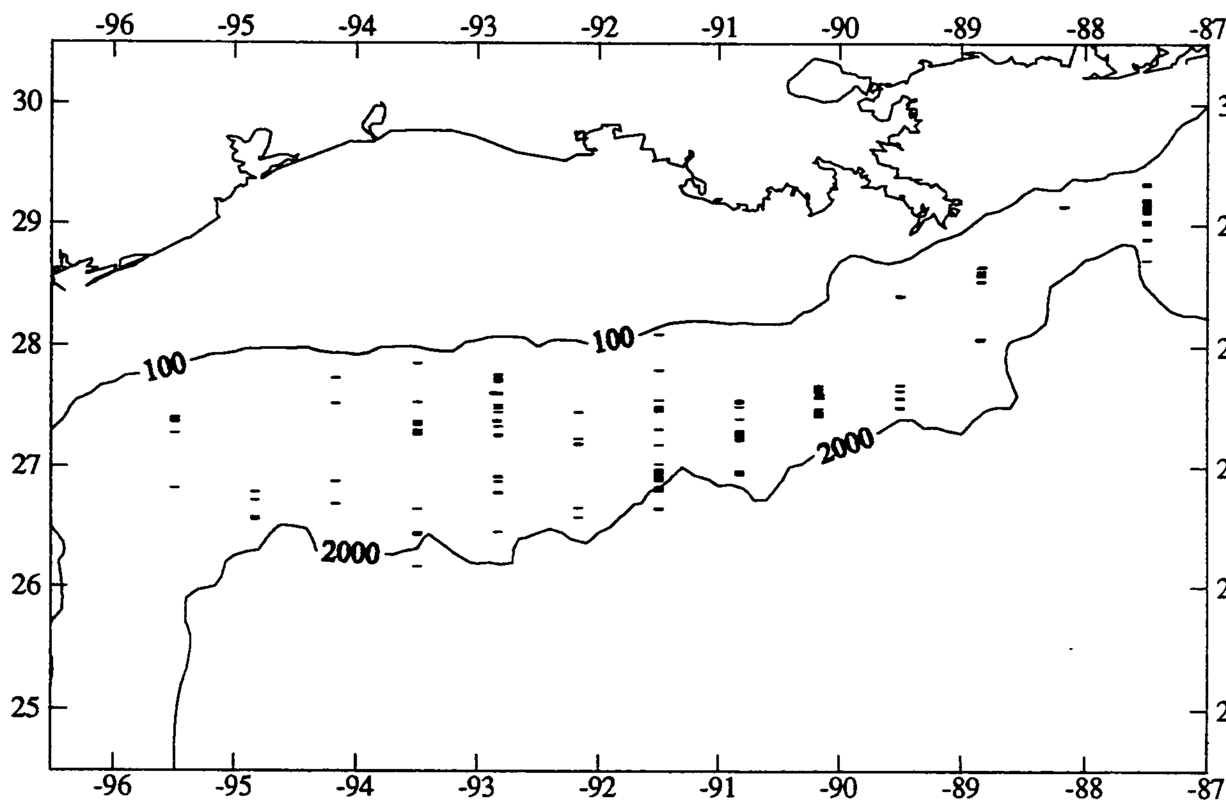

Figure 4.23. *Pelican* Cruise 4 acoustic contacts, except sperm whales.

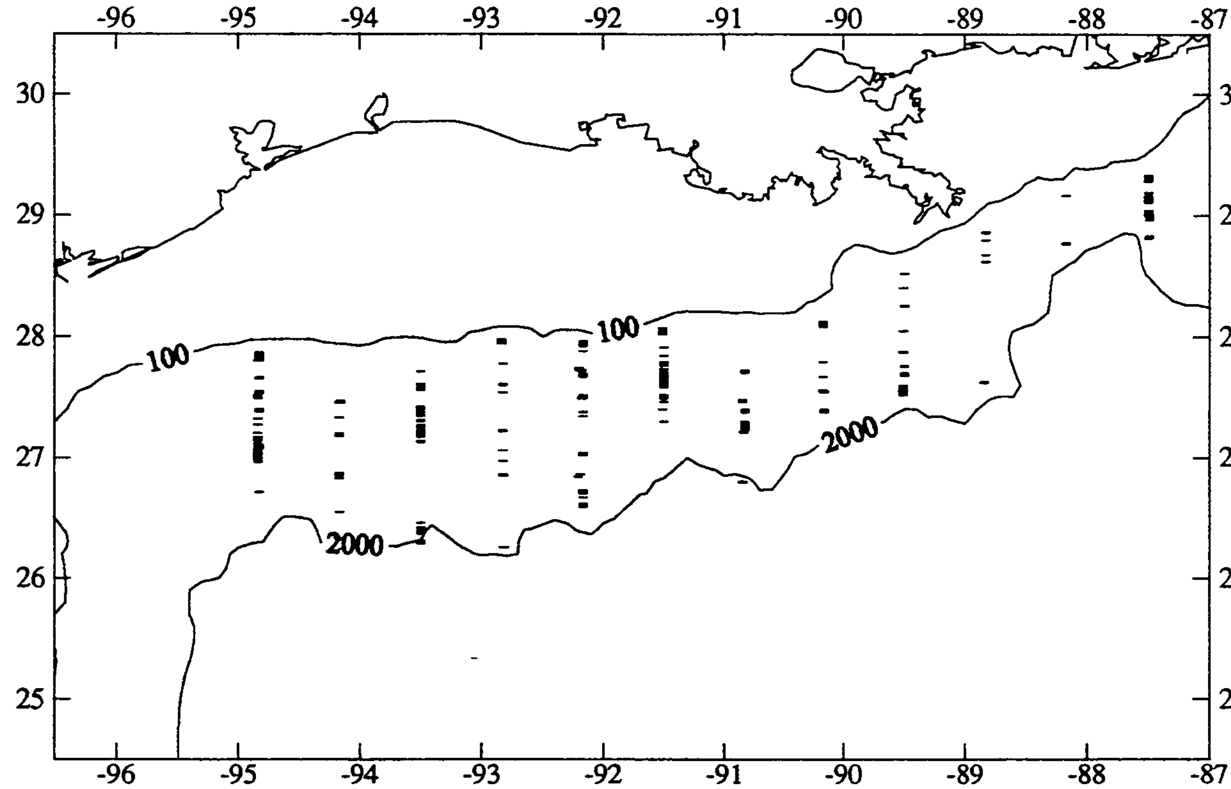

Figure 4.24. *Pelican* Cruise 5 acoustic contacts, except sperm whales.

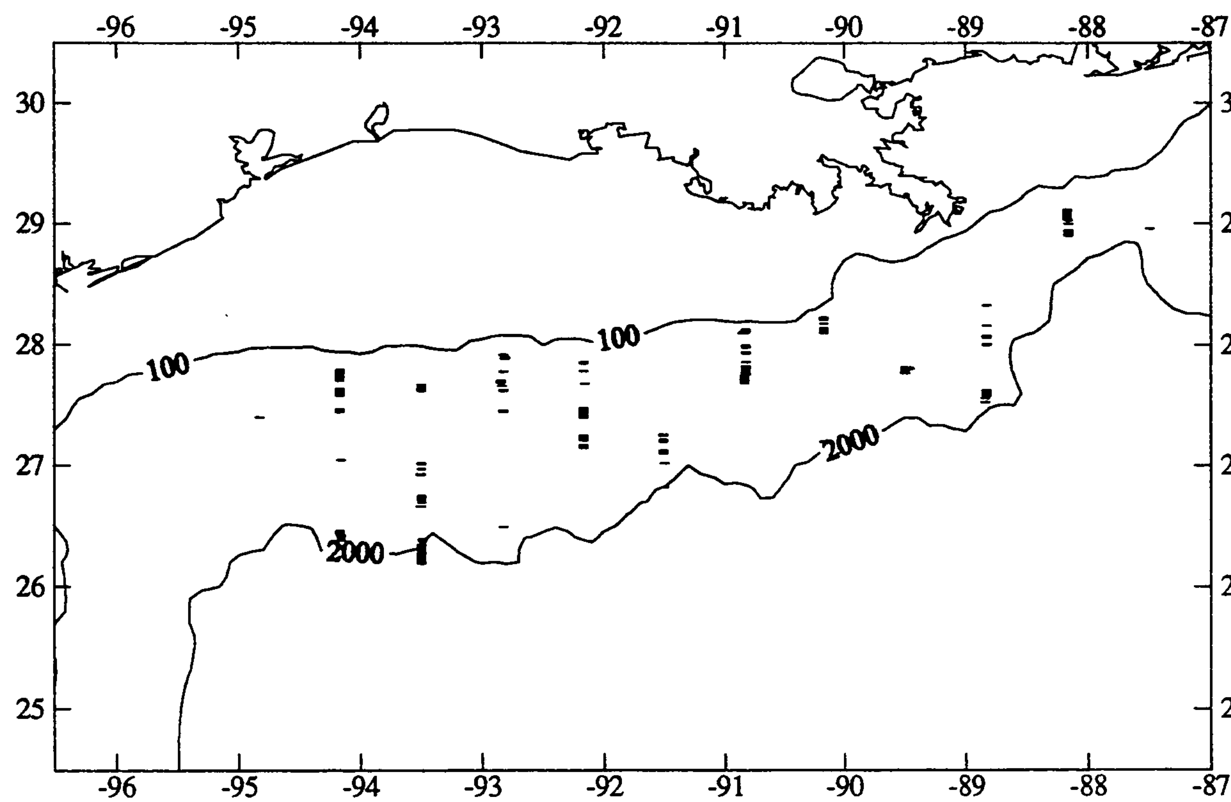

Figure 4.25. *Pelican* Cruise 6 acoustic contacts, except sperm whales.

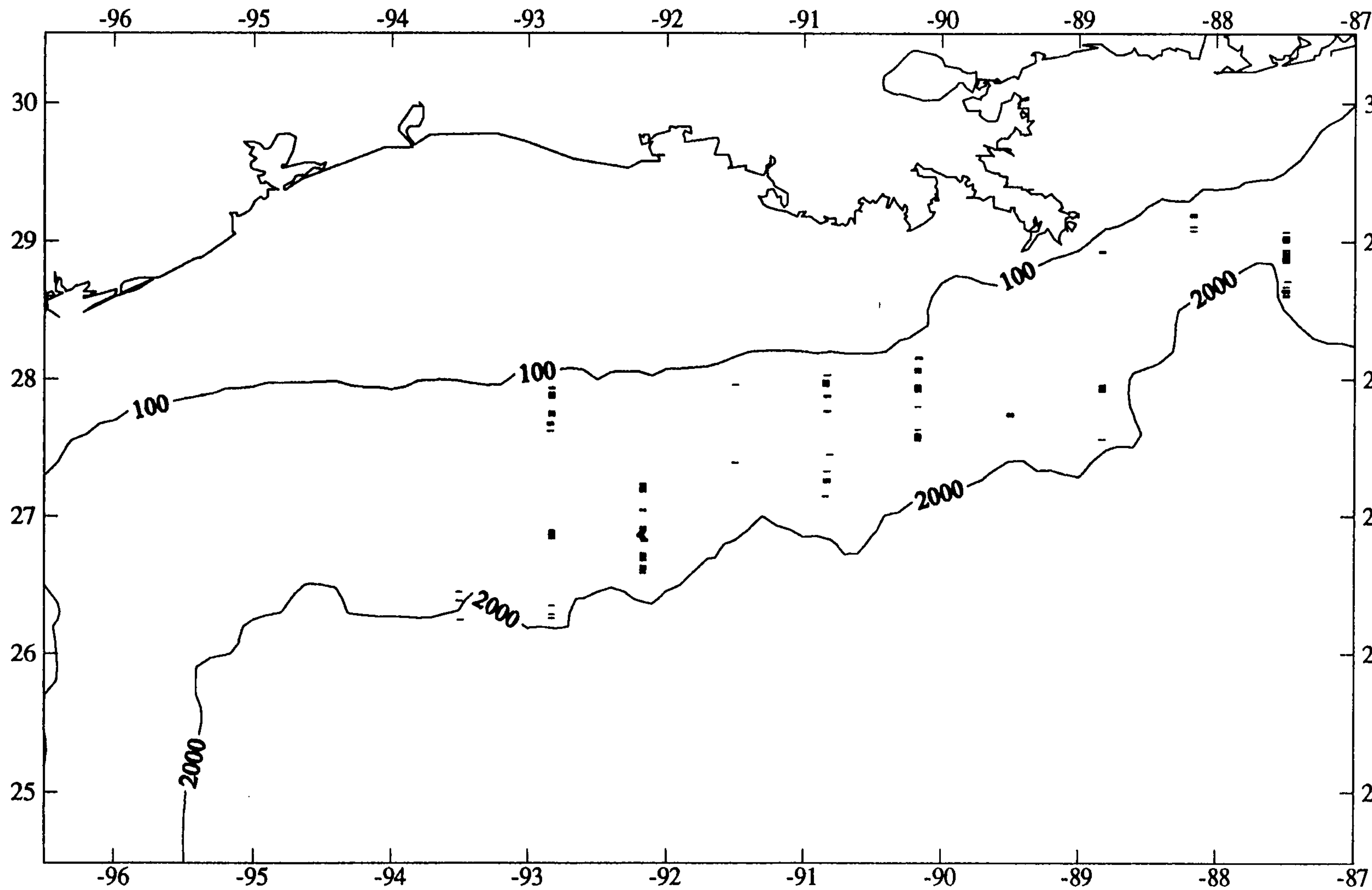

Figure 4.26. *Pelican* Cruise 7 acoustic contacts, except sperm whales.

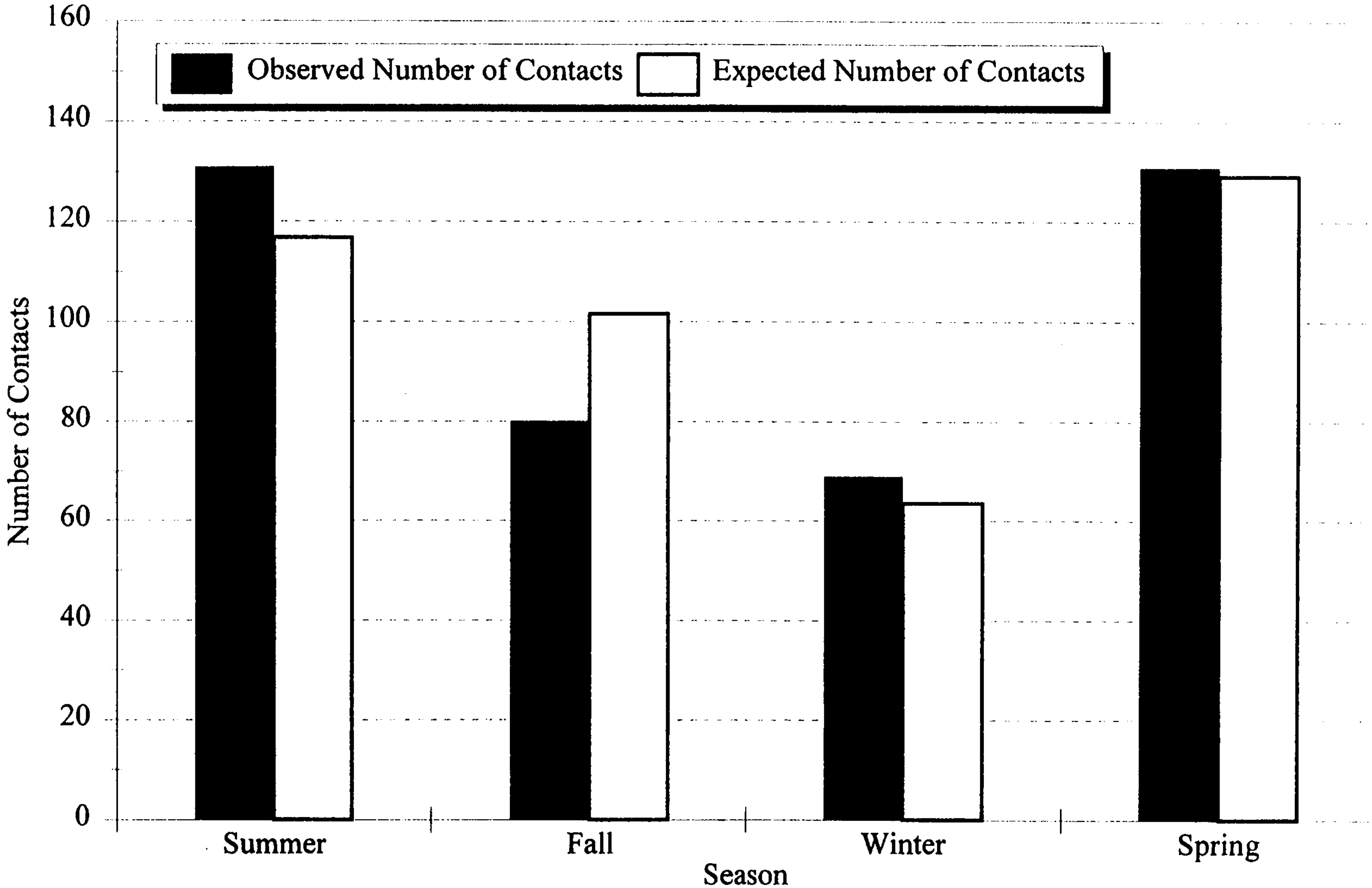

Figure 4.27. Number of acoustic contacts of all cetaceans, except sperm whales, by season.

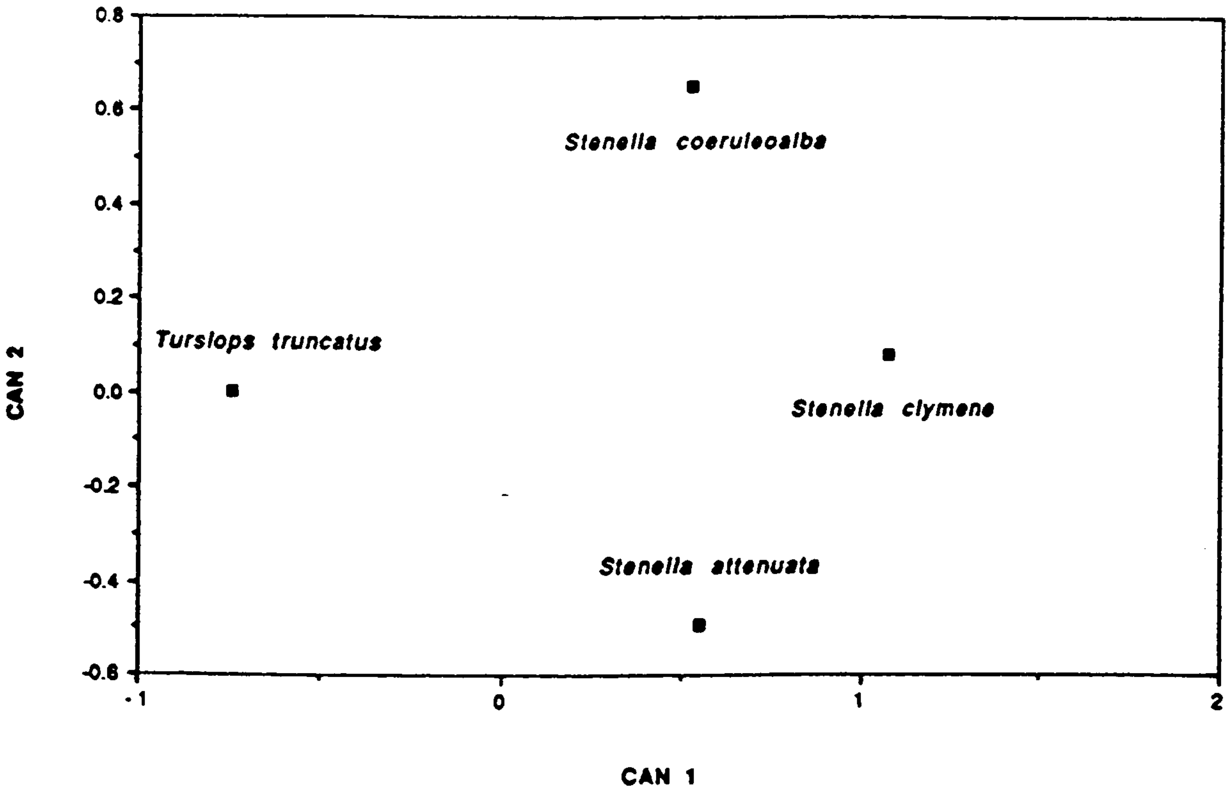

Figure 4.28. Plot of the first two canonical variates as computed from the linear combination of the measured whistle variables for four species.

different from those of the more pelagic stenellids. It would be useful to compare the signals of the more coastal Atlantic spotted dolphins to both bottlenose and the more pelagic stenellid species.

Although based on small sample sizes, it was apparent that these techniques can be used to discriminate pelagic from coastal dolphins. With a larger sample size, it may be possible to discriminate between at least three of the stenellids as well as bottlenose dolphins, pilot whales, false killer whales, and possibly Risso's dolphins.

4.3.5 *Sperm Whale Group Size Estimates*

An examination of the physical spacing of the GulfCet cetacean visual and acoustic contacts illustrated which level of social organization was enumerated. In acoustic censusing, the exact location of detected animals is not known, although sperm whales can acoustically be detected up to 11.1 km away. Any contact within 11.1 km of another was, therefore, summed together as a single contact. The mean length of acoustic contacts was 12.1 km (SD = 0.88, range 0.4-74 km, n = 69), with on average 32.5 km between successive contacts on the same track-line (SD = 2.60 n = 22). Given the length of these contacts, it is likely that the acoustic technique enumerated groups, not clusters.

The visual survey team on the same vessel that towed the hydrophone array made 48 sperm whale sightings (both on- and off-effort). Of those 48 contacts, 43 were concurrent with acoustic contacts. On seven occasions there were multiple visual contacts within the space of a single acoustic contact; that is, on seven occasions the latitudinal extent of a single acoustic contact encompassed multiple visual contacts. The mean group size for the 48 visual sightings was 3.8 animals/visual contact (Table 4.6). For the seven acoustic contacts that had multiple concurrent visual contacts, the mean number of animals per visual contact was 3.9 sperm whales. When the multiple visual contacts within the space of the seven acoustic contacts were summed, the overall mean was 7.3 animals per acoustic contact (n = 7). Alternatively stated, 43 visual sightings averaging 3.9 animals/contact can be reduced to 23 contacts averaging 7.3 animals per contact. Based on this logic, the number of sperm whales in a group is 7.3 animals. Since clusters contain approximately 1.7-3.4 individuals, sperm whale groups in the northern Gulf of Mexico consist of 2-4 clusters, fewer than in other areas of the world.

An examination of the other GulfCet visual data sets using the same 11.1 km clustering distance used with the acoustic data provides a useful comparison of the spatial distribution of sperm whales. An analysis of the *Oregon II* shipboard visual data indicated that on 21 occasions there were multiple visual sightings within 11.1 km of one another. The mean distance between successive contacts on the same track-line was 15.2 km (SD = 1.56, n = 39, range = 0.22-92.7 km). Without using the 11.1 km pooling distance, the mean contact size was 2.12 animals/contact (Table 4.6). Using the 11.1 km pooling distance, the mean group size was 5.16 animals. In other words, 34 visual contacts with an average contact size of 2.12 were reduced to 14 contacts averaging 5.16 animals.

Table 4.6. Summary statistics of number of sperm whales per visual sighting for *Pelican/Longhorn* and *Oregon II* visual teams.

	Pelican/Longhorn			*Oregon II*	
	All visually sighted	Concurrent with acoustic contact	Summed over concurrent acoustic contact	All	Summed
Mean	3.81	3.91	7.3	2.12	5.16
SD	3.18	3.32	5.94	1.18	2.66
Minimum	1	1	1	1	2
Maximum	17	17	22	6	12
n	48	43	23	34	14

For the aerial survey data, there was only one occurrence of multiple sightings within 11.1 km of each other, with two whales in each group. Using the logic employed for pooling the acoustic contacts, the two contacts would have counted as one, with a total of four whales. The mean distance between same line aerial sightings of sperm whales was 57.3 km (SD = 10.22, n = 5, range = 3.4 -105.3 km).

It is apparent from this analysis that the acoustic procedures censused a different level of sperm whale social organization than the visual survey, representing more animals per contact. The acoustic team enumerated groups of whales, whereas the visual team enumerated clusters of whales. Therefore, in the calculation of sperm whale abundance (below), 7.30 animals was used as the sperm whale group size.

4.3.5.1 *Sperm Whale Abundance Estimate*

A total of 67 sperm whale acoustic on-effort contacts was made along 85 track-lines. The mean sperm whale contact density was 2.8 x 10^{-4} contacts/km^2 or 44 groups in the study area. Using 7.3 individuals per group, the overall corrected mean sperm whale density was 2.041 individuals/1,000 km^2 (SD = 2.38, n = 85). The coefficient of variation was 12.6%. The log-normal upper and lower confidence intervals were 1.712 and 2.433 individuals/1,000 km^2. Within the 154,621 km^2 study area, the total estimated population of sperm whales is 316 individuals (log-normal 95% CI = 265-377). For perspective, this means that one sperm whale group should be detected every 161 km.

The five eastern-most track-lines had the highest densities (Figure 4.29). The study area can be split into three sections, a western section containing track lines 2-6, a central region containing lines 7-10, and an eastern region containing lines 11-14. The four regions were significantly different at $\alpha = 0.1$

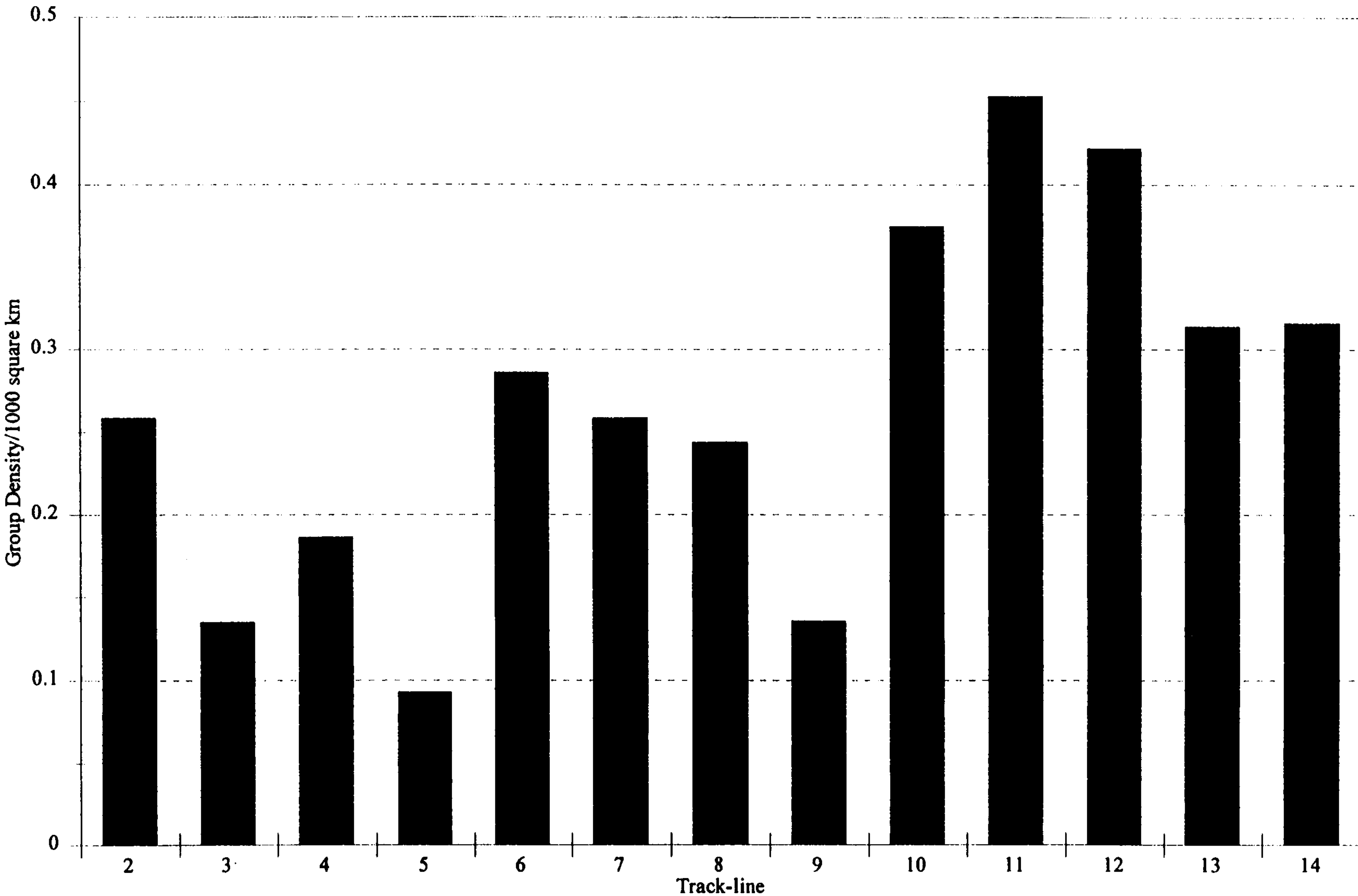

Figure 4.29. Sperm whale group density by track line.

(H = 4.918, p = 0.0855, n = 85). The western region was significantly different from the eastern (Mann-Whitney U test, p = 0.033). Track line 11 had the highest densities and was significantly different from the three legs with the lowest densities, lines, 3, 9, and 5. There were no significant seasonal density differences (H = 2.421, p = 0.4898, n = 85).

4.3.5.2 *Dolphin Abundance Estimate*

A total of 369 dolphin acoustic on-effort contacts were made along the same 85 track-lines used to describe the sperm whale abundance. Using an acoustic detection range of 2 km and same correction factor derived from the sperm whale detection function, the mean dolphin contact density was 8.08 x 10^{-3} contacts/km^2 or 1,298 groups in the entire study area. Using a weighted mean of 28.32 animals/group, the overall mean dolphin density was 2.29 x 10^{-1} animals/km^2 or 229 dolphins/1,000 km^2. Using the same coefficient of variation from the sperm whale estimate (12.6%) the log-normal upper and lower confidence intervals were 273 and 193 dolphins/1,000 km^2. The total estimated dolphin population within the study area was 36,760 animals (log-normal 95% CI = 30,835-43,821). This means that, on average, one dolphin group was detected every 31 km.

The track-line with the highest density (12.9 groups/1,000 km^2) was line 14 (the eastern-most) whereas the track-line with the lowest density (3.2 groups/1,000 km^2) was track-line 2 (the most westerly) (Figure 4.30). Beyond these east-west extremes, there did not appear to be other geographic patterns. If the study area is divided into eastern, central, and western regions, as above, there were no significant regional differences (H = 2.929, p = 0.2313, n = 85). Similarly, there were no seasonal differences (H = 3.369, p = 0.3382, n = 85). Groups density by season was summer (9.0 groups/1,000 km^2), winter (8.5 groups/1,000 km^2), spring (8.35 groups/1,000 km^2), and fall (6.75 groups/1,000 km^2). An examination of the densities by cruise indicated wide interannual variations. *Longhorn* Cruise 1, the first spring cruise, had the second lowest density (5.6 groups/1,000 km^2), while *Pelican* Cruise 5, the second spring cruise, had the highest mean density (11.3 groups/1,000 km^2). In most cases, when comparing the two seasonal cruises, the density for one cruise was approximately half of the other cruise. Even the annual pattern was mixed. For example, with the two spring cruises, the first cruise had the lower density, whereas for the two summer cruises, the first cruise had the higher density. Overall, there appeared to be little discernible seasonal or regional pattern to dolphin densities.

There were no significant correlations between sperm whale and dolphin group densities by either track-line or season. There was a negative correlation between sperm whale and dolphin densities for spring, summer, and winter indicating that during those seasons high dolphin densities were related to low sperm whale densities or vice versa. Only during the fall was there a positive correlation. These patterns were made difficult to interpret by the lack of significant correlations. On average only 10.4% (SD = 8.1%) of the variation in sperm whale densities was explained by variation in dolphin densities.

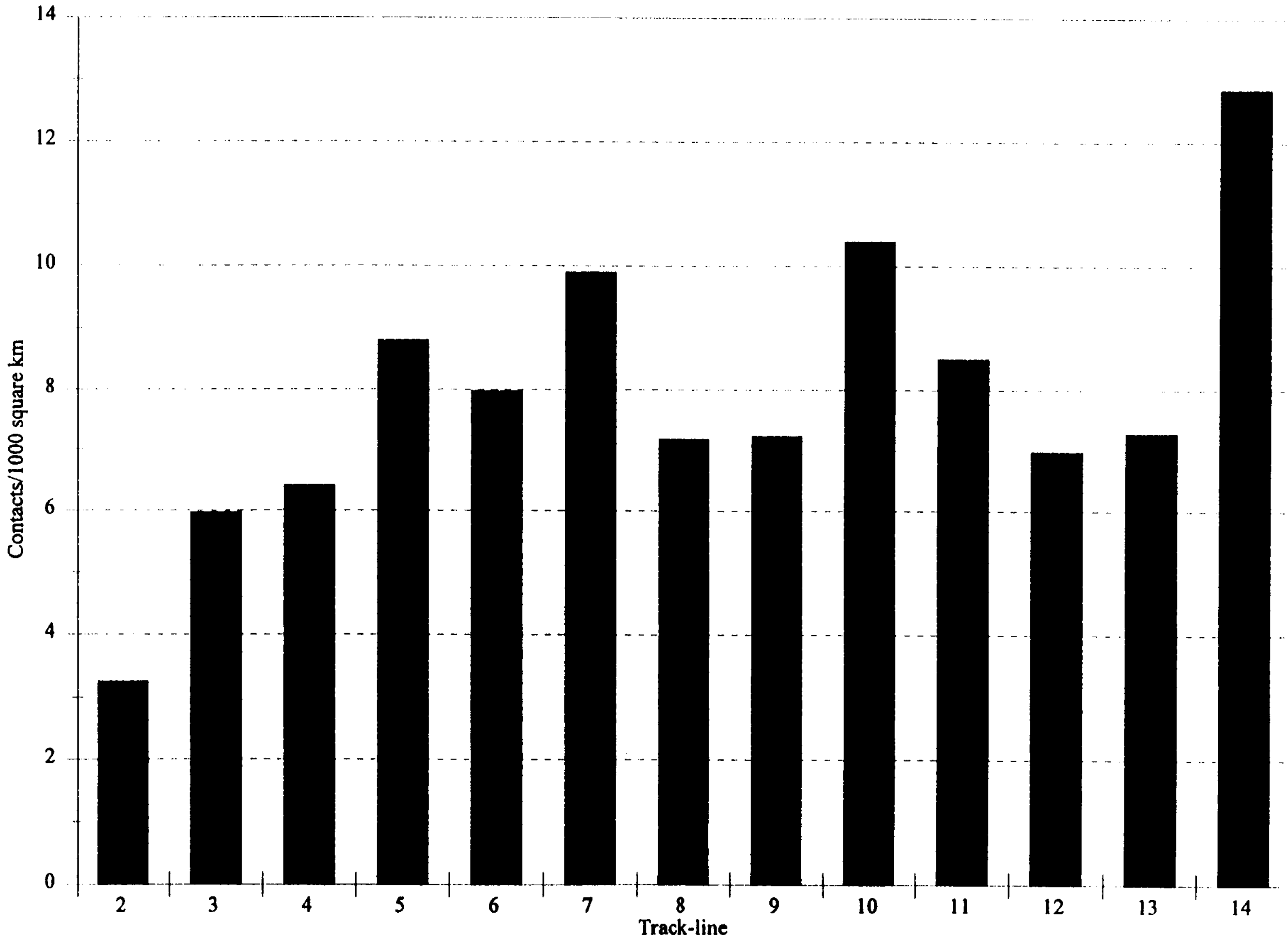

Figure 4.30. Density of dolphin contacts, per 1,000 square km, by track-line.

4.4 Discussion

4.4.1 *Sperm Whale Distribution and Density Estimates*

Sperm whales were consistently located by the acoustic survey in several locations, in particular at specific spots on *Pelican/Longhorn* track-lines 2, 6, 11, and 12. These locations were distributed across the study area. This suggests the possibility of site fidelity in sperm whales (the same individuals consistently located in the same area). Alternatively, there may be large populations in those locales and the animals were simply contacted more often there.

The manner in which sperm whales occupied their habitat, as measured by the dimensions of acoustic contacts, varied by season and cruise. Sperm whale groups occupied larger areas in the later cruises (Cruises 6 and 7) than the first five *Pelican/Longhorn* cruises. They occupied larger areas in the summer than spring. Similarly, contacts during both summer and fall occupied greater areas than during winter. In other words, sperm whale groups appeared to occupy larger areas in the warm weather seasons than during periods with colder weather.

Estimates of sperm whale density were made from three sources, aerial visual, shipboard visual, and shipboard acoustic data (see Chapter 3, Table 3.21). As expected, the aerial estimate was the lowest (1.01 whales/1,000 km^2) because sperm whales occur primarily beyond the 1,000 m isobath. The shipboard visual and shipboard acoustic density estimates were similar (2.02 and 1.96, respectively). The estimates were not significantly different using the criteria of non-overlap of 95% confidence interval. This indicated that the acoustic estimate may be as reliable as the visual estimates, and that there was little, if any, bias in the accuracy of the visual estimates due to lack of detection because of long-duration diving. However, this conclusion assumes accurate determination of sperm whale group size and requires further evaluation regarding the compatibility of the visual and acoustic methods.

The distance between same-track-line sperm whale contacts for the three different techniques provides a measure of similarity. The acoustic method detected sperm whales when they occurred on the same track-line, on average every 12.1 km, which was very similar to the shipboard visual distance of 15.2 km. This is compared to 57.3 km for the aerial method. This suggests that the two shipboard methods are detecting animals at approximately the same rate, whereas the aerial method is detecting animals less often. This, in turn, suggests that slower moving ships may be a more appropriate censusing platform than planes for species that spend appreciable time underwater, such as sperm whales and beaked whales.

4.4.2 *Dolphin Density Estimates*

The acousic survey yielded higher dolphin densities than the shipboard visual and aerial visual surveys. The most meaningful comparison among the techniques was of density of groups, since it avoided calculations of group size. The estimated density of dolphin groups was 8.08 groups/1,000 km^2 for the acoustic survey, 4.39 groups/1,000 km^2 for shipboard visual, and

4.95 groups/1,000 km^2 for aerial visual (see Chapter 3, Table 3.21). The dolphin abundance estimates from the acoustic survey were 1.98 times those of the shipboard visual survey (36,760 and 18,584, respectively). Based on overlap of the 95% confidence intervals, these estimates were not significantly different. The question arises, nevertheless, as to which estimate was the better representation of the true condition. In large part because there was a higher contact rate for the acoustic survey, it appears likely that the acoustic method was encountering more animals than the visual method. Given the similar detection ranges, it is also likely that hearing was a more sensitive detector than vision, perhaps because it was not so sensitively biased by adverse detection conditions. Subjectively, it is easier to detect sounds in a noisy environment than it is to visually detect animals when there is appreciable waves and wind. These differences, however, should not mask the great similarity between the two estimates. Assuming that the distribution of the sperm whales and dolphins was linked to their food resources, the lack of correlation between dolphin and sperm whale densities suggests that the distribution of the two groups were not motivated by the same resources. The most common dolphins is the study area are the various stenellid species. These species were largely piscivorous, whereas sperm whales are largely squid eaters. The data were insufficient to allow correlation sperm whale densities with those delphinids that also feed on squid, such as Risso's dolphins and pilot whales.

4.4.3 *Summary*

Acoustic survey methods are currently not a replacement for the shipboard visual survey methods. They do provide a significant and useful supplement and are a valuable and effective monitoring tool for future surveys. With the increased concern about the potential impacts of man-made noise on marine mammals and especially cetaceans, baseline data on the acoustic environment of various ocean areas including the Gulf of Mexico has taken on added significance. Studies by Ridgway (1983) and others point also to the use of data on vocal patterns of cetaceans as an indicator of individual physiological status and possibly the status of populations. Cetaceans along with many other vocal species do appear to cease or significantly change their vocal behavior in response to stress.

During the GulfCet program, the acoustic survey has demonstrated:

- Sperm whales and baleen whales can be detected and identified.

- Several species of dolphin can be detected and identified based on differences in onset frequency and other signal parameters.

- The ability to conduct acoustic surveys independent of poor weather and lack of daylight significantly increases the level of survey effort (acoustic effort occurred during 95% of the time versus 42% for visual concurrent surveys.

- 65% of dolphin acoustic contacts occurred at night while only 35% occurred during daylight hours, even though effort during daylight and at night was equal.
- The range of detection of cetaceans is significantly greater for acoustic versus visual methods. The acoustic encounter rate was 22% higher than the visual encounter rate.
- Density estimates are comparable to those from the shipboard survey.
- The increased duration of contacts permits a more synoptic view of the distribution providing more information on temporal and spatial changes in cetacean distribution and behavior.

Current disadvantages of acoustic surveys include:

- Inability to estimate group size precisely without extrapolation from visual sightings.
- Identification of acoustic contacts. Currently, several species can be identified by signal characteristics such as frequency, duration, and is labor intensive although much effort is being placed on development of automated signal identification.

This project has demonstrated that visual and acoustic survey methodologies complement each other and can be conducted simultaneously from the same platform. This provides a comprehensive and efficient survey technique that optimizes ship time by increasing percentage of time on-effort. Continued development of hydrophone array technology will permit higher towing speeds and improved signal-to-noise ratio which will increase detection range and contact rate. These array advancements, in conjunction with improved signal recognition methods, may eventually permit acoustic censusing to be a stand alone technology.

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V. BEHAVIOR OF CETACEANS RELATIVE TO SURVEY VESSELS

B. Würsig, S.K. Lynn, and K.D. Mullin

5.1 Introduction

There is great variability in morphology, group size, and behavior of the approximately 20 cetacean species that are commonly found in the north-central and western Gulf of Mexico (Jefferson et al. 1993). The size of these animals ranges from small delphinids of 2.5 meters to sperm whales at over 15 meters in length. Groups may be found containing single to hundreds of individuals, while behavior ranges from those animals that habitually approach boats and even bowride to those that ignore or avoid vessels (Leatherwood and Reeves 1983). Variation in these characteristics can result in differing abilities to detect, identify, and accurately count animals, but descriptive characteristics of detection variables, especially those stemming from different behaviors, have been reported only rarely (Barlow 1995). This chapter investigates the effect of behavior on sightability of cetaceans.

There are often differences in the distances at which cetaceans are first seen, first identified, and at which they are most accurately counted. These differences in detection distance are determined by morphology and behavior, but also by variability in weather (i.e., sighting conditions). For example, sperm whales can often be seen, identified, and counted over one kilometer from the survey vessel, often in rather inclement weather. Beaked whales (ziphiids) and pygmy/dwarf sperm whales (*Kogia* spp.), on the other hand, may or may not be seen at distance, and their often cryptic behavioral nature may preclude identification. A major difficulty in the present study was the inability to consistently deviate from the track-line once a distant marine mammal group was sighted. This restriction, due not only to the multipurpose nature of the survey design but also to ship time (of the Texas Institute of Oceanography part of the surveys) and cost limitations, precluded identification and enumeration of some observed animals, and thus decreased the overall sighting data base.

Most marine mammal surveys have not taken into account variability in morphology and behavior related to sighting conditions. Weather has been considered and animals are usually only counted under certain weather conditions, such as Beaufort sea state 3 or less (Barlow and Lee 1994). However, personal experience (Würsig, Lynn, and Mullin, personal observation) has shown that there are strong differences in initial sightability of smaller cetaceans, even between Beaufort sea states 0-1, and 2-3. A particularly dramatic example confronted GulfCet observers on 23 August 1994 (during TIO Cruise 8), when they experienced Beaufort sea state 0-1 for three hours in the afternoon. During that time, at least five small cetacean groups were seen more than 5 km from the vessel, with some of these groups being probable resightings. Before and after these excellent sighting conditions, when sea state was greater than 2, no small odontocetes were seen in the same area, despite the same vigilance of observation. It seems convincing, although it is difficult to put into a numerical basis, that the change in sea state caused a change in sightability of at least some of these more distant cetaceans.

The present analysis does not attempt to augment discussion of the complex issues of weather-related (as well as observer-related) differences in sightability (see Breese and Tershy 1993). However, the differences in sightability and identifiability of species or species categories as a result of their differing morphology and behavioral reactions are addressed. Observations of responses to survey aircraft provide an understanding of sensitivity to disturbance of different species and species categories.

5.2 Methods

5.2.1 *Shipboard Observations*

Visual surveys for cetaceans were performed from the upper decks of the following vessels: NOAA Ship *Oregon II* (52 m long) where observations were made 10.1 m above sea level; R/V *Longhorn* (32 m) with sightings made at 7.7 m above sea level; and the R/V *Pelican* (32 m) where the sighting platform was 8.9 m above sea level. Details of observation and survey protocol are given in Chapter 3. The equation used to determine the distance to cetaceans from the vessel (based on binocular reticles) is given in Appendix A. Behavioral reactions could not be determined for many sightings, but for those for which adequate behavioral notes were made, categories of avoidance (-), no reaction (0), approach to vessel (+), and bowriding (b) were given. It was often very difficult to categorize potential reaction to disturbance, and the analyses only included clear reactions, for which the authors could unequivocally assign a behavioral response. A (-) assignation was earned when an individual or group moved away from the vessel or appeared to dive in response to the vessel, in either case making it more difficult to identify the animal(s) than with a neutral or positive response. A (0) designation means that the animal(s) showed no apparent response relative to the approach or pass-by of the vessel. This is to be distinguished from the many cases during which it could not be determined whether there was a response; none of these cases are presented. A (+) indicates that the animal(s) approached the vessel during at least some time of their observation, and it is likely that a positive mark would have enhanced identifiability if the animals were seen at distance. However, a (+) response was earned even if the animals were not identified because of their positive response; only their actions were of importance. Finally, a (b) for bowriding is an extreme case of a (+) response; all such animals encountered during regular daylight on-effort watches were identified.

Pooling of some species was accomplished in a manner similar to the criteria and justification for pooling for estimates of abundance, as given in Chapter 3. It was felt that a similar pooling regime should be followed for heuristic comparisons of the estimates as well as this behavioral data base. Briefly, the following cetaceans were pooled into categories: (1) pygmy/dwarf sperm whales and beaked whales; (2) small delphinids; (3) Atlantic spotted dolphins (4) bottlenose dolphins; (5) larger delphinids; and (6) sperm whales. However, separate species or species groups within pooled categories are also discussed, as these relate to differences in morphology, behavior, and hence potential sightability. Due to a presently small data base of behavioral reactions, no formal attempts were made to separate reactions relative to the three observation vessels. The differences among vessels, if they existed, were judged to be much smaller than the differences among species and species categories. Differences in initial sighting distance were analyzed with a Kruskal-Wallis test, followed by Fisher's LSD post hoc.

5.2.2 *Aerial Observations*

As required by Marine Mammal Research Permit Number 738 issued by the NMFS to the Southeast Fisheries Science Center, a subjective assessment of the response of each cetacean group to the survey aircraft was made and recorded. For each cetacean group encountered, four questions were addressed:

- What was the behavior of the group when first sighted?

- Did the survey aircraft approach within 305 m (1,000 feet), straight-line distance, of the group?

- Did the behavior change during the observation period?

- If so, what was the new behavior?

When a cetacean group was encountered, the data recorder would fill out a standardized sighting sheet with lists of these four questions and possible behaviors. The data recorder would prompt the other observers to make behavior determinations and would record the responses. Details of how each question was answered follow.

- What was the behavior of the group when first sighted?

When a group was sighted, the observer started making an assessment of the behavior of the group immediately and continued while the aircraft approached the group. As the aircraft approached the group, the other observer and data recorder would attempt to get into a position to observe the group and participate in determinations of behavior and changes in behavior.

The group behavior was defined as the most frequently displayed behavior of the majority of the animals in a group. Groups were usually circled for the minimum time necessary to make species identification and to estimate the number of animals in the group. This time was usually about 10 minutes but in the extreme case was up to 50 minutes. The time spent circling was dependent on size of the group, how the group was aggregated, and the ease of identification. The observers' ability to make an identification was affected by the species, weather conditions, and behavior of the animals. In some cases, additional time was spent circling in order to take photographs and to teach new observers the distinguishing characteristics of a species. Behaviors were categorized as: resting, feeding, complex social, milling, spyhopping, traveling (north, south, east or west), traveling fast, diving, breaching, and other (described on sighting sheet).

At least one observer in the aircraft, usually two, had in excess of 1,000 hours conducting aerial surveys of cetaceans in the northern Gulf of Mexico and Atlantic Ocean. All the observers had additional experience observing cetaceans during ship surveys. For continuity, the most experienced observer was almost always involved in determinations of behavior.

• Did the survey aircraft approach within 305 m (1,000 feet), straight-line distance, of the group?

The data recorder also determined if the aircraft approached within 305 m of the group. The data recorder recorded the sighting angle or interval of the sighting and monitored the altitude of the aircraft by communicating with the pilots.

Since the survey altitude was 229 m (750 feet), the aircraft was within 305 m if the Perpendicular Sighting Distance (PSD) was less than or equal to 202 m (661 feet) (sighting angle of 41 degrees or less). In some cases, the pilots were asked to increase the altitude while approaching and before circling in an attempt to increase the observation period of species that were known to be cryptic (e.g., pygmy/dwarf sperm whales and beaked whales). In some cases, for photographic purposes or identification, pilots were asked to make several fly-bys at less than 229 m.

• Did the behavior change during the observation period?

If the behavior of the majority of the animals in the group changed and remained changed during the remainder of the observation period, an affirmative answer was recorded. Often, while circling a group, dives occurred at the same time the aircraft passed overhead or closest to the group. This was considered a response to the aircraft. A change in direction of travel was considered a behavioral response.

• What was the new behavior?

The new behavior was assessed in the same manner as the initial behavior.

Data on the reaction of cetaceans to GulfCet aerial surveys provided a second behavioral database, independent of shipboard observations. Frequencies of change in behavior provide an initial evaluation of sensitivities of species and behaviors to disturbance.

5.3 Results

A list of the data presented here can be found in Appendix A.

5.3.1 *Shipboard Observations*

Distance at initial sighting of cetaceans from the survey ships are described for 655 sightings (*Oregon II* and *Pelican/Longhorn* combined) for which cetaceans were identified to species or species category (Figure 5.1). Mean initial sighting distance was 2.3 ± 1.77 km (SD) (n = 655), with mean sightings as close as 1.6 ± 1.50 (SD) km (n=110) for bottlenose dolphins, 1.6 ± 1.33 (SD) km (n=46) for beaked whales, and as far as 4.2 ± 1.46 (SD) km (n=6) for killer whales. Summaries for all species and categories are in Figures 5.2 and 5.3, respectively. Behavioral reactions are in Table 5.1.

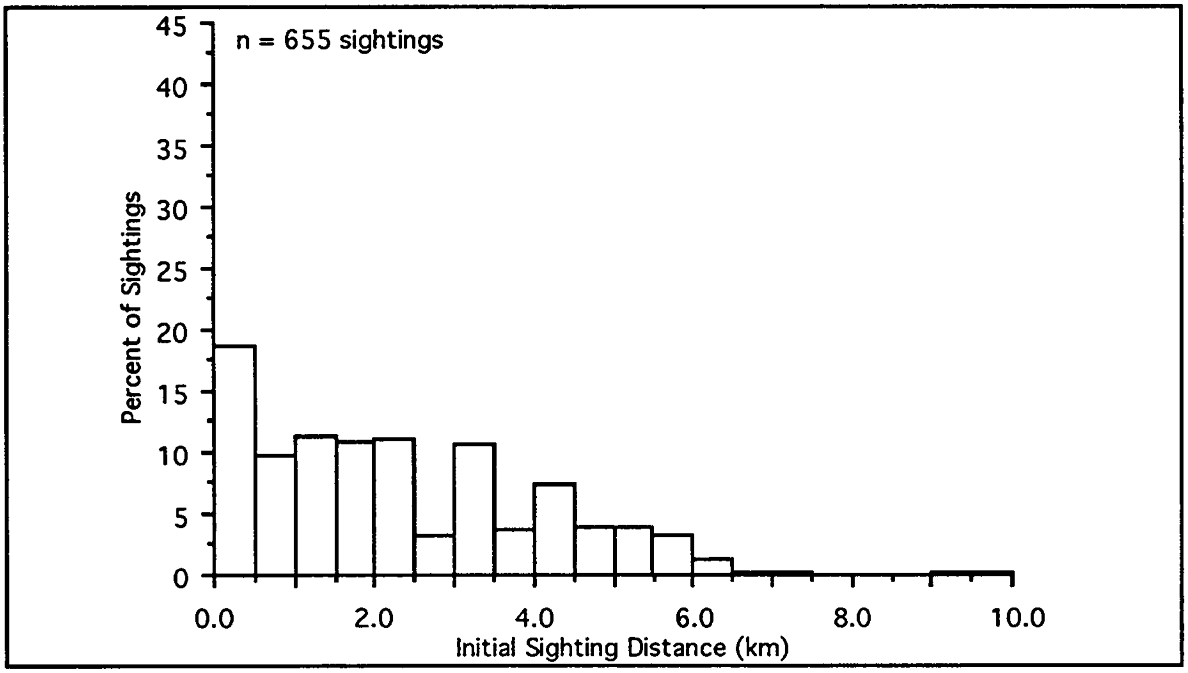

Figure 5.1. Distance from ship of cetaceans when initially sighted.

5.3.1.1 *Category 1: Pygmy/Dwarf Sperm Whales and Beaked Whales*

This pooled category of cetaceans had an initial mean sighting distance of 1.7 ± 1.28 (SD) km (n = 86). Eleven of 15 sightings (73%) involved animals reacting negatively to the vessel by orienting away; in no instance did members of this category appear to react positively to the vessel. None bowrode. The designation of "cryptic" is certainly appropriate, and it is unknown how many pygmy/dwarf sperm whales and beaked whales were unseen, unidentified, and uncounted because of their cryptic nature.

5.3.1.2 *Category 2: Small Delphinids*

This category of delphinids consisted of pantropical spotted dolphins, clymene dolphins, striped dolphins, spinner dolphins, melon-headed whales, rough toothed dolphins, and Fraser's dolphins.

The initial sighting distance of this category was 2.4 ± 1.83 (SD) km (n = 264). With the exception of striped dolphins, all stenellids habitually approached the vessel and rode the bow: 83% of pantropical spotted dolphins (137 of 165 sightings), 100% of spinner dolphins (14 of 14 sightings), and 92% of clymene dolphins (22 of 24 sightings) bowrode. The overall reaction for striped dolphins was different, however, with only 14 of 27 sighted groups (52%) riding the bow. For the entire small delphinid category, nine of the 13 negative (-) reactions to the survey vessel (where the animal oriented away from the vessel or abruptly dove) were exhibited by striped dolphins. Positive reactions (+) combined with bowriding occurred for 90% of Category 2 behaviors.

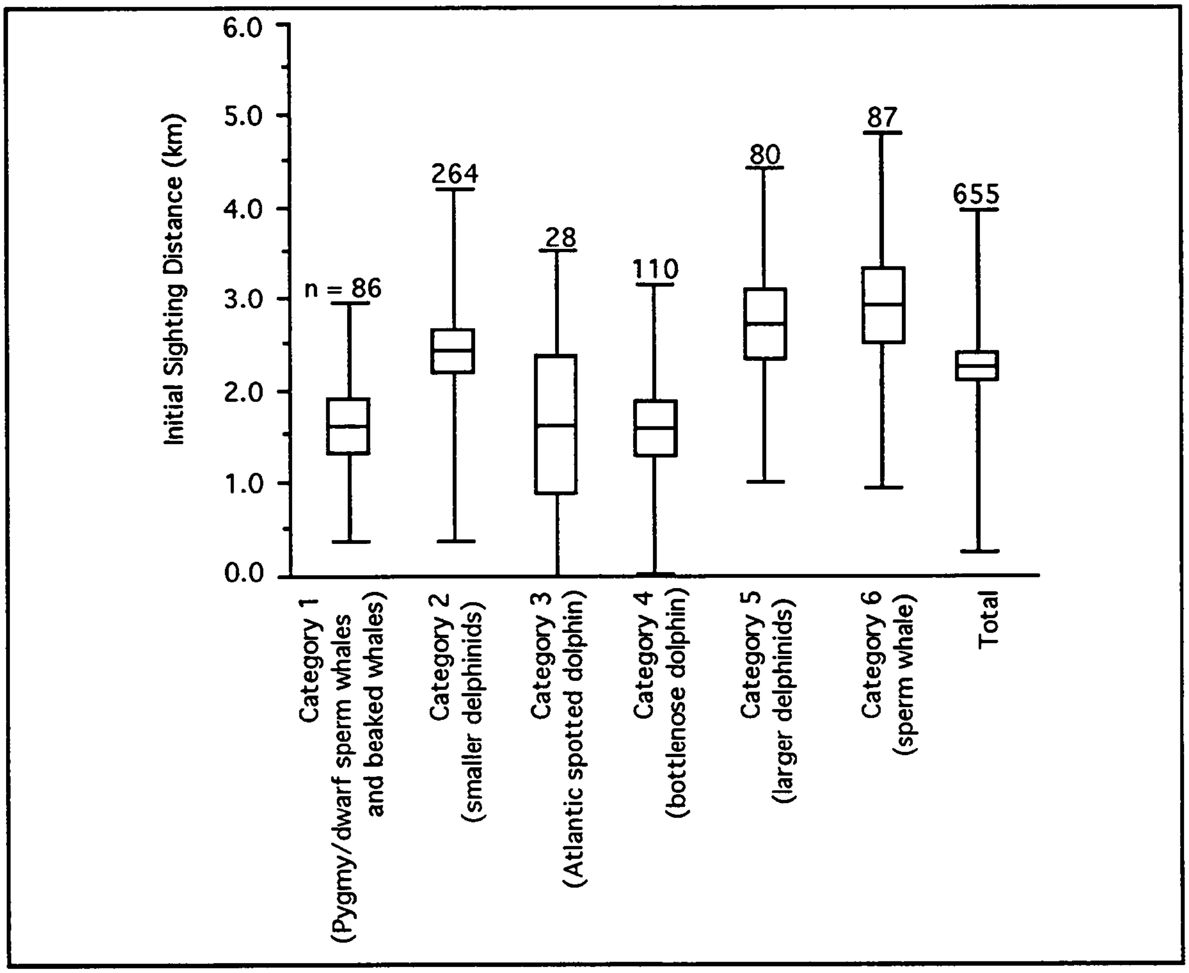

Figure 5.2. Initial sighting distances from ship for species categories. Data are represented with the mean as the central horizontal line, standard deviation as the outer two lines, and 95% confidence interval as the box. Sample sizes are shown at the top of each category.

5.3.1.3 *Categories 3 and 4: Atlantic Spotted Dolphins and Bottlenose Dolphins*

The two species of dolphins that occur over the broad continental shelf of the present study area have similar sighting characteristics and at times school together. They were first seen at 1.6 ± 1.58 (SD) km (n = 138) distance; and, overall, 79% of the members (a similar 77% for bottlenose dolphins and 85% for Atlantic spotted dolphins) of sighted groups came to the ship and rode the bow wave for at least one minute, and at times rode for over one-half hour. Fourteen of 88 behavioral descriptions of bottlenose dolphins and two of 22 of Atlantic spotted dolphins were classed as no (0) reaction, and throughout the study area no reactions were classed as negative. Overall, positive reactions combined with bowriding occurred for 86% of these groups.

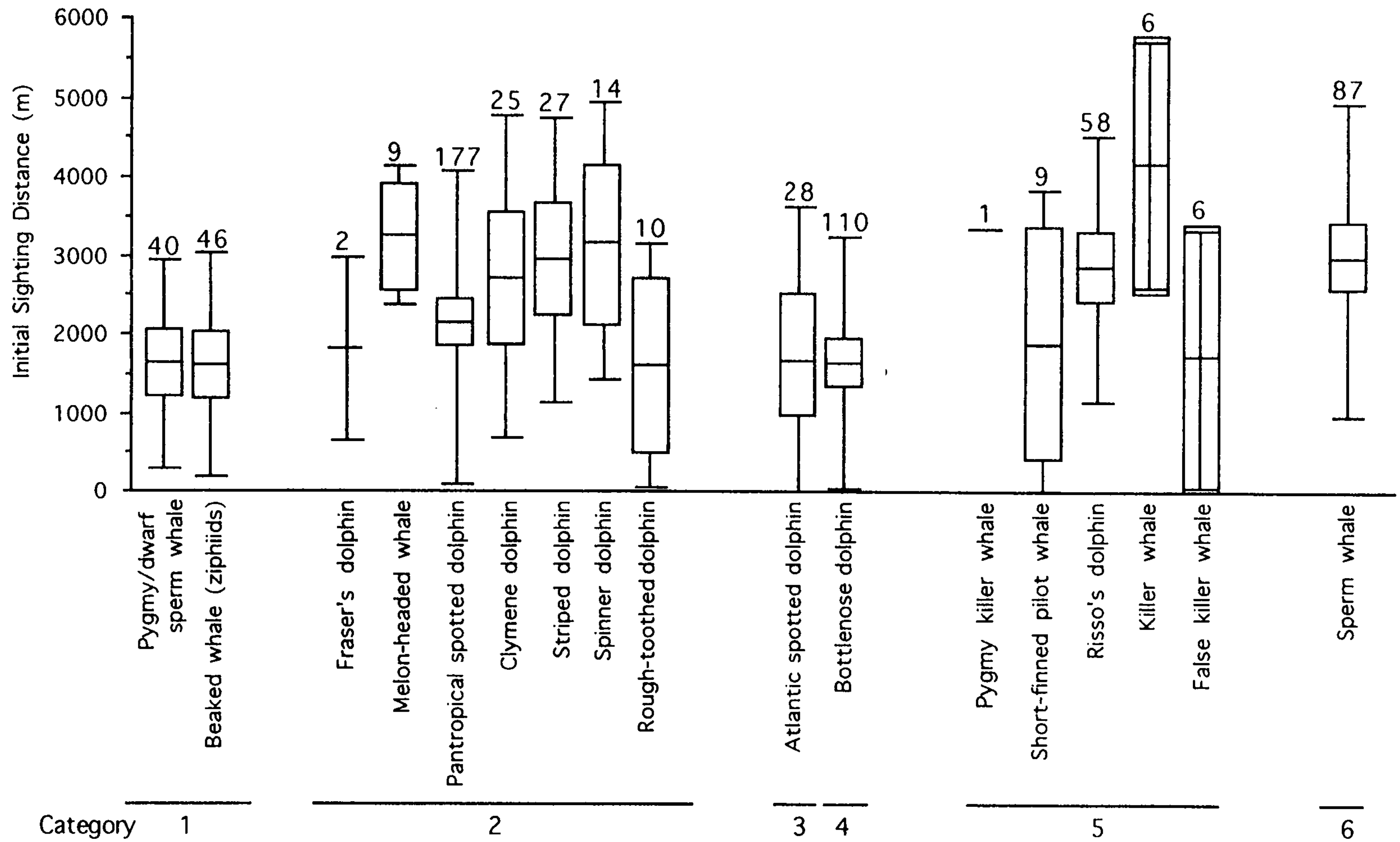

Figure 5.3. Initial sighting distances by individual species and six pooled groups. Data are represented with the mean as the central line, standard deviation as the outer lines, and 95% confidence intervals as boxes. Sample sizes are shown at the top of each species.

Table 5.1. Behavioral reactions* of cetaceans relative to the survey ship.

	Species	Reaction (-)	(0)	(+)	(b)	%(b)	Total
Category 1	Pygmy/dwarf sperm whales	6	1	0	0	0	7
	Beaked whales	5	3	0	0	0	8
	Subtotal	11	4	0	0		15
Category 2 (smaller delphinids)	Fraser's dolphin	1	0	0	1	50%	2
	Melon-headed whale	1	1	2	3	43%	7
	Pantropical spotted dolphin	1	9	18	137	83%	165
	Striped dolphin	9	2	2	14	52%	27
	Spinner dolphin	0	0	0	14	100%	14
	Clymene dolphin	1	0	1	22	92%	24
	Rough-toothed dolphin	0	0	2	6	75%	8
	Subtotal	13	12	25	197		247
Category 3	Atlantic spotted dolphin	0	2	2	22	85%	26
Category 4	Bottlenose dolphin	0	14	6	68	77%	88
	Subtotal	0	16	8	90		114
Category 5 (larger delphinids)	Pygmy killer whale	1	0	0	0		1
	Short-finned pilot whale	1	4	0	1	17%	6
	Risso's dolphin	5	13	7	5	17%	30
	Killer whale	0	2	0	4	67%	6
	False killer whale	0	1	1	3	60%	5
	Subtotal	7	20	8	13		48

* (–) indicates animal orienting away from vessel or abrupt diving.
(0) indicates no reaction.
(+) indicates approach.
(b) indicates bowriding.
%(b) indicates percentage of bowriding per total reactions.

5.3.1.4 *Category 5: Large Delphinids and Small Whales*

This category consisted of short-finned pilot whales, Risso's dolphins, false killer whales, killer whales, and the smallest member of the category, the pygmy killer whale. The mean distance of first sighting was 2.7 ± 1.65 (SD) km (n = 80), with killer whales sighted at greater distance, 4.1 ± 1.46 (SD) km (n = 6), than any other species. Pilot whales and Risso's dolphins exhibited the least attraction to the vessel, with only one of six in the former and 12 of 30 in the latter species moving towards the vessel or bowriding.

5.3.1.5 *Category 6: Sperm Whales*

Sperm whales were sighted at a mean distance of 3.0 ± 1.86 (SD) km (n = 87). Generally, sperm whale reaction was not described in the sighting notes, but the overall impression was that reactions tended to be non-existent for all but approaches to within several hundred meters. Eleven of 15 sightings with behavioral notes were labeled as (0) reaction, none as (+) reaction, and 4 as (-), consisting of the whales diving abruptly in apparent response to the vessel, all within 200 m.

Sperm whales were unlikely to be misidentified even at several kilometers distance, due to their characteristic bushy, single-spouted blow at the very front of the head, and due to their unique head-to-dorsal-hump surface profile. However, sperm whales dive for long times, often greater than one-half hour, and accurate counts of animals as a survey vessel passes through an area are therefore difficult.

5.3.1.6 *General*

Overall, killer whales were initially sighted at the greatest distance from the survey vessels (n = 6, Figure 5.3). This distance was significantly greater than for all other animals ($p < 0.0001$ for all comparisons, Fisher's LSD), except for melon-headed whales. Results for paired comparisons between species are given in Appendix A. The cryptic pygmy/dwarf sperm whales and beaked whales, Category 1, were not sighted at distances significantly different from Atlantic spotted dolphins or bottlenose dolphins categories (categories 3 and 4, respectively, Table 5.2). These three categories were sighted closer to the ship than the small delphinids, large delphinids, and sperm whales (Categories 2, 5, and 6, respectively). There was a significant difference between initial sighting distances of small and large delphinids ($p = 0.005$), but not between the small delphinids and sperm whales ($p = 0.09$), and the large delphinids and sperm whales ($p = 0.41$).

Overall, the pygmy/dwarf sperm whales and beaked whales showed the greatest percentage (73%) of negative (-) reactions, with the large delphinids at 15%, the small delphinids at 6%, and the Atlantic spotted and bottlenose dolphins at 0% each. Risso's dolphins, of the large delphinid category, reacted negatively 17% of the time (five of 30 sightings), and striped dolphins, of the small delphinid category, reacted negatively 33% of the time (nine of 27 sightings). Spinner dolphins, rough-toothed dolphins, bottlenose dolphins,

Table 5.2. Paired comparisons (Fisher's LSD) of initial sighting distances for the 6 species categories. "S" denotes significant comparisons (p ≤ 0.05).

Comparison	Mean difference	Critical difference	p value	
Category 1 vs. Category 2	-724.4	414.6	0.0006	S
Category 1 vs. Category 6	-1,312.5	507.7	<0.0001	S
Category 1 vs. Category 5	-1,096.6	518.6	<0.0001	S
Category 1 vs. Categories 3 & 4	58.1	458.7	0.8036	
Category 2 vs. Category 6	-588.1	412.8	0.0053	S
Category 2 vs. Category 5	-372.2	426.1	0.0868	
Category 2 vs. Categories 3 & 4	782.6	350.7	<0.0001	S
Category 6 vs. Category 5	215.9	517.2	0.4127	
Category 6 vs. Categories 3 & 4	1,370.6	457.1	<0.0001	S
Category 5 vs. Categories 3 & 4	1,154.7	469.2	<0.0001	S

killer whales, and false killer whales never appeared to react negatively towards the vessel. On the other hand, pygmy/dwarf sperm whales, beaked whales, and the pygmy killer whale (with only one sample for it, however) never showed positive reactions, including bowriding.

5.3.2 *Aerial Observations*

Aerial surveys encountered many of the same species as the ship-based surveys. Additionally, aerial observers saw one sei or Bryde's whale. Melon-headed whales and pygmy killer whales were grouped together for aerial surveys, rather than separately, as in the preceding analyses of shipboard observations.

Species which were found to respond to the ship (either positively or negatively) were also found to change behavior in response to the survey aircraft's activities (Figure 5.4, Table 5.3). Pygmy/dwarf sperm whales changed their behavior in response to the survey airplane during 40% of their sightings (and beaked whales during 89%, though with only nine sightings). Several of the smaller delphinids also showed sensitivity to disturbance by the airplane. Pantropical spotted, clymene, striped, and spinner dolphins all were judged to have changed their behavior in response to the airplane during over 40% of their sightings.

As with reactions to the boat, species' reactions to the airplane differed (Table 5.4). Over 85% of the responses of pygmy/dwarf sperm whales and beaked whales, were to dive. Many of the small delphinids dove approximately 50% of the time, or exhibited an undefined "other" behavior. These differences reflect the findings from shipboard observations; pygmy/dwarf sperm whales and beaked whales usually exhibited negative reactions, while small delphinids often come to ride the bow (Table 5.1). From the air, responses of striped dolphins were not distinguishable from those of other stenellids, while toward the boat, striped dolphins displayed negative reactions more frequently than

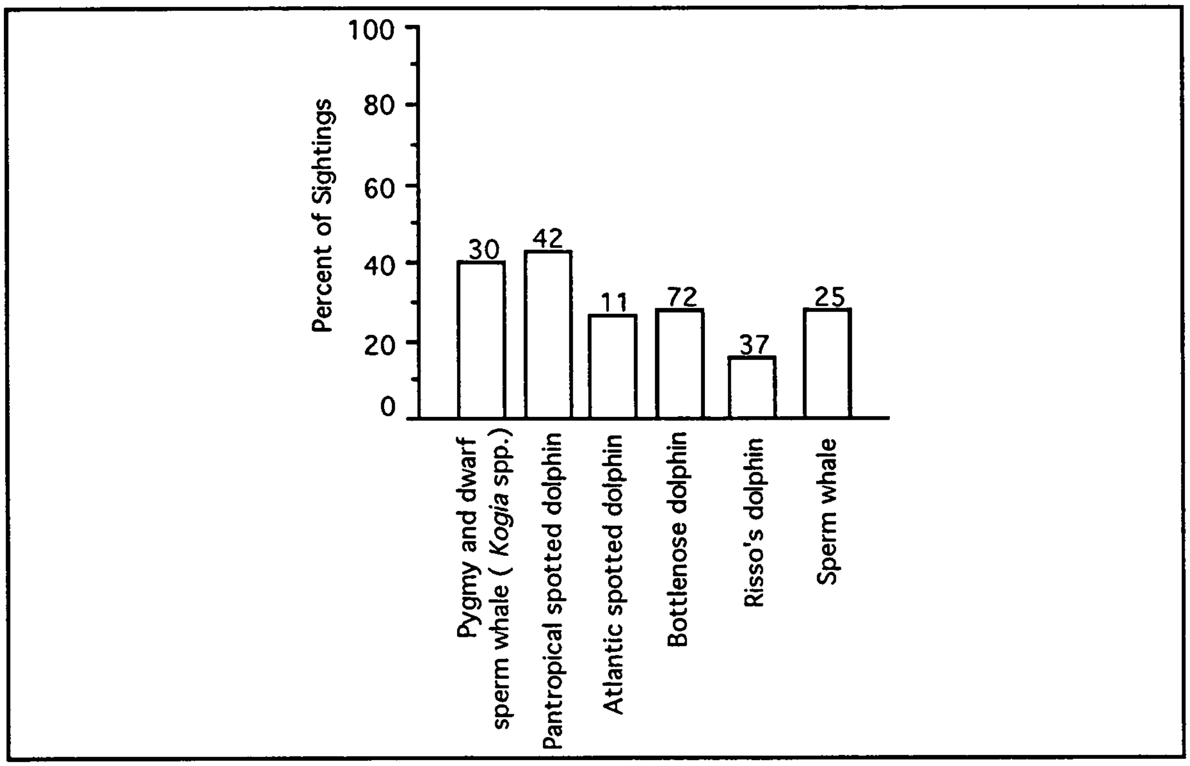

Figure 5.4. Percentage of sightings during which cetaceans (species with ≥ 10 sightings) exhibited a change in behavior relative to aerial surveys. Numbers above columns indicate the total number of sightings for a species.

other small delphinids. While "diving" and "other" were the most common responses by cetaceans to disturbance from the airplane, 33% of bottlenose dolphin responses were to begin traveling or to change direction of travel.

As a generalization (over all cetacean species), the behavioral states "milling" and "resting" appeared to be sensitive to disturbance; over 39% of initial observations of these behavioral states were followed by observations of a new behavior (Table 5.3). Cetaceans changed from these behaviors to new behaviors from 40-100% of the time, except for melon-headed and pygmy killer whales, rough-toothed dolphins, and Risso's dolphins, which never responded while in these behavioral states. Some species were also sensitive to disturbance while traveling.

5.4 Discussion

Sperm whales are easy to sight and identify, and reactions relative to the vessel may be unimportant in estimating abundance. However, a caveat must be made: it is possible that sperm whales that hear an approaching or passing vessel change their dive times. They may remain submerged longer than they

Table 5.3. Sensitivity of cetaceans and initial behaviors to disturbance by survey aircraft. The proportion of times an initial behavior changed to the total number of times that behavior was seen is expressed. The observation frequencies from which these data are derived are given in Appendix A.

	Diving	Feeding	Milling	Resting	Social	Travel	Unknown	Other	Overall
Pygmy/dwarf sperm whale	0.00			0.50		0.00	0.00	1.00	**0.40**
Beaked whale (ziphiids)				1.00		0.50			**0.89**
Fraser's dolphin						0.00			**0.00**
Melon-headed whale and pygmy killer whale*				0.00		0.17	1.00		**0.25**
Pantropical spotted dolphin			0.00	0.00		0.48	0.67	0.00	**0.43**
Clymene dolphin						0.71			**0.71**
Striped dolphin						0.71		1.00	**0.75**
Spinner dolphin						1.00			**1.00**
Rough-toothed dolphin		0.00	0.50	0.00	0.00	0.00	0.00		**0.13**
Atlantic spotted dolphin		0.50		1.00		0.13			**0.27**
Bottlenose dolphin		0.00	0.63	0.57	0.00	0.20	0.25		**0.28**
Short-finned pilot whale			1.00			0.25	0.00		**0.29**
Risso's dolphin			0.00	0.00	0.00	0.19	0.40		**0.16**
False killer whale							0.00		**0.00**
Sperm whale				0.40		0.00	0.50		**0.28**
Sei and Bryde's whale							1.00		**1.00**
Mean (over all cetaceans)	**0.00**	**0.17**	**0.43**	**0.39**	**0.00**	**0.31**	**0.38**	**0.67**	
n	1	3	5	9	3	14	10	3	

* Note: Melon-headed whale and pygmy killer whale sightings were pooled for aerial surveys.

Table 5.4. Responses of cetaceans, grouped by species categories, to the survey aircraft. The number of times a species responded with a particular behavior is expressed as a proportion of its total number of responses.

	Diving	Feeding	Milling	Resting	Social	Travel	Unknown	Other	Total number of responses
Pygmy/dwarf sperm whales	1	0	0	0	0	0	0	0	12
Beaked whales (ziphiids)	0.87	0	0	0	0	0	0.12	0	8
Fraser's dolphin	0	0	0	0	0	0	0	0	0
Melon-headed whale and pygmy killer whales*	0	0	0.50	0	0	0	0.50	0	2
Pantropical spotted dolphin	0.28	0	0.11	0	0	0.11	0	0.50	18
Clymene dolphin	0.40	0	0	0	0	0	0	0.60	5
Striped dolphin	0.50	0	0	0	0	0	0	0.50	6
Spinner dolphin	0.50	0	0	0	0	0	0	0.50	4
Rough-toothed dolphin	0	0	0	0	0	0	1	0	1
Atlantic spotted dolphin	0.33	0	0	0	0	0.33	0.33	0	3
Bottlenose dolphin	0.48	0	0	0	0	0.14	0	0.33	20
Short-finned pilot whale	0	0	0	0	0	0	0	1	2
Risso's dolphin	0.17	0	0	0	0	0.17	0	0.67	6
False killer whale	0	0	0	0	0	0	0	0	0
Sperm whale	0.86	0	0	0	0	0	0	0.14	7
Sei and Bryde's whale	1	0	0	0	0	0	0	0	1
Overall proportion	0.53	0	0.03	0	0	0.07	0.04	0.33	95

* Note: Melon-headed whale and pygmy killer whale sightings were pooled for aerial surveys.

would otherwise or shorten their surface time in response to the vessel. Neither of these possibilities is indicated by present information however. It is assumed that behavioral reactions do not consistently cause over- or undercounts of sperm whales. As a matter of fact, the consistency of density estimates between visual and acoustic surveys (Chapter 10) indicates that overall sperm whale numbers were probably well represented in the study. It is, however, possible that the number of sperm whales within sighting distance is at times undercounted simply because of their normally long submergences, and this surface/dive ratio cannot be assessed without further work.

Bottlenose dolphins and Atlantic spotted dolphins are relatively easy to sight and identify, in large part because of their habit of approaching vessels. The behavior patterns relative to vessels are quite similar for the two species, and population estimates of the two species relative to one another are not likely to be skewed due to behavioral reactions, as long as animals are sighted before they respond to the vessel. However, their proclivity for bow-riding may result in overcounts relative to other less attracted species.

The small delphinids are also rather similar in reaction, except for the striped dolphin and perhaps the lesser seen and known Fraser's dolphins and melon-headed whales. For the striped dolphin, there was a strong indication of avoidance reaction and apparent leaping away from the vessel at distances as far as three kilometers. All nine negative reactions that were observed nevertheless resulted in species identifications, simply because the dolphins were leaping at distance, and therefore allowed their clearly marked flanks to be seen. There are no data on how many times striped dolphins avoided the vessels and were thereby not seen or, if seen, not identified to species category or species. It is probable that striped dolphins are undercounted relative to other stenellids.

A similar problem of potential undercounting may exist for Fraser's dolphins and melon-headed whales, which were only identified two and seven times, respectively. Fraser's dolphins bow-rode one of two times (50%) and melon-headed whales showed positive reactions or bow-rode five of seven times (71%). These data would indicate that positive and other reactions might balance out, but the numbers of identified sightings are simply too small, and the possibility exists that these delphinids are more cryptic than indicated. Further work, including detailed comparisons with aerial surveys, may shed light on this question.

The mid-sized blackfish of the large delphinid category are probably seen with approximately equal frequency with varied reactions to the vessel. They are also large and identifiable enough to be seen and counted from well over one kilometer. The killer whales are probably overcounted relative to others, with killer whales in approximately the same category as the easily seen sperm whales. On the other side of this scale are beaked whales and especially pygmy/dwarf sperm whales. Beaked whales are often not identifiable to species, but at least can be placed into the beaked whale category much of the time. Pygmy/dwarf sperm whales are smaller and generally behaviorally cryptic, and so the assumption can be made that these two species of physeterids are undercounted to a relatively higher but unknown degree.

The noise of the survey vessel, both from the engines and propeller cavitation, alert cetaceans to the vessel's presence (Richardson et al. 1995). Cetaceans that react positively are probably either curious or are gauging the possibility of riding bow or stern waves of the vessel. The forward leaps of spotted dolphins, for example, as they race towards the bow, can be described as a play activity which makes these animals very easy to see indeed. Cetaceans also become habituated to vessels, and much "ignoring" of the survey vessels is probably due to habituation in a propeller-noisy environment such as the northern Gulf of Mexico. It is unclear why some cetaceans, even those not known to have been harassed or killed by humans on any large scale, are habitually or at times evasive. Perhaps the noise of the vessel is disruptive to feeding or resting or other activities.

Distances at which ship noises are heard are variable by ship, weather (sea state and rain) conditions, oceanography, depth of dive of the target species, frequencies of sensitivity, general ambient noise conditions, and the angle at which the species is seen from the bow (Greene 1991, Malme 1991). These variable factors make it very difficult to summarize distances of potential noise influence. However, supply vessels of the approximate sizes of our survey vessels have sound levels in the 20 Hz to 1000 Hz range of about 120 to 150 dB re. 1 μPa at a distance of 0.2 km, and about 105 to as high as 125 dB re. 1 μPa at a distance of 9-10 km while underway (Greene and Moore 1991). The hearing sensitivity of the toothed whales in the present study are well above 100 Hz, with the smaller delphinids doing almost all communicating and echolocating well above 1000 Hz (Au 1993).

Aerial survey data concerning the sensitivity to disturbance support conclusions from the shipboard observations. Cryptic species, such as pygmy/dwarf sperm whales and beaked whales, which were seen resting on most occasions, responded to the airplane a high proportion of the time, and responded by diving over 85% of the time. Less cryptic species, such as the small delphinids, may respond as often, but their response does not necessarily make them harder to identify. Additionally, certain behavioral states, such as resting or milling, appear to be more sensitive to disturbance than others, and this also varies by species.

These data indicate that the sightability and identification of cetaceans may change with the variable behavior of species or species categories. However, behavior is even more variable than summarized in this section, with potential differences by group size, age and sex, time of day, season, weather, and other factors. For example, spinner dolphins of Hawaii are known to be more shy and cryptic while resting in early morning, and more aerially demonstrative in the afternoon (Würsig et al. 1994). Dusky dolphins, *Lagenorhynchus obscurus*, of the southern hemisphere attune their human interactions, including approaches to boats, closely to group size and whether or not they have fed in the previous several hours (Würsig and Würsig 1980). They show marked differences in human interaction responses relative to age and sex, and seasonality. Sperm whales and several species of baleen whales may increase their aerial activity prior to and in the initial stages of a drastic weather change (Würsig and Lynn, personal observation). It is likely that similar differences exist for the cetaceans of the north-central and western

Gulf of Mexico, but our behavioral data base, gleaned literally while transiting past the animals, is at present too meager for more definitive statements.

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VI. OCEANOGRAPHIC SURVEYS

G.S. Fargion, N. May, T.D. Leming, and C. Schroeder

6.1 Introduction

The physical and biological characteristics of the Gulf of Mexico are remarkable in their variability and intensity. Due to these characteristics, oceanographic features may have very important implications for cetacean habitat, possibly affecting cetacean distribution patterns. Therefore, one goal of the GulfCet program was to develop an understanding of mesoscale oceanographic features and their potential effect on the spatial and temporal distribution of cetacean species in the north-central and western Gulf of Mexico.

Recent research indicates that cetaceans may aggregate in areas where upwelling and eddies dominate the circulation (Brown and Winn 1989). This is probably due to the increased primary productivity and subsequent increased density of prey species which characterize these areas. Fresh water influx and its associated higher nutrient concentration can have a similar effect on productivity levels. Further, Biggs (1992) has shown that anticyclonic (warm) eddies in the western Gulf are biologically impoverished, while cyclonic (cold) eddies located peripherally to anticyclonic features have higher nutrient levels and a higher level of primary productivity.

Hydrographic data were collected during 11 shipboard surveys and synoptically by satellite remote sensing. Sea surface temperature satellite images were generated from data collected by NOAA's Advanced Very High Resolution Radiometer (AVHRR) polar orbiting satellites.

6.2 Hydrographic Data Collection and Analysis

6.2.1 *Background*

This section presents an overview of the extensive hydrographic data set collected during the GulfCet program. Its objective is to provide the information needed to understand methods of data acquisition and processing. Pre-analysis corrections or adjustments are identified and discussed.

The variability in certain environmental parameters was used to delineate the mesoscale features in the north-central and western Gulf. Differences in temperature and salinity (T-S) were used to characterize water masses in the Gulf. Gulf Common Water (GCW) and Caribbean Subtropical Underwater (SUW) can both be found within the top 250 m of water depth, while Antarctic Intermediate Water (AAIW) is located deeper, at a depth of 600 to 1,000 m. In addition, temperature and salinity changes were used to detect warm and cold water rings (eddies) as well as fresh water input. Dynamic height, as an indicator of geostrophic flow, was employed to detect general circulation patterns, including eddies. Chlorophyll a concentrations were used as an indicator of primary productivity. Standard hydrographic techniques were used to measure these parameters.

Table 6.1. TIO and SEFSC hydrographic cruise chronology.

Date	Hydrographic Survey	Date	Hydrographic Survey
15 April- 1 May 1992	TIO Spring Cruise 1 R/V *Longhorn*	3 May- 15 June 1993	SEFSC Spring Cruise 204 NOAA Ship *Oregon II*
17 April- 8 June 1992	SEFSC Spring Cruise 199 NOAA Ship *Oregon II*	23 May- 5 June 1993	TIO Spring Cruise 5 R/V *Pelican*
10 August- 24 August 1992	TIO Summer Cruise 2 R/V *Pelican*	28 August- 5 September 1993	TIO Summer Cruise 6 R/V *Pelican*
8 November- 22 November 1992	TIO Fall Cruise 3 R/V *Pelican*	3 December- 14 December 1993	TIO Fall Cruise 7 R/V *Pelican*
5 January- 13 February 1993	SEFSC Winter Cruise 203 NOAA Ship *Oregon II*	15 April- 10 June 1994	SEFSC Spring Cruise 209 NOAA Ship *Oregon II*
12 February- 27 February 1993	TIO Winter Cruise 4 R/V *Pelican*		

Hydrographic data collected during GulfCet cruises have being submitted to the National Oceanographic Data Center (NODC) and are available to the public from that source. Table 6.1 details the chronology of shipboard hydrographic surveys completed for the GulfCet program.

6.2.2 *Transect and Cruise Design*

Shipboard hydrographic data were collected using two distinct cruise track designs, each of which is described in detail in section 3.2.1.1 of this report. Four SEFSC *Oregon II* surveys were completed in the spring and winter and sampled the entire northern Gulf (Figures 6.1-6.3). The *Oregon II* cetacean surveys occurred simultaneously with an ichthyoplankton survey and were divided into three legs. Hydrographic stations were located every 30-40 minutes of latitude or longitude along the cruise track.

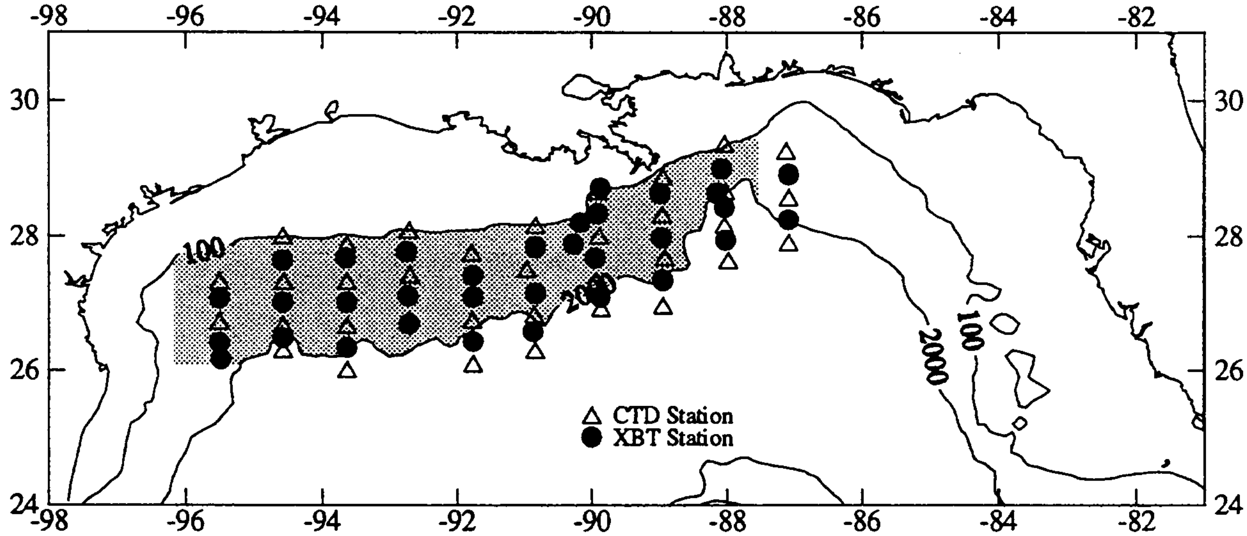

Figure 6.1. Representative *Oregon II* hydrographic survey station plan for leg 1.

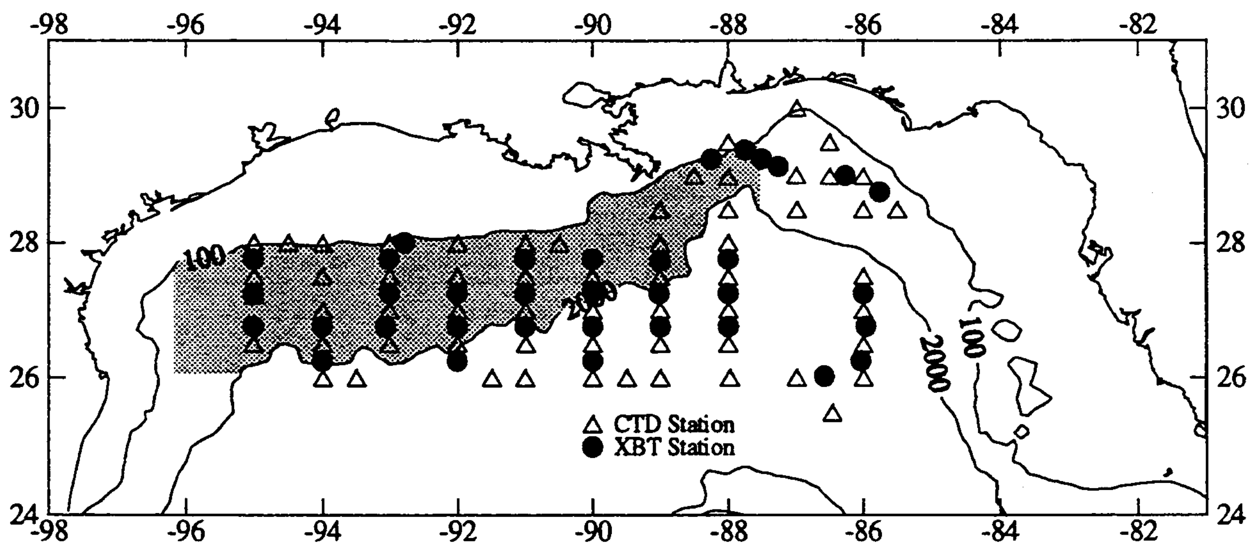

Figure 6.2. Representative *Oregon II* hydrographic survey station plan for leg 2.

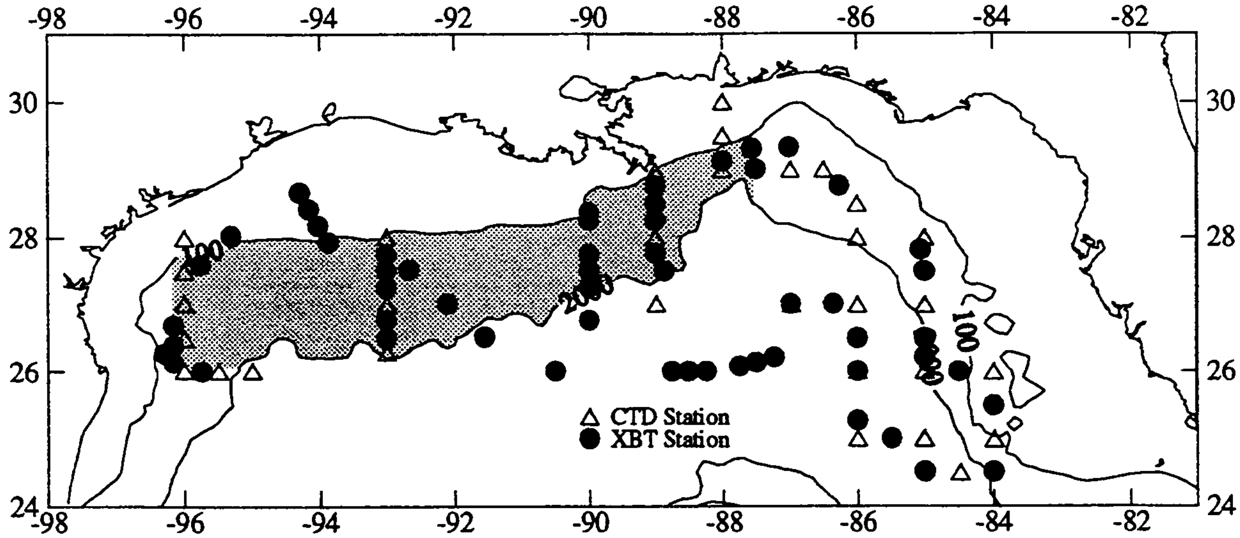

Figure 6.3. Representative *Oregon II* hydrographic survey station plan for leg 3.

Conductivity-Temperature-Depth (CTD) hydrocasts were conducted at every other ichthyoplankton station at night, with three casts made during daylight hours (dawn, midday, and sunset). CTD hydrocasts ordinarily were lowered to a maximum depth of 200 m, but were deepened to 500 m for the GulfCet project. An expendable bathythermograph (XBT) was dropped midway between CTD stations. In general, the cruise track remained relatively consistent for the four surveys, but the frequency of CTD and XBT casts and the station positions varied among the four cruises. The *Oregon II* data shown in the following sections represent all stations that were sampled during each cruise and are not limited to just those in the GulfCet study area.

Since 1990, similar *Oregon II* vessel surveys have been conducted annually during the spring, summer, and winter in the northern Gulf of Mexico. Data from these hydrographic surveys are stored in the Southeast Area Monitoring and Assessment Program (SEAMAP) data base maintained by the National Oceanic and Atmospheric Administration (NOAA).

The second cruise track design was implemented for the *Longhorn* and *Pelican* surveys and covered the GulfCet study area once per season, for a total of seven hydrographic surveys. A transect consisting of 14 north-south track-lines was followed during the cruises. The hydrographic survey was designed to sample the meso- to large-scale features in the Gulf. The choice of location and spacing of the 50 CTD hydrographic stations for this study was based on the following:

a) spatial scale estimates of oceanographic features in the study area (e.g., slope eddy radii of 50-100 km) from bibliographic references;
b) acoustic and visual survey constraints;
c) ship time constraints;

d) similar survey patterns in other MMS Programs: Louisiana and Texas Shelf Circulation and Transport Process Study (LATEX A), Louisiana and Texas Mississippi River Plume Study (LATEX B), and Louisiana and Texas Eddy Circulation Study (LATEX C);
e) CTD time estimates; and
f) previous historical data.

As a result, CTD stations were located at the 100 and 2,000 m isobaths (except at the Mexican border), and at 74 km (40 nautical mile) intervals on each track-line. The location and spacing of the 84 XBT hydrographic stations was based on the 200, 350, 500, 800, 1,000, and 1,500 m isobaths at each of the 14 north-south track-lines (Figure 6.4).

6.2.3 *Shipboard Measurements and Procedures*

6.2.3.1 *Conductivity, Temperature, Depth (CTD) Hydrocasts*

Data collected during each *Oregon II* cruise were obtained following standard SEFSC protocol, and further details are available in individual *Oregon II* cruise reports (U.S. Dept. of Commerce 1992, 1993a, 1993b, 1994). Few modifications were made to the original cruise design, with the exception of deepening the CTD hydrocasts from 200 to 500 m, and changing the data acquisition rate of the CTD instrument. The CTD data for spring Cruise 199 were acquired at 8 Hz and averaged at 1 second intervals, while the CTD data for the remaining three *Oregon II* cruises were also acquired at 8 Hz, but not averaged.

Vertical salinity and temperature profiles were measured each day on *Oregon II* cruises. A Sea-Bird Electronics, Inc. (SBE) SeaCat™ or Sealogger™ CTD and rosette were lowered to the sea bottom or to a maximum depth of 500 m. Niskin bottles were closed on the upcast, and data from these samples were later used to verify CTD data. While the actual depths sampled were variable, the standard cruise plan called for water samples at the surface, mid-depth, and the bottom. Surface chlorophyll for *Oregon II* cruises were derived from sea water samples taken at regular intervals along the ship transect. Up to nine liters of water were collected using either a surface bucket or a Niskin bottle during a hydrocast. One milliliter of a 1% suspension of $MgCO_3$ was added to each of three three-liter replicate seawater samples as each was filtered through GF/C filters. The replicate samples were frozen until they were analyzed for chlorophyll a using Strickland and Parsons (1972) spectrophotometric method.

Vertical profiles of salinity, temperature, oxygen, and beam attenuation coefficient (transmissometry) were measured at every *Longhorn* and *Pelican* CTD station. A rosette with 12 5-liter Niskin bottles was lowered with the CTD. A SBE 9 Plus™ CTD was used on every cruise except summer Cruise 2, where a SBE 9 was used. During the downcast, temperature, salinity, and beam attenuation coefficient were graphically displayed in real-time as a function of depth. CTD data were acquired at 24 Hz. While the CTD/rosette equilibrated at the bottom depth for five minutes, the sampling depths for the upcast were selected. The upcast was identical to the downcast except the instrument was stopped at the selected sampling depths and the Niskin bottles were tripped. The CTD/rosette was lowered to the sea floor or to a maximum depth of 1,000 m. At stations less

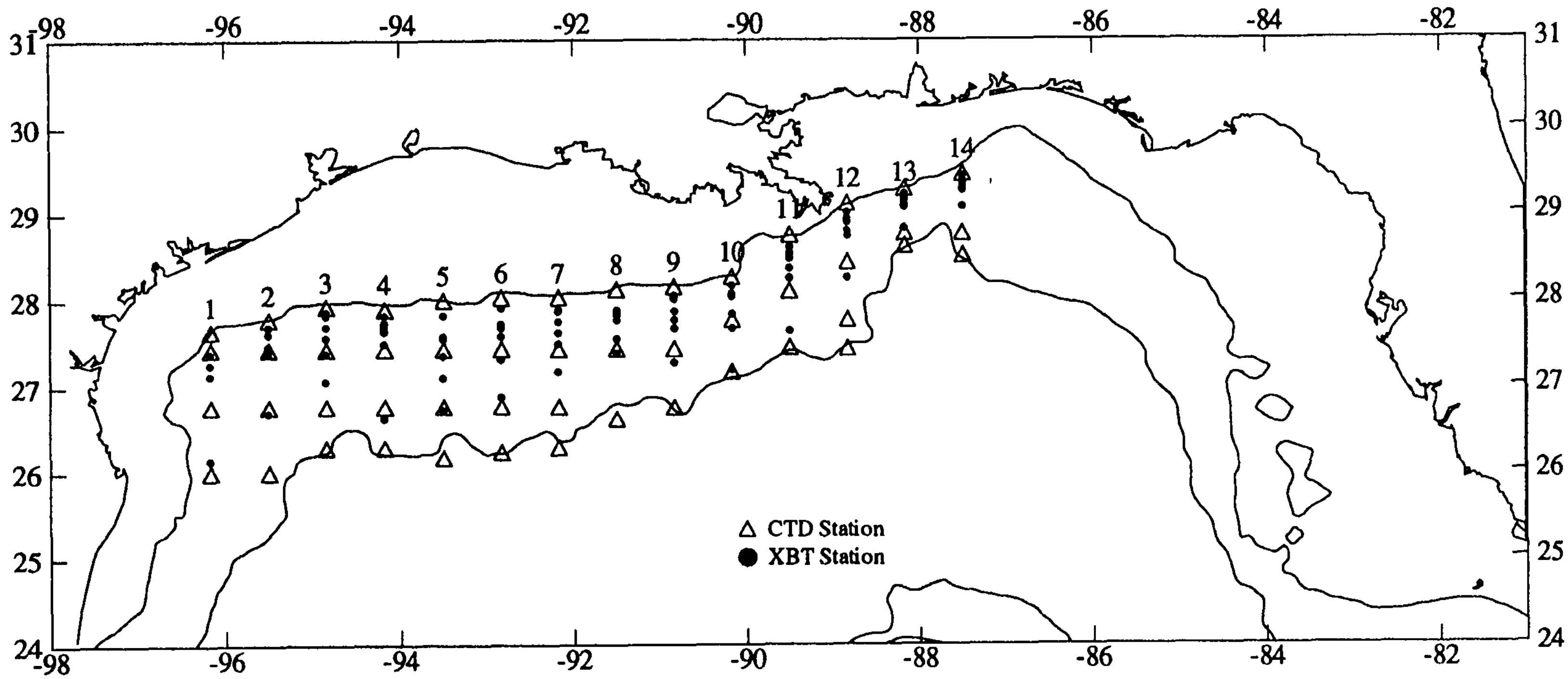

Figure 6.4. *Longhorn* and *Pelican* hydrographic survey station plan.

than 500 m deep, *in situ* fluorescence was also measured. Secchi depths and environmental data were also gathered using World Meteorological Organization (WMO) codes.

The *Pelican/Longhorn* water sample depth selection was based on chlorophyll sample criteria and followed these general guidelines:

- At 100 m stations, water samples were taken at depths of 0, 5, 15, 20, 30, 40, 50, 60,70, 80, 90, and 100 m.
- At all other stations, water sampling depths were 0, 10, 20, 30, 40, 55, 70, 85, 100, 125, 150, and 1,000 m (at stations where that sampling depth was appropriate) .

Nutrient samples were only collected on *Pelican* summer Cruise 6.

A salinity sample was always taken from the shallowest and deepest bottle of *Pelican* hydrocast. Salinity samples were analyzed at TAMU Department of Oceanography using a Guideline Connectively Coupled Salinometer™. One liter water samples for chlorophyll analysis were filtered at sea using GF/F filters after adding $MgCO_3$ to stabilize the pigments. The sample filters were stored in liquid nitrogen at sea and transferred to a -76°C freezer at TAMUG for storage until they were analyzed. The samples were analyzed for chlorophyll a and phaeopigments using a Turner Designs Fluorometer and following a modified Strickland and Parsons (1972) procedure. Precision of chlorophyll and phaeopigment analysis was ± 0.01 $\mu g\ l^{-1}$. Replicates of *Pelican* track-line 4 chlorophyll samples were given to the MMS LATEX A program for high-performance liquid chromatography (HPLC) pigment analysis. Data from these samples were used as quality control for *Pelican*'s chlorophyll data.

6.2.3.2 *Expendable Bathythermograph (XBT) Surveys*

During *Oregon II* cruises, XBTs were launched between CTD stations (refer to Figures 6.1-6.3), and on some legs in place of CTDs due to CTD instrument failure. XBTs were launched at depths of 200, 350, 500, 800, 1,000, and 1,500 meters along each *Pelican/Longhorn* cruise track-line. Additional XBTs were launched at some marine mammal sightings, for acoustic array calibration, and when unusual hydrographic features were detected. The probes were deployed while underway, with the ship speed not exceeding seven knots. T-7, T-10, or T-20 XBT probes (depending upon the depth) were the primary types of probes used on all surveys (Sparton of Canada, Ltd. or Sippican XBT probes).

6.2.3.3 *Continuous Flow-through Systems*

A continuous flow SBE thermo-salinograph and fluorometer were operated throughout each *Oregon II* cruise. Navigation, surface water salinity, and temperature were recorded at 60 seconds intervals. The SBE sensor components were sent for factory recalibration once per year.

The *Pelican* cruises used the Multiple Interface Data Acquisition System (MIDAS) (Walser et al. 1992) to continuously record navigation data, surface hydrographic data (salinity, temperature, fluorescence, light transmission, and sea water flow rate), and meteorological data (wind speed, wind direction, air temperature, barometric pressure, and solar irradiance). The MIDAS was configured to sample these data at an average of every fifteen seconds. This system used a SBE conductivity-temperature sensor and a Sea Tech, Inc. fluorometer and transmissometer. The conductivity-temperature sensor was calibrated annually by the manufacturer.

6.2.4. *Data Analysis*

The analyses that are accepted as routine within the oceanographic community are not described in detail.

6.2.4.1 *XBT and CTD Data Processing*

Raw XBT frequency data for *Pelican/Longhorn* cruises 1 and 2 and all *Oregon II* surveys were processed with an in-house conversion program using Sparton of Canada, Ltd. drop rates. *Pelican* Cruises 3 through 7 used Sparton's software (Sparton of Canada, Ltd. 1992). All processed XBT data were interpolated at 1 m intervals using a program developed at Scripps Institution of Oceanography (La Jolla, CA). *Pelican/Longhorn* XBT data were listed in 10 m steps (Appendix C), while *Oregon II* XBT data are listed in standard depths (Appendix B).

All XBT data were calibrated against CTD temperature data according to Singer's (1990) procedure. XBT depths were adjusted using the following first order empirical fit:

$$\text{New XBT depth} = 0.047 \cdot (\text{old XBT depth}) - 3.$$

Data corrected by this method are not found in the XBT data listings (Appendices B and C), but were used to generate any plots that required XBT temperature data.

All CTD data were processed using Seasoft™ software (Sea-Bird Electronics, Inc. 1992). The following CTD data processing steps were used:

1. DATCNV: Converts raw data to binary engineering units and stores data in CNV files.
2. SPLIT: Splits the CNV (converted) files into upcast and downcast files.
3. WILDEDIT: Checks for and marks 'wild' data points.
4. FILTER: Filters data columns to produce zero phase time shifts.
5. ALIGNCTD: Aligns specific temperature, conductivity, and oxygen measurements with their corresponding pressure measurements.
6. In-house program: Converts temperature to ITS-90 scale (UNESCO/JPOTS 1991).
7. CELLTM: Removes conductivity cell thermal mass effects from conductivity data.
8. LOOPEDIT: Marks the scan where CTD is moving less than the minimum velocity or traveling backwards due to ship roll.
9. DERIVE: Computes dissolved oxygen and depth.
10. BINAVG: Averages the data into 1 m. depth bins.

11. DERIVE: Computes salinity (PSS-78), density (EOS80), potential temperature (Pot.Temp), specific volume anomaly (SVA), and sound velocity (Chen-Millero) using Fofonoff and Millard's (1983) formulas.

All CTD salinity data were calibrated against bottle data. SEFSC used the PV-WAVE™ program to interrogate and verify salinity values. TIO CTD salinity data were also verified against bottle values. Any differences were found to be within the accuracy range of the instrument. Corrections from temperature and salinity sensor calibrations were also made. These sensors were sent to Sea-Bird Electronics, Inc. for calibration after 100 hydrocasts.

All XBT temperature data were corrected and integrated with CTD temperature data to compute isotherm depths. The 20°C, 15°C, and 8°C isotherm depths were used to show shallow, mid-water, and deep features, respectively.

The fresh water fraction was computed for 0 to 3 m water depths for each *Pelican* CTD station. The salinity values for these depths were averaged, and a reference salinity value of 36.560 psu was used. This value was obtained from the LATEX A program and was the highest salinity value obtained from their 1992 LATEX H01 cruise. The following equation developed by Dinnel and Wiseman (1986) was used to determine the fresh water fractions for the study area:

$$F = \frac{S_b - S}{S_b}$$

Where: S_b = Reference salinity
S = Salinity average
F = Fresh water fraction.

6.2.4.2 *Chlorophyll Data*

Chlorophyll a and phaeopigment concentration values for *Pelican/Longhorn* CTD stations are listed in Appendix C of Volume III. The chlorophyll a concentrations for the upper 100 m at each CTD station were used to define a chlorophyll function, c = f(d), where c represents chlorophyll a concentrations and d equals depth (up to 100 m). The integral of this function was then calculated numerically using the trapezoidal approximation:

$$\sum_{d=0}^{99} \frac{|c_d + 1 - c_d|}{2} + c_d$$

The individual integral values were treated statistically by season.

The surface chlorophyll data from *Oregon II* cruises were gridded and an interpolated surface was computed for each cruise leg. The interpolated values were then extracted for each transect and marine mammal position.

6.2.4.3 *Continuous Flow-through Systems*

The MIDAS continuously recorded data (*Pelican* cruises) were processed with an in-house program that cut cruise track-lines from the continuously recorded file and plotted raw data with no corrections.

The *Oregon II* continuous flow-through salinity and temperature data were processed and integrated into the overall transect database. Due to spiking and high frequency noise, both temperature and salinity data were low-pass filtered after collection. The low-pass filter used a spatial frequency cutoff of 1 cycle per 2 grid units (i.e., all spatial frequency signals higher than 1 cycle per 2.2 km were eliminated).

6.2.4.4 *Dynamic Height*

Height differences in the ocean surface would normally be expressed in relation to sea level, but since these differences are reflective of variations in pressure, oceanographers have devised dynamic height to relate these differences. Dynamic height is calculated from a distribution of water densities and actually shows a water column's ability to do work due to the differences in geopotential. In short, it is the potential for gravity to do work because of the height of the water in relation to some reference level (Pickard and Emery 1990). Differences in dynamic height (topography or geopotential height) provide oceanographers with a measure of the horizontal pressure gradient from which geostrophic flow or current velocities may be derived.

Corrected XBT data were combined with corrected CTD data to compute dynamic heights. A micro VAX 3600 computer was used for the calculations of dynamic height and mass transport/geostrophic velocity between station pairs, as described by Biggs et al. (1991). The dynamic height computations for the *Pelican/Longhorn* Cruises 1-4, and 6-7 were referenced to the 800 db surface. *Pelican* Cruise 5 and all the *Oregon II* cruise calculations were referenced to the 500 db surface (as 500 m was the maximum depth sampled). Hofmann and Worley (1986) have shown empirically that the optimum reference level of no motion in the central and western Gulf is near the bottom boundary of the Antarctic Intermediate Water (AAIW) at a depth of 850 to 950 m. Their model is supported by transport calculations for anticyclonic eddies (Biggs 1992).

6.3 Hydrographic Results

6.3.1 *Cruise Summaries*

From April 1992 through June 1994, the GulfCet program gathered hydrographic data from seven *Pelican/Longhorn* surveys (one cruise per season) and four *Oregon II* surveys (three spring and one winter) in the north-central and western Gulf of Mexico (refer to Table 6.1). The results from these hydrographic surveys are presented in this section.

The first survey (Cruise 1), was a spring cruise aboard the University of Texas at Austin's ship, R/V *Longhorn*. This cruise was divided into three legs because of personnel transfers and inclement weather. The following are the dates for each leg of the cruise: *Leg 1*: 15-17 April 1992, *Leg 2*: 20-21 April 1992, and *Leg 3:* 23 April-1 May 1992. No navigation or meteorological system was available for this cruise. Technical difficulties with the CTD hydrocasts resulted in fewer CTD stations being sampled than had been planned, but more XBTs were deployed to compensate for this (Table 6.2). A complete description of all

Table 6.2. The type and number of stations and samples taken on the *Oregon II* and *Pelican/Longhorn* hydrographic cruises.

	CTD Stations	XBT Stations	Salinity Samples	Chlorophyll Samples
Oregon II				
Cruise 199- Spring 1992	111	114	232	85
Cruise 203- Winter 1993	106	76	79	107
Cruise 204- Spring 1993	128	136	108	151
Cruise 209- Spring 1994	117	184	100	-
Pelican/Longhorn				
Cruise 1- Spring 1992 (*Longhorn*)	17	96	157	171
Cruise 2- Summer 1992	44	78	84	273
Cruise 3- Fall 1992	39	77	75	436
Cruise 4- Winter 1993	44	85	80	476
Cruise 5- Spring 1993	42	75	84	111
Cruise 6- Summer 1993	38	95	146	341
Cruise 7- Fall 1993	32	74	75	216
Totals				
Oregon II	462	510	519	343
Pelican/Longhorn	256	580	701	2024
Combined	718	1090	1220	2,367

Pelican/Longhorn hydrographic cruises. may be found in TAMUG's hydrographic data technical reports (Fargion and Davis 1993a, 1993b, 1993c, 1993d, 1994a, 1994b, and 1994c).

Following Cruise 1, all Texas A&M University cruises were conducted aboard the R/V *Pelican*. This vessel presented several advantages over the R/V *Longhorn*: increased platform stability for the marine mammal visual survey, increased laboratory space, and a continuously recording navigation and meteorological system.

All of the National Marine Fisheries Service surveys were aboard the NOAA Ship *Oregon II*. The first *Oregon II* survey (Cruise 199) was a spring cruise. This cruise was divided into three legs; *Leg* 1: 17 April-4 May 1992, *Leg* 2: 6 May- 25 May 1992, and *Leg* 3: 26 May- 8 June 1992. The first two legs covered the off-shelf waters of the northern Gulf between 83°-96°W longitude. These legs were part of the SEAMAP ichthyoplankton survey. The third leg concentrated on the GulfCet study area between 87°-96°W longitude. Further information concerning this cruise's hydrographic data may be found in *Cruise Results: NOAA Ship* Oregon II *Cruise 92-02 (199)* (U.S. Dept. of Commerce 1992).

Track-line 1 was dropped from the station plan for the first *Pelican* summer cruise (Cruise 2) and in all succeeding cruises due to schedule constraints.

Refer to the technical report for Cruise 2 for complete details (Fargion and Davis 1993b). *Pelican* Cruise 3 was a fall survey that did not sample track-line 10 or a portion of line 11 due to inclement weather.

The second *Oregon II* survey (Cruise 203) occurred in the winter of 1993. This survey also consisted of three legs, all essentially within the GulfCet study area between 87°-96°W longitude. This cruise covered north-south transects between the 90 m to 1830 m contours of this area. The chronological breakdown of the cruise is as follows: *Leg* 1: 5-17 January 1993, *Leg* 2: 18-30 January 1993, *Leg* 3: 1-14 February 1993. A more detailed summary of this cruise's hydrographic data may be found in *Cruise Results: NOAA Ship* Oregon II *Cruise 93-01 (203)* (U.S. Dept. of Commerce 1993a).

Fargion and Davis (1993d) summarize the winter *Pelican* survey (Cruise 4) in their fourth hydrographic technical report. *Pelican* Cruise 5 was a spring survey that dropped track-line 2 from the station plan due to ship time scheduling constraints. In addition, CTDs were cast to a maximum of 500 m.

Cruise 204 was the second *Oregon II* spring cruise that surveyed the SEAMAP and GulfCet study areas. It was separated into three parts: *Leg* 1: 3-17 May 1993, *Leg* 2: 18 May- 2 June 1993, and *Leg* 3: 4-15 June 1993. *Cruise Results: NOAA Ship* Oregon II *Cruise 93-02 (204)* (U.S. Dept. of Commerce 1993b) details the hydrographic collections made during this survey.

The second summer *Pelican* survey (Cruise 6) dropped track-lines 2 and 3 from the station plan because of ship schedule restrictions. A maximum depth of 800 m was used for the CTD to save time. The last *Pelican* cruise (Cruise 7) was completed in late fall of 1993. Track-lines 2, 3, 4, and half of 5 were dropped from the station plan due to crew member illness that required the ship to return to Galveston. The cruise was aborted at that point. Again, 800 m was the maximum depth to which the CTD was lowered to maximize available time.

Following the recommendation of the GulfCet Scientific Review Board (SRB), a spring *Oregon II* cruise was made rather than a second winter survey. This decision was based in the better sighting conditions that exist in the spring. This fourth survey was *Oregon II* Cruise 209, and was the last survey to be completed for the GulfCet project. This cruise was divided into four legs: *Leg* 1: 16-23 April 1994, *Leg* 2: 27 April-7 May 1994, *Leg* 3: 8-13 May 1994, and *Leg* 4: 14-18 May 1994. *Cruise Results: NOAA Ship* Oregon II *Cruise 209* presents a summary of this survey (U.S. Dept. of Commerce 1994).

Hydrographic data for the four *Oregon II* cruises are included in Appendix B, and Data for *Pelican/Longhorn* Cruises 1-7 are included in Appendix C. The combined total of hydrographic stations sampled by the GulfCet program were 1,808.

6.3.2 *Temperature-Salinity Relationships*

Temperature versus salinity (T-S) plots were computed for all the *Pelican* and *Oregon II* surveys (Figures 6.5 and 6.6). These plots show that for temperatures colder than 18°C there is a close T-S relationship with little scatter. This indicates that waters in the study area constitute essentially a single system.

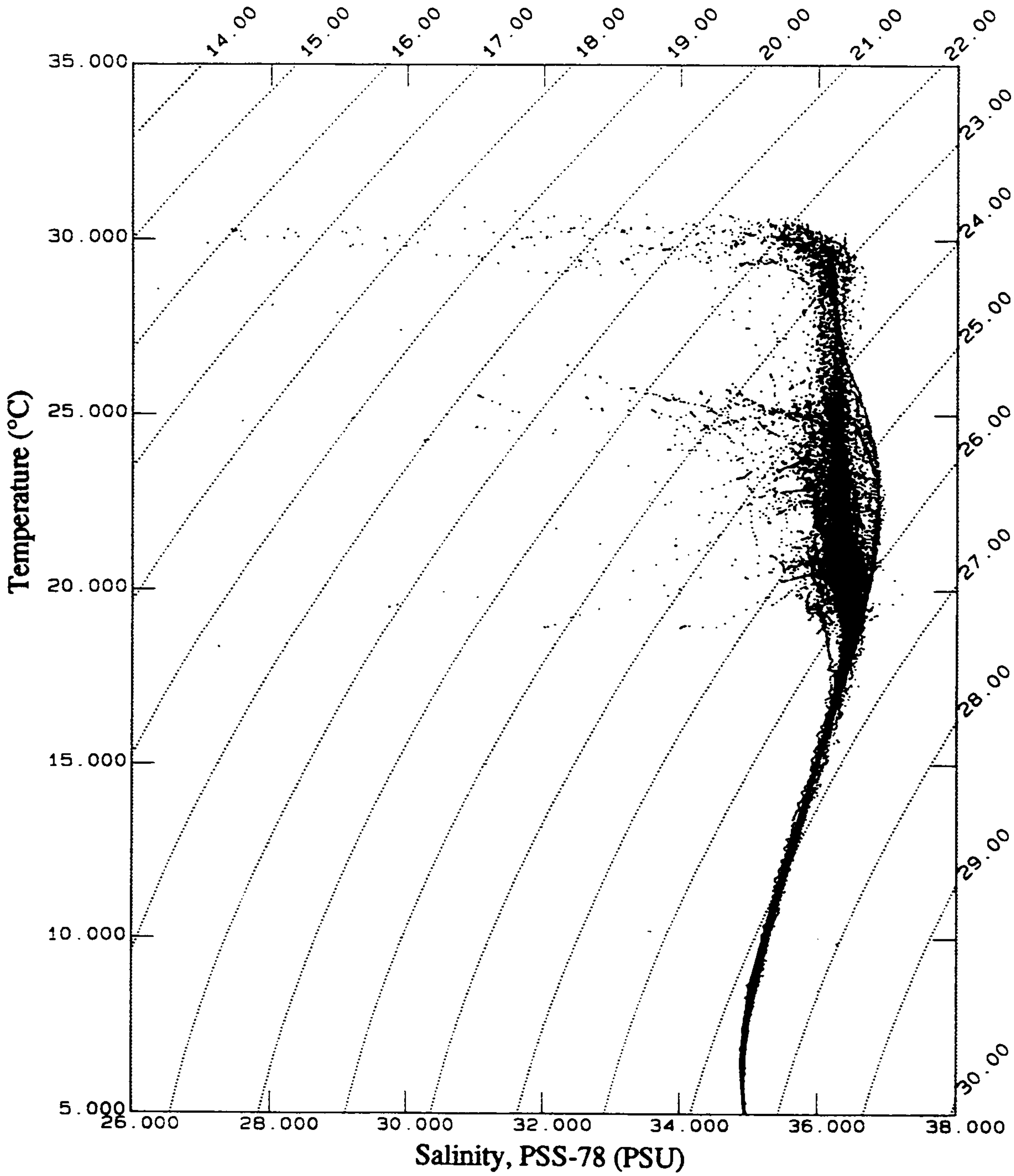

Figure 6.5. Temperature versus salinity relationship for all TIO CTD stations from *Pelican* and *Longhorn* cruises (1-7).

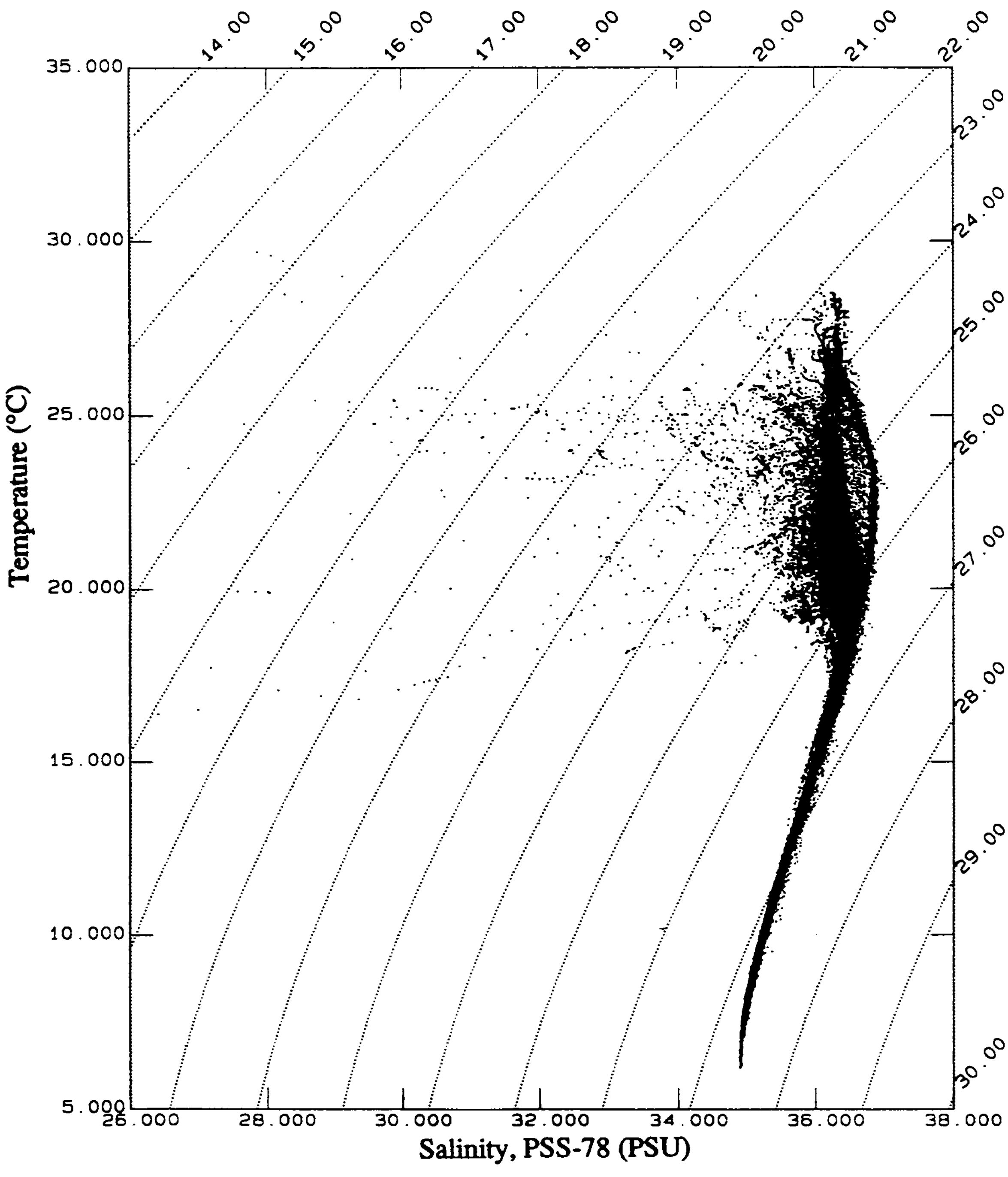

Figure 6.6. Temperature versus salinity relationship for all SEFSC CTD stations from *Oregon II* cruises (199-209).

Data from the combined GulfCet hydrographic stations reveals a distinct salinity maximum greater than 36.6 practical salinity units (psu) with an accompanying temperature of approximately 22-23° C. The minimum salinity of less than 34.9 psu excludes the surface fresh water found near the Mississippi River plume (which was as low as 12.8 psu). These salinity signatures are characteristic of SUW and AAIW, respectively. Usually the SUW salinity maximum is centered at about 200 m and the AAIW salinity minimum in the eastern Gulf occurs between the depths of 800 to 1,000 m (shallower in the western Gulf) (Nowlin and McLellan 1967). The intense salinity maximum of the SUW was found in the region of the Loop Current and in warm anticyclonic eddies derived from this current.

Pelican/Longhorn cruises detected several warm anticyclonic eddies in the GulfCet study area that were characterized by a salinity greater than 36.6 psu. These eddies were: Eddy Triton (T) (Cruise 2), Eddy Unchained (U) (Cruise 2), (Eddy Vazquez (V) (Cruises 3 and 4), Eddy Whopper (W) (Cruise 6), and Eddy Extra (X) (Cruises 6 and 7). Figure 6.7 presents an example of the T-S characteristics of one of these eddies, in this case, Eddy V. The T-S plots characterizing the other eddies are found in Appendix C. The T-S plots can be used to describe the spin down of an eddy. While an eddy is spinning down, the salinity maximum will gradually decrease as more GCW (salinity 36.4 to 36.5 psu) mixes with the core water.

XBT temperature versus depth data have been plotted to show the temperature range, the depth range of the mixed layer, and the interannual variability of temperature profiles during all GulfCet surveys in the period 1992-1994. XBT temperature data have been plotted by probe type. Figures 6.8 and 6.9 present T-7 probe data for all *Pelican* and *Oregon II* surveys, respectively.

Surface water temperatures throughout the study area ranged from 16.8°C to 30.4°C. The mixed layer was seasonally deepest in the winter, ranging from the shallower spring-summer depth range of 0-50 m and a fall-winter depth range of 35-110 m. A good deal of the scattering observed in the temperature profiles may possibly be due to the presence of warm or cold eddies in the Gulf.

6.3.3 *20°C, 15°C, and 8°C Isotherm Depths*

The 20°C, 15°C, and 8°C isotherm depths were used to show shallow, mid-water, and deep features, respectively. For this study the 20°C, 15°C, and 8°C isotherm contour maps were always compared with the dynamic height topography maps (over 800 db) to assure that the features were accurately characterized. A comparison between the 15° and 8° C isotherms can reveal different sizes and areas of eddy location and whether the vertical axis of the eddy core is tilted.

The phenomenon of eddies shedding from the Loop Current in the northern Gulf is a major feature of the meso- to large-scale Gulf circulation. Eddies are shed at a rate of one to three per year (Berger 1995). These warm-core anticyclonic rings have a diameter of 300-400 km and a possible depth signature of about 600 m. Topographical gradients in the isothermal surface indicate the position of the eddies. In particular, doming isotherms may represent the initial stages of development of a cyclonic eddy feature. Cyclonic

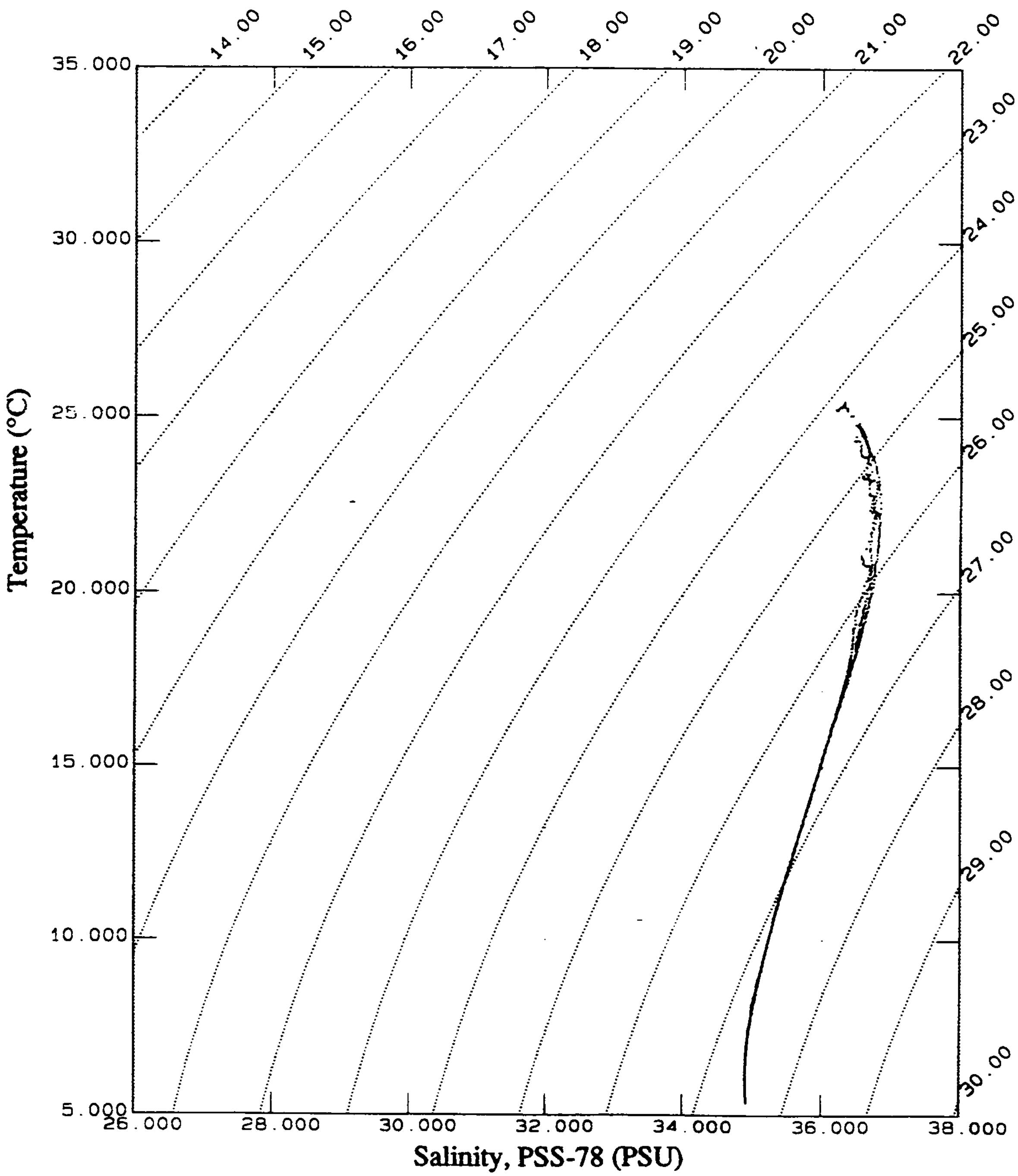

Figure 6.7. *Pelican* fall Cruise 3 temperature versus salinity relationship for CTD stations within Eddy V.

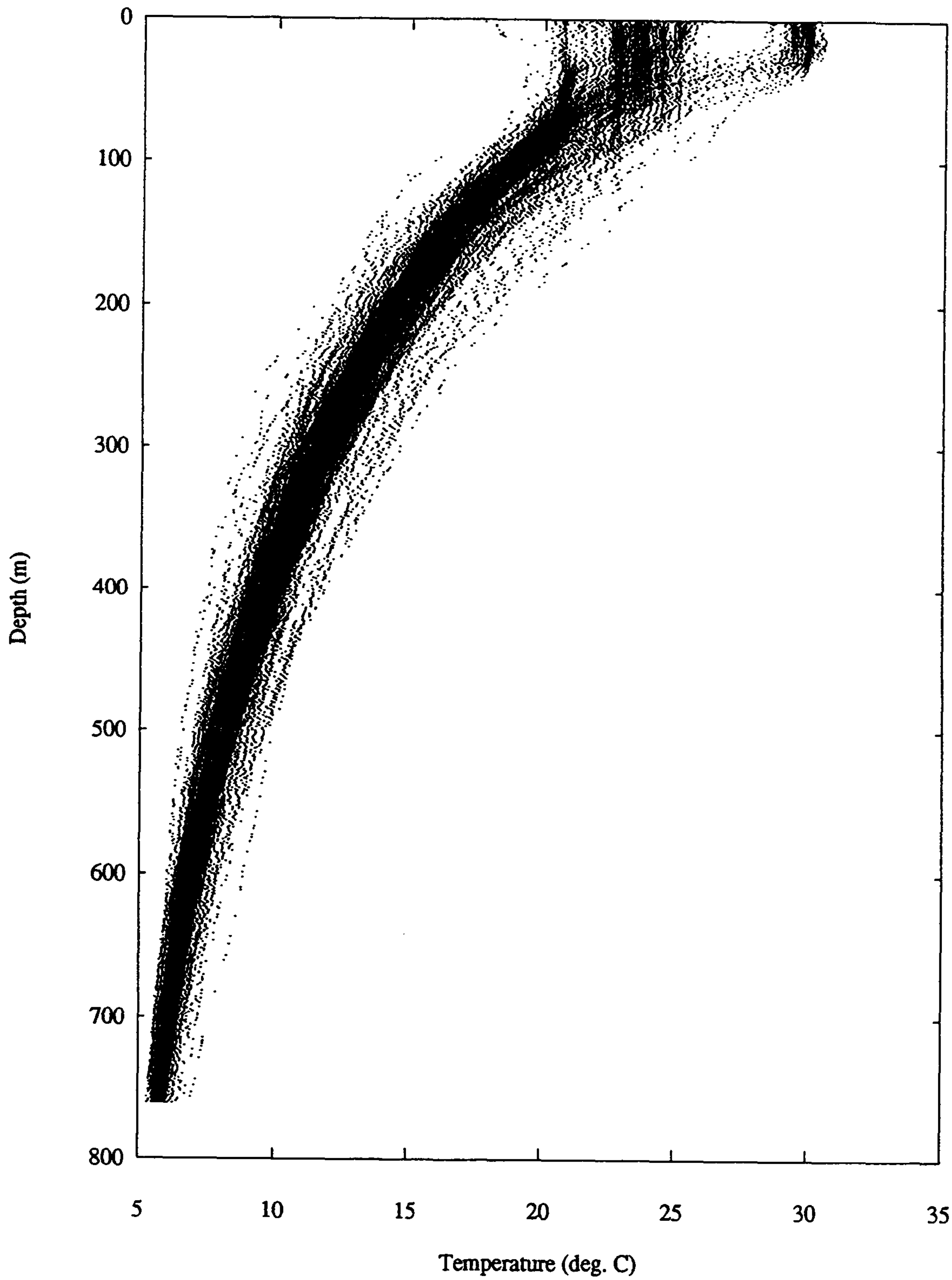

Figure 6.8. T-7 XBT temperature data for *Pelican* and *Longhorn* Cruises 1-7 (every sixth data point was plotted).

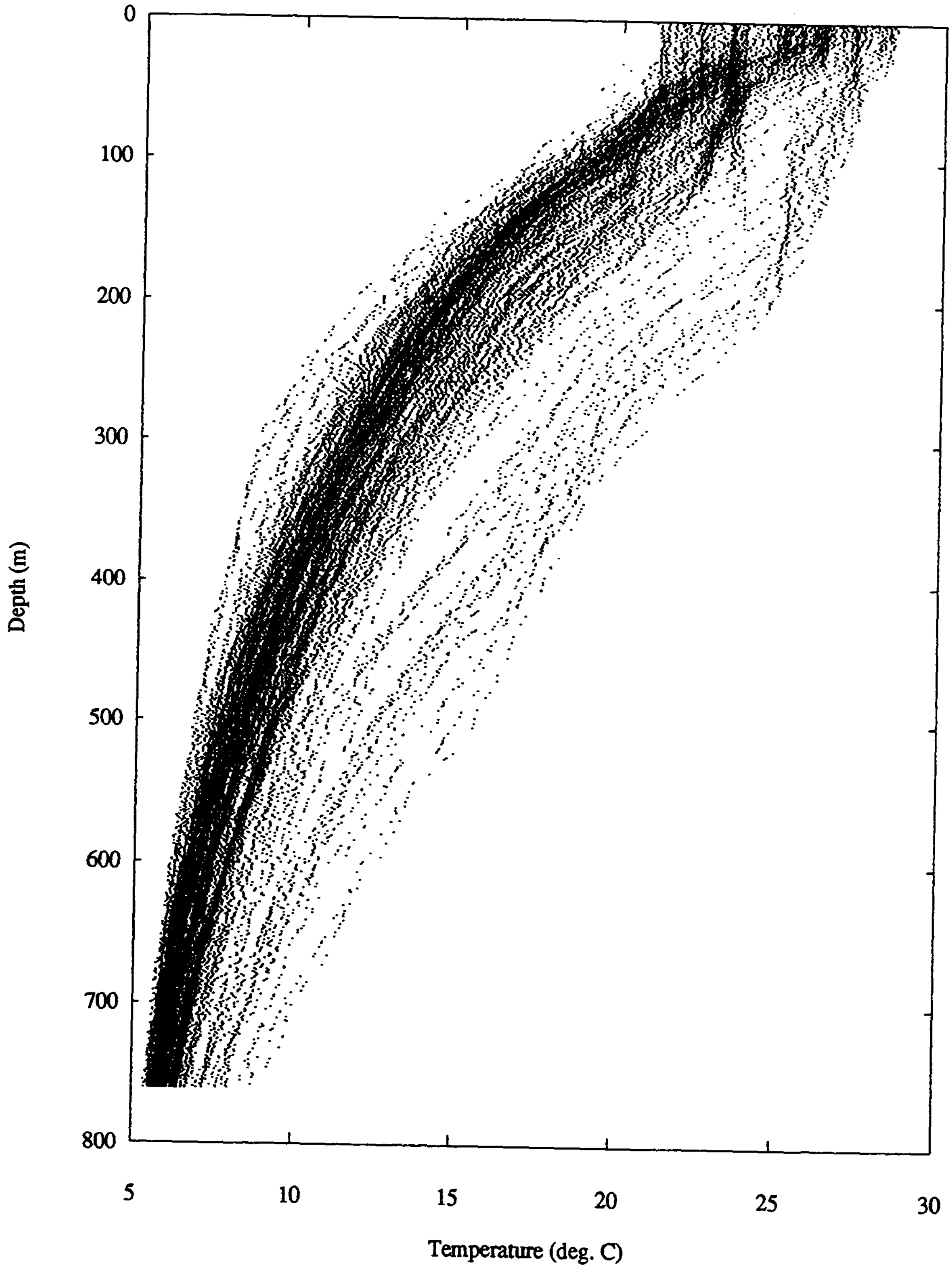

Figure 6.9. T-7 XBT temperature data for *Oregon II* Cruises 199-209 (every sixth data point was plotted).

eddies are peripherally linked to a primary anticyclonic eddy and evolve in strength during subsequent stages of eddy-slope interaction. This intensification of the anticyclonic-cyclonic eddy pair (oppositely rotating vortices) has been observed in the western Gulf in the past (Merrell and Morrison 1981, Brooks and Legeckis 1982, Merrell and Vazquez 1983, Brooks 1984).

Within eddies, there is spatial variability in all isotherm depths. This feature can be useful as an eddy detecting tool. Within the upper temperature profile of a warm-core (anticyclonic) eddy, the isotherm depths are found to be below those of the surrounding water column (i.e., the 15°C isotherm depth may be depressed as much as 100 m lower than its average depth outside the eddy). Regions where the temperature surface is deep or depressed correspond to anticyclonic (clockwise or warm) eddies. Conversely, shallow (or doming) temperature surfaces correspond to cyclonic (counterclockwise or cold) eddies. When the western Gulf surface waters are warmer than 15°C, the temperature isobaths appear to be relatively flat. Therefore, the 15°C and 20°C isotherms do not always detect cyclonic (cold) eddies. By comparison, the 8°C isotherm exhibits the greatest depth difference, often being depressed more than 150 m in an anticyclonic eddy. Therefore, the 8°C isotherm depth was the best contour level to use for detecting anticyclonic and cyclonic features.

Figures 6.10 through 6.12 are examples of the three isotherm depth topographies used to analyze the temperature data from *Pelican* winter Cruise 4. Of these, the 8°C isotherm, when referenced with the dynamic height topography from the same cruise, proved to be the most useful tool to detect warm and cold water eddies at depths greater than 800 m. In shallower water, the 15° C isotherm is the only usable isotherm with which to detect warm or cold eddies. A NOAA-AVHRR SST (°C) satellite image of the western Gulf (Figure 6.13) from the same period (February 1993) verified that the position of anticyclonic Eddy V in the western Gulf corresponded to that which the 8°C isotherm detected. The presence of the cold/cyclonic eddy paired with Eddy V could not be verified by this satellite image even though the 8°C isotherm had detected it. The warm-core eddy also visible near the Mississippi delta was apparent from the isotherm data, but disappeared rapidly from AVHRR images. The three isotherm contours were prepared for all the GulfCet hydrographic surveys and are located by cruise in Appendices B and C.

6.3.4 *Dynamic Height*

Dynamic topography highs and lows were used to describe anticyclonic and cyclonic eddies. An estimate of an eddy's life span is nine months to one year, and as an eddy ages it spins down. Spinning down means that an eddy loses vorticity, and as a consequence, external water begins to mix with the discrete inner core water. The changes in dynamic height can be an indicator of the life span of a particular eddy.

Prominent anticyclonic eddies in the western Gulf were detected during the GulfCet 1992-1994 hydrographic surveys. Although dynamic heights were computed for each of the *Oregon II* CTD stations, due to the spatial resolution of

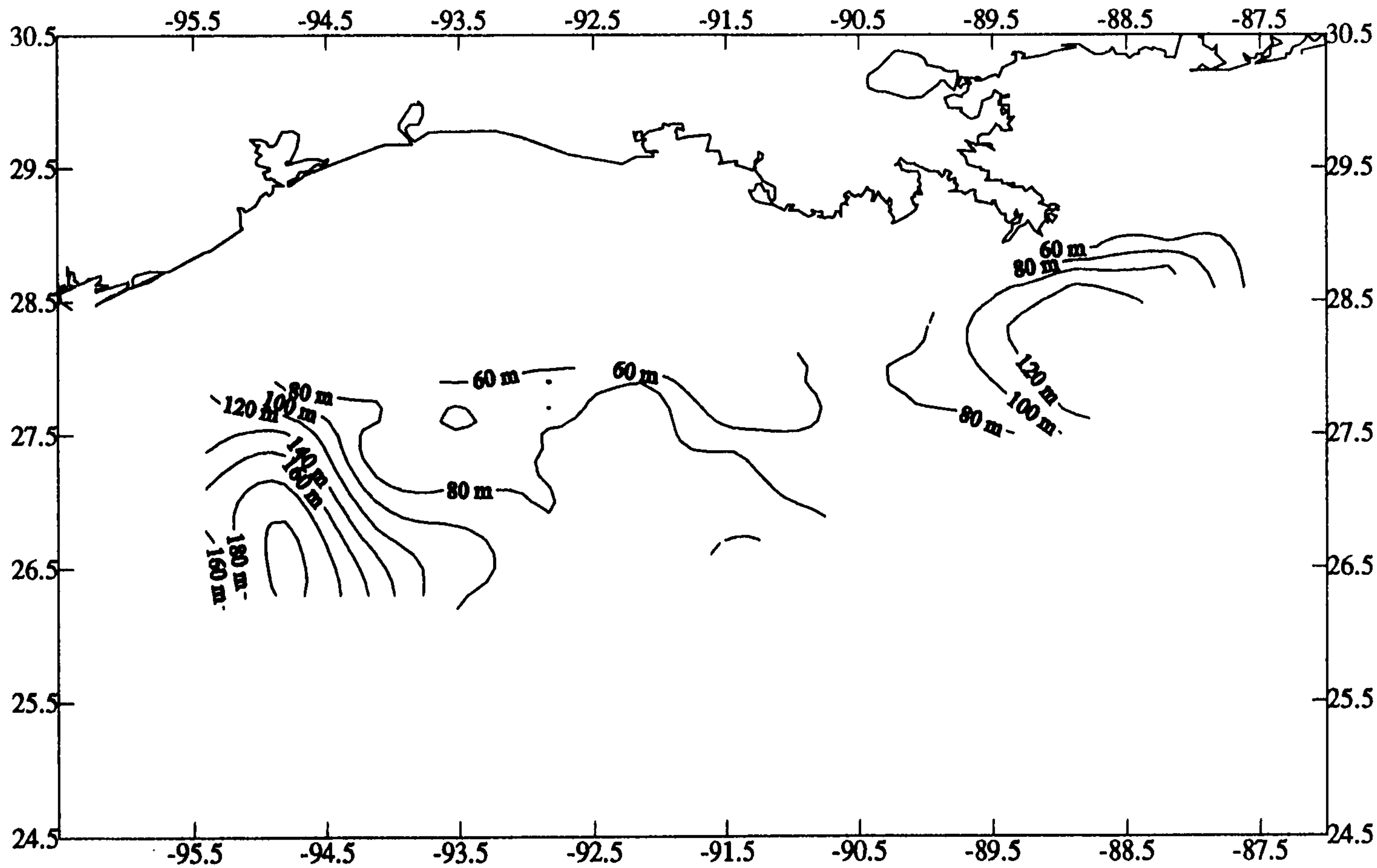

Figure 6.10. Topography of the 20 °C isotherm based on all XBT and CTD data from winter *Pelican* Cruise 4, 12-27 February 1993.

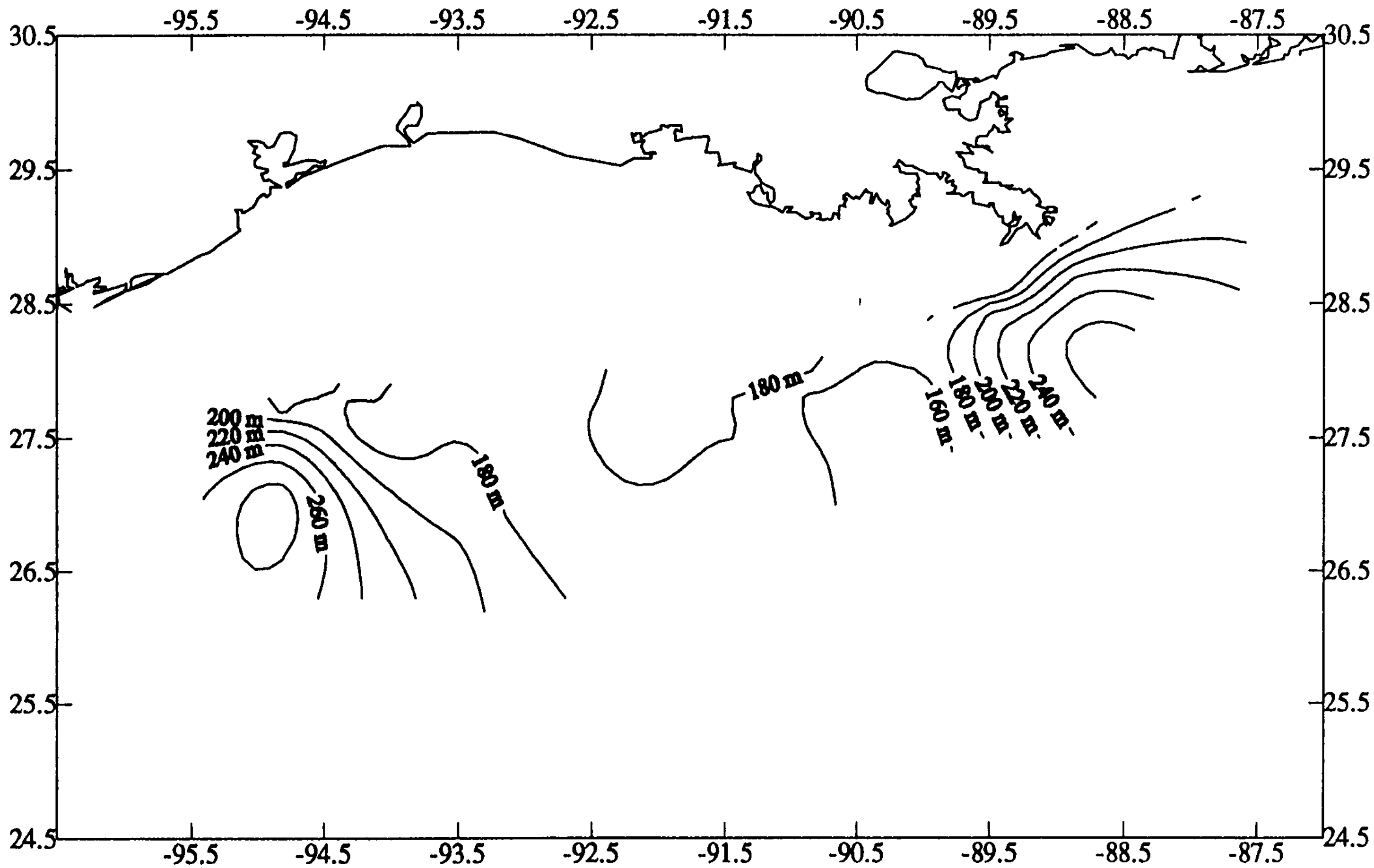

Figure 6.11. Topography of the 15 °C isotherm based on all XBT and CTD data from winter *Pelican* Cruise 4, 12-27 February 1993.

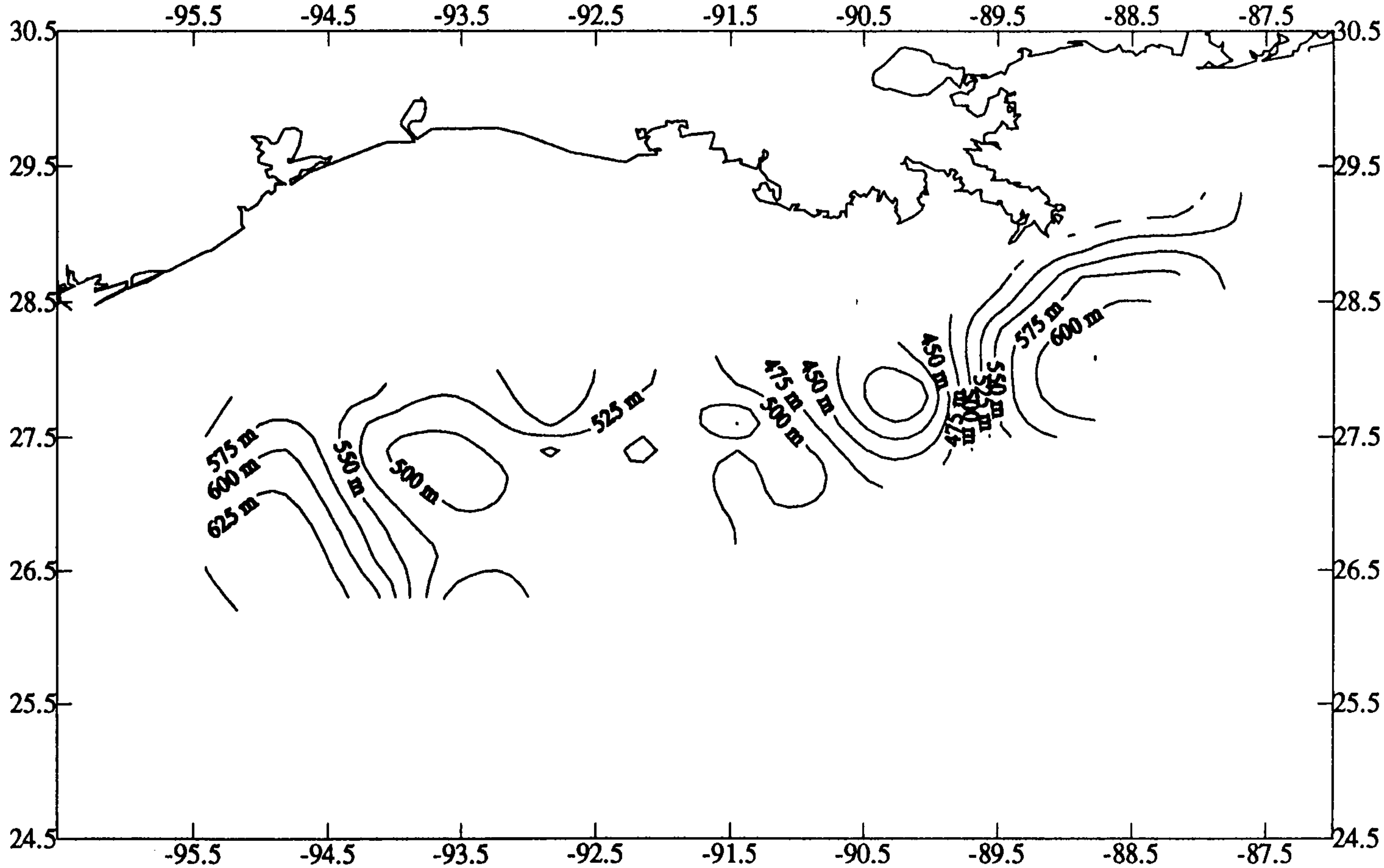

Figure 6.12. Topography of the 8 °C isotherm based on all XBT and CTD data from winter *Pelican* Cruise 4, 12-27 February 1993.

Figure 6.13. NOAA-AVHRR SST (°C) analysis of the western Gulf of Mexico for 12 February 1993, coinciding with the beginning of *Pelican* winter cruise 4 (image courtesy of Coastal Studies Institute, Louisiana State University).

the station grid and the shallowness of the CTD casts (i.e., 200 m), dynamic heights could not be assigned to any individual oceanographic feature nor could a dynamic height contour map be produced for the *Oregon II* surveys.

6.3.5 *1992-1994 Oceanographic Features*

The following summary describes the major hydrographic features found in the GulfCet study area by season during the 1992-1994 period. Table 6.3 lists the cruise, the feature identified during that cruise, the depth of the 8°C isotherm, and the dynamic height used to identify these features. The locations of these features are referenced by *Pelican* survey track-lines (see Figure 6.4 for orientation of track-lines) and general direction:

Spring 1992: Eddy Triton (T) was present in the northwestern Gulf during spring 1992 as determined by *Oregon II* Cruise 199 and by *Longhorn* Cruise 1. The *Longhorn* located the following features: anticyclonic Eddy T on track-line 1; a cyclonic eddy on track-line 7; and the north edge of the Loop Current on track-lines 12-13. An overview of the Gulf was given by *Oregon II* survey 199 . The Loop Current strongly intruded into the north-central Gulf and the cyclonic eddy associated with Eddy T moved to the northwestern corner of the Gulf (see isotherm figures in Appendix B and C).

Summer 1992: Eddy T was also seen on *Pelican* Cruise 2 (August 1992) on track-lines 2 and 3 with an associated strong cyclonic eddy on track-line 5. During this cruise, Eddy U, a new Loop Current eddy, was seen in the central area of the study on track-line 8 with an associated cyclonic eddy on track-line 11. Figure 6.14 is a composite figure of dynamic heights and the track of LATEX C drifter buoy number 447 for the month of August 1992. The dynamic height contours show the position of Eddy T in the western part of the map and just the northern tip of Eddy U in the center. The drifter is within Eddy U itself, and its track implies both the size and location of this eddy.

Fall 1992: The third *Pelican* cruise detected anticyclonic Eddy V on track-lines 2 to 4. Eddy V was completely surveyed by this cruise and a drifter buoy, and it had a diameter of 100 km. Figure 6.15 is also a composite of dynamic heights and LATEX C drifter buoy #2447 track for November 1992. This figure clearly shows the location of the eddy as well as the circulation pattern within the eddy.

Winter 1993: Data from both *Pelican* Cruise 4 and *Oregon II* Cruise 203 showed that anticyclonic Eddy V had moved northward onto the continental slope and retained the same diameter as noted on the previous cruise. The *Pelican* located Eddy V on track-lines 2 and 3 with an associated cyclonic eddy. Also detected was a second strong cyclonic eddy on track-lines 9 and 10 associated with an anticyclonic eddy on track-line 12 (see Figure 6.12).

Table 6.3. **Oceanographic features located during 1992-1994 and their properties.**

Survey	Date	Oceano-graphic Feature	8°C Iso-therm Depth (m)	Dyn. Height (800 db)
Longhorn spring Cruise 1	15 May 1992- 1 Apr 1992	Eddy T cyclonic Eddy Loop Current	> 625 < 475 > 600	115
Oregon II spring Cruise 199	15 May 1992- 8 Jun 1992	Loop Current	> 700	
Pelican summer Cruise 2	10 Aug 24 1992- 24 Aug 1992	NW corner of Eddy U & cyclonic Eddy Eddy T& cyclonic Eddy	 > 600 < 475 > 625 < 425	 > 135 > 125
Pelican fall Cruise 3	8 Nov 1992- 22 Nov 1992	Eddy V	650	140
Oregon II winter Cruise 203	4 Jan 1993- 14 Feb 1993	Eddy V & cyclonic eddy	>650	
Pelican winter Cruise 4	12 Feb 1993- 27 Feb 1993	Eddy V & cyclonic eddy, "no name" Eddy & cyclonic eddy	625 600 < 400	125 110
Oregon II spring Cruise 204	6 May 1993- 13 Jun 1993	Loop Current & ps. Eddy V	 > 750	
Pelican spring Cruise 5	23 May 1993- 5 June 1993	Eddy V not present, cyclonic eddies	 < 450	
Pelican summer Cruise 6	28 Aug 1993- 5 Sep 1993	North side Eddy W & cyclonic eddy, & Eddy X	575 < 450 > 675	125 > 145
Pelican fall Cruise 7	3 Dec 1993- 14 Dec 1993	North side Eddy X & cyclonic eddies	 > 625 < 475	 >125
Oregon II spring Cruise 209	12 Apr 1994- 10 Jun 1994			

This anticyclonic eddy was not named, but was also evident in satellite images (see Figure 6.13). Cruise 203 data showed the development of a strong cyclonic eddy and confirmed the presence of Eddy V in the NW corner of the study area in January. A contour of the dynamic heights obtained from Cruise 4 is represented in Figure 6.16.

Spring 1993: Data from the *Pelican*'s second spring survey (Cruise 5) showed that a very complex topography existed. There were small, strong cyclonic eddies and possibly a small anticyclonic eddy in the northeast corner of the Gulf (Figure 6.17). An overview

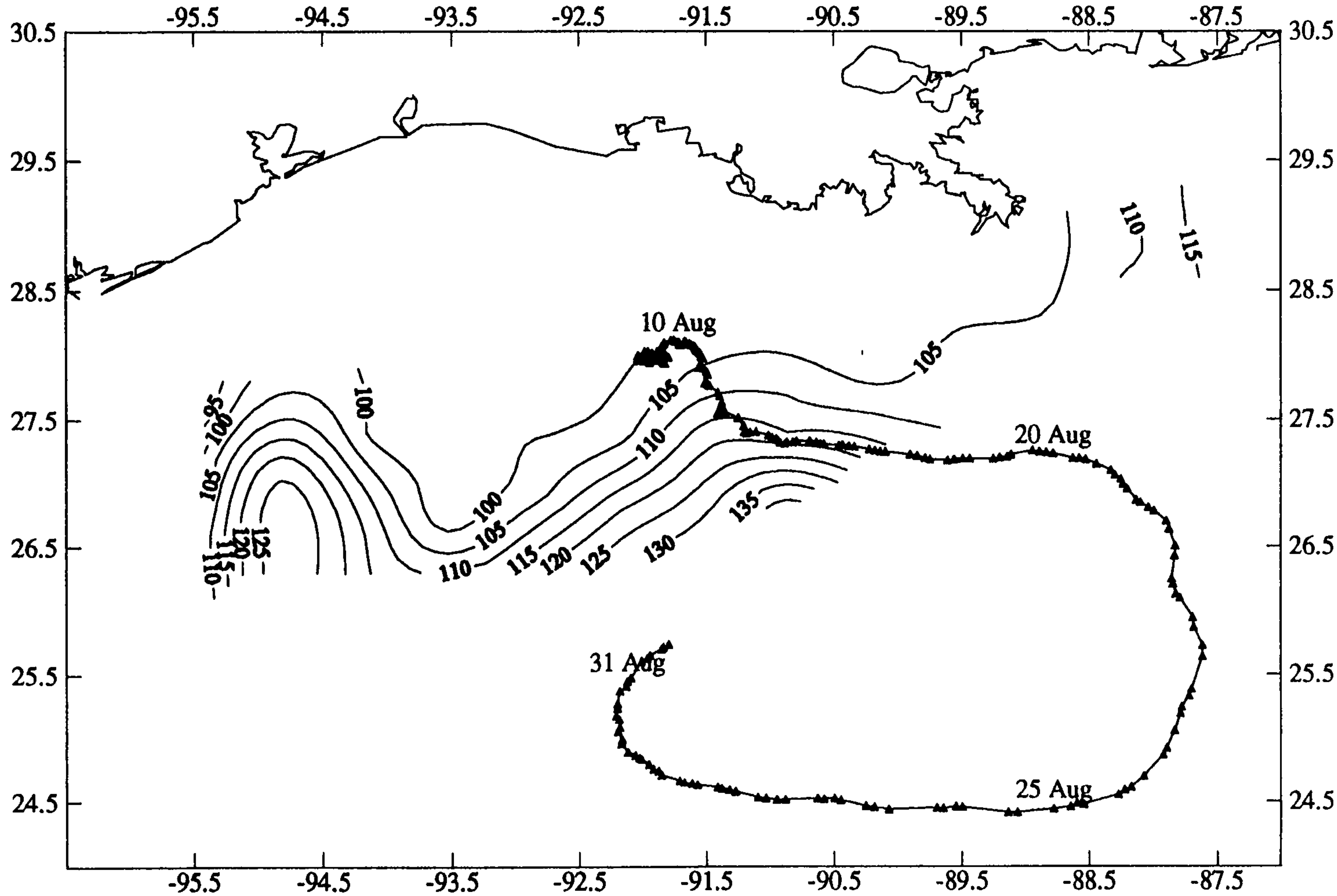

Figure 6.14. *Pelican* summer Cruise 2 surface dynamic topography (dyn cm) with respect to 800 m, with LATEX-C drifter #2447 track from August 1992 superimposed (drifter track data courtesy of LATEX-C program).

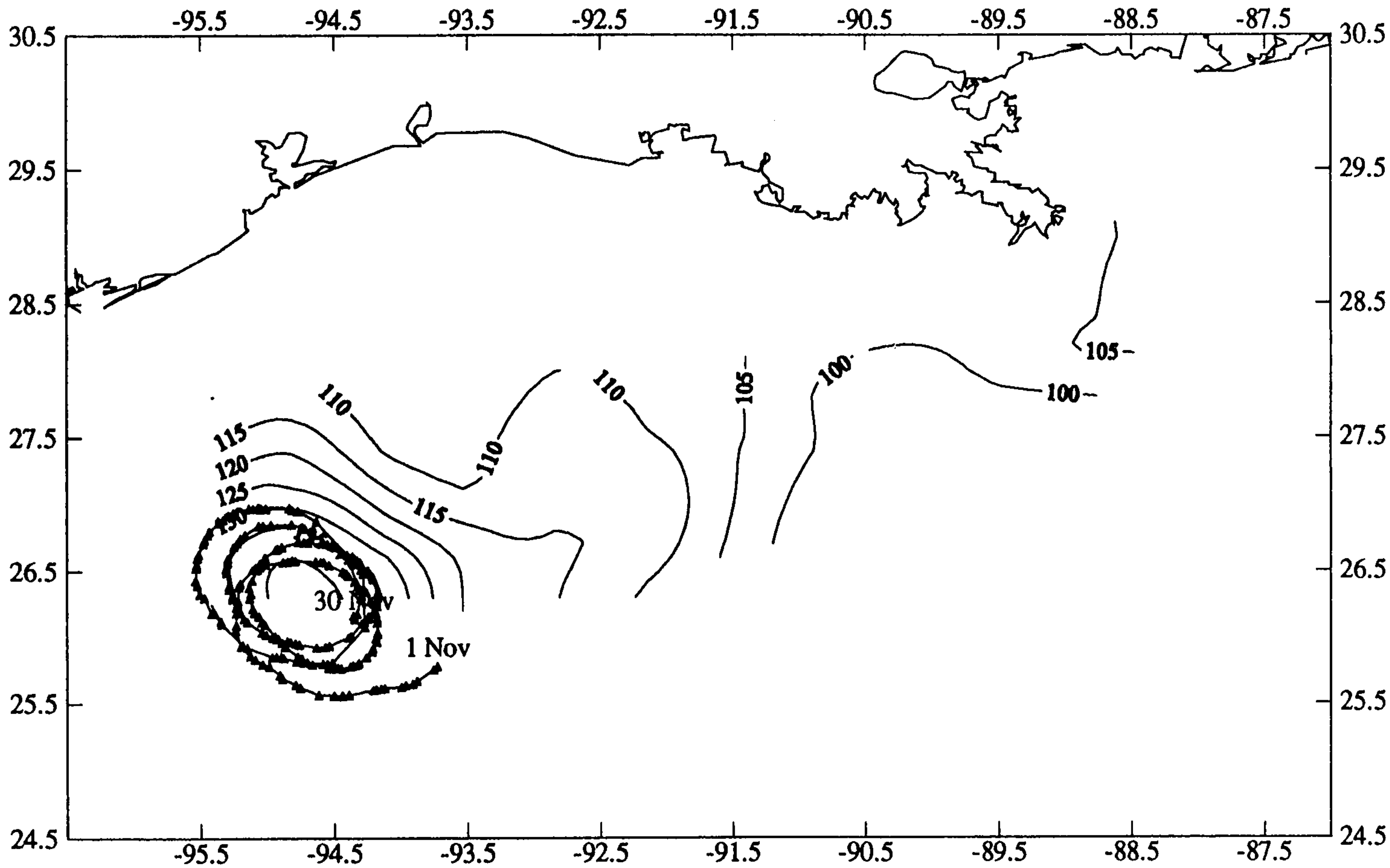

Figure 6.15. *Pelican* fall Cruise 3 surface dynamic topography (dyn cm) with respect to 800 m, with LATEX-C drifter #2447 track from November 1992 superimposed (drifter track data courtesy of LATEX-C program).

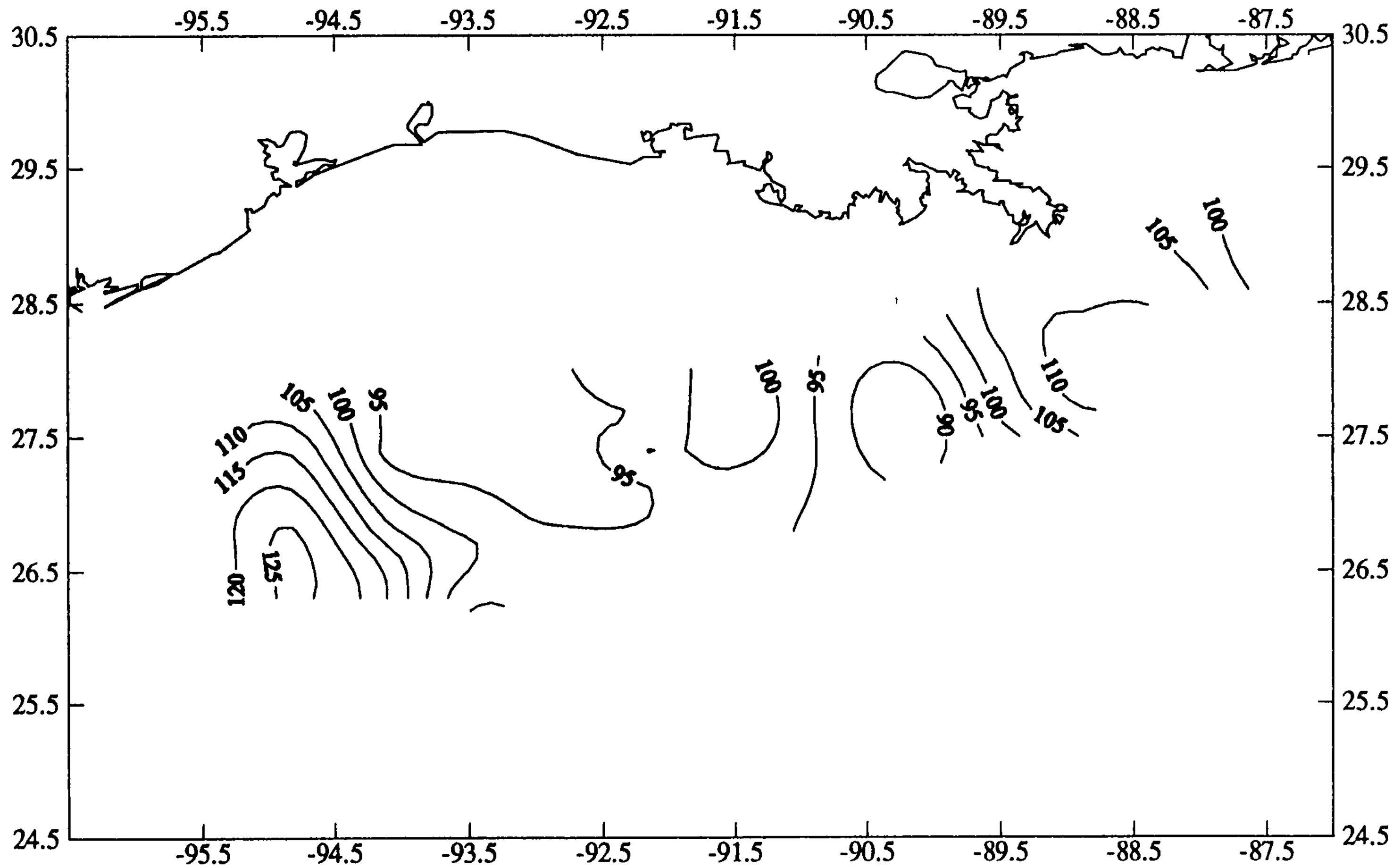

Figure 6.16. *Pelican* winter Cruise 4 surface dynamic topography (dyn cm) with respect to 800 m.

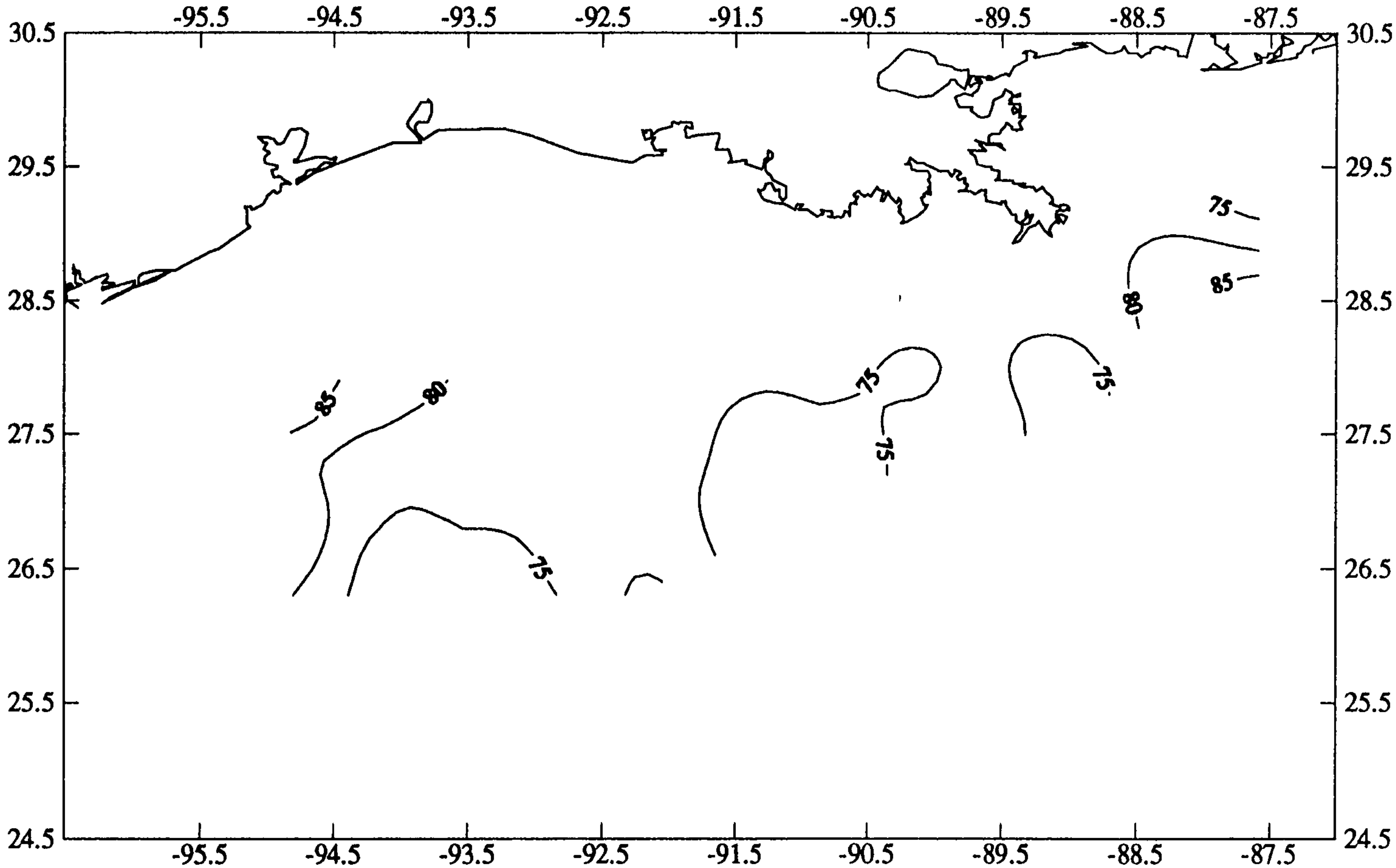

Figure 6.17. *Pelican* spring Cruise 5 surface dynamic topography (dyn cm) with respect to 500 m.

of the Gulf was provided by *Oregon II* Cruise 204. The Loop Current showed a strong intrusion with cyclonic eddies on its western side, while Eddy V spun down (see Appendix C isotherm figures). Eddy V was no longer present in the northwest Gulf by early June. Eddy V showed a very complex cyclonic-anticyclonic-cyclonic triad system that interacted, merged, and separated over the period of late March through May 1993 (Jockens et al. 1994). The detection, spin down, and fate of Eddy V were all possible to determine by merging all ship and satellite data.

Summer 1993: *Pelican* Cruise 6 located anticyclonic Eddy W on track-lines 4-7. Eddy W was elongated and squashed with an associated cyclonic eddy on track-line 7. A second very strong, anticyclonic Eddy X was found on track-line 12, and was possibly associated with a cyclonic eddy (Figure 6.18). Eddy X had a diameter of about 300 km.

Fall 1993: The last *Pelican* survey, Cruise 7, detected a cyclonic-anticyclonic-cyclonic ring triad. Eddy X was found on track-line 9, with cyclonic eddies on either side. Eddy X moved east along the 2,000 m isobath (Figure 6.19). Eddy X interacted with an isolated cyclonic eddy on the lower continental slope between 93° and 92°W causing the cyclonic eddy to move eastward towards the Loop Current.

Spring 1994: The last *Oregon II* survey, Cruise 209, covered most of the northern Gulf, but no major features were observed.

6.3.6 *Chlorophyll a Concentrations*

Chlorophyll concentrations can be used as an estimate of primary productivity. Oceanographic features such as upwelling, eddies, and fresh water inflow are associated with increased nutrient levels and, therefore, with increased chlorophyll concentration. High chlorophyll concentrations indicate an area that may also have an accompanying increase in densities of higher trophic level species upon which marine mammals feed. In such cases, chlorophyll concentration may affect marine mammal distribution.

Literature on primary productivity indicates that most oceanic regions of the Gulf are oligotrophic. Data from ship surveys of the 1960s and 1970s showed that the surface mixed layer of the Gulf seldom had a chlorophyll concentration of more than a few tenths of a milligram per cubic meter, and that these waters were also depleted of nitrates and were low in zooplankton biomass (El-Sayed 1972, Biggs 1992). However, within the Mississippi River plume, at the cooler periphery of the Loop Current where the nutracline was shallower, and in other local regions where higher nutrient concentrations are present, chlorophyll concentration is dramatically increased (Biggs 1992).

Vertical profiles of chlorophyll a concentrations from the *Pelican* inshore (100 m CTD stations), offshore (all CTD stations except 100 m), and the

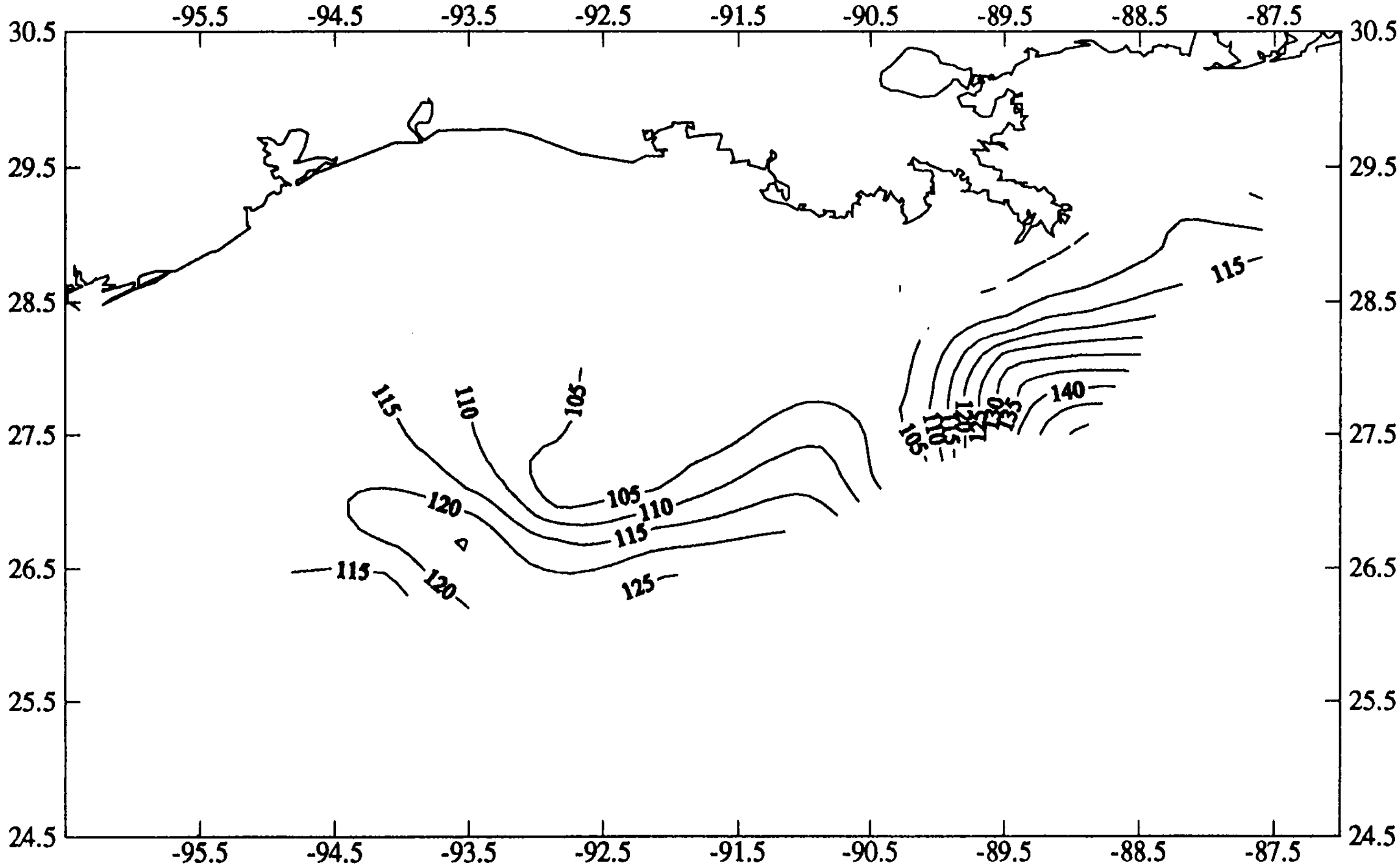

Figure 6.18. *Pelican* summer Cruise 6 surface dynamic topography (dyn cm) with respect to 800 m.

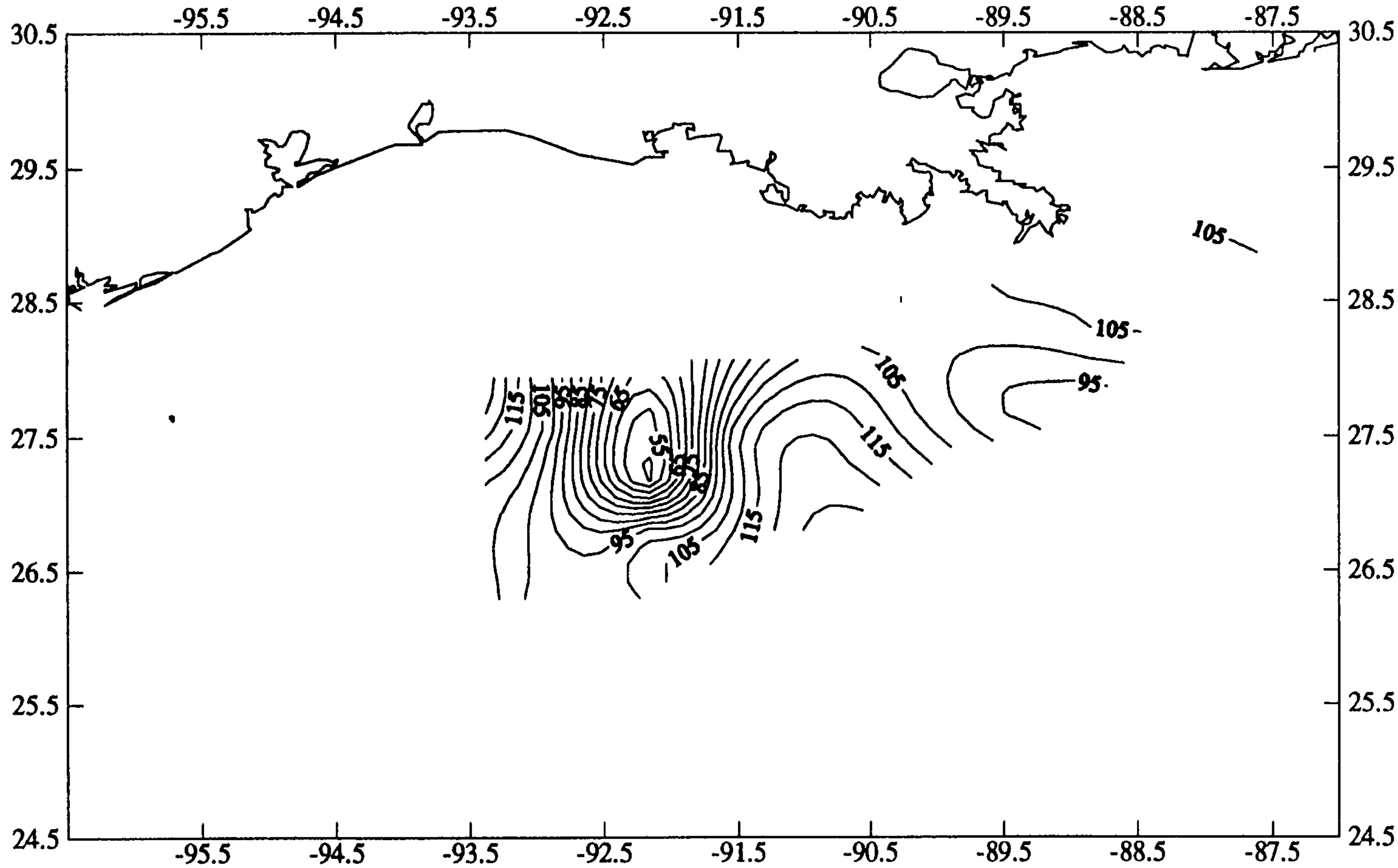

Figure 6.19. *Pelican* fall Cruise 7 surface dynamic topography (dyn cm) with respect to 800 m.

Mississippi River plume stations in the Gulf were plotted (Figures 6.20-6.22). Chlorophyll values presented a gradient inshore to offshore (high to low) with no clear secondary chlorophyll peak. Chlorophyll a concentrations from inshore stations had a mean of 0.4 mg/m^3 and a maximum of 28.15 mg/m^3, while offshore stations had a mean of 0.2 mg/m^3 and a maximum of 2.74 mg/m^3.

To examine seasonality, chlorophyll a concentrations for all *Pelican* CTD stations were integrated (up to 100 m) by season, and these integrals were then plotted. Figures 6.23 and 6.24 are the resulting contour maps for *Pelican* Cruises 3 and 4. Surface chlorophyll a concentration values from all *Pelican* CTD stations were plotted by quarter. The winter quarter consisted of the months December, January, and February; the spring quarter included March, April, and May; and so on. These divisions made it possible to determine if a spring or fall bloom occurred, which would have been the expected result. The data indicate that neither a spring nor fall bloom occurred during the survey period. Even when the Mississippi River influence was removed as a possible bias, the data show that no spring or fall phytoplankton bloom occurred. While seasonal chlorophyll signals were detected in the surface chlorophyll a values (Table 6.4), they seemed to be a poor estimate of integral water column chlorophyll values.

No integral values were obtained for *Pelican* Cruise 5; it was the only survey used to obtain the spring values, and was a shorter survey with fewer CTD stations. *Longhorn* Cruise 1 was the other spring survey and this cruise, due to equipment failures, resulted in fewer CTD stations than had been desired. Along with fewer samples to begin with, the chlorophyll data from this cruise were available for only half the CTD stations. "Hot spots" of chlorophyll were detected offshore in *Pelican* Cruises 3 and 4. The higher values on Cruise 3 (integral = 40 mg/m^2) were probably due to fresh water that was pushed seaward to at least the 1,000 m isobath by northeasterly winds (refer to Figure 6.23 and wind figures later in this section). The high values (integral $\geq$65 mg/m^2) seen in *Pelican* Cruise 4 were located at the edge of a warm anticyclonic eddy ("no name") off the Mississippi delta (see Figure 6.24). The other area showing a high offshore value (integral = 50 mg/m^2) was probably related to fresh water from the Mississippi River extending offshore from wind forcing.

Replicates of chlorophyll samples for Pelican track-line 4, totaling 117 samples, were analyzed by the LATEX A program. These HPLC data were used as quality control for TIO analyzed samples from the *Pelican*.

6.3.7 *Mississippi River Discharge*

The Mississippi and other rivers, with their associated nutrient and sediment loads and pollutants, have a great impact on all aspects of continental margin oceanography in the northern Gulf. The discharge/plume relationship reveals that wind forcing is a critical factor in determining plume size and orientation (Walker and Rouse 1993). The Mississippi River plume was detected

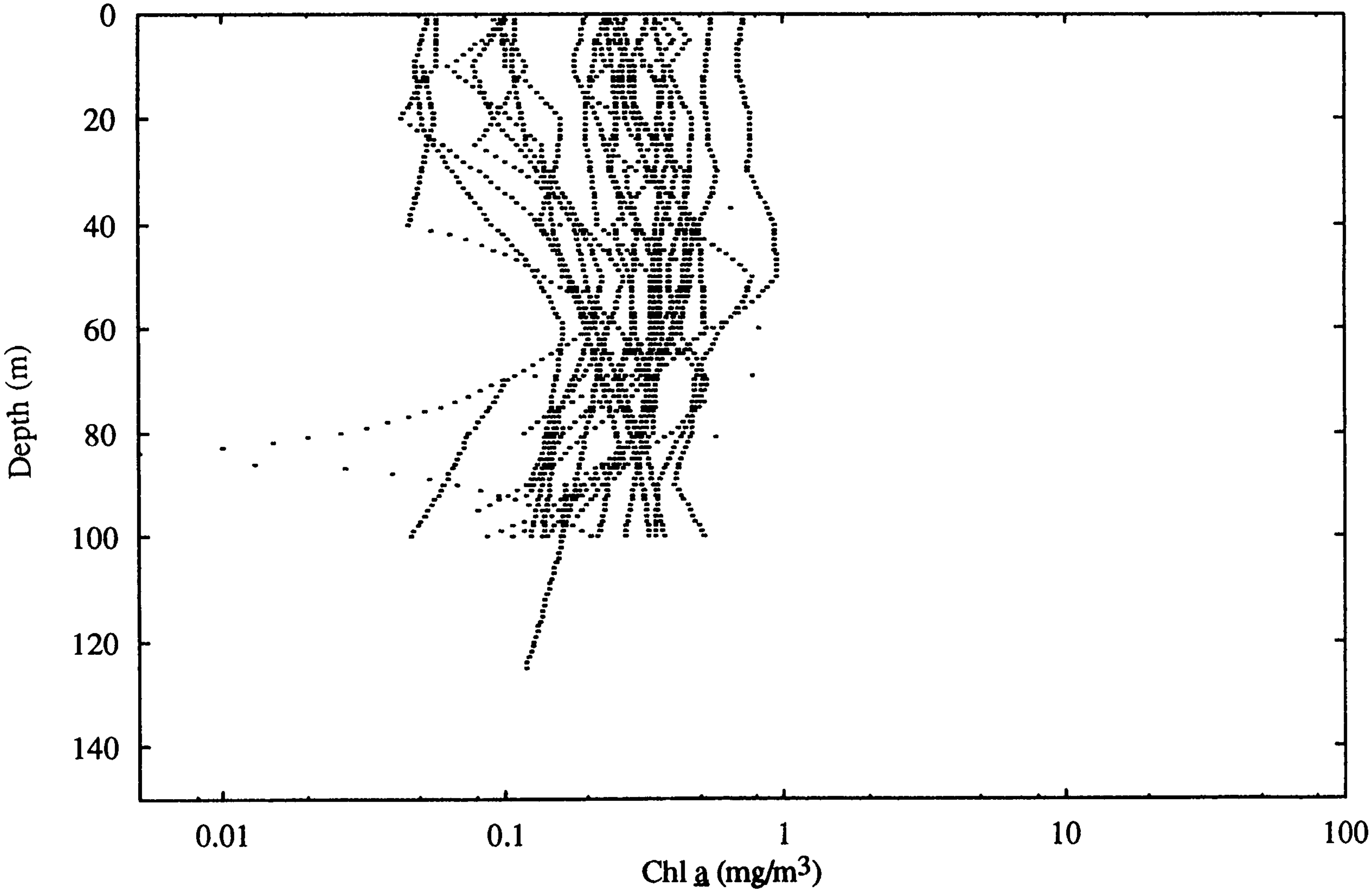

Figure 6.20. Vertical profile of chlorophyll a concentrations (mg/m^3) from inshore (100 m CTD) *Pelican* stations.

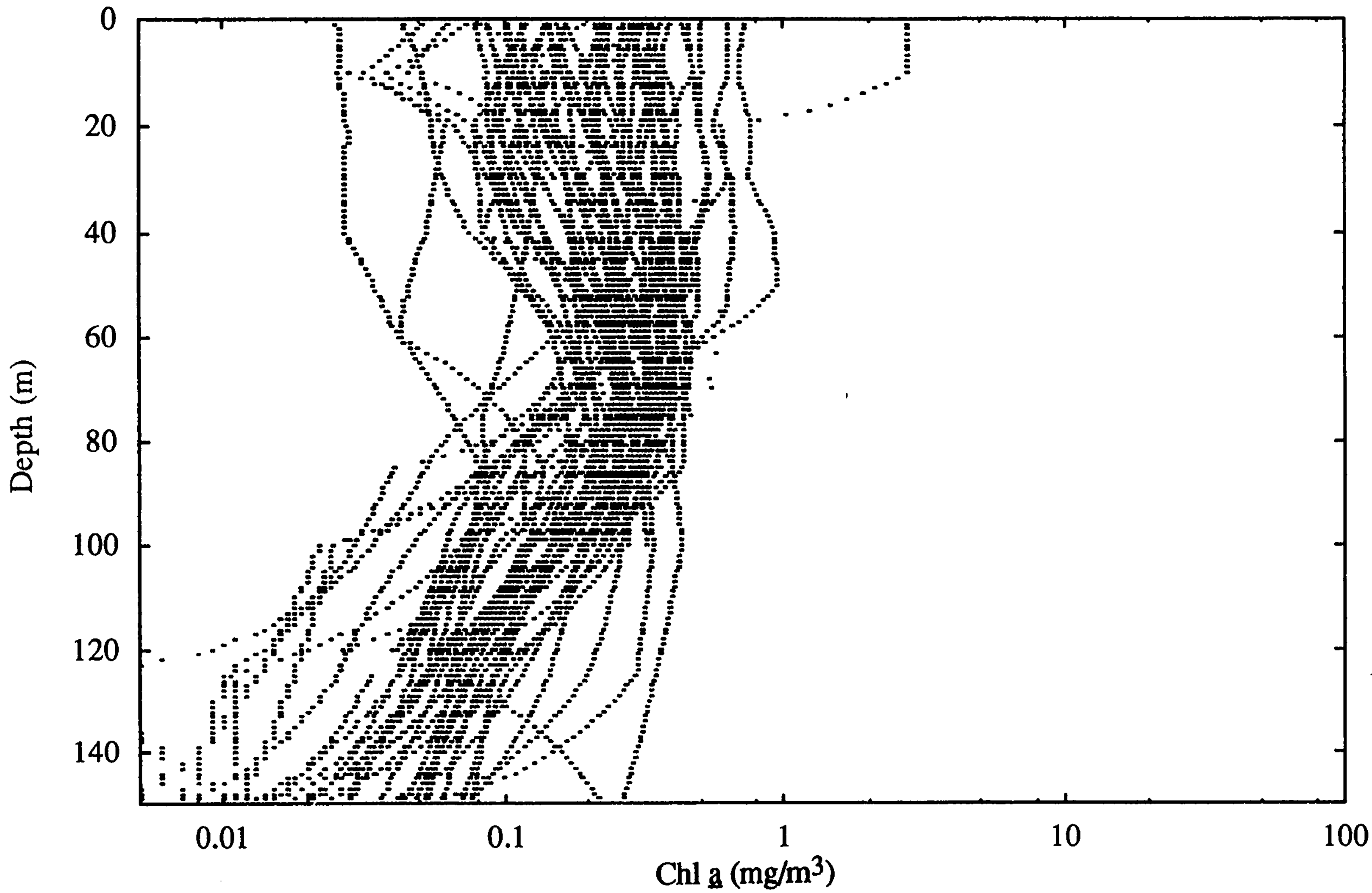

Figure 6.21. Vertical profile of chlorophyll a concentrations (mg/m³) from offshore (all CTD stations except 100 m) *Pelican* stations.

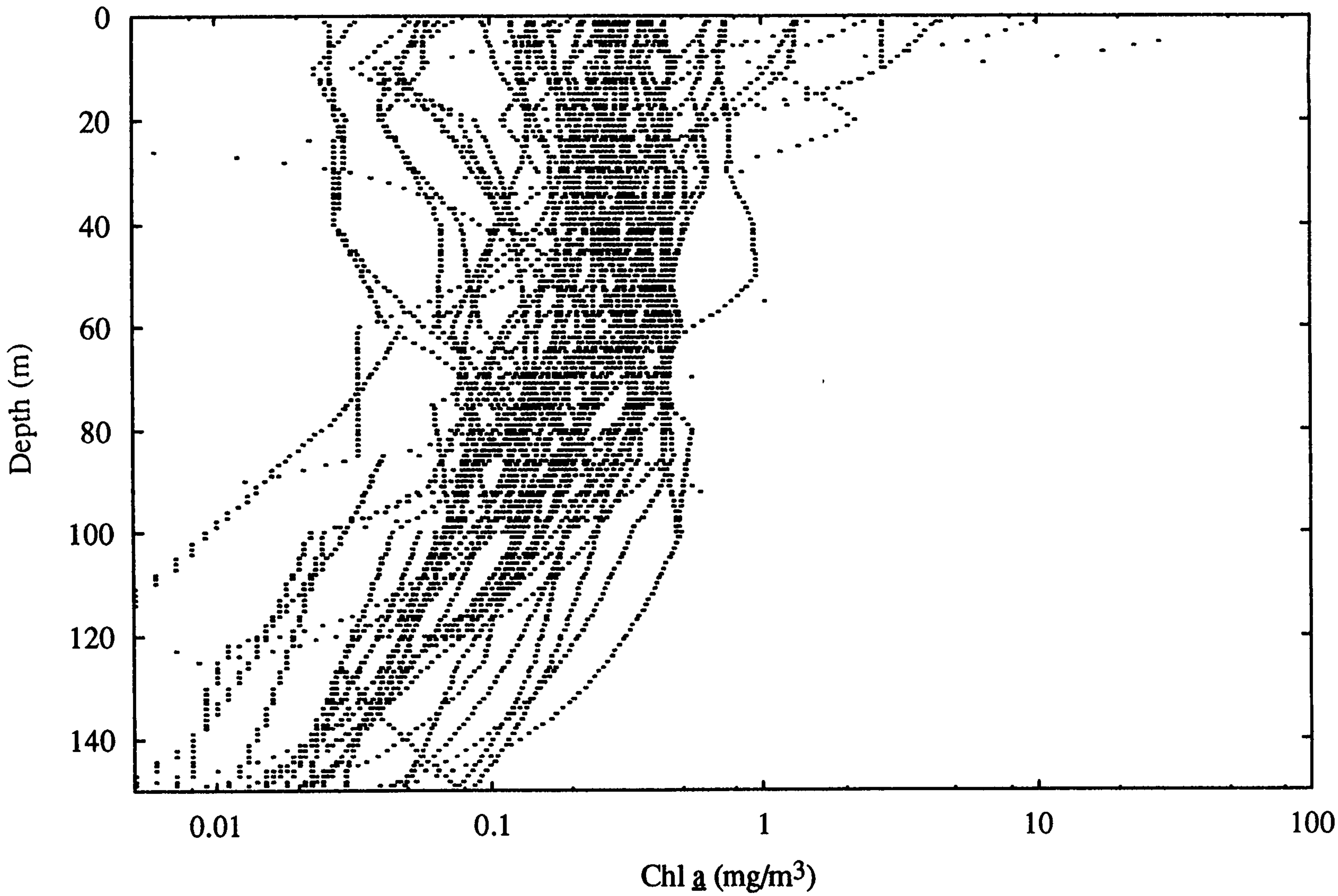

Figure 6.22. Vertical profile of chlorophyll a concentrations (mg/m^3) from *Pelican* Mississippi River plume stations (11-106, 12-119, 12-125, 13-126, and 13-133).

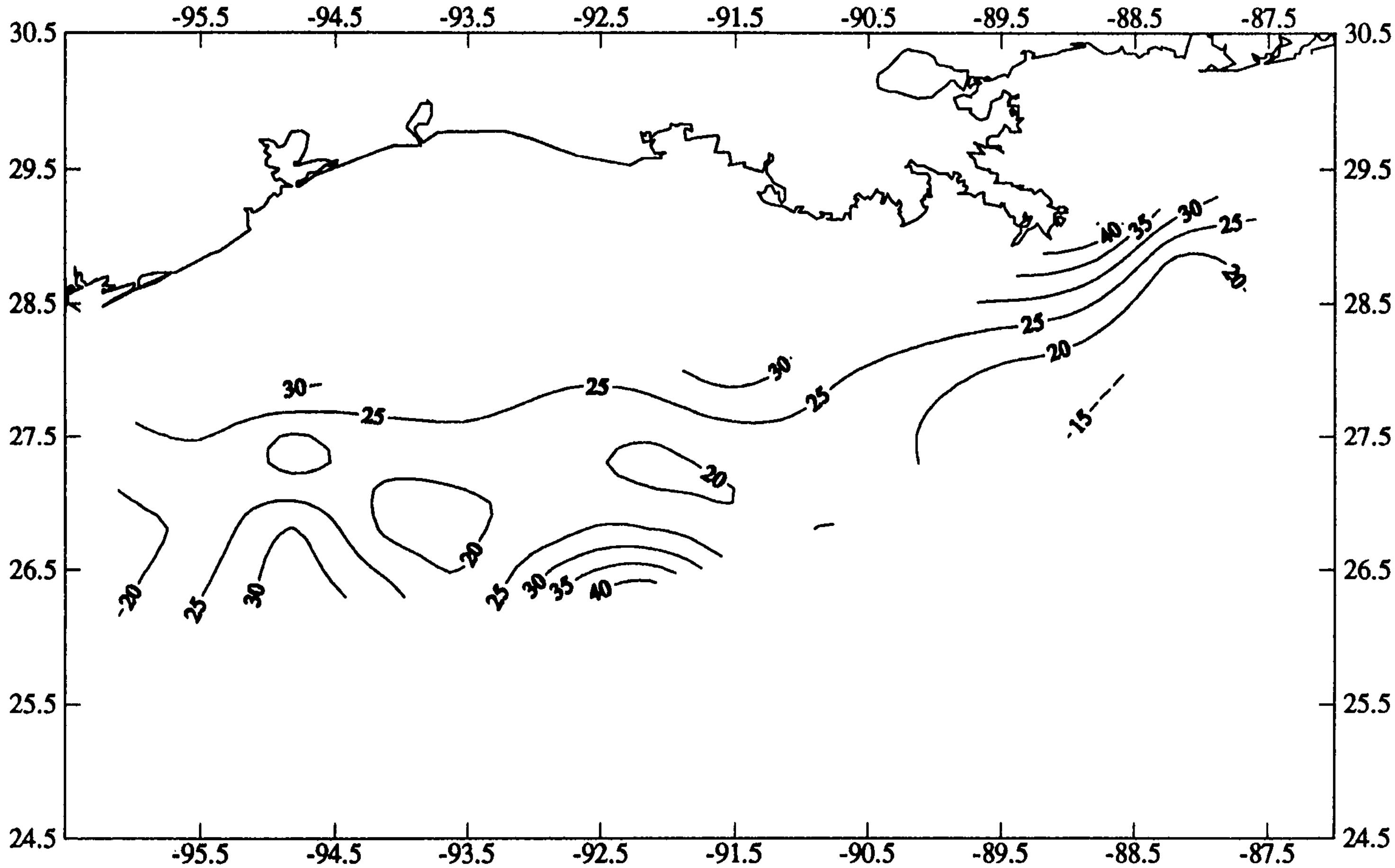

Figure 6.23. Integrals (mg/m²) of chlorophyll a concentrations versus depth (up to 100 m) for *Pelican* fall Cruise 3.

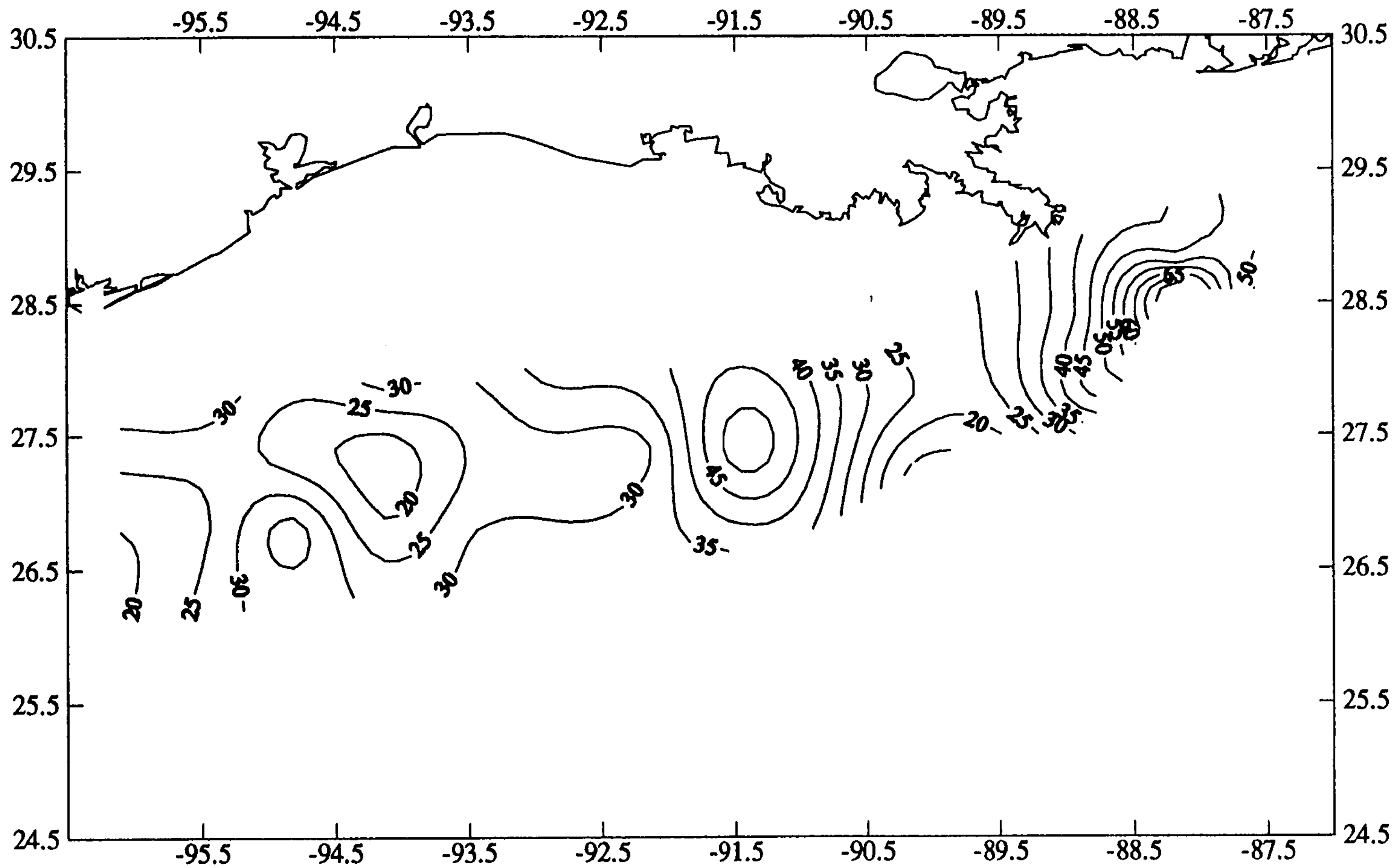

Figure 6.24. Integrals (mg/m²) of chlorophyll a concentrations versus depth (up to 100 m) for *Pelican* winter Cruise 4.

Table 6.4. Chlorophyll a concentrations (mg/m^3) and integral values (mg/m^2) by quarter for all seven *Pelican* cruises (100 m integration level).

	Minimum	Maximum	Mean	Standard Deviation	N
Surface Chl a Conc. (All)	0.001	10.884	0.416	1.023	203
Chl a Integrals (All)	5.198	79.624	24.260	11.510	155
Surface Chl a Conc. (Spring)	0.061	2.646	0.310	0.495	29
Chl a Integrals (Spring)[1]					
Surface Chl a Conc. (Summer)	0.025	10.884	0.512	1.622	49
Chl a Integrals (Summer)	5.198	40.536	20.240	8.160	35
Surface Chl a Conc. (Fall)	0.037	0.715	0.243	0.160	59
Chl a Integrals (Fall)	9.310	46.765	21.894	8.174	52
Surface Chl a Conc. (Winter)	0	6.201	0.551	1.054	66
Chl a Integrals (Winter)	8.670	79.624	26.740	12.654	68

[1] Insufficient data to generate integral values.

using shipboard data, fresh water fraction maps, salinity maps, sea surface temperature (from continuous flow-through data), and AVHRR satellite images.

Two major events related to the Mississippi River plume and fresh water input into the Gulf occurred during the study period 1992-1993. The first occurred in the fall of 1992 when Mississippi River fresh water extended outward into the Gulf to the 1,000 m isobath. The second event was the "great" flood during summer 1993. Colder coastal waters were trackable as a distinct plume using sea surface temperature AVHRR (4, 11, and 13 October 1992) images. Figure 6.25 shows the mushroom-shaped plume, with a maximum observed extrusion to 27°N and 91°30'W. This plume was advected between two eddies, Eddy V and Eddy U, surveyed by LATEX C, Survey F04 (P. Hamilton personal communication). This fresh water extrusion was still detectable during the *Pelican* November 1992 Cruise 3. It is clear from *Pelican* Cruise 3 data that the fresh water seen in late October traveled further seaward, extending as far as the 2,000 m isobath. Figure 6.26 is a plot of the *Pelican* Cruise 3 wind data that was extracted from the MIDAS database. This diagram clearly showed the northeasterly to easterly wind forcing responsible for the southerly intrusion of the Mississippi River plume fresh water into the Gulf.

During the summer of 1993, anomalously high rainfall was experienced over the midwestern U.S.A. During the subsequent flood, the Mississippi River discharge was described as streaming to the east (Walker et al. 1994). This was a rare occurrence as ordinarily the flow of fresh water is to the west. This event was shown in an August 1993 satellite image (Figure 6.27) and confirmed by *Pelican* salinity data (from Cruise 6). Salinity contours representing the usual flow of fresh water discharge (August 1992) as well as the anomalous August 1993 discharge may be found in Appendix C. Wind was also thought to be a significant factor in the eastward flow of the river water during this interval.

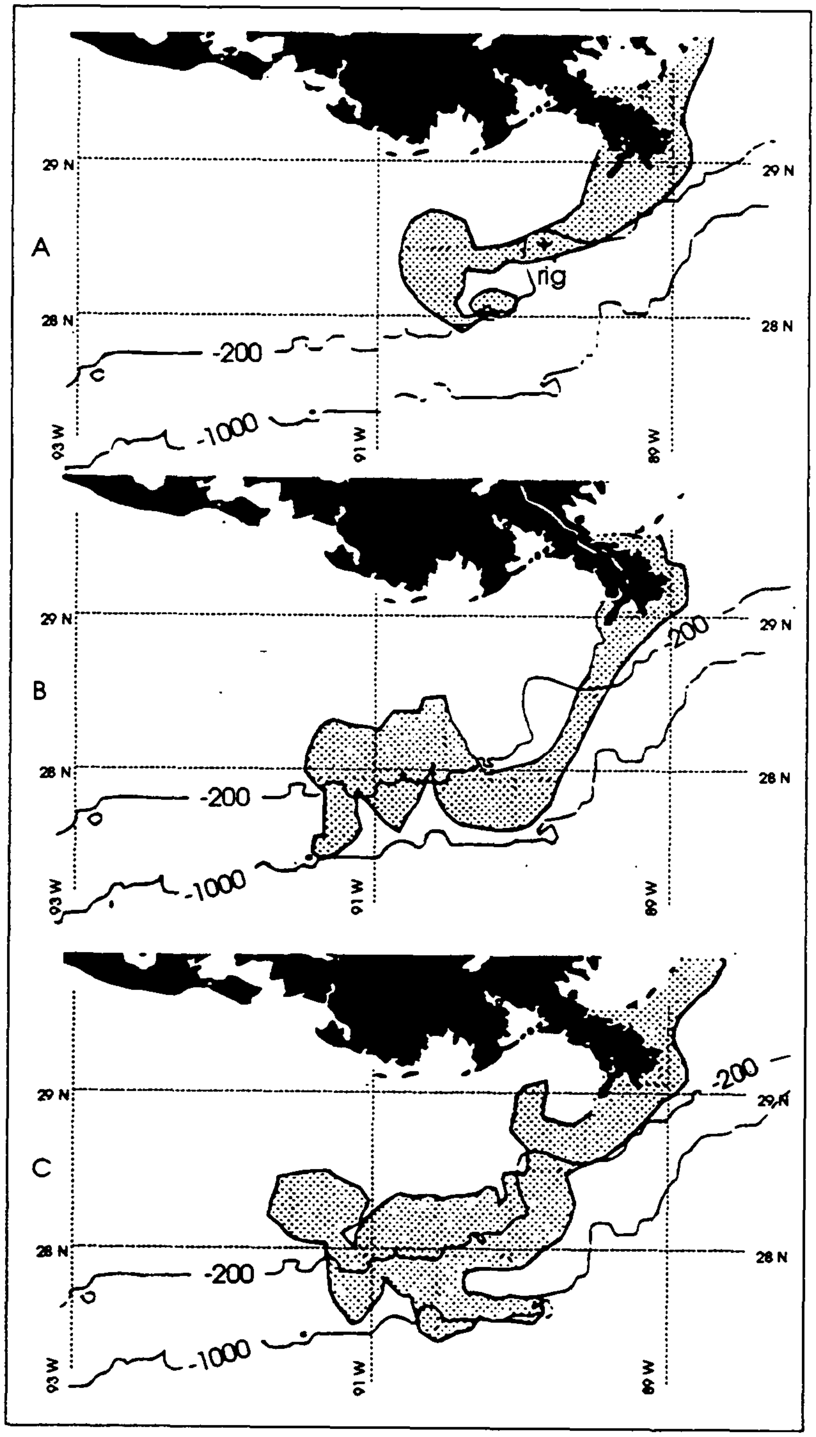

Figure 6.25. Time series diagrams showing the Mississippi River plume and associated primary SST fronts on (a) 4 October 1992, (b) 11 October 1992, and (c) 13 October 1992. The mushroom-shaped plume can be seen by 13 October (courtesy Coastal Studies Institute, Louisiana State University).

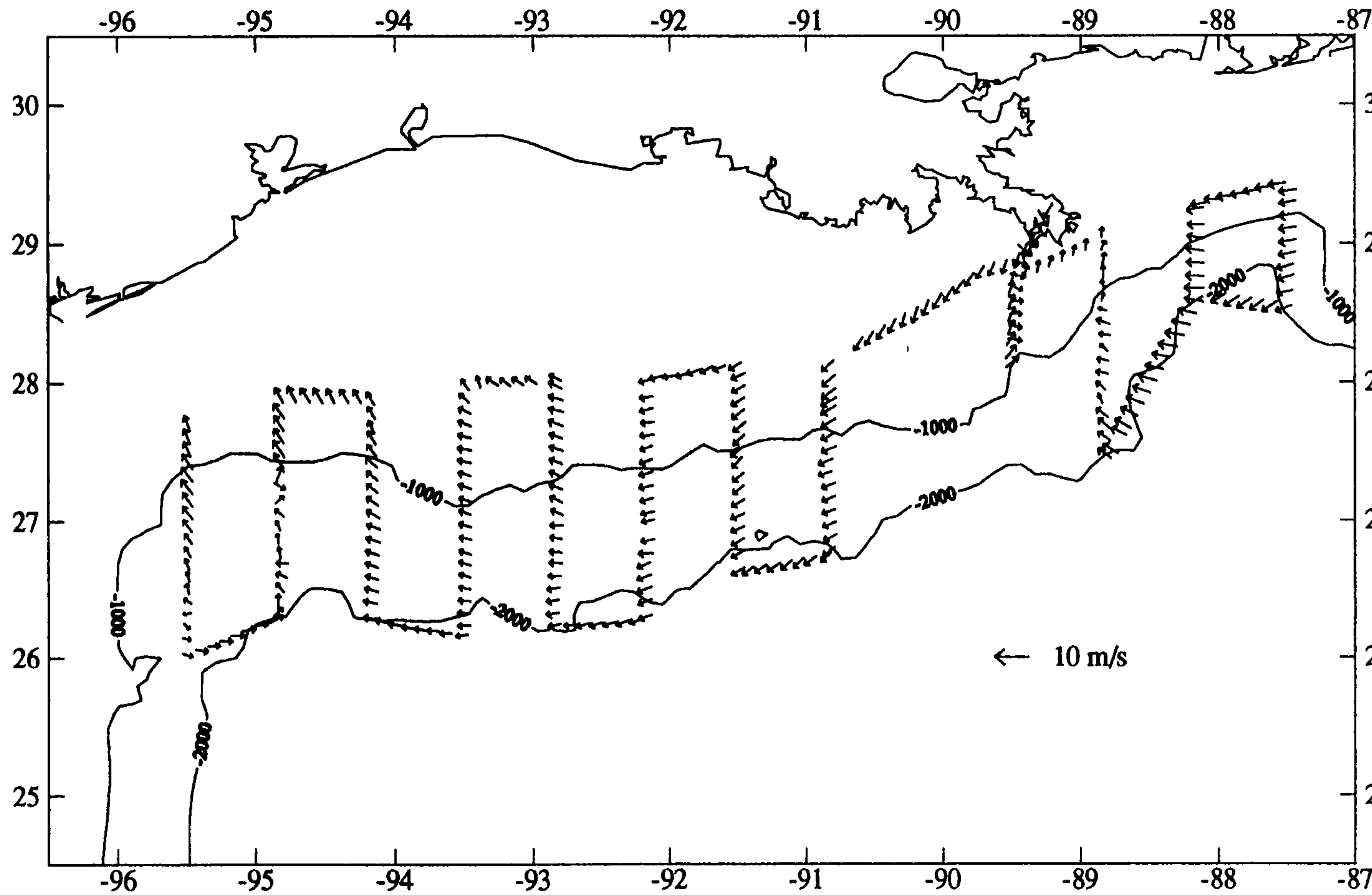

Figure 6.26. *Pelican* fall 1992 Cruise 3 MIDAS wind data plotted to show the northeasterly to easterly wind forcing in area of freshwater extrusion near 27°N, 91°30'W.

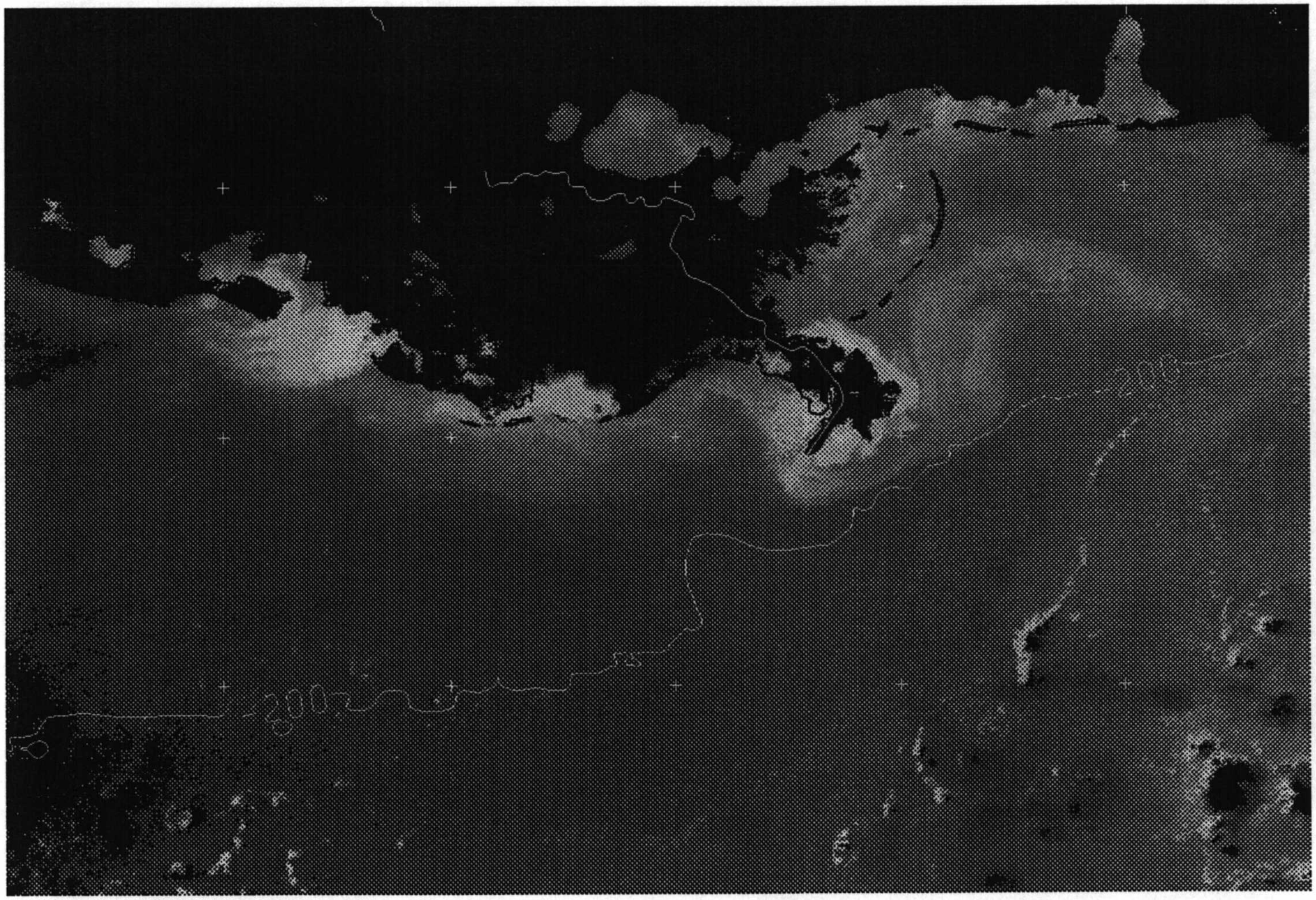

Figure 6.27. NOAA-AVHRR reflectance analysis of the central-western Gulf of Mexico for 10 August 1993 (image courtesy of the Coastal Studies Institute, Louisiana State University).

Figure 6.28 shows the wind data taken on *Pelican* Cruise 6 and the northwesterly to westerly wind patterns that prevailed during late August 1993 in the region east of the Mississippi River delta.

Figures 6.29 and 6.30 shows the fresh water content (or fraction) for August 1992 and August 1993, respectively. A maximum of 56% of fresh water was found east of the Mississippi delta during the summer cruise in 1993. The Mississippi River water was moving eastward, and the fresh water fraction remained above 20% to 87°30'W and seaward to the 2,000 meter contour. The values east of the delta were approximately double those obtained in August 1992 (see Figure 6.29). The fresh water fraction southwest of the delta was 35% in 1993, considerably lower than the fresh water contribution east of the delta, but slightly higher than that encountered in August 1992 (22%).

6.4 Discussion of the Major Oceanographic Features of the North-Central and Western Gulf of Mexico

The GulfCet hydrographic surveys have focused on sampling the meso- to large-scale features of the northwestern (NW) and central (C) Gulf of Mexico. GulfCet data often showed eddy progression to the edge of the Texas-Louisiana shelf. The GulfCet hydrographic program obtained valuable information from other MMS sponsored hydrographic studies concurrently sampling the northern Gulf. These studies included the three program units of the Louisiana-Texas Shelf Physical Oceanography Program (LATEX); LATEX A studied the shelf circulation, LATEX B the Mississippi river plume, and LATEX C the eddy system. The Ship of Opportunity Program (SOOP) also examined the eddy system over the continental slope of the NW Gulf. Therefore, a total of five recent studies have investigated the hydrographic features found in the northwestern to central Gulf, and together provide a nearly comprehensive hydrographic data set for this area for the period 1992-93.

The primary physical oceanographic components of the Gulf are the Loop Current, eddies derived from this feature, and the Mississippi River plume. Eddies are important physically and biologically because they function as pumps, mixing water masses and their constituent organic and inorganic compounds. An eddy's capability for moving great distances coupled with its vorticity and ability to diverge circulation all have an affect on the location of upwelling and downwelling regions in the Gulf. Biggs and Müller-Karger (1994) suggested that the co-occurrence of cyclonic circulation cells in association with anticyclonic eddies may enhance primary productivity by increasing nutrient resources in the upper 200 m. Cyclonic eddies lead to higher production because of the increased upward nutrient flux at their periphery. Furthermore, this cyclonic eddy-anticyclonic eddy pairing transports high-chlorophyll shelf water seaward at least 100-200 km.

Over the period 1992-1993, ship surveys, aerial surveys and satellite coverage allowed continuous monitoring of the Loop Current, eddy shedding, and eddy propagation at unprecedented spatial and temporal resolution. At least three anticyclonic eddies (U, W, and X), each with a diameter of at least 300 km, were shed from the Loop Current during this period, and moved with their

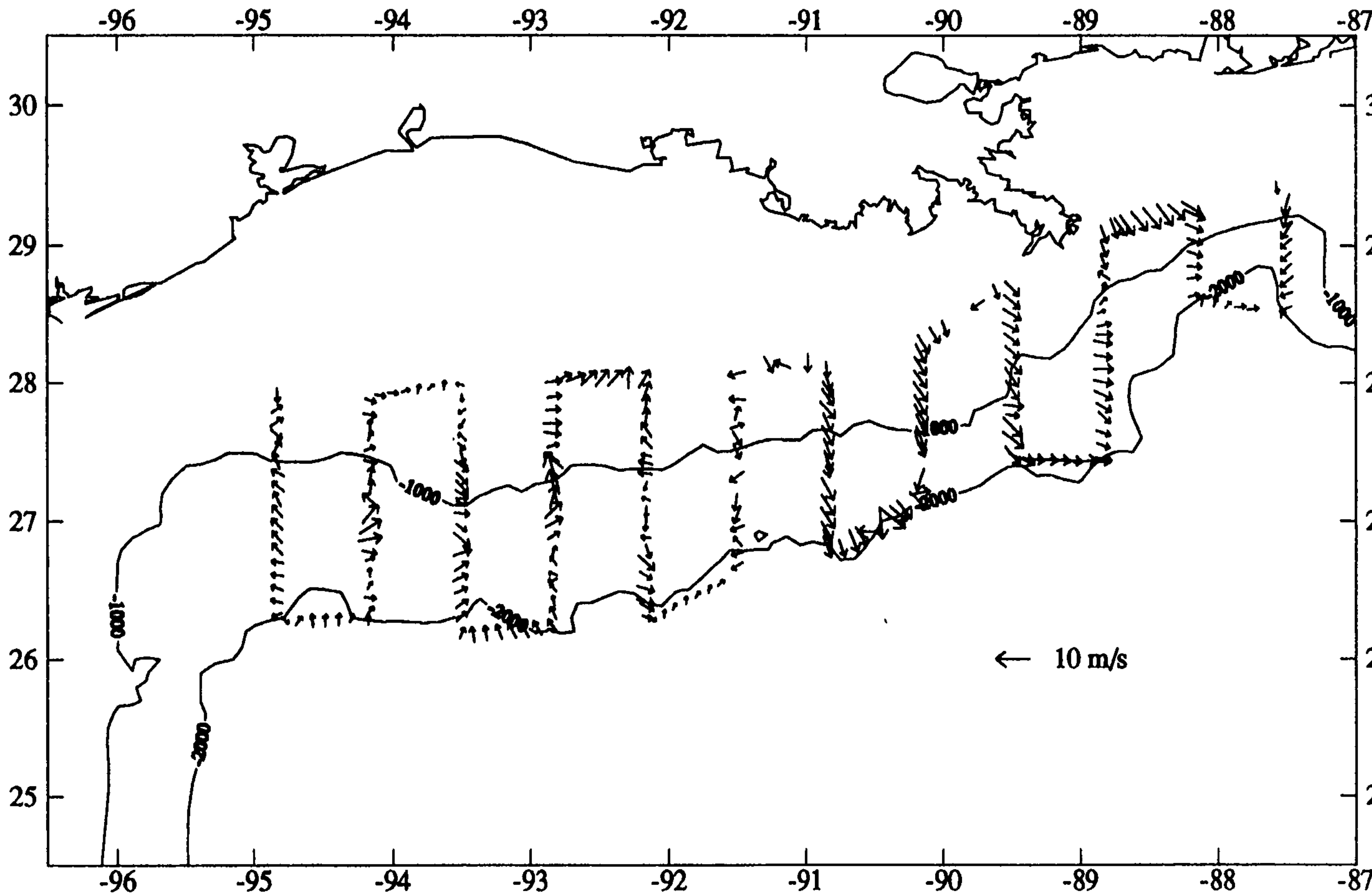

Figure 6.28. *Pelican* summer Cruise 6 MIDAS wind data plot to show the northwesterly to westerly wind forcing in the Mississippi River plume region.

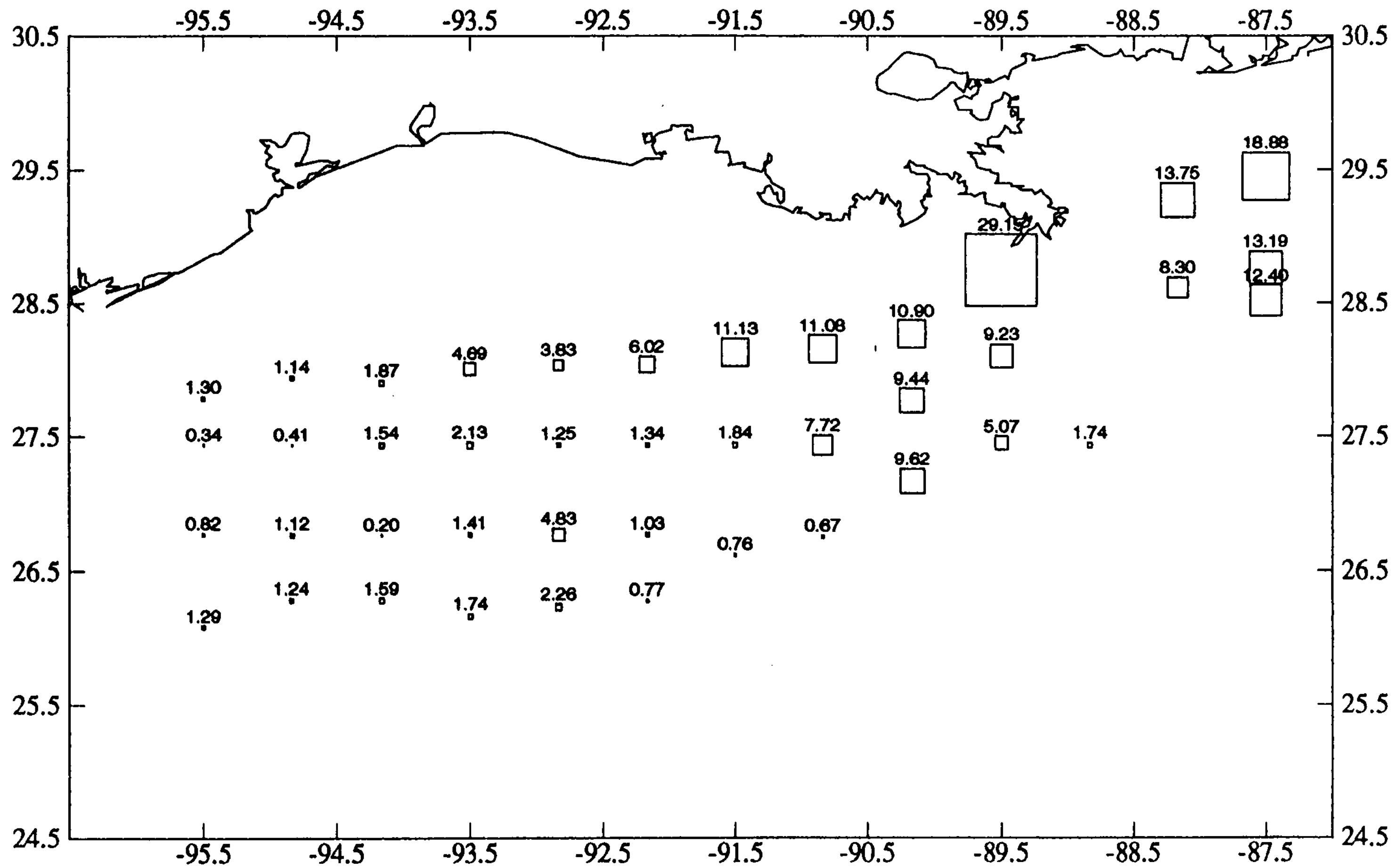

Figure 6.29. Fresh water fraction (%) for 0-3 m depths during the August 1992 *Pelican* summer Cruise 2.

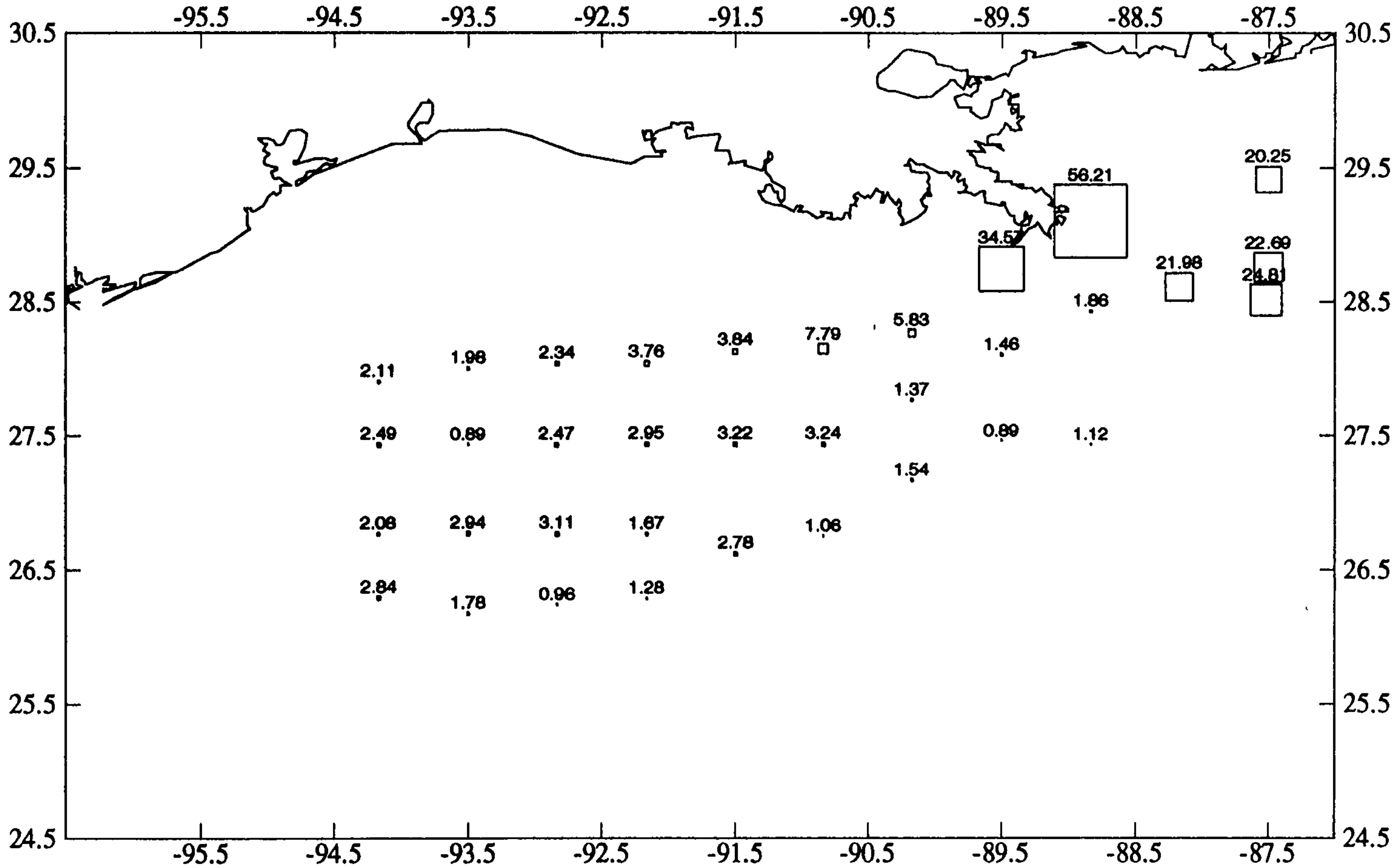

Figure 6.30. Fresh water fraction (%) for 0-3 m depths during the August 1993 *Pelican* summer Cruise 6.

associated cyclonic eddies into the western Gulf. Table 6.5 is a chronological listing of the eddies or oceanographic feature found by each of the aforementioned programs. This table summarizes the survey dates, identity of the study program, and the eddy characteristics (i.e., the depth of the 8 °C isotherm and the dynamic height computed at a 800 db reference level). The integration of hydrographic data with satellite data paints a picture of a complex region where cyclonic-anticyclonic pairs and cyclonic-anticyclonic-cyclonic triad systems interact, merge, and separate several times before disintegrating, or "spinning down" (Jockens et al. 1994).

6.4.1 *Eddy Histories*

Eddy Triton (T) detached from the Loop Current in late summer 1991 with a diameter over 300 km (Biggs et al. 1992). This warm anticyclonic eddy was located in the central Gulf for several months and drifted slowly to the west-southwest (WSW). Biggs et al. (1992) reported a probable interaction between the Loop Current and Eddy Triton in early December 1991. By January 1992, Triton was nearly circular in shape with a diameter of 270 km and exhibited a dynamic height higher than 125 dyn cm at 800 db (Biggs and Müller-Karger 1994, Biggs et al. 1995a). Eddy Triton was located near 25.7°N and 91°W and moved west of 94°W after April 1992. *Pelican* Cruise 1 located the northwestern perimeter of Triton (refer to Appendix C isotherm and dynamic height figures). By late summer 1992, Eddy Triton interacted with the continental margin of the NW Gulf and had a dynamic height of 125 dyn cm. During this interaction with the continental margin, the anticyclonic eddy may have shed vorticity as local regions of cyclonic circulation (Biggs et al. 1992).

Eddy Unchained (U) was shed in mid-summer 1992. This eddy was detected by satellite altimeter data as an anticyclonic geopotential anomaly of +50 dyn cm (Hamilton et al. 1994, Hamilton et al. 1995, Biggs et al. 1995a) and captured an Argos drifter buoy 02447 from the Louisiana shelf in August 1992. During *Pelican* Cruise 2 (August 1992), new Eddy U, as well as old Eddy T, were present in the central and NW corner of the Gulf. Eddy Triton was spinning down in the NW corner with a dynamic height of 125 dyn cm, while Eddy U had a dynamic height greater than 140 dyn cm. Eddy U was vigorous and large, about 300 km diameter, and centered at 25°N and 90°W in September 1992 (Hamilton et al. 1995).

In early fall 1992, drifter trajectory and satellite altimeter data showed that this vigorous eddy (U) soon cleaved into two eddies; a minor eddy, Eddy V, with a dynamic anomaly of +27 dyn cm, and a major eddy, still referred to as Eddy U, with a dynamic anomaly of +40 dyn cm portions (Biggs et al. 1994). A NOAA-AVHRR image of 12 October 1992 captured these two eddies after the split (Figure 6.31). Two hydrographic surveys by SOOP and LATEX C in late October confirmed the separation of V from U (Table 6.5). Dynamic heights at this time were 142 dyn cm and 157 dyn cm for Eddies V and U, respectively (Biggs et al. 1994, Hamilton et al. 1995).

During this period, the smaller Eddy V was centered at the base of the northwestern continental slope, NW of Eddy U. Between September and

Table 6.5. Oceanographic features located during GulfCet, LATEX, and SOOP programs during 1992-1993, and their properties.

Survey	Date	Oceanographic Feature	8°C Isotherm Depth (m)	Dyn. Height (800 db)
GulfCet *Longhorn* Cruise 1	15 May 1992- 1 Apr 1992	Eddy T	> 625 m	115 cm
GulfCet *Oregon II* Cruise 199	15 May 1992- 8 Jun 1992	Loop Current		
LATEX C Surveys F02 & F03	7 Aug 1992 9 Aug 1992	Eddy U	550 m	115 cm
GulfCet *Pelican* Cruise 2	10 Aug 24 1992- 24 Aug 1992	NW corner of Eddy U, Eddy T	 > 600 m 625 m	 > 135 cm > 125 cm
LATEX C Survey F04	11 Oct 1992	Eddy U & Eddy V	both > 675 m	
SOOP Cruise 92G-13	28 Oct 1992- 31 Oct 1992	Eddy U & Eddy V	718 m 656 m	157 cm 142 cm
GulfCet *Pelican* Cruise 3	8 Nov 1992- 22 Nov 1992	Eddy V	650 m	140 cm
LATEX C Survey F05	19 Dec 1992	Eddy V	650 m	
LATEX C Surveys F06 & F07	4 Jan 1993 6 Jan 1993	Eddy V	> 650 m	135 cm
SOOP Cruise 93G-01	9 Jan 1993- 12 Jan 1993	Eddy V	678 m	133 cm
GulfCet *Oregon II* Cruise 203	4 Jan 1993- 14 Feb 1993	Eddy V	>650 m	
GulfCet *Pelican* Cruise 4	12 Feb 1993- 27 Feb 1993	Eddy V & "no name" Eddy	625 m 600 m	125 cm 110 cm
LATEX C Surveys F08 & F09	12 May 1993 16 May 1993	Eddy V (moving inshore)	600 m	
GulfCet *Oregon II* Cruise 204	6 May 1993- 13 June 1993	Loop Current & ps. Eddy V	> 750 m	
GulfCet *Pelican* Cruise 5	23 May 1993- 5 June 1993	Eddy V not present		
SOOP Cruise 93G-07	1 June 1993- 4 June 1993	Eddy W	788 m	170 cm
LATEX C Surveys F010 & F011	28 Aug 1993- 5 Sept 1993	North side Eddy W & Eddy X	575 m > 675 m	125 cm > 145 cm
GulfCet *Pelican* Cruise 6	28 Aug 1993- 5 Sept 1993	North side Eddy W & Eddy X	575 m > 675 m	125 cm > 145 cm
LATEX C Survey F012	28 Oct 1993 31 Oct 1993 1 Nov 1993	Eddy W	650 m	
GulfCet *Pelican* Cruise 7	3 Dec 1993- 14 Dec 1993	North side Eddy X	 > 625 m	 >125 cm
LATEX C Surveys F013 & F014	16-18 Dec 1993 23 Dec 1993	Eddy X	> 625 m	130 cm

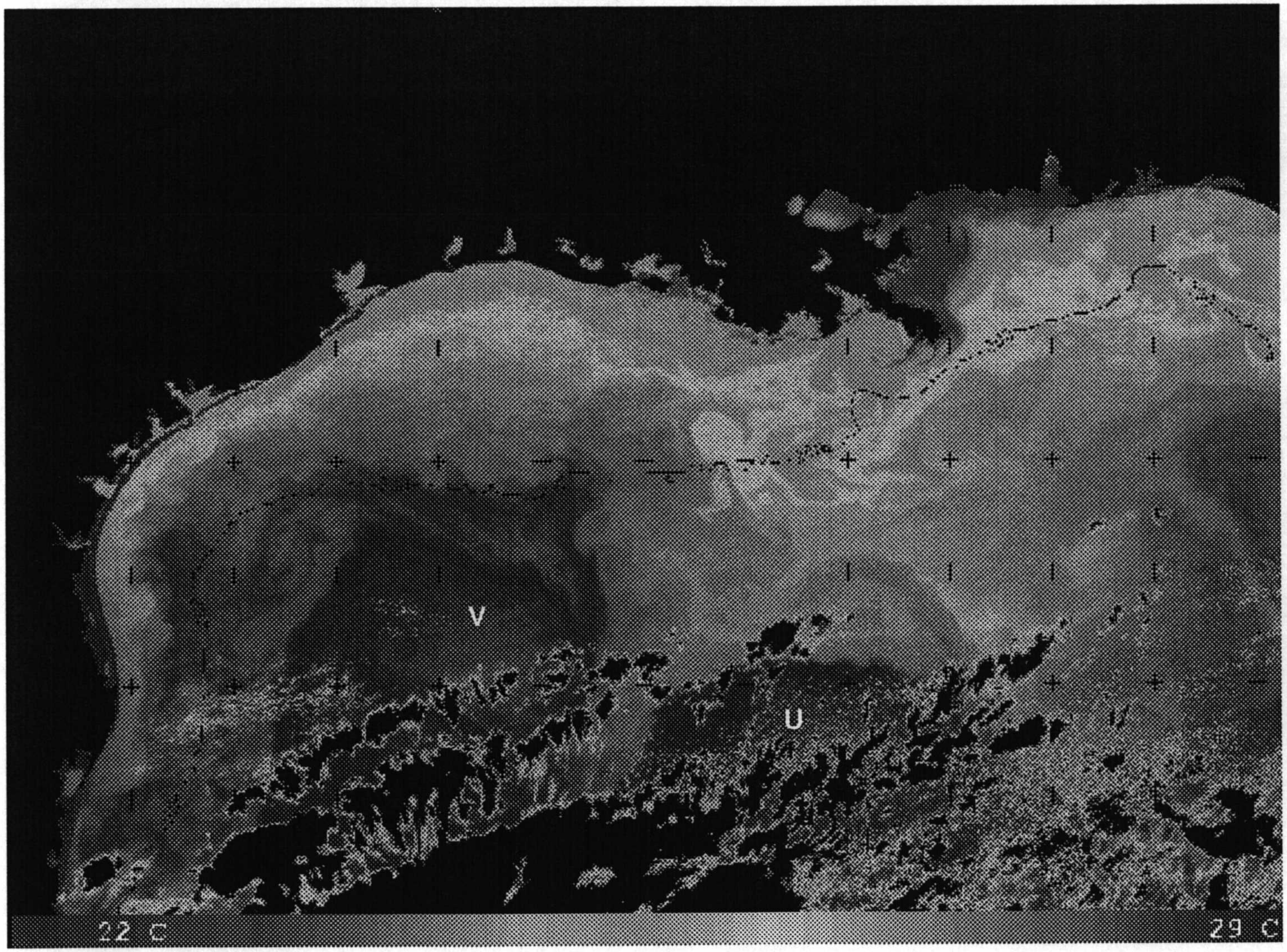

Figure 6.31. NOAA-AVHRR SST (°C) analysis of the western Gulf of Mexico for 12 October 1992, showing Eddy V (northwest) and Eddy U (southeast) (image courtesy of the Coastal Studies Institute, Louisiana State University).

December 1992, Eddy V moved westward along the 2000 m isobath. The remainder of Eddy U advected WSW until it eventually collided with the continental margin of the western Gulf in spring 1993 (Biggs et al. 1994).

Pelican Cruise 3 surveyed Eddy V at the base of the NW corner of the Gulf in late November 1992. The dynamic height of Eddy V was greater than 140 dyn cm. At the same time, Eddy V was entirely surveyed by LATEX A drifter 02447.

In the later half of December 1992, Eddy V abruptly moved northward onto the continental slope in the northwest corner of the Gulf. It remained about the same size (~100 km diameter) and in approximately the same position through May 1993 (Fargion et al. 1994a). In January 1993, a LATEX C survey showed Eddy V to have a dynamic height greater than 135 dyn cm (Fargion et al. 1994a). In the ensuing months, Eddy V continued to spin down while remaining in the same region (NW corner). In late February 1993, *Pelican* Cruise 4 found that Eddy V continued to spin down to a dynamic height of ~125 dyn cm. A NOAA-AVHRR image in mid-February confirmed the location of both Eddies U and V in the Gulf, with Eddy U in the southwest and Eddy V spinning down in the northwest. This image also indicated an interaction between the two eddies with a subsequent water exchange.

Altimetry data suggested that Eddies U and V began to coalesce by mid-to late-March 1993 (Jockens et al. 1994). In early April, LATEX C drifter buoy 02449, which had been circulating in Eddy U, shot north-northeast into the region occupied by Eddy V (Figure 6.32). Throughout the remainder of April, the joined eddies were centered about 24.5°N and 96°W with an arm of Eddy U extending to the Northeast into the region formerly occupied by Eddy V. Thereafter, Eddy V existed primarily as an "arm" extension of Eddy U. Satellite altimetry data showed the presence of cyclonic rings on the northwest and southeast flanks of Eddy V (Jockens et al. 1994). As April progressed, the arm strengthened and extended further north. A NOAA-AVHRR image in mid-April confirmed the altimeter data (Figure 6.33).

In late April to early May 1993, Eddy V was beginning to pinch off Eddy U again, and had its center located at ~27°N x 94.5°W. A LATEX A hydrographic cruise confirmed the presence on the shelf of the anticyclonic Eddy V with associated cyclonic circulation to its northwest (Jockens et al. 1994). Altimetry and NOAA-AVHRR data confirmed that Eddy U and Eddy V separated again by the second week of May (Jockens et al. 1994). The thermal structure obtained from a LATEX C aerial survey in mid-May also showed a full separation of Eddy V from Eddy U, and a weakening of Eddy V. LATEX A drifter buoy 6938, deployed in early-May, circulated in Eddy V throughout May. Satellite altimeter data also indicated cyclonic circulation to the South of Eddy V (Jockens et al. 1994). All that remained of Eddy V by the end of May to the beginning of June was a small region adjacent to the shelf with a weak, generally anticyclonic circulation, and a broad region of cyclonic circulation to the Southeast. *Pelican* Cruise 5 in early June showed, at the most, a weak anticyclonic or absent anticyclonic circulation in the former region of Eddy V. At the same time, drifter buoy 6938 changed course to move in a cyclonic loop to the southeast of Eddy V (Jockens et al. 1994). Eddy V appears to have dissipated completely in the summer of 1993. There is evidence from June and July drifter tracks that a cyclonic eddy may have formed in that region.

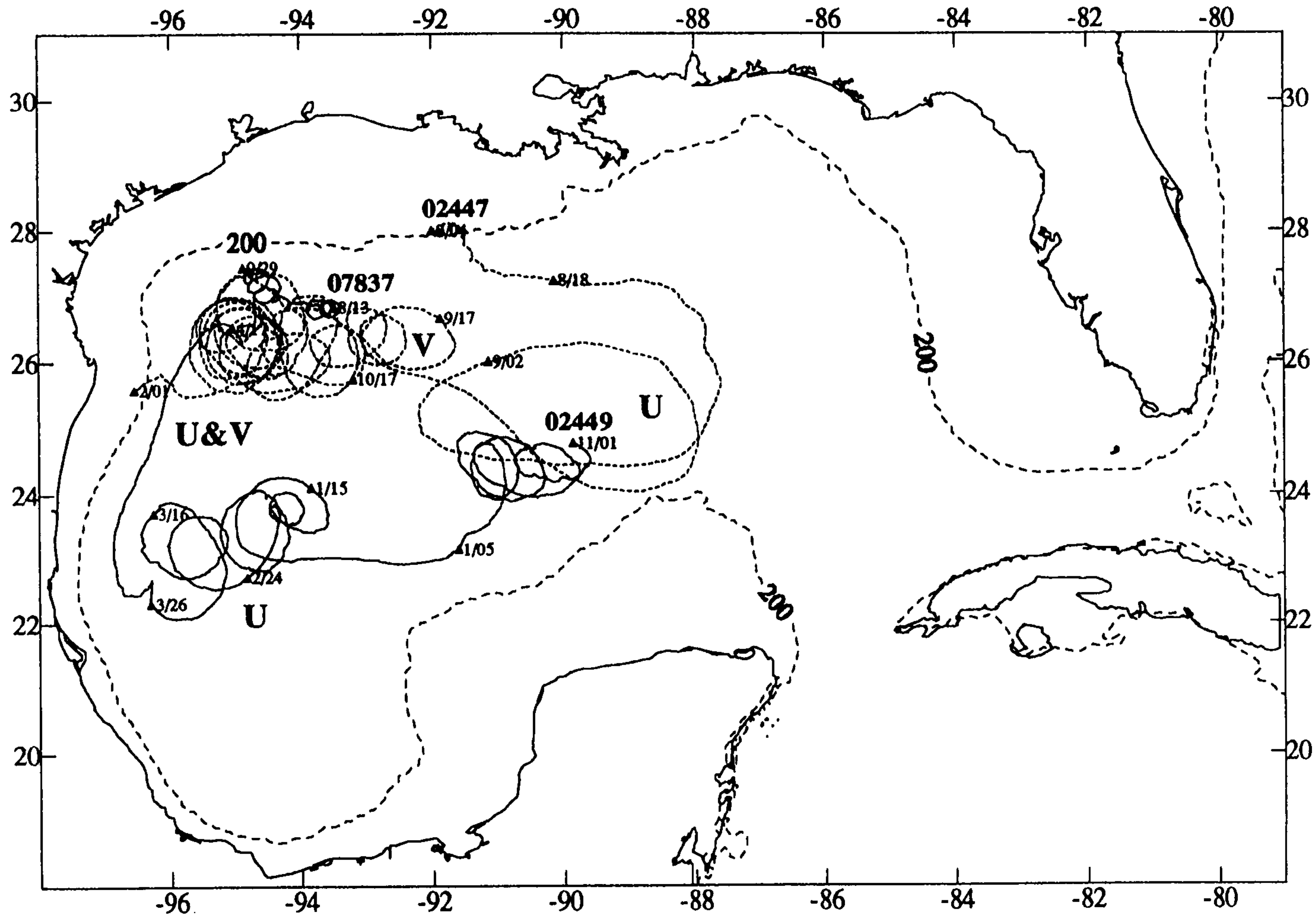

Figure 6.32. Smoothed tracks of LATEX-C drifter buoys 02447, 02449, and 07837, indicating Eddies U and V separately and after their coalescing (drifter buoy data courtesy of the LATEX-C program).

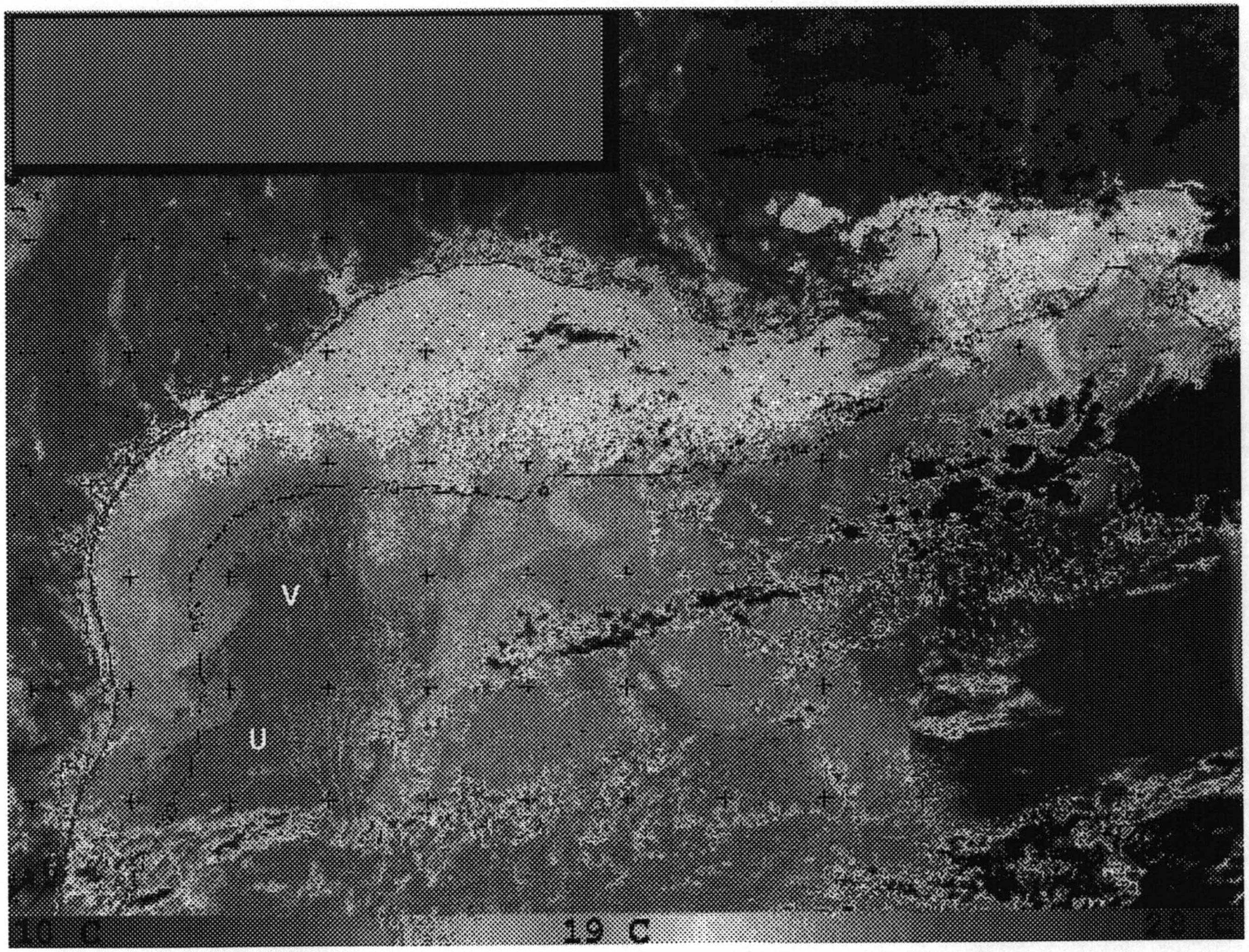

Figure 6.33. NOAA-AVHRR SST (°C) analysis in the western Gulf of Mexico for 18 April 1993, showing Eddy U and Eddy V interacting (image courtesy of the Coastal Studies Institute, Louisiana State University).

Eddy W was formed in June 1993. It was a large eddy that formed a subsidiary warm anticyclonic eddy, similar in size to Eddy V, at the base of the continental slope at about 93°W. Unlike Eddy V, however, this northern portion of Eddy W apparently interacted with a cyclonic eddy on the lower slope and moved rapidly south by southeast, away from the slope in August 1993 (Hamilton et al. 1994, Hamilton et al. 1995, Biggs et al. 1994). Eddy W had an anticyclonic geopotential anomaly of +55 dyn cm. Similar to Eddy U, Eddy W also split into two portions shortly after its formation. A combination of drifter, altimeter, and SST data showed that the northern (minor) portion collided with the continental margin of the NW Gulf in summer 1993, while the southern (major) portion advected WSW and collided with the western margin of the Gulf in December 1993 (Biggs et al. 1994, Fargion et al. 1995). Eddy W was surveyed in August of 1993 by GulfCet *Pelican* Cruise 6 while the eddy moved in the NW corner of the Gulf. At that time, the eddy had a "bone" shape with a dynamic height of 120 dyn cm.

By late August 1993, Eddy X, a large vigorous Loop Current eddy, was located by ship (*Pelican* Cruise 6) on the continental slope at 89.5°W. It was shown to have a dynamic height of 145 dyn cm. Eddy X interacted with an isolated cyclonic eddy on the lower slope between 93° and 92°W, causing the cyclonic eddy to move eastward towards the Loop Current (Hamilton et al. 1995). Eddy X subsequently moved westward along the base of the slope as tracked by AVHRR satellite data in late November (Figure 6.34). In the satellite images from that time, Eddy W appears to be in the NW corner with the cyclonic eddy on the eastern side. In early December 1993, Eddy X was surveyed by ship (*Pelican* Cruise 7) and had a dynamic height greater than 125 dyn cm.

Analysis of NOAA-AVHRR satellite data suggests that Eddies W and X began to coalesce by mid-to-late December, and by early January 1994 they appear to have formed one large eddy with elongated arms (Figure 6.35). Unfortunately, altimeter data were not available for this period. Intense cloud cover over the Gulf resulted in poor NOAA-AVHRR satellite coverage for the first quarter of 1994. The first cloud-free NOAA-AVHRR image was in early May 1994, and no evidence of Eddy W or X was found in the NW corner of the Gulf (Figure 6.36). Clarification of the fate of these eddies will probably be resolved by the LATEX C and SOOP programs, which are to be conducted through 1995.

The life span of the minor portions of Eddies U and W averaged 9 months, while the longevity of the major portions of these eddies averaged 12 months before being lost into the background altimeter sea surface height (SSH) signal (Biggs et al. 1994). A possible four-stage scenario for dissipation of these eddies has been suggested by Dietrich and Lin (1994):

1. The dissipation first occurs at the outer edges, probably because of lateral mixing, so that the eddy decreases in size while maintaining its intensity.

2. This mixing reduces the swirl near the outer edges of the surface eddy, so the outward pressure gradient causes an outward secondary flow.

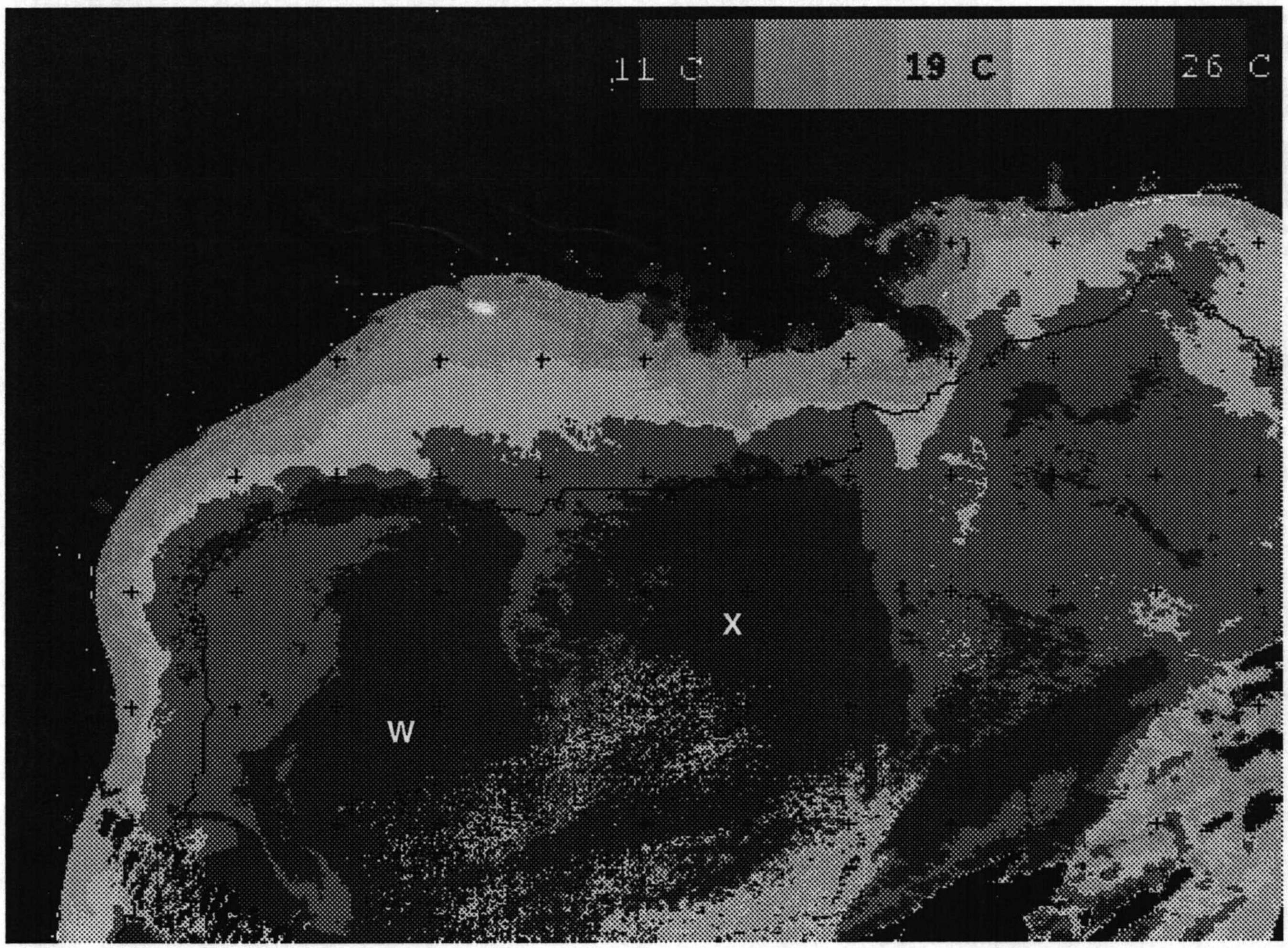

Figure 6.34. NOAA-AVHRR SST (°C) analysis of the western Gulf of Mexico for 28 November 1993, indicating Eddy X (north-central) and Eddy W (northwest) (image courtesy of the Coastal Studies Institute, Louisiana State University).

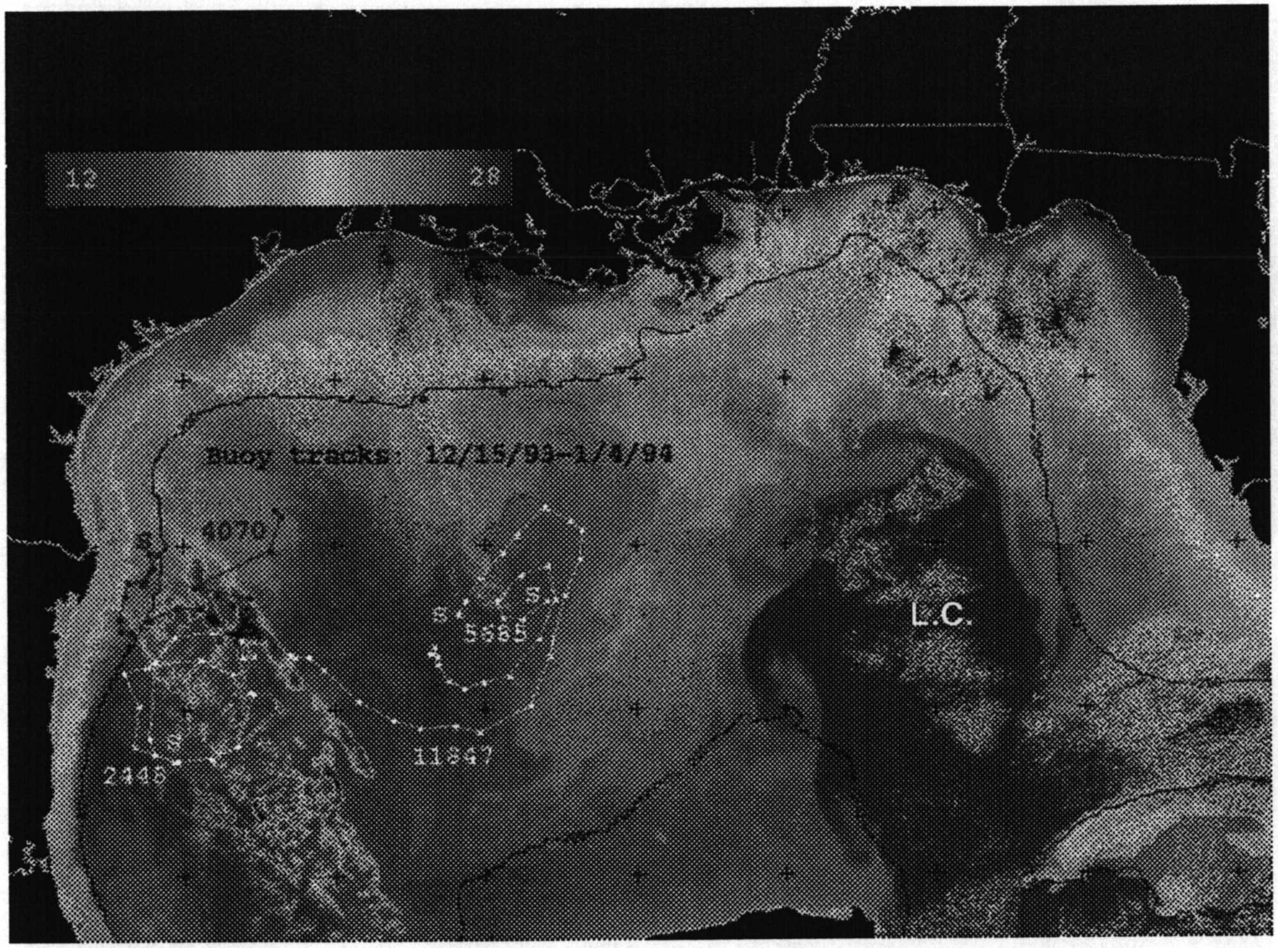

Figure 6.35. NOAA-AVHRR SST (°C) analysis of the western Gulf of Mexico, showing the Loop Current (L.C.) and Eddies X and W merging together to form one large eddy in the SW corner of the Gulf. Drifter buoy tracks from 15 December 1993 to 4 January 1994 have been superimposed over this image to show the coalescence (image courtesy of the Coastal Studies Institute, Louisiana State University, and drifter buoy data courtesy of the LATEX program).

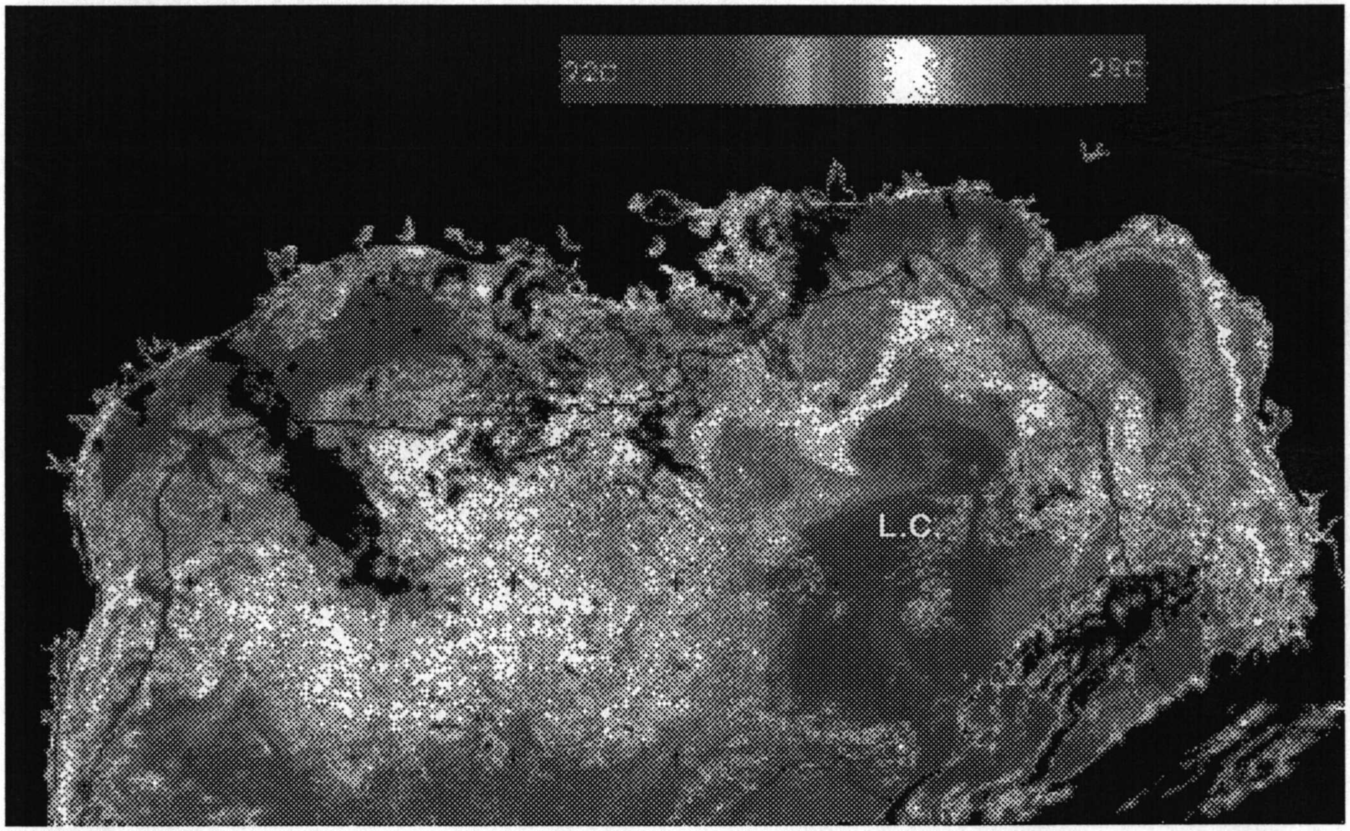

Figure 6.36. NOAA-AVHRR SST (°C) analysis of the western Gulf of Mexico for 7 May 1994, showing the Loop Current (L.C.) with no eddies visible in the central or NW Gulf (image courtesy of the Coastal Studies Institute, Louisiana State University).

3. Mass conservation requires upwelling of cooler water in the central region of the surface eddy, which is trapped above the thermocline because of the strong stratification.

4. The upwelling requires an inward flow toward the eddy core just above the thermocline. The cooling between the surface and the thermocline lowers the surface pressure and increases the pressure near and below the thermocline, resulting in a downward intensification of the eddy.

In terms of water properties, these eddies appear as warm salty bodies. Salinity plots, referenced at 25 and 26 sigma-theta, show that the vertical structure of a recent Loop Current eddy is strongly concentrated above the thermocline, while old anticyclonic eddies in the western Gulf may be strongly concentrated below the surface (200-300 m). Temperature-salinity (T-S) plots of CTD hydrocasts made near ring centers show that four eddies, T, U, V, and X can be distinguished by the high salinity signature of their SCU (> 36.5 PSU in the range 24.5-26.6 sigma theta) (Appendix C Figures). The T-S relationships show the salinity signature of the GCW as the eddies spin down.

6.4.2 *Fresh water Influx*

Two major events related to the Mississippi River occurred during 1992-1993. The first occurred in the fall of 1992 when Mississippi River fresh water extended outward into the Gulf to the 1,000 m isobath. The second event was the "great" flood of 1993, occurring during the summer of 1993. Walker and Rouse (1993) reported an unusual Mississippi River plume feature which occurred in October 1992. Under maximum discharge and under strong northeasterly winds, shelf water was rapidly forced away from the Mississippi River delta and over the continental slope, extending from 88°20'W to 90°50'W and offshore farther than the 1,000 m isobath. This observation was confirmed the following month by *Pelican* Cruise 3, but the fresh water intrusion into the Gulf had extended to the 2,000 m isobath. This nutrient laden fresh water resulted in higher values of chlorophyll at those stations touched by the plume.

A combination of natural variability and global-scale circulation anomalies during the 1992-1993 period resulted in severe and persistent precipitation over the central United States and brought the total flow of the Mississippi River to new records. Monthly mean Mississippi River discharges during April and May were 50% higher than the long-term mean (1930-1992), and August discharge was higher than the long-term peak monthly mean discharge which usually occurs in April (see Chapter 2, Figure 2.4). Undoubtedly, the 1993 El Niño/Southern Oscillation (ENSO) event contributed to the flooding of the Mississippi and Missouri River valleys (Richards et al. 1994). The "Great Flood" of the Mississippi River caused significant changes to the landscape and ultimately, to the coastal ocean. This flooding event was exceptional for the season (summer), duration (weeks to months) and magnitude, all of which created unusual hydrographic features in the Gulf of Mexico. The effects of fresh water were detected not only in the northern Gulf, but also in the Florida Keys and along the U.S. east coast (Walker et al. 1994). The most obvious effect of the increased Mississippi River flow was increased nutrient influx with correspondingly increased phytoplankton concentrations. Dortch (1994) reported that total phytoplankton concentration during the period of flooding was more than an order of magnitude greater than normal. High concentrations of phytoplankton result in an increased carbon flux to the bottom, either as a result of dead plankton sinking or as zooplankton fecal pellets. This higher flux consequently creates large areas of hypoxia.

Wind measurements from Louisiana coastal stations and continental shelf buoys suggested that the eastward flow of the Mississippi plume in the summer 1993 was at least partially wind-driven (Walker et al. 1994). From mid-July through August, surface winds along the Louisiana coast were predominantly westerly and southwesterly. Another concurrent factor was the presence of Eddy X at the delta of Mississippi. Eddy X could have enhanced the eastward direction of the plume of fresh water.

Previous studies have shown a positive correlation between the Mississippi River flow and the interannual variations in chlorophyll concentration, which in turn influences the development of primary productivity in the Gulf. Higher chlorophyll values have been found in association with the fresh water influx from the Mississippi river and cold cyclonic eddies (Fargion et al. 1994b).

6.4.3 *Conclusion*

The *Pelican* and *Oregon II* sampling grid has proved to be useful in sampling the meso- to large-scale features of the Gulf of Mexico. GulfCet was able to detect all the major eddies and events present in the northern Gulf from 1992 to 1993. The hydrographic sampling program was able to detect all the major warm-core eddies as well as their affiliated cold-core eddies. The detection of these cold or cyclonic eddies is particularly significant as upwelled water, with its subsequently higher nutrient and oxygen content, is the result of these oceanographic features.

The study area in 1992-1993 presented a complex hydrographic scenario. The following features were seen: a) new warm anticyclonic eddies with associated cyclonic eddies moved in and out the northern Gulf; b) recently formed warm anticyclonic eddies interacted with older eddies in the northwestern corner of Gulf; and c) unusual fresh water outflow extended offshore as far as the 2,000 m isobath in fall of 1992 and in the summer of 1993 fresh water discharge streamed to the east of the delta. As a result of eddy movement, each of the GulfCet surveys had a unique opportunity to view meso- to large-scale hydrographic features. No generalizations can be made regarding eddy path, residence time, or frequency of occurrence in the study area. Generally, however, after separation from the Loop Current, anticyclonic eddies drift westward until their progress is halted by the northwestern continental slope, in the "eddy graveyard". Some eddies reached the western margin in just a few months, while others took longer and cleaved into secondary eddies during the westward transit. Recent altimeter studies indicate that the interaction of these Loop Current eddies with the western margin of the Gulf of Mexico could drive a Western Boundary Current there (Biggs et al. 1995b).

In the north-central and western Gulf, anticyclonic warm eddies with their affiliated cold cyclonic eddies and the fresh water influx from the Mississippi River are the primary features which can enhance primary productivity and subsequently increase production at higher trophic levels. Biggs and Müller-Karger (1994) reported that the continental slope of the NW Gulf is a region where pelagic predators are abundant. Since these predators (such as skipjack, blackfin tuna, blue marlin, swordfish, and shark) require consistent food sources, they are not likely to be sustained by low primary productivity or infrequent episodes of enhanced primary productivity. Primary productivity, therefore, must be maintained relatively consistently. Particular areas where this level of production are likely to remain relatively consistent are the Mississippi River plume vicinity and the area just peripheral to the eddy pathway from the Loop Current. It is suspected that cetacean food sources, as well, would most likely be concentrated in these areas of consistently higher primary productivity. Cetacean foraging efficiency would be maximized when effort was concentrated in these areas. Therefore, it would seem likely that these areas would be preferred habitats for many marine mammals present in the Gulf.

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VII. BIRD SURVEYS

D.E. Peake

7.1 Introduction

The GulfCet project greatly expanded the knowledge of birdlife in the Gulf of Mexico. Although much information exists concerning the coastal seabirds, very little is known regarding the species composition, distribution, and abundance of pelagic birds in the north-central and western Gulf (Clapp et al. 1982, Clapp et al. 1983). Duncan and Harvard (1980) conducted the only other ship-based pelagic bird census in the Gulf. The Duncan and Harvard study was, however, narrowly focused on the waters offshore of Alabama. Fritts et al. (1983) conducted an aerial census in the Gulf, but it was primarily limited to the continental shelf.

7.2 Methods

Detailed bird observations were made on five *Pelican* cruises (numbers 3, 4, 5, 6, and 7) and the four *Oregon II* cruises (see Chapter 3 for descriptions of transect lines, dates, etc.). During a 30-month period, the survey effort consisted of 160 days at sea in the GulfCet study area. Fifty-five percent of the observations occurred during spring months, 28% during winter, 11% during fall, and 6% during summer.

On *Pelican* Cruises 3-6, a bird observer collected data continuously during daylight hours. On-effort observations were defined in the same manner as for the shipboard marine mammal data collection (Chapter 3). Sampling occurred on the north-south track-lines and on transit between the track-lines. Bird observations were made with hand held 8X or 10X binoculars and were possible when marine mammal observations had been discontinued (up to Beaufort 6 sea state and in light rain and fog).

The methods described by Tasker et al. (1984) were used as a guide for the 300 m strip transect protocol followed for bird observations on *Pelican* Cruises. Sighting effort was concentrated on the area from the bow to the beam of the ship, out to a distance of 300 m on one side of the ship only. All birds seen within 300 m of the ship in this 90° arc were recorded. These data were used for density, distribution, and sighting rate analyses. Birds observed outside the strip area were also recorded, and these data were used for distribution and sighting rates. With the exception of *Pelican* Cruise 3, the distance from the bird to the observer was estimated using the Heineman range finder (Heineman 1981). On Cruise 3, the distance was visually estimated. Sighting data included time, latitude, longitude, species, number of individuals, distance of bird from the ship, behavior of the bird, association with other birds, age and sex of the bird (if this data could be determined), and other comments of the observer concerning the sighting. Weather and sea state were recorded at the beginning and end of each track-line. The line transect method was not used on *Pelican* Cruise 7, but bird species and the numbers of birds sighted were recorded.

For the *Oregon II* cruises, bird observations were done by the marine mammal observers during their normal observing duties. The observations were made along the same track-lines as the marine mammal census, but a 300 meter strip transect was not done. Observations were made using hand-held binoculars and 25X deck-mounted binoculars. Information regarding species, sighting time, location, and number of individuals was recorded and the observations were supervised by an experienced seabird observer. Detailed information regarding time spent on-effort looking for birds was not recorded.

The American Ornithologists' Union (1983) "Check-list of North American Birds" and supplements to that list (1985, 1987, and 1989) were the basis for the bird nomenclature used. Group size for individual species was calculated by dividing the number of individuals seen by the total number of sightings. The latitude and longitude of each sighting was used to extract the estimated depth from the ETOPO-5 data set (Herring 1993). The Two-Sample Wilcoxin Rank-Sum Test was used to compare water depth at sighting location for several species pairs. The species were chosen because they were similar species or because they were often found in the same areas.

7.3 Results

Of the 3,276 total bird sightings, 2,692 were seabirds. Seabirds are defined as coastal, offshore, or pelagic species of birds which have their usual habitats and food sources in the sea (Harrison 1983). Non-seabird species accounted for 584 sightings. Thirty-two species representing nine families and three orders of seabirds were observed (Table 7.1). The scientific and common names of the bird species sighted, a complete listing of the bird sightings, and distribution maps for species with only a few sightings are provided in Appendix A.

7.3.1 *Seabirds*

Table 7.2 shows the seabird species sighted on *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209. The table includes information regarding species, the number of sightings, mean group size, group size range, and mean water depth and depth range at sighting locations. Table 7.3 summarizes the contribution of the most frequently sighted birds to the percent of the total seabird sightings. Overall sighting rates are listed by season and survey for each species in Table 7.4. For *Pelican* Cruises 3-6, the sightings per hour of on-effort observation and number of individuals seen per hour of on-effort observation are listed in Tables 7.5 and 7.6, respectively.

7.3.1.1 *Distribution*

Order Procellariiformes

The Order Procellariiformes is represented by sightings of one unidentified *Pterodroma* sp. petrel, two shearwater species, and three storm-petrel species. Although only one previous record exists for the Gulf, the most likely *Pterodroma* species is the Black-capped Petrel which breeds on Hispaniola (Clapp et al. 1982). Cory's Shearwater was sighted five times at scattered locations throughout the study area on *Pelican* Cruises 3, 5, and 6 (see

Table 7.1. Orders, families, and species of seabirds identified on the GulfCet cruises.

Order Procellariiformes			
	Family Procellariidae (gadfly petrels and shearwaters)		
			gadfly-petrel (*Pterodroma* sp.)
			Cory's Shearwater (*Calonectris diomedea*)
			Audubon's Shearwater (*Puffinus lherminieri*)
	Family Hydrobatidae (storm-petrels)		
			Wilson's Storm-Petrel (*Oceanites oceanicus*)
			Band-rumped Storm-Petrel (*Oceanodroma castro*)
			Leach's Storm-Petrel (*Oceanodroma leucorhoa*)
Order Pelecaniformes			
	Family Phaethontidae (tropicbirds)		
			Red-billed Tropicbird (*Phaethon aethereus*)
			White-tailed Tropic-bird (*Phaethon lepturus*)
	Family Pelecanidae		
			Brown Pelican (*Pelecanus occidentalis*)
	Family Sulidae (gannets and boobies)		
			Northern Gannet (*Sula bassanus*)
			Masked Booby (*Sula dactylatra*)
	Family Phalacrocoracidae (cormorants)		
			Unidentified Cormorant (*Phalacrocorax* sp.)
	Family Fregatidae (frigatebirds)		
			Magnificient Frigatebird (*Fregata magnificens*)
Order Charadriiformes			
	Family Scolopacidae (sandpipers and allies)		
		Subfamily Phalaropidinae	
			Red Phalarope (*Phaloropus fulicaria*)
	Family Laridae (jaegers, gulls, terns, and skimmers)		
		Subfamily Stercorariinae (jaegers)	
			Pomarine Jaeger (*Stercorarius pomarinus*)
			Parasitic Jaeger (*Stercorarius parasiticus*)
		Subfamily Larinae (gulls)	
			Laughing Gull (*Larus atricilla*)
			Franklin's Gull (*Larus pipixcan*)
			Bonaparte's Gull (*Larus philadelphia*)
			Ring-billed Gull (*Larus delawarensis*)
			Herring Gull (*Larus argentatus*)
		Subfamily Sterninae (terns)	
			Gull-billed Tern (*Sterna nilotica*)
			Royal Tern (*Sterna maxima*)
			Sandwich Tern (*Sterna sandvicensis*)
			Common Tern (*Sterna hirundo*)
			Forster's Tern (*Sterna forsteri*)
			Least Tern (*Sterna antillarum*)
			Bridled Tern (*Sterna anaethetus*)
			Sooty Tern (*Sterna fuscata*)
			Black Tern (*Chilidonias niger*)
			Brown Noddy (*Anous stolidus*)
		Subfamily Rynchopinae (skimmers)	
			Black Skimmer (*Rynchops niger*)

Table 7.2. **Seabird sighting results for *Pelican* Cruises 3-7, with range of water depth at sighting location, mean water depth at sighting location, and mean group size *of seabirds sighted.***

Species	Number Sightings	Mean Depth (m)	Depth Range (m)	Mean Group Size	Group Size Range
Unidentified gadfly-petrel	1	1314	1314	1.0	1
Cory's Shearwater	5	1004	89-1809	1.4	1-3
Audubon's Shearwater	127	1209	106-2184	1.7	1-32
Wilson's Storm-Petrel	54	747	111-1998	1.4	1-12
Band-rumped Storm-Petrel	41	1332	216-2714	1.3	1-5
Leach's Storm-Petrel	8	719	405-1153	1.1	1-2
Unidentified storm-petrels	572	1044	196-1997	1.3	1-18
Red-billed Tropicbird	1	1837	1837	1.0	1
White-tailed Tropicbird	3	1805	1677-1982	1.3	1-2
Magnificent Frigatebird	15	723	75-1772	1.5	1-4
Unidentified frigatebird	15	828	192-1399	1.8	1-11
Unidentified cormorant	1	1335	1335	1.0	1
Northern Gannet	49	792	103-2341	1.9	1-20
Masked Booby	77	1142	111-2306	1.2	1-4
Brown Pelican	1	100	100	1.0	1
Red Phalarope	1	1995	1995	1.0	1
Unidentified phalarope	2	1132	850-1415	5.5	5-6
Pomarine Jaeger	292	1335	109-2587	1.9	1-20
Parasitic Jaeger	3	656	338-815	1.0	1
Unidentified jaegers	247	1228	102-2380	2.0	1-100
Laughing Gull	369	805	100-2313	2.1	1-50
Franklin's Gull	1	1406	1406	1.0	1
Bonaparte Gull	1	219	219	1.0	1
Ring-billed Gull	16	982	131-1733	1.8	1-5
Herring Gull	102	699	9-2584	2.0	1-20
Gull-billed Tern	1	471	471	1.0	1
Royal Tern	17	674	9-2584	1.3	1-3
Sandwich Tern	19	795	102-1825	1.8	1-4
Common Tern	7	1196	106-1410	1.7	1-2
Forster's Tern	2	490	312-669	1.0	1
Least Tern	3	592	106-1880	1.7	1-2
Bridled Tern	113	886	104-2176	1.8	1-25
Sooty Tern	40	1212	125-1993	5.8	1-48
Black Tern	412	752	75-2104	9.8	1-400
Brown Noddy	2	1493	1396-1591	1.0	1
Unidentified tern	251	1097	136-2006	1.2	1-2
Black Skimmer	4	849	252-1431	2.2	1-3

Table 7.3. **Summary of seabird sightings by percentage of total seabird sightings.**

Species or species category	Percentage of total seabird sightngs*
Total terns	(32.4)
Total storm-petrels	(25.1)
Unidentified storm-petrels	21.2
Total jaegers	(20.0)
Black Tern	15.3
Laughing Gull	13.7
Pomarine Jaeger	10.8
Unidentified tern	9.3
Unidentified jaegers	9.2
Audubon's Shearwater	4.7
Bridled Tern	4.2
Herring Gull	3.8
Masked Booby	2.9
Wilson's Storm-Petrel	2.0
Northern Gannet	1.8
Band-rumped Storm-Petrel	1.5
Sooty Tern	1.5
Total frigatebirds	(1.1)

* Species listed are those which compromise more than 1% of the total seabird sightings. Sighting percentages for species groupings listed in parentheses represent the totals of species categories also considered separately and should not be summed with other percentages.

Appendix A for distribution map). It is likely that the birds recorded as unidentified large shearwaters were Cory's Shearwaters, but sighting conditions did not permit separation from other possibilities, such as Greater Shearwater. However, it was possible to separate them from smaller shearwaters, such as Audubon's Shearwater. Audubon's Shearwaters were sighted on *Pelican* Cruises 3, 5, 6 (one sighting on Cruise 6 consisted of 32 individuals), and 7 and *Oregon II* Cruises 199, 203, 204, and 209 (Figure 7.1). Sightings of small *Puffinus* shearwaters were listed as unidentified small shearwaters if sighting conditions did not allow absolute separation of Audubon's Shearwater from other possibilities such as Manx Shearwater and Little Shearwater. Manx Shearwater is rare in the Gulf, while Little Shearwater has not been sighted there (Clapp et al. 1982).

Three species of the Family Hydrobatidae were sighted: Wilson's Storm-Petrel, Band-rumped Storm-Petrel, and Leach's Storm-Petrel. Fifty-four Wilson's Storm-Petrel sightings were made on *Pelican* Cruise 5 and all three spring *Oregon II* cruises (Figure 7.2). Forty-one sightings of the Band-rumped Storm-

Table 7.4. **Mean bird sightings per day by season.**

Species	Spring	Summer	Fall	Winter	Annual mean
Black Tern	3.53	10.10			3.408
Pomarine Jaeger	1.16		2.61	2.59	1.590
Laughing Gull	1.75	0.50	0.28	3.76	1.573
Unidentified storm-petrel	5.24	0.30	0.11	0.06	1.428
Unidentified jaeger	0.93		2.17	2.28	1.345
Audubon's Shearwater	0.89	3.50	0.33	0.15	1.218
Unidentified tern	2.42	1.30	0.78	0.04	1.135
Bridled Tern	0.98	2.50	0.06		0.885
Herring Gull	0.03		0.28	1.72	0.508
Masked Booby	0.66	0.90	0.33	0.07	0.490
Magnificent Frigatebird		1.50			0.375
Sooty Tern	0.22	0.90		0.02	0.285
Northern Gannet	0.01		0.22	0.81	0.260
Sandwich Tern	0.10	0.50	0.06		0.165
Wilson's Storm-Petrel	0.63				0.158
Common Tern	0.02	0.50			0.130
Band-rumped Storm-Petrel	0.47				0.118
Cory's Shearwater	0.05	0.20	0.11		0.090
Royal Tern	0.09	0.10		0.15	0.085
Ring-billed Gull				0.30	0.075
White-tailed Tropicbird	0.01	0.20	0.06		0.068
Least Tern	0.02	0.20			0.055
Unidentified frigatebird	0.16				0.040
Leach's Storm-Petrel	0.09				0.023
Parasitic Jaeger	0.03				0.008
Black Skimmer	0.03				0.008
Unidentified phalarope	0.02				0.005
Forster's Tern	0.02				0.005
Brown Noddy	0.02				0.005
Unidentified gadfly-petrel				0.02	0.005
Unidentified cormorant				0.02	0.005
Bonaparte's Gull				0.02	0.005
Red Phalarope	0.01				0.003
Red-billed Tropicbird	0.01				0.003
Gull-billed Tern	0.01				0.003
Franklin's Gull	0.01				0.003
Brown Pelican	0.01				0.003

Table 7.5. Summary of bird sightings per effort-hour for *Pelican* Cruises 3, 4, 5, and 6 as well as the mean for the four cruises combined.

Species	*Pelican* Cruise 3 (fall)	4 (winter)	5 (spring)	6 (summer)	Overall mean
	(Birds/hour)				
Cory's Shearwater	0.030		0.016	0.014	0.0149
Audubon's Shearwater	0.074		0.016	0.434	0.1309
Unidentified gadfly-petrel		0.010			0.0025
Wilson's Storm-Petrel					0.0000
Band-rumped Storm-Petrel			0.176		0.0440
Unidentified storm-petrel	0.015	0.012	0.016	0.042	0.0212
White-tailed Tropicbird				0.014	0.0035
Northern Gannet	0.029	0.181			0.0526
Masked Booby	0.044		0.016	0.112	0.0430
Magnificent Frigatebird				0.140	0.0350
Pomarine Jaeger	0.265	0.677	0.048		0.2475
Unidentified jaeger	0.440	0.072	0.032		0.1360
Laughing Gull	0.030	0.677		0.042	0.1871
Bonaparte's Gull		0.012			0.0030
Herring Gull	0.015	0.496			0.1277
Royal Tern		0.024	0.032	0.014	0.0175
Sandwich Tern				0.070	0.0175
Common Tern				0.056	0.0140
Least Tern				0.028	0.0070
Unidentified white backed tern	0.030	0.012		0.014	0.0139
Bridled Tern			0.048	0.294	0.0855
Sooty Tern			0.016	0.098	0.0285
Unidentified dark backed tern		0.012	0.016	0.112	0.0350
Black Tern				0.785	0.1963
Brown Noddy			0.032		0.0080

Petrel were made on *Pelican* Cruise 5 and *Oregon II* Cruises 199, 204, and 209 (Figure 7.3). Eight Leach's Storm-Petrel sightings were made on *Oregon II* Cruises 199, 204, and 209. Unidentified storm-petrels were sighted on *Pelican* Cruises 3-6 and all four *Oregon II* cruises (Figure 7.4). The total of all storm-petrel (Wilson's Storm-Petrel, Band-rumped Storm-Petrel, Leach's Storm-Petrel, plus unidentified storm-petrel) sightings represented 25.1% of all of the GulfCet seabird sightings (Table 7.3).

Table 7.6. Summary of the number of bird individuals seen per effort-hour on *Pelican* Cruises 3, 4, 5, and 6, including the mean for the four cruises.

Species	*Pelican* Cruise 3 (fall)	4 (winter)	5 (spring)	6 (summer)	Overall mean
	(Birds/hour)				
Cory's Shearwater	0.030		0.048	0.014	0.0229
Audubon's Shearwater	0.088		0.016	1.290	0.3485
Unidentified gadfly-petrel		0.010			0.0025
Wilson's Storm-Petrel					0.0000
Band-rumped Storm-Petrel			0.223		0.0558
Unidentified storm-petrel	0.029	0.012	0.016	0.056	0.0284
White-tailed Tropicbird				0.028	0.0070
Northern Gannet	0.044	0.604			0.1621
Masked Booby	0.074		0.016	0.126	0.0539
Magnificent Frigatebird				0.196	0.0490
Pomarine Jaeger	0.295	0.967	0.048		0.3275
Unidentified jaeger	0.781	0.085	0.032		0.2244
Laughing Gull	0.030	1.170		0.042	0.3104
Bonaparte Gull		0.012			0.0030
Herring Gull	0.015	1.050			0.2662
Royal Tern		0.024	0.048	0.028	0.0250
Sandwich Tern				0.140	0.0350
Common Tern				0.056	0.0140
Least Tern				0.056	0.0140
Unidentified white backed tern	0.044	0.012		0.014	0.0175
Bridled Tern			0.064	0.509	0.1432
Sooty Tern			0.032	0.504	0.1340
Unidentified dark backed tern		0.012	0.032	0.140	0.0460
Black Tern				23.200	5.8000
Brown Noddy			0.032		0.0080

Order Pelecaniformes

Two species of the Family Phaethontidae were observed in the GulfCet study area. The Red-billed Tropicbird was spotted on *Oregon II* Cruise 209, and White-tailed Tropicbirds were sighted on *Pelican* Cruises 3 and 6 and *Oregon II* Cruise 204. All four sightings occurred in waters deeper than 1,500 meters. Clapp et al. (1982) have suggested that these species may be more common far offshore than previous records had indicated.

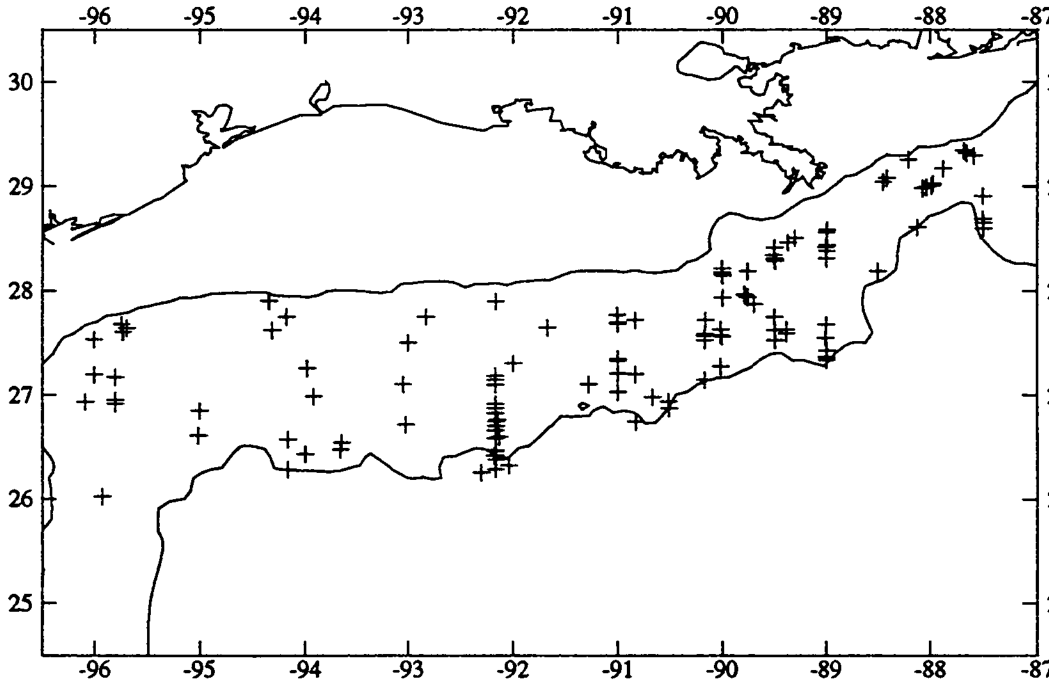

Figure 7.1. Audubon's shearwater sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

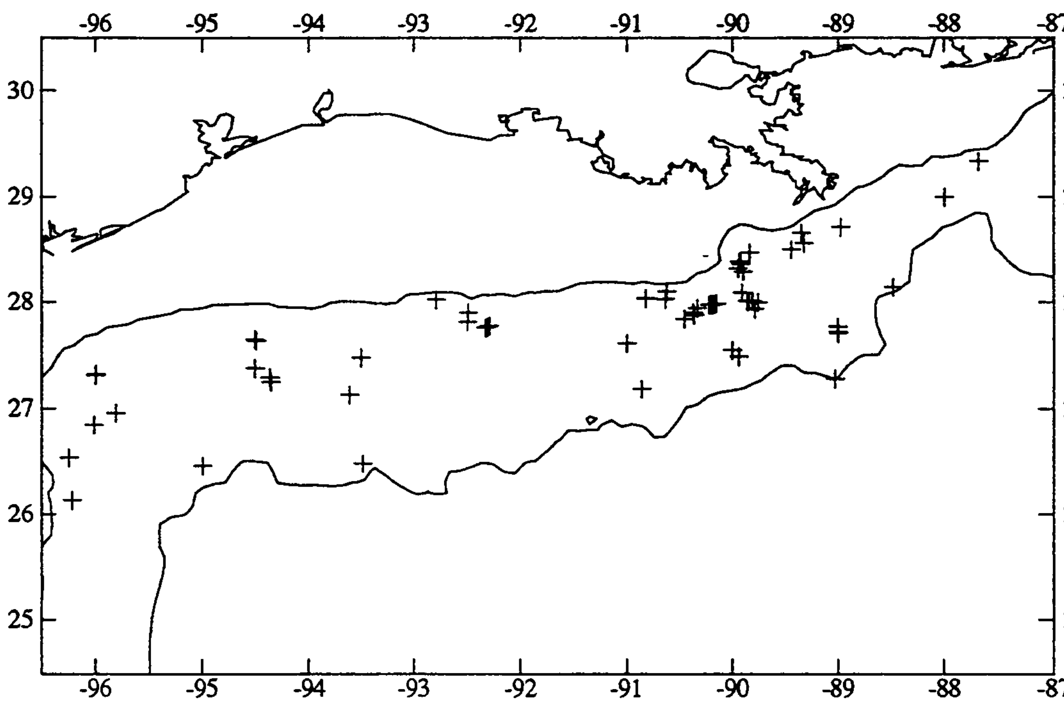

Figure 7.2. Wilson's Storm-Petrel sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

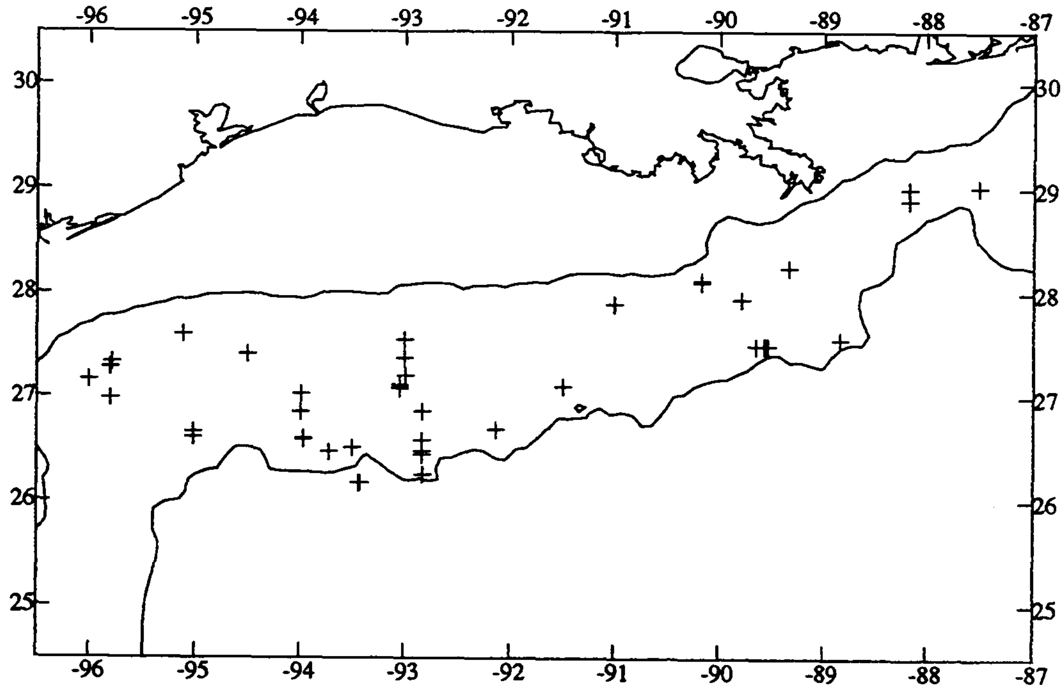

Figure 7.3. Band-rumped Storm-Petrel sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

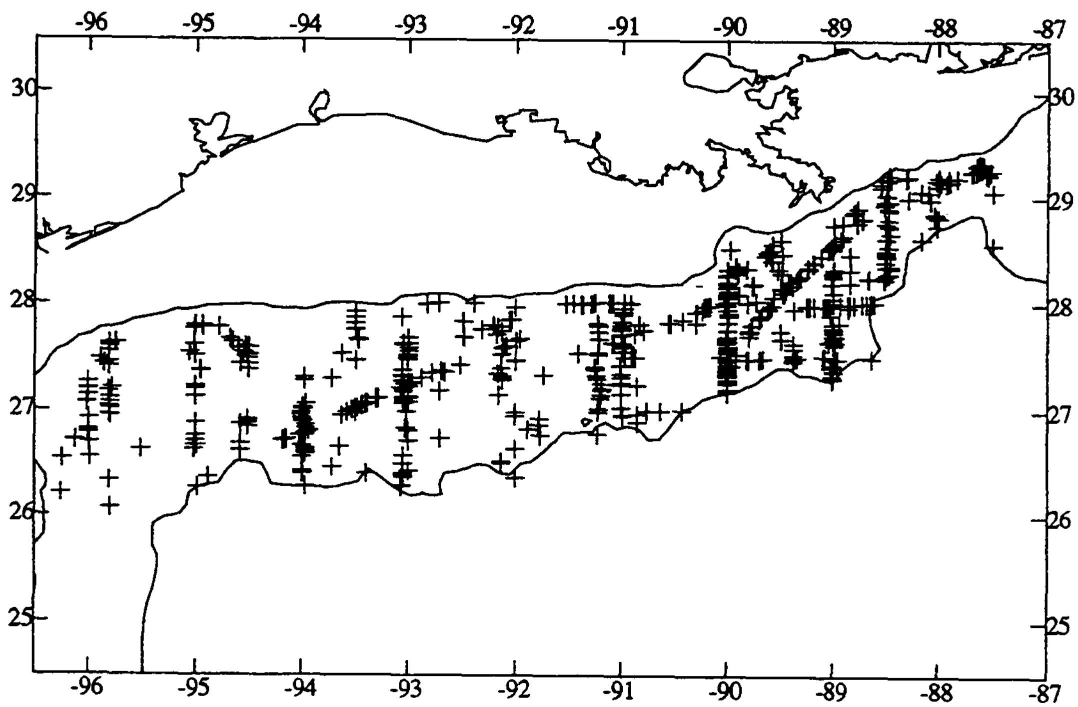

Figure 7.4. Unidentified Storm-Petrel sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

The Magnificent Frigatebird was the only member of the Family Fregatidae identified (Figure 7.5). The records for unidentified Frigatebirds (Figure 7.6) most likely represent Magnificent Frigatebirds, since no other species has been recorded in the Gulf (Clapp et al. 1982). Frigatebirds were noted only during the April-November time period.

The Family Phalacrocoracidae was represented by one sighting of an unidentified *Phalacrocorax* spp. noted on *Oregon II* Cruise 203. Two species of the Family Sulidae were sighted, the Northern Gannet and the Masked Booby. Since the Gulf is primarily a winter habitat for the Northern Gannet (Clapp et al. 1982), it is not unexpected that all but one of the sightings occurred from November through February. Sightings of the Northern Gannet were made on *Pelican* Cruises 3, 4, and 7 and *Oregon II* Cruises 203 and 209 (Figure 7.7). The Masked Booby was seen on *Pelican* Cruises 3, 5, 6, and 7 and *Oregon II* Cruises 199, 203, 204, and 209. However, 92% of the sightings occurred from April through November (Figure 7.8).

A single Brown Pelican, Family Pelecanidae, was seen on *Oregon II* Cruise 199. This species is typically found nearshore and only rarely found farther than 65 km offshore (Schreiber 1978). The paucity of GulfCet sightings was therefore as expected.

<u>Order Charadriiformes</u>

Only three sightings of Phalaropes (Family Scolopacidae, Subfamily Phalaropidinae) were made: one of Red Phalarope and two of unidentified phalarope (Table 7.2). The Family Laridae, however, comprises 70.7% of all seabird sightings and contains 18 of the 32 species seen (Table 7.3).

Pomarine Jaegers were sighted 292 times on *Pelican* Cruises 3, 4, 5, and 7 and *Oregon II* Cruises 199, 203, 204, and 209 (Figure 7.9). Parasitic Jaegers were seen only three times, all on *Oregon II* Cruise 204. Unidentified jaegers were sighted 247 times and were observed on the same cruises as Pomarine Jaeger, with the exception of *Pelican* Cruise 7 (Figure 7.10). On 24 February 1993 (*Pelican* Cruise 4), one flock of at least 100 unidentified jaegers was seen apparently feeding on the water surface in the vicinity of sperm whales. Pomarine Jaegers represented 10.8%, Parasitic Jaegers 0.1%, unidentified jaegers 9.2%, and all jaegers together 20.0% of the seabird sightings (Table 7.3).

The Laughing Gull, with 368 sightings, was the most commonly seen species of gull and was observed on *Pelican* Cruises 3-7 and all four *Oregon II* cruises (Figure 7.11). Only one sighting each was made of the Franklin's Gull (*Oregon II* Cruise 199) and the Bonaparte's Gull (*Pelican* Cruise 4). The Ring-billed Gull was seen 16 times, on *Oregon II* Cruise 203 (Figure 7.12). The Herring Gull was sighted 102 times, and 97% of sightings occurred on the cruises occurring November through February

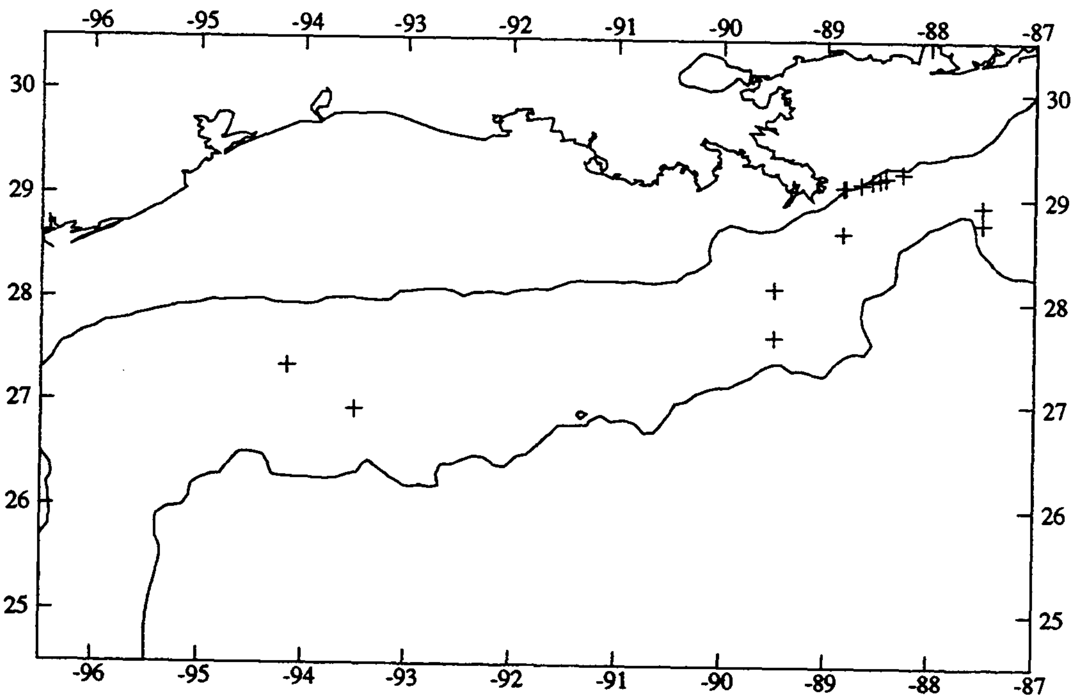

Figure 7.5. Magnificent Frigatebird sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

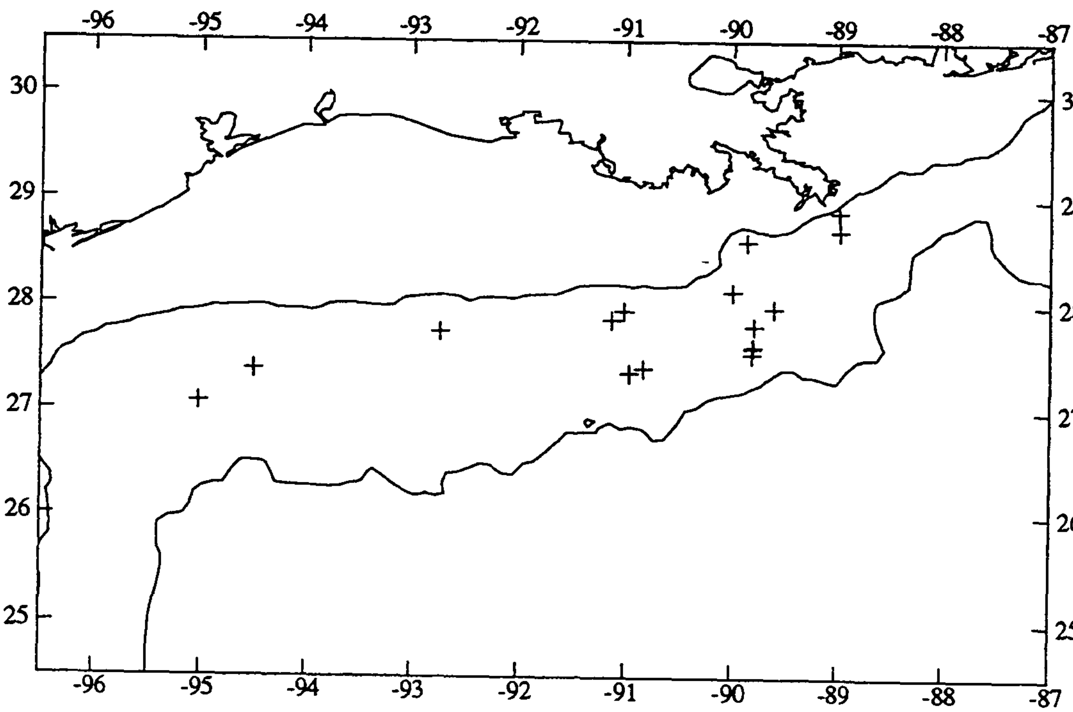

Figure 7.6. Unidentified frigatebird sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

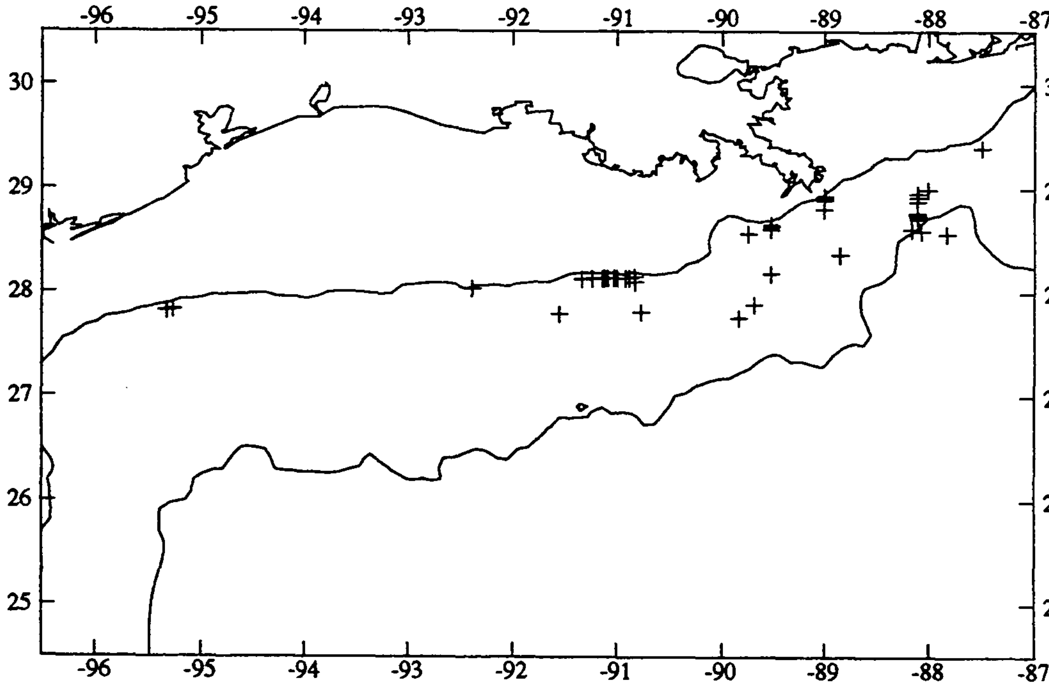

Figure 7.7. Northern Gannett sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

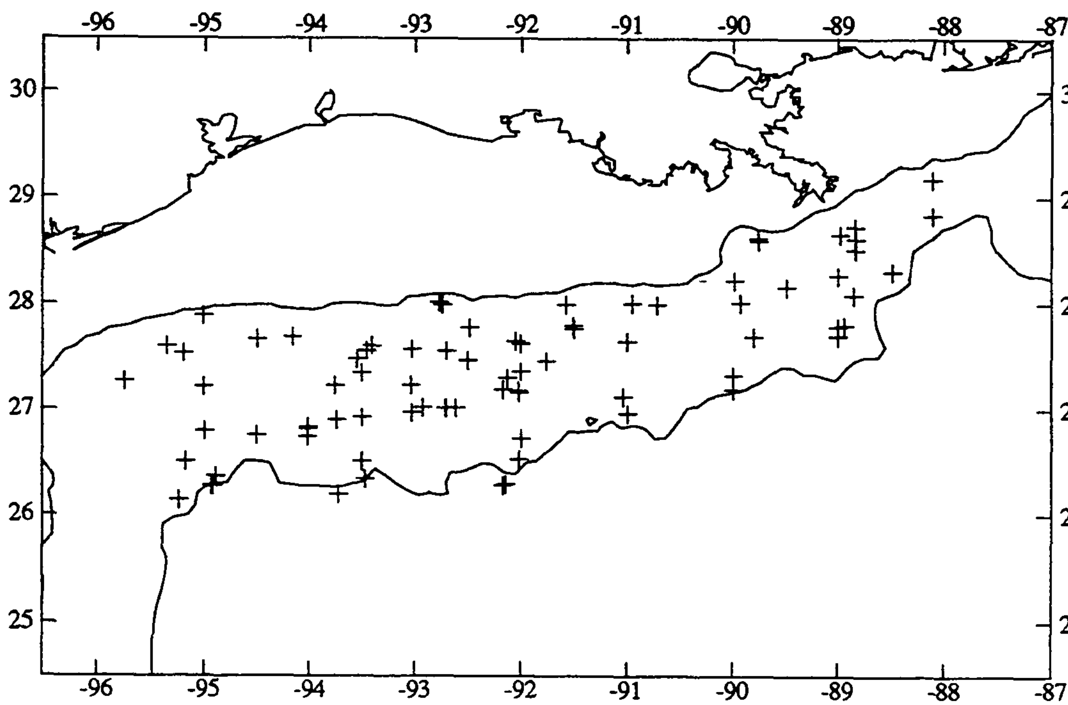

Figure 7.8. Masked Booby sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

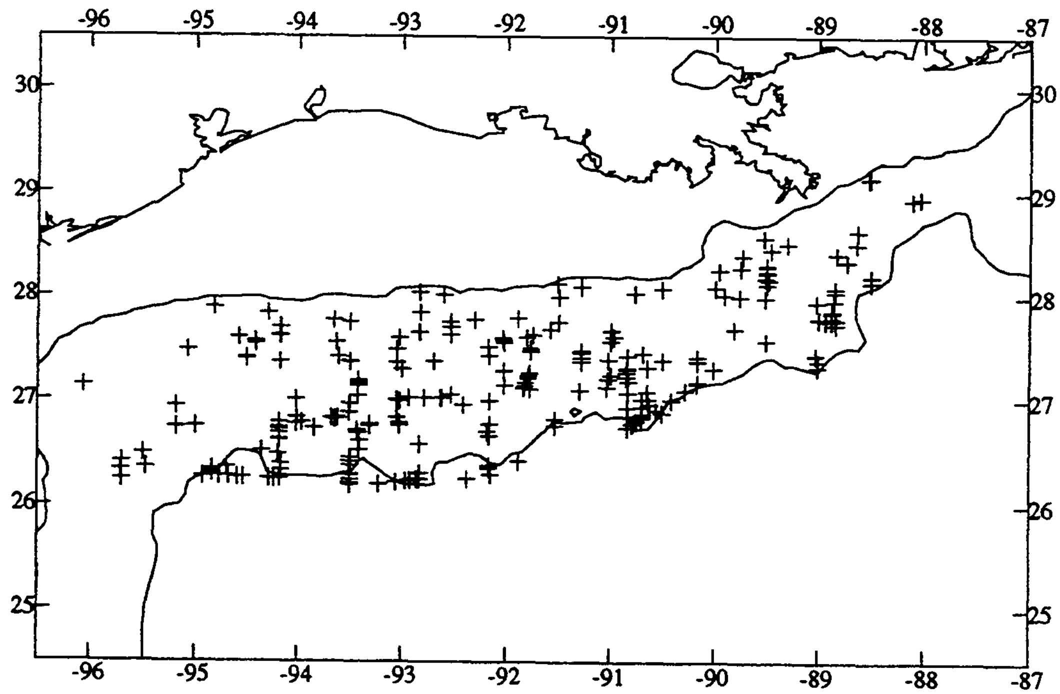

Figure 7.9. Pomarine Jaeger sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

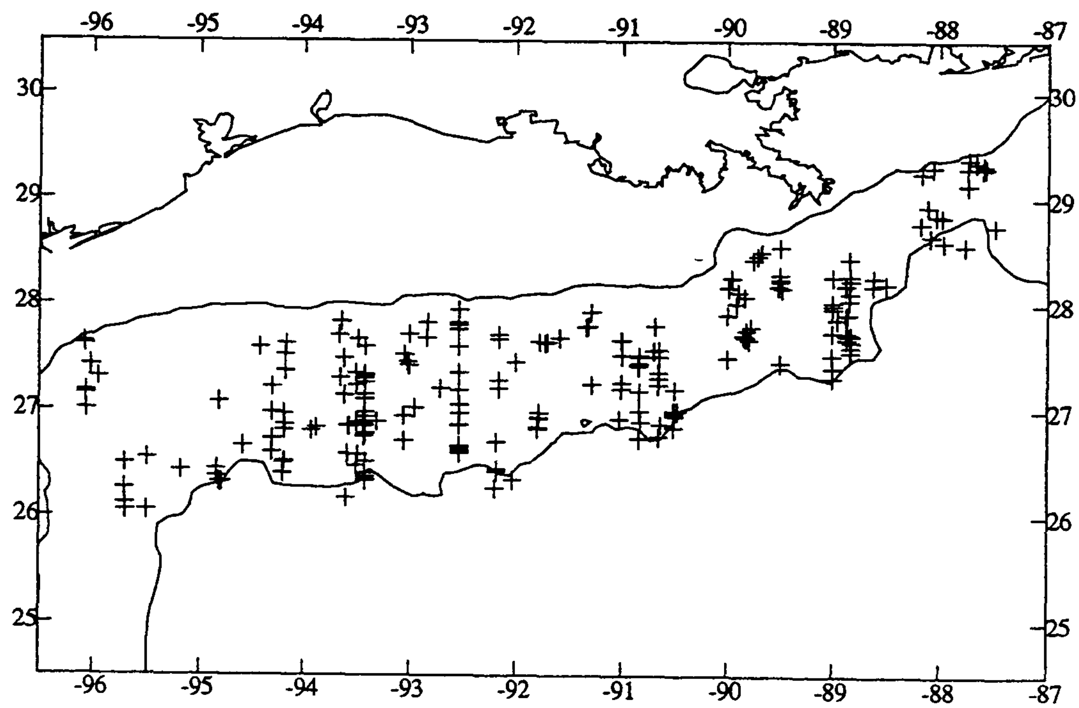

Figure 7.10. Unidentified jaeger sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

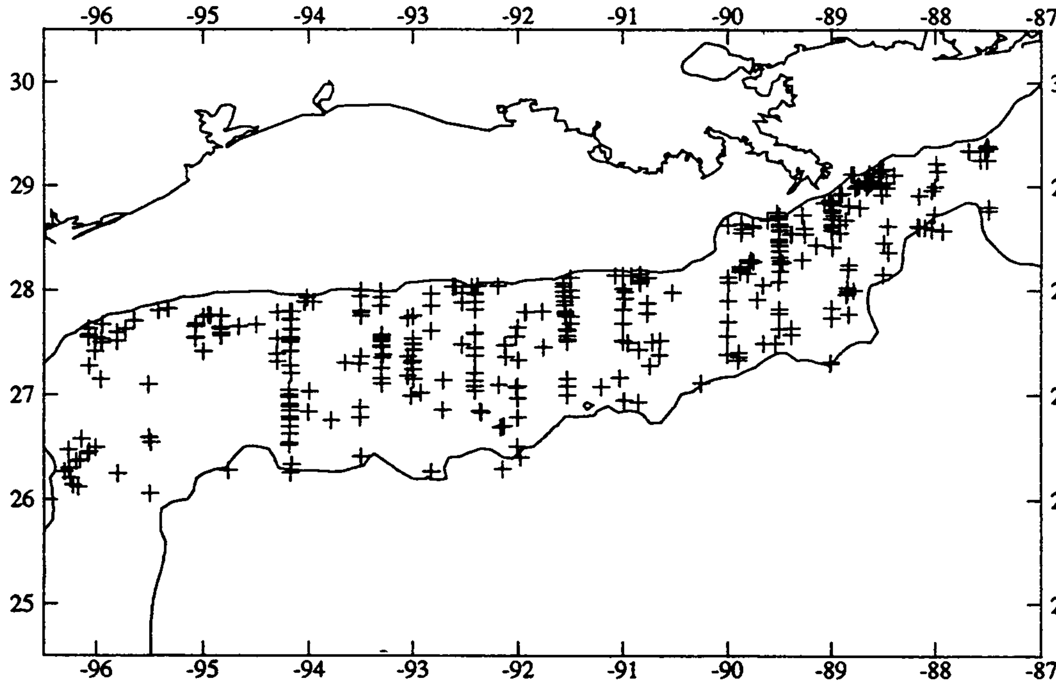

Figure 7.11. Laughing Gull sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

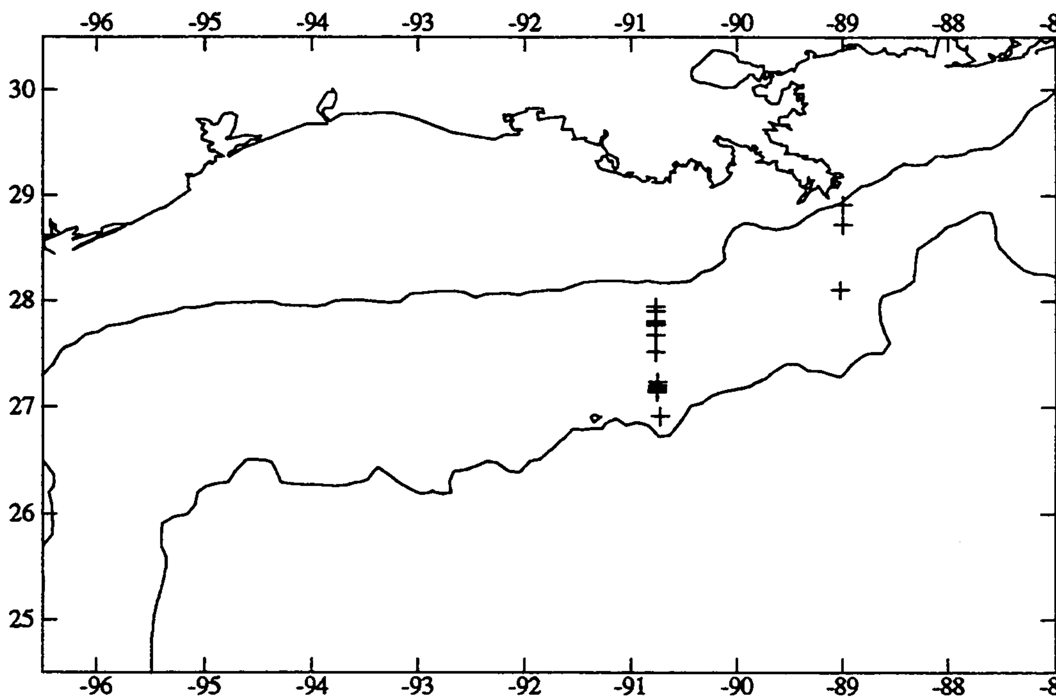

Figure 7.12. Ring-billed Gull sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

(Figure 7.13). The Laughing Gull comprised 13.7%, Franklin's Gull and Bonaparte's Gull 0.03% each, Ring-billed Gull 0.6%, and Herring Gull 3.8% of all seabird sightings (Table 7.3). All gulls together represent 18.4% of the GulfCet seabird sightings.

Ten species of terns were noted during the GulfCet study, more species than any other group of seabirds. The Gull-billed Tern was only seen once on *Oregon II* Cruise 199. The Royal Tern was sighted 17 times on *Pelican* Cruises 4-6 and *Oregon II* Cruises 203, 204, and 209 (Figure 7.14). The Sandwich Tern was seen on *Pelican* Cruises 3 and 6 and *Oregon II* Cruises 204 and 209 (Figure 7.15). The Forster's Tern was sighted once on *Oregon II* Cruise 199, and the Common Tern was identified on *Pelican* Cruise 6 and *Oregon II* Cruise 209 only, as was the Least Tern. Bridled Tern sightings were made on *Pelican* Cruises 3, 5, and 6, and *Oregon II* Cruises 199, 204, and 209 (Figure 7.16). The Sooty Tern was observed 40 times on *Pelican* Cruises 4 and 6 and *Oregon II* Cruises 199, 203, 204, and 209 (Figure 7.17). Sightings made on *Pelican* Cruises 4, 5 and 6 listed as large dark-backed terns were either Bridled or Sooty Terns. *Pelican* Cruise 6 and *Oregon II* Cruises 199, 204, and 209 produced 412 Black Tern sightings (Figure 7.18). The Brown Noddy was sighted twice on *Pelican* Cruise 5, with both sightings being made in the same vicinity of the Gulf (27°15.00'N, 90°50.07'W and 27°15.05'N, 91°30.03'W). Of all GulfCet seabird records, 32.4% were represented by this subfamily, but only three species, Bridled Tern, Sooty Tern, and Black Tern, comprise more than 1% of the total sightings; 9.3% of the seabird records were of unidentified terns (Figure 7.19, Table 7.3).

7.3.1.2 *Seasonality*

While birds were sighted throughout the GulfCet study area during all four seasons, the species composition varied during the year (Tables 7.4-7.7, Figures 7.20-7.24). Table 7.7 lists species diversity by season.

Spring

Spring produced the greatest species diversity (28 species) and the second highest total bird sighting rate (19.8 bird sightings per day) (Table 7.7). If the Black Tern is excluded, then spring also had the greatest overall daily sighting rate. Many of the species sighted during this period, however, were seen very few times, and part of the apparent diversity could be a result of having more census days, enabling rare species to be observed. Figure 7.20 shows the bird sightings per day for the combined *Pelican* and *Oregon II* records and the number of sightings and individuals per hour sighted on *Pelican* Cruise 5. Although the *Oregon II* cruises provided most of the records for this season, the conclusions were similar. Seven of the 11 most commonly sighted species were the same on both vessels. Storm Petrels were the most frequently sighted birds, with jaegers and Bridled Terns also comprising many sightings. Black Tern was not sighted on *Pelican* Cruise 5 but was noted on all of the *Oregon II* spring cruises. The most abundant species on *Pelican* Cruise 5 was the Band-rumped Storm-Petrel; 2.9 times as many were noted as total jaegers and 3.9 times the number of Bridled Tern. Finding storm-petrels to be major component of the avifauna was unexpected based on previous information

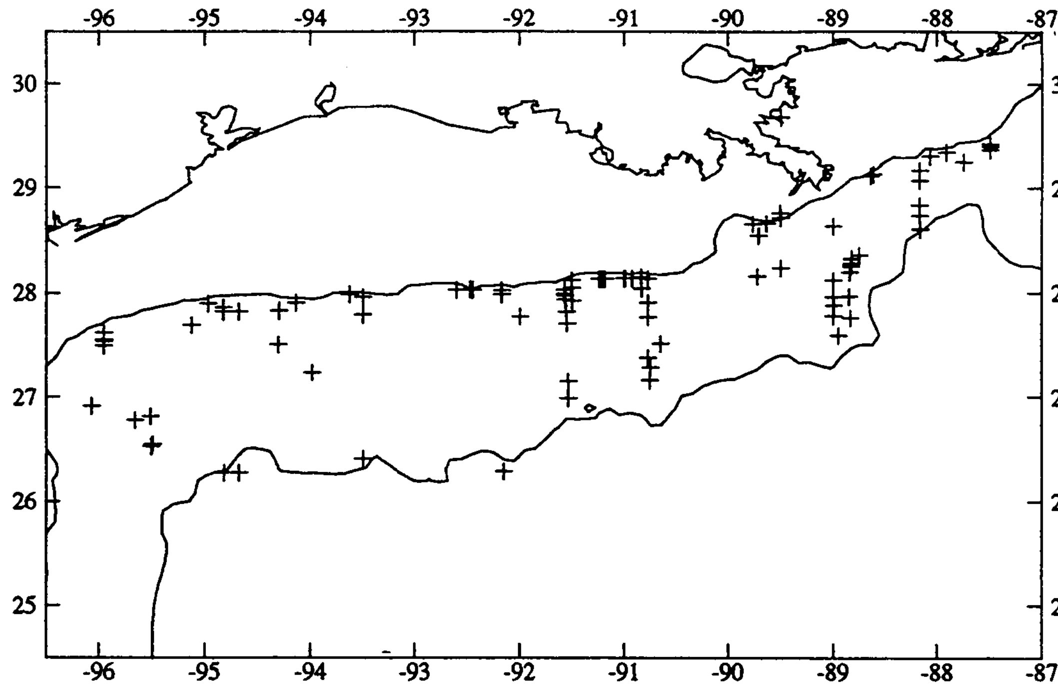

Figure 7.13. Herring Gull sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

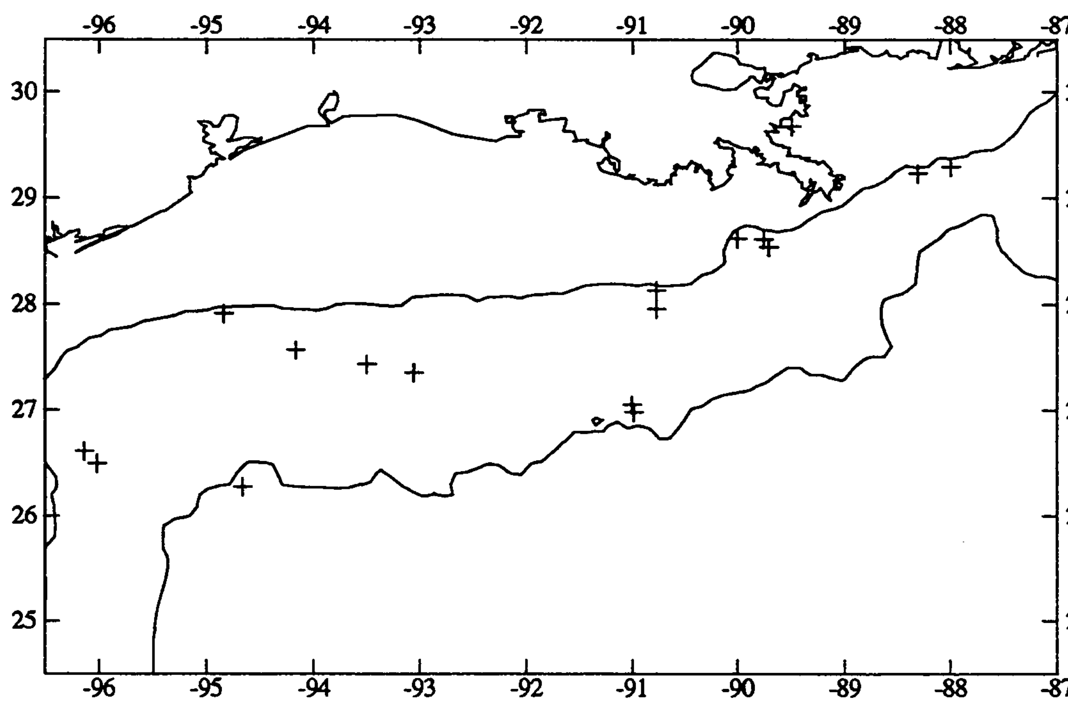

Figure 7.14. Royal Tern sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

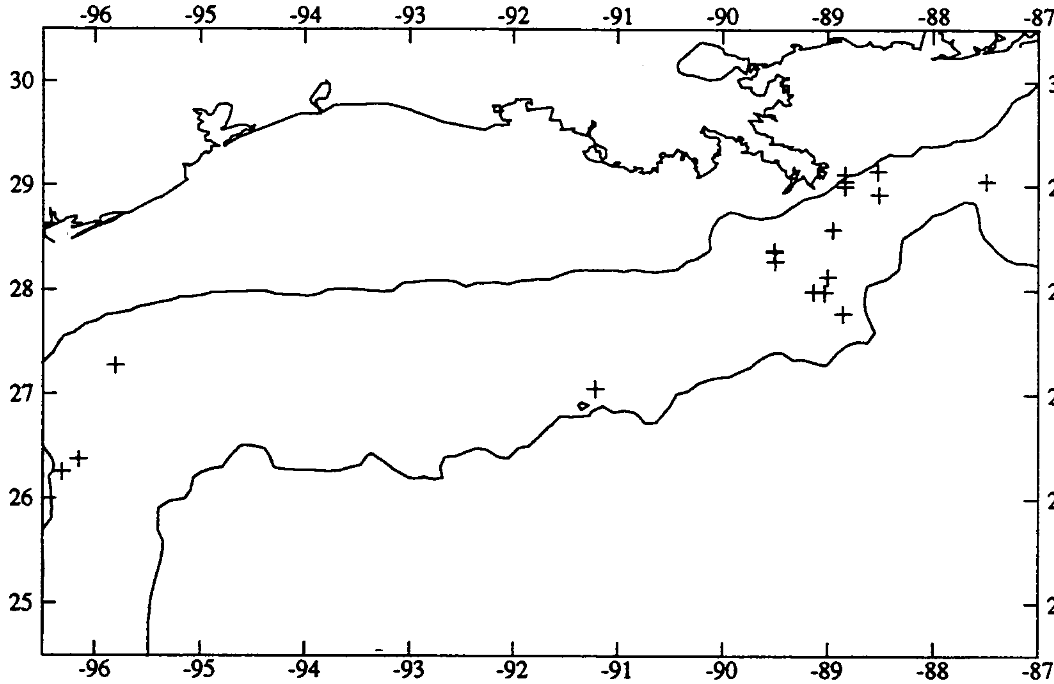

Figure 7.15. Sandwich Tern sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

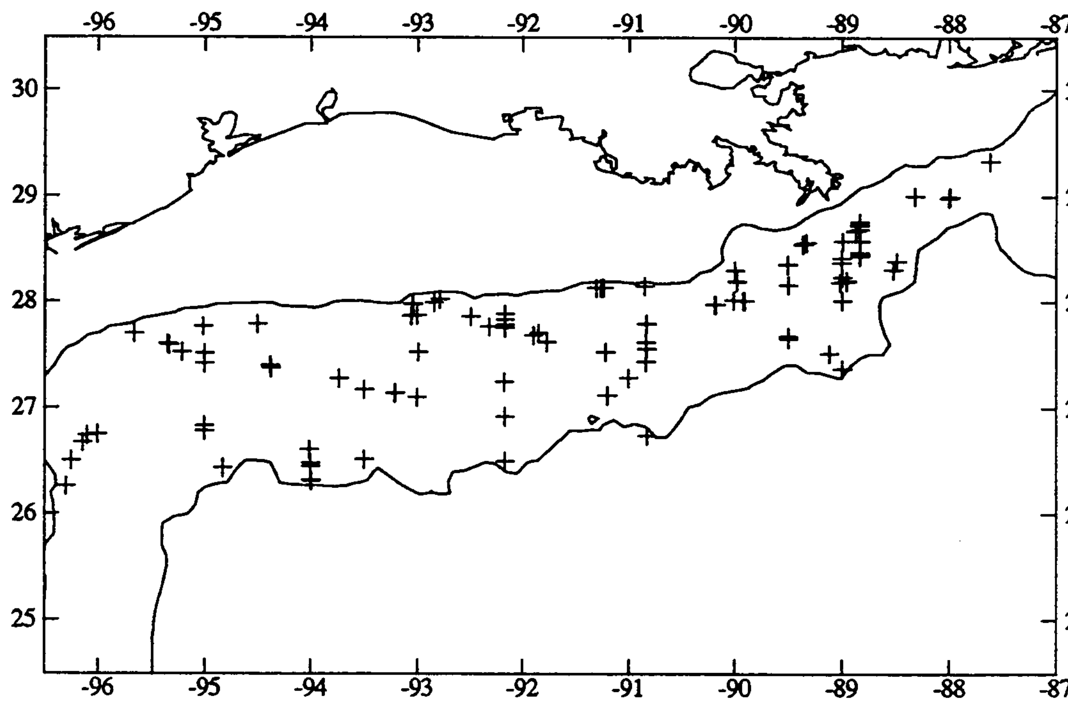

Figure 7.16. Bridled Tern sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

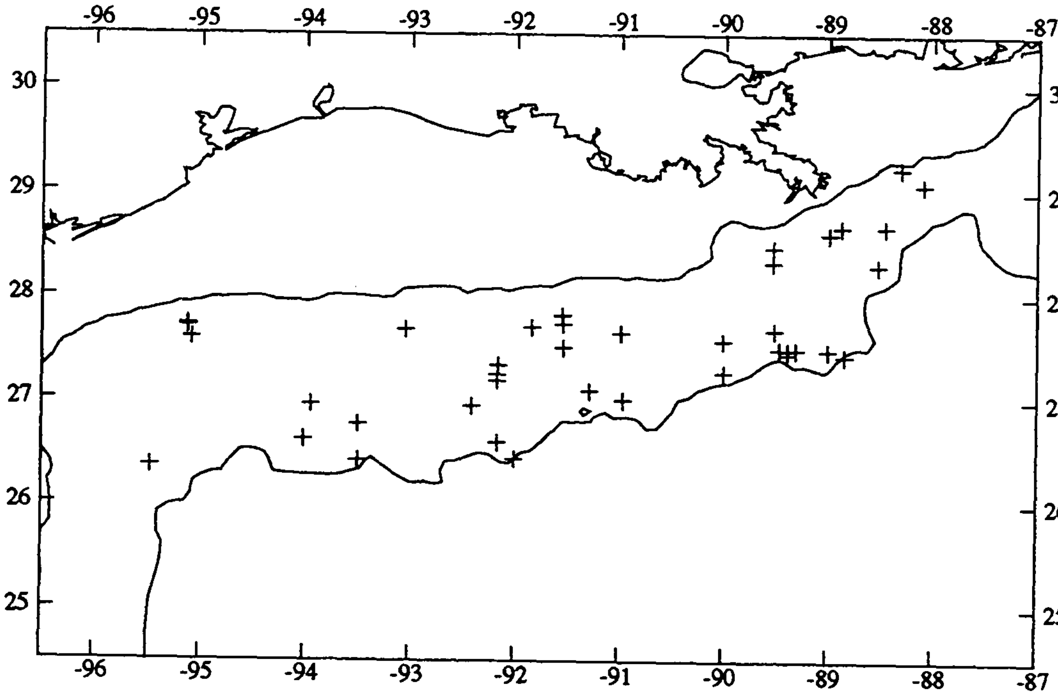

Figure 7.17. Sooty Tern sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

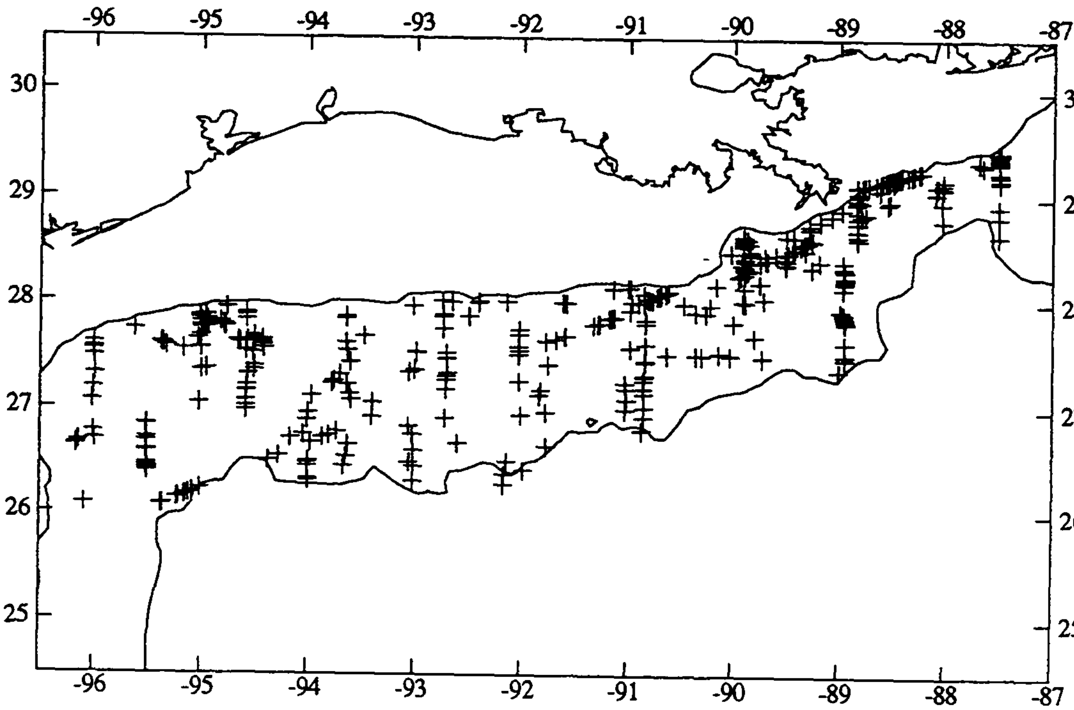

Figure 7.18. Black Tern sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

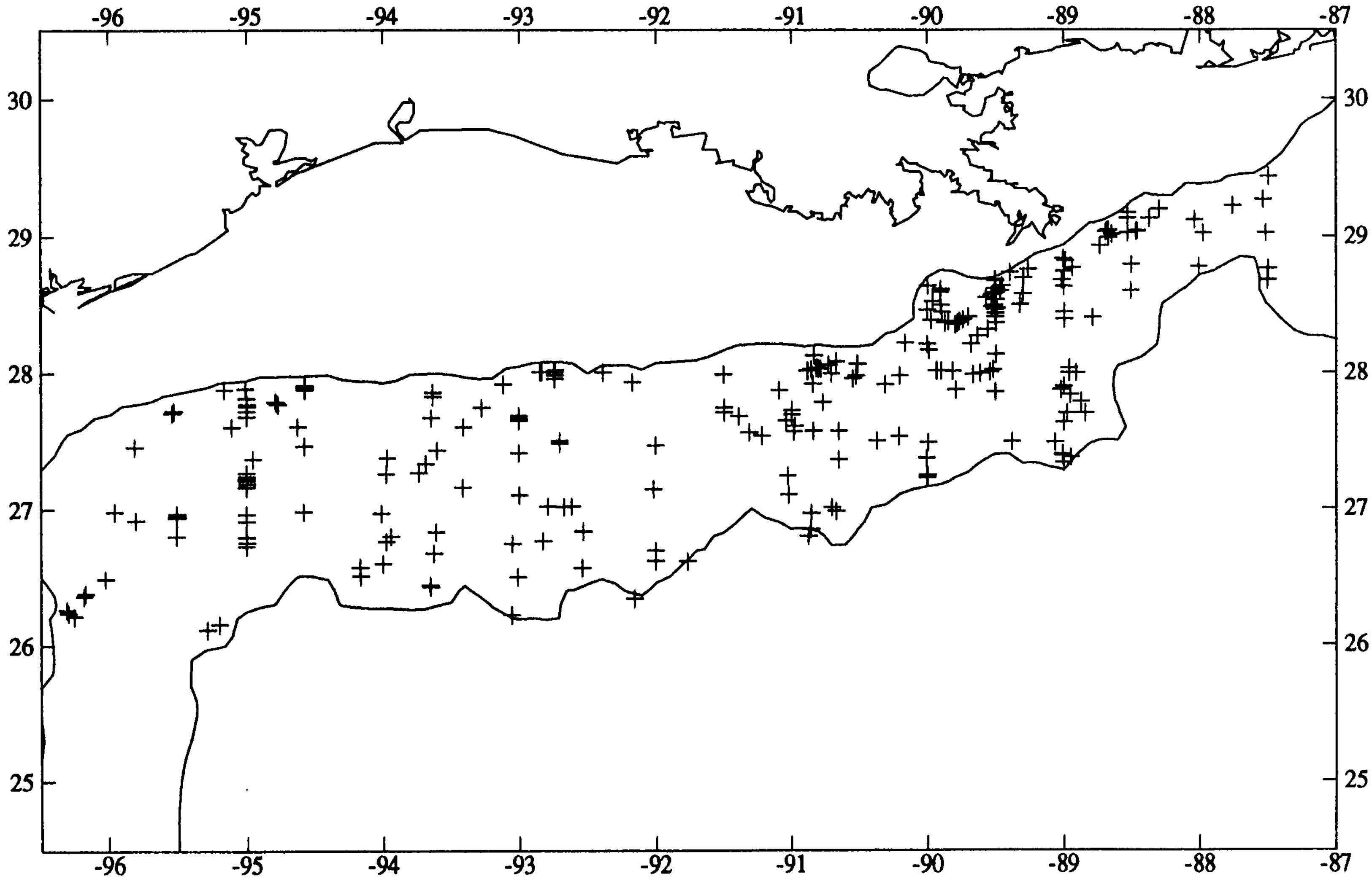

Figure 7.19. Unidentified tern sightings for *Pelican* Cruises 3-7 and *Oregon II* Cruises 199, 203, 204, and 209.

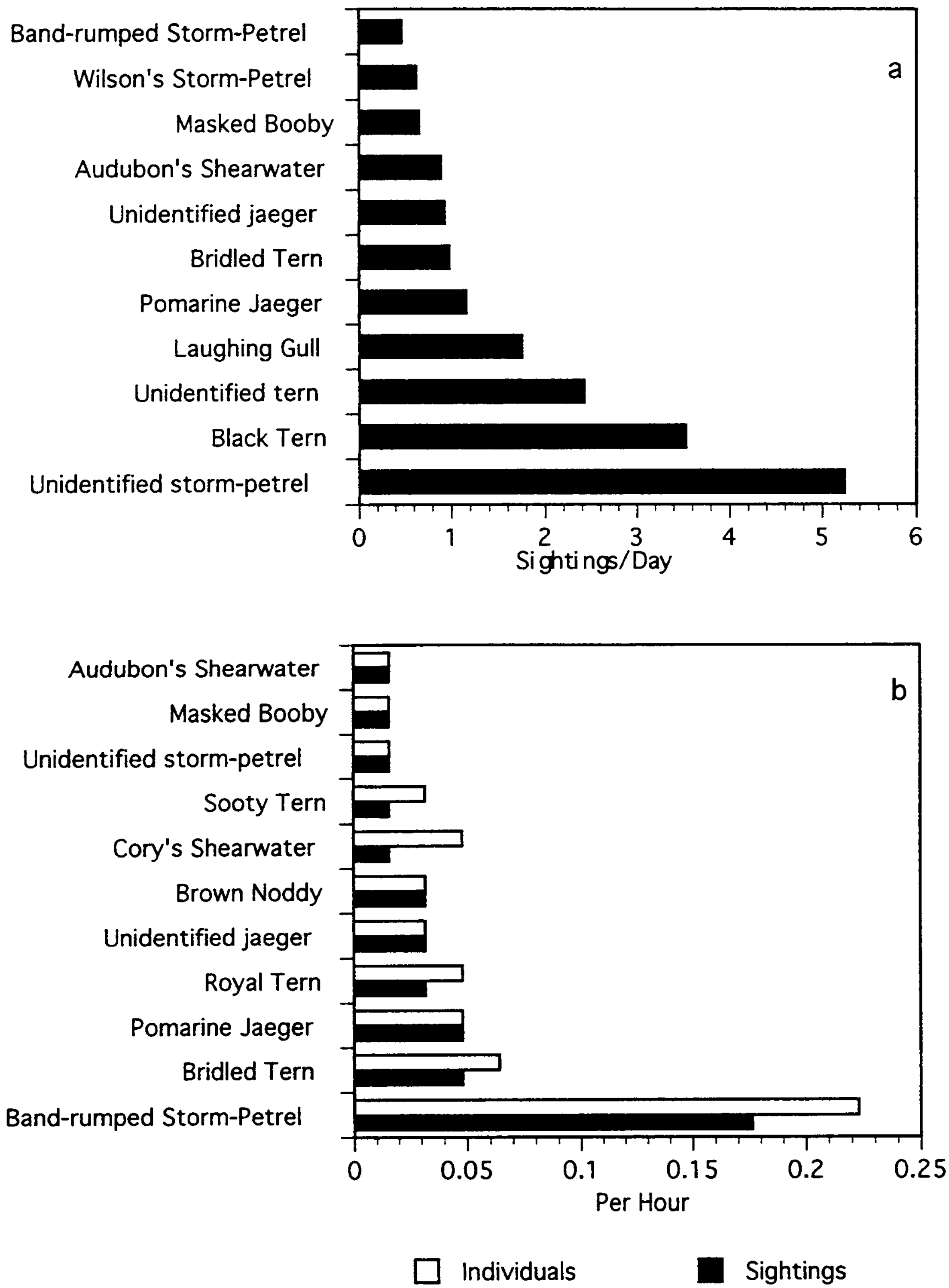

Figure 7.20. Spring sightings. (a) Mean number of combined bird sightings per day for *Oregon II* Cruises 199, 204, 209, and *Pelican* Cruise 5. (b) Number of sightings and individuals observed per hour during *Pelican* Cruise 5.

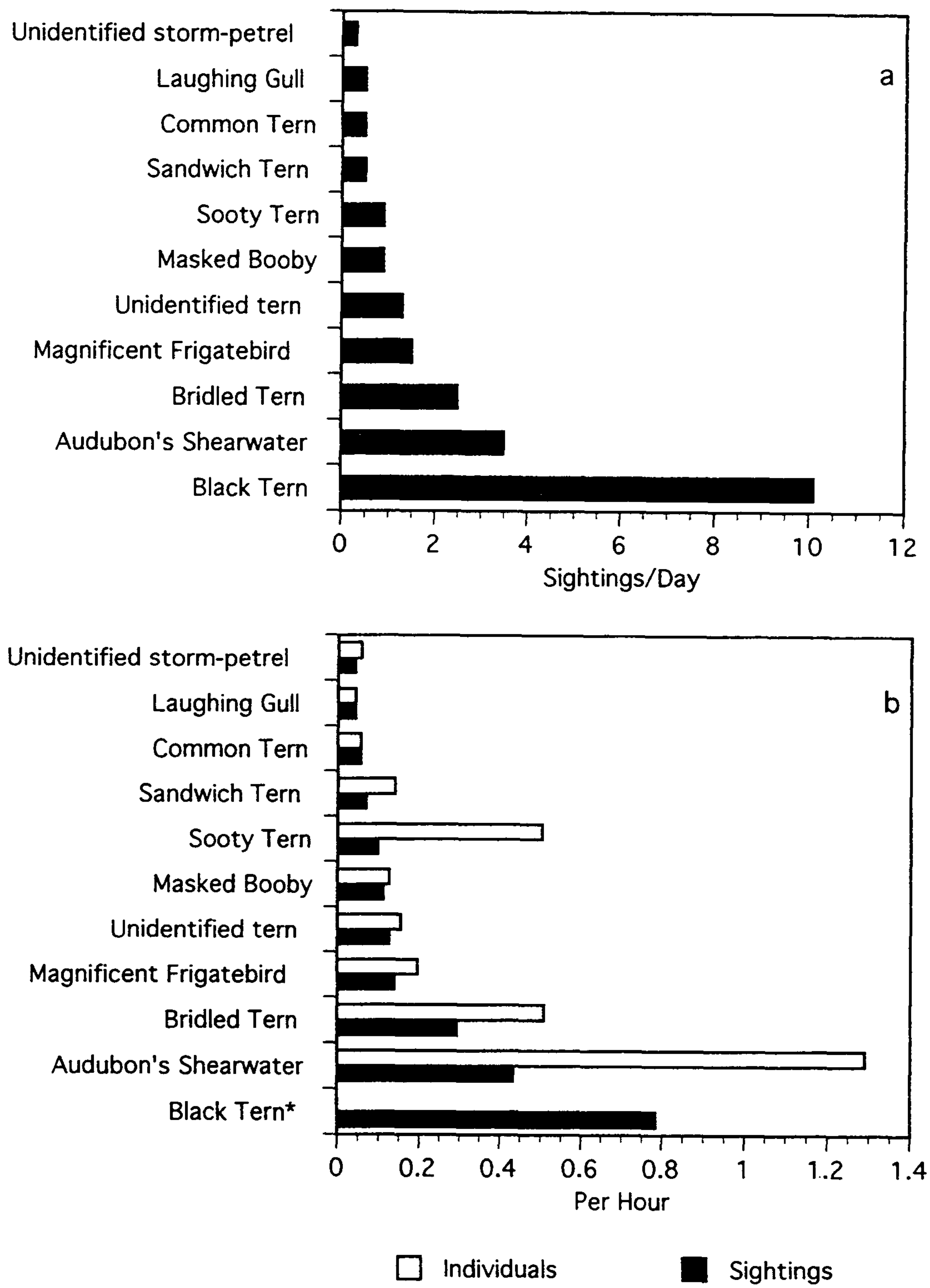

Figure 7.21. Summer sightings. (a) Mean number of bird sightings per day for *Pelican* Cruise 6. (b) Number of sightings and individuals observed per hour during *Pelican* Cruise 6. *Black Terns were sighted at a rate of 23.2 individuals per hour, not shown.

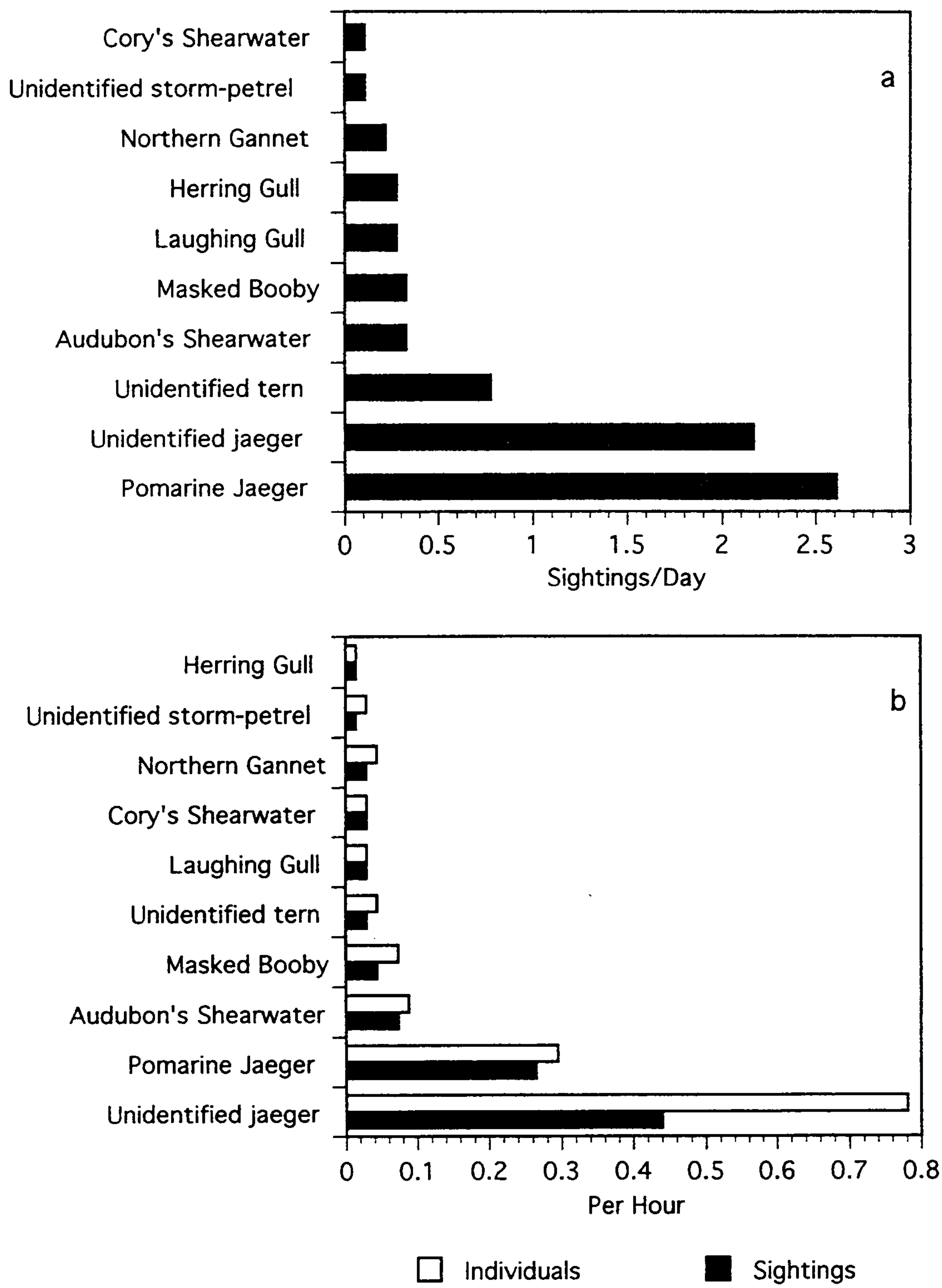

Figure 7.22. Fall sightings. (a) Mean number of combined bird sightings per day for *Pelican* Cruises 3 and 7. (b) Number of sightings and individuals observed per hour during *Pelican* Cruise 3.

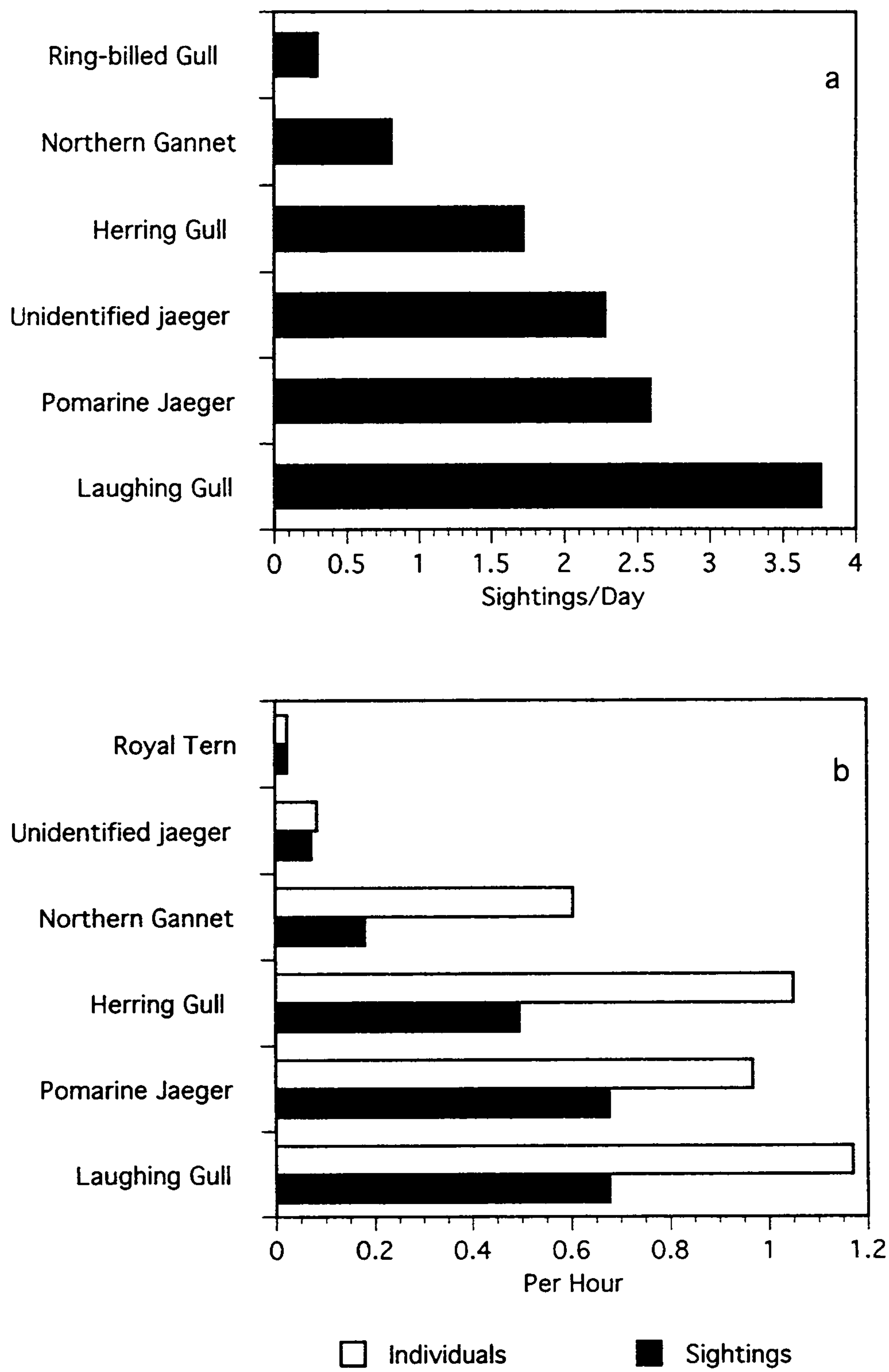

Figure 7.23. Winter sightings. (a) Mean number of combined bird sightings per day for *Oregon II* Cruise 203 and *Pelican* Cruise 4. (b) Number of sightings and individuals observed per hour during *Pelican* Cruise 4.

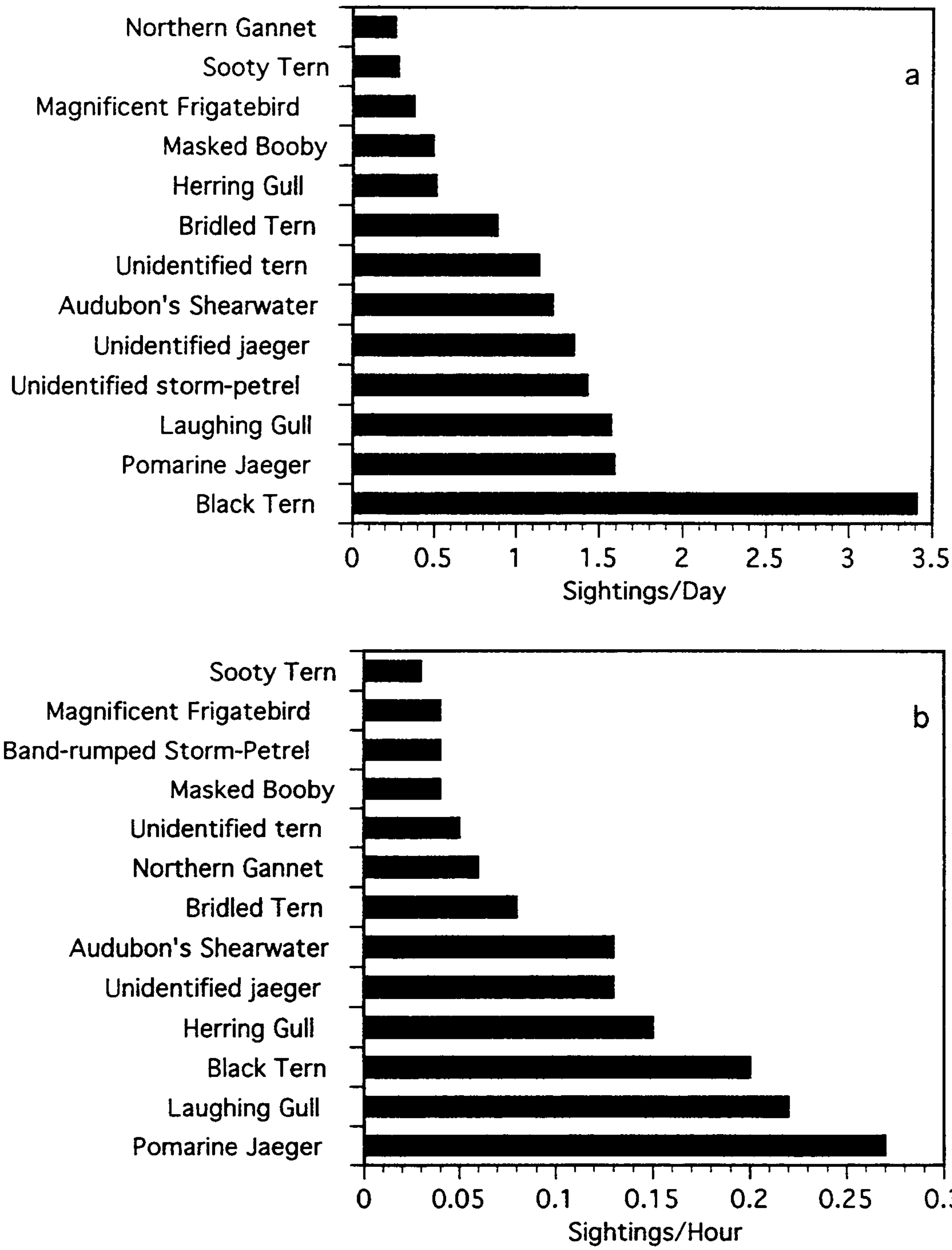

Figure 7.24. All seasons. (a) Mean number of combined bird sightings per day for *Oregon II* Cruises 199, 203 204, 209 and *Pelican* Cruises 3-7. (b) Number of sightings and individuals observed per hour during *Pelican* Cruise 3-7.

Table 7.7. **Summary of seasonal species diversity and total bird sightings per day.**

Season	Fall	Winter	Spring	Summer	Annual mean
Total number species	12	12	28	14	16.50
Total number bird sightings per day	8.1	12.0	19.8	23.2	15.77

(Clapp et al. 1982). Since storm-petrels are not as easily seen as larger species, the relative abundance may be higher.

Summer

This season had the fewest observation days, and all of the data were from *Pelican* Cruise 6. Summer had the second highest species diversity (14 species), and the highest number (23.2) of bird sightings per day (Table 7.7 and Figure 7.21). Black Tern was the predominant species, with 44% of the sightings. Most of the Black Tern sightings were restricted to an area near the mouth of the Mississippi River. The next most abundant summer seabird was the Audubon's Shearwater. *Puffinus* shearwaters were 2.6 times as numerous as both Bridled and Sooty Terns, 6.9 times as abundant as Magnificent Frigatebird, and 10.9 times as common as Masked Booby.

Fall

The fall data come from *Pelican* Cruises 3 and 7, which provided the lowest total bird sightings per day (8.11) (Table 7.7). With 12 species of seabirds sighted, fall tied with winter for the lowest seabird diversity (Table 7.7). Since these cruises were both late in the season, relative abundance may be different earlier in the season. For example, Cory's Shearwater has been reported to be most abundant in the Gulf in late September through early October (Pulich 1982), but few were seen on *Pelican* Cruise 3 and none on *Pelican* Cruise 7. Figure 7.22 shows the sighting rates for the 11 most frequently sighted species sighted during the fall cruises. On *Pelican* Cruise 3, jaegers (Pomarine Jaeger plus unidentified jaegers) predominated; they were 5.6 times as abundant as the next most common group, *Puffinus* shearwaters (unidentified small *Puffinus* sp. and Audubon's Shearwaters) and 15.3-times as abundant as the third most common species sighted, the Masked Booby.

Winter

Pelican Cruise 4 and *Oregon II* Cruise 203 were made during winter which made this season the second most heavily sampled period. Winter ranked third in the number of bird sightings (12.0 per hour) and is tied with fall for the lowest species diversity, with only 12 species of seabirds noted (Table 7.7). The

Laughing Gull, jaegers (Pomarine Jaeger plus unidentified jaegers), the Herring Gull, and the Northern Gannet appear to be the most abundant birds during this season (Figure 7.23). The Laughing Gull was the most abundant species on *Pelican* Cruise 4; it was 1.1 times as abundant as both the Herring Gull and jaegers and 1.9 times as abundant as the Northern Gannet. The remainder of the species were sighted very rarely.

Year

Although the Black Tern was the most commonly sighted species, it was present only in the spring and summer seasons (Figure 7.25). With the exception of the Laughing Gull and the Herring Gull, all of the species observed were primarily pelagic. The dominant birds include a genus (*Stercorarius*, jaegers) and two species (the Band-rumped Storm-Petrel and the Audubon's Shearwater) not listed by Fritts et al. (1983) as important components of the bird fauna of the Gulf.

7.3.1.3 *Habitat*

Although the complexity of the hydrography of the Gulf makes the analysis of habitat difficult, at least one variable (water depth) seems significantly related to bird distribution (Table 7.2). The difference between depth at sighting location for certain species pairs was significant (Table 7.8), with the exception of Audubon's Shearwater and Sooty Tern, and Pomarine Jaeger, and unidentified jaegers.

Although other significant habitat variables have not been identified for these species, depth seems unlikely to be the only important habitat variable. Some species, such as Northern Gannet and Masked Booby, seem to partition habitat further on the basis of season. The Northern Gannet was most common in winter when the Masked Booby was least common. The lack of a significant difference between water depth at sighting location for the Audubon's Shearwater compared to the Sooty Tern suggests a similar habitat preference.

Table 7.8. Comparison of selected species pairs by depth using the Two-Sample Wilcoxin Rank-Sum Test.

Species	Number sightings	Z-Score	p
Audubon's Shearwater and Sooty Tern	165	-0.07	0.945
Wilson's and Band-Rumped Storm-Petrel	95	4.56	0.0001
Northern Gannet and Masked Booby	123	-3.05	0.0023
Pomarine Jaeger and unidentified jaeger	515	-1.76	0.0785
Pomarine Jaeger and Laughing Gull	631	10.35	0.0001
Laughing Gull and Herring Gull	464	2.68	0.0075
Bridled and Sooty Tern	153	2.99	0.0028

Most of the pelagic bird species were observed resting on the surface of the water (Cory's Shearwater, Audubon's Shearwater, storm-petrels, Masked Booby, jaegers, and gulls) or on flotsam (Bridled, Sooty, and Black Terns).

7.3.2 *Non-seabirds*

Although the Gulf does not represent a significant feeding or resting area for most non-seabird species, it is an important migratory pathway for neotropical migrants (Wallace and Mahan 1975). The *Pelican* and *Oregon II* cruises produced 584 records for non-seabirds (Table 7.9). These sightings represent at least 21 species with 31 duck (Order Anseriformes) sightings, 165 heron or egret (Order Ciconiformes) sightings, one falcon (Order Falconiformes) sighting, one owl (Order Strigiformes) sighting, one goatsucker (Order Caprimulgiformes) sighting, one hummingbird (Order Apodiformes) sighting, and 249 passerine (Order Passeriformes) sightings.

Table 7.9. Non-seabird sightings by season for *Pelican* Cruises 3-7 and all four *Oregon II* cruises.

Species	Fall	Winter	Spring	Summer	Total
Herons					
Great Blue Heron	1	2			3
Great Egret				1	1
Snowy Egret				1	1
Little Blue Heron			1	5	6
Tricolored Heron				1	1
Cattle Egret	1		6	1	8
Yellow-crowned Night Heron		1			1
Unidentified Heron or Egret			130	11	141
Passerines					
Tree Swallow	1				1
Purple Martin		2			2
Northern Rough-winged					0
Swallow	1			1	2
Barn Swallow			1	16	17
Unidentified Swallow	1	1			2
Unidentified Thrush				2	2
Northern Mockingbird	1			1	2
Yellow Warbler				2	2
Louisiana Waterthrush				1	1
Wilson's Warbler				1	1
Unidentified Warbler				1	1
Scarlet Tanager				1	1
Orchard Oriole				1	1
Unidentified oriole				1	1
Unidentified Passerine	2	4	203	2	211
Total Sightings	8	10	341	50	409

7.4 Discussion

Since GulfCet bird observations were made on only 160 days during a 30-month period, conclusions about seasonal distribution will require further study. Observations were made during all months except March, July, and October. Since March and October are months when significant seabird migration occurs (Clapp et al. 1982), some important seabird species present in the Gulf during these months may be underrepresented or missing from the GulfCet data.

7.4.1 *Species Accounts*

The following species accounts are restricted to the seabirds which were the most notable in the GulfCet study area.

Procellariiformes

The GulfCet results supported the conclusions of Fritts et al. (1983), Pulich (1982) and Clapp et al. (1982) that Cory's Shearwater was a regular but uncommon species in the Gulf from May through November. The first sighting records for the state of Louisiana for Cory's Shearwater were made by Fritts and Reynolds (1981) in October, and subsequent sightings were obtained in 1991 (Jackson 1992). The GulfCet sightings added three records to Louisiana waters.

Audubon's Shearwater is believed to have an Atlantic breeding population of 5,000 pairs in the Caribbean (van Halewyn and Norton 1984). This species is thought to be very common seasonally off the southeastern United States during late spring, summer, and fall months (Clapp et al. 1982), but has been considered casual to regular in low numbers in the Gulf (Duncan and Harvard 1980, Clapp et al. 1982). The GulfCet sightings for this species suggested greatest abundance from May through November, a period similar to that noted off the southeastern United States (Clapp et al. 1982). The GulfCet data differed from the findings of Fritts et al. (1983), who found Audubon's Shearwaters most numerous between October and April. The many GulfCet sightings suggest a much greater abundance in the Gulf than reported by Fritts et al. (1983), and implied the opposite relative abundance compared to Cory's Shearwater (Pulich 1982).

The GulfCet data supported the findings of Fritts et al. (1983) that storm-petrels (Family Hydrobatidae) are more numerous and widespread in the Gulf than previously thought and are an important component of the Gulf avifauna. These data, however, did not support the assumption by Fritts et al. (1983) that Wilson's Storm-Petrel is the predominant storm-petrel species in the Gulf and other species are very rare. Storm-petrels were sighted in all four seasons, but were most common in spring. Although reported by Duncan and Harvard (1980) as common and sometimes abundant in eastern portions of the Gulf, the overall abundance of the Wilson's Storm-Petrel in the Gulf remains uncertain.

Traditionally, the Band-rumped Storm-Petrel has been considered casual or rare in the Gulf (Duncan and Harvard 1980, Clapp et al. 1982). However, the GulfCet data suggested that it is much more common than previously thought and that it may be the most numerous pelagic bird species in the Gulf during certain times of year. The GulfCet sightings may represent the first records for the state of Louisiana.

Pelicaniformes

The three White-tailed Tropicbird records for the study supported the conclusion of Clapp et al. (1982) that this species occurs regularly in small numbers in the Gulf. Approximately 20 previous records exist for the Gulf. One of the GulfCet records was from the area covered by the Texas Rare Bird Committee. Although this species has been previously reported from Texas, no records have been substantiated by specimens or photographs. Currently this species is not officially on the Texas State Bird List. Similarly, the one Red-billed Tropicbird record was from the area covered by the Louisiana State Rare Bird Committee, and no previous record exists for this species from Louisiana.

Although the near-shore roosting of Magnificent Frigatebirds along the Gulf Coast is well described, the pelagic distribution of this species has been poorly described (Clapp et al. 1982). The GulfCet sightings suggested that, at least in late summer, Magnificent Frigatebirds were widespread in low numbers in the pelagic waters of the Gulf.

GulfCet records for the Northern Gannet were consistent with previous findings (Clapp et al. 1982) that this species is an uncommon winter resident in the Gulf. The GulfCet sightings were concentrated mainly near the continental shelf break, and the numbers of Northern Gannets wintering in the Gulf may be greater over the continental shelf than elsewhere in the Gulf. On *Pelican* Cruise 4, Northern Gannet sightings seemed to be concentrated in an area of high primary productivity. The depths where Northern Gannet and Masked Booby occurred were significantly different, group sizes were not. The GulfCet sightings of Masked Booby supported the findings of Duncan and Harvard (1980) and Clapp et al. (1982) that Masked Booby is an uncommon to common species in the Gulf. The breeding population in the Caribbean and southern Gulf is limited to approximately 2,500 pairs (van Halewyn and Norton 1984). This species has demonstrated some association with oil platforms (Ortego 1978). The distribution and abundance of this species should be monitored closely for the potential effects of deep water oil and gas production and exploration in the Gulf.

Charadriiformes

Unless most of the phalaropes using the Gulf pass through during March and early April and again in late September and October, phalaropes are very rare in the Gulf. However, these are the periods of peak occurrence for the southeastern U.S. and the Gulf (Clapp et al. 1983). The one sighting identified to species was Red Phalarope rather than the species more commonly reported from the Gulf, the Red-necked Phalarope. The GulfCet records indicated that large offshore wintering populations, which have been suggested for the latter species (Clapp et al. 1983), are unlikely in the north-western and central Gulf.

While the Pomarine Jaeger has been regarded as uncommon in the Gulf (Duncan and Harvard 1980), the GulfCet data indicated that this species is a common, deep water species from November to June. It had the greatest relative abundance of all species in fall and was also one of the most common winter species. The GulfCet data suggested that the Gulf may be a major wintering area for this species. The Pomarine Jaeger is considered a kleptoparasite (Harrison 1983). However, the winter distribution in the Gulf is farther offshore than that of the Laughing Gull, a likely food source, and the difference in water depth at sightings was significantly different for these two species. One group of Pomarine Jaegers (seen on *Pelican* Cruise 4) was associated with a flock of Sooty Terns, but Sooty Terns are rare in the Gulf in winter and cannot be the primary kleptoparasitized species.

Although many jaegers were recorded as unidentified, most were probably Pomarine Jaegers because of the very small number identified as Parasitic Jaegers. Statistical comparison of the Pomarine Jaegers and unidentified jaegers by water depth revealed no significant difference. The flock of at least 100 individuals noted on *Pelican* Cruise 4 apparently represented the largest number of jaegers sighted at one time in the Gulf.

Laughing Gulls were most abundant during winter, less common in spring and fall, and rare in summer. Fritts et al. (1983) noted a similar deep-water abundance in winter and speculated that the birds moved further offshore to avoid competition with larger gulls. The GulfCet data, however, suggested a similar abundance and distribution for Laughing Gull and Herring Gull during the winter, and another explanation for the deep water distribution of Laughing Gulls in winter seems necessary. Several birds were seen associated with sargassum, and some were noted picking at the algae.

The Herring Gull was also common during the winter months. Most sightings occurred near the edge of the continental shelf, but many sightings occurred in the deepest waters of the study area. No data were obtained to suggest this species' food source.

White-backed *Sterna* terns (Gull-billed Tern, Royal Tern, Sandwich Tern, Forster's Tern, Common Tern, and Least Tern) are common in the nearshore areas along the Gulf coast (Clapp et al. 1983). Gull-billed, Royal, Sandwich, Forster's, and Least Terns are common breeding birds in this area, but the Common Tern is a rare breeding species along the Gulf coast. Fritts et al. (1983) had very few records for any of these species in areas with water deeper than 50-100 m. The few GulfCet records for these species suggested that none has significant abundance in the deeper waters of the Gulf despite the heavy use of the continental shelf by these species.

Evidence has shown the Bridled Tern to be more common in the Gulf than previously thought (Duncan and Harvard 1980, Clapp et al. 1983). Although noted to be regular in offshore Alabama waters (Duncan and Harvard 1980), very few sightings have been made in the waters offshore of Louisiana and Texas, where most of the 113 GulfCet sightings occurred. Water depth at sighting was significantly different for Bridled and Sooty Tern, and the group sizes were significantly different. The records were concentrated in spring and summer.

Sooty Terns breed in coastal Louisiana and Texas in small numbers, and a large colony exists in the Dry Tortugas, Florida (Clapp et al. 1983). Fritts et al. (1983) reported five sightings from the offshore waters of Louisiana and Texas. The 40 GulfCet sightings add to the pelagic Gulf sightings. The Sooty Tern was observed throughout the year with the maximum number of sightings during summer and fall.

The large offshore concentrations of the Black Tern noted on *Pelican* Cruise 6 seemed to be located mainly over the Mississippi River plume, and most of the sightings on this cruise occurred in areas with low salinity surface water. One sighting occurred along a front of brown water and clear blue water. Black Terns were noted over the brown water and not beyond, whereas Bridled Terns were simultaneously noted over the blue water flying parallel to the front but not over the brown water. Many of the sightings on this cruise were of flocks over fish schools, but birds were also observed sitting on flotsam, such as water hyacinth (*Eichhornia crassipes*).

Although Fritts et al. (1983) did not describe large concentrations of Black Terns in offshore Louisiana waters, the study area for that survey was west of the Mississippi River plume. Very few Black Tern sightings were made on *Pelican* Cruise 6 within the study area of Fritts et al. (1983), despite the numerous sightings in areas east of there. Both Fritts et al. (1983) and Clapp et al. (1983) concluded that Black Terns have a low susceptibility to oiling in the Gulf. GulfCet data, however, suggest that in areas near the mouth of the Mississippi River during migration in August, large numbers of Black Terns are susceptible to oiling.

Brown Noddy

Except for an observation reported by Fritts et al. (1983) of a bird seen 220 km off western Louisiana, the two GulfCet records for Brown Noddy were apparently the only ones for this species for Louisiana not associated with a hurricane or tropical storm.

7.4.2 *Summary*

The bird survey conducted during the GulfCet cruises was the first extensive, offshore study for the north-western and central Gulf of Mexico. Duncan and Harvard (1980) performed a shipboard survey in the offshore waters of Alabama, and Fritts et al. (1983) did aerial censusing in waters offshore of Texas and Louisiana. Aerial census data, however, may be biased towards larger, more visible species (Fritts et al 1983). Most of the remaining information regarding pelagic seabirds in the Gulf has been based on occasional trips by groups of bird watchers or on records of birds occurring onshore after storms. Clapp et al. (1982, 1983) summarized all published seabird records for the Gulf except for jaegers and several species of gull. The GulfCet bird data not only increases and supports existing knowledge of the Gulf pelagic avifauna, but also adds important new information regarding the offshore seasonal occurrence, relative abundance, and distribution of several species.

The 2,692 seabird records obtained during the GulfCet Project greatly expand the number of published offshore bird sightings in the Gulf. Thirty-two species of seabirds were observed, but of the birds identified to species, 14 species represent over 99% of the total sightings. New insight into the distribution and abundance has been added to Audubon's Shearwaters, storm-petrels (especially the Band-rumped Storm-Petrel), phalaropes, jaegers (especially the Pomarine Jaeger), Laughing Gulls, Herring Gulls, Bridled Terns, Sooty Terns, and Black Terns. Some conclusions regarding distribution relative to water depth for some species are possible. Records of species rare in the north-central and western Gulf, including White-tailed and Red-billed Tropicbird and Brown Noddy, were obtained. Although much data has been collected covering most of the year, information regarding species present during March, July, and October was low, and habitat variables for all of the Gulf pelagic species need further investigation. Most of the pelagic bird species, including species with limited Atlantic Ocean populations such as the Audubon's Shearwater and the Band-rumped Storm-Petrel, could potentially be negatively affected by oil spills.

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VIII. STUDIES OF SPERM WHALES

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This chapter describes the results of two aspects of the GulfCet Program: (1) satellite tagging of sperm whales, and (2) a sperm whale focal cruise (R/V *Pelican* Cruise 8).

8.1 Satellite Tagging of Sperm Whales

Oregon State University (OSU) attempted to place satellite-linked depth recorders (SLDRs) and location-only satellite telemeters on sperm whales to determine their movements, diving behavior, and preferred habitat. To accomplish this goal, three cruises were undertaken: two in the Gulf of Mexico (October 1992 and June 1993) and one in the Galapagos (March 1993). The Galapagos cruise was intended as a test for tag deployment and attachment.

8.1.1 *Data Acquisition*

The satellite telemeters used for this project were designed and built by OSU using Wildlife Computers™ controller boards and Telonics™ ST-6 Platform Transmitter Terminals (PTTs) and housed in a stainless steel cylinder (5 cm diameter, 19 cm long, 0.8 kg in weight). The exterior of the housing had attachments which consisted of two stainless steel rods (12.7 cm long, 0.6 cm diameter) with one pair of folding toggles mounted behind double-edged blades at the end of each rod (Figure 8.1).

The transmitters were attached to whales with a compound crossbow capable of generating 68 kg of force. The satellite telemeter was held in a "C"-shaped cup at one end of an aluminum shaft. The shaft with the satellite telemeter was then fired from the crossbow. A line (9 kg test) attached to the aluminum shaft enabled the satellite telemeter to be recovered if it missed the whale. Once the satellite telemeter was attached to the whale, the shaft fell away.

The Telonics™ PTTs transmitted a 400 mW signal every 40 seconds when in the programmed "on" mode. To conserve battery power, the tag was equipped with a saltwater switch so that it transmitted only at the surface. A small VHF radio transmitter was attached to the housing to enable real-time tracking at sea. The VHF transmitters were tuned to specific frequencies, had different repetition rates, and transmitted continuously.

All satellite telemeters were identifiable by a code transmitted to the satellite as part of a 256 bit data stream. The SLDRs collected data over eight, three-hour summary periods daily. These data included three histograms: depth of dives, duration of dives, and time spent at various depth ranges. Other data for each three hour period included the longest dive, deepest dive, duration of deepest dive, temperature at deepest depth, longest surface duration uninterrupted by a submergence of greater than six seconds, and total surface duration.

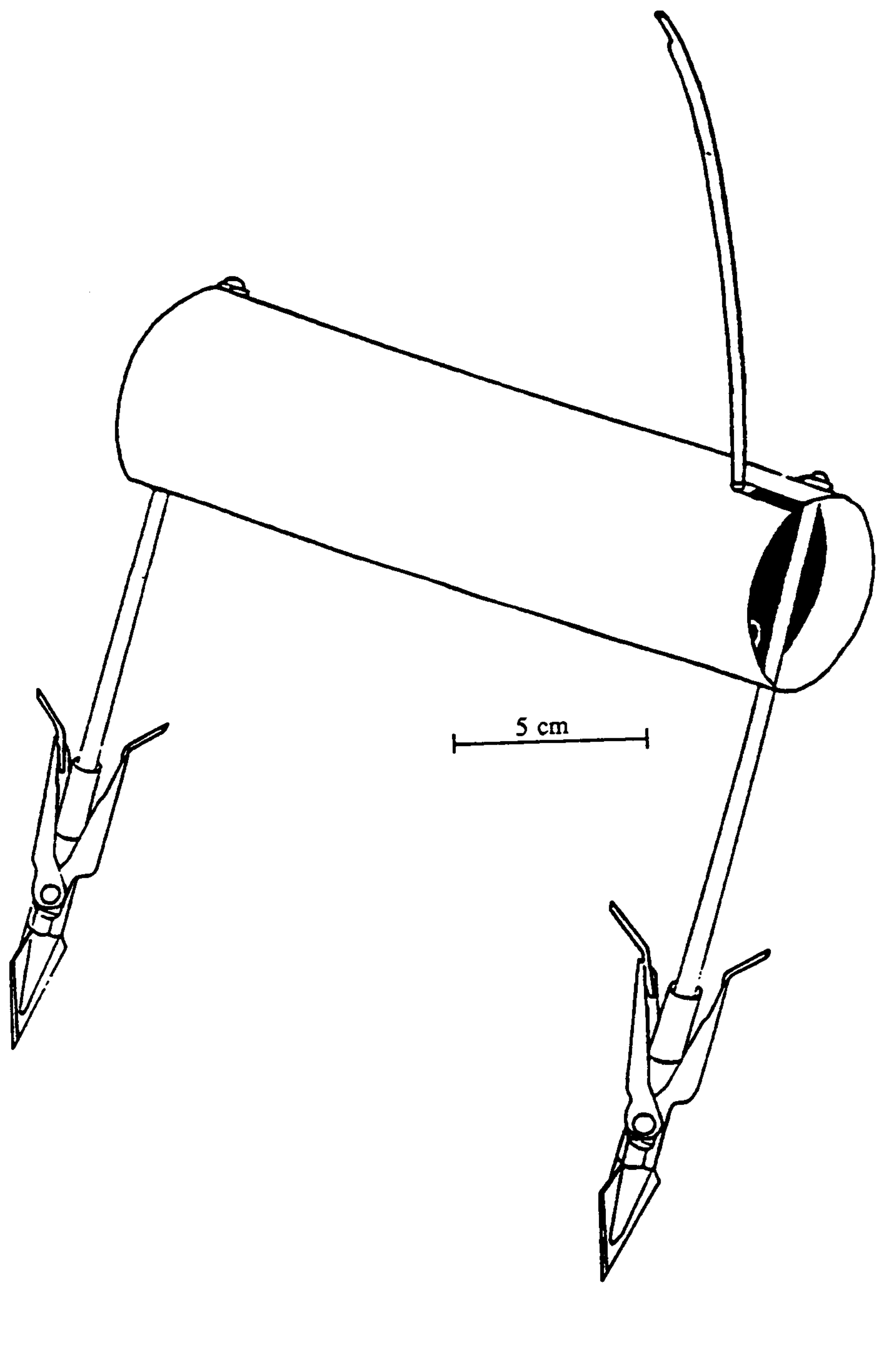

Figure 8.1. Diagram of the satellite telemeter.

Transmission was scheduled for four two-hour periods (eight hours) daily. A status message was relayed *in lieu* of the collected data every 15th transmission. This message provided information on battery voltage, sea surface temperature, number of transmissions, current zero depth offset, and a current assessment of saltwater resistance. All messages included a cyclic redundancy code for error detection purposes.

The Wildlife Computers™ pressure transducer and software were tested extensively using a relay box to simulate dives to different depths and durations. The satellite telemeter housing was tested to 2,000 m in a pressure bomb. After these tests, the transmitter, batteries, and controller board were potted in epoxy to provide greater structural strength.

8.1.2 *Tagging Cruise Chronology*

Cruise 1: The first tagging cruise was conducted from 30 September to 14 October 1992. The R/V *McGrail*, a 25 m converted Coast Guard Cutter operated by TAMUG, was used. The *McGrail* arrived in Venice, LA on 31 September and left for Galveston 14 October 1992. Only 4.5 of the 13 days were workable due to inclement weather and equipment failures on the vessel.

The cruise covered an area where previous GulfCet cruises and aerial surveys had observed sperm whales, but was limited to the ship's operational range (to 185 km offshore from Venice). Visual contact with sperm whales was made only once for approximately four hours. On 9 October, 8-10 sperm whales were sighted. Unfortunately, the boat could not maneuver well enough at slow speed to get close enough to tag any animals. The whales changed their course when the ship approached to within 8 m.

Cruise 2: This cruise was conducted in the eastern Pacific Ocean, near the Galapagos Islands, from 20 March to 31 March 1993. The R/V *Odyssey*, a 30 m sailboat owned and operated by the Whale Conservation Institute, was used. Three SLDRs were supplied by the GulfCet Program. The other operating costs for this cruise were provided by OSU's Marine Mammal Foundation.

The purpose of this cruise was to test techniques to approach and attach SLDRs to sperm whales. The waters around the Galapagos were an ideal testing ground because, unlike the Gulf of Mexico, the seasonality and distribution of large numbers of sperm whales has been well documented for this area (e.g., Whitehead et al. 1989, Whitehead and Waters 1990).

Several hundred sperm whales were located and followed over a five-day period using visual and acoustic contacts. Whales occasionally changed direction during close vessel approaches, but did not show a "flight" response to the boat.

On 26 March, a SLDR was successfully attached to a sperm whale. The telemeter was placed about 0.5 m from the whale's dorsal ridge and appeared to be flush against the animal's skin. The animal did not appear to startle or take flight after attachment of the telemeter, but continued its initial submergence pattern and surfaced a few minutes later, 100 m from the boat.

Two other tagging attempts were unsuccessful: in the first instance, the telemeter hit the dorsal ridge of the animal and glanced off. In the second case, the animal arched suddenly so the tag missed its target completely. The animal then fluked and broke the retrieval line, preventing tag recovery.

Cruise 3: The second GulfCet tagging cruise used the R/V *Acadiana*, a twin diesel, 18 m vessel chartered from LUMCON. The OSU team arrived in Cocodrie, LA on 1 June 1993. Construction of a tagging platform and some remaining LUMCON charter activities were completed by 5 June. The ship left Cocodrie on 6 June and returned on 29 June. Fourteen of the scheduled 24 days were workable; four days were used for transit between Cocodrie and Port Eads, LA (6, 14, 16, and 29 June); one day the ship fulfilled a previous charter obligation (15 June); five days were spent in port during Tropical Storm Arlene (17 to 21 June).

The tagging platform was constructed from a two-piece, 9-m long, fiberglass extension ladder with a pulpit at the end made of wood. The platform was stabilized with tension wires and extended 3.5 m off the starboard side of the ship. The platform was extremely stable, and it was possible to pull it in while underway and during docking.

Visual observations and sonobuoys were used to locate whales. The areas surveyed were based on previous GulfCet aerial and shipboard sightings. During 24-hour operation, watches were held from 0600-2000 daily with two OSU persons on watch at all times. All cetacean sightings were recorded. At night, the scientific crew stood 2-hour watches that included acoustic stations (monitoring a suspended hydrophone) and maintaining vessel safety.

When whales were spotted, one observer remained in visual contact with the animals while the other scientists prepared the tagging equipment, 35-mm cameras, video recording equipment, and data sheets. VHF radio headsets were worn by the captain and scientific crew to communicate the whale's location and to coordinate the ship's movements for tagging.

The vessel covered 2,331 km searching for sperm whales (Figure 8.2). Sperm whales were seen on seven days and heard on 11 days. The number of sperm whales ranged from 4-22 per day with up to eight animals seen at one time (Table 8.1). A maximum of 87 individuals was seen during the cruise. Animals were sighted most often in the afternoon.

Animals were approached to within 75 m, at which time the vessel was slowed and one engine shut down to reduce noise for the final approach. The sperm whales were generally small; most were judged by eye to be less than 8 m in length and were considered too small to tag; a few were up to 8 m. Even these presented a small target and needed to be within 5 m of the ship and perpendicular to the tagging platform (approximately parallel to the vessel's starboard side) before a shot could be attempted. Positioning was critical for successful tagging. Because there were subdermal anchors at each end of the cylindrical tag, the tag's trajectory had to be perpendicular to the whale or the tag would not attach properly. Tagging attempts were made only when the animal's back was well out of the water and not arched.

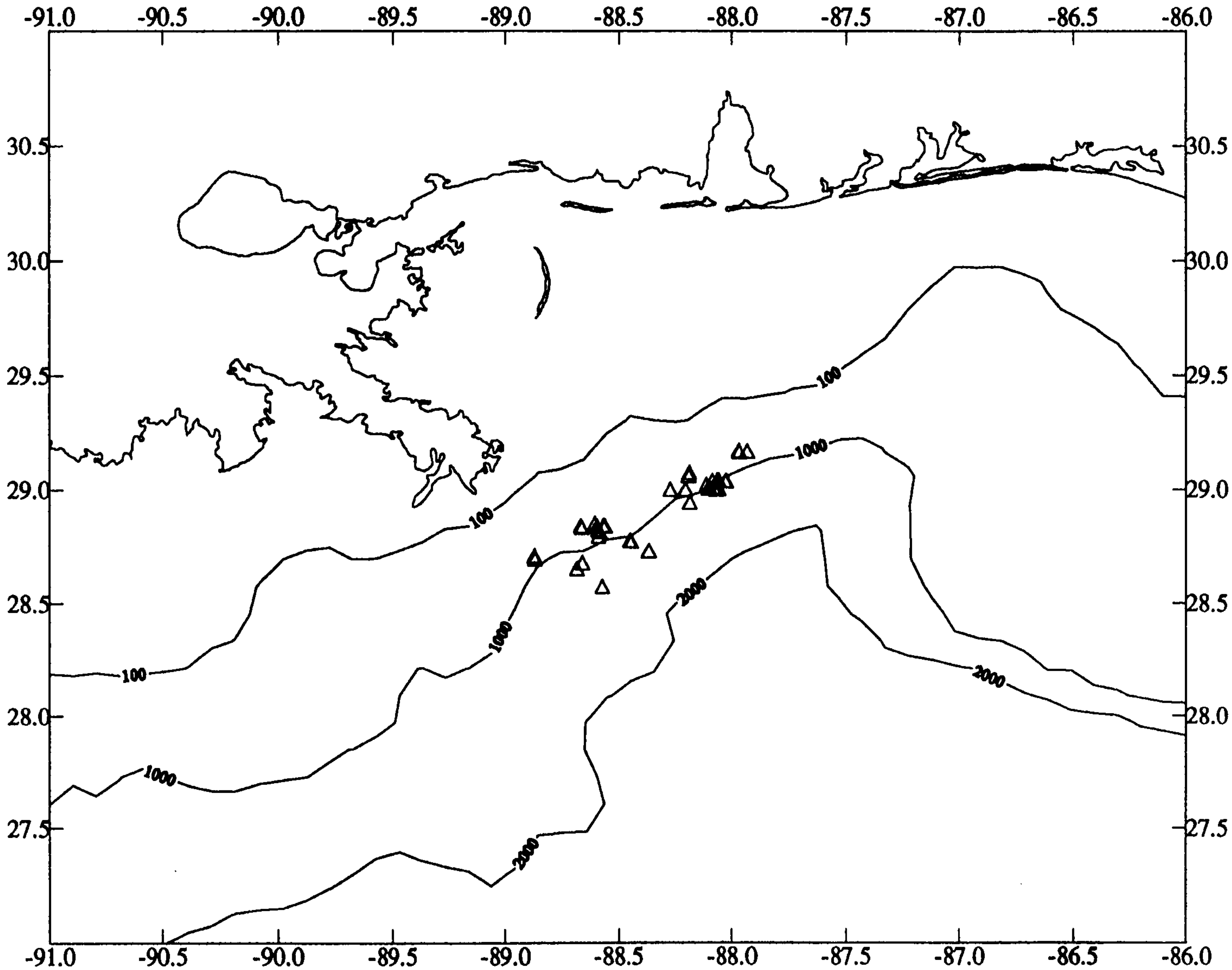

Figure 8.2. Sperm whale sightings, 6 to 29 June 1993, aboard R/V *Acadiana*.

Table 8.1. Sperm whale sightings, 7-29 June 1993, R/V *Acadiana.*

Date	Time	Latitude	Longitude	Number
7 June 1993	1608	29°02.35	88°01.54	7
7 June 1993	1710	29°02.23	88°03.50	3
7 June 1993	1900	29°02.26	88°05.15	4
12 June 1993	1520	28°49.32	88°35.48	3
12 June 1993	1750	28°50.40	88°35.71	3
12 June 1993	1810	28°40.68	88°39.67	1
12 June 1993	1945	28°50.36	88°40.09	4
13 June 1993	0815	28°42.47	88°52.71	2
13 June 1993	0828	28°42.01	88°52.24	2
13 June 1993	0845	28°41.68	88°52.14	1
13 June 1993	1637	28°43.85	88°22.01	3
13 June 1993	1740	28°46.40	88°26.66	1
13 June 1993	1900	28°50.47	88°34.07	5
13 June 1993	1915	28°50.29	88°34.40	4
23 June 1993	1240	28°56.25	88°11.17	2
23 June 1993	1345	28°57.70	88°12.43	2
23 June 1993	1426	29°00.12	88°12.91	3
23 June 1993	1430	29°00.39	88°12.81	3
23 June 1993	1508	29°00.13	88°12.33	1
23 June 1993	1725	28°56.56	88°11.26	3
23 June 1993	1740	28°56.70	88°11.57	1
23 June 1993	1835	28°59.58	88°16.94	4
23 June 1993	1908	28°58.59	88°17.53	3
24 June 1993	1145	29°00.37	88°12.41	2
24 June 1993	1308	29°02.34	88°12.09	2
24 June 1993	1347	29°04.42	88°11.47	3
24 June 1993	1450	29°03.63	88°11.62	4
29 June 1993	1805	28°39.70	88°41.00	2
29 June 1993	1830	28°38.80	88°41.55	2
			mean	2.8
			SD	1.35
			n	29

Two animals were tagged. The first whale (about 8 m in length) was tagged on 7 June with an SLDR. Only one message was heard from this tag. Photos revealed that the tag was located on the dorsal ridge with the forward tine of the housing implanted 5-8 cm in the blubber and the rear tine only implanted 2.5 cm. It is believed that this tag fell off the animal shortly after attachment due to incomplete penetration of the tines into the blubber. The second animal (about 7 m in length) was tagged on 11 June with a location-only telemeter. The telemeter placement was good. Although penetration was not complete, it was judged to be adequate. Further shock tests have been conducted without failures, so at present it is not known why this telemeter failed. All other opportunities (12-13 June and 23-24 June) for tagging were with animals judged to be too small. No whales were seen on four of the last five days despite excellent weather and sighting conditions (25-29 June).

A seismic vessel, the *Acadian Commander*, began seismic surveys on 23 June in an area where whales had been seen routinely (Figure 8.3). The seismic surveys were expected to continue for 30 days. Whales were seen on the periphery of the seismic survey area on the 23 and 24 June (Figure 8.4), but not in the middle of the area where we had seen many whales regularly before the seismic work began. No whales were seen in or near this area for the survey days after 24 June (Figure 8.5) (Mate et al. 1994). While the change observed in whale distribution may have been due to normal movements or a change in prey concentration, it did coincide with the onset of seismic activity. Therefore, there may be a cause-and-effect relationship, and the possibility can only be resolved with further investigation. Six species of other cetaceans were seen during this cruise (Table 8.2). A log of sea bird sightings was not maintained.

8.1.3 *Summary*

Previous information about sperm whales in the Gulf has indicated that they are sparsely distributed and have very small pod sizes (see Chapter 2). The sperm whales sighted during the tagging cruises were in a patchy distribution over a large geographic region and were usually in loose groups of 2-8 animals.

Of particular interest was the small size of the sperm whales sighted. None of the animals were thought to be over 8 m. Four whales appeared small enough to be calves, which may have been recently weaned. At one point, the ship was in an area with about eight small animals at the surface. The ship stayed in this area for two hours and there was no evidence of any larger animals. Large animals would be expected if these small ones were part of a mixed group of females, calves, and juveniles. This juvenile group social structure may be unique to this area. It has never been reported in the scientific literature and certainly deserves more attention. The Smithsonian's stranding records were examined (Mead, personal communication), and the conclusions drawn from those data were that sperm whales of normal size do exist in the Gulf, and that the animals seen on the tagging cruises were not merely from a population of small individuals.

While searching for sperm whales in the Gulf of Mexico in 1993, some circumstantial evidence was obtained that seismic vessel activity may affect the distribution of sperm whales (Mate et al. 1994). During five of the first nine survey days, sperm whales were consistently sighted, generally in a localized geographic area. During this time, the *Acadian Commander* was preparing to begin seismic testing. During the first two days of seismic activity (34 guns shooting every 10 seconds at 1800 psi, 24 hours a day), only a few sperm whales were located on the margins of the seismic survey area. No whales were found for the next five days in that region. Although observations represent circumstantial evidence, the change in whale sightings after the onset of seismic activity is sufficient to warrant concern and additional studies. Richardson et al. (1995) summarize data on marine mammal reactions to seismic activity.

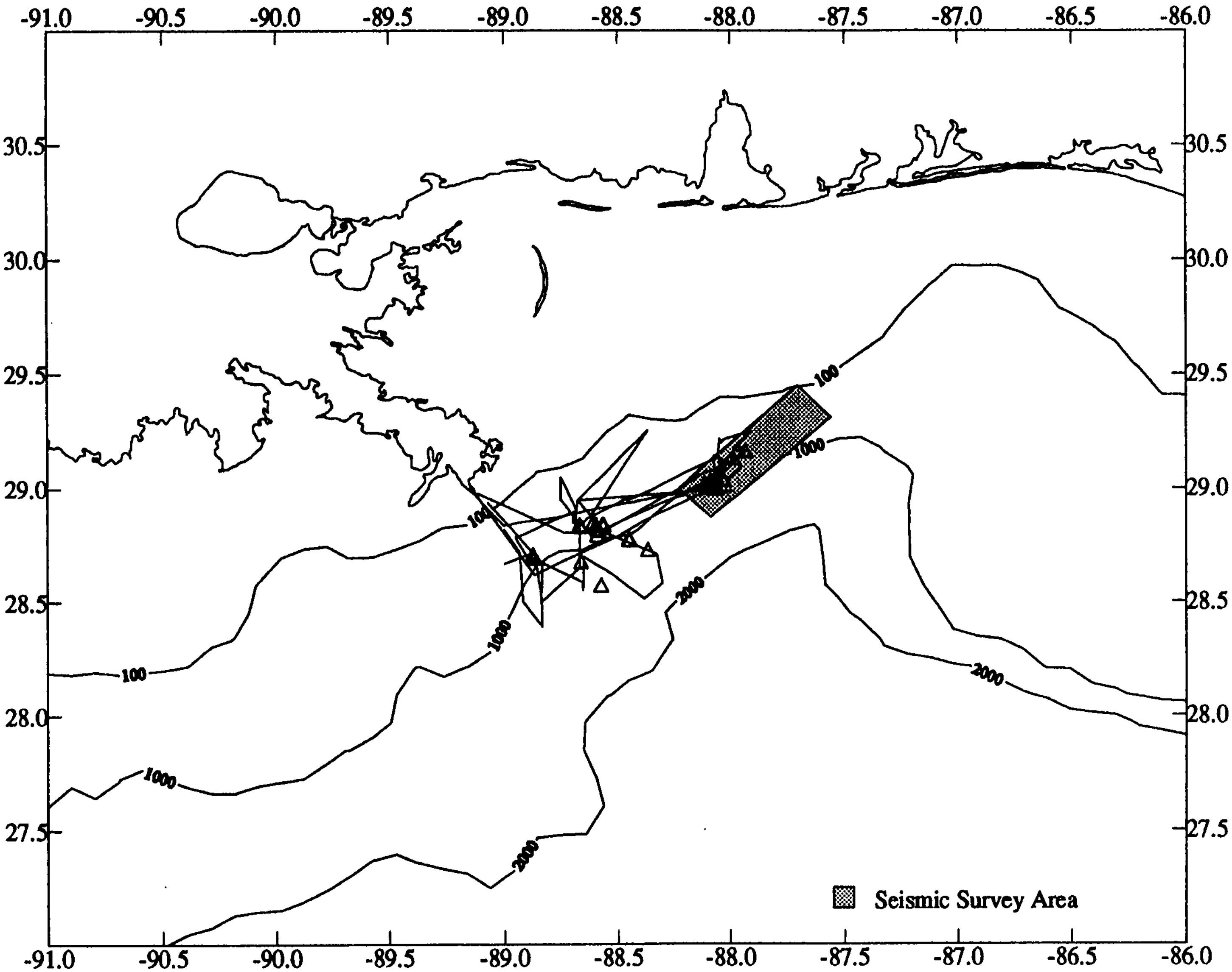

Figure 8.3. R/V *Acadiana* cruise track and sperm whale sightings 6 June to 22 June 1993, prior to seismic activity.

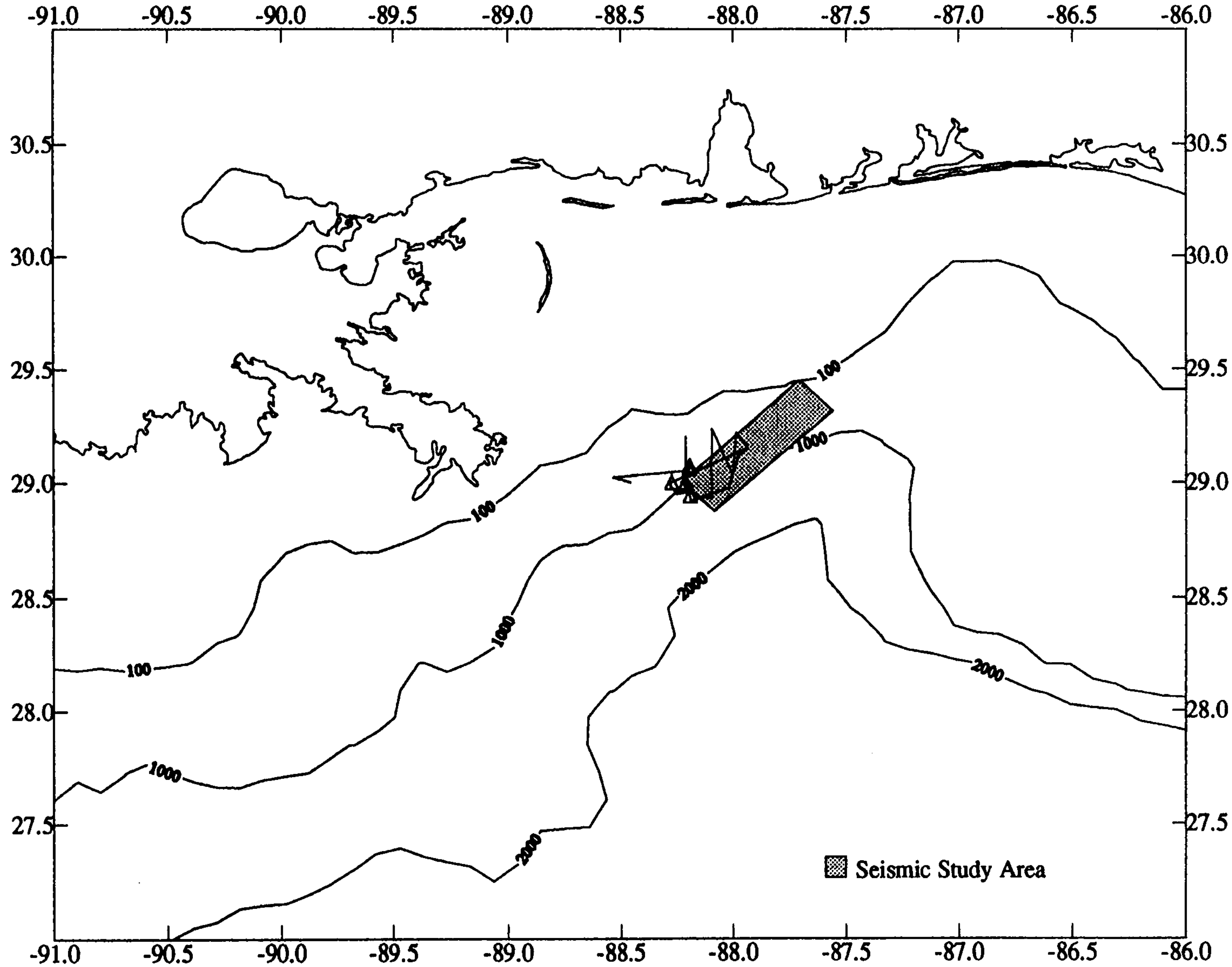

Figure 8.4. R/V *Acadiana* cruise track and sperm whale sightings 23 June to 24 June 1993, with seismic activity beginning.

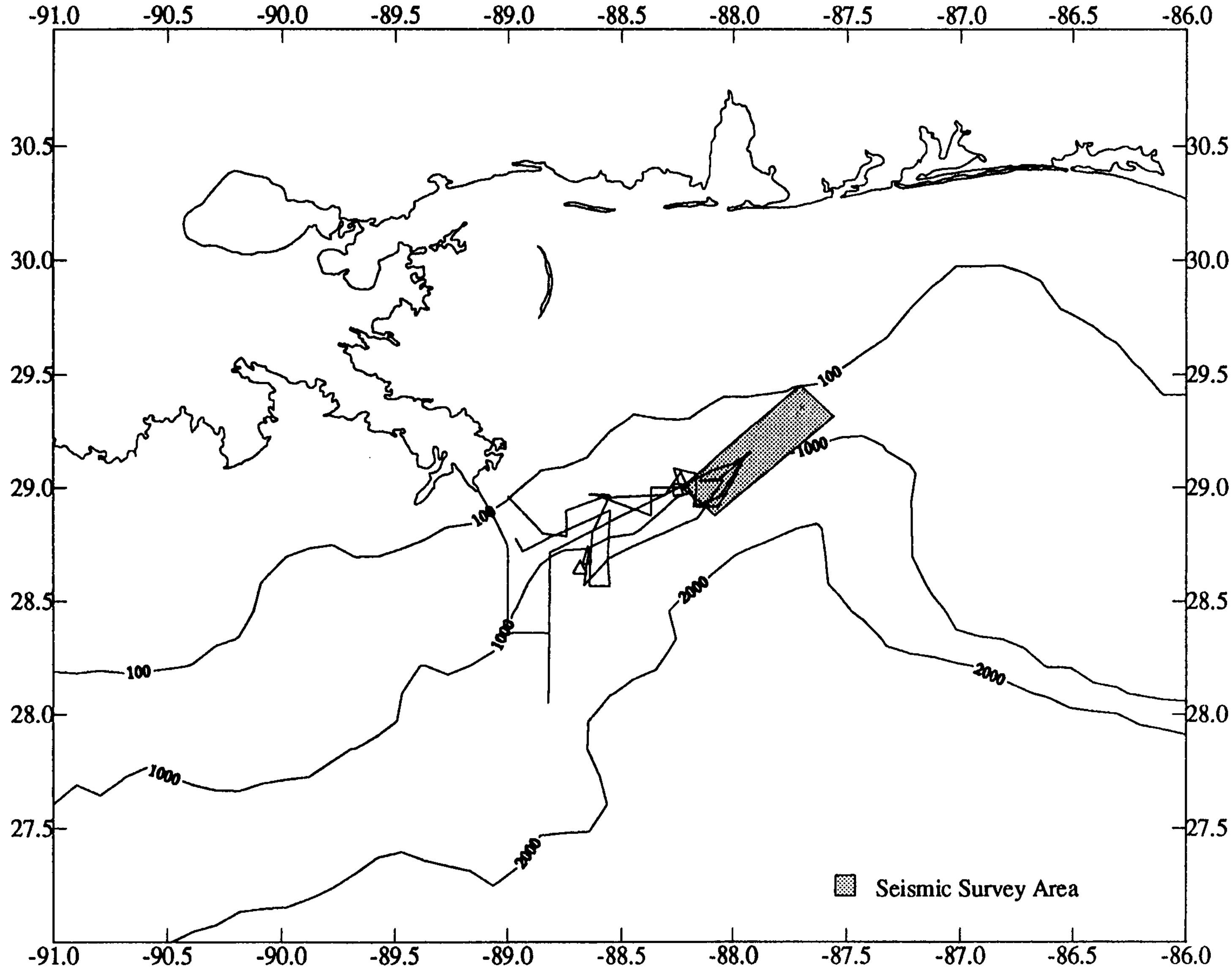

Figure 8.5. R/V *Acadiana* cruise track and sperm whale sightings 25 June to 29 June 1993, with seismic vessel activity.

Table 8.2. Cetaceans other than sperm whales seen on a sperm whale tagging cruise 7-29 June 1993 (100% confidence).

Date	Time	Latitude	Longitude	Species	Number
7 June 1993	1420	28°40.64	89°05.69	Bottlenose dolphin	2
7 June 1993	1940	28°36.70	88°43.03	Pantropical spotted dolphin	15-20
12 June 1993	1350	28°54.29	88°23.85	Clymene dolphin	25-30
23 June 1993	1930	28°59.40	88°17.64	Fraser's dolphin	3
24 June 1993	0745	29°07.13	87°58.52	Pantropical spotted dolphin	25
24 June 1993	1010	28°58.11	88°02.64	Pantropical spotted dolphin	35-40
24 June 1993	1345	29°04.80	88°10.94	Rough-toothed dolphin	8
27 June 1993	1920	28°46.40	88°57.81	Risso's dolphin	5

Satellite telemeters were attached to two small animals on this cruise: an SLDR and a location-only telemeter. The lack of penetration of the tines appeared to be due to the tough skin and blubber on the animal's dorsal ridge. The small size of the animals that were tagged may have exacerbated this problem. The attachment methods have worked very well on right whales and bowhead whales (Mate et al. 1992, Mate and Krutzikowsky in prep.), but may have to be modified for sperm whales.

8.2 Sperm Whale Focal Cruise

Sperm whales have been consistently found in a small area off the mouth of the Mississippi River, both historically (Chapter 2) and in the present study (Chapters 3 and 4). This situation provided the opportunity to locate whales for the tagging program, and also raised a question as to why these animals should be so consistently found at this location. In order to begin addressing this question, a sperm whale focal cruise was undertaken (*Pelican* Cruise 8). The purpose of the cruise was to monitor sperm whale movements and behavioral patterns and to begin describing individuals in order to determine whether they utilize this area over multiple seasons and years. Both acoustic and visual means were used to locate and follow whales in the vicinity of the mouth of the Mississippi River.

The R/V *Pelican* was used from 20-28 August 1994 to follow sperm whales for visual and acoustic observation in an area approximately 40 km southeast of the mouth of the Mississippi River. There were two aspects of the acoustic effort: using the horizontal towed array to locate and follow animals, particularly at night when no visual effort was possible, and using a combination of horizontal and vertical arrays to localize vocalizing sperm whales. The visual effort concentrated on locating and following animals, describing behavior, and obtaining fluke identification photos. Sightings and effort are summarized in Appendix A.

8.2.1 *Locating and Tracking Sperm Whales*

Survey effort started on 20 August at the head of the Mississippi Canyon. An absence of sperm whale sightings and acoustic contacts during 10.52 hr of effort prompted a move east to an area which had produced a large number of sperm whale sightings and acoustic contacts during earlier GulfCet cruises. The first contact with sperm whales was made at 28°38.49'N, 89°00.69'W at 1920 hr on 20 August, very near the location on *Pelican/Longhorn* transect leg 12 where whales had previously been located. For the next four days, until the evening of 24 August, whales were followed using visual and acoustic methods. Contact was maintained approximately 80% of the time, within an area of 12 x 21 NM (Figure 8.6). During the tracking period, vertical hydrophone arrays were deployed for acoustic localization, and photos were taken for individual identification. By the evening of the fourth day it was clear that many animals were concentrated around the location where they had initially been contacted. After completing day time efforts to obtain fluke identification photographs, the nights of 24, 26, and 27 August were spent transiting east, southeast, and south, respectively, to acoustically determine the dispersion of sperm whales in the area. In each case, when we departed

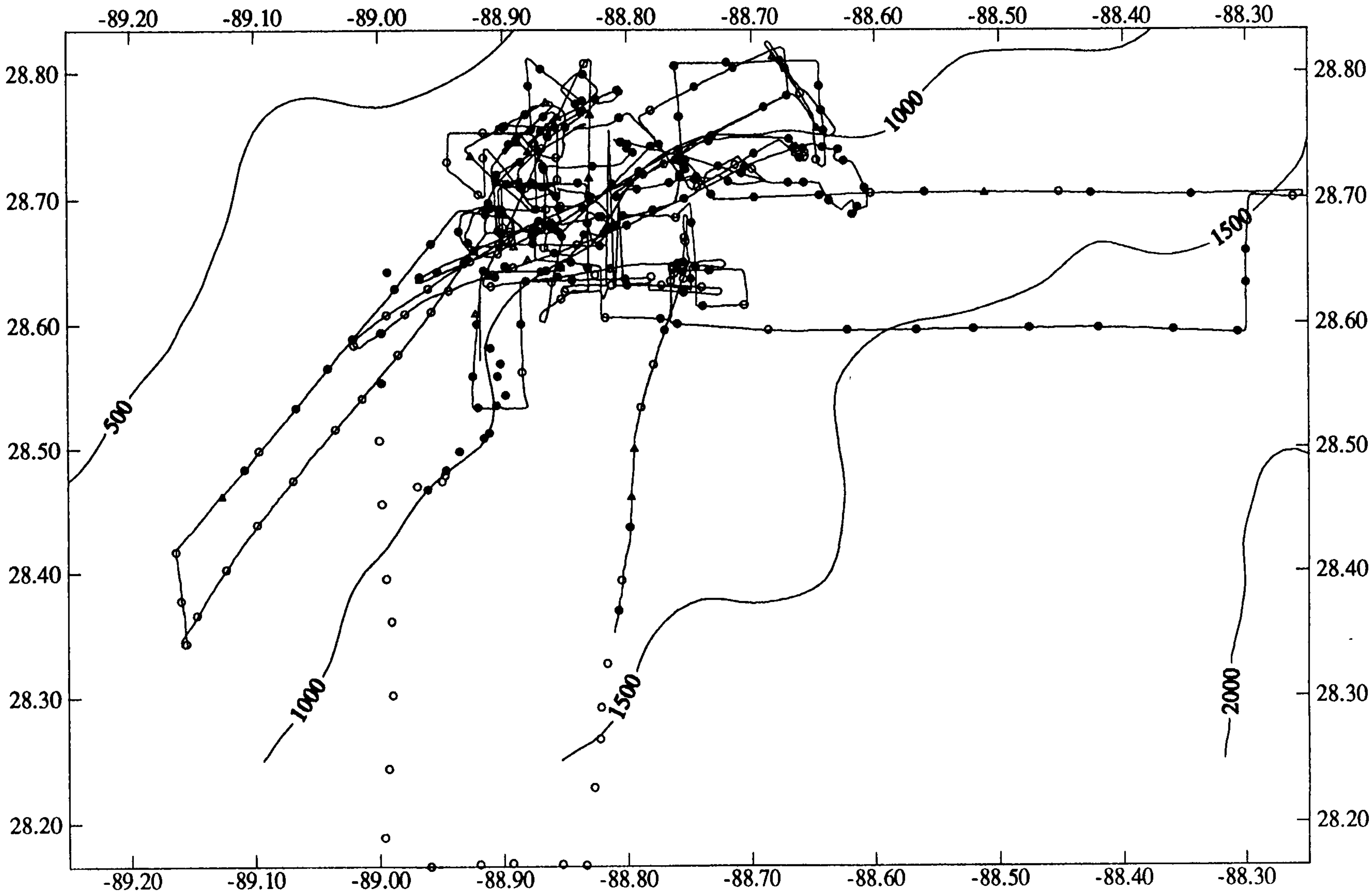

Figure 8.6. Cruise track of R/V *Pelican*, 20-28 August 1994 (TIO Cruise 8), and sperm whale sightings. The presence (filled circles) or absence (open circles) of sperm whales is shown in half-hour intervals (whether detected visually or acoustically). Triangles indicate no effort.

the vicinity of 28°70'N, 88°85'W we lost contact with whales, but upon returning to the area they were again located and followed, suggesting that they were the only sperm whales in the area. The southwestern leg followed a preferred depth contour (1,200 m), yet no new animals could be located. Sperm whales were consistently located and followed within the area of concentration through 28 August, after which the ship returned to port. The ability to locate, follow, and maintain visual and acoustic contact with sperm whales day and night over an eight day period is an indication of the efficacy of the dual use of acoustic and visual methods.

8.2.2 *Acoustic Localization of Vocalizing Sperm Whales*

The towed linear hydrophone array and vertically deployed sonobuoy triads were used in an attempt to localize vocalizing sperm whales at depth. A total of forty-nine sonobuoys were deployed, thirty-three of which were used in three-buoy vertical arrays. The linear array was towed near the surface while the sonobuoy arrays were deployed at either 20, 100, and 300 m or 100, 120, and 300 m depths (Figure 8.7). The localization analysis was based on a matched field processing approach and performed at sea. Given an estimate of the acoustic environment, known receiver positions, and assuming linear ray paths, the most probable location of the source was determined by finding the best match between observed arrival time differences and time differences between several hundred pre-defined locations in the acoustic field. The location associated with the set of travel time differences most closely matching the set produced by the source was presumed to be an approximate source location. Travel time differences for these points were computed taking into account the temperature effect on the vertical sound speed profile. Thirty XBTs were deployed and provided temperature vs. depth data. Salinity was assumed to be 35 ppt.

Results from one trial analysis (at midnight, 24 August) show three of five vocalizing animals near 600 m deep (Figure 8.8), in water 1,247 m deep. The shallowest localization was at approximately 100 m. There were no indications of animals vocalizing at or near the surface.

8.2.3 *Photo-identification of Sperm Whales*

Arnbom (1987) showed that individual sperm whales can be photographically identified from distinctive marks and notches on their flukes. Photo-identification was conducted from a 4.2 meter inflatable Avon and individual sperm whale flukes were photographed with 35-mm cameras equipped with 200- and 300-mm zoom lenses, as well as HI8 video. Opportunistic photographs were also taken from the main research vessel. Photo-identification from the small inflatable was conducted at irregular intervals during the study, with major efforts on 23, 25, and 28 August. Three researchers independently agreed on individual identifications.

Twenty individual sperm whales were identified from photographic and video images, two of them calves (Schiro et al. 1995). Identified individuals slowly meandered within the study area each day. However, over the study period, identified individuals moved several kilometers to the east then back to the

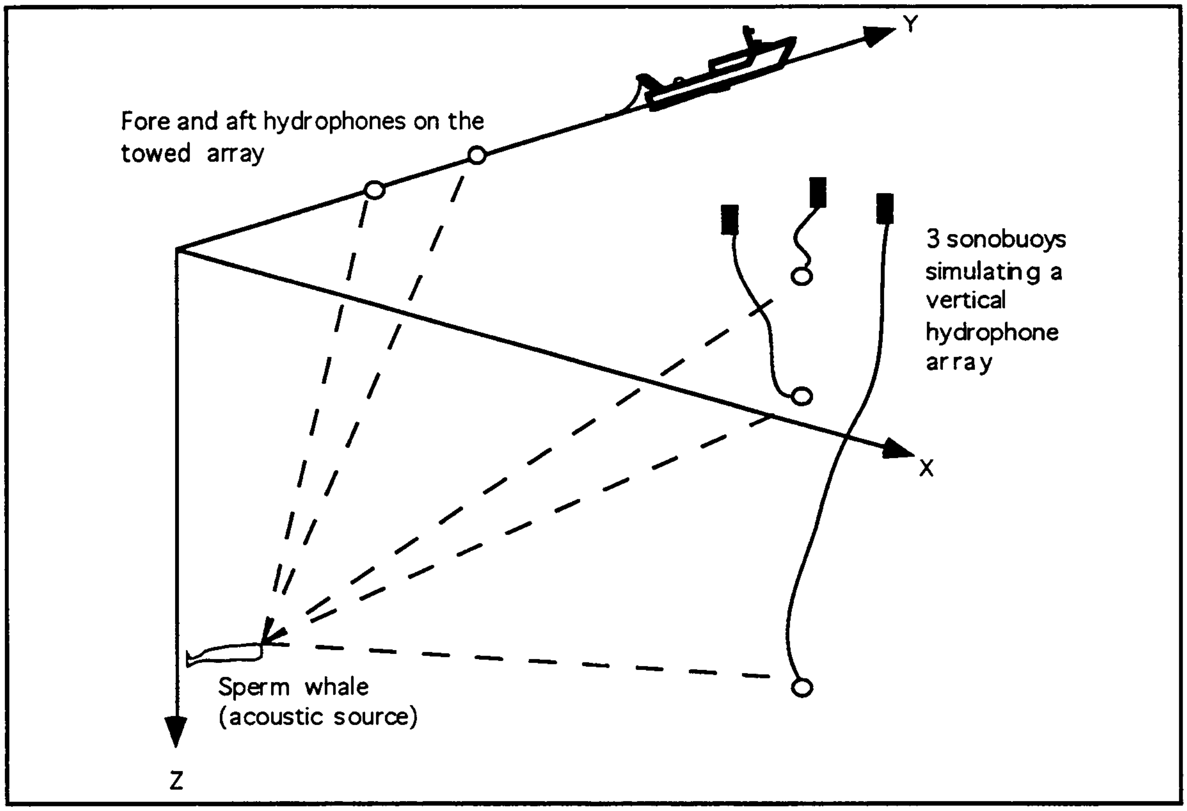

Figure 8.7. Illustration of the use of the horizontal and vertical hydrophone arrays to locate sperm whales in 3-dimensional space. The horizontal towed array was composed of two receivers separated by 60 m. The vertical array was composed of 3 sonobuoys deployed in close proximity to each other at depths of 100, 120, and 300 m.

west near the original contact position. By the last day of observations (28 August), some sub-groups with identified individuals had moved several kilometers to the southwest.

Nine of the 20 identified individuals were resighted (photographed again in a new subgroup) during the cruise (Figure 8.9). Six of these individuals were resighted only on the same day during which they were initially sighted. Sighting intervals for 4 individuals resighted over multiple days ranged from 1-4 days. One individual was sighted on 3 different days. Whales sighted on multiple days had a mean distance between resightings of 19.3 ± 6.73 (SD) km (n = 5 resightings, 4 whales). Distances ranged from 10.3-26.2 km.

It was the impression of the researchers that only a maximum of 50 animals (possibly fewer) was seen and that many of the same animals were sighted throughout the survey. All sightings on this survey were made within 20 NM of the location where sperm whales were first encountered (near 28°38'N, 89°00'W).

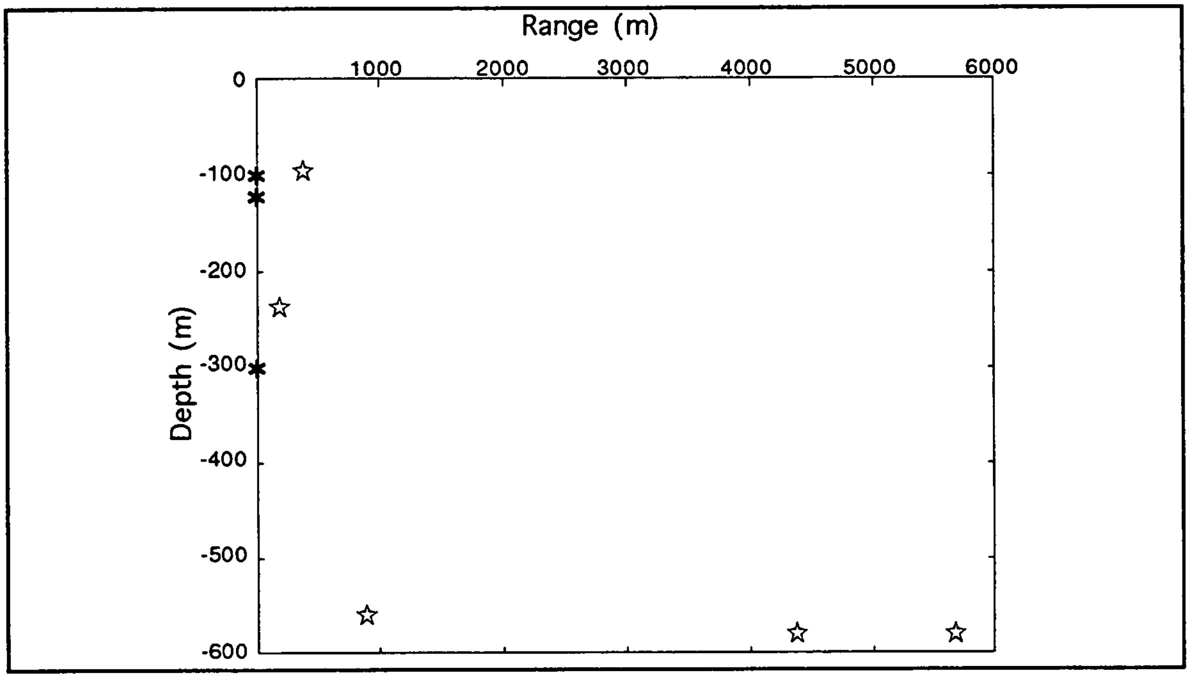

Figure 8.8. The results of localizing vocalizing sperm whales using vertical and horizontal arrays. Asterixes = sonobuoy locations and stars = estimated whale locations.

8.2.4 *An Interaction Between Sperm Whales and Pilot Whales*

On 24 August 1994 an unusual interaction between pilot whales and sperm whales was observed at 28°43.20'N, 88°44.13'W (Weller et al. in press). This location is within the general region where we had been observing sperm whales throughout the cruise. The defense reaction of sperm whales to the presence of pilot whales is described here. While the true nature of the interaction is difficult to interpret, this account provides suggestive evidence that short-finned pilot whales may aggress toward or at least threaten sperm whales. Pilot whales are not generally known to prey on other marine mammals; however, records from the eastern tropical Pacific document that this species does chase, attack, and may occasionally eat young dolphins during fishery operations (Perryman and Foster 1980). In captivity, pilot whales have been noted to aggress toward humans (Norris 1967), and to eat still-born or young dolphins (Brown et al. 1966, cited in Perryman and Foster 1980). A male pilot whale off Hawaii bit into the thigh of a woman, and took her at least 12 m below the surface in possibly aggressive or play related behavior (Shane et al. 1993).

The following report describes the general behavior state and salient behavioral events recorded during the 150 minute interspecific interaction. Real time field notes, 35-mm photographs, and video tape with running spoken commentary were used as the basis for this description. The term "adult" sperm

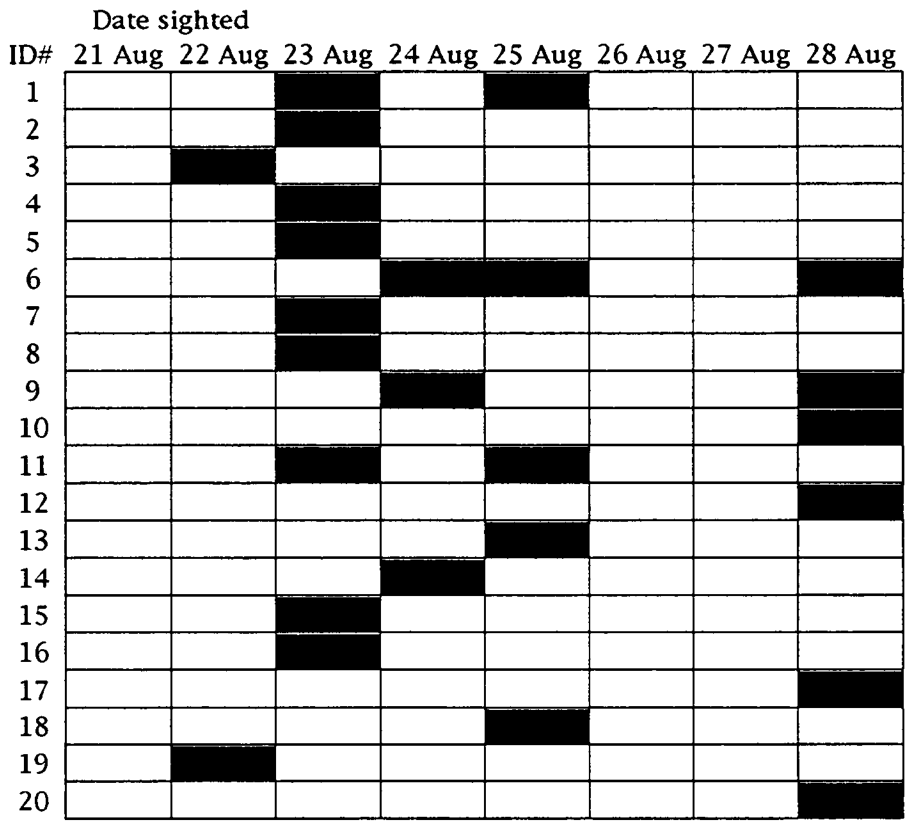

Figure 8.9. Sighting dates of identified sperm whales. The absence of identifications on 26 and 27 August was due to the lack of photographic effort.

whale refers to presumed adult females and immatures (as opposed to small calves). Based on size estimates, the presence of a mature male was not observed.

At 1410 hr (28°39.20'N, 88°41.91'W) a large school of approximately 30 short-finned pilot whales was sighted via 25 x 150 binoculars. Individuals were dispersed in numerous subgroups and spread over a 2-5 km area, with some animals approaching the research vessel within 200 m and paralleling its course directly abeam. Low directional leaping and rapid surfacing was noted at this time, and two of the observers (B. Würsig and D.W. Weller) commented that the apparent size of these pilot whales exceeded what they had observed in other geographic locations.

At 1446 hr (28°43.20'N, 88°44.13'W) a subgroup of sperm whales was sighted near the horizon just prior to their fluke-up dives. Eighteen minutes later, at 1504 hr, a mixed aggregation of sperm whales (referred to as "group 1") and pilot whales was sighted. The observation of several large pilot whales tail lunging and tail slapping at the head of an adult sperm whale suggested that this might be an agonistic encounter. As the research vessel approached, the composition of the aggregation was noted to consist of a sperm whale mother/calf pair surrounded by 8-10 pilot whales. The pilot whales appeared excited, as evidenced by rapid swimming and surfacings, fluke-up dives, and variable movements along the flanks, heads, and flukes of the sperm whales. The behavior of the mother/calf pair appeared distressed, as suggested by high head rises, frequent respirations, fluke swiping, and erratic changes in body orientation and posturing.

Also in view at this time, and at an approximate distance of 500 m, was a mixed group of six adult sperm whales and one calf (referred to as "group 2") and approximately 20 pilot whales. At 1532 hr, after 28 min of observation on group 1, the research vessel motored to within 300 m of group 2, attempting to stay near the whales but not approaching them directly. The remaining 122 min of behavioral observation was done at a distance no greater then 300 m and at zero or minimal vessel power.

Considerable fusion in the composition of group 2 was noted across the observation period. At 1600 hr, group 1 and attendant pilot whales joined group 2, increasing the overall sperm whale group size to seven adults and two calves. At least three additional lone adult sperm whales, also escorted by pilot whales, approached group 2 at rapid swim speeds, and eventually joined the interaction (one as late as 1705 hr), resulting in a total of 10 adults, two calves, and 30-45 pilot whales. The increase in the number of sperm whales appeared to be correlated with a decrease in pilot whale activity. The presence of calves may explain why these sperm whales did not attempt to flee by vertical descent.

The spatial proximity of individual sperm whales remained close, often huddled together and touching, throughout the observation. This huddling behavior included the creation of numerous marguerite formations (Nishiwaki 1962) over the duration of the interaction. The marguerite formation was assembled horizontally at the water surface with heads in and flukes out, and at times vertically, providing a three dimensional marguerite in which whales were pitch-poling with heads at the surface and flukes suspended below. In most cases, one or both of the young calves were directly in the center of these formations. The marguerite was not always a complete circle and seemed to wax and wane with increases and decreases in overall pilot whale activity.

During marguerite formations and periods of tight huddling, the following behavioral events were observed for sperm whales: (1) open mouth behavior: lower jaw agape exposing the teeth and associated white mouth and lips; (2) inverted surface posturing: inverted, ventrum-up body position at the surface of the water exposing underside of lower jaw; (3) lateral fluke swishes: a portion of a fluke blade above the water surface and rapidly thrust in a lateral or sideways orientation; (4) peduncle arching: caudal peduncle arched above the surface of the water (particularly frequent in calves); (5) underwater bubble clouds: underwater exhalation of air; (6) tail slapping: repeated horizontal fluke slaps on surface of water; (7) spy hopping: lifting of head above surface of water; and (8) inverted underwater posturing: inverted body position directly below a calf at the surface situated between two adults.

Harassment strategies of the pilot whales remained mostly veiled. The pilot whales remained near and among the sperm whales for the majority of the observation period. Many fluke-up dives and caudal arches were noted and some rapid "surge" swimming (in which a burst of white water was created at the surface by the forward movement of a pilot whale) was observed. The pilot whales appeared to take particular interest in attempts to penetrate the marguerite formation of the sperm whales. In one instance two pilot whales swam toward an adult sperm whale, inverted themselves just prior to interspecific body contact and slid over the sperm whale's dorsum and back and directly into the center of the marguerite. At no time were either species seen to bite the other, nor was any blood or any other sign of injury observed, including fresh rake marks.

The pilot whales did not seem to act in any particularly coordinated fashion except for a "stand off" in which approximately 25 pilot whales simultaneously clustered behind the flukes of the sperm whales who were in a distinct staggered-line-abreast formation. At other times, groups of both species formed lines facing each other, at a distance of less than one sperm whale body length.

At 1715 hr (28°43.45'N, 88°45.21'W) five rough-toothed dolphins approached the interaction, at first swimming among the pilot whales and sperm whales, and eventually remaining directly below the bow of the vessel. At 1734 hr all of the pilot whales had departed and most of the sperm whales had sounded. Several sperm whales remained rafting or pitch-poling vertically in the water. At 1820 hr all sperm whales had departed. Remains of two partially digested and apparently regurgitated squid were seen floating in the water column at this time and one was collected.

Vocalizations of both species were gathered using sonobuoys deployed within 1 km of the interaction and recorded on a Racal V-Store tape recorder. Sound recordings were made at 3-3/4 ips with an associated bandwidth of DC-12.5 kHz. The sperm whales maintained a stereotypical steady vocal pulsing throughout the interaction while pilot whale vocalizations were mostly infrequent whistles, with occasional burst pulse 'tonal' signals. While there were no direct correlations between vocalizations and behavior, the sperm whales produced a number of four, six, and seven pulse codas at the start of our observations and at the end of the interaction. No rough-toothed dolphin vocalizations were heard until at least 10 minutes after they had joined the interaction. Once the pilot whales departed the area, and after a series of codas, the sperm whales gradually became silent.

Our interpretation of this interspecific interaction as agonistic is based upon the defense behavior displayed by the sperm whales. Accounts of how this species reacts to deleterious stimuli such as whalers, killer whales, false killer whales, and sharks closely parallel the behaviors observed here.

Nishiwaki (1962) described the marguerite formation after observing all members of a sperm whale group circle a harpooned affiliate in a heads-in and flukes-out arrangement resembling the petals of a marguerite flower. Berzin (1971) reports a similar account from whalers in the northern Pacific in which a group of hunted sperm whales maintained a large circle of adults surrounding young animals. Best et al. (1984) described an apparent calving episode in which a tightly bunched group of sperm whales, with all calves in the center, were threshing their flukes. These authors then state that outside of the "circle" (it is difficult to assess if this was indeed an actual marguerite) were numerous killer whales and dozens of sharks. Palacios and Mate (1994) observed the marguerite formation during an attack by false killer whales on sperm whales near the Galápagos Islands.

Indications of the generality and rate of occurrence of instances such as that observed in the Gulf of Mexico can be obtained from observations during tracking of sperm whales in the South Pacific between 1985-1993 (see Smith and Whitehead 1993, Dufault and Whitehead, in press, for some details of the research). During 165 24-hour days of tracking sperm whales from 10-12 m auxiliary sailing vessels (principally off the Galápagos Islands and mainland Ecuador) there were 18 instances in which sperm whales and short-finned pilot whales were visible at the same time. In five of these cases, apparent harassment of the sperm whales by 12-50 pilot whales was observed, and in two of them (both off mainland Ecuador, and, as determined by individual identification studies [Arnbom 1987], containing different groups of sperm whales) the sperm whales were observed to adopt the marguerite formation. In neither observation of the marguerite formation were first-year sperm whale calves present. In four of the five harassment cases, including both times the marguerite was observed, the pilot whales were accompanied by 12-50 bottlenose dolphins; however, it seemed to be the pilot whales that were most affecting the behavior of the sperm whales. Harassment incidents lasted between 10-60 min, and behavior of both species was generally similar to that observed in the Gulf of Mexico, although observations were less complete and detailed. The two observations of the marguerite formation during apparent pilot whale harassment were the only two clear observations of this behavior during the South Pacific studies.

L. Ballance (personal communication, National Marine Fisheries Service, La Jolla, CA) observed a group of eight sperm whales, including one calf, form a marguerite as a possible response to killer whales in the eastern tropical Pacific. Interpretation of this account is complicated, however, by the presence of a mixed aggregation of pilot whales and bottlenose dolphins swimming around the sperm whales in an excited manner. Ballance suggests that these smaller delphinids may have been seeking refuge from the killer whales by associating with the sperm whales. However, it may also be true that the sperm whales formed the marguerite in response to the pilot whales (and possibly the bottlenose dolphins).

In contrast to all of the above accounts, Arnbom et al. (1987) report the reaction of sperm whales to an attack by killer whales. These sperm whales did not create a defense marguerite but rather faced their aggressors in more of an offensive manner. However, similar to the acoustic behavior of sperm whales reported here, Arnbom et al. (1987) also found that the sperm whales eventually became silent after the encounter.

Reports of sperm whales forming the marguerite are relatively uncommon in the literature. Most existing accounts suggest that the marguerite is a defense response to some perceived threat to injured or particularly vulnerable individuals (calves), similar to what is commonly reported for terrestrial animals. While the defense reaction of sperm whales reported here and by others (Nishiwaki 1962, Berzin 1971, Best et al. 1984, Palacios and Mate 1994, Ballance personal communication) varies from that of Arnbom et al. (1987), differences may simply reflect divergent strategies activated by perceived risk and potential vulnerability at both the individual and group level.

Attack responses of sperm whales toward whaleboats are well documented and include inverted body posturing, lateral fluke swipes, head rises, and inverted open mouth behaviors (Caldwell et al. 1978, Norris 1967). Many of these discrete behavioral events, reported for whales in obvious distress, were also prevalent throughout the interaction reported here.

The sperm whale defense responses described here suggest that these animals were reacting to a perceived threat. No actual combat or overt fighting was observed, and no evidence of injury to either species was noted. Therefore, we hypothesize that the pilot whales were testing the vulnerability of these sperm whales to assess the potential for separating particularly weak or young individuals from the group. The pilot whales were cautious in their threats (as are most terrestrial mammals) due to the potential for injury. Thus, no blatant or brazenly obvious attacks were attempted by the pilot whales, most likely as a result of a perceived lack of general sperm whale vulnerability. It is also possible that the pilot whales were engaged in play or practice of predation, with no real intent to harm or kill the sperm whales. The presence of apparent blackfish tooth rakes on the dorsal fins and flukes of sperm whales from both the Gulf of Mexico and South Pacific suggests that this type of non-lethal predation may be occurring. Killer whales are known to teach cooperative hunting strategies to their young (Lopez and Lopez 1985), but we have no evidence for this point in the present case. A final alternative explanation may be that of competitive exclusion occurring between two squid-eating species.

In combination with the few accounts of pilot whales aggressing towards other marine mammals and evidence that several blackfish species including false killer whales and pygmy killer whales may attack and eat other cetaceans (Perryman and Foster 1980, Hoyt 1981, Palacios and Mate 1994) it is not unreasonable to speculate that this interaction was aggressive in nature.

8.2.5 *Summary*

Sperm whales were located and followed within a small area off the mouth of the Mississippi River from 20-28 August 1994. Estimated at no more than 50 animals, they were followed for approximately 80% of the time using a combination of visual and acoustic means. Three-dimensional localizations showed that whales vocalized at depths as great as 600 m (in 1,250 m of water). The results of the two aspects of acoustic effort, whale tracking and localization, demonstrate that sperm whales can be both tracked as well as localized in three dimensions using acoustic means.

Twenty individuals were photographically identified. Sighting intervals for four individuals resighted over multiple days ranged from 1-3 days. The mean distance between resights over multiple days was 19.3 km, ranging from 10.3-

26.2 km. A rarely observed aggressive interaction between pilot whales and sperm whales was also observed.

Historical records show no seasonal change in the distribution or abundance of sperm whales in the north-central Gulf of Mexico (Chapter 2), and it is possible that individual females, calves, and immature whales, at least, reside permanently in the Gulf of Mexico. Questions about site fidelity and subgroup isolation must remain unresolved until a significant proportion of the population is identified and more is known about long-term movements of sperm whales in the Gulf. This will require continued photo-identification effort to allow the description of the population's age, sex, and social structures.

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IX. CETACEAN HABITAT

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9.1 Introduction

There are many factors that influence the spatial and temporal distribution and abundance of marine mammals. These factors may be broadly divided into those that are environmental, biotic, and anthropogenic (Borcard et al. 1992). Environmental variables include those that are physicochemical, climatological, acoustic, and geomorphological. Environmental factors operate on time scales ranging from less than a day to many millennia. Diel, seasonal, interannual, and decadal patterns of variability or periodicity may occur for each factor. Biotic variables include competition among animals, reproduction, and predation. Anthropogenic factors include, among others, historical hunting, pollution, ship activity, commercial and recreational fishing, oil and gas development and production, and seismic exploration. One of the major impacts of many of these factors is the alteration of the acoustic environment, vital to cetaceans for navigation, foraging, and social communication (Evans 1971). The spatial structuring of marine mammal communities may be influenced by many of these factors, the relative contributions of which are difficult to quantify.

The correlation of environmental features with sighting data can improve our understanding of cetacean ecology and indicate which, if any, oceanographic variables may be driving cetacean distribution (Smith and Gaskin 1983, Hui 1985, Smith et al. 1986, Brown and Winn 1989, Reilly 1990, and Waring et al. 1993). Shipboard and aerial sightings were analyzed to determine an average species habitat profile. Seven environmental variables were chosen to characterize habitat based on their ability to represent oceanographic, topographic, and acoustic variables: 1) sea surface temperature (SST) from ship data and AVHRR infrared satellite images, 2) sea surface temperature gradient, 3) temperature at 100 m, 4) depth of the 15° C isotherm, 5) surface salinity, 6) bottom depth, and 7) bottom depth gradient. Environmental profiles were assembled for 13 species or species categories that had at least 10 sightings with most of these variables. Environmental profiles were assembled for the other species or species categories that had fewer sightings (see Appendix A), but these were not included in the statistical comparisons.

Several of the seven variables are standard hydrographic indices used in water column analyses. SST, SST gradient, temperature at 100 m, and depth of the 15° C isotherm, when combined with dynamic height data, can provide information on the position, depth and size of distinctive mesoscale oceanographic features, such as the Loop Current, warm-core eddies and cold-core eddies (Biggs et al. 1995; see also Chapter 6 of this report). These variables are also useful in locating thermal fronts or upwelling areas that may be associated with increased primary productivity and prey concentrations, potentially attracting marine mammals. These variables may also cause acoustic propagation anomalies (Smith et al. 1986, Biggs 1992, Biggs and

Müller-Krager 1994), that could affect foraging behavior (Evans 1971, Au 1993).

In the northern Gulf, salinity is an important hydrographic variable because of the high fresh water discharge from the Mississippi River. This discharge can extend over the continental slope and, in conjunction with wind, can affect the circulation, salinity, and acoustic propagation patterns of the north-central Gulf (Walker et al. 1994, see also Chapter 6 of this report).

Water depth and subsurface topography appear to influence cetacean distribution (Hui 1979, 1985; Kenney and Winn 1987). Since several of the species in the GulfCet study area were known to be deep divers based on their diet (Clarke 1986, Jefferson et al. 1993), bottom depth and bottom depth gradient were considered to be important variables for the analysis. The continental shelf break and continental slope of the GulfCet study area contain some of the most variable topography in the Gulf. Although smaller cetaceans may be confined to the upper 200 m of the water column (Williams et al. 1993), many prey on deep scattering layer (DSL) organisms that are accessible at night when the DSL migrates toward the surface (Ridgway and Harrison 1994). Sperm whales, pygmy/dwarf sperm whales and beaked whales are capable of diving much deeper and probably exploit much of the water column down to and below 1,000 m (Clarke 1986, Jefferson et al. 1993).

We would have liked to include sea-surface chlorophyll concentration as one of the environmental variables, as it has been shown to correlate with the distribution of zooplankton and larger nekton that may influence cetacean distribution (Smith et al. 1986). However, without the satellite-based Coastal Zone Color Scanner (CZCS) to determine surface pigment concentrations, the resolution of our data from water samples was insufficient for quantitative inclusion in the habitat analysis.

9.2 Methods

9.2.1 *Geographic Information System (GIS)*

The data used in the characterization of habitat were based on the results from Chapter 3 (Visual Surveys Aboard Ships and Aircraft) and Chapter 6 (Oceanography). A GIS was used to integrate the marine mammal sightings and oceanographic data. The locations of cetacean sightings were recorded in latitude and longitude coordinates with a global positioning system (GPS) or LORAN-C aboard the survey ships and aircraft (see Chapter 3 for details). SST (°C) data were collected by the Advanced Very High Resolution Radiometer (AVHRR) carried aboard the NOAA polar orbiting satellites (see Appendix B for images). Subsurface water temperature and salinity (psu) were measured with CTD casts (temperature only with XBT casts) at stations along the survey lines (see Chapter 6 for details). The point measurements acquired during an entire cruise were contoured for each depth interval using Surfer™ software. Bottom depth and bottom depth gradient were determined from a bathymetric map of the Gulf of Mexico with a resolution of 5 minutes of arc (Herring 1993). The maps were imported into an AGIS™ Geographic Information System (Delta Data Systems, Inc., Picayune, MS). Mean values for the seven variables for the study area were extracted from the GIS.

9.2.2 *Statistical Methods*

The seven environmental variables were analyzed using the Kruskall-Wallis test with *a posteriori* comparisons (significance considered at $\alpha = 0.05$) for the 13 species or species categories that had 10 or more sightings for most of the variables (Tables 9.1 and 9.2).

9.3 Environmental Profiles

Sea Surface Temperature (SST)

Only eight of the 13 species or species categories had 10 or more sightings for SST (Tables 9.1 and 9.2), and there was a significant difference among these six (KW = 20.7, df = 7, p = 0.004). There was a gradient of species found in cooler water to those found in warmer water (Figure 9.1). Atlantic spotted dolphins, striped dolphins and sperm whales occurred in the coolest water and, as a group, were significantly different from pantropical spotted dolphins, but overlapped with the group comprising bottlenose dolphins, Risso's dolphins, pygmy/dwarf sperm whales, and beaked whales. The mean annual SST for the study area was 24.6° C ± 2.5 SD.

Sea Surface Temperature Gradient

As with SST, there were only eight species or species categories that had 10 or more sightings for SST gradient (Tables 9.1 and 9.2), and there was a significant difference among these eight (KW = 15.7, df = 7, p = 0.03). There was a gradient of species found in shallower SST gradients to those found in steeper SST gradients (Figure 9.2). Atlantic spotted dolphins and striped dolphins occurred in the shallowest SST gradients and, as a group, were significantly different from beaked whales, but overlapped with bottlenose dolphins, Risso's dolphins, pantropical spotted dolphins, sperm whales and pygmy/dwarf sperm whales. The mean annual SST gradient for the study area was 0.03°/1.1 km ± 0.07 SD

Depth of the 15° C Isotherm

There was no significant difference among nine species or species categories (KW = 11.8, df = 8, p = 0.16) with regard to the depth of the 15° C isotherm (Tables 9.1 and 9.2). The overall mean for the nine species or species categories was 205.3 m ± 30.2 SD. The mean annual depth of the 15°C isotherm for the study area was 199.0 m ± 33.3 SD.

Water Temperature at 100 m

There was no significant difference among nine species or species categories (KW = 14.6, df = 8, p = 0.07) with regard to water temperature at 100 m (Tables 9.1 and 9.2). The overall mean for the nine species or species categories was 19.5° C ± 0.44 SD. The mean annual water temperature at 100 m for the study area was 19.8° C ± 1.5 SD.

Table 9.1. Cetacean species or species categories that had 10 or more sightings for most of the seven environmental variables used in the statistical comparison (indicated with an X).

Species or species category	SST (°C)	SST gradient (°C/1.1 km)	Depth of the 15° C isotherm (m)	Temperature at 100 m (°C)	Surface salinity (psu)	Bottom depth (m)	Bottom depth gradient (m/1.1 km)
Atlantic spotted dolphin	X	X	X	X	-	X	X
Bottlenose dolphin	X	X	X	X	X	X	X
Risso's dolphin	X	X	X	X	X	X	X
Pygmy/dwarf sperm whale	X	X	X	X	-	X	X
Sperm whale	X	X	X	X	X	X	X
Mesoplodon spp.	-	-	X	X	-	X	X
Clymene dolphin	-	-	X	X	-	X	X
Pantropical spotted dolphin	X	X	X	X	X	X	X
Striped dolphin	X	X	X	X	-	X	X
Spinner dolphin	-	-	-	-	-	X	X
Rough-toothed dolphin	-	-	-	-	-	X	X
Short-finned pilot whale	-	-	-	-	-	X	X
Beaked whale	X	X	-	-	-	X	X

Table 9.2. Environmental profiles for the cetacean species or species categories that had 10 or more sightings for most of the variables.

Species or species category	Sample statistic	SST (°C)	SST gradient (°C/1.1 km)	Depth of 15°C isotherm (m)	Temperature at 100 m (°C)	Surface salinity (psu)	Bottom depth (m)	Bottom depth gradient (m/1.1 km)
Atlantic spotted dolphin	mean	22.6	0.09	184.20	19.30	34.94	197.1	11.2
	median	22.5	0.02	185.20	19.19	36.00	173.4	7.1
	n	19	19	18	18	8	30	30
	minimum	17.9	0.0	141.2	18.2	27.4	102	1
	maximum	28.7	0.6	216.6	22.6	36.2	589	37
Bottlenose dolphin	mean	24.2	0.08	188.70	19.06	33.60	293.5	16.4
	median	23.8	0.05	190.75	18.83	35.93	216.6	12.0
	n	84	81	68	68	19	149	149
	minimum	14.6	0.0	150.9	16.9	15.8	101	0
	maximum	30.7	0.5	271.6	22.6	36.5	1226	120
Risso's dolphin	mean	24.4	0.09	194.54	19.32	34.88	713.7	23.3
	median	24.3	0.05	195.40	18.92	35.72	571.0	20.9
	n	38	38	31	31	11	67	67
	minimum	19.0	0.0	145.7	18.1	24.8	150	3
	maximum	29.5	0.3	256.4	23.0	36.6	1997	58
Pygmy/dwarf sperm whale	mean	24.6	0.09	205.41	19.72	35.57	928.5	20.6
	median	24.5	0.07	199.7	19.75	35.75	860.8	17.1
	n	34	34	29	28	4	72	72
	minimum	18.9	0.0	145.3	17.7	34.7	176	2
	maximum	29.7	0.3	277.1	22.0	36.1	1989	91

Table 9.2. Environmental profiles for the cetacean species or species categories that had 10 or more sightings for most of the variables. (continued)

Species or species category	Sample statistic	SST (°C)	SST gradient (°C/1.1 km)	Depth of 15°C isotherm (m)	Temperature at 100 m (°C)	Surface salinity (psu)	Bottom depth (m)	Bottom depth gradient (m/1.1 km)
Sperm whale	mean	23.7	0.07	194.80	19.91	35.82	1104.9	24.2
	median	23.3	0.05	194.60	19.59	36.21	1009.3	18.8
	n	37	36	41	38	15	65	65
	minimum	18.1	0.0	160.9	17.3	33.4	480	3
	maximum	29.5	0.4	254.8	24.4	36.3	1957	90
Mesoplodon spp.	mean	25.2	0.09	195.35	20.25	36.01	1196.9	14.8
	median	26.6	0.09	188.40	19.64	35.86	1126.5	13.5
	n	6	6	10	10	3	13	13
	minimum	18.2	0.0	160.5	18.9	35.8	680	4
	maximum	28.6	0.2	256.4	22.4	36.4	1933	26
Clymene dolphin	mean	24.3	0.04	190.35	19.22	36.15	1261.0	17.5
	median	23.5	0.02	175.90	19.19	36.39	1304.0	16.1
	n	9	9	17	17	5	22	22
	minimum	21.3	0.0	150.4	17.6	35.5	612	2
	maximum	27.4	0.1	284.1	22.5	36.4	1979	40
Pantropical spotted dolphin	mean	25.3	0.07	197.82	19.24	35.64	1241.9	19.0
	median	25.4	0.05	196.30	19.24	35.99	1287.2	16.5
	n	60	58	69	57	31	103	103
	minimum	19.1	0.0	145.3	17.0	31.8	364	2
	maximum	29.7	0.5	266.9	22.4	36.6	1999	120

Table 9.2. Environmental profiles for the cetacean species or species categories that had 10 or more sightings for most of the variables. (continued)

Species or species category	Sample statistic	SST (°C)	SST gradient (°C/1.1 km)	Depth of 15°C isotherm (m)	Temperature at 100 m (°C)	Surface salinity (psu)	Bottom depth (m)	Bottom depth gradient (m/1.1 km)
Striped dolphin	mean	23.6	0.02	200.47	19.24	34.72	1235.2	24.5
	median	22.2	0.01	199.05	18.93	34.82	1214.9	23.0
	n	13	12	12	12	7	18	18
	minimum	19.6	0.0	160.6	17.9	32.6	570	6
	maximum	30.0	0.1	248.9	22.4	36.3	1997	71
Spinner dolphin	mean	24.1	0.53	187.01	18.96	36.09	1111.0	23.3
	median	23.4	0.03	184.80	18.89	36.09	927.0	22.4
	n	7	7	8	8	2	13	13
	minimum	18.1	0.0	154.8	17.3	36.0	526	7
	maximum	29.7	0.1	230.0	21.5	36.2	1776	38
Rough-toothed dolphin	mean	25.1	0.11	208.07	19.92	35.23	950.5	18.4
	median	25.4	0.02	197.10	19.24	34.83	1066.6	13.3
	n	9	9	7	7	3	16	16
	minimum	21.9	0.0	180.5	18.5	34.7	194	7
	maximum	27.9	0.6	267.3	22.9	36.1	1524	73
Short-finned pilot whale	mean	24.0	0.03	174.69	19.09	35.72	863.4	17.0
	median	22.8	0.01	165.20	18.87	35.98	716.8	11.5
	n	9	8	8	8	3	21	21
	minimum	21.7	0.0	157.1	17.9	35.0	246	3
	maximum	29.0	0.1	203.6	21.0	36.2	1906	69
Beaked whale	mean	24.8	0.12	173.47	18.66	35.84	1273.7	17.9
	median	24.7	0.10	165.35	18.79	35.80	1292.7	19.3
	n	12	12	6	7	4	16	16
	minimum	21.5	0.0	159.3	17.9	35.5	253	3
	maximum	28.8	0.3	203.1	19.3	36.2	1852	33

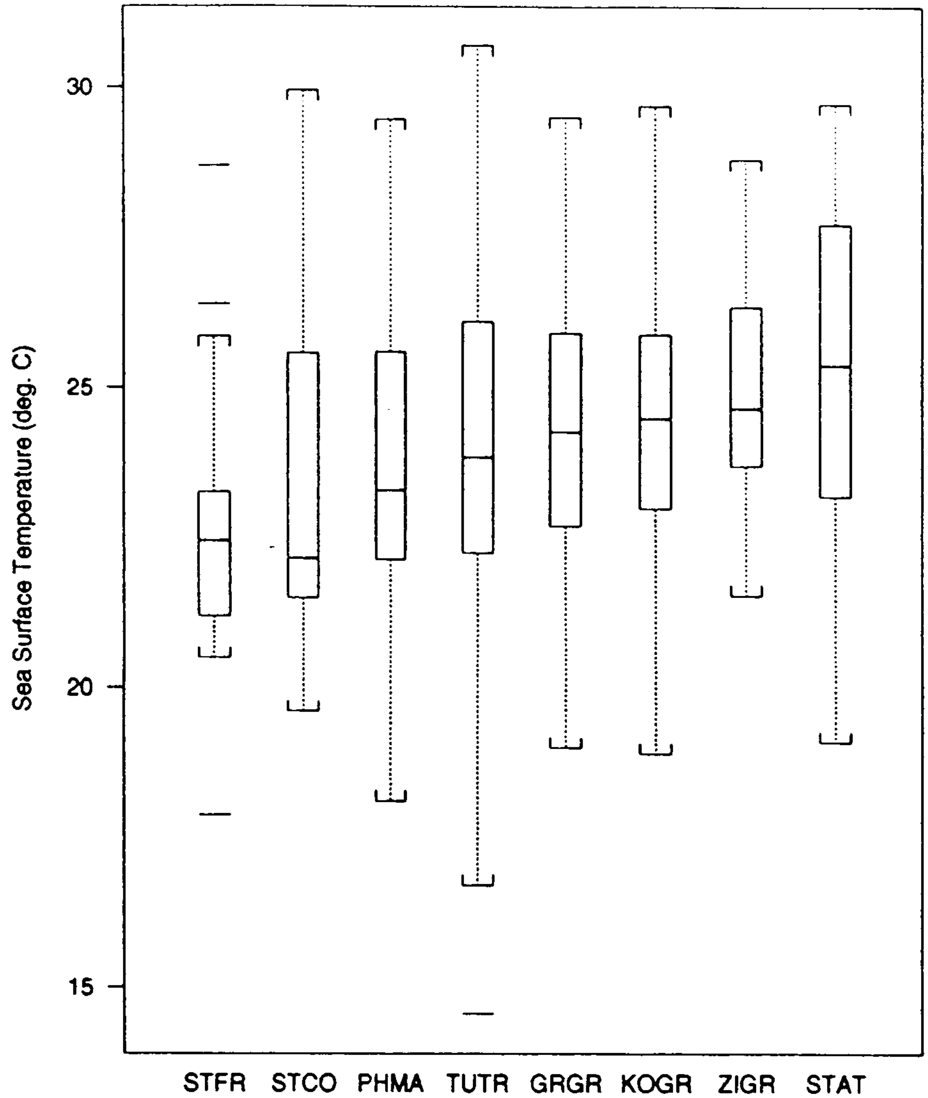

Figure 9.1. Box plots of the sea surface temperature associated with sightings of eight cetacean species or species categories. The mid-line is the median, the box encompasses the interquartile range, and the dotted lines with brackets are 1.5 x the interquartile range. Outlying points are shown individually by horizontal bars. Codes: STFR = Atlantic spotted dolphin, STCO = striped dolphin, PHMA = sperm whale, TUTR = bottlenose dolphin, GRGR = Risso's dolphin, KOGR = pygmy/dwarf sperm whale, ZIGR = beaked whale, STAT = pantropical spotted dolphin.

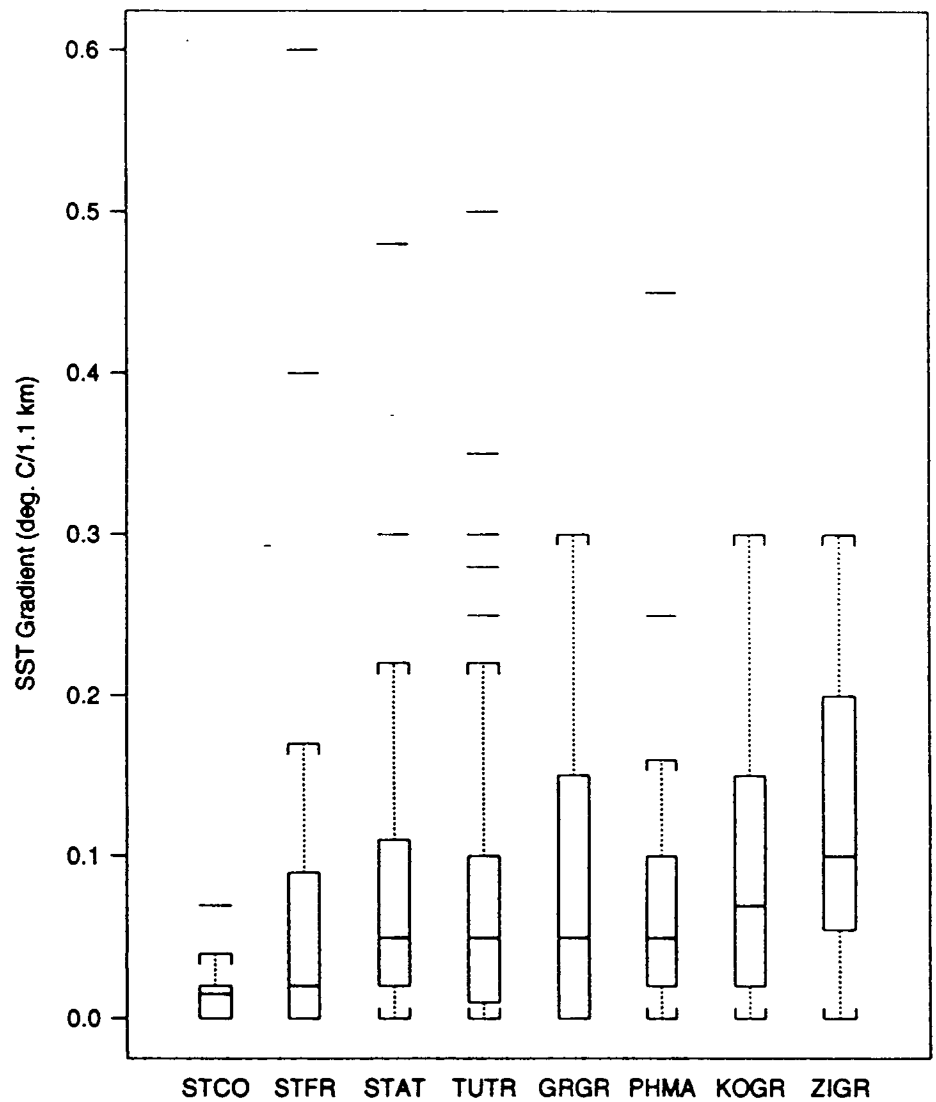

Figure 9.2. Box plots of the sea surface temperature gradient associated with sightings of eight cetacean species or species categories. The mid-line is the median, the box encompasses the interquartile range, and the dotted lines with brackets are 1.5 x the interquartile range. Outlying points are shown individually by horizontal bars. Codes: STFR = Atlantic spotted dolphin, STCO = striped dolphin, PHMA = sperm whale, TUTR = bottlenose dolphin, GRGR = Risso's dolphin, KOGR = pygmy/dwarf sperm whale, ZIGR = beaked whale, STAT = pantropical spotted dolphin.

Surface Salinity

Only four of the 13 species or species categories had 10 or more sightings for surface salinity, and there was no significant difference among these four (KW = 2.4, df = 3, p = 0.49) (Tables 9.1 and 9.2). The overall mean was 34.98 psu ± 0.99 SD. The mean annual surface salinity for the study area was 35.31 psu ± 2.16 SD.

Bottom Depth

There was a significant difference among the 13 species or species categories (KW = 362.6, df = 12, p < 0.001) with regard to bottom depth (Tables 9.1 and 9.2). *A posteriori* comparisons indicated that there were three distinct groups:

Group 1 Atlantic spotted dolphins (mean = 197.1 m, SE = 19.3, n = 30)

Group 2 bottlenose dolphins (mean = 293.5 m, SE = 17.0, n = 149)

Group 3 Risso's dolphins (mean = 713.7 m, SE = 52.4, n = 67)
short-finned pilot whales (mean = 863.4 m, SE = 86.8, n = 21)
pygmy/dwarf sperm whales (mean = 928.5 m, SE = 57.9, n = 72)
rough-toothed dolphins (mean = 950.5 m, SE = 109.7, n = 16)
spinner dolphins (mean = 1111.0 m, SE = 112.3, n = 13)
sperm whales (mean = 1104.9 m, SE = 41.9, n = 65)
striped dolphins (mean = 1235.2 m, SE = 111.1, n = 18)
Mesoplodon spp. (mean = 1196.9 m, SE = 100.2, n = 13)
pantropical spotted dolphins (mean = 1241.9 m, SE = 42.0, n = 103)
Clymene dolphins (mean = 1261.0 m, SE = 83.6, n = 22)
beaked whales (mean = 1273.7 m, SE = 97.8, n = 16)

The mean water depth for Atlantic spotted dolphins was significantly shallower than that of bottlenose dolphins. On average, Atlantic spotted dolphins occurred on the continental shelf while the bottlenose dolphins were seen along the shelf break.

The species in Group 3 occurred in the deepest water along the continental slope. Within this group, there was a gradient of species found in shallower water to those found in deeper water (Figure 9.3). Risso's dolphins and short-finned pilot whales occurred in shallower water along the upper slope and, as a subgroup, were significantly different from striped dolphins, *Mesoplodon* spp., pantropical spotted dolphins, clymene dolphins and beaked whales which occurred in the deepest water. Pygmy/dwarf sperm whales, rough-toothed dolphins, spinner dolphins and sperm whales occurred at depths in the middle of these two subgroups and linked them together. The mean depth in the study area was 986 m ± 570 SD.

Bottom Depth Gradient

There was a significant difference among the 13 species or species categories (KW=53.1, df=12, p < 0.001) with regard to bottom depth gradient (Tables 9.1

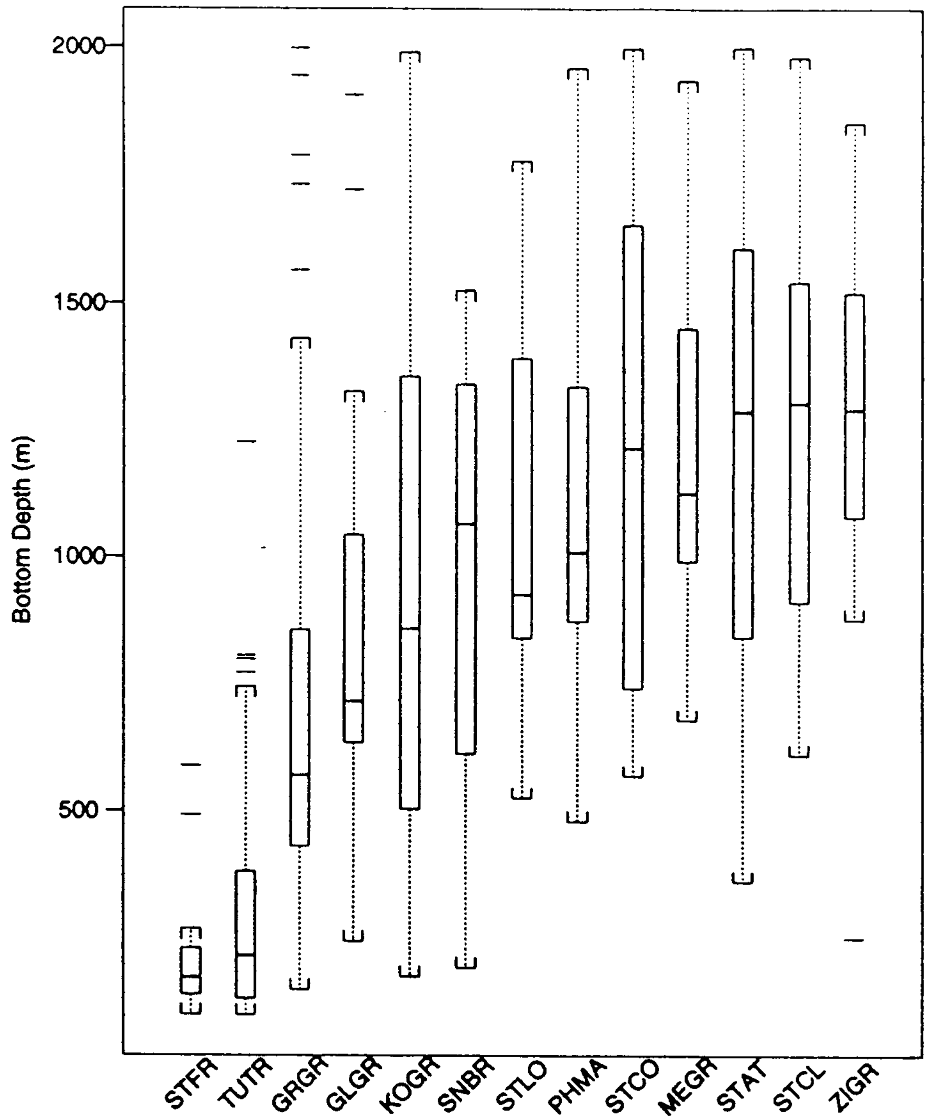

Figure 9.3. Box plots of the bottom depth associated with sightings of eight cetacean species or species categories. The mid-line is the median, the box encompasses the interquartile range, and the dotted lines with brackets are 1.5 x the interquartile range. Outlying points are shown individually by horizontal bars. Codes: STFR = Atlantic spotted dolphin, STCO = striped dolphin, PHMA = sperm whale, TUTR = bottlenose dolphin, GRGR = Risso's dolphin, KOGR = pygmy/dwarf sperm whale, ZIGR = beaked whale, STAT = pantropical spotted dolphin.

and 9.2). There was a gradation from species found over shallower bottom depth gradients to those found over steeper bottom depth gradients (Figure 9.4). Atlantic spotted dolphin occurred over the shallowest bottom depth gradient and were significantly different from the group with the steepest gradient which included sperm whales, Risso's dolphins, striped dolphins, and spinner dolphins. The other species occurred over bottom depth gradients in the middle. The mean bottom depth gradient in the study area was 16.5 m/1.1 km ± 14.6 SD.

9.4 Discussion

The mean, annual marine environment in the upper layer of the study area may be described as subtropical to tropical in temperature with normal seasonal variation in the depth of the mixed layer (i.e., deepest [35-110 m] in the winter and shallowest [< 50 m] in the summer). Salinity ranges from 34.9-36.5, excluding areas affected by the Mississippi River effluent (see Chapter 6 and Appendix B for details). The surface circulation is dominated by persistent warm-core (anticyclonic) eddies 100-300 km in diameter that separate from the Loop Current in the eastern Gulf and drift westward until they dissipate along the continental slope (Hofmann and Worley 1986, Biggs 1992). Generally, one or more of these warm-core eddies is present in the Gulf at any one time. These dynamic circulation features transport large quantities of high-salinity, nutrient-poor water across the near-surface environment of the northern Gulf. Cold-core (cyclonic) eddies can be generated as the anticyclonic eddy interacts with the continental margin. As a result, the temperature and salinity in the upper 200-300 m can vary depending on whether measurements are taken inside or outside of these distinctive but ephemeral circulation features. Below a depth of several hundred meters, the Gulf has stable temperature-salinity characteristics that are independent of warm-core or cold-core eddies.

Primary productivity was low (< 0.4 mg chlorophyll $\underline{a}/m^3$) throughout most of the study area (see Chapter 6). Although the data from this study were insufficient to detect a seasonal phytoplankton bloom, pigment concentrations in Gulf waters beyond the shelf break do exhibit a seasonal cycle with highest concentrations between December and February and lowest values between May and July (Müller-Karger et al. 1991). The general oligotrophic conditions observed in this study are in agreement with previous reports of low concentrations of phytoplankton, nutrients, and zooplankton in the Gulf (El-Sayed 1972, Müller-Karger et al. 1991, Biggs 1992). However, higher nutrient concentrations associated with cold-core eddies and effluent from the Mississippi River increase plankton biomass and result in local "hot spots" of primary (> 5 mg chlorophyll $\underline{a}/m^3$) and secondary productivity, including fish species of commercial significance (Parsons et al. 1985, Park et al. 1989, Govoni et al. 1989, Ortner et al. 1989, Chapter 6 and Appendix C). In addition, offshore jets of shelf-borne phytoplankton created by the confluence of warm-core and cold-core eddy pairs can also increase production beyond the continental slope (Biggs and Müller-Karger 1994).

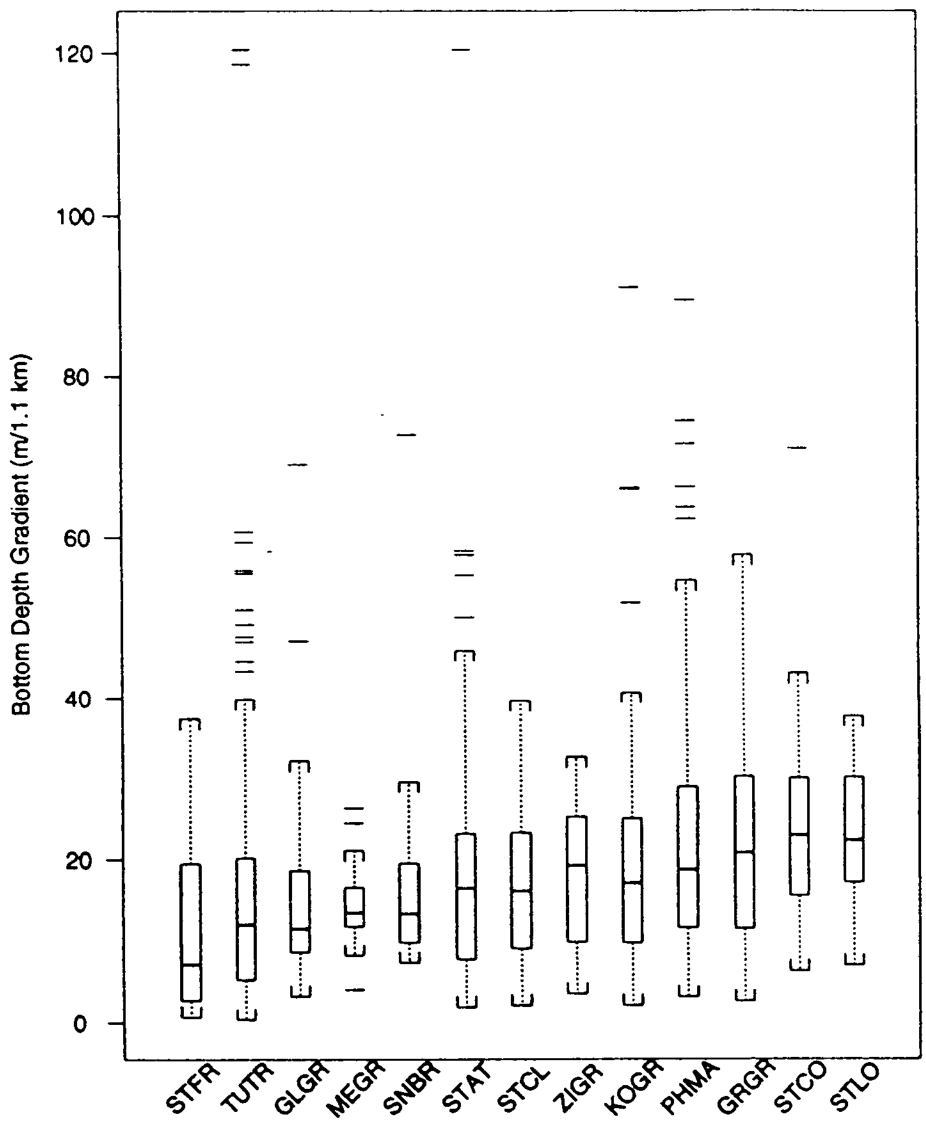

Figure 9.4. Box plots of the bottom depth gradient associated with sightings of eight cetacean species or species categories. The mid-line is the median, the box encompasses the interquartile range, and the dotted lines with brackets are 1.5 x the interquartile range. Outlying points are shown individually by horizontal bars. Codes: STFR = Atlantic spotted dolphin, STCO = striped dolphin, PHMA = sperm whale, TUTR = bottlenose dolphin, GRGR = Risso's dolphin, KOGR = pygmy/dwarf sperm whale, ZIGR = beaked whale, STAT = pantropical spotted dolphin.

The cetaceans in this study occurred in water with a relatively narrow range of annual SSTs, similar to those reported previously for cetaceans in the northern Gulf (Fritts et al. 1983) and for pantropical spotted and spinner dolphins in the eastern tropical Pacific (Au and Perryman 1985, Perrin and Hohn 1994, Perrin and Gilpatrick 1994, Perrin et al. 1994b). The seasonal variation in SST in the Gulf typically ranges from 5-7° C, with little interannual variation (Müller-Krager et al. 1991). It is noteworthy that the deep diving species (e.g., Risso's dolphins, sperm whales, pygmy/dwarf sperm whales, and beaked whales) in this study occurred in water with the steepest SST gradient. These species are known to feed on squid and may be foraging along thermal fronts associated with eddy systems. These areas may be associated with upwelling events that are more productive than the warmer, oligotrophic surface water (Biggs 1992, Biggs and Müller-Karger 1994). SST gradient also seems to be a reasonable correlate to the distribution and migration of yellowfin tuna which feed on many of the same organisms as the dolphin species encountered (Perrin et al. 1973, Sharp and Dizon 1978)

The mean values for the depth of the 15 °C isotherm (< 250 m), the temperature at 100 m (< 22° C) and surface salinity (< 36.6 psu) indicate that most of the cetacean sightings were outside of the Subtropical Underwater that flows into the Gulf through the Yucatan Straits and is found in the region of the Loop Current and warm-core rings derived from that current (Hofmann and Worley 1986). As the warm-core rings move westward across the northern Gulf, they mix with Gulf Common Water. Discharge from the Mississippi and Atchafalaya rivers gives rise to a band of low-salinity water that usually flows westward over the continental shelf but can have a freshening influence as far south as 26°N (Nowlin 1972). The relatively stable, mean surface salinity beyond the shelf edge is probably responsible for the absence of any significant difference for this environmental variable among cetacean species in the study area. However, the large range of salinities recorded (some as low as 15.8 psu) for those species frequently observed along the shelf break in the north-central Gulf reflects the mixing of the Mississippi River discharge and near-shore water.

Bottom depth showed the clearest indication of habitat partitioning in the study area. Atlantic spotted dolphins were consistently found in the shallowest water on the continental shelf and along the shelf break. In addition, the bottom depth gradient was less for Atlantic spotted dolphins than for any other species. This agrees with observations of this species along the west Florida shelf (Mullin unpubl. obs.). Mullin et al. (1994) sighted Atlantic spotted dolphins in offshore waters along the Louisiana coast that were in deeper water (mean depth of 367 m) than those seen in this study. However, the continental shelf is very narrow with a steep bottom gradient along the Louisiana coast, so that small movements offshore result in a rapid change in depth. Overall, it appears that Atlantic spotted dolphins prefer shallow water with a gently sloping bottom typical of the continental shelf, although they may also occur along the shelf break and upper continental slope. Their occurrence in shallow, shelf waters may be related to prey preference and foraging strategies. Atlantic spotted dolphins are known to feed on small cephalopods, fish, and benthic invertebrates (Perrin et al. 1994a). Fertl and Würsig (1995) described the behavior of Atlantic spotted dolphins feeding in a coordinated manner on a school of clupeid fish. A rehabilitated Atlantic spotted dolphin that was monitored with a satellite-linked time-depth recorder along the Texas coast for 24 days spent most of its time at depths less than 10 m. However, the dolphin consistently made dives that were on or near the seafloor in 30 m of water (Davis et al. in press).

The bottlenose dolphins in this study were found most commonly along the upper slope in water significantly deeper than that for Atlantic spotted dolphins. This species also occurs in nearshore waters where it is more abundant than the Atlantic spotted dolphin (Perrin et al. 1994a). However, morphometric, hematological and hemoglobin differences indicate that the larger, offshore bottlenose dolphins may not mix with the nearshore population (Hersh and Duffield 1990). The mean depths from this study for offshore bottlenose dolphins and Atlantic spotted dolphins are biased towards deeper depths because we did not survey the entire range of their habitat that includes shallower waters of the continental shelf. Pelagic bottlenose dolphins feed on a variety of epipelagic and mesopelagic fish, squid, and crustaceans (Walker 1981, Barros and Odell 1990)

The deep water cetaceans of Group 3 are diverse in size, diving ability, and prey preference. Large species such as the sperm whale, *Mesoplondon* spp. and beaked whales are known or believed to be deep divers that feed on squid and mesopelagic or deep water benthic fish (Raun et al. 1970, Berzin 1971, Rice 1989, Heyning 1989, Clarke 1986, Findlay et al. 1992). Sperm whales are capable of exploiting most of the water column in the study area and regularly occur in water over 1,000 m deep. Previous sightings of sperm whales in the Gulf were in waters of similar depth to that of this study (Fritts et al. 1983, Collum and Fritts 1985). Their frequent occurrence near the Mississippi Canyon suggests that this may be an important part of their habitat in the north-central Gulf. However, sperm whales were not commonly sighted near DeSoto Canyon in the Gulf, and submarine canyons were apparently not important habitat for sperm whales off the North Atlantic coast (Kenney and Winn 1987). The combination of deep water within 20 km of the Mississippi River delta and the enhanced primary productivity associated with the river discharge (see Chapter 6) may increase the abundance of squid and be responsible for the year-round occurrence of sperm whales in this part of the north-central Gulf. Of the 42 species of cephalopods known to occur in the Gulf, most are contiguous with species from the North Atlantic (Voss 1956). Less than 10% of these species are endemic to the Gulf and apparently these are confined to benthic species.

Risso's dolphins and short-finned pilot whales occurred most commonly along the mid-to-upper slope, often in areas with a steep bottom gradient. A similar range of bottom depths was observed for these species by Fritts et al. (1983) and Mullin et al. (1994) for the northern Gulf, by Dohl et al. (1981) along the California coast, and by Findlay et al. (1992) along the South African coast. The deeper water and steep bottom gradient characteristic of Risso's dolphin and pilot whale habitat may be linked to their diet of squid (Evans 1987, Jefferson et al. 1993). However, no information on the diving and feeding behavior of these species is available.

Pygmy/dwarf sperm whales feed on squid, benthic and mesopelagic fish, and crustaceans (Fitch and Brownell 1968). Their bottom feeding habits and considerable body oxygen stores for their size suggest that they make deep dives along the continental slope (Raun et al. 1970, Caldwell and Caldwell 1989). The apparent preference of dwarf sperm whales for areas over or near the shelf break is consistent with their greater frequency of sightings in this study. Nevertheless, pygmy sperm whales have historically stranded more frequently in the Gulf than dwarf sperm whales (Schmidly and Scarbrough 1990, see Chapter 2 of this report). Without surveying the entire Gulf, the habitat differences between these two species remain speculative.

Rough-toothed, spinner, clymene, pantropical, and striped dolphins are all small cetaceans that occur over deep water beyond the continental shelf (Jefferson et al. 1993), although their small size probably limits them to the upper 200 m of the water column (Williams et al. 1993). Their occurrence in deep water may be linked to the offshore location of their prey (Ridgway and Harrison 1994). For example, striped dolphins off the coast of Japan feed on myctophid fish and squid, many with luminous organs, associated with the deep scattering layer (Miyazaki et al. 1973). In the eastern tropical Pacific, spinner dolphins also feed on vertically migrating fish, especially myctophids (Fitch and Brownell 1968). It is difficult to say anything definitive about the habitat of the species not discussed above (see Appendix A) because of the relatively small number of sightings. The average SST, SST gradient, depth of the 15° C isotherm, water temperature at 100 m, and surface salinity were similar to those of the species in Table 9.2. The false killer whales were generally sighted over the mid-slope, although they could occur from the shelf break to the lower slope. Fraser's dolphins, melon-headed whales, and killer whales generally occurred from the mid-to-lower slope over areas with a steep bottom gradient. A Bryde's whale was sighted in shallow water on the shelf break. Similar depth ranges for many of these species have been recorded by Fritts et al. (1983) and Mullin et al. (1994) for the northern Gulf.

9.5 Conclusions

Although the study area covered 154,621 km^2 (about 10% of the Gulf), it may represent only a part of the home range of the species observed. Even during normal years, the oceanographic features of the north-central and western Gulf are very complex and dynamic due to the formation of warm-core rings from the Loop Current and seasonal fresh water discharge from the Mississippi and other rivers. The GulfCet aerial and shipboard surveys occurred during a period when several warm-core rings moved through the northern Gulf. At the same time, there was an unusually large influx of fresh water from the Mississippi River due to record rainfall in the midwestern states in 1993. As a result, some of the oceanographic variables were atypical during the two years of this study, and the data were insufficient to address seasonal and interannual variability in habitat.

The mean, annual marine habitat for cetaceans in the study area is subtropical to tropical in the upper 200-300 m, with relatively low primary productivity. Cooler, nutrient-rich water below this layer is brought to the surface by the upwelling influences of cold-core eddies. Nutrients are also introduced into the Gulf by the Mississippi River. This results in a patchy distribution of primary productivity with "hot spots" of chlorophyll a that may increase secondary productivity and attract cetaceans. Additional studies will be needed to examine the distribution of cetaceans around these areas of high productivity.

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X. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

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The GulfCet Program was the first attempt to determine the distribution and abundance of cetaceans along the entire continental slope in the north-central and western Gulf of Mexico. Although the scope of this program was greater than previous studies in this part of the Gulf (Fritts et al. 1983, Mullin et al. 1994), the total area surveyed represented only 10% of the entire Gulf and was small (0.008%) in comparison to cetacean surveys and habitat characterization in the eastern tropical Pacific Ocean (ETP) (Wade and Gerrodette 1993).

Cetaceans were commonly observed throughout the GulfCet study area during all four seasons. However, the determination could not be made whether animals were in transit or resident in the study area for extended periods, and it is likely that the small study area encompasses only a portion of the home range for many of the species observed. For example, a radio-tagged pantropical spotted dolphin in the ETP moved over 500 km (3-times the maximum latitudinal dimension of the GulfCet study area) in 27 days (Perrin et al. 1979). Without additional information on daily movement patterns and feeding behavior, we can only speculate whether the association of animals with mesoscale oceanographic features such as cold-core rings is biologically meaningful.

The diversity of cetaceans in the study area was comparable to that along the continental slope of northeastern United States and in the ETP (Hain et al. 1985, Wade and Gerrodette 1993). However, the overall density of cetaceans in the GulfCet study area was significantly lower (<25%) than in these latter two regions. In addition, baleen whales, especially fin whales (*Balenoptera physalus*), made up a significant number (ca. 10%) of identified sightings along the northeastern United States (Hain et al. 1985), but were practically absent from the GulfCet study area. Group density in the study area was approximately the same as that found in the ETP.

The lower densities of whales in the Gulf compared to the northeastern United States and ETP could be related to the more oligotrophic conditions and a smaller food base that cannot support a high density of cetaceans. The estimated biomass of cetaceans in the study area was 9,131 metric tons (Table 10.1). Of this biomass, sperm whales represented 68.6%. Together, sperm whales, pantropical spotted dolphins, short-finned pilot whales, bottlenose dolphins, melon-headed whales, killer whales, and striped dolphins constituted 92.7% of the cetacean biomass. The minimum estimated food requirement for all cetaceans (assuming adult body masses for each species) was estimated to be 80,694 metric tons/year, of which sperm whales consumed 42%. Dividing the minimum food requirement by the size of the study area gives a cetacean food consumption rate of 0.52 metric tons/km^2/year. This value is about 20% of the estimated annual food consumption per km^2 for cetaceans living along the continental slope in the northeastern United States, and it may reflect the lower primary and secondary productivity of the Gulf (Hain et al. 1985).

Table 10.1. Cetaceans ranked by abundance with mean body mass, species-total biomass (percent of total biomass shown in parentheses), and minimum food requirements.

Species or species category	Abundance[1]	Mean adult body mass (kg)[2]	Species-total biomass (kg)[3] (with % total)		Min. food requirement (metric tons/yr)[4]
Pantropical spotted dolphin	7,105	90	639,450	(7.00)	13,261
Bottlenose dolphin	2,538	150	380,700	(4.17)	6,948
Striped dolphin	2,091	90	188,190	(2.06)	3,903
Melon-headed whale	2,076	160	330,720	(3.62)	5,940
Clymene dolphin	1,695	50	84,750	(0.93)	2,036
Atlantic spotted dolphin	1,145	100	114,500	(1.25)	2,312
Spinner dolphin	840	50	42,000	(0.46)	1,008
Risso's dolphin	529	300	158,700	(1.74)	2,436
Sperm whale	313	20,000	6,260,000	(68.56)	33,624
Short-finned pilot whale	215	2,000	430,000	(4.71)	4,107
Rough-toothed dolphin	177	100	17,700	(0.19)	358
Unidentified Ziphiidae	124	1,350.[5]	167,400	(1.83)	1,764
Dwarf sperm whale	88	135	11,880	(0.13)	223
Killer whale	71	3,000	213,000	(2.33)	1,838
Fraser's dolphin	65	160	10,400	(0.11)	187
Pygmy killer whale	36	110	3,960	(0.04)	78
Pygmy sperm whale	19	315	5,985	(0.07)	91
Cuvier's beaked whale	14	1,800	25,200	(0.28)	247
False killer whale	10	1,000	10,000	(0.11)	114
Bryde's whale	3	12,000	36,000	(0.39)	220
Total			9,130,535		80,695

[1] Annual abundance estimated from GulfCet shipboard 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, metric tons/year) for each species or species category was calculated as: MFR = $[(A \cdot B \cdot C) + (D \cdot E)]$, 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); and E = 1 kcal/g wet weight, the assumed caloric density of prey (Hinga 1979, Hain et al. 1985).
[5] Average of body masses for Cuvier's beaked whale (1,800 kg) and Blainville's beaked whale (900 kg).

Without synoptic data on the abundance and distribution of cetaceans in the entire Gulf of Mexico, we cannot determine the importance of the GulfCet study area for the 20 species sighted. However, approximately 19,000 cetaceans utilize the study area annually, which indicates that the continental slope in the north-central and western Gulf is of some importance to these animals. The dynamic hydrography of the north-central and western Gulf resulting from the formation and movement of warm-core and cold-core rings and the outflow of fresh water from the Mississippi River makes a description of average habitat difficult and may obscure important associations of cetaceans with distinctive hydrographic features associated with feeding.

To obtain a more complete understanding of the seasonal and annual distribution, abundance, and habitat utilization of cetaceans, a survey of the entire Gulf and the satellite and conventional radio-tracking of the predominant species, such as pantropical dolphins, could be conducted. In addition to location at sea, the satellite telemeters can record information on diving behavior that could provide clues concerning potential prey species and resource partitioning among cetaceans (Evans 1971, Tanaka 1987, Mate 1989, Merrick et al. 1994). This information, in addition to trophic level studies of primary and secondary productivity and prey distribution, could enable researchers to gain a better understanding of the factors that influence the distribution of cetaceans. The diet of a significant number of the cetaceans in the Gulf is dominated by cephalopods and mesopelagic fishes associated with the vertically migrating acoustic deep scattering layer (Perrin et al. 1973). A long-term monitoring program is needed to obtain baseline information on cetaceans before oil and gas development moves further onto the continental slope. Concurrent with synoptic surveys, focal studies could examine the presence of cetaceans around distinctive oceanographic features, such as cold-core eddies and the Mississippi River freshwater plume, in order to better understand the influence of these features on cetacean distribution.

During the implementation of the focal studies, behavioral data could be gathered to determine whether animals are using certain areas for specific activities, such as social/sexual behavior, foraging, resting, or transiting. The behavioral studies could be conducted concurrently with aerial surveys and shipboard visual and acoustic surveys. However, dedicated cruises are also needed to study: 1) behavioral patterns, 2) at-sea movements and diving behavior, and 3) the reaction of cetaceans to oil and gas exploration and development activities. During these cruises, sperm whales chould be further photo-identified and skin and blubber biopsies taken to improve our understanding of population biology and toxin loads of sperm whales.

Seventy-eight percent of the oil and 97% of the gas production in United States federal waters occurs in the Gulf of Mexico, primarily along the Texas-Louisiana continental shelf (Minerals Management Service, New Orleans, LA, November 1995). During the period 1984 to 1994, the MMS western and central Gulf regions produced about 3.4×10^9 barrels of crude oil and 50.2×10^9 million cubic feet of natural gas (Technical Information Management System Database, Offshore Systems Center, Minerals Management Service, New Orleans, LA, July 1995). In addition to oil and gas exploration along the continental shelf, 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. This, coupled with the move of the petroleum industry into deeper waters in their continuing quest for new oil and gas reserves, may result in significant impact on cetaceans along the continental slope of the Gulf (Tucker and Associates, Inc. 1990). The long-term consequences of human activity cannot be predicted with certainty. However, it can be anticipated that cetaceans will encounter oil and gas exploration and production activity as these move further onto the continental slope. These activities include construction, oil spills, ship traffic, seismic exploration, and underwater noise.

Major construction activities will include the installation of drilling rigs, platforms, and pipelines. There are three primary concerns associated with construction activities on the continental shelf and slope. These involve sea floor disturbance, the attraction of fish and invertebrates to submerged structures, and the potential interaction of these structures with resident or migrating cetaceans (Phillips and James 1988). Stationary rigs may alter habitat by acting as fish attractants, enhancing prey availability for certain species of cetaceans. Negative impacts to cetaceans may result from seismic exploration activities (Richardson et al. 1995), the sounds produced by rig construction and oil and gas exploration and production, and the potential for collisions with increased ship activity. The only way to determine the long term effects of these activities is through a monitoring program that commences ahead of the widespread implementation of deep water exploration and production. Such a monitoring program would involve traditional aerial and shipboard visual surveys, shipboard acoustic surveys, behavioral observations of the cetaceans encountered, and satellite and conventional radio telemetry studies of the predominant cetacean species. The shipboard acoustic surveys are particularly useful because they monitor the presence of vocalizing cetaceans as well as ambient noise levels. In addition, this kind of data can be archived for later analysis as exploration and production activities develop and change over long periods of time.

The Gulf of Mexico is rich in species occurring throughout the food chain that are acoustically very 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 the explosive removal of platforms and other noise associated with oil and gas development. This fact makes the northern Gulf of Mexico ideal for using acoustic monitoring to study the seasonal movements, distribution, and abundance of cetaceans.

The sound reception and production capabilities of many suborders and families of marine animals are well known (Richardson et al. 1995). Every group of cetacean studied has been found to vocalize and to have broad-band hearing sensitivity. This includes all of the 28 species thought to occur in the Gulf of Mexico, even though quantitative data on hearing exists for only four or 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 marine mammals, to man-made noise emphasizes the concerns expressed by the National Research Council's Ocean Studies Board Committee and the need for better and precise measurements of the acoustic environment of marine animals (National Reseach Council 1994; Richardson et al. 1995). In their 1994

Report to Congress, the Marine Mammal Commission stated these same concerns and noted that acoustic monitoring would be useful. 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 have also been recorded. These data await analysis and interpretation.

In conclusion, the continental slope in the north-central and western Gulf of Mexico is an area that supports a diverse cetacean community, but one whose density does not equal areas such as the northeastern United States and the ETP. Very complex and dynamic oceanographic and mesoscale features typify this area of the Gulf and show large annual and inter-annual variability. This makes it difficult to predict the distribution of cetaceans based on existing data. However, the GulfCet program has demonstrated that any future monitoring programs would need to be long-term, with relatively intensive sampling effort in order to detect significant changes in the density and distribution of cetaceans. Of special interest is the demonstration of acoustic monitoring techniques, which hold great promise for long-term monitoring programs of cetacean distribution and abundance.

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The Department of the Interior Mission

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

The Minerals Management Service Mission

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

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **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.