

**DISTRIBUTION, RESIDENCY, AND SEASONAL MOVEMENTS OF THE
GREEN SEA TURTLE, *CHELONIA MYDAS* (Linnaeus, 1758), IN TEXAS**

A Dissertation

by

DONNA JILL SHAVER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2000

Major Subject: Zoology

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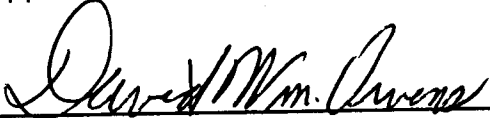
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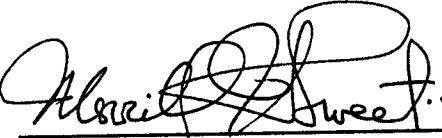
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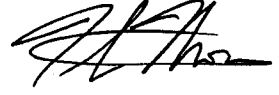
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ABSTRACT

Distribution, Residency, and Seasonal Movements of the
Green Sea Turtle, *Chelonia mydas* (Linnaeus, 1758),
in Texas. (May 2000)

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Data on residency, seasonality, yearly relative abundance, distribution, movements, migration, sex ratios, sizes, and mortality factors of green turtles (*Chelonia mydas*) in Texas were collected through investigation of nests, and stranded, netted, and satellite-tracked turtles.

Six hundred seven green turtles were located stranded along the Texas coast from 1980 to 1998, including 471 found from 1989 to 1997. Strandings were distributed throughout Texas, but were most numerous in south Texas. Of the 298 stranded turtles for which possible stranding causes were identified, 230 were victims of hypothermic stunning.

Two hundred fifty-eight green turtles ($n = 383$ captures) were netted in the Mansfield Channel during 1149 h of effort (3.63 turtles/km-h) from June 1989 through December 1997. Seventy-three of the 258 individuals were recaptured.

Yearly numbers of stranded turtles and yearly catch-per-unit-effort (CPUE) followed similar trends and were correlated. Monthly trends of stranding

numbers and CPUE differed dramatically. Strandings were most numerous during the winter and CPUE was highest during the summer and fall. The sex ratio for stranded turtles (1980-1998:1.09F:1:00M; 1989-1997: 0.94F:1:00M) differed from the sex ratio for netted turtles (4.16F:1.0M). Turtles found stranded (mean = 37.8 cm SLCL) were larger than those netted (mean = 32.4 cm SLCL).

Six confirmed green turtle nests were documented on the Texas coast, including one found in 1987 and five in 1998. Ninety-eight percent of the stranded and all of the netted green turtles were juveniles. The Mansfield Channel is a developmental habitat for juvenile green turtles. Some netted and tracked green turtles remained at the Mansfield Channel jetty area, some used the Mansfield Channel as a passageway between the Laguna Madre and Gulf of Mexico, and some moved southward within Gulf of Mexico waters to off the coast of Mexico.

Water temperature varied seasonally and influenced strandings, CPUE, and movements. CPUE was positively correlated with water temperature and no turtles were caught in January and when mean water temperatures were below 15.5 C. Some tracked turtles moved southward during periods of declining temperatures, but others over-wintered in south Texas waters.

DEDICATION

This dissertation is dedicated to my husband, John E. Miller, and my deceased mother, Dolores R. Shaver. During the course of my degree program both were diagnosed with cancer and insisted that I never give up on my dream to receive my Ph.D. Both provided tremendous support and understanding during the course of my research and education and showed me what really matters in life.

ACKNOWLEDGEMENTS

I would like to thank Drs. David Owens, Merrill Sweet, William Grant, and Duncan MacKenzie for contributing to my academic development. I am deeply indebted to Dr. David Owens for the opportunity to work with him and for his support.

Drs. Richard Byles and Pamela Plotkin deserve special recognition for the technical guidance, sound advice, and encouragement that they provided. The National Biological Survey/Service (NBS), and the U.S. Geological Survey which later incorporated the NBS, allowed me time to work on my doctoral program. I thank Dr. Denny Buckler, Dr. Denny Fenn, Susan Finger, Dr. Larry Ludke, Dr. Bill Mauck, and Dr. Jim Weaver for their support of my efforts. This dissertation would not have been possible without financial support from the NBS, National Marine Fisheries Service, National Park Service, Southwest Parks and Monuments Association, U.S. Fish and Wildlife Service, and U.S. Geological Survey.

I am tremendously grateful to Padre Island National Seashore (PAIS) for providing assistance and logistical support. I thank the PAIS superintendents and the numerous park staff members and volunteers that assisted with various aspects of this work. I would like to acknowledge the following individuals for their contributions: Kathleen Abate, Jane Allen, Sean Baker, David Bieniek, Peter Bohls, Kristey Bosworth, Kirsten Brennan, Bonnie Brewer, Andy Bymers, Sandi Carrigan, Gary Carroll, Dr. Allan Chaney, Elizabeth Cheeseman,

TABLE OF CONTENTS (continued)

	Page
APPENDIX VII.....	263
VITA.....	273

LIST OF TABLES

TABLE	Page
1 Probable stranding causes for <i>Chelonia mydas</i> found stranded on the Texas coast from 1980 to 1998, as determined from codes in data fields NOTE1-NOTE6.....	22
2 Numbers of <i>Chelonia mydas</i> documented stranded as a result of hypothermic stunning on the Texas coast from 1980 to 1998.....	23
3 Confirmed <i>Chelonia mydas</i> nests and tracks located on the Texas coast from 1987 to 1998.....	52
4 Straight-line carapace lengths (SLCL) and weights of <i>Chelonia mydas</i> hatchlings that emerged from nests detected along the Texas coast from 1987 to 1998 and incubated at the Padre Island National Seashore incubation facility.....	53
5 <i>Chelonia mydas</i> that measured less than 10.0 cm straight-line carapace length (SLCL) or greater than 85.0 cm SLCL and were located stranded along the Texas coast from 1980 to 1998.....	54
6 ST-10, ST-6, and ST-14 specifications.....	132
7 PTT model, duty cycle, and attachment.....	133
8 PTT deployment, transmission period, and dates captured before deployment.....	135
9 Recapture of PTT outfitted turtles or transmitters.....	138

LIST OF FIGURES

FIGURE	Page
1 Map showing statistical zones and locations where stranded <i>Chelonia mydas</i> were found on the Texas coast from 1980 to 1998.....	12
2 Yearly numbers of <i>Chelonia mydas</i> found stranded in inshore and offshore areas on the Texas coast from 1980 to 1998.....	16
3 Monthly numbers of <i>Chelonia mydas</i> found stranded in inshore and offshore areas on the Texas coast from 1980 to 1998.....	17
4 Numbers of <i>Chelonia mydas</i> found stranded in statistical zones on the Texas coast from 1980 to 1998.....	18
5 Length frequency distribution of <i>Chelonia mydas</i> found stranded in inshore and offshore areas on the Texas coast from 1980 to 1998.....	20
6 Locations on the Texas coast where <i>Chelonia mydas</i> nests and other possible nesting-related observations were documented from 1980 to 1998.....	51
7 Map of the Texas coast showing the location of the Mansfield Channel and Laguna Madre.....	64
8 Yearly numbers of <i>Chelonia mydas</i> caught per km-h at the Mansfield Channel jetties from June 1989 to December 1997 (n = 383 captures of 258 individuals).....	71
9 Mean monthly water temperatures ($\pm$ SD) at the Mansfield Channel jetties from June 1989 to December 1997.....	72
10 Monthly numbers of <i>Chelonia mydas</i> caught per km-h at the Mansfield Channel jetties from June 1989 to December 1997 (n = 383 captures of 258 individuals).....	74
11 Number of days from the first to last capture of 73 <i>Chelonia mydas</i> netted and recaptured at the Mansfield Channel jetties from June 1989 to December 1997.....	75

LIST OF FIGURES (continued)

FIGURE	Page
12 Initial capture straight-line carapace lengths of 258 <i>Chelonia mydas</i> netted at the Mansfield Channel jetties from June 1989 to December 1997.....	77
13 Testosterone titers for 177 <i>Chelonia mydas</i> netted (n = 230 samples) at the Mansfield Channel jetties from June 1989 to December 1997.....	79
14 Testosterone titers against straight-line carapace lengths for 177 <i>Chelonia mydas</i> netted (n = 230 samples) at the Mansfield Channel jetties from June 1989 to December 1997.....	80
15 Yearly mean straight-line carapace lengths of <i>Chelonia mydas</i> and yearly numbers captured per km-h at the Mansfield Channel jetties from June 1989 to December 1997.....	82
16 Map of the Texas coast showing statistical zones and the Mansfield Channel.....	103
17 Yearly numbers of <i>Chelonia mydas</i> found stranded on the Texas coast and caught per km-h at the Mansfield Channel jetties from 1989 to 1997.....	108
18 The relationship between the numbers of <i>Chelonia mydas</i> found stranded on the Texas coast and caught per km-h at the Mansfield Channel jetties from 1989 to 1997.....	111
19 The relationship between the numbers of <i>Chelonia mydas</i> found stranded on the Texas coast and caught per km-h at the Mansfield Channel jetties from 1989 to 1996.....	112
20 Monthly numbers of <i>Chelonia mydas</i> found stranded on the Texas coast and caught per km-h at the Mansfield Channel jetties from 1989 to 1997.....	113
21 Length frequency distribution of <i>Chelonia mydas</i> found stranded on the Texas coast and caught per km-h at the Mansfield Channel jetties from 1989 to 1997.....	116

LIST OF FIGURES (continued)

FIGURE	Page
22	Yearly mean ($\pm$ SD) straight-line carapace lengths (cm) of <i>Chelonia mydas</i> found stranded on the Texas coast and netted at the Mansfield Channel jetties from 1989 to 1997..... 118

CHAPTER I

INTRODUCTION

Green Turtle Biology

The green turtle (*Chelonia mydas* Linnaeus, 1758) is listed under the Endangered Species Act of 1973 as threatened throughout its range with the exception of the breeding colony populations on the Pacific coast of Mexico and Florida coast of the United States, which are afforded endangered status. Although green turtles were once commercially exploited in Texas, today they are greatly depleted and primarily smaller-sized individuals (juveniles) inhabit Texas waters. Little biological and trend data are available for juvenile *C. mydas* in Texas or elsewhere. During this study, data were collected on green turtles in Texas through strandings, nestings, netting activities, and satellite tracking. Information yielded will enhance the understanding of this species and serve as a basis for development of increased protection measures.

Green turtles migrate extensively and occur in different habitats during different stages of their lives. For their first year of life or longer, green turtles are pelagic and passively drift in oceanic currents and gyre systems (Carr, 1980, 1982; Carr and Meylan, 1980; Hirth, 1997; Musick and Limpus, 1997). At roughly 20-40 cm curved carapace length or larger, juveniles leave the pelagic

This dissertation follows the style and format of Copeia.

zone and actively recruit to shallow water developmental habitats in tropical and temperature zones (Carr, 1967; Mendonca, 1981; Balazs, 1982; Witzell, 1982; Mendonca and Ehrhart, 1982; Ehrhart, 1983; Henwood and Ogren, 1987; Bjorndal and Bolten, 1988; Boulon and Frazer, 1990; Collazo et al., 1992; Hirth et al., 1992; Meylan et al., 1992; Coyne and Landry, 1994; Shaver, 1994).

Juveniles may enter a series of developmental habitats to locate appropriate forage (sea grasses and macroalgae) and thermal conditions (Hirth, 1997; Musick and Limpus, 1997). Generally, pubescent green turtles move into adult foraging habitats and adults migrate between foraging and nesting grounds (Balazs, 1976; Carr et al., 1978; Meylan, 1982; Mortimer and Carr, 1987; Limpus et al., 1992; Hirth, 1997; Musick and Limpus, 1997).

Numerous historical accounts substantiate that large numbers of green turtles once occupied Texas waters (Hildebrand, 1983; Doughty, 1984). A green turtle fishery, operating almost exclusively within inshore waters (bays, estuaries, and passes) began in Texas during the mid-1800s (Hildebrand, 1982; Doughty, 1984). However, by 1900 the catch declined to such an extent that the turtle fishing and processing industry was virtually eliminated (Hildebrand, 1982).

Green turtles still inhabit Texas waters but in greatly reduced numbers compared to during the mid-1800s (Hildebrand, 1982). Survivorship of green turtles in Texas is currently diminished due to several natural (hypothermic stunning) and human-related (dredging, hook-and-line capture, debris ingestion

and entanglement, boat propeller collisions, etc.) factors (Hildebrand, 1983). However, the relative importance of these factors and their impacts on the green turtle population in Texas are unknown.

Most biological and trend data for green turtles have been collected for nesting females, eggs, and hatchlings at various nesting beaches throughout the world. However, there has been little documentation of green turtle nesting on the Texas coast (Neck, 1978; Shaver, 1989). Most recent records of green turtles in Texas are of smaller-sized individuals (Hildebrand, 1982), obtained from individual strandings (Rabalais and Rabalais, 1980; Shaver, 1990a, 1990b; Hildebrand, 1982, 1983; Manzella and Williams, 1992), observations of a few individuals swimming or caught incidental to fishing operations (Rabalais and Rabalais, 1980; Hildebrand, 1982; Manzella and Williams, 1990), radio and sonic tracking of a few individuals in the Lower Laguna Madre and Brazos Santiago Pass (Renaud et al., 1995; Arms, 1996), and short-term netting studies conducted in the Mansfield Channel (Shaver, 1994), Lower Laguna Madre (Coyne, 1994; Shaver, 1994), and Brazos Santiago Pass (Coyne, 1994).

Relatively little is known about juvenile green turtles in developmental habitats in Texas or elsewhere. However, these areas are important to the survivorship of juvenile sea turtles and require adequate study and protection (Zug and Glor, 1998; Bjørndal, 1999). It is hypothesized that transient and seasonally resident juvenile green turtles use the Mansfield Channel as an intermediate developmental habitat between the pelagic habitat and lagoonal

feeding pastures and as a route for movement between the Gulf of Mexico and Laguna Madre (Shaver, 1994). However, it is unknown whether turtles remain at the Mansfield Channel year-round and where they travel after leaving the Mansfield Channel.

The National Marine Fisheries Service (NMFS) uses data from long-term directed capture studies of sea turtles and from the Sea Turtle Stranding and Salvage Network (STSSN) to aid with formulation of management decisions. Previously, most information was derived from stranded turtles, but recently greater emphasis has been placed on gathering data from directed capture studies conducted in "marine index areas" (Bjorndal, 1999) such as the Mansfield Channel. However, it is unknown how comparative the Mansfield Channel capture data and Texas stranding data are in terms of yearly and seasonal numerical trends, sizes, and sex ratios. Furthermore, it is unknown whether the Mansfield Channel netting data can accurately be used as an index of the green turtle population inhabiting Texas waters.

Data collected through strandings, nestings, netting activities, and satellite tracking will allow investigation of residency, seasonality, relative abundance, distribution, winter dormancy, movements, migration, size, growth, sex ratios, and mortality factors of green turtles in Texas. These topics are among the list assembled by Bjorndal (1999) as high priority information needs for the management and conservation of sea turtles. Data collected will also address recovery task priority items identified in the Green Turtle Recovery Plan. These

recovery task priority items include the following: determine seasonal distribution, abundance, population characteristics, and status in inshore and nearshore waters (priority 1); monitor trends in nesting activity (priority 1); evaluate nest success and implement nest protection measures (priority 1); determine growth rates, age at sexual maturity, and survivorship rates (priority 2); identify important marine foraging habitat (priority 2); determine threats along migratory routes and on foraging grounds (priority 2); determine seasonality and abundance at dredging locations (priority 3); and determine distribution and seasonal use of marine habitats associated with oil and gas development (priority 3) (NMFS and U.S. Fish and Wildlife Service, 1991). Information gained will enhance understanding of this species and be useful to managers attempting to assess population trends, formulate management decisions, and develop regulations to increase protection. Such information is needed to aid with the re-building of the green turtle population in Texas, which was decimated nearly a century ago.

Objectives

The studies reported herein were undertaken to (1) determine and compare sizes, sex ratios, and seasonal and yearly variations in the numbers of green turtles netted at the Mansfield Channel jetties and stranded in Texas; (2) determine the relationship of water temperature to seasonal variations in green turtle catch-per-unit-effort (CPUE), stranding numbers, and movements;

(3) determine spatial distributions of, and mortality factors for, green turtles stranded in Texas; (4) determine the residency durations of green turtles captured at the Mansfield Channel jetties; (5) determine and compare seasonal and yearly variations in movements of green turtles from the Mansfield Channel jetties to other waters in the United States and Mexico; and (6) determine the extent of green turtle nesting on the Texas coast.

CHAPTER II

STRANDED GREEN TURTLES

Introduction

Green turtles (*Chelonia mydas*) were once so abundant in Texas waters that they were commercially exploited (Smith, 1954; Hildebrand, 1982; Doughty, 1984; Witzell, 1994a, 1994b). The Texas green turtle fishery was in excess of 230,000 kg/year at its peak, but virtually nothing when the catch of turtles was outlawed in 1963 (Hildebrand, 1982). There is evidence that over-harvesting and the severe freezes of 1894-1895 and 1899 played a role in the decline of the Texas sea turtle industry (Hildebrand, 1982). Smith (1954) stated that the green turtle was no longer common in the western or northern part of the Gulf of Mexico and Breuer (1962) failed to even mention the presence of green turtles in the Lower Laguna Madre during his ecological survey of the area.

Little is known about green turtle utilization of Texas waters during recent years. Investigation of green turtles found stranded on the Texas coast could increase understanding of green turtle abundance, seasonality, distribution, sizes and sexes, and mortality factors in Texas. Stranded sea turtles are dead or live turtles that are found washed ashore or floating; live floating turtles are generally in a weakened condition (Schroeder, 1988; Teas, 1993).

The Sea Turtle Stranding and Salvage Network (STSSN) was established in 1980 to document strandings of marine turtles on United States beaches

located along the Gulf of Mexico, Atlantic Ocean, and Caribbean Sea (Schroeder, 1988; Shaver and Teas, 1999). Because some stranded turtles go undetected, the numbers reported by the STSSN are considered to be minimum estimates of the total number of strandings (Schroeder, 1988; Teas, 1993). Additionally, the numbers of dead turtles reported by the STSSN likely underestimate at-sea mortality, since only a portion of dead turtles actually wash ashore (Murphy and Hopkins-Murphy, 1989; Epperly et al., 1996). The STSSN database provides the only long-term, comprehensive database of sea turtle strandings for the Gulf of Mexico. Prior to 1980, some sea turtles were documented stranded on the Texas coast, but most early records were gathered opportunistically or in conjunction with other studies (Rabalais and Rabalais, 1980; Hildebrand, 1982, 1983).

Several factors have been implicated in sea turtle strandings along the Texas coast (Whistler, 1989; Magnuson et al., 1990; Plotkin and Amos, 1990; Shaver, 1990a, 1990b, 1998, 1999a; Caillouet et al., 1991, 1996; Plotkin et al., 1993; Shaver and Plotkin, 1998). General sources of green turtle strandings in the U.S. have been summarized by several authors (Thompson, 1988; Magnuson et al., 1990; National Marine Fisheries Service and U.S. Fish and Wildlife Service, 1991; Hirth, 1997; Renaud et al., 1997). However, no attempt has been made to use the long-term STSSN database to examine the demographics and stranding factors for green turtles in Texas and to quantify the relative importance of these stranding factors.

Hypothermic stunning may be one of the most important causes for green turtles to strand on the Texas coast. Cold or hypothermic stunning occurs when sea turtles are exposed to water temperatures that drop below 8 C during the sudden onset of a cold front (George, 1997; Spotila et al., 1997). During these times, turtles lose their ability to swim and dive, float to the surface, and can succumb if not rescued (Spotila et al., 1997). Hildebrand (1983) suggested that climatic factors, particularly periods of freezing temperatures that cause hypothermic stunning, must play a large role in the success or failure of the green turtle on the Texas coast. Sudden drops in water temperature due to excessively cold weather fronts have resulted in mortality to sea turtles (Hildebrand, 1982; Shaver, 1990a, 1990b) and other marine life on the Texas coast, particularly in the very shallow waters of the Laguna Madre, located in south Texas (Breuer, 1962; Shew et al., 1981). Hypothermic stunning of sea turtles during cold weather episodes has also been reported in Western Europe (Brongersma, 1982; Davenport, 1997), New England (Shoop, 1980; Meylan and Sadove, 1986; Burke and Standora, 1991; Morreale et al., 1992; Gerle and DiGiovanni, 1998), and the Indian River Lagoon System, Florida (Mendonca, 1981, 1983; Mendonca and Ehrhart, 1982; Witherington and Ehrhart, 1989a; Schroeder et al., 1990; Schroeder and Owens, 1994). Species affected in the U.S. have included Kemp's ridley (*Lepidochelys kempii* Garman, 1880), green, and loggerhead (*Caretta caretta* Linnaeus, 1758) turtles.

Incidental capture in shrimp trawls has been identified as the most important

human-related source of mortality of sea turtles in the U.S. (Magnuson et al., 1990) and may be a threat to green turtles in Texas waters. Incidental capture during recreational or other commercial fishing activities, collision with boat propellers, oiling, entanglement, ingestion of fishing gear and marine debris, and other factors may also be important mortality factors for green turtles in Texas. To conserve and restore green turtles in Texas, preventable sources of mortality must be identified, quantified, and reduced.

This study was undertaken to gain information on green turtles in Texas waters through analysis of STSSN records for green turtles found stranded in Texas from 1980-1998. The objectives of this study were to quantify sizes and sexes of stranded turtles, temporal and spatial trends of strandings, and causes of strandings. These topics addressed many of the high priority information needs outlined by Bjorndal (1999) for the management and conservation of sea turtles.

Materials and Methods

Detection and documentation of stranded turtles.—Stranded green turtles were documented by the STSSN from 1980-1998. Stranded turtles were located by STSSN network participants in response to information provided by beach visitors and during systematic surveys conducted on some Gulf of Mexico beaches in Texas. Few systematic surveys were conducted prior to 1986. Year-round, systematic surveys to locate stranded turtles were most

comprehensive from 1986-1990 and 1995-1998. From 1990-1994, the survey areas and frequency were reduced. The coast was divided into statistical zones 17-21, with most of zone 17 being located in Louisiana and the southern boundary of zone 21 being at the U.S./Mexico border (Fig. 1). It was further divided into offshore (beaches or waters of the Gulf of Mexico) and inshore (beaches or waters of passes and bays) areas. Overall, relatively little effort was made to survey offshore beaches located within the small section of zone 17 in Texas and the northern portion of zone 19. Additionally, effort to survey inshore areas was extremely limited.

For each stranded turtle, information was collected on species, stranding date and location, tag numbers (if applicable), visible injuries, condition, and final disposition of the animal. The curved carapace length (CCL) and curved carapace width (CCW) and/or straight-line carapace length (SLCL) and straight-line carapace width (SLCW) of most turtles were measured. Curved measurements were obtained using a flexible, fiberglass tape measure and straight measurements using calipers. Length was notch to tip, taken from the anterior point at midline (nuchal scute) to the posterior tip of the supracaudals (Bolten, 1999). Information was recorded on standardized forms that were forwarded to the state and subsequently to the national STSSN coordinators.

Live stranded turtles were taken to various rehabilitation facilities located in Texas. Most of the turtles that died during rehabilitation and many of the dead stranded turtles were salvaged for later necropsy. General necropsies, similar

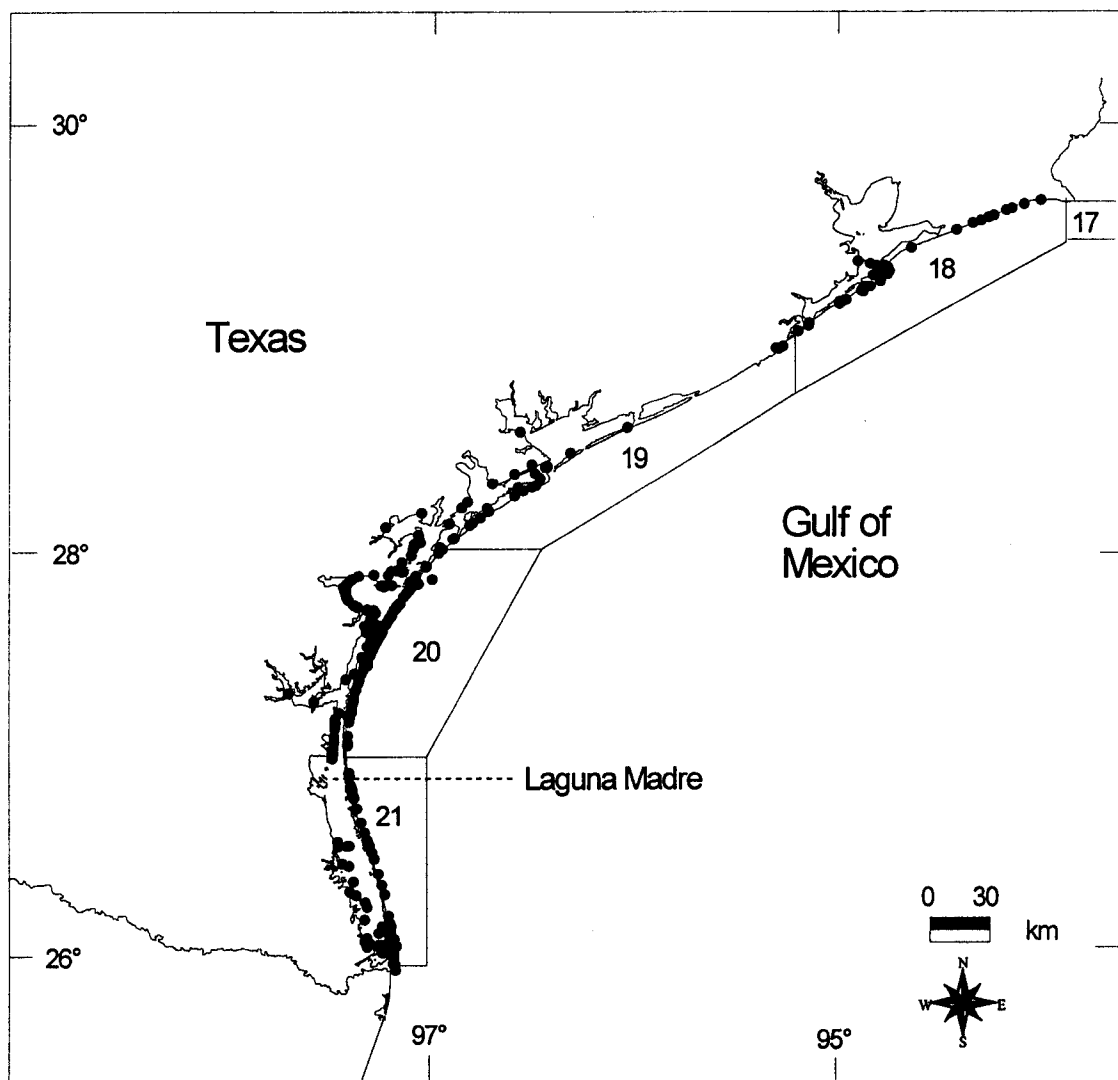


Fig. 1. Map showing statistical zones and locations where stranded *Chelonia mydas* were found on the Texas coast from 1980 to 1998.

to those described by Wolke and George (1981), were performed by a limited number of STSSN participants and veterinarians. During necropsy, the sex of the turtle was determined by visual examination of the gonads. Sex of a few very large turtles was obtained via tail length evaluation, when necropsies were not conducted. Gut contents were analyzed for some of the dead turtles necropsied. Results for a subset of those necropsied and analyzed for gut contents were entered into the STSSN database.

Data analysis.—The Texas STSSN database was queried for records of green turtles found stranded in Texas from 1980 through 1998. Following protocol established by the STSSN (Teas, 1993), turtles that were known to have been entrapped in intake canals of power plants or captured during active commercial or recreational fishing were categorized as “incidental captures” (not strandings) and not included in this analysis.

Strandings were categorized by month, season, year, area (inshore or offshore), and statistical zone. Seasons were defined as winter (December-February), spring (March-May), summer (June-August), and fall (September-November). For turtles with only CCL measurements, the conversion factor of Teas (1993) was used to convert CCL to SLCL. Turtles were categorized as “hatchlings/post-hatchlings” when they were less than 10.0 cm SLCL. Turtles were classified as “adults” when they attained adult size (Musick and Limpus, 1997) by exceeding 83.2 cm SLCL, the minimum size of nesting females

recorded in Florida by Witherington and Ehrhart (1989b). Turtles were considered to be "juveniles" when they were larger than hatchlings/post-hatchlings, but smaller than adults. Entries in STSSN database fields NOTE1-NOTE6 were summarized. When possible, injuries and anomalous conditions listed in these note fields were used to identify the factor that possibly contributed to stranding of each turtle.

All means are followed by $\pm$ one standard deviation. Data were tested for normality and homogeneity of variance prior to using parametric procedures. When parametric assumptions were not met, equivalent non-parametric procedures were used. Mann-Whitney rank sum tests were used to compare the median SLCLs of turtles found in offshore and inshore areas. Median SLCLs of stranded turtles were compared for each season and for each year using Kruskal-Wallis one way analysis of variance on ranks tests, followed by all pairwise multiple comparison tests (Dunn's method) to determine which season(s) and which year(s) were significantly different. Median SLCLs of females, males, and unknown sex turtles were compared using a Kruskal-Wallis one way analysis of variance on ranks test. A Spearman rank order correlation was used to determine whether there was first-order autocorrelation between SLCL by year and year - 1. Linear regression was used to determine if there was a significant linear relationship between study year and yearly mean SLCL. A chi-square test was used to compare the sex ratio for stranded turtles with a 1:1 ratio. Chi-square tests were also used to compare sex ratios of turtles found

stranded during each season and during each year (in which 5 or more individuals were identified of both sexes) with a 1:1 ratio.

Results

From 1980 to 1998, 607 green turtles were located stranded along the Texas coast (Fig. 1). Two hundred nineteen (36.1%) of the turtles were found alive and 388 (63.9%) were dead when located. The number found varied by year, and generally increased throughout time (Fig. 2). Stranding numbers also varied by month, with largest numbers found during colder winter months (Fig. 3).

Of the 607 stranded green turtles, 363 (59.8%) were located in inshore, 242 (39.9%) in offshore, and two (0.3%) in unknown areas (Figs. 2-4). Most strandings in inshore areas occurred in December, January, and February and most strandings in offshore areas occurred in April and May (Fig. 3).

Strandings were distributed throughout Texas (Fig. 1), with 0 (0.0%) in zone 17, 39 (6.4%) in zone 18, 46 (7.6%) in zone 19, 256 (42.2%) in zone 20, 265 (43.7%) in zone 21, and one (0.1%) for which the stranding zone was not identified (Fig. 4). However, both inshore and offshore strandings were concentrated in south Texas. Inshore strandings were most numerous in zone 21 (in the Laguna Madre) and offshore strandings were most numerous in zone 20 (Fig. 4).

Stranded *C. mydas* ranged from 4.0 to 99.2 cm SLCL ($\bar{x} = 37.7 \pm 13.7$ cm,

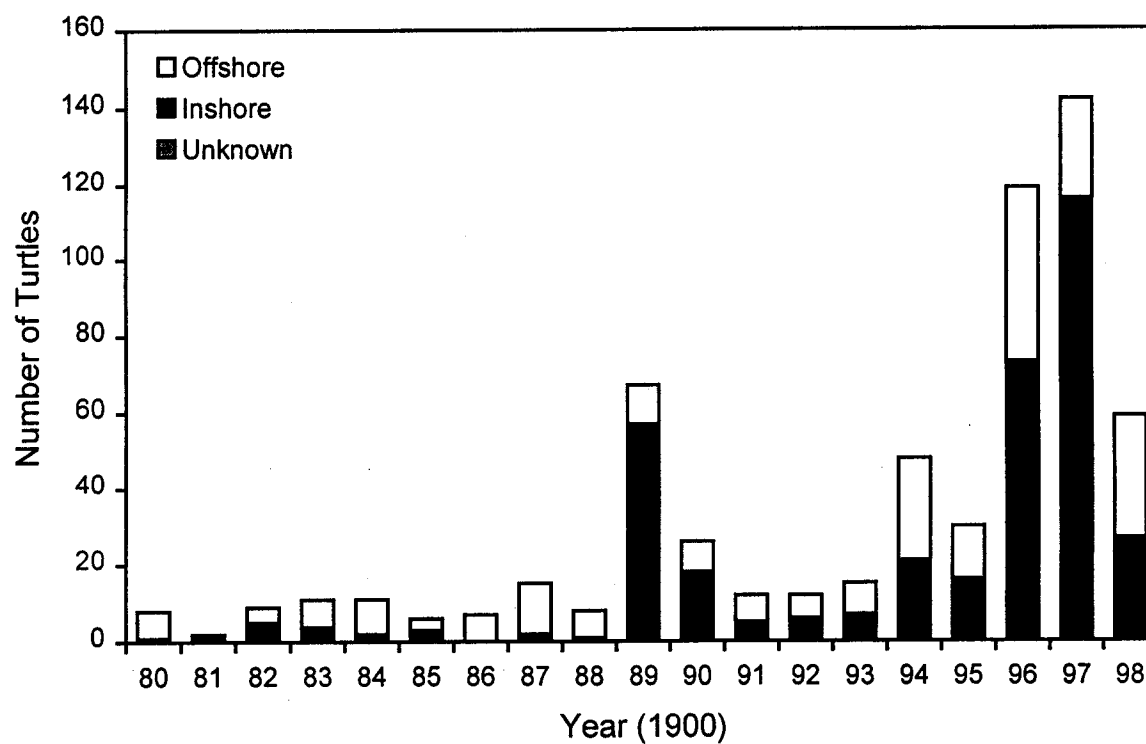


Fig. 2. Yearly numbers of *Chelonia mydas* found stranded in inshore and offshore areas on the Texas coast from 1980 to 1998.

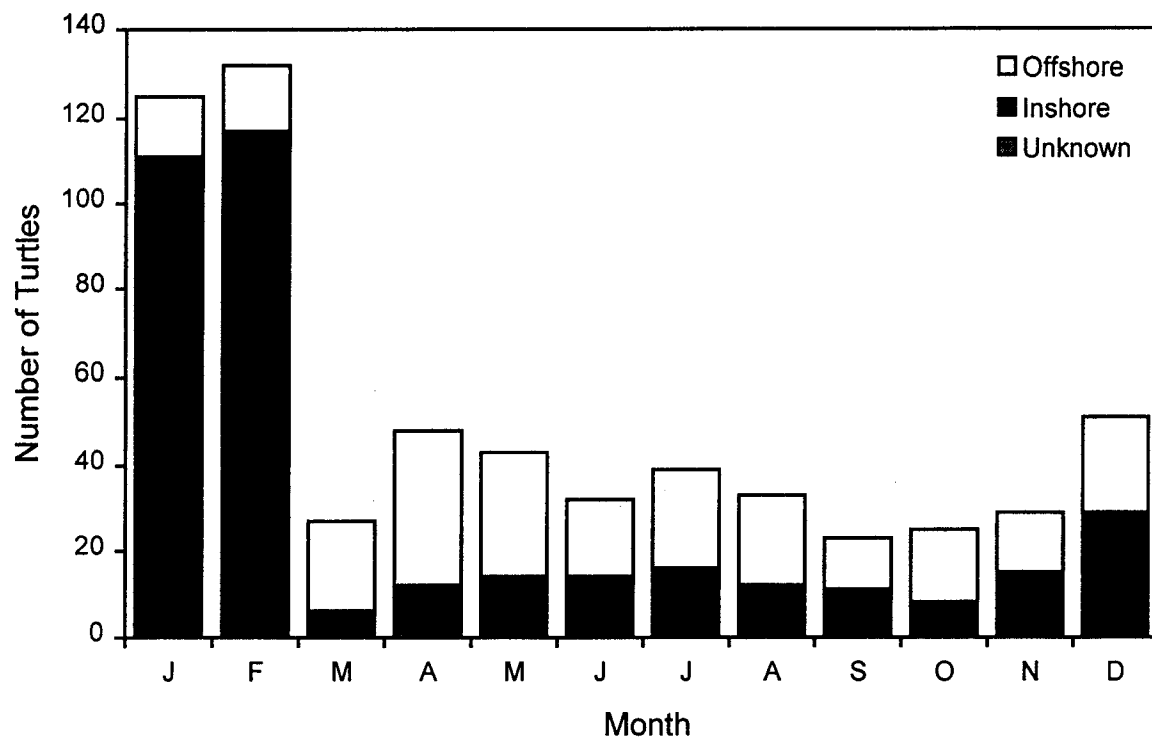


Fig. 3. Monthly numbers of *Chelonia mydas* found stranded in inshore and offshore areas on the Texas coast from 1980 to 1998.

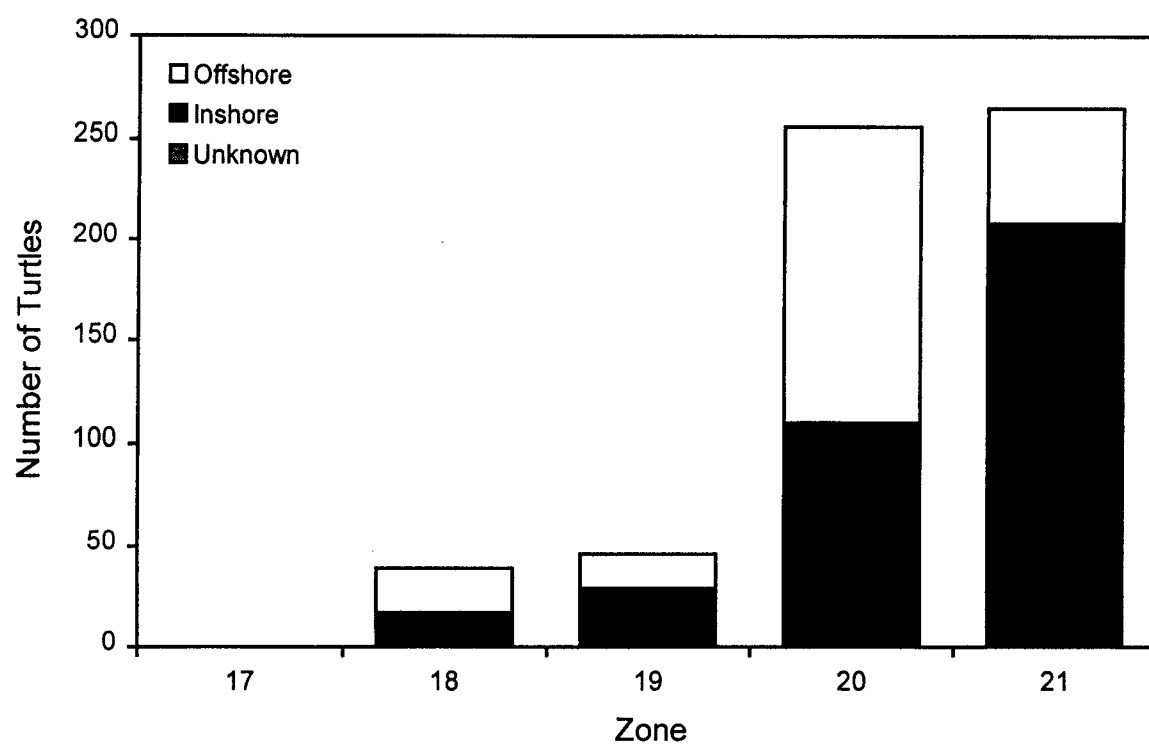


Fig. 4. Numbers of *Chelonia mydas* found stranded in statistical zones on the Texas coast from 1980 to 1998.

$n = 528$) (Fig. 5). Of the 528 for which measurements were obtained 4 were hatchlings/post-hatchlings, 517 were juveniles, and 7 were adults. Stranded individuals found inshore ranged from 13.0 to 98.5 cm SLCL ($\bar{x} = 40.1 \pm 11.1$ cm, $n = 313$) and found offshore ranged from 4.0 to 99.2 cm, ($\bar{x} = 34.4 \pm 16.2$ cm, $n = 213$). Turtles found stranded inshore were significantly larger than turtles found stranded offshore ($T = 41929.000$, $n(\text{small}) = 213$, $n(\text{big}) = 313$, $P \leq 0.001$).

No significant first-order autocorrelation was found between SLCL by year and year - 1 ($r = -0.110$, $P = 0.656$, $n = 18$). A linear model was not useful to describe the relationship between year and yearly mean SLCL ($r^2 = 0.006$, $P = 0.757$, $n = 19$). Transforming the SLCL data and fitting a variety of sigmoid curves to the data did not result in any regression models that were statistically significant. Yearly median SLCL differed among study years ($H = 67.638$, $df = 18$, $P < 0.001$); turtles found stranded in 1993 were smaller than those found in 1985 ($Q = 4.009$, $P < 0.05$), 1989 ($Q = 5.460$, $P < 0.05$), and 1997 ($Q = 5.042$, $P < 0.05$). Median SLCL differed among seasons ($H = 67.175$, $df = 3$, $P < 0.001$); turtles found stranded in the winter were larger than those found in the spring ($Q = 7.045$, $P < 0.05$), summer ($Q = 4.669$, $P < 0.05$), and fall ($Q = 5.007$, $P < 0.05$).

Necropsies were performed on 155 of the stranded turtles. Of the 136 individuals that sex was determined for by necropsy and tail length evaluation, 71 were females and 65 were males. Median SLCLs of females, males, and

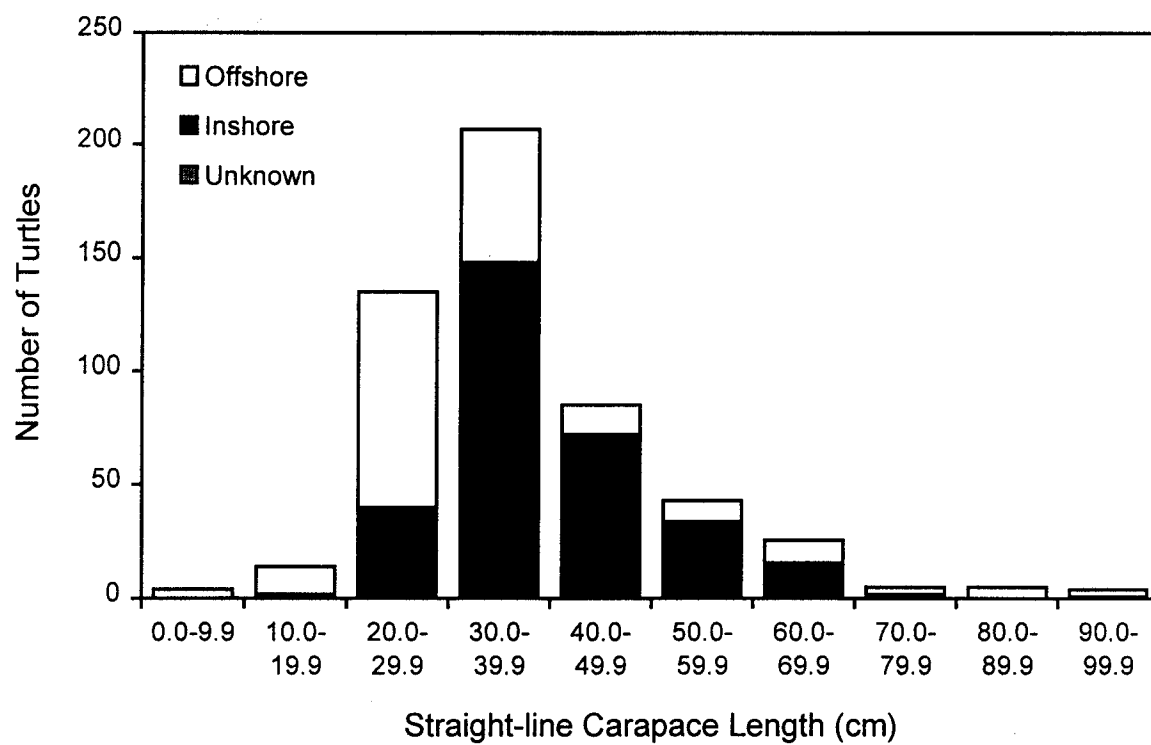


Fig. 5. Length frequency distribution of *Chelonia mydas* found stranded in inshore and offshore areas on the Texas coast from 1980 to 1998.

unknown sex turtles did not differ ($H = 0.0248$, $df = 2$, $P = 0.988$). The 1.09F:1.00M sex ratio was not significantly different from a 1:1 ratio (chi-square = 0.26, $df = 1$, $P > 0.05$). Most of the 136 individuals that sex was determined for were found during 1994, 1996, and 1997; the sex ratio was not significantly different from a 1:1 ratio during those 3 years (in all cases: chi-square < 1.960, $df = 1$, $P > 0.05$). The sex ratio was not significantly different from a 1:1 ratio during all 4 seasons (in all cases: chi-square < 0.862, $df = 1$, $P > 0.05$).

A variety of injuries, anomalous conditions, and stranding attributes noted in the field and during necropsy were listed in fields NOTE1-NOTE6 (Appendix I). Some individuals had more than one note code and some had no note codes. Many of the entries described injuries that could have occurred pre- or post-mortem. From a summary of the entries in these note fields and examination of each stranding record, probable stranding causes were identified for 298 turtles (Table 1). Hypothermic stunning was identified as the likely stranding cause for 230 of the 298 (Table 1) and these 230 were found during 8 different years (Table 2). Sixty-eight of the 298 stranded due to a variety of other causes (Table 1). Stranding causes were not identified for the remaining 309 turtles.

Discussion

From the time that the STSSN was established in 1980, through 1998, the numbers of green turtles documented stranded in Texas each year generally increased. This increase undoubtedly reflected improvements in STSSN

Table 1. Probable stranding causes for *Chelonia mydas* found stranded on the Texas coast from 1980 to 1998, as determined from codes in data fields

NOTE1-NOTE6.

Cause [note codes]	Number of individuals
Hypothermic stunning [08]	230
Entanglement in debris, rope, abandoned net, gill net, fishing net [13, 28, 41, 48, 59, AO, AP]	14
Fishing line entanglement or ingestion, embedded hooks [11, 24, 90, 95, AE]	14
Tar and/or oil on body [49]	14
Trapped in jetty rocks [AX]	11
Emaciated or buoyancy problems [33, 36, BF]	8
Dredging [96]	6
Red tide [86]	1

Table 2. Numbers of *Chelonia mydas* documented stranded as a result of hypothermic stunning on the Texas coast from 1980 to 1998.

Event	Number of		Number	
	turtles	Dates	inshore/offshore	Zones(n)
1	3	11-13 Jan. 1982	3/0	19(1), 20(2)
2	4	18-22 Dec. 1983	4/0	21(4)
3	1	13 Jan. 1984	1/0	20(1)
4	46	6-14 Feb. 1989	46/0	18(1), 20(9), 21(36)
5	5	20-23 Dec. 1989	4/1	20(3), 21(2)
6	9	2 Jan.-14 Feb. 1990	9/0	20(4), 21(5)
7	2	27-30 Dec. 1990	1/1	20(1), 21(1)
8	2	12 Nov.-26 Dec. 1995	1/1	20(2)
9	52	4 Jan.-15 Feb. 1996	52/0	18(1), 20(3), 21(48)
10	3	20-21 Dec. 1996	2/1	19(1), 20(1), 21(1)
11	96	6 Jan.-7 Feb. 1997	91/5	18(2), 20(21), 21(73)
12	7	26-31 Dec. 1998	7/0	20(2), 21(5)
Total	230	-	221/9	18(4), 19(2), 20(49), 21(175)

coverage (Shaver, 1999a) and perhaps increased public awareness and reporting of strandings. The increased number of strandings could have also reflected increased mortality due to certain sources or increased green turtle population levels. Green turtle populations on foraging grounds at Caribbean islands (Bjorndal and Bolten, 1996; Engstrom et al., 1998; Lahanas et al., 1998) and off the coast of Nicaragua (Bass et al., 1998a) are composed of animals originating from a wide area of the Atlantic. However, based on preliminary analyses of genetic samples, most juvenile green turtles inhabiting Texas waters are probably from nesting populations in the Gulf of Mexico (Florida and/or the Gulf coast of Mexico) (P. Dutton, pers. comm.). The numbers of nests found in both of these areas have increased during the last two decades (R. Marquez, pers. comm.; Dodd, 1982; Magnuson et al., 1990; Dodd and Byles, 1991; Owen et al., 1994; Meylan et al., 1995). There is also some evidence that the numbers of juvenile green turtles have been increasing in Texas and Florida during the last 20 years. During the early 1980s, it was thought that there was a low abundance of green turtles in Texas (Rabalais and Rabalais, 1980; Hildebrand, 1982, 1983; Fritts et al., 1983). However, during the 1990s, numerous green turtles have been found stranded in Texas and captured during netting studies conducted in Texas inshore waters (see Chapter IV). Wilcox et al. (1998) felt that increases (beginning in 1993) in the number of green turtles captured from the intake canal of the St. Lucie nuclear power plant may reflect a larger green turtle population in nearshore waters of

east-central Florida.

Demographics.—Ninety-eight percent of the stranded green turtles were categorized as juveniles. Based on these analyses, the vast majority of turtles occupying Texas waters are juveniles. The majority of green turtles in U.S. waters are immature (Thompson, 1988) and the finding that most of the green turtles documented stranded in Texas were juveniles is consistent with other recent studies conducted in Texas and Florida. All green turtles measured during directed capture studies in south Texas inshore waters (see Chapter IV) and in Florida (Mendonca and Ehrhart, 1982; Henwood and Ogren, 1987; Guseman and Ehrhart, 1990; Wershoven and Wershoven, 1992; Ehrhart and Redfoot, 1995; Schroeder and Foley, 1995; Schmid, 1998) were juveniles. Juveniles comprised the vast majority of stranded green turtles that were documented in south Texas from 1976-1979 (Rabalais and Rabalais, 1980) and entrained at a power plant in Florida (Ernest et al., 1989; Wilcox et al., 1998).

Juveniles probably use Texas waters for foraging, developmental, and migratory habitat. Turtles found stranded inshore were significantly larger than turtles found stranded offshore. Since most turtles found stranded during the winter were located inshore (in contrast to during other seasons), it is not surprising that turtles found stranded during the winter were significantly larger than those found during other seasons. The largest number of juveniles found inshore was in the 30.0-39.9 cm size grouping, whereas the largest number of

juveniles found offshore was in the 20.0-29.9 cm SLCL size grouping (Fig. 5). These results may indicate that most juvenile recruitment into nearshore Gulf waters along the Texas coast occurs at 20.0-29.9 cm SLCL and into inshore areas at 30.0-39.9 cm SLCL. Alternatively, the larger size of turtles found in inshore areas may support the hypothesis that juveniles that enter Texas inshore waters use them as developmental and foraging habitat and grow in size. Juveniles may use Gulf waters off the Texas coast for migration to foraging and developmental habitat, leading to lower residency times and growth rates there.

Very few hatchlings/post-hatchlings ($n = 4$) and adults ($n = 7$) were found stranded in Texas. The lack of many records of stranded hatchlings and post-hatchlings in Texas from 1980-1998 is not surprising based on the biology of this species and limited use of the Texas coast for nesting during this time (see Chapter III). Hatchlings disperse from the nesting beach, become planktonic, and enter the pelagic zone. Hatchlings from eggs laid in Texas or elsewhere should not be close enough to shore to strand on Texas Gulf beaches unless injuries, tropical disturbances, strong winds, or strong currents cause them to wash back ashore. The relatively small number of hatchlings/post-hatchlings released from Texas nests during those years limited the number of turtles available to be washed ashore when rough water conditions arose.

Since few sea turtles survive to adulthood, it is not surprising that fewer adults were found stranded than juveniles. However, the number of adults

found was very small, likely indicating that Texas was not used by a large number of adult green turtles for foraging grounds, nesting grounds, or migratory corridors during the study period. As juveniles that occur in Texas approach maturity, they may depart to adult foraging grounds located elsewhere. Some of the seven stranded turtles classified as adults because they exceeded the minimum size of nesting turtles may not have been sexually mature (Carr and Goodman, 1970; Limpus et al., 1994; Miller, 1997; Musick and Limpus, 1997). Little green turtle nesting was documented in Texas between 1980-1998 (see Chapter III).

In 1890, 249,480 kg of green turtles were harvested from Texas, with an average weight of 113 kg/turtle (Hildebrand, 1983). For the captured turtles to have reached an average weight of 113 kg/turtle, it is likely that some adults were included. It is possible that the turtle capture and processing industry selected for larger turtles. Alternatively, the average size of turtles in Texas waters may have decreased, with juveniles comprising a larger proportion of the population in 1980-1998 than they did during the mid-1800s. This shift could have occurred due to extirpation of a local green turtle population that used Texas waters for adult foraging, nesting, or migration habitat. Historically, the most significant green turtle nesting area in Florida was on beaches of the Dry Tortugas, where up to 2,800 females nested per year, but this aggregation was extirpated by the 1900s (Thompson, 1988). A nesting population could have also been present in Texas during the mid-1800s, but later eliminated.

Fisheries for this species were centered along the Texas coast and both the Florida east and west coasts (Ehrhart, 1983; Hildebrand, 1982, 1983).

However, an increase in the proportion of juveniles could also support the hypothesis that the population is increasing. Since green turtles require 20-50 years to reach maturity (see Hirth, 1997), it would take many decades for the population to re-build and for the population structure to stabilize after harvest was ceased. Habitat alteration or mortality factors that occurred after 1890 and impacted large green turtles in Texas also could have led to a decrease in the average size of green turtles there. Hildebrand (1983) suggested that large green turtles may not be able to coexist with boat traffic, fishing gear, hypothermic stunning, and loss of grass bed habitat through dredging.

No clear pattern has emerged for sex ratios in immature sea turtle populations (Bolten et al., 1992). The 1.09F:1.00M sex ratio found in the present study was slightly, but not significantly, skewed towards females. Sex ratios found in other studies of green turtles that examined primarily immature individuals have been skewed towards females. However, in most instances the sex ratios did not significantly differ from 1:1. Meylan et al. (1994), using serum testosterone assays and verification via laparoscopy, found a sex ratio that did not differ significantly from 1:1 for green turtles netted in Bermuda. Using serum testosterone assays, Wibbels et al. (1993) found a sex ratio of 1.03F:1.00M in Hawaii, Bolten et al. (1992) found a sex ratio of 1.41 F:1.00M in the Bahamas, Wibbels et al. (1989) found a sex ratio of 1.99F:1.00M in

Australia, Bass et al. (1998b) found a sex ratio of 5.57F:1.00M in North Carolina, Redfoot et al. (1996) found a sex ratio of 12.00F:1.00M in Florida, and Provancha et al. (1998) found a sex ratio of 17.00F:1.00M in Florida. Using necropsies, Koga and Balazs (1996) found a sex ratio of 1.16F:1.00M in Hawaii and Schroeder and Owens (1994) found a sex ratio of 1.75F:1.00M in Florida.

Stranded green turtles were found both in inshore and offshore areas and in all zones along the Texas coast. However, the largest concentration of stranded green turtles was in the Lower Laguna Madre, near Port Isabel. Based upon stranding records, the green turtle is not uniformly distributed along the Texas coast (Figs. 1, 4). Spatial differences in the numbers of turtles found stranded in Texas likely reflected actual differences in relative abundance of green turtles throughout the State. Strandings were most numerous in areas where green turtle food was more abundant and water turbidity was lower. Water turbidity is lower in south Texas and most of the turtles were found stranded in south Texas. Juvenile and adult green turtles are almost exclusively herbivorous, feeding on macroalgae and/or seagrasses (see Hirth, 1997). These food items are more abundant in south Texas bay, lagoon, and jetty habitats (Edwards, 1976; Armstrong, 1987; Quammen and Onuf, 1993; Coyne, 1994; Kaldy et al., 1995; Lehman, 1999) and most stranded turtles were found inshore in zones 20 and 21. Additionally, these food items are less abundant in Gulf waters along the Texas coast (Britton and Morton, 1989) and fewer green turtles were found stranded offshore than inshore.

If the relative abundance of green turtles documented stranded at various Texas inshore areas is representative, the area where most green turtles are concentrated in Texas inshore waters may have changed since the 1800s. Hildebrand (1982) reported that during the 1800s people collected cold stunned green turtles for food on the shore of Corpus Christi Bay, but did not mention such activities occurring in the Lower Laguna Madre. Hildebrand (1982) also stated that nearly all green turtles from the fishery operating during that time were caught in Aransas Bay, Matagorda Bay, and the Lower Laguna Madre and that the total weight of captured turtles was roughly ten times higher in Aransas Bay than the Lower Laguna Madre. This disparity in catch could have reflected geographic variations in catch effort or catchability. Alternatively, habitat changes may have rendered the Aransas Bay and Corpus Christi Bay areas less attractive, and the Lower Laguna Madre more attractive, to green turtles than they once were. In the 1940s, salinities of 60-100 ppt were recorded in the Laguna Madre and hypersalinity could have limited the distribution of sea grasses (Quammen and Onuf, 1993) and sea turtles there during and before that time. However, hydrological alterations (due to dredging and other factors) and a climatic shift that occurred between 1948 and 1965 decreased salinity in the Laguna Madre (Quammen and Onuf, 1993). Turtle grass (*Thalassia testudinum*), intolerant to hypersalinity, has expanded in the Lower Laguna Madre since 1967. Small patches of *Thalassia* are now common in the Lower Laguna Madre as far north as the Arroyo Colorado. During the last 50 years,

higher levels of human activity and habitat destruction have occurred in the Corpus Christi Bay and Aransas Bay areas than in the Lower Laguna Madre and this could have also influenced green turtle distribution and abundance.

The distribution of strandings may have been influenced by spatial differences in stranding network coverage. Limited visitation to inshore shorelines and lack of systematic STSSN surveys there likely limited observations of inshore green turtle strandings. Passive transport of dead or injured turtles, before they washed ashore, also may have influenced the final distribution of stranded turtles. Some of the turtles found inshore may have succumbed in the Gulf of Mexico and either drifted inshore or been deposited there intentionally. Similarly, some of the turtles killed in inshore areas, particularly near pass entrances, could have drifted into the Gulf of Mexico and later washed ashore on offshore beaches.

Stranding distribution, abundance, and temporal patterns may have reflected impacts of mortality factors. These sources of injury and death vary in importance for different locations, for different periods of time, and for different life stages (Shaver, 1999a). A variety of natural and human-related factors cause sea turtles to strand (Magnuson et al., 1990; George, 1997; Lutcavage et al., 1997). There are several natural and human-related sources of sea turtle injury and mortality in the Texas inshore and offshore areas. Comments listed on STSSN forms revealed possible causes for strandings of 298 of the 607 turtles found during 1980-1998.

Hypothermic stunning.—Hypothermic stunning was the stranding cause listed on the largest number of stranding forms. Clearly, hypothermic stunning is a significant threat to green turtles in Texas, particularly within south Texas inshore waters. Of the 298 turtles for which stranding sources were identified, 230 were located during or shortly after periods of freezing air temperatures and were probable victims of hypothermic stunning. The overall temporal and spatial distribution of green turtle strandings (Figs. 1-4, Table 2) were dominated by the influences of hypothermic stunning. The years (1989, 1996, and 1997) and months (December-February) with the largest number of green turtle strandings were the years and months with the largest number of green turtles found stranded as a result of hypothermic stunning. Also, the locations where most green turtles were found stranded in inshore waters (zones 20 and 21) were the locations where most green turtles stranded as a result of hypothermic stunning.

Changes in temperatures have profound impacts on the behavior and survival of sea turtles (Mendonca, 1983; Birse and Davenport, 1987; Read et al., 1996; Davenport, 1997; Lutcavage and Lutz, 1997). Green turtles reduce swimming activity at the onset of cold water temperatures (below 20 C) and they become semi-torpid and cease feeding at temperatures below 15 C (Moon, 1992; Moon et al., 1997). Sea turtles initially react to exposure to 10 C water by bobbing at the surface and die between 5 and 6 C (Schwartz, 1978).

As winter approaches and water temperatures drop, many sea turtles

emigrate from temperate areas and migrate towards warmer tropical waters (Carr and Caldwell, 1956; Byles, 1988; Witherington and Ehrhart, 1989a; Keinath, 1993; Coles et al., 1994; Epperly et al., 1995a, 1995b, 1995c; Lutcavage and Lutz, 1997), thereby reducing their vulnerability to cold stunning. However, many green turtles inhabit south Texas (Coyne, 1994; Shaver, 1990a, 1990b, 1994; Arms, 1996) and southeast Florida (Mendonca and Ehrhart, 1982; Ernest et al., 1989; Witherington and Ehrhart, 1989a; Schroeder et al., 1990; Ehrhart and Redfoot, 1995; Wilcox et al., 1998) inshore waters during the winter and captures of green turtles increased in some of these areas during the winter months (Ernest et al., 1989; Coyne, 1994; Ehrhart and Redfoot, 1995; Wilcox et al., 1998). Williams and Renaud (1998) found that two green turtles tracked using satellite telemetry left the Matagorda Bay, Texas, and moved into south Texas offshore waters during the winter. Green turtles may also migrate and recruit into south Texas inshore waters during the fall and winter, as hypothesized for the Mosquito Lagoon, Florida (Mendonca and Ehrhart, 1982; Mendonca, 1983). Turtles can safely overwinter and remain active there during some years (Arms, 1996), but face the threat of hypothermic stunning there during years when severe freezes occur. Dormancy may be another strategy for surviving low water temperatures (Carr and Caldwell, 1956; Felger et al., 1976; Carr et al., 1980; Ogren and McVea, 1982; Witherington and Ehrhart, 1989a; Lutcavage and Lutz, 1997). Moon (1992) induced hibernation-like dormancy at cold temperatures in the laboratory, but no evidence of winter

dormancy has been found in Texas (Fritts et al., 1983).

Of the 230 hypothermic stunned turtles documented from 1980-1998, 194 were found during three hypothermic stunning events (Table 2). There are several possibilities why far more turtles were detected during the February 1989, January-February 1996, and January-February 1997 hypothermic stunning events than during other times after 1980 when freezing air temperatures, dead fish, and hypothermic stunned turtles were found. The magnitude and rapidity of the water temperature decline may have been greater and had more devastating effects during these three periods of freezing air temperatures. More turtles may have become victims of hypothermic stunning during these three periods because there were more turtles available to be affected then. More turtles may have overwintered during those years. Also, more green turtles may have been present due to increased population levels during the late-1980s and 1990s. Another possible cause for the discrepancy in the numbers found could be that more interest and effort was undertaken to detect and report hypothermic stunned turtles in 1989 and thereafter.

The vast majority of the hypothermic stunning was recorded in inshore waters of zones 20 and 21, in the Laguna Madre, where extensive seagrass beds are found (Quammen and Onuf, 1993). The Laguna Madre is a 200-km long hypersaline marine estuary with an average depth of 1.2 m, less than any other Texas estuary (Armstrong, 1987). Circulation of seawater into and out of the Laguna Madre is highly restricted, with only one indirect and two direct

water exchange passages to the Gulf of Mexico (Shew et al., 1981). The Laguna Madre is used extensively by green turtles (Coyne, 1994; Coyne and Landry, 1994; Shaver, 1994; Arms, 1996), but restricted access to the Gulf of Mexico, hypothermic stunning, and hypersalinity may limit their numbers and distribution in the Laguna Madre.

Sea turtles feeding in shallow enclosed areas are the most susceptible to cold stunning (Ogren and McVea, 1982; Witherington and Ehrhart, 1989a; George, 1997; Lutcavage and Lutz, 1997). Green turtles occupying the Laguna Madre may be particularly susceptible to hypothermic stunning because of the shallow water and limited access points to the Gulf of Mexico. Because the Laguna Madre is the shallowest of any Texas bay system, its waters likely cool faster. When waters cool rapidly, there may be insufficient time for the turtles to reach deeper channels of the Laguna Madre or locate the few passes that connect to the Gulf of Mexico, where warmer waters could be found. Thus, the turtles occurring in these shallow areas may become trapped and fall victim to hypothermic stunning. The Laguna Madre is somewhat analogous to the Indian River Lagoon System (IRLS), located in central and south Florida, in terms of geographic configuration and hypothermic stunnings of green turtles. The IRLS (particularly the Mosquito Lagoon at the northern reaches of the IRLS) has relatively shallow water, a limited number of exits to the Atlantic Ocean, and the most documented green turtle hypothermic stunnings of any location in Florida (Mendonca, 1981, 1983; Mendonca and Ehrhart, 1982; Witherington and

Ehrhart, 1989a; Lutcavage and Lutz, 1997). During major cold stunning events, most of the green turtle population inhabiting the IRLS may be affected (Witherington and Ehrhart, 1989a; Schroeder et al., 1990) and a similar situation could occur in the Laguna Madre.

Cold stunning can result in substantial mortality, but this mortality can be reduced by human intervention. Many of the 230 cold stunned green turtles documented were found alive, transported to rehabilitation facilities, and later released. However, early detection of these turtles was critical to their survival. The earliest cold stunned turtles were located alive, whereas days after the initiation of a cold stunning event none of the affected turtles were found alive. During cold stunning events in IRLS, Florida (Witherington et al., 1989a; Schroeder et al., 1990) and New England, the percent mortality also increased with each subsequent day of recovery efforts.

One cold stunned green turtle was located alive in the Lower Laguna Madre ($26^{\circ}04'06''\text{N}$, $97^{\circ}09'51''\text{W}$) on 5 February 1996, rehabilitated, released at that stranding location on 7 February 1996, and found stranded dead in the Lower Laguna Madre ($26^{\circ}07'30''\text{N}$, $97^{\circ}10'26''\text{W}$) on 3 December 1999. Even though the second stranding was after the termination of the study period, this record is noteworthy. Rescue and rehabilitation likely extended the life of this turtle for these 3.8 years. Additionally, because the second stranding was at nearly the same location as the first stranding, this record demonstrated site fidelity of this turtle to the Lower Laguna Madre, although it cannot be proven that it remained

there for this entire time. During this intervening time, the turtle grew from 38.1 to 65.0 cm SLCL.

Other stranding causes.—A variety of other factors also caused green turtles to strand in Texas from 1980-1998. Based upon note codes in the STSSN database, probable stranding causes other than hypothermic stunning were identified for 68 turtles. These included: entanglement in debris, rope, abandoned netting, gill netting, or fish netting (n = 14); entanglement in or ingestion of fishing line or hooks (n = 14); tar and/or oil on body (n = 14); trapped in jetty rocks (n = 11); emaciated or buoyancy problems (n = 8); dredging (n = 6); and, red tide (n = 1). Examination of note codes in the STSSN database provided no readily discernible stranding cause for 309 of the 607 green turtles found stranded on the Texas coast from 1980-1998. This large number for which no obvious stranding cause was identified is not surprising, given that the cause of mortality is often not definitely identified from stranded turtles (Thompson, 1988; Hirth, 1997). Had more turtles been necropsied and analyzed for gut contents, and more results of those analyses entered into the STSSN database, it is possible that stranding causes could have been identified for more turtles. The 309 likely stranded due to some of the causes listed above and other causes.

Many turtles had note code entries reporting damaged or missing body parts, but it was impossible to determine from these records whether the injuries

occurred pre- or post-mortem and hence whether they caused the strandings. Boat strikes and propeller injuries that were noted for 30 turtles could have occurred before or after death. Since propeller injuries (a series of parallel grooves) are relatively easy for STSSN participants to identify, it is reasonable to estimate that a maximum of 30 of the 309 turtles stranded due to this factor. A variety of fisheries interactions kill sea turtles (Thompson, 1988; Ehrhart et al., 1990; Magnuson et al., 1990; Renaud et al., 1997; Oravetz, 1999). This analysis underestimated strandings due to various types of fisheries interactions because turtles reported as incidental captures from active recreational and commercial fishing were not included in stranding totals. Additionally, fisheries interactions would not have been identified as the stranding causes for turtles that were caught incidentally, released, and later found stranded unless these turtles exhibited obvious signs of incidental capture that were listed on the STSSN forms.

Recreational fishing was implicated in the strandings of 14 turtles that had conclusive signs of entanglement in, or ingestion of, fishing line or hooks. Several of the 309 turtles for which stranding causes were not identified could have been hooked during recreational fishing, released, and ultimately stranded as a result of this capture.

One turtle was found in a gill net (Appendix I) and is among the 14 that stranded as a result of entanglement in debris, rope, abandoned netting, gill netting, or fish netting. It is likely that some of the other turtles documented

from 1980-1998 also stranded due to being captured in gill nets. In Texas, a total gill net ban occurred in 1988, although there were various phasing out steps that began in the 1970s (M. Ray, pers. comm.). Although gill netting has not been legal in Texas since 1988, illegal gill netting still occasionally occurs in south Texas offshore waters.

One stranded turtle was found in the holding tank of a shrimp trawler (Appendix I). Since it could not be proven that this turtle was caught in a shrimp trawl, it was included among the 309 for which no stranding cause was found. However, it is probable that this turtle and many others of the 309 stranded as a result of incidental capture in shrimp trawls. Stranded sea turtles, whether alive or dead, exhibit no known external or internal signs of capture in shrimp trawls (Caillouet et al., 1996). Hence, this factor would not have been recorded in note codes on stranding forms and not quantified during this study. However, it is likely that incidental capture in shrimp trawls resulted in a large number of the offshore and inshore strandings of green turtles along the Texas coast from 1980-1998.

Green turtles have been and are caught in shrimp trawls in U.S. waters and these captures often result in the turtles' injury or death and their subsequent stranding on the beach (Murphy and Hopkins-Murphy, 1989; Caillouet et al., 1991; 1996; Renaud et al., 1997). TEDs (Turtle Excluder Devices) were developed to reduce sea turtle mortality due to incidental capture in shrimp trawls. TEDs became mandatory in Gulf waters off the Texas coast during 1990

and in Texas inshore waters during 1994. Prior to the mandatory use of TEDs, Magnuson et al. (1990) concluded that the most important human-associated source of mortality for sea turtles in U.S. waters was incidental capture in shrimp trawls, which accounted for more deaths than all other human activities combined, and Thompson (1988) estimated shrimpers caught and killed green turtles at a level which directly reflected their proportional contribution to the total number of sea turtles in the southeastern U.S. Despite mandatory use of TEDs, a correlation continued between shrimping effort in Gulf of Mexico waters off the Texas coast and sea turtle strandings on Texas offshore beaches (Caillouet et al., 1996; Shaver, 1998).

During this study, offshore strandings of green turtles peaked in April and May and were less numerous in June (Fig. 3). This decrease in June coincided with the Texas Closure, when Gulf waters off the Texas coast were closed to shrimp trawling, and strandings of loggerhead and Kemp's ridley turtles also decreased dramatically (Shaver, 1998). However, during the Texas Closure, shrimp trawling was permitted within inshore waters, and strandings typically increased in inshore waters during the Texas Closure (Shaver, 1998).

Although marine debris was found in several of the turtles necropsied (Appendix I), in most instances the amounts were minimal and probably not the cause of stranding or death (Shaver and Plotkin, 1998). Plotkin and Amos (1990) found that seven of the 15 green turtles stranded on the south Texas coast from 1986 through 1988 contained ingested marine debris. Results of gut

content analyses from these and some other turtles were entered into the STSSN database. However, ingestion of marine debris or illness could have resulted in emaciation or buoyancy problems, the stranding cause found for eight turtles.

Eleven turtles were found stranded due to becoming trapped in jetty rocks. Green turtles lodge themselves between rocks for sleeping and may become trapped there by heavy currents or waves. Some of the green turtles that stranded on Texas offshore beaches, but were not linked to a particular stranding source, may have been washed ashore by strong currents and waves. However, this factor was not entered into note codes for any turtles and hence was not quantified during this study. Four hatchlings/post-hatchlings, and a few other turtles that measured from 10.0 to 15.0 cm SLCL, likely stranded on offshore beaches due to tropical storms or strong currents/winds. These turtles normally are pelagic and should not have been found stranded unless swept closer to shore than normal due to rough water conditions. Slightly larger green turtles that were migrating through or recruiting into nearshore waters could also have stranded on offshore beaches due to strong currents and high winds. These turtles may have entered the surf zone to avoid shark predation, but then inadvertently been washed ashore. Turtles found trapped in jetty rocks and washed ashore due to rough water conditions are often located alive and can be saved if found promptly.

Tar and/or oil on the body was identified as the stranding cause for 14 turtles

and, since this is such an easily identifiable condition, it is unlikely that any of the other 309 turtles washed ashore due to this factor. Dredging of navigable waterways caused six turtles to strand. Some other turtles from the 309 may also have stranded from dredging, but during the study period, efforts were made to decrease dredging-related injuries and deaths by the extensive use of pipeline dredges and observers at more injurious hopper dredging operations. One green turtle stranded due to a red tide. It is doubtful that this stranding factor failed to be identified for other affected turtles; STSSN participants were aware when these noticeable, well-publicized red tide events occurred. Although green turtles have possibly been killed by explosions used to remove offshore oil and gas platforms (Thompson, 1988; Renaud et al., 1997), no turtles from this analysis were linked to this stranding source.

Fibropapillomatosis.—No stranding forms noted the presence of tumors on the turtles. Fibropapillomatosis is a major epizootic disease with sub-lethal and lethal effects to a variety of species of sea turtles (George, 1997). This disease has never been documented in green turtles found in Texas. However, it has been documented in green turtles from scattered locations throughout the world (see Hirth, 1997) and is considered a major threat to some green turtle populations (Ehrhart and Redfoot, 1995). The incidence of turtles with fibropapillomatosis has increased rapidly since the 1980s, has varied between years and locations, and has ranged from 0-92% (George, 1997). In the U.S.,

large numbers of green turtles have been found afflicted with this disease in Florida (Smith and Coates, 1938; Guseman and Ehrhart, 1990; Ehrhart and Redfoot, 1995; Schroeder and Foley, 1995; Schmid, 1998; Hiram and Ehrhart, 1999) and Hawaii (Balazs, 1991). However, during studies conducted in some areas of Florida, no turtles with fibropapillomatosis were found (Guseman and Ehrhart, 1990; Redfoot et al., 1996; Schmid, 1998).

Given the size and primary stranding location of green turtles found washed ashore in Texas, it is surprising that fibropapillomatosis was not found in any individuals. Juvenile turtles ranging from 40-90 cm carapace length appear to be most affected by this disease (George, 1997) and 31.1% of the turtles found stranded in Texas were in this size range. It is thought that green turtles frequenting near-shore waters, areas adjacent to large human populations, and areas with low water turnover, such as lagoons, have a higher incidence of fibropapillomatosis than individuals in deeper, more remote waters (Limpus et al., 1994; George, 1997). Most inshore strandings of green turtles in Texas were in the vicinity of shallow water areas and large human populations. Schroeder and Foley (1995) used the incidence of fibropapillomatosis as an indicator of the health status of green turtles. Using this standard, green turtles inhabiting Texas waters would be considered very healthy.

Conclusions.—The population of green turtles in Texas, comprised mostly of juveniles, may currently be re-building and the large number of green turtles

found stranded from 1980-1998 demonstrate the current importance of Texas waters to green turtles. To help ensure recovery of the green turtle population, various sources of mortality must be reduced. STSSN efforts to document stranded turtles, monitor stranding trends, and investigate possible sources of mortality should be continued. Human intervention can help decrease some of the human-related and natural sources of mortality. Attempts should be made to locate cold stunned turtles as soon as water temperatures fall below 10 C. These turtles may represent a substantial proportion of the green turtles occupying Texas inshore waters. Cold stunned green turtles can be rehabilitated and ultimately released if they are detected prior to prolonged exposure to cold temperatures. TED usage, education, and enforcement activities must be continued to aid with protection of green turtles from the impacts of incidental capture in shrimp trawls. Illegal gill netting in south Texas waters must be stopped. Reduction of the amount of debris, fishing gear, and oil discarded into Texas waters would also be beneficial to green turtle survival.

CHAPTER III

GREEN TURTLE NESTING

Introduction

Little is known about green turtle (*Chelonia mydas*) nesting on the Texas coast. Prior to 1987, there had been no confirmed records of green turtle nesting in Texas. In 1889, geologist Robert Penrose reported observing numerous 91-122 cm long turtles laying eggs in south Texas, at the mouth of the Rio Grande, in the sandy river bank shores (Neck, 1978). Neck (1978) thought that these were probably green turtles, but Hildebrand (1982) thought that they were likely Kemp's ridley turtles (*Lepidochelys kempii*). Based on size, it is more likely that these were green turtles rather than smaller Kemp's ridley turtles; 90 green turtles measured while nesting in Florida ranged from 83.2 to 116.7 cm straight-line carapace length (SLCL) (Witherington and Ehrhart, 1989b).

Carr (1967) relayed a report made in 1958 by a man who traveled the South Padre Island, Texas, shore frequently in a beach buggy to fish, who said that once in a while he saw turtle tracks there. It is possible that the tracks were from nesting green turtles, since this species leaves relatively prominent tracks. However, the exact species cannot be discerned from this report since all five sea turtle species that occur in the northwestern Gulf of Mexico have nested on the south Texas coast (Hildebrand, 1963, 1982, 1983; Shaver, 1989, 1999b).

The presence of adult and hatchling green turtles in Texas waters, or

washed ashore (stranded) on Texas beaches, could also provide some indication of nesting on the Texas coast. Green turtles were once commercially exploited in Texas (Witzell, 1994a, 1994b). The turtle fishery began in the mid-1800s, but the catch declined greatly by 1900 and was virtually non-existent when turtle fisheries were outlawed in 1963 (Hildebrand, 1982; Doughty, 1984). It is unknown whether reproductively active turtles were among those that were slaughtered, but the season of capture and large size of turtles caught support the hypothesis that some of the turtles may have been adults. The scattered accounts of the fishery show that turtles were caught primarily from April to November (Hildebrand, 1982), which would coincide with the breeding season for this species in the Western Atlantic Ocean, off North America (Hirth, 1997). In 1890, 249,480 kg of green turtles were harvested from Texas, with an average weight of 113 kg/turtle (Hildebrand, 1983; Doughty, 1984). Adult female green turtles that nested in Florida weighed from 104.3 to 176.8 kg, with a mean of 136.1 kg (Witherington and Ehrhart, 1989b). For the captured turtles to have reached an average weight of 113 kg/turtle, it is likely that some adults were included.

Over two decades ago, Hildebrand (1983) noted that there were virtually no recent records of large green turtles from bays, but that adult males and females were captured infrequently offshore by shrimp boats. Between 1976-1979, a green turtle measuring 88.9 cm was found washed ashore on Mustang Island, Texas, and a hatchling measuring 7.6 cm was found washed ashore on

North Padre Island (Rabalais and Rabalais, 1980). In 1980, the Sea Turtle Stranding and Salvage Network (STSSN) was established to document strandings of marine turtles on United States beaches located along the Gulf of Mexico, Atlantic Ocean, and Caribbean Sea (Schroeder, 1988) and the network has continued to operate since that time.

Little has been written about green turtles nesting on the Texas coast and no attempt has been made to summarize Texas strandings of adult and hatchling green turtles since the inception of the STSSN.

The objective of this study was to identify whether green turtles are using the Texas coast for nesting. Data for this study were accumulated through documentation and investigation of nests and tracks, stranded hatchlings, and stranded adults.

Materials and Methods

Nest and track detection and documentation.—Efforts to detect and protect nesting sea turtles and their eggs on North Padre Island began in 1986 and continued through 1998. From 1986-1998, Padre Island National Seashore (PAIS) staff members and volunteers conducted daytime patrols for nesting turtles and tracks along the entire 128 km Gulf of Mexico shoreline of North Padre Island, including 104 km of PAIS and 24 km north of the PAIS north boundary. Patrols were conducted from about April through July and patrol effort increased over time. From 1986-1994, the entire North Padre Island

target patrol area was covered from 2-5 days each week. From 1995-1997, the entire area was covered 7 days each week. In 1998, the entire area was repeatedly traversed each day. From 1986-1998, North Padre Island was the only area on the Texas coast specifically patrolled to detect sea turtle nesting. However, patrols for stranded turtles were conducted on most Texas Gulf beaches at least once a week throughout the year, and during those patrols, STSSN personnel also looked for nesting sea turtles and their tracks.

Sea turtle tracks and nests found on the Texas coast were identified to species and their locations were documented. Efforts were made to find eggs at all track locations. Locations where eggs were found were considered to be confirmed nests. Locations where tracks but no eggs were found were considered to be confirmed tracks; there was no further differentiation between false crawls (non-nesting emergences) and nesting crawls (crawls resulting from nesting attempts in which eggs were deposited) (Schroeder and Murphy, 1999). All eggs found were counted, and those that were intact were retrieved from the beach, placed into Styrofoam boxes containing sand from the nest site, and transferred to the PAIS incubation facility for protected care. Hatchlings that emerged from these eggs were counted, weighed, measured for SLCL, and released on the beach at PAIS.

Efforts to detect and investigate stranded turtles.—Whistler (1989) described procedures for locating and documenting stranded turtles in Texas. Stranded

turtles were located by STSSN network participants in response to information provided by beach visitors and during systematic surveys conducted on some Gulf of Mexico beaches of the state. Few systematic surveys were conducted prior to 1986. Year-round, systematic surveys to locate stranded turtles were most comprehensive from 1986-1990 and 1995-1998. From 1990-1994, the survey areas and frequency were reduced. Overall, little effort was made to survey the Matagorda Peninsula and inshore (bay and pass) areas.

For each stranded turtle found, information was collected on species, stranding date, and stranding location. SLCL and curved carapace length (CCL) of many of the turtles were measured. General necropsies, similar to those described by Wolke and George (1981), were performed on some of the dead turtles and, during necropsy, the sex of the turtle was determined by visual examination of the gonads. Tail length was used to identify the sex of some adult turtles that were not necropsied. Information was recorded on standardized forms that were forwarded to the state and subsequently to the national STSSN coordinators.

The Texas STSSN database was queried for records of hatchling and adult green turtles found stranded in Texas from 1980-1998. For turtles with only CCL measurements, the conversion factor of Teas (1993) was used to convert CCL to SLCL. Turtles were classified as "hatchlings" when they were less than 10.0 cm SLCL and as "adults" when they exceeded 83.2 cm SLCL, the minimum size of nesting females measured by Witherington and Ehrhart (1989b).

Results

Six confirmed green turtle nests were located on the Texas coast from 1987 through 1998 (Fig. 6; Table 3). One was found in 1987 and five in 1998. All six were found at Padre Island National Seashore. All were located by tracks and the nesting females were not observed. A fishing guide who attended PAIS nesting training sessions found one of the nest sites and PAIS patrollers found the others. Clutch size for the six nests ranged from 2 to 128 eggs (Table 3). From the 513 eggs that were located intact, 437 eggs (85.2%) hatched. Since no hatchlings died prior to release, hatching success (the number of hatchlings that hatched out of their egg shells) and emergence success (the number of hatchlings that were released) (Miller, 1999) were identical for these clutches. The 437 hatchlings ranged from 4.646-5.670 cm SLCL (Table 4). All 437 hatchlings were released on the beach at PAIS and entered the Gulf of Mexico. However, one individual was recaptured in the surf and retained for rehabilitation, but later died.

Also located on the Texas coast from 1987 through 1998 were five green turtle tracks at which no eggs were found (Fig. 6; Table 3). All of these tracks were found at PAIS by turtle patrollers.

Four hatchling and seven adult green turtles were found stranded on the south Texas coast from 1980 through 1998 (Table 5). The hatchlings were found in south Texas, at North Padre, South Padre, and Mustang islands, and the adults were located throughout the State. Sex of three of the adults was

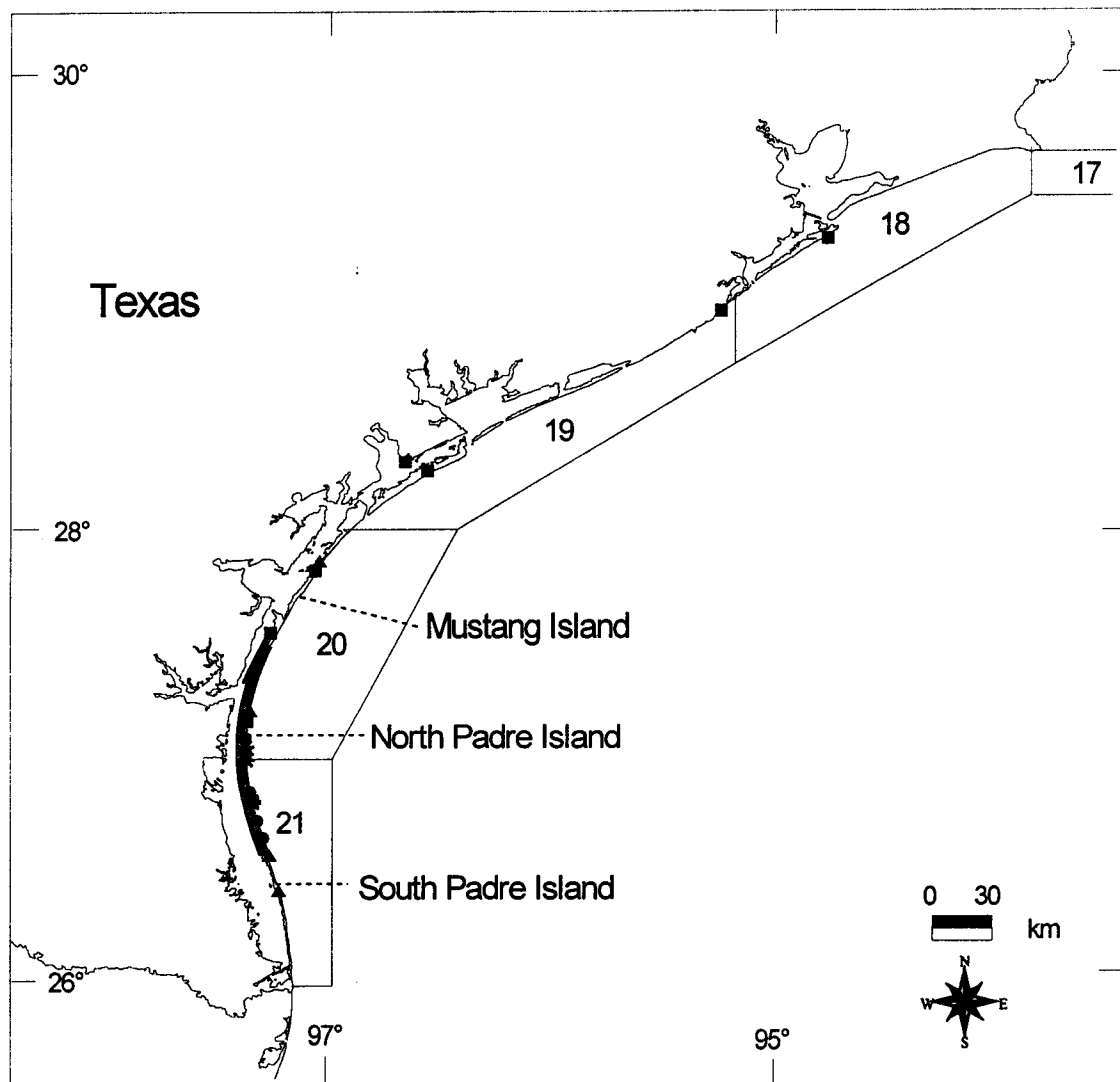


Fig. 6. Locations on the Texas coast where *Chelonia mydas* nests and other possible nesting-related observations were documented from 1980 to 1998. ● = confirmed nests (n=6), * = tracks (n=5), ■ = stranded adults (n=7), and ▲ = stranded hatchlings (n=4). Padre Island National Seashore is shown as the gray shaded area on North Padre Island.

Table 3. Confirmed *Chelonia mydas* nests and tracks located on the Texas coast from 1987 to 1998. Locations are listed as kilometer markers at Padre Island National Seashore, Texas.

Clutch number	Location	Type	Date found	Number of eggs ^a	Percent hatched	Number of
						hatchlings released
1987-21	68.2 km	nest	13 July 1987	2	50.0	0
-	68.7 km	tracks	12 July 1989	-	-	-
-	41.8 km	tracks	11 July 1990	-	-	-
-	48.3 km	tracks	14 July 1992	-	-	-
1998-12	37.5 km	nest	3 June 1998	114	93.0	106
1998-13	87.7 km	nest	7 June 1998	108	70.4	76
1998-15	78.8 km	nest	10 June 1998	70	68.6	48
-	45.5 km	tracks	30 June 1998	-	-	-
-	69.7 km	tracks	4 July 1998	-	-	-
1998-20	64.4 km	nest	18 July 1998	91	95.6	87
1998-21	67.6 km	nest	18 July 1998	128	93.0	119

^a One egg from clutch 1998-12 was broken and not included in totals.

Table 4. Straight-line carapace lengths (SLCL) and weights of *Chelonia mydas* hatchlings that emerged from nests detected along the Texas coast from 1987 to 1998 and incubated at the Padre Island National Seashore incubation facility.

Clutch		SLCL (cm)			Weight (g)		
number	n	Range	$\bar{x}$ (SE)	Median	Range	$\bar{x}$ (SE)	Median
1987-21	1	5.430	-	-	28.86	-	-
1998-12	106	4.646-5.480	5.203(.014)	5.235	22.25-28.33	26.07(.12)	26.31
1998-13	76	4.745-5.516	5.149(.020)	5.152	23.53-31.15	27.50(.18)	27.75
1998-15	48	4.691-5.261	4.995(.025)	5.002	22.80-31.87	28.22(.28)	28.58
1998-20	87	4.922-5.410	5.191(.011)	5.197	24.27-27.87	26.42(.08)	26.35
1998-21	119	5.252-5.670	5.474(.008)	5.476	28.76-32.27	30.38(.07)	30.42

Table 5. *Chelonia mydas* that measured less than 10.0 cm straight-line carapace length (SLCL) or greater than 85.0 cm SLCL and were located stranded along the Texas coast from 1980 to 1998.

Turtle number	Date	SLCL (cm)	Reliability observer	Sex
			placed on species identification	(method identified)
1	2 May 1980	4.0	Positive	Unknown
2	12 June 1980	85.9	Positive	Unknown
3	9 Sept. 1980	5.8	Positive	Unknown
4	26 June 1982	97.8	Probable	Male (tail length)
5	14 Sept. 1984	5.8	Positive	Unknown
6	16 May 1985	85.6	Positive	Female (tail length)
7	21 July 1987	91.5	Positive	Unknown
8	29 Aug. 1989	98.5	Positive	Male (tail length)
9	31 Aug. 1989	99.2	Positive	Unknown
10	15 Aug. 1996	86.0	Positive	Female (necropsy)
11	6 Sept. 1998	7.0	Probable	Unknown

identified by tail length and of one of the adults by necropsy (Table 5). Two were males and two were females. Only one of the seven adults was necropsied, and this adult female did not contain eggs.

Discussion

Six confirmed green turtle nests were located on the Texas coast through 1998. These six provide a minimum estimate of the number of green turtle nests that were deposited on the Texas coast and it is likely that additional nesting occurred but went undocumented both historically and recently.

The nest located in 1987 was the first confirmed green turtle nest for the Texas coast (Shaver, 1989), although historic nesting has been suspected (Neck, 1978) and probably occurred. By 1900, the green turtle population in Texas had been reduced dramatically, as evidenced by the collapse of the green turtle fishing industry. This population decline could have also virtually eliminated nesting by this species on Texas shores before accurate accounts of nesting could be gathered. Numerous American rookeries have been totally destroyed due to human over-harvest of eggs and/or turtles (Bustard, 1972).

All confirmed green turtle tracks and nests located on the Texas coast through 1998 were found on North Padre Island at PAIS. Before PAIS was established in 1962, human visitation there was minimal due to difficult access and use of the area as a privately owned cattle ranch and a military bombing range. Even after visitation to PAIS increased, green turtle nests could have

been missed because green turtles nest at night, when visitation is reduced, and biologists were looking for sea turtle nests until 1986. Tracks left on the beach by the nesting females may not have been identifiable to beach visitors; none of the confirmed tracks and nests located on the Texas coast were initially found by general beach visitors. Even after North Padre Island patrols were initiated in 1986, tracks and nests could have been missed because patrol effort and nest detection proficiency were limited before 1995. Also, North Padre Island patrols were designed to detect nesting by Kemp's ridley turtles and hence the patrols usually ended before the termination of the green turtle nesting season. Nests also could have gone undetected on other Texas beaches that were not patrolled.

The most nests documented on the Texas coast in a single year was five, found in 1998. These five clutches could have been from a minimum of two different females to a maximum of four different females; at least two different turtles had to have laid the clutches since two were found on the same day. The documentation of five nests in 1998, and virtually no confirmed Texas nests prior to that time, could have been related to the increased nesting patrol effort and nest detection proficiency on North Padre Island after 1995. Some of the five track sites where no eggs were found could have been nest locations; relatively inexperienced personnel may have missed finding the egg chambers, particularly before 1995. Because green turtles often nest at 2-3 year intervals and nesting numbers fluctuate tremendously from year to year (see Hirth,

1997), there likely would have only been one or two peak nesting years between 1995 and 1998. It is also possible that the relatively large number found in 1998 was an anomaly.

Alternatively, the increase in the number of detected nests could be the result of increased nesting in the area. Green turtle nesting has increased dramatically both at Rancho Nuevo, Mexico (R. Marquez, pers. comm.) and in Florida (Owen et al., 1994; Meylan et al., 1995) during recent years.

If indeed the numbers of green turtles nesting on the Texas coast is increasing, it is remotely possible that this is the result of Operation Green Turtle. From 1959 through 1968, over 130,000 green turtle hatchlings and eggs from Tortuguero, Costa Rica, were shipped to 17 countries throughout the Greater Caribbean, in an attempt to re-establish extirpated green turtle nesting populations throughout the region (Carr, 1967; Owens et al., 1982; Eliazar et al., 1998). Some of the hatchlings were released off the south Texas coast. Since green turtles require 20-50 years to reach maturity (see Hirth, 1997), individuals that survived from this project could have reached sexual maturity as early as 1989. Although there has been no known nesting from this project (Eliazar et al., 1998), the turtles were not tagged and hence could not be identified if they nested (Owens et al., 1982). It is possible, but not very likely that turtles from this project are among those that nested on the Texas coast. Relatively few hatchlings were released off the Texas coast and hatchlings are thought to have a low survivorship rate. Additionally, since the hatchlings were

released after their swim frenzy, their survivorship and imprinting mechanisms may have been impaired (Eliazar et al., 1998). Genetic evidence supports the hypothesis that green turtles return to their natal beach to nest (Bowen et al., 1992; Allard et al., 1994; Bowen and Karl, 1997), possibly through natal homing or imprinting. However, Kemp's ridleys experimentally imprinted to PAIS were the first and only sea turtles confirmed to have nested outside of captivity at a site that they were transplanted to as eggs or hatchlings (Shaver, 1996).

Information regarding nesting can sometimes be inferred from examination of stranded adults and hatchlings. Reproductively active adults and hatchlings that emerged from nests could be injured or killed and subsequently wash ashore. However, such records do not prove Texas nesting since the adults could have been in Texas waters for foraging or migration and the hatchlings could have emerged from nests in Mexico and drifted northward with prevailing currents.

Seven stranded green turtles found between 1980 and 1998 were classified as adults because they exceeded the minimum size of nesting turtles. However, some of these individuals may not have been sexually mature animals. Musick and Limpus (1997) suggested that turtles be considered adults when they exceeded the minimum breeding size, but could not be assessed for maturity via direct examination of gonads or from past breeding history. However, size is often a poor predictor of maturity (Carr and Goodman, 1970; Limpus et al., 1994; Miller, 1997; Musick and Limpus, 1997). Only one of the

seven adult-sized turtles was necropsied, but her maturity was not determined since she did not contain eggs and her gonads were not closely examined for follicle development. Even if the seven turtles were sexually mature, they could have been in Texas waters for foraging or migration rather than for breeding. Although these seven individuals were found during the green turtle breeding season, they were distributed throughout the state and not clustered in south Texas where the six confirmed nests were found. Thus, these seven individuals provide little insight into nesting on the Texas coast.

Two of the four hatchlings documented stranded in south Texas from 1980-1998 may have originated from nests that went undetected on the Texas coast. Turtles #3 and #5 (Table 5) were within the size range of green turtles hatched at PAIS (Table 4) and were located in September, a month during which many of the green turtles hatched at PAIS were released. Additionally, these two individuals were found at PAIS during 1980 and 1984, a few years before PAIS nesting patrols began. However, the other two hatchlings were probably not from undetected green turtle nests. Turtle #1 (Table 5) was smaller than green turtles hatched at PAIS and found earlier in the year than all confirmed green turtle nests located there. Based upon size and stranding date, it is likely that this hatchling was a misidentified Kemp's ridley. Turtle #11 (Table 5) likely emerged from a nest in Mexico since it was larger than all green turtles hatched at PAIS, located just north of the U.S./ Mexico border, and found during a time when prevailing currents could have pushed it northward from Mexico.

The green turtle was once so abundant on the Texas coast that it supported a commercial fishing and processing industry. Unfortunately, historic nesting levels in Texas will likely never be known. However, data on green turtle nesting during 1998 can provide a good baseline for future comparisons. Additional years of data collection are needed to determine the extent and trends of green turtle nesting in Texas. To help conserve and restore green turtles to their former prominence on Texas coast, patrols to detect and protect green turtle nests should be continued on North Padre Island. If nests are found at other locations in Texas, it would also be beneficial to initiate systematic detection and protection efforts there.

CHAPTER IV

NETTED GREEN TURTLES

Introduction

Most studies of sea turtle populations have been conducted at nesting beaches, but the number of research projects involving capture of turtles in the marine environment has increased during the last decade (Bjorndal and Bolten, 1998; Epperly, 1998). Information gathered during these in-water studies can increase understanding of sea turtle biology, particularly for poorly known juveniles. Such information is needed for comprehensive management of sea turtle populations (Bjorndal, 1999). However, most of the in-water studies conducted to date have employed protocols that seriously limit scientists' ability to use the collected data to compare between studies and discern long-term trends. Limiting methodological parameters include (1) short-term data collection; (2) data collection for only a portion of the year; (3) varying amounts of effort and/or failure to calculate catch-per-unit-effort (CPUE) indices; (4) data collection at different sampling sites that are reported in aggregate; and (5) variations in method of capture (turtle rodeo, encirclement nets, entanglement nets, etc.) that are reported in aggregate.

Green turtles (*Chelonia mydas*) were once so abundant in Texas that they were commercially harvested, but the population became severely depleted by 1900 (Hildebrand, 1982; Doughty, 1984). Most recent records of green turtles

in Texas are of juveniles (Rabalais and Rabalais, 1980; Hildebrand, 1982, 1983; Shaver, 1990a, 1994; Coyne, 1994; Renaud et al., 1995; Arms, 1996) and south Texas bays, passes, and jetty areas may serve as important developmental, foraging, and resting habitats for juvenile green turtles (Coyne, 1994; Shaver, 1994; Goodman et al., 1996). Juvenile green turtles enter developmental habitats which (1) contain only immature individuals; (2) are usually found inshore or nearshore; (3) are entered and departed at regular sizes; and (4) likely include a mixture of turtles from different nesting populations (Meylan and Meylan, 1998). Developmental habitats are important to the survivorship of juvenile sea turtles and require adequate study and protection (Zug and Glor, 1998; Bjorndal, 1999).

Little quantitative information is available on seasonal and yearly trends, residency times, sizes, and sex ratios of green turtles in Texas. Only two short-term, directed capture studies targeted at green turtles have been conducted in Texas. Coyne (1994) used encirclement and entanglement nets during a 2-year long investigation in the Lower Laguna Madre and Brazos Santiago Pass. Shaver (1994) reported results of the first 4.5 years of entanglement netting at the Mansfield Channel, which are included in the present study. This study was undertaken to test the hypothesis that the Mansfield Channel is a developmental habitat. During an 8.5-year long, year-round, directed capture study conducted at the Mansfield Channel, data were gathered on the seasonal and yearly variations in CPUE, residency times, and sizes of green turtles.

Materials and Methods

Study area.—The Laguna Madre is a hypersaline marine estuary that lies on the margin of the Gulf of Mexico between Padre Island and the mainland of south Texas. It extends from the southern edge of Corpus Christi Bay to the lower tip of Texas (Fig. 7) (Breuer, 1962; Weise and White, 1980; Shew et al., 1981; Armstrong, 1987; Quammen and Onuf, 1993). The length of the estuary is 200 km, maximum width is 16.1 km, and average depth is 1.2 m. Circulation of seawater into and out of the Laguna Madre is highly restricted and the only direct water exchange passages to the Gulf of Mexico occur at the Mansfield Channel and Brazos Santiago Pass (Fig. 7). Although the Aransas Pass provides a connection between the Gulf of Mexico and Corpus Christi Bay, water exchange between Corpus Christi Bay and the Laguna Madre is limited (Shew et al., 1981). The Laguna Madre is divided into two hydrogeographic regimes, the Upper Laguna Madre (307 km²) and the Lower Laguna Madre (691 km²), by a large expanse of sand and mudflats almost midway between the northern and southern ends. Several seagrass and algae species are present within the Laguna Madre (Shew et al., 1981; Armstrong, 1987).

The Mansfield Channel is 15.2 km long (east-west orientation), 91.4 m wide (north-south), and 4.9 m deep. It cuts through Padre Island and the Lower Laguna Madre to the mainland of Texas and is maintained through dredging by the U.S. Army Corps of Engineers. A pair of 700 m long jetties armor the Gulf of Mexico entrance to the channel (Kieslich, 1977). The submerged portions of

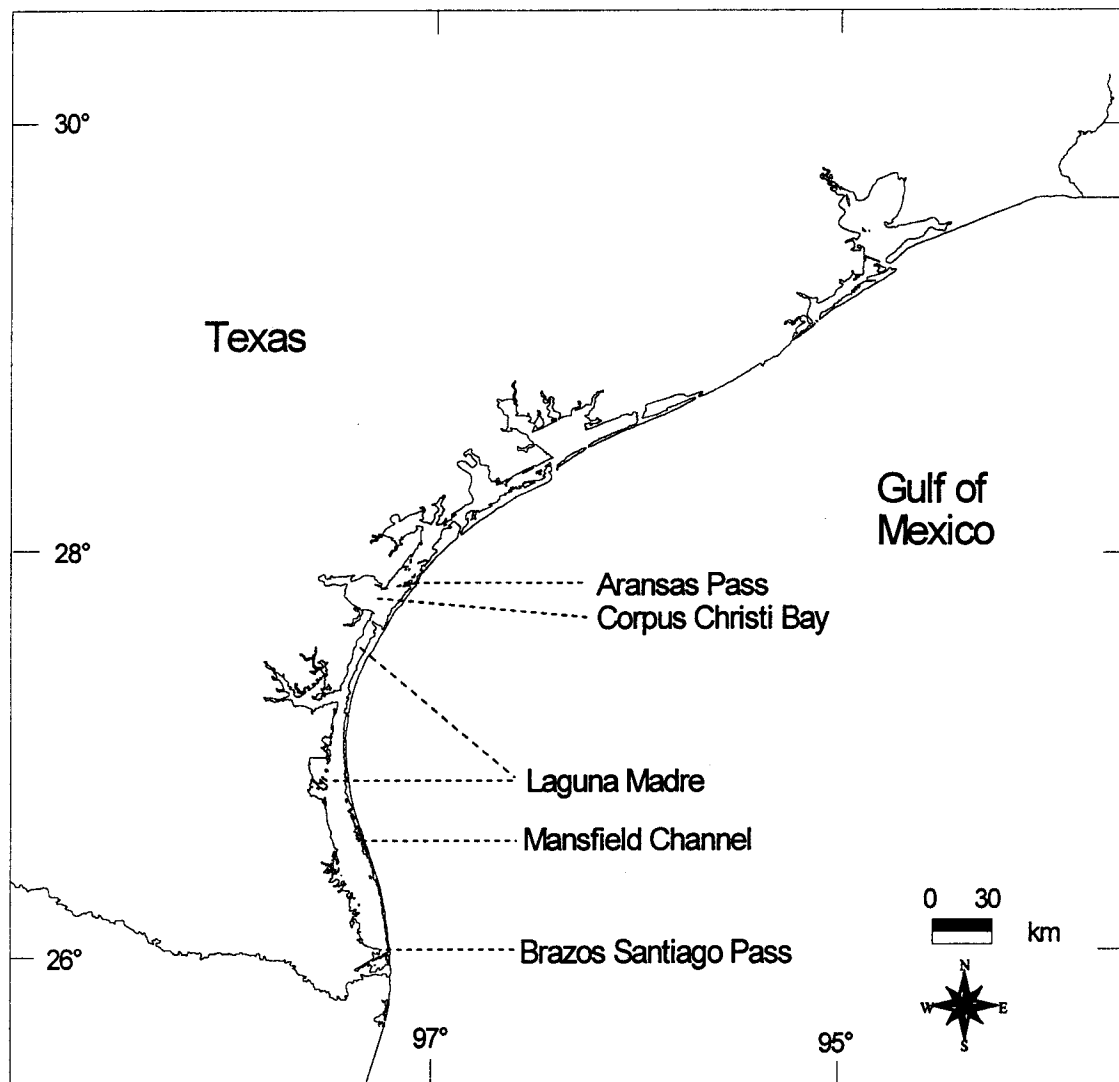


Fig. 7. Map of the Texas coast showing the location of the Mansfield Channel and Laguna Madre.

the jetties are densely covered with several species of algae (Kaldy et al., 1995). The channel and jetties are man-made and were constructed between 1957 and 1965 (Kieslich, 1977). The sampling location for this study was at the base of the north jetty (26°33'50"N, 97°16'45"W).

Netting and tagging.—Green turtles were captured with an entanglement net (91.4 m long, 2.4 m deep, 25 cm stretch mesh) that was set in approximately 1.5 m water depth at the Mansfield Channel jetties. Slack was left in the net so that turtles could become entangled in loose webbing (Ehrhart and Ogren, 1999). The net was placed parallel to the base of the north jetty and extended west from the tip of a wing jetty, cutting off most access into and out of a protected cove area. It was set at dawn and retrieved one hour prior to dusk, or earlier if inclement weather conditions developed. Netting was conducted during daylight hours to encompass the time when juvenile green turtles are most active (Bjorndal, 1980; Mendonca, 1983; Ogden et al., 1983; Renaud et al., 1994a; Arms, 1996). The entanglement net was deployed for a total of 1149 h from June 1989 to December 1997. Netting was conducted year-round, on 1 day per month (at least 5 h/day) except during (1) November 1990, when netting was not done; (2) November 1996, when netting was limited to only 45 min; and (3) 10 months when netting was undertaken on 2-3 days per month. Overall, the number of hours netted per month ranged from 0.0-33.2 h ($\bar{x} = 11.2 \pm 4.2$ h, $n = 103$). The median number of hours netted/year did not differ among study



years (Kruskal Wallis one way analysis of variance on ranks, $H = 8.151$, $df = 8$, $P = 0.419$).

During sampling, the net was examined every 30 to 45 min and captured organisms were removed. Captured turtles were transported to a temporary holding site located on the beach, approximately 150 m from the net location. Turtles were placed into pools containing approximately 12 cm of seawater. During summer months, a shade structure was erected over the pools to prevent overheating of the turtles.

Immediately after arrival at the temporary holding site, an attempt was made to collect a blood sample from the cervical sinus of most turtles (Owens and Ruiz, 1980; Owens, 1982, 1999). Blood samples were collected using vacutainers and needles that were 3.8 cm long, 21 gauge or 2.5 cm long, 22 gauge. Samples never exceeded 0.06% of the total body weight, the maximum that can be safely collected from a healthy turtle (Jacobson and Bolten, 1996). Samples were spun in a centrifuge for 5 min to separate the serum and plasma. Separated samples were placed on ice and frozen within 24 h. Sex of netted turtles was determined using serum testosterone radioimmunoassays (Owens et al., 1978; Wibbels et al., 1987, 1989, 1991; Wibbels, 1988, 1999; Valverde, 1996; Owens, 1982, 1997). Turtles with testosterone titers less than 10 picograms/ml (pg/ml) were classified as "females", greater than 20 pg/ml as "males", and between 10 and 20 pg/ml as "unknown" (Bolten et al., 1992). Turtles were also classified as unknown if they were sampled during more than

one month and all of their samples were not consistently classified as male or female.

Carapace lengths and widths of each captured turtle were measured to the nearest 0.1 cm. Straight-line carapace length (SLCL) and curved carapace length (CCL) were measured from the anterior point of midline (nuchal notch) to the posterior end of the posterior marginal. Straight-line carapace width (SLCW) and curved carapace width (CCW) were measured at the widest point. Straight measurements were obtained using calipers and curved measurements using a flexible tape measure (Bolten, 1999). Weight (WT) was measured with a spring scale to the nearest 0.2 kg. To avoid individual differences in measurement technique (Bjorndal and Bolten, 1988; Boulon and Frazer, 1990; Frazer, 1998), size and weight measurements were made by one individual whenever possible.

Each captured turtle was examined for the presence of tags and tag scars. Most turtles received inconel #681 tags on either both front flippers or a front and a rear flipper (Balazs, 1999). However, a few turtles were marked with only one inconel tag (on a front flipper) or an inconel tag and Jumbo-Roto plastic tag (Appendix II). Each turtle captured between March 1995 and December 1997 was also marked with a Passive Integrated Transponder (PIT) tag. The few turtles that were too small for #681 inconel tags received PIT tags (Appendix II).

Each turtle was photographed and examined for distinctive physical attributes such as missing flippers, unusual scute counts, and wounds. After

analysis of variance on ranks test, followed by an all pairwise multiple comparison test (Dunn's method), to determine which year(s) were significantly different. The same procedure was used to compare SLCL for each season and for each year. For these analyses, the SLCL for an individual was only included once for each season and once for each calendar year that it was captured and the measurement used was the one obtained the first time that it was captured during that season and during that year. Spearman rank order correlations were used to determine whether there were first-order autocorrelations between CPUE by year and year – 1 and between mean SLCL by year and year – 1. Linear regression was used to determine if there were significant linear relationships between (1) study year and yearly CPUE; (2) study year and yearly mean SLCL; and (3) yearly CPUE and yearly mean SLCL.

Results

CPUE and environmental variables.—Two hundred fifty-eight green turtles ($n = 383$ captures) were netted in the Mansfield Channel during 1149 h of effort (3.63 turtles/km-h) from June 1989 through December 1997 (Fig. 8).

Monthly water temperatures recorded at the study site ranged from 9.5–31.5 C ($\bar{x} = 23.1 \pm 5.3$ C, $n = 102$) and monthly salinities from 20.0–42.0 ppt ($\bar{x} = 33.9 \pm 3.9$ ppt, $n = 102$). Water temperatures (Fig. 9) and salinities were lowest in the winter.

Green turtles were caught at the Mansfield Channel during all months of the

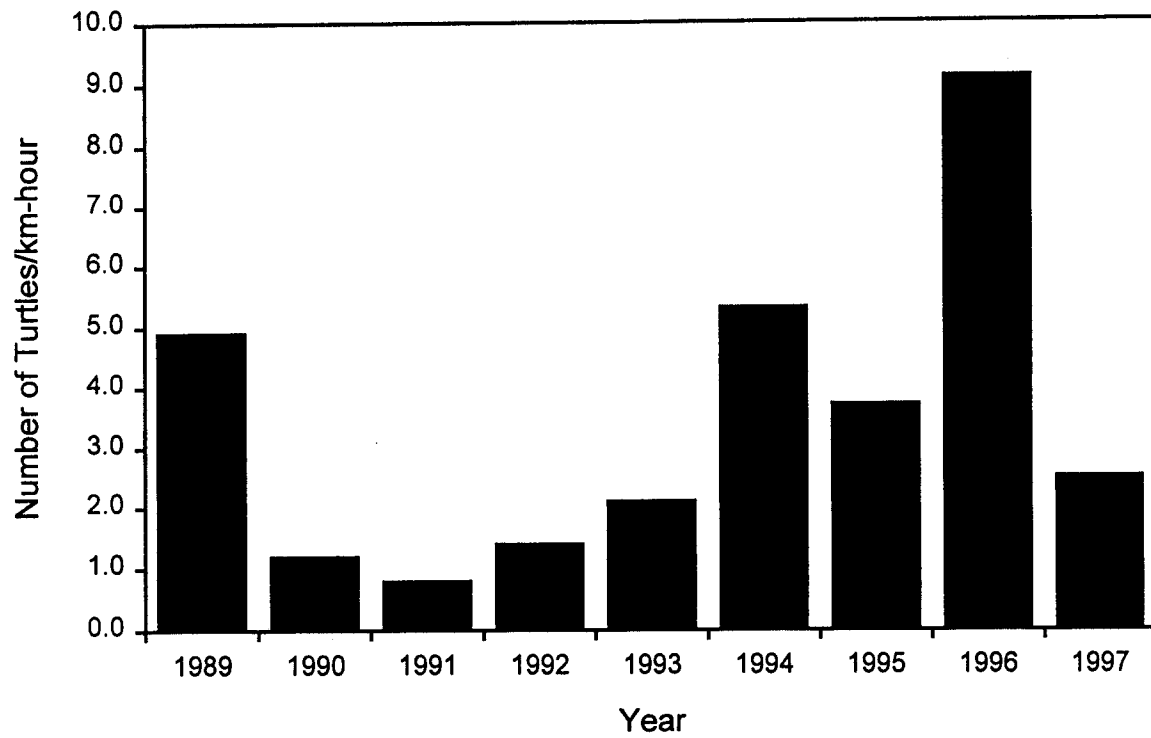


Fig. 8. Yearly numbers of *Chelonia mydas* caught per km-h at the Mansfield Channel jetties from June 1989 to December 1997 ($n = 383$ captures of 258 individuals).

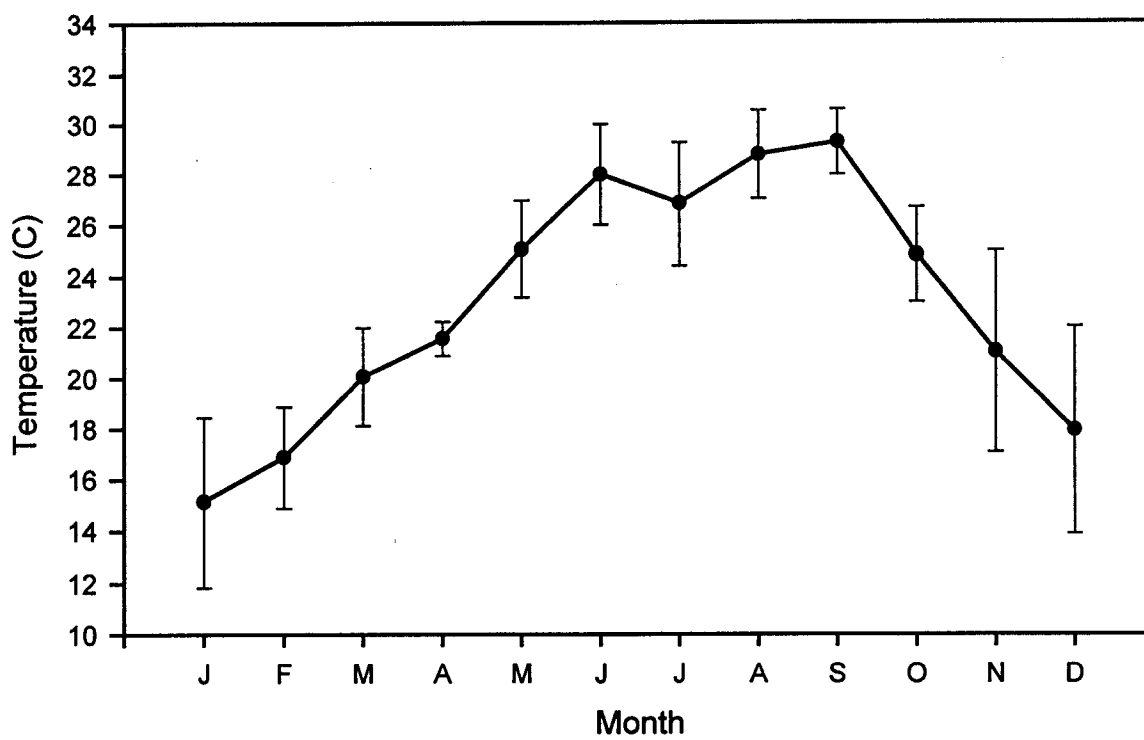


Fig. 9. Mean monthly water temperatures ($\pm$ SD) at the Mansfield Channel jetties from June 1989 to December 1997.

year except January (Fig. 10). Although CPUE was positively correlated with water temperature ($r = 0.527$, $n = 102$, $P < 0.0001$) and water salinity ($r = 0.257$, $n = 102$, $P = 0.0094$), an intercorrelation was found among these two environmental parameters ($r = 0.456$, $n = 102$, $P < 0.0001$). No turtles were caught when mean water temperatures were below 15.5 C.

Recapture rates and size.—Two hundred fifty-eight individual green turtles were captured. All were juveniles and none showed any evidence of fibropapillomatosis (George, 1997). Seventy-three of the 258 (28.3%) were recaptured during netting, for a total of 383 green turtle captures from 1989-1997. One hundred eighty-five of the 258 were caught only once, 46 were caught twice, 16 were caught three times, three were caught four times, three were caught five times, four were caught six times, and one was caught seven times. The recapture rate was 32.6%. The mean interval between the first and last capture of the 73 recaptured individuals was 185 ± 200 days (range = 11-963 days). Twenty-nine of the 73 turtles that were recaptured were caught during two or more calendar years, but only 10 of the 73 were last recaptured more than one year after initial capture (Fig. 11).

The percent of turtles initially captured within a particular season and subsequently recaptured varied throughout the year. Only 25 of 139 turtles (18.0%) initially captured between September and February were ever recaptured, but 48 of 119 turtles (40.3%) initially captured between March and

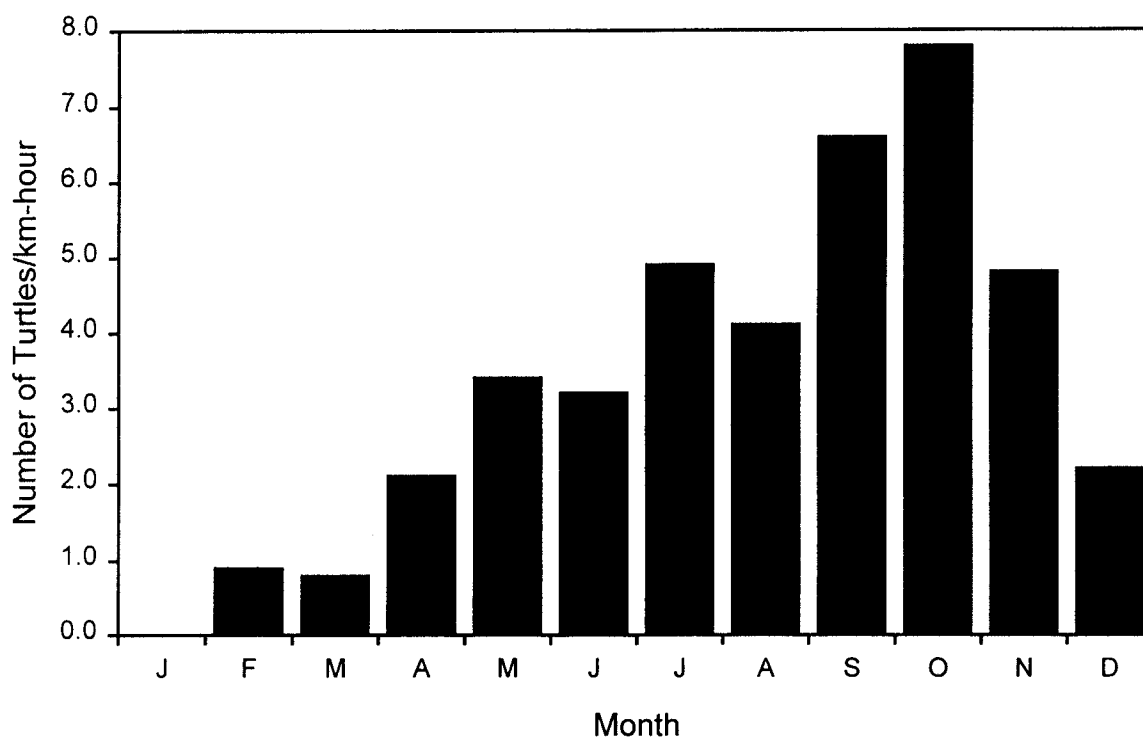


Fig. 10. Monthly numbers of *Chelonia mydas* caught per km-h at the Mansfield Channel jetties from June 1989 to December 1997 (n = 383 captures of 258 individuals).

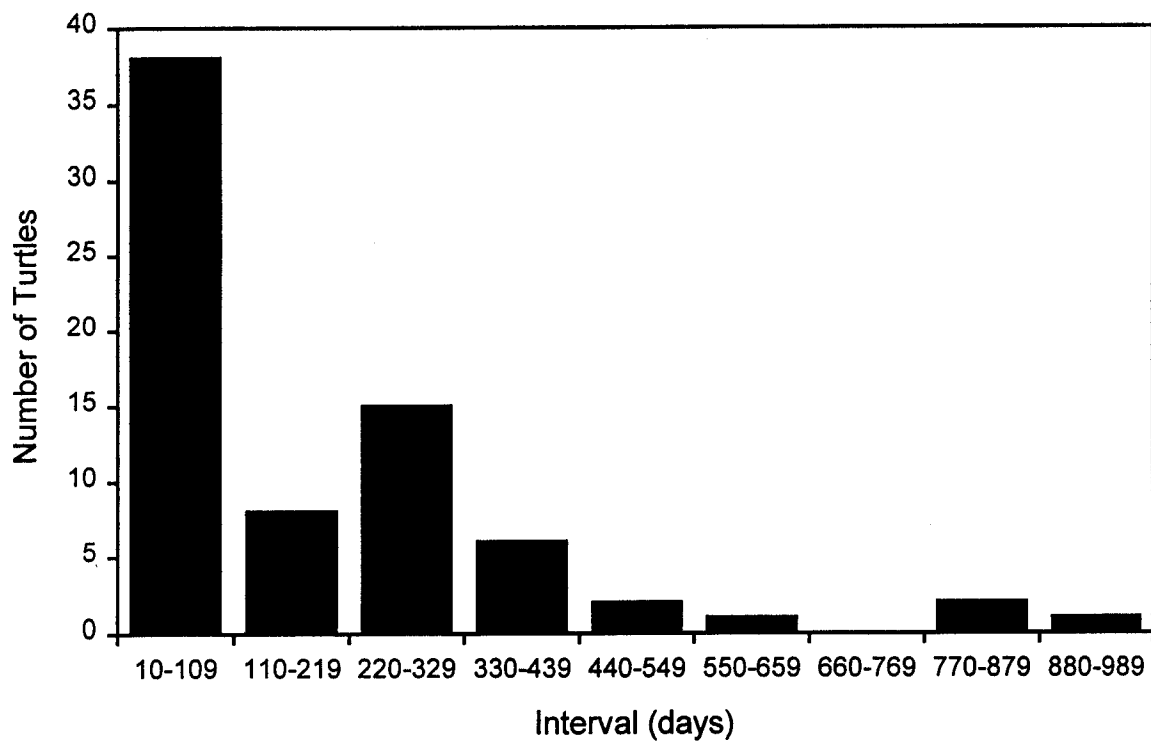


Fig. 11. Number of days from the first to last capture of 73 *Chelonia mydas* netted and recaptured at the Mansfield Channel jetties from June 1989 to December 1997.

August were subsequently recaptured.

Initial capture SLCL ranged from 24.7 to 52.0 cm ($\bar{x} = 32.4 \pm 4.5$ cm, $n = 258$) (Fig. 12), SLCW ranged from 19.7 to 41.5 cm ($\bar{x} = 26.3 \pm 3.7$ cm, $n = 258$), and WT ranged from 2.0 to 20.0 kg ($\bar{x} = 4.9 \pm 2.3$ kg, $n = 258$). Two hundred forty-two of the 258 turtles (93.8%) measured less than 40.0 cm SLCL at initial capture (Fig. 12).

Sex ratio.—Blood samples were obtained from 177 individuals ($n = 230$ samples). Testosterone titers of samples classified as females ranged from 0.61-9.75 pg/ml ($\bar{x} = 3.73 \pm 2.13$ pg/ml, $n = 175$), as males from 20.50-242.00 pg/ml ($\bar{x} = 53.03 \pm 42.52$ pg/ml, $n = 38$), and as unknown from 10.20-19.10 pg/ml ($\bar{x} = 14.18 \pm 2.73$ pg/ml, $n = 17$). There was not a bi-modal distribution of testosterone titers (Fig. 13). Median testosterone titers did not vary seasonally ($H = 7.479$, $df = 3$, $P = 0.058$). Thirty-five of the 177 individuals were sampled on more than one date; of those 35, all samples were consistently classified as female for 25 and as male for five. One turtle classified as a female was independently verified to be a female based upon a necropsy performed after it was located stranded. Of the 177 individuals, 129 were females, 31 were males, and 17 were unknown. The resulting sex ratio of 4.16F:1.0M was significantly different from a 1:1 ratio (chi-square = 60.025, $df = 1$, $P < 0.05$).

In an attempt to validate radioimmunoassay results, the sex ratio data were analyzed by considering sizes of the turtles and seasons when the samples

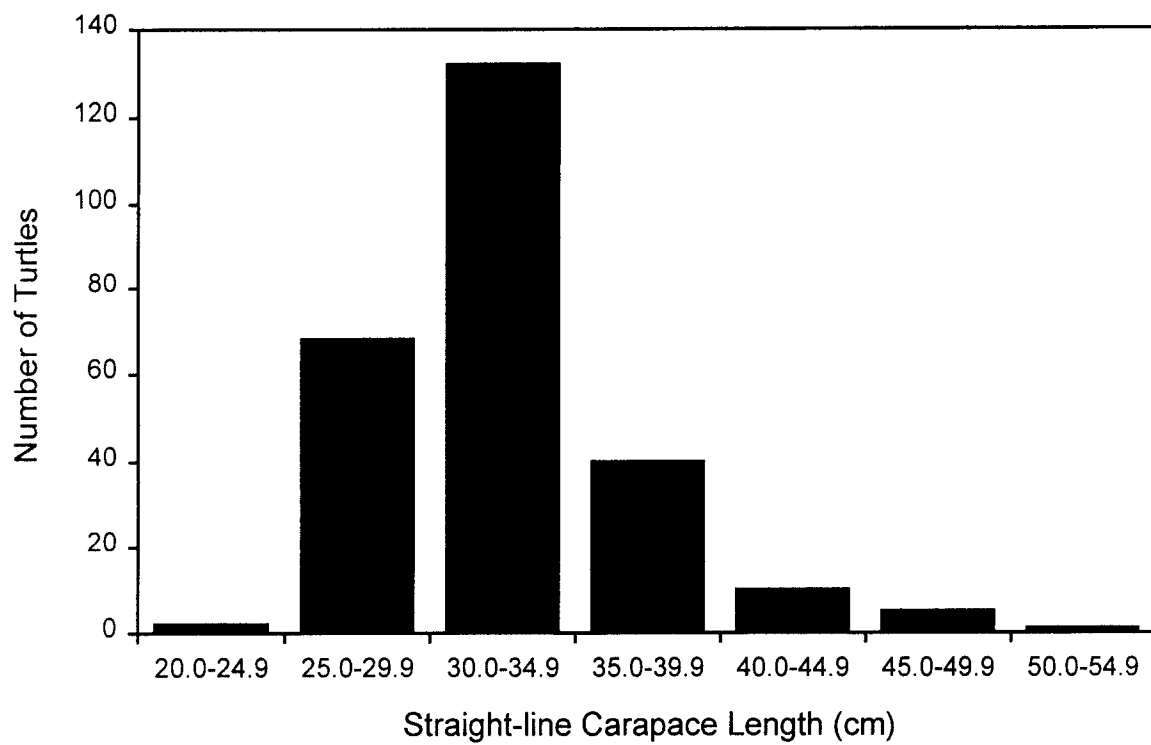


Fig. 12. Initial capture straight-line carapace lengths of 258 *Chelonia mydas* netted at the Mansfield Channel jetties from June 1989 to December 1997.

were taken (Gregory, 1996; Wibbels, 1999). Most of the blood samples analyzed were collected during the spring, summer, and fall and during 1994, 1995, and 1996. The sex ratio was female dominated and significantly different from a 1:1 ratio in those 3 seasons (in all cases: chi-square > 13.333, df = 1, $P < 0.05$) and in those 3 years (in all cases: chi-square > 4.628, df = 1, $P < 0.05$). Median SLCLs of females, males, and unknown sex turtles did not differ ($H = 1.434$, df = 2, $P = 0.488$). Although there was considerable variation in testosterone titers (Fig. 13, 14), there was no significant correlation between SLCL and testosterone titers for samples identified as females ($r = 0.014$, $n = 175$, $P = 0.850$) and males ($r = -0.023$, $n = 38$, $P = 0.888$). The sex ratio continued to be female dominated when criteria were hypothetically shifted downward so that turtles were classified as females at less than 5 pg/ml and unknown at between 5 and 20 pg/ml (3.00F:1.00M) and when samples obtained at water temperatures below 22 C were eliminated (4.14F:1.00M).

Variations in CPUE and SLCL.—Yearly CPUE was inversely correlated with yearly mean SLCL ($r^2 = 0.569$, $n = 9$, $P = 0.019$). The equation of the regression line is the following: $CPUE = 40.126 - (1.078 * SLCL)$. No significant first-order autocorrelation was found between CPUE by year and year - 1 ($r = 0.405$, $n = 8$, $P = 0.290$) and between SLCL by year and year - 1 ($r = 0.119$, $n = 8$, $P = 0.749$). Linear models were not useful to describe the relationship between year and yearly CPUE ($r^2 = 0.167$, $n = 9$, $P = 0.275$) and

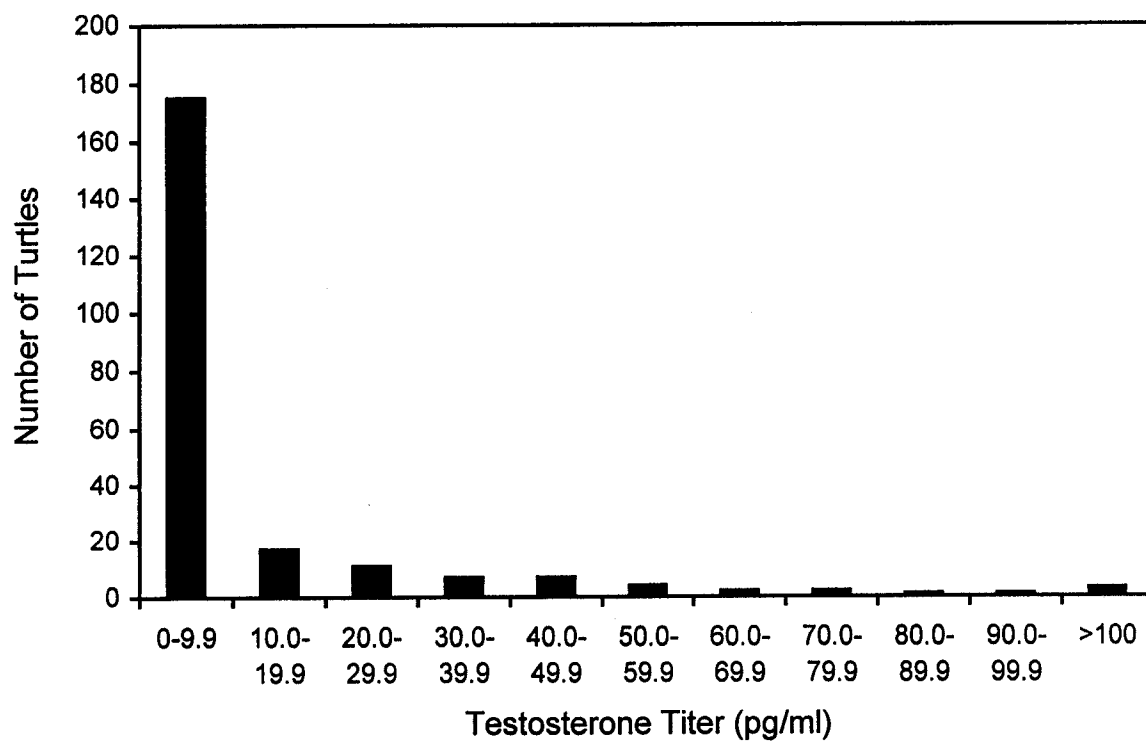


Fig. 13. Testosterone titers for 177 *Chelonia mydas* netted (n = 230 samples) at the Mansfield Channel jetties from June 1989 to December 1997.

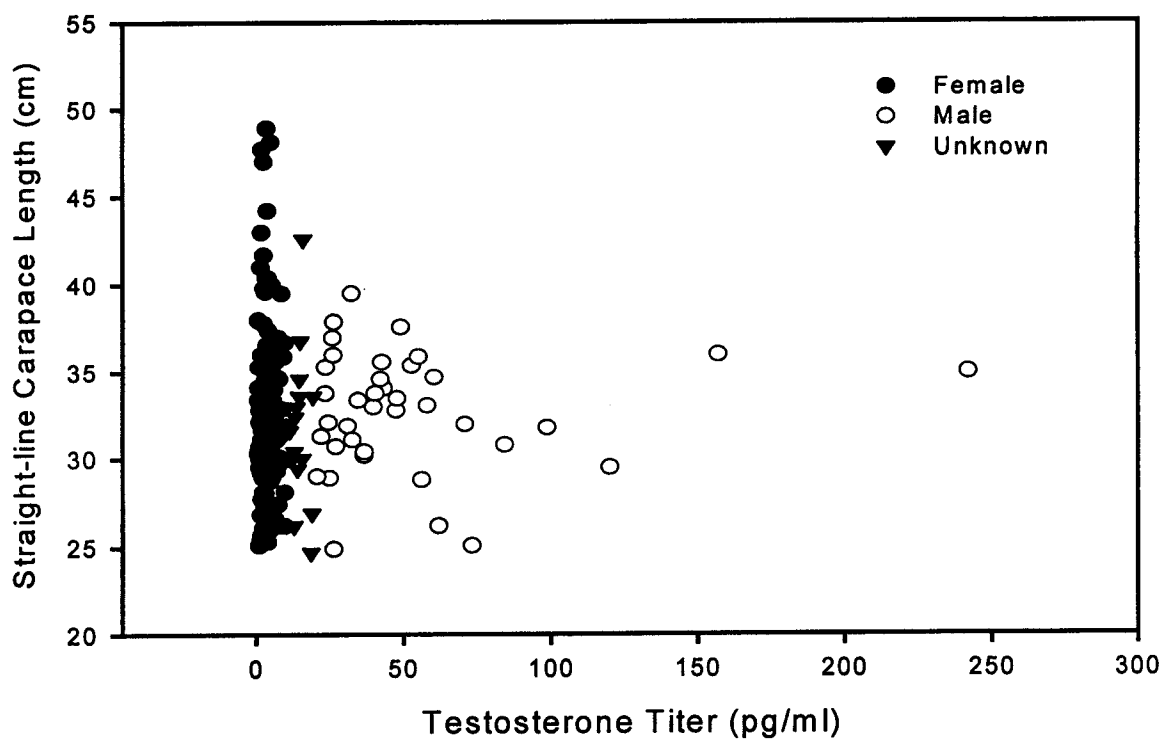


Fig. 14. Testosterone titers against straight-line carapace lengths for 177 *Chelonia mydas* netted ($n = 230$ samples) at the Mansfield Channel jetties from June 1989 to December 1997.

between year and yearly mean SLCL ($r^2 = 0.310$, $n = 9$, $P = 0.119$) (Fig. 15).

Transforming the data and fitting a variety of sigmoid curves to the data did not result in any regression models that were statistically significant for SLCL, but did result in the following polynomial model for CPUE: $\log(\text{CPUE}) =$

$163165182.578 - (245580.702 \times \text{year}) + (123.208 \times \text{year}^2) - (0.0206 \times \text{year}^3)$ ($r^2 = 0.880$, $n = 9$, $P = 0.010$). Median CPUE differed among study years ($H = 27.270$, $df = 8$, $P < 0.001$); CPUE was larger in 1996 than in 1990 ($Q = 3.293$, $P < 0.05$) and 1991 ($Q = 3.959$, $P < 0.05$). Median SLCL differed among study years ($H = 35.496$, $df = 8$, $P < 0.001$); turtles netted in 1996 were smaller than turtles netted in 1991 ($Q = 3.540$, $P < 0.05$), 1994 ($Q = 4.215$, $P < 0.05$), and 1995 ($Q = 3.855$, $P < 0.05$). Median SLCL did not differ among seasons ($H = 2.495$, $df = 3$, $P = 0.476$).

Tag loss and tags from other projects.—Inconel tags were applied to 248 of the 258 individuals netted at the Mansfield Channel. Twenty-two inconel tags were documented missing from turtles that were recaptured. These tags were lost from front and rear flippers from a total of 17 different individuals (Appendix II). These 22 tags were detected missing from 70-700 days ($\bar{x} = 295 \pm 159$ days) after application. Eight turtles that were missing all previously applied inconel tags were matched to their missing tags from tag scars, photographs, descriptions, and measurements. One PIT tag was detected missing 37 days after it was applied; a total of 160 turtles received PIT tags. Tags from another

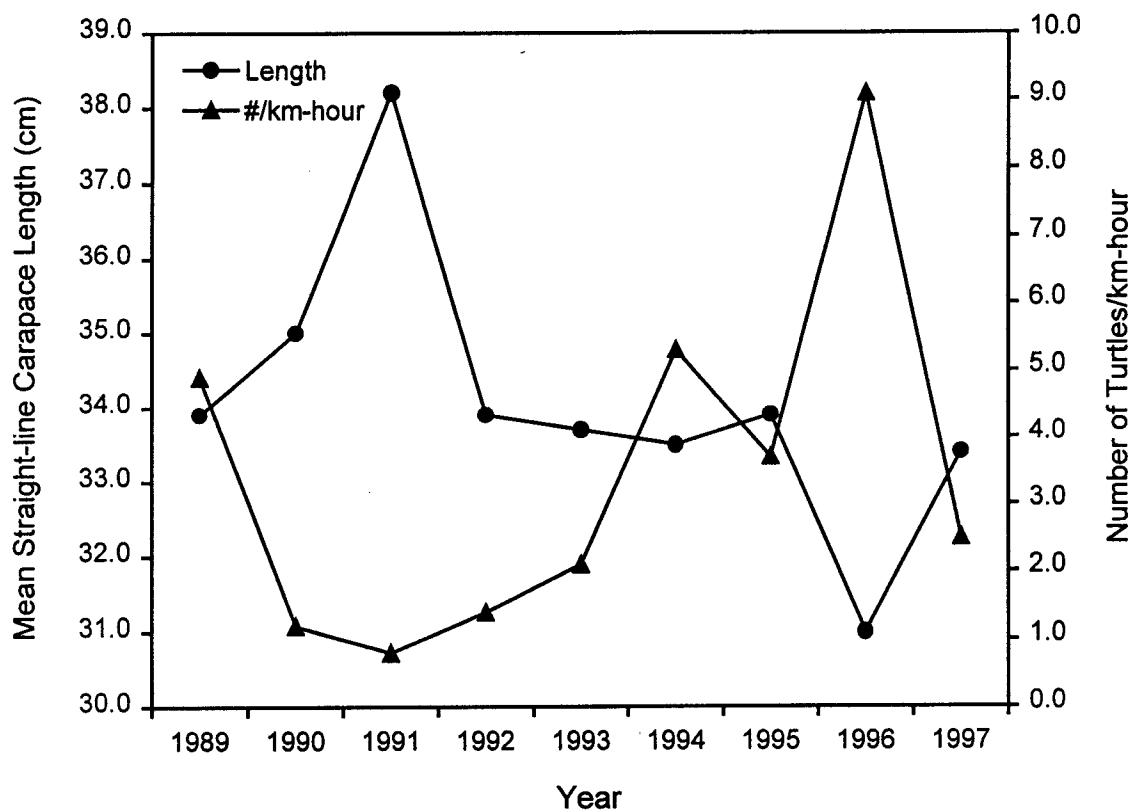


Fig. 15. Yearly mean straight-line carapace lengths of *Chelonia mydas* and yearly numbers captured per km-h at the Mansfield Channel jetties from June 1989 to December 1997.

netting project (Coyne, 1994) were found on one turtle. This turtle was initially captured, tagged, and released at the Brazos Santiago Pass and later captured at the Mansfield Channel jetties on six occasions.

Tag reports from other sources.—Eleven of the 258 turtles were reported to the Sea Turtle Stranding and Salvage Network (see Chapter II) as being found stranded ($n = 7$) or accidentally captured by hook-and-line ($n = 4$). Four of the 11 were located at the Mansfield Channel jetties, six at other areas in south Texas, and one at the Gulf beach in Tamaulipas, Mexico (Appendix III). These reports were from 4-566 days ($\bar{x} = 203 \pm 190$ days, $n = 11$) after these turtles were last netted at the Mansfield Channel jetties.

Discussion

All green turtles netted at the Mansfield Channel jetties were juveniles and results from this study support the hypothesis that this area is a developmental habitat for green turtles. All characteristics of developmental habitats listed by Meylan and Meylan (1998) that were within the scope of this study were met. These included that the Mansfield Channel jetty area (1) contained only immature individuals; (2) was located nearshore and inshore; and (3) was entered and departed at regular sizes.

The relatively high capture and recapture rates indicate that the waters of Mansfield Channel jetty area should be considered an important developmental

habitat for green turtles. Methodological differences prohibit direct comparison of CPUE indices between this and most other directed capture surveys of immature green turtles that have been conducted world-wide. However, the CPUE recorded during this study (3.63 turtles/km-h) far exceeded the CPUE documented during all other entanglement netting studies conducted during the last two decades that reported CPUE for green turtles. These other studies were conducted at the Brazos Santiago Pass, Texas (0.10 turtles/km-h) (Coyne et al., 1995), Lower Laguna Madre, Texas (0.36 turtles/km-h) (Coyne et al., 1995), Indian River Lagoon, Florida (0.36 turtles/km-h) (Provancha et al., 1998), and Waccasassa and Corrigan Reefs, Florida (0.000-0.2547 turtles/km-h) (Schmid, 1998). The Brazos Santiago Pass (Coyne, 1994; Goodman et al., 1996), Lower Laguna Madre (Coyne, 1994) and Indian River Lagoon (Guseman and Ehrhart, 1990; Provancha et al., 1998; Zug and Glor, 1998) are considered developmental habitats for green turtles.

Factors that could have resulted in CPUE being higher at the Mansfield Channel include differences in physical characteristics of the study sites, sampling protocols, and green turtle abundance. Physical characteristics of the Mansfield study site may have been more conducive to successful netting efforts there. Coyne (1994) had difficulty setting entanglement nets at the Brazos Santiago Pass jetties. Although differences in sampling protocols could have led to differences in CPUE, the Mansfield Channel CPUE would have been even higher had sampling been focused when captures were most

numerous, as occurred in some of the other studies, rather than year-round, as occurred at the Mansfield Channel. Lastly, it is possible that green turtles were concentrated at the Mansfield Channel in greater abundance. Regardless of why CPUE was higher, the fact that it was higher than at these other areas thought to be developmental habitats supports the hypothesis that the Mansfield Channel jetty area is an important developmental habitat.

It is likely that green turtles use the Mansfield Channel jetty area for both foraging and resting. Green turtles were observed foraging on algae growing on jetty rocks and algae predominated in the fecal and lavage samples analyzed from netted turtles (Shaver, unpubl. data). Coyne (1994) found algae predominated in the diet of green turtles at the Brazos Santiago Pass. Macroalgae also was a food source for juvenile green turtles occupying reef habitats in other areas (Balazs, 1982; Wershoven and Wershoven, 1989; Green, 1993; Forbes, 1994). Green turtles were also observed resting wedged between jetty rocks at the Mansfield Channel. Resting green turtles have been observed wedged in reef crevices and under ledges at several other locations worldwide (Witzell, 1982; Wershoven and Wershoven, 1989; Sanches and Bellini, 1999; Hirth et al., 1992). Green turtles may also wedge themselves between jetty rocks at the Mansfield Channel to avoid predation by sharks. In order to avoid predation from sharks and large teleosts, the smallest green turtles that recruit into nearshore areas after leaving the pelagic zone tend to use structured habitats such as reefs that provide cover (Musick and Limpus,

1997). Goodman et al. (1996) hypothesized that the Brazos Santiago Pass jetties provide green turtles with a refuge from predators.

Some turtles likely stop at the Mansfield Channel jetties prior to continuing travels within Gulf waters. Because the Mansfield Channel is one of only two direct water exchange passages between the Laguna Madre and Gulf of Mexico, it is probably a route for sea turtle movement between these two bodies of water. Some green turtles likely use the Mansfield Channel to recruit into the Laguna Madre for developmental and foraging habitat. Also, as water temperatures decrease, green turtles may move through the Mansfield Channel in search of warmer waters (deeper or further south) within the Laguna Madre or Gulf of Mexico.

CPUE and environmental variables.—Because netting was typically conducted on only one day per month, monthly CPUE indices could have been affected by unusual weather and other anomalous conditions that occurred within the area on the given sample day (Butler et al., 1987; Shaver, 1994). To avoid the potential bias of daily conditions, examination of trends is best accomplished by grouping CPUE indices by year (Fig. 8) and by month, over several years (Fig. 10).

Seasonal variations in CPUE at the Mansfield Channel jetties (Fig. 10) probably reflected seasonal differences in green turtle abundance there. CPUE was generally highest during the summer and fall, corresponding to peak

months of green turtle capture (June-September) documented for the Texas turtle fishery during the late 1800s (Doughty, 1984).

The primary environmental variable affecting green turtle abundance at the Mansfield Channel was probably water temperature. CPUE was higher at warmer water temperatures. No turtles were caught during January, the month with the coldest mean water temperatures (Fig. 9). Additionally, no turtles were caught at mean water temperatures less than 15.5 C. Mean water temperature peaked in September (Fig. 9) and CPUE peaked in October (Fig. 10).

This seasonal pattern of CPUE at the Mansfield Channel differs from patterns at some other areas in south Texas and central and south Florida. In the Indian River Lagoon System (IRLS), Florida, an inverse relationship was found between CPUE and water temperature (Ehrhart and Redfoot, 1995). CPUE indices were higher in the winter at the Lower Laguna Madre (Coyne, 1994) and IRLS (Ehrhart and Redfoot, 1995). Also, captures were most numerous during the winter in the St. Lucie Nuclear Power Plant, Hutchinson Island, Florida (Wilcox et al., 1998). Green turtles likely influx into the Mosquito Lagoon (part of the IRLS) in the fall and, based on cold stunnings documented during the winter, some must overwinter there (Mendonca and Ehrhart, 1982; Mendonca, 1983). Williams and Renaud (1998) found that two green turtles tracked using satellite telemetry left the Matagorda Bay, Texas, and moved into south Texas offshore waters during the winter. Green turtles may also migrate and recruit into south Texas inshore waters during the fall and winter; cold

stunnings and radio tracking (Arms, 1996) have demonstrated that some green turtles overwinter in the Lower Laguna Madre.

As winter approaches and water temperatures drop, many sea turtles emigrate from temperate areas and migrate towards warmer tropical waters (Carr and Caldwell, 1956; Byles, 1988; Witherington and Ehrhart, 1989a; Keinath, 1993; Coles et al., 1994; Epperly et al., 1995a, 1995b, 1995c; Lutcavage and Lutz, 1997), while those in tropical areas are more localized in their movements (Musick and Limpus, 1997). On the Atlantic coast of the U.S., year-round residency of juvenile green turtles seems to be restricted to nearshore and estuarine habitats of central Florida and southward (Zug and Glor, 1998). A similar situation could occur on the Gulf coast, with year-round green turtle residency being restricted to nearshore and estuarine habitats of south Texas and southward. Thus, during the fall and winter, south Texas waters could include a mixture of year-round residents and migrants from more northern waters.

The seasonal differences in CPUE for the Mansfield Channel, versus the Lower Laguna Madre and IRLS, could be related to differences in the amount of access to oceanic waters. In the Lower Laguna Madre and IRLS there are few passages that allow access to warmer waters of the Gulf of Mexico and Atlantic Ocean, respectively. Erratic, long-distance wandering in the Mosquito Lagoon at water temperatures from 11-18 C (Mendonca, 1983) may have been in attempt to leave the lagoon, which can serve as a trap due to limited access

points (Lutcavage and Lutz, 1997). In contrast, the Mansfield Channel jetties are located at the intersection of the Gulf of Mexico and the Mansfield Channel, which provides a passageway between the Gulf of Mexico and the Laguna Madre. Thus, it would be much easier for green turtles to leave the Mansfield Channel jetty area during periods of cold water temperatures.

It is likely that most green turtles left the jetty area during colder periods, perhaps only temporarily, and entered warmer waters. One of the primary reasons for green turtles to inhabit the jetty area is for foraging, and these opportunities would be vastly diminished during colder periods since green turtles cease feeding at water temperatures from 11-18 C (Mendonca, 1983; Moon, 1992; Moon et al., 1997). However, it cannot be ruled out that green turtles remained in the area during colder months and were less active and less vulnerable to capture then. Goodman et al. (1996) suggested year-round dependence of green turtles on the Brazos Santiago Pass, located only 56 km south of the Mansfield Channel. Dormancy occurs at temperatures below 15 C and may be a strategy for surviving low water temperatures (Carr and Caldwell, 1956; Felger et al., 1976; Carr et al., 1980; Ogren and McVea, 1982; Witherington and Ehrhart, 1989a; Lutcavage and Lutz, 1997). However, no evidence of prolonged, winter dormancy has been found in Texas (Fritts et al., 1983).

Recapture rates and size.—Overall, 28.3% of green turtles netted at the Mansfield Channel were recaptured. Few other similar netting studies conducted in Florida and Texas reported net recapture rates for juvenile green turtles. However, considering the few that could be compared, the netting recapture rate for this study (32.6%) was intermediate between those recorded at the Lower Laguna Madre and Brazos Santiago Pass (43.3%) (Coyne, 1994), Trident Submarine Basin, Port Canaveral, Florida (38.2%) (Redfoot et al., 1996), and the Waccasassa and Corrigan Reefs, Florida (10.0%) (Schmid, 1998). The relatively high recapture rate recorded at the Mansfield Channel indicates site fidelity of some green turtles to the area.

Since it was impossible to determine whether turtles remained at the Mansfield Channel jetties during the entire time between successive captures, precise residency times cannot be accurately calculated. However, recapture rates and sizes of turtles captured provide information on residency and habitat use patterns. Based upon variations in recapture rates and intervals from first to last capture, it appears that (1) a mixture of both transient and seasonally resident green turtles inhabit the Mansfield Channel jetty area; and (2) most individuals probably remain for periods ranging from a few days to a few months and do not return after that time. However, a few were caught during different years, and thus some turtles must return if they do not overwinter there.

All green turtles netted were juveniles. Similarly, all green turtles measured during directed capture studies in south Texas inshore waters (Coyne, 1994)

and in Florida (Mendonca and Ehrhart, 1982; Henwood and Ogren, 1987; Guseman and Ehrhart, 1990; Wershoven and Wershoven, 1992; Ehrhart and Redfoot, 1995; Schroeder and Foley, 1995; Schmid, 1998) were juveniles.

The mean SLCL for green turtles at the Mansfield Channel (32.4 cm) was slightly larger than at the Brazos Santiago Pass and smaller than at that Lower Laguna Madre (Coyne, 1994). It was smaller (although sometimes only slightly smaller) than the mean SLCLs recorded at various sites in Florida (Henwood and Ogren, 1987; Ernest et al., 1989; Guseman and Ehrhart, 1990; Wershoven and Wershoven, 1992; Schroeder and Foley, 1995; Redfoot et al., 1996; Schmid, 1998; Schroeder et al., 1998). Guseman and Ehrhart (1990) found a smaller mean SLCL for green turtles netted at a *Sabellariid* reef located within nearshore waters off the east coast of Florida than within the nearby Mosquito Lagoon and hypothesized that the reef area may be an intermediate developmental habitat for green turtles between the pelagic environment and lagoonal feeding pastures. The mean SLCL of green turtles at the Mansfield Channel would indicate that it should be considered similarly.

Juvenile green turtles recruit to coastal developmental habitats at about 25 to 40 cm CCL or larger (Balazs, 1982; Bjorndal and Bolten, 1988; Musick and Limpus, 1997; Zug and Glor, 1998). The green turtles at the Mansfield Channel likely include new recruits from the pelagic environment as well as some individuals that are leaving developmental habitats. The smallest turtles netted at the Mansfield Channel were in the 20.0-29.9 cm SLCL size class and the

largest in the 50.0-59.9 cm size class. Zug and Glor (1998) used skeletochronology to age a sample of 59 juvenile green turtles (28.1-74.2 cm SLCL) obtained from the IRLS during a December 1989 cold stunning event. Based on these analyses, they estimated that juvenile green turtles in the western Atlantic switch from the pelagic zone to coastal developmental habitats at predominately 5-6 years of age, live in developmental habitats for 6 or more years, and leave developmental habitats at roughly 10-14 years of age (at 50.0-79.9 cm SLCL). These results might also apply to green turtles at the Mansfield Channel and elsewhere in south Texas, due to the similar size-specific growth patterns that have been documented there (Shaver, 1994; Zug and Glor, 1998).

Sex ratios.—The 4.16F:1.00M sex ratio found in the present study was significantly skewed towards females, but was within the range of sex ratios documented during other studies. Sex ratios found in other studies of green turtles that examined primarily immature individuals have been skewed towards females. However, in most instances the sex ratios did not significantly differ from 1:1. Meylan et al. (1994), using serum testosterone assays and verification via laparoscopy, found a sex ratio that did not differ significantly from 1:1 for green turtles netted in Bermuda. Using serum testosterone assays, Wibbels et al. (1993) found a sex ratio of 1.03F:1.00M in Hawaii, Bolten et al. (1992) found a sex ratio of 1.41 F:1.00M in the Bahamas, Wibbels et al. (1989) found a sex ratio of 1.99F:1.00M in Australia, Bass et al. (1998b) found a sex

ratio of 5.57F:1.00M in North Carolina, Redfoot et al. (1996) found a sex ratio of 12.00F:1.00M in Florida, and Provancha et al. (1998) found a sex ratio of 17.00F:1.00M in Florida. Using necropsies, Koga and Balazs (1996) found a sex ratio of 1.16F:1.00M in Hawaii and Schroeder and Owens (1994) found a sex ratio of 1.75F:1.00M in Florida.

Serum testosterone level can be used as an accurate indicator of sex in immature sea turtles (Owens et al., 1978; Wibbels et al., 1987, 1989; Wibbels, 1988). However, results from such analyses can be influenced by different mass recovery equations used at different laboratories, physiology of the turtle, size, season, and location (Gregory, 1996). Sex ratio results from the present study did not appear to be biased towards females due to different laboratories, inaccurate sex classification criteria, sizes of the turtles, or seasons when the samples were taken. All samples were analyzed at one laboratory that has conducted such work for nearly two decades. Although Bolten et al. (1992) found a significant correlation between SLCL and testosterone titers for immature male green turtles, no such correlation was found during the present study or by Wibbels (1988). In the present study, the same "conservative" criteria as Bolten et al. (1992) and Bass et al. (1998b) were used to classify sex for immature green turtles according to testosterone titer. Furthermore, when the data were re-analyzed using hypothetical classification criteria that were even more conservative, the sex ratio continued to be female dominated. The frequency distribution of testosterone titers was not bi-modal. Schroeder and

Owens (1994) also failed to find a bi-modal distribution and cautioned that this could result in unreliable sex ratio predictions. However, more studies of immature sea turtles failed to find a bi-modal distribution (Gregory, 1996; Leon and Diez, 1999) than found one (Wibbels et al., 1987; Casale et al., 1998).

Braun-McNeill et al. (in press) found that cool water temperatures (below 20 C) depressed testosterone titers of immature loggerheads, resulting in a bias against males. However, the sex ratio for this study continued to be skewed towards females when samples obtained at water temperatures below 22 C were eliminated. Delays ranging from several hours to weeks in obtaining blood samples from captured turtles can result in alteration of testosterone levels and hence in sex ratios estimated from radioimmunoassays (Wibbels et al., 1987; Schroeder and Owens, 1994; Owens, 1997; Casale et al., 1998). However, Gregory and Schmid (1998) found that mean testosterone concentrations were not significantly different for samples obtained at 30-60 min after initial capture. Since the majority of samples were obtained within 15-60 min after capture and none were collected more than 3 h after capture, it is unlikely that sample collection delay was a factor that influenced the sex ratio estimate.

Variations in CPUE and SLCL.—There was no long-term positive or negative trend in CPUE over the study years. However, yearly CPUE varied substantially despite consistent sampling location, method, and effort. CPUE could have varied due to changes in habitat quality. Capture rates may have

been influenced by the densities of an exotic mussel, *Perna perna* Linnaeus, 1758, at the jetties. *Perna perna* were first collected from the Aransas Pass jetties in February 1990 and had successfully colonized the intertidal zone of the jetty rocks at the Mansfield Channel by December 1991 (Hicks and Tunnell, 1993). These organisms encrust jetty rocks, thereby reducing space available on the rocks for algal growth. Since green turtles feed upon algae at the jetties, the initial presence of these organisms may have hindered their foraging. However, during later study years, the mussels proliferated, formed dense mats, and became covered with the same algae species as the jetty rocks (D. Hicks, pers. comm.). During this time, turtles grazing on algae may have inadvertently consumed small amounts of this mollusc, adding to the nutritional value of their forage from the jetties; small *P. perna* fragments were found in the fecal and lavage samples collected from netted turtles (Shaver, unpubl. data). CPUE was reduced during 1997 and, since the first part of 1997, the densities of *P. perna* have been quite low (D. Hicks, pers. comm.).

Yearly CPUE and yearly mean SLCL were significantly, negatively correlated. Although it is doubtful that green turtles were at their carrying capacity at the Mansfield Channel jetties, the size of turtles present at the jetties may have influenced CPUE.

Lastly, annual fluctuations in CPUE could reflect annual differences in population levels. Numbers of nesting green turtle females vary enormously from year to year (Carr, 1980; Richardson, 1999), resulting in large variations in

number of hatchlings produced each year. If the turtles occupying a given developmental habitat originate from only one or just a few nesting beaches, one might expect that the number of juveniles recruiting into developmental habitats would also vary annually. Based on preliminary analyses of genetic samples, most juvenile green turtles inhabiting Texas waters likely originated from nesting beaches in Florida and/or the Gulf of Mexico (P. Dutton, pers. comm.). However, since the precise nesting beaches are unknown, the annual nesting trends at those beaches cannot be compared with the CPUE data.

Tag loss and tag returns.—Tag loss is a recognized problem in sea turtle research (Balazs, 1982; Henwood, 1986; Limpus, 1992; Alvarado et al., 1993; Parmenter, 1993; Bjorndal et al., 1996; Gorham et al., 1998; Balazs, 1999; Van Dam and Diaz, 1999). Some degree of tag loss has been documented for all of the tag types used during this study. It is likely that the relative performance of different tags varies with tag design, tagging position, tag application proficiency, tag age, species and size of turtle tagged, and environment (Henwood, 1986; Limpus, 1992; Gorham et al., 1998). The amount of tag loss documented during this study was within the range documented previously. However, since tags were only detected missing when turtles were recaptured, the exact date of tag loss could not be ascertained and turtles that were not recaptured could not be assessed for tag loss.

Eight turtles with tag scars were matched to their lost tags by comparing

photographs, measurements, and descriptions of physical characteristics (injuries, scale and scute patterns). The pattern of scales, scutes, and injuries often provided a unique combination that allowed matching through photographs. Photoidentification has been used to identify and match individuals of other sea turtle species and other taxa. Pink spot shape, size, color, and pattern appear to be unique to each individual nesting leatherback (*Dermochelys coriacea* Vandelli, 1761) and photoidentification has been used to supplement recognition of previously tagged individuals (McDonald and Dutton, 1996a, 1996b, 1998; McDonald et al., 1996). Meekins (1988) used photography as a method to identify individual nesting loggerhead turtles (*Caretta caretta*) on which tagging was prohibited, by comparing the pattern of encrusted organisms. However, due to the rapid growth of barnacles at the Mansfield Channel, the locations and numbers of barnacles on the turtles were not useful for identification of turtles during this study. Doody (1995) used photography for recognition of patterned amphibians.

These eight individuals were matched to their tagging history because their tag scars were recognized. However, Bjorndal et al. (1996) found that the presence of tag scars on nesting green turtles at Tortuguero, Costa Rica, was an underestimate of total tag loss since only 37% of lost tags were detected by tag scars. If some turtles lost all of their tags during this study, but had no tag scars, tag loss would have been underestimated, recapture rates would have been underestimated, and the total number of individuals captured would have

been overestimated. However, the magnitude of this potential problem should have diminished after all turtles were marked with PIT tags; 160 of the 258 individuals were marked with PIT tags and only one PIT tag was detected lost.

Although only 11 of the 258 turtles initially tagged at the Mansfield Channel were later reported elsewhere, these reports enhanced knowledge regarding dispersal of green turtles from the Mansfield Channel jetties. Those 11 found stranded and caught on hook-and-line (1) extended the length of time that 10 of the 11 were documented in south Texas; (2) documented movement of one individual to Mexico; and (3) documented movement of six turtles from the Mansfield Channel to the Gulf of Mexico and Laguna Madre. These tag returns constitute the first published records of green turtles moving from Texas to Mexico and dispersing from the Mansfield Channel to the Gulf of Mexico and Laguna Madre. The record of the turtle initially captured at the Brazos Santiago Pass and subsequently captured six times at the Mansfield Channel constitutes the first time that green turtles have been documented moving between different jetty systems in Texas.

Conclusions.—The Mansfield Channel is an important developmental habitat for juvenile green turtles. A high CPUE and relatively high recapture rate were recorded during this study. If the incidence of fibropapillomatosis, growth rates, and residence times are indicators of population health status (Schroeder and Foley, 1995; Bjorndal, 1999), the green turtles inhabiting the Mansfield Channel

should be considered very healthy. The high biomass of algae recorded on the north jetty at Mansfield Channel indicates that these plants represent a substantial food and habitat resource, which is available year-round (Kaldy et al., 1995). Furthermore, compared to the Aransas Pass and Brazos Santiago Pass jetties, the Mansfield Channel jetties are comparably remote and less heavily utilized by humans. However, turtles in this area could still be threatened from fishing, dredging, boating, and trash ingestion. Although the jetties and channel are man-made habitats, they are now used extensively by green turtles. To help ensure the re-building of the green turtle population in Texas, this important developmental habitat must receive adequate protection.

CHAPTER V

COMPARISONS OF STRANDED AND NETTED TURTLES

Introduction

The green turtle (*Chelonia mydas*) is listed under the Endangered Species Act of 1973 as threatened throughout its range with the exception of the breeding colony populations on the Pacific coast of Mexico and Florida coast of the United States, which are afforded endangered status. Although green turtles were once commercially exploited in Texas, today they are greatly depleted and primarily smaller sized individuals (juveniles) inhabit Texas waters (Hildebrand, 1982, 1983; Doughty, 1984). Little biological and trend data are available for juvenile *C. mydas* in Texas or elsewhere.

Most studies of sea turtle populations have been conducted at nesting beaches, but the number of research projects involving capture of turtles in the marine environment has increased during the last decade (Bjorndal and Bolten, 1998; Epperly, 1998). Information gathered during these in-water studies can increase understanding of sea turtle biology, particularly for poorly known juveniles. Such information is needed for comprehensive management of sea turtle populations (Bjorndal, 1999).

The National Marine Fisheries Service (NMFS) uses data from long-term directed capture studies of sea turtles and from the Sea Turtle Stranding and Salvage Network (STSSN) to aid with formulation of management decisions.

The STSSN was established in 1980 to document strandings of marine turtles on United States beaches located along the Gulf of Mexico, Atlantic Ocean, and Caribbean Sea (Schroeder, 1988; Shaver and Teas, 1999). Previously, most information was derived from stranded turtles, but recently greater emphasis has been placed on gathering data from directed capture studies conducted in "marine index areas" (Bjorndal, 1999) such as the Mansfield Channel, Texas. In fact, some have suggested that in-water studies show such promise that investigations of stranded turtles may no longer be necessary. However, it is unknown how comparative the Mansfield Channel capture data and Texas stranding data are and whether the Mansfield Channel netting data can accurately be used as an index of the green turtle population inhabiting Texas waters.

This study was undertaken to test the hypothesis that the directed capture data from the Mansfield Channel can be used as an "index" to green turtles in Texas. To accomplish this, comparisons were made between monthly and yearly variations in the numerical trends, sizes, and sex ratios of green turtles netted at the Mansfield Channel jetties and stranded in Texas from 1989 to 1997.

Information from this study will enhance understanding of green turtles in Texas and be useful to managers attempting to assess population trends, formulate management decisions, and develop regulations to increase protection. It will also, for the first time, quantitatively compare two long-term

data sets to investigate the concept of marine index areas that are beginning to be utilized as the basis for the formulation of management actions to protect and restore sea turtle populations worldwide.

Materials and Methods

Documentation of stranded and netted turtles.—Green turtles found stranded in Texas were documented by the STSSN from 1980 to 1998 (see Chapter II). Stranding records from 1989 through 1997 were extracted from the STSSN database and re-analyzed for this study. Green turtles were captured with an entanglement net set at the base of the north jetty at the Mansfield Channel (26°33'50"N, 97°16'45"W), located in south Texas (Fig. 16), from June 1989 through December 1997 (see Chapter IV). All netting records (including netting recaptures) were used for this study.

Data collection protocols for stranded and netted turtles were presented in Chapters II and IV, respectively. Stranded and netted turtles were categorized by month, season, year, straight-line carapace length (SLCL), and sex. Seasons were defined as winter (December-February), spring (March-May), summer (June-August), and fall (September-November). All netted turtles were measured for SLCL. However, some stranded turtles were not measured for SLCL and, for stranded turtles with only curved carapace length (CCL) measurements, the conversion factor of Teas (1993) was used to convert CCL to SLCL. Turtles were classified as "hatchlings/post-hatchlings" when they were

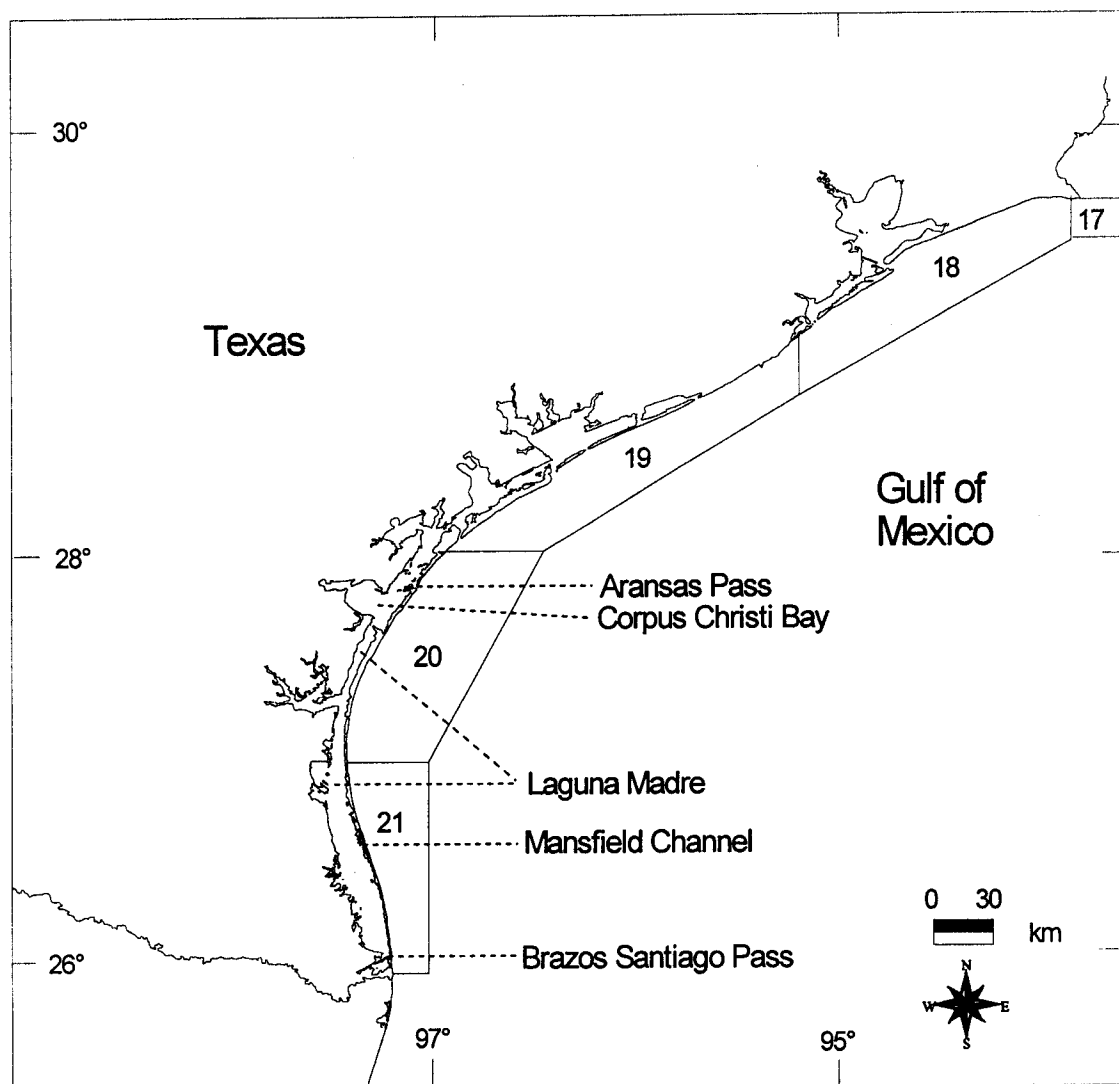


Fig. 16. Map of the Texas coast showing statistical zones and the Mansfield Channel.

less than 10.0 cm SLCL. Turtles were classified as "adults" when they attained adult size (Musick and Limpus, 1997) by exceeding 83.2 cm SLCL, the minimum size of nesting females recorded in Florida by Witherington and Ehrhart (1989b). Turtles were considered to be "juveniles" when they were larger than hatchlings/post-hatchlings, but smaller than adults. Sex of some stranded turtles was determined during necropsy (see Chapter II) and of some netted turtles using serum testosterone radioimmunoassays (see Chapter IV). Stranded turtles were also categorized by statistical zone (Fig. 16) and area (inshore or offshore); inshore areas were the passes and bays and offshore areas were the beaches and waters of the Gulf of Mexico.

Data analysis.—All means are followed by $\pm$ one standard deviation. Data were tested for normality and homogeneity of variance prior to using parametric procedures. When parametric assumptions were not met, equivalent non-parametric procedures were used.

CPUE indices were derived for each sample month and each sample year. These indices were expressed as the number of turtles caught per km-h (Guseman and Ehrhart, 1990) and obtained by dividing the number of turtles caught by the number of netting hours and multiplying by 10.9, a factor which extrapolates the number of turtles caught within 91.4 m of net to 1 km of net. A Spearman rank order correlation was used to evaluate the association between monthly CPUE and water temperature. Median CPUE for each year were

compared using a Kruskal-Wallis one way analysis of variance on ranks test, followed by an all pairwise multiple comparison test (Dunn's method), to determine which year(s) were significantly different.

Chi-square tests were used to compare the sex ratios for stranded turtles and for netted individuals with a 1:1 ratio. A test for binomial proportions was used to compare the sex ratio of stranded and netted turtles. For the remainder of analyses involving sex ratios and comparisons by sex, each capture from which a blood sample was obtained was included. Chi-square tests were used to compare sex ratios for turtles found stranded and netted during each season and during each year (in which 5 or more individuals were identified of both sexes) with a 1:1 ratio. Kruskal-Wallis one way analysis of variance on ranks tests were used to compare median SLCLs of females, males, and unknown sex turtles for (1) stranded turtles and (2) netted turtles. Mann-Whitney rank sum tests were used to compare median SLCLs of stranded and netted turtles for (1) females; (2) males; and (3) unknown sex turtles.

Mann-Whitney rank sum tests were used to compare (1) median SLCLs of stranded and netted turtles and (2) median SLCLs of turtles found stranded in offshore and inshore areas. Median SLCLs of turtles found stranded offshore, turtles found stranded inshore, and turtles netted (initial capture measurements) were compared using a Kruskal-Wallis one way analysis of variance on ranks test, followed by an all pairwise multiple comparison test (Dunn's method) to determine which differed.

For seasonal and yearly comparisons of SLCL, the SLCL for a netted individual was only included once for each season and once for each calendar year that it was captured and the measurement used was the one obtained the first time that it was captured during that season and during that year. Median SLCLs of both stranded and netted turtles were compared for each season and for each year using Kruskal-Wallis one way analysis of variance on ranks tests, followed by all pairwise multiple comparison tests (Dunn's method), to determine which seasons(s) and year(s) were significantly different. Mann-Whitney rank sum tests were used to compare median SLCLs of stranded and netted turtles during each of the 4 seasons.

Spearman rank order correlations were used to determine whether there were first-order autocorrelations between (1) number of strandings (overall, inshore, offshore) by year and year – 1; (2) CPUE by year and year – 1; and (3) mean SLCL by year and year – 1 (for both stranded and netted turtles). Spearman rank order correlations were used to determine whether there were correlations between (1) yearly number of strandings and yearly CPUE; and (2) yearly mean SLCLs of stranded and netted turtles. Linear regression was used to determine if there were significant linear relationships between (1) study year and yearly number of turtles found stranded (overall, inshore, offshore); (2) study year and yearly CPUE; (3) study year and yearly mean SLCL (for both stranded and netted turtles); (4) yearly CPUE and yearly mean SLCL (for netted turtles); and (5) yearly number of turtles found stranded and yearly CPUE.

Results

Overall numbers of stranded turtles and CPUE.—From 1989 through 1997, 471 green turtles were located stranded along the Texas coast. Of the 471 stranded green turtles, 318 (67.5%) were located in inshore, 152 (32.3%) in offshore, and one (0.2%) in unknown areas. Strandings were distributed throughout Texas, with 0 (0.0%) in zone 17, 29 (6.2%) in zone 18, 34 (7.2%) in zone 19, 177 (37.6%) in zone 20, and 231 (49.0%) in zone 21. Both inshore and offshore strandings were concentrated in south Texas. Inshore strandings were most numerous in zone 21 (in the Laguna Madre) and offshore strandings were most numerous in zone 20.

Two hundred fifty-eight green turtles ($n = 383$ captures) were netted in the Mansfield Channel during 1149 h of effort (3.63 turtles/km-h) from June 1989 through December 1997.

Yearly numbers.—Stranding numbers found varied during different study years (Fig. 17). No significant first-order autocorrelation was found between number of strandings by year and year $- 1$ ($r = 0.620$, $n = 8$, $P = 0.080$). A linear model was not useful to describe the relationship between year and yearly number of stranded turtles ($r^2 = 0.381$, $n = 9$, $P = 0.077$). Transforming the data and fitting a variety of sigmoid curves to the data resulted in the following polynomial model: number of strandings = $108188001.006 - (1617304.914 \times \text{year}) + (805.859 \times \text{year}^2) - (0.134 \times \text{year}^3)$ ($r^2 = 0.910$, $n = 9$, $P = 0.005$). No significant

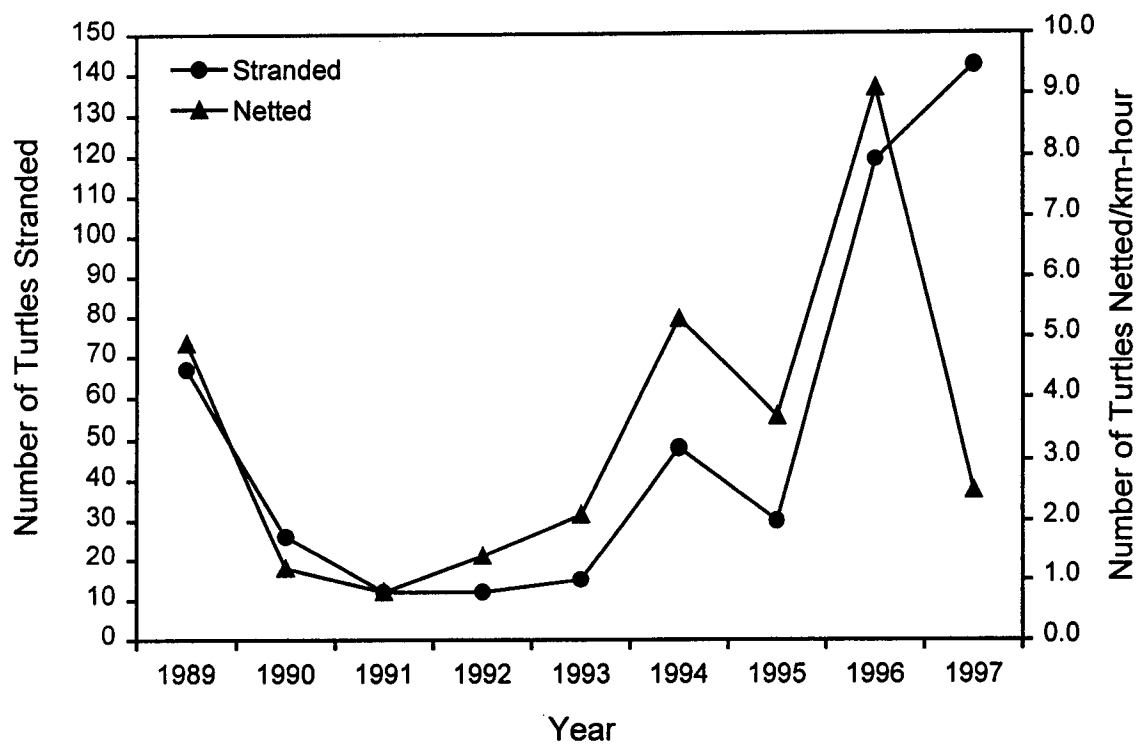


Fig. 17. Yearly numbers of *Chelonia mydas* found stranded on the Texas coast and caught per km-h at the Mansfield Channel jetties from 1989 to 1997.

first-order autocorrelation was found between number of offshore strandings by year and year - 1 ($r = 0.566$, $n = 8$, $P = 0.120$). Offshore strandings increased during the study years ($r^2 = 0.517$, $n = 9$, $P = 0.029$). The equation of the regression line as follows: number of offshore strandings = $-7058.261 + (3.550 \times \text{year})$. No significant first-order autocorrelation was found between number of inshore strandings by year and year - 1 ($r = 0.428$, $n = 8$, $P = 0.260$). A linear model was not useful to describe the relationship between year and yearly number of inshore strandings ($r^2 = 0.268$, $n = 9$, $P = 0.153$). Transforming the data and fitting a variety of sigmoid curves to the data resulted in the following polynomial model: number of inshore strandings = $-1065819154.455 + (1614543.465 \times \text{year}) - (815.228 \times \text{year}^2) + (0.137 \times \text{year}^3)$ ($r^2 = 0.949$, $n = 9$, $P = 0.001$).

CPUE varied during different study years (Fig. 17). Median CPUE differed among study years ($H = 27.270$, $df = 8$, $P < 0.001$); CPUE was higher in 1996 than in 1990 ($Q = 3.293$, $P < 0.05$) and 1991 ($Q = 3.959$, $P < 0.05$). No significant first-order autocorrelation was found between CPUE by year and year - 1 ($r = 0.405$, $n = 8$, $P = 0.290$). A linear model was not useful to describe the relationship between year and yearly CPUE ($r^2 = 0.167$, $n = 9$, $P = 0.275$). Transforming the data and fitting a variety of sigmoid curves to the data resulted in the following polynomial model: $\log(\text{CPUE}) = 163165182.578 - (245580.702 \times \text{year}) + (123.208 \times \text{year}^2) - (0.0206 \times \text{year}^3)$ ($r^2 = 0.880$, $n = 9$, $P = 0.010$).

The yearly number of turtles found stranded and yearly CPUE for 1989-1997

were correlated ($r = 0.753$, $n = 9$, $P = 0.0158$) (Figs. 17, 18). A linear model was not useful to describe the relationship between the untransformed values for yearly number of strandings and yearly CPUE ($r^2 = 0.340$, $n = 9$, $P = 0.100$). However, $\log_{10}$ transforming the data resulted in the following linear model: $\log_{10}(\text{number of strandings}) = 1.193 + (0.857 \times \log_{10}(\text{CPUE}))$ ($r^2 = 0.535$, $n = 9$, $P = 0.025$). After plotting the untransformed values for the yearly number of strandings and yearly CPUE for years 1989-1997, it appeared that 1997 was an outlier (Figs. 17, 18). These analyses were repeated eliminating the point for 1997. The number of turtles found stranded and CPUE for 1989-1996 were positively correlated ($r = 0.886$, $n = 8$, $P < 0.001$). For years 1989-1996, a linear model was useful to describe the relationship between yearly number of strandings and yearly CPUE ($r^2 = 0.910$, $n = 8$, $P < 0.001$); the equation of the regression line is as follows: $\text{number of strandings} = 16.246 + (10.484 \times \text{CPUE})$ (Fig. 19).

Monthly numbers.—Most strandings in inshore areas occurred in December, January, and February and most strandings in offshore areas occurred in April and May. Green turtles were caught at the Mansfield Channel during all months of the year except January (Fig. 20). CPUE was positively correlated with water temperature ($r = 0.527$, $n = 102$, $P < 0.0001$) and no turtles were caught when mean water temperatures were below 15.5 C. Overall, strandings were most numerous during colder months, whereas CPUE indices were highest during

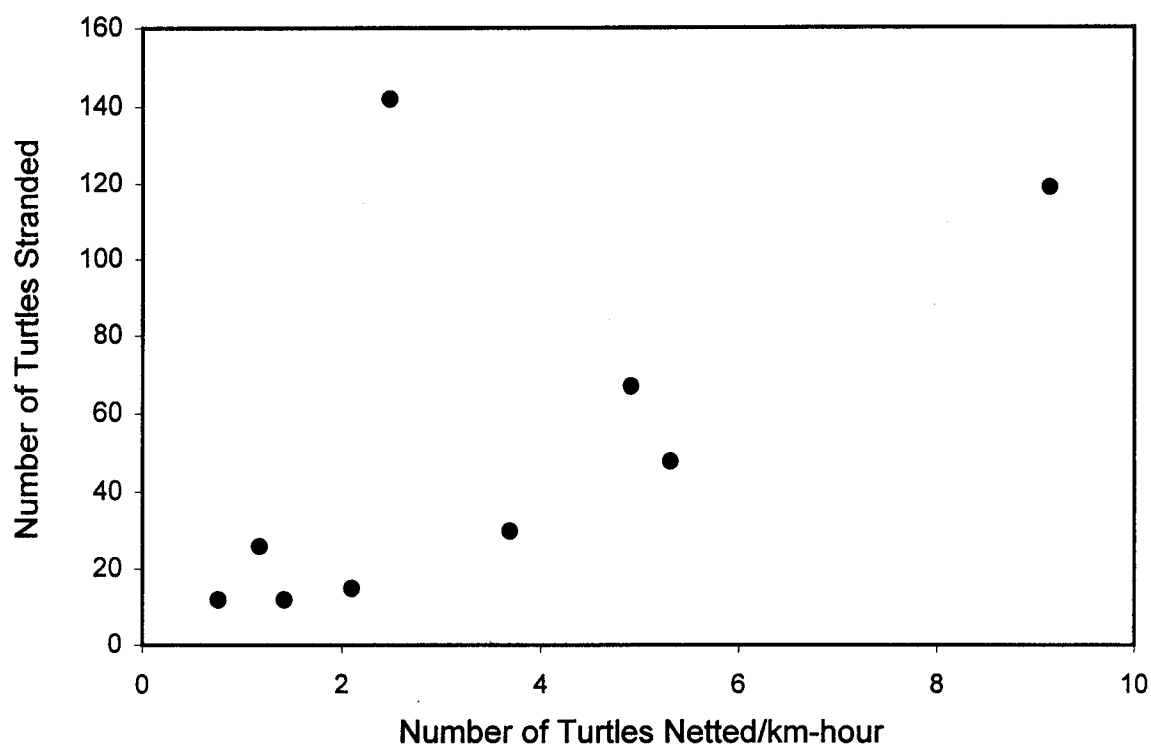


Fig. 18. The relationship between the numbers of *Chelonia mydas* found stranded on the Texas coast and caught per km-h at the Mansfield Channel jetties from 1989 to 1997.

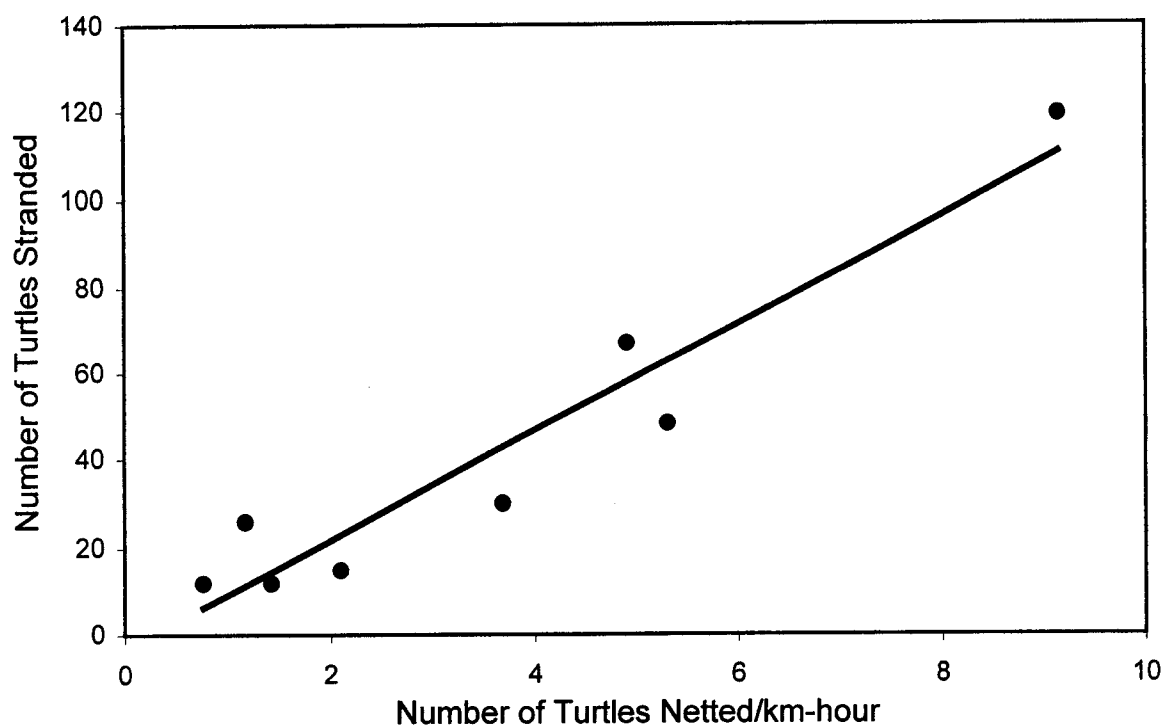


Fig. 19. The relationship between the numbers of *Chelonia mydas* found stranded on the Texas coast and caught per km-h at the Mansfield Channel jetties from 1989 to 1996. The regression equation is as follows: number of strandings = $16.246 + (10.484 \times \text{CPUE})$ ($r^2 = 0.910$, $n = 8$, $P < 0.001$).

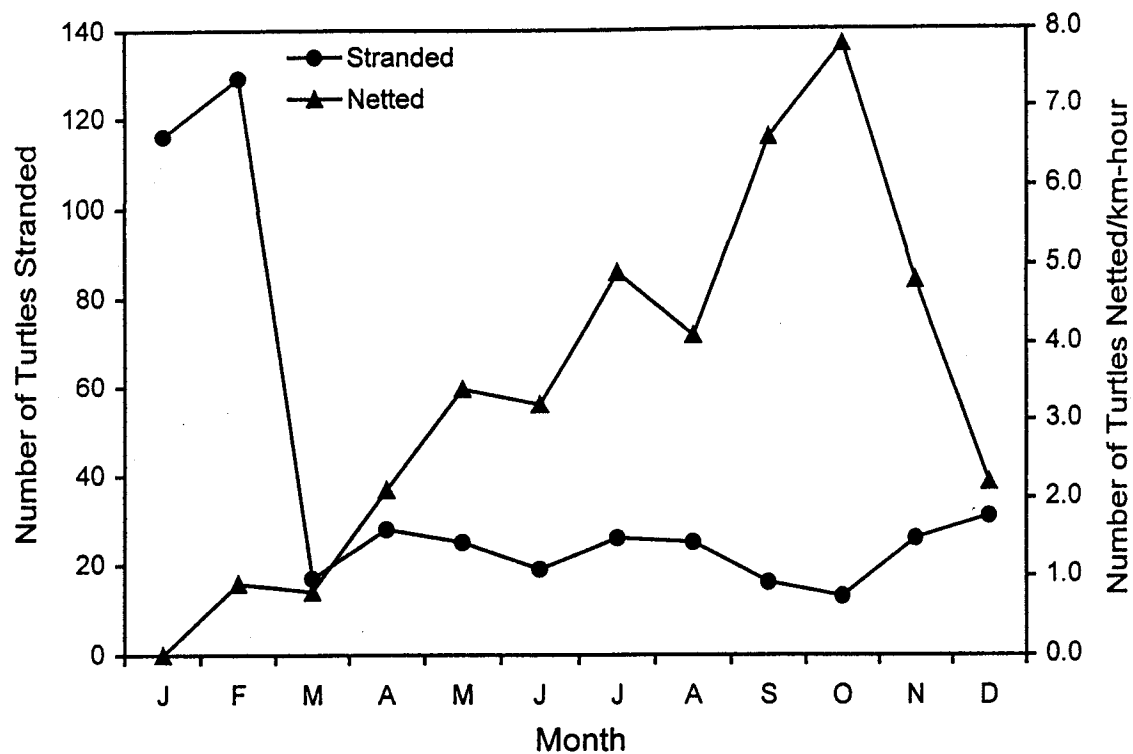


Fig. 20. Monthly numbers of *Chelonia mydas* found stranded on the Texas coast and caught per km-h at the Mansfield Channel jetties from 1989 to 1997.

warmer months (Fig. 20).

Sex ratio.—Of the 97 stranded turtles that sex was determined for by necropsy, 47 were females and 50 were males. The resulting 0.94F:1.00M sex ratio was not significantly different from a 1:1 ratio (chi-square = 0.09, df = 1, $P > 0.05$). Most of the 97 individuals that sex was determined for were found during 1994, 1996, and 1997; the sex ratio was not significantly different from a 1:1 ratio during those 3 years (in all cases: chi-square < 1.960, df = 1, $P > 0.05$). The sex ratio was not significantly different from a 1:1 ratio during all 4 seasons (in all cases: chi-square < 0.750, df = 1, $P > 0.05$).

Blood samples were obtained from 177 netted individuals ($n = 230$ samples) (see Chapter IV). Thirty-five of the 177 individuals were sampled on more than one date; all samples were consistently classified as either female or male for 30 of those 35 (Appendix II). Of the 177 individuals, 129 were females, 31 were males, and 17 were unknown. The resulting 4.16F:1.0M sex ratio was significantly different from a 1:1 ratio (chi-square = 60.025, df = 1, $P < 0.05$). Most of the blood samples analyzed were collected during the spring, summer, and fall and during 1994, 1995, and 1996. The sex ratio was female dominated and significantly different from a 1:1 ratio in those 3 seasons (in all cases: chi-square > 13.333, df = 1, $P < 0.05$) and in those 3 years (in all cases: chi-square > 4.628, df = 1, $P < 0.05$).

There was a significantly higher proportion of females among the netted than

among the stranded turtles (95% confidence interval = 0.205-0.439, $P < 0.05$).

Size overall.—Stranded *C. mydas* ranged from 10.6 to 99.2 cm SLCL ($\bar{x} = 37.8 \pm 12.1$ cm, $n = 409$) (Fig. 21). Of the 409 for which measurements were obtained, none were hatchlings/post-hatchlings, 406 were juveniles, and three were adults. Two hundred eighty-one of the 409 (68.7%) measured less than 40.0 cm SLCL. Stranded individuals found inshore ranged from 13.0 to 98.5 cm SLCL ($\bar{x} = 40.3 \pm 11.3$ cm, $n = 277$) and found offshore ranged from 10.6 to 99.2 cm, ($\bar{x} = 32.8 \pm 12.3$ cm, $n = 131$). Turtles found stranded inshore were significantly larger than turtles found stranded offshore ($T = 17746.000$, $n(\text{small}) = 131$, $n(\text{big}) = 277$, $P \leq 0.001$).

All netted turtles were juveniles (Fig. 21). Initial capture SLCL ranged from 24.7 to 52.0 cm ($\bar{x} = 32.4 \pm 4.5$ cm, $n = 258$). Two hundred forty-two of the 258 individuals (93.8%) measured less than 40.0 cm SLCL at initial capture.

Turtles found stranded were significantly larger than turtles netted ($T = 71358.000$, $n(\text{small}) = 258$, $n(\text{big}) = 409$, $P \leq 0.001$). The SLCLs of turtles found stranded inshore, turtles found stranded offshore, and netted turtles differed ($H = 125.154$, $df = 2$, $P < 0.001$); turtles found stranded inshore were larger than turtles found stranded offshore ($Q = 9.327$, $P < 0.05$) and turtles netted ($Q = 9.349$, $P < 0.05$). However, median SLCLs of turtles found stranded offshore and netted turtles did not differ ($Q = 1.678$, $P > 0.05$).

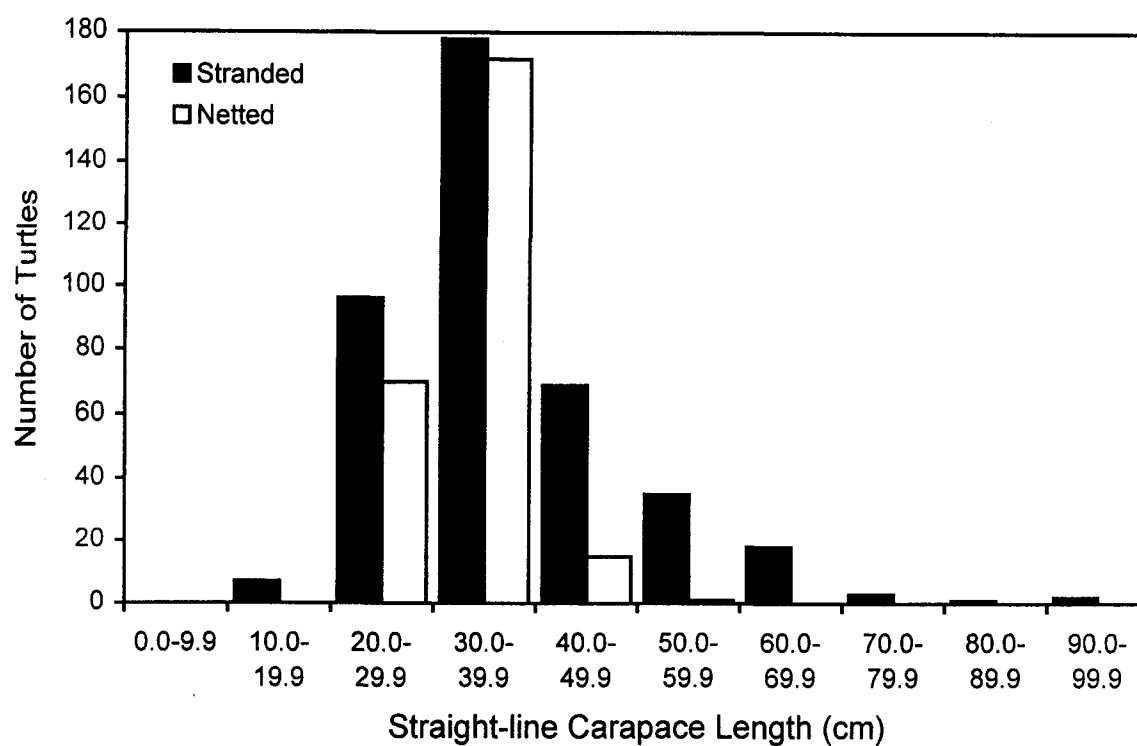


Fig. 21. Length frequency distribution of *Chelonia mydas* found stranded on the Texas coast and caught per km-h at the Mansfield Channel jetties from 1989 to 1997.

Size by year.—No significant first-order autocorrelation was found between SLCL by year and year – 1 for stranded turtles ($r = 0.119$, $P = 0.749$, $n = 8$). A linear model was not useful to describe the relationship between year and yearly mean SLCL of stranded turtles ($r^2 = 0.002$, $n = 9$, $P = 0.909$) (Fig. 22). Transforming the data and fitting a variety of sigmoid curves to the data did not result in any regression models that were statistically significant. Yearly median SLCL of stranded turtles differed among study years ($H = 58.321$, $df = 8$, $P < 0.001$). Turtles found stranded in 1989 and 1997 were larger than those found in 1992 (1989: $Q = 4.353$, $P < 0.05$; 1997: $Q = 3.831$, $P < 0.05$), 1993 (1989: $Q = 5.633$, $P < 0.05$; 1997: $Q = 5.160$, $P < 0.05$), and 1994 (1989: $Q = 4.280$, $P < 0.05$; 1997: $Q = 3.626$, $P < 0.05$). Also, turtles found stranded in 1993 were smaller than those found in 1995 ($Q = 3.575$, $P < 0.05$) and 1996 ($Q = 4.202$, $P < 0.05$).

No significant first-order autocorrelation was found between SLCL by year and year – 1 for netted turtles ($r = 0.119$, $n = 8$, $P = 0.749$). Linear models were not useful to describe the relationship between year and yearly mean SLCL of netted turtles ($r^2 = 0.310$, $n = 9$, $P = 0.119$) (Fig. 22). Transforming the data and fitting a variety of sigmoid curves to the data did not result in any regression models that were statistically significant. Yearly median SLCL of netted turtles differed among study years ($H = 35.496$, $df = 8$, $P < 0.001$); turtles netted in 1996 were smaller than those netted 1991 ($Q = 3.540$, $P < 0.05$), 1994 ($Q = 4.215$, $P < 0.05$), and 1995 ($Q = 3.855$, $P < 0.05$). Yearly CPUE was inversely

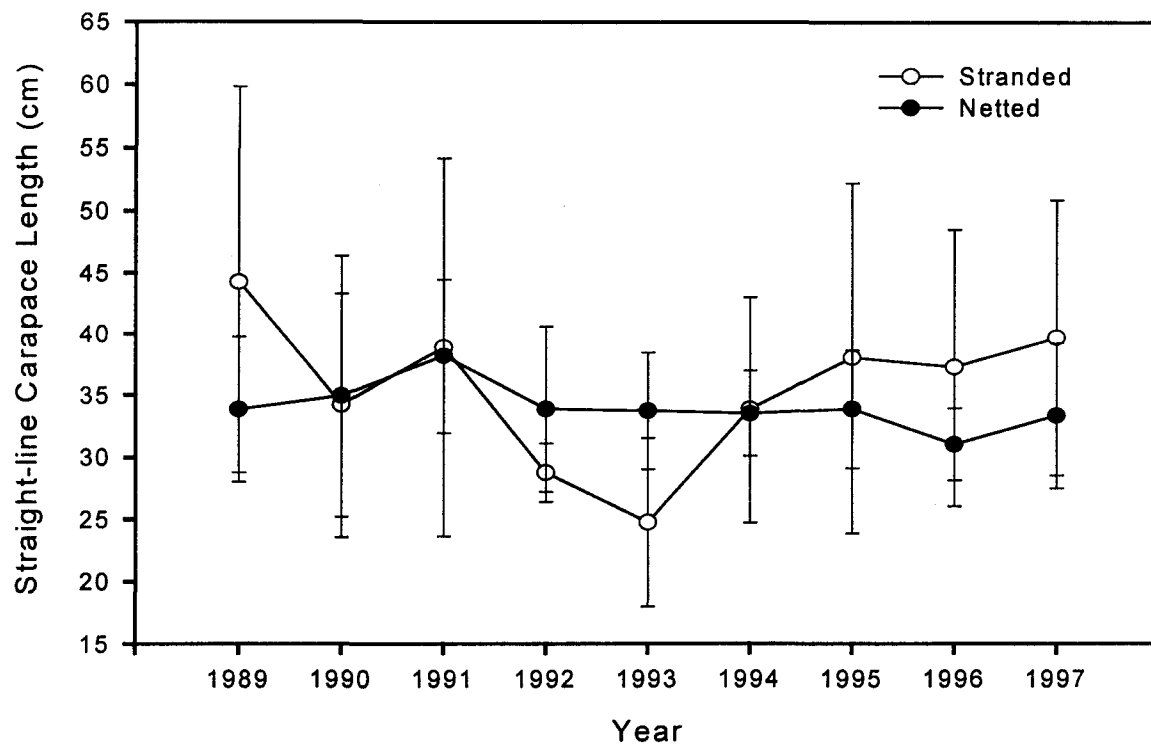


Fig. 22. Yearly mean ($\pm$ SD) straight-line carapace lengths (cm) of *Chelonia mydas* found stranded on the Texas coast and netted at the Mansfield Channel jetties from 1989 to 1997.

correlated with yearly mean SLCL ($r^2 = 0.569$, $n = 9$, $P = 0.019$). The equation of the regression line is: $CPUE = 40.126 - (1.078 * SLCL)$.

Yearly mean SLCLs of stranded and netted turtles were not correlated ($r = -0.0167$, $n = 9$, $P = 0.948$) (Fig. 22).

Size by season.—Median SLCL of stranded turtles differed among seasons ($H = 67.883$, $df = 3$, $P < 0.001$); turtles found stranded during the winter were larger than those found in the spring ($Q = 6.408$, $P < 0.05$), summer ($Q = 4.908$, $P < 0.05$), and fall ($Q = 5.225$, $P < 0.05$). Median SLCL of netted turtles (at initial capture within a season) did not differ among seasons ($H = 2.495$, $df = 3$, $P = 0.476$). During the winter, stranded turtles were larger than netted turtles ($T = 1137.000$, $n(\text{small}) = 16$, $n(\text{big}) = 241$, $P = 0.001$). However, median SLCLs of stranded and netted turtles did not differ during the spring ($T = 1736.500$, $n(\text{small}) = 33$, $n(\text{big}) = 61$, $P = 0.182$), summer ($T = 3989.500$, $n(\text{small}) = 62$, $n(\text{big}) = 71$, $P = 0.458$), and fall ($T = 3194.500$, $n(\text{small}) = 45$, $n(\text{big}) = 110$, $P = 0.214$).

Size by sex.—For those stranded turtles measured, median SLCLs of females ($n = 46$), males ($n = 49$), and unknown sex turtles ($n = 314$) did not differ ($H = 4.490$, $df = 2$, $P = 0.106$). Median SLCLs for netted turtles ($n = 230$ blood samples) identified as females ($n = 175$), males ($n = 38$), and unknown ($n = 17$) did not differ ($H = 1.434$, $df = 2$, $P = 0.488$). Median SLCLs of stranded females

and netted females did not differ ($T = 5513.500$, $n(\text{small}) = 46$, $n(\text{big}) = 175$, $P = 0.292$). Median SLCLs of stranded males and netted males did not differ ($T = 1533.000$, $n(\text{small}) = 38$, $n(\text{big}) = 49$, $P = 0.236$). However, the median SLCL was larger for stranded unknown sex turtles than for netted unknown sex turtles ($T = 1878.000$, $n(\text{small}) = 17$, $n(\text{big}) = 314$, $P = 0.014$).

Discussion

Yearly numbers, monthly numbers, sex ratios, and sizes were compared for turtles found stranded in Texas and netted at the Mansfield Channel. Stranding and capture data corresponded in some instances, but differed in others. For those areas of data correspondence, capture data from the Mansfield Channel may be useful as a predictor of the overall green turtle population in Texas.

Yearly numbers.—Yearly numbers of stranded turtles and yearly CPUE followed very similar trends (Fig. 17), especially when the point for 1997 was eliminated. It is likely that 1997 was an outlier because the largest hypothermic stunning event on the Texas coast in decades, was documented then (see Chapter II). Thus, yearly CPUE at the Mansfield Channel may be a useful predictor for the yearly number of sea turtles found stranded on the Texas coast, at least during years without atypical catastrophic events. Furthermore, yearly CPUE at the Mansfield Channel may be an index to overall population trends for green turtles in Texas. However, additional studies are needed to quantify the

relationships between abundance and both CPUE data and stranding numbers.

Both stranding numbers and CPUE varied considerably during different years, but there was no clear increase or decrease over the study years (except for an increase in offshore strandings). A clearer trend might have been found had netting been conducted for more years. Based on long-term CPUE data, Ehrhart and Redfoot (1995) speculated that the juvenile green turtle population of the central Indian River system, Florida grew during the 1980s and early 1990s.

Monthly numbers.—The monthly trends of stranding numbers and CPUE differed dramatically. Strandings were most numerous during the winter and CPUE was highest in the summer and fall. Thus, monthly CPUE data from the Mansfield Channel are a poor predictor for monthly variations of overall green turtle strandings in Texas.

Monthly variations in stranding numbers may have reflected variations in green turtle abundance in Texas. Most strandings were documented in south Texas, within the Lower Laguna Madre. During the fall and winter, south Texas waters could include a mixture of year-round residents and migrants from more northern waters. Thus, green turtle abundance may have been higher in some south Texas areas during the winter. However, monthly variations in stranding numbers could have also reflected seasonal variations in mortality. Strandings were highly dominated by hypothermic stunnings, which occurred during the

winter (see Chapter II). Doughty (1984) reported that large numbers of green turtles were found washed ashore in Texas during periods of freezing temperatures in the 1800s. He did not mention strandings during other times of the year, but several human-related sources of mortality that occur today were not present then.

Monthly variations in CPUE probably reflected seasonal differences in turtle abundance at the Mansfield Channel. However, vulnerability of green turtles to capture could vary seasonally and also influence CPUE. Most captures of green turtles by the fishery that operated in Texas passes and lagoons during the 1800s were between June and September (Doughty, 1984), but it is unknown if capture effort was evenly distributed throughout the year. Coyne (1994) logged higher CPUE during the winter for green turtles caught in entanglement nets set in the Lower Laguna Madre. Ehrhart and Redfoot (1995) found a significant increase in green turtle CPUE within the Indian River system during the winter months, particularly in January and February. The seasonal differences in CPUE for the Mansfield Channel, versus the Lower Laguna Madre and Indian River system, could be related to differences in the amount of access to oceanic waters. It would be much easier for green turtles to leave the Mansfield Channel jetty area during periods of cold water temperatures, leading to decreased population levels and CPUE there during that time. However, green turtle abundance may actually increase within the Lower Laguna Madre during the winter if turtles indeed emigrate there during the fall and winter and

remain there, unable to escape during periods of freezing air temperatures.

Sex ratio.—Sex ratio data for the stranded and netted turtles did not correspond well. The sex ratio of stranded turtles (0.94F:1.00M) was slightly male dominated, but the sex ratio of netted turtles (4.16F:1.00M) was significantly female dominated. Males did not outnumber females in any of the other published studies of sex ratio for immature green turtles (see Chapters II, IV). However, the sex ratio of netted turtles was within the range found during these other investigations.

It seems doubtful that both of these sex ratios were accurate and that stranded and netted turtles differed so greatly in sex composition. Thus, methodology to identify sex of stranded and/or netted turtles may have led to data skewing or inaccuracies.

General necropsies were performed on many of the dead stranded turtles by a limited number of STSSN participants and veterinarians. During necropsy the sex of the turtle was determined by visual examination of the gonads. It is possible that some of the investigators misidentified the sex of stranded turtles. Most examined were small juveniles and it is more difficult to differentiate the gonads for smaller turtles. Also, it is possible that the gonads of females decomposed faster (D. Owens, pers. comm.), yielding an underestimate of the number of females.

Sex of netted turtles was determined by serum testosterone

radioimmunoassay. Serum testosterone level can be used as an accurate indicator of sex in immature sea turtles (Owens et al., 1978; Wibbels et al., 1987, 1989; Wibbels, 1988). Although results from such analyses can be influenced by a variety of factors (Schroeder and Owens, 1994; Gregory, 1996), sex ratio results from the netting study did not appear to be biased towards females due to different analysis laboratories, inaccurate sex classification criteria, sizes of the turtles, or seasons when the samples were obtained (see Chapter IV). It would have been beneficial to conduct laparoscopic examinations of gonads to verify sex of netted turtles, but this was not done.

For the 471 stranded turtles, only 97 were identified as females or males. Most of the remaining 374 stranded turtles were not examined, but a few were necropsied and could not be identified as males or females. Of the 117 netted individuals sampled for blood, 129 were classified as females, 31 as males and 17 as unknown; 141 other individuals were not sampled. Thus, over 50% of both stranded and netted turtles were not examined for sex. Different sex ratios might have been found had more turtles been analyzed.

Size.—The size range for stranded turtles (10.6-99.2 cm SLCL) was larger than for netted turtles (24.7-52.0 cm SLCL). Also, turtles found stranded were larger ($\bar{x}$ = 37.8 cm SLCL) than those netted ($\bar{x}$ = 32.4 cm SLCL). Thus, based upon size composition comparisons, turtles netted at the Mansfield Channel should not be used at a strict index of the overall population of green turtles occurring

within Texas waters. Use of netting data as an index to strandings may only be valid for a limited geographical area in the vicinity of the netting site. Mendonca and Ehrhart (1982) and Witherington and Ehrhart (1989a) found similar size distributions for net captured and cold stunned green turtles from the Indian River system.

Turtles found stranded offshore ($\bar{x}$ = 32.8 cm SLCL) were smaller than turtles found stranded inshore ($\bar{x}$ = 40.3 cm SLCL) and thus the sizes of netted turtles may be more reflective of turtles found stranded offshore. However, the range SLCLs for turtles found stranded offshore (10.6-99.2 cm) was much larger than for netted turtles. The smallest and largest of stranded turtles would probably not have been captured in entanglement nets set at the Mansfield Channel, since neither have been documented stranded in the study site and the smallest turtles would have escaped through the net mesh.

The SLCLs of green turtles netted in the Lower Laguna Madre (range = 29.6-81.5, $\bar{x}$ = 44.6) were significantly larger than of those at the Brazos Santiago Pass (range = 22.1-47.9, $\bar{x}$ = 31.3). Similarly, Guseman and Ehrhart (1990) found that green turtles netted within the Indian River lagoon system, Florida, were significantly larger than turtles netted at a *Sabellariid* reef in nearby nearshore waters. Differences in size compositions of the turtles at the jetty and nearshore areas versus in the inshore areas may reflect differences in habitat use of these areas. Turtles that enter these inshore areas may establish residency for longer periods of time and grow to a size larger than most found at

the jetties and reefs.

Size data from the netting study may be a more useful index for certain seasons or sexes of turtles. During the winter, turtles found stranded were larger than those netted, but no other seasonal differences were recorded in sizes among the two groups. Unknown sex stranded turtles were larger than unknown sex netted turtles, but no differences were found for males and females.

Conclusions.—One of the most important uses of CPUE data is for the assessment of long-term population trends. Yearly CPUE at the Mansfield Channel may be a useful predictor for the yearly number of sea turtles found stranded on the Texas coast. However, netting data from Mansfield Channel cannot be used as an absolute index to understand all aspects of the overall green turtle population in Texas. Strandings were most numerous in south Texas, particularly inshore in zone 21. The Mansfield Channel jetties are located in zone 21. Although, netting data from the epicenter of the strandings (Lower Laguna Madre) would likely provide a better index of the overall green turtle population in Texas, CPUE at the Mansfield Channel jetties was much higher than in the Lower Laguna Madre. If index areas are established for the purpose of gathering biological and trend data for green turtles in Texas, it may be necessary to establish a series of areas to cover the full spectrum of variations that were documented during the present study. However, directed

capture netting studies are expensive, labor-intensive, and potentially dangerous to both netted turtles and netting personnel. Researchers must ensure that netting protocols are employed that will allow comparisons of CPUE data between sites, but these standardizations are sometimes impossible because habitat conditions limit the gear and protocols that can be used. Directed capture studies can greatly advance understanding of sea turtle biology (Bjorndal, 1999). However, as currently conducted, these studies may merely provide an index to a specific area and hence should not replace STSSN efforts.

CHAPTER VI

TRACKED GREEN TURTLES

Introduction

Green turtles (*Chelonia mydas*) were commercially exploited on the Gulf coasts of Texas and Mexico during the late 1800s (Smith, 1954; Hildebrand, 1982; Doughty, 1984; Witzell, 1994a, 1994b). However, the population plummeted and the green turtle was listed as a threatened species in the U.S. in 1973. The Lower Laguna Madre, Mansfield Channel, and Brazos Santiago Pass are important developmental habitats for green turtles in Texas (see Chapters II, IV). However, knowledge of seasonal variations in movements and habitat utilization of these areas is limited. It is unknown whether juvenile green turtles leave the Mansfield Channel during the winter (at least temporarily) and whether they use the Mansfield Channel as a passageway between the Laguna Madre and Gulf of Mexico. Furthermore, juvenile green turtle usage of western Gulf of Mexico waters off Mexico and movements between there and south Texas are poorly documented.

Changes in temperatures have profound impacts on the behavior and survival of sea turtles (Mendonca, 1983; Birse and Davenport, 1987; Read et al., 1996; Davenport, 1997; Lutcavage and Lutz, 1997). As winter approaches and water temperatures drop, many sea turtles emigrate from temperate areas and migrate towards warmer tropical waters (Carr and Caldwell, 1956; Byles,

1988; Witherington and Ehrhart, 1989a; Keinath, 1993; Chester et al., 1994; Coles et al., 1994; Epperly et al., 1995a, 1995b, 1995c; Lutcavage and Lutz, 1997), thereby reducing their vulnerability to cold stunning. However, many green turtles inhabit south Texas inshore waters during the winter (Coyne, 1994; Shaver, 1990a, 1990b, 1994; Arms, 1996). Turtles can safely overwinter and remain active there during some years (Arms, 1996), but face the threat of hypothermic stunning during years when severe freezes occur. As water temperatures decrease, juvenile green turtles may move in search of warmer waters located within deeper areas or in Mexico.

Satellite technology has been used to investigate the movements of sea turtles since the late 1970s (Stoneburner, 1982; Timko and Kolz, 1982). Earlier transmitters were relatively large and hence could only be attached to large sea turtles. Most satellite tracking studies have investigated the movements of adult sea turtles (Stoneburner, 1982; Renaud, 1995a; Beavers and Casano, 1996; Plotkin et al., 1996; Renaud et al., 1996a; Sakamoto et al., 1997), particularly within nesting seasons and between nesting and foraging areas (Balazs, 1976, 1994; Timko and Kolz, 1982; Byles, 1989; Byles and Dodd, 1989; Hays et al., 1991; Hays, 1992; Keinath and Musick, 1993; Balazs et al., 1994; Byles and Plotkin, 1994; Byles and Swimmer, 1994; Plotkin, 1994; Plotkin et al., 1995, 1996; Byles et al., 1995; Papi et al., 1995, 1997; Luschi et al., 1996, 1998; Sakamoto et al., 1997; Hughes et al., 1998). However, results from these studies are not directly applicable to juveniles, which do not undertake

reproductive migrations between nesting and foraging grounds. A few studies have been undertaken to investigate the movements of juvenile sea turtles in near-shore areas (Byles, 1988; Renaud, 1990, 1995a; Keinath, 1993; Renaud and Carpenter, 1994; Renaud et al., 1994b, 1996b, 1998; Gitschlag, 1996; Keinath et al., 1996; Williams and Renaud, 1998) and pelagic areas (Bolten et al., 1995). However, previous to this study, only two juvenile green turtles were satellite tracked in the Gulf of Mexico; these two turtles were tagged in Matagorda Bay, Texas and tracked for less than a year (Williams and Renaud, 1998).

This study was undertaken to gain information on green turtles in Texas waters through satellite tracking of 30 individuals from 1995 to 1998. The objectives of this study were to (1) investigate the long-distance and long-term movements of juvenile green turtles in the Mansfield Channel, Laguna Madre, and Gulf of Mexico and (2) investigate the seasonal and yearly variations in movements and habitat utilization within those waters. This study addressed several recovery task priority items for the green turtle (NMFS and USFWS, 1991a) and many high priority information needs outlined by Bjorndal (1999) for the management and conservation of sea turtles.

Materials and Methods

PTT deployment.—Thirty juvenile green turtles were outfitted with satellite (UHF) radio transmitters. These platform transmitter terminals (PTTs),

configured in a backpack style, were manufactured by Telonics, Inc., of Mesa, Arizona, and included models ST-10 ($n = 11$), ST-6 ($n = 16$), and ST-14 ($n = 3$) (Tables 6, 7). The two styles of ST-10 PTTs used differed slightly in dimensions (Table 6). One PTT (7682) was applied to a turtle that was found cold stunned (see Chapter II) on Boca Chica Beach, near the entrance to South Bay ($26^{\circ}02'45''\text{N}$, $97^{\circ}11'48''\text{W}$), on 5 February 1996, and released near the stranding location on 9 February 1996. Twenty-nine were applied on turtles that were netted at the Mansfield Channel (see Chapter IV) from 14 April 1995 through 3 December 1997 (Table 8). The 29 had been netted at the Mansfield Channel from 1-6 times at the time of PTT deployment and were netted there from 0-2 subsequent times after deployment (Tables 8, 9). One netted turtle that was tracked (7676) was caught at Brazos Santiago Pass on 14 January 1993 and subsequently on six occasions at the Mansfield Channel (Table 8); this was the only individual tracked known to have ever been tagged at a location other than the Mansfield Channel.

Most PTTs were deployed during the fall (September-November) ($n = 17$) with decreasing numbers deployed during the winter (December-February) ($n = 7$), spring (March-May) ($n = 5$), and summer (June-August) ($n = 1$), to focus tracking efforts on months with the highest probability of documenting long-distance movements. The 30 turtles ranged from 30.6 to 53.3 cm SLCL ($\bar{x} = 37.9 \pm 5.2$ cm) and 3.2 to 27.7 kg weight ($\bar{x} = 7.7 \pm 4.6$ kg). For all PTTs, PTT weight did not exceed 10% of the weight of the turtle (Byles and Keinath, 1990).

Table 6. ST-10, ST-6, and ST-14 specifications.

	ST-10a	ST-10b	ST-6	ST-14
N	3	8	16	3
Dimensions (cm)	10.0x4.8x2.0	13.4x4.7x1.9	15.0x6.5x5.0	16.5x9.8x3.0
Weight in air (g)	125	200	475	750
Battery (cells)	two 2/3 A	four 2/3 A	four C	three C
Power output (watt)	0.25 to 0.40	0.25 to 0.40	0.25 to 0.40	1.0

Table 7. PTT model, duty cycle, and attachment. Attachment sites are the lodging in Port Mansfield, Texas (PM), Padre Island National Seashore lab (PAIS), beach at the netting site (beach), or Gladys Porter Zoo (GPZ).

PTT	Model	Duty	PTT	Attachment	Attachment	Antenna	Fairing
		cycle	age	site	method		
7660	ST-10b	8/52	new	PM	straps	forward	no
7661	ST-10b	8/52	new	PAIS	straps	forward	no
7662	ST-6	6/6	new	PM	straps	forward	yes
7663	ST-6	6/6	new	PM	straps	forward	yes
7667	ST-10a	6/6	new	beach	fiberglass only	backward	no
7668	ST-10a	6/6	new	PM	fiberglass only	backward	no
7669	ST-10a	6/6	new	PM	fiberglass only	backward	no
7670	ST-10b	8/52	new	PAIS	straps	forward	no
7671	ST-6	6/6	new	PAIS	straps	forward	no
7671A	ST-6	6/6	refurbished	PM	straps	forward	yes
7672	ST-14	6/6	new	PM	straps	forward	no
7672A	ST-6	6/6	new	PM	straps	forward	yes
7673	ST-10b	8/52	new	PAIS	straps	forward	no
7674	ST-6	6/6	new	PM	straps	forward	no

Table 7. Continued.

PTT	Model	Duty	PTT	Attachment	Attachment	Antenna	Fairing
		cycle	age	site	method		
7674A	ST-6	6/6	refurbished	PM	straps	forward	yes
7675	ST-6	6/6	new	PAIS	harness	forward	no
7675A	ST-6	6/6	new	PM	straps	forward	no
7676	ST-6	6/6	new	PM	straps	forward	no
7676A	ST-10b	8/52	new	PAIS	straps	forward	no
7677	ST-6	6/6	new	PAIS	straps	forward	no
7677A	ST-6	6/6	new	PM	straps	forward	no
7678	ST-6	6/6	new	PAIS	straps	forward	no
7680	ST-6	6/6	new	PAIS	harness	forward	no
7681	ST-14	6/6	new	PAIS	harness	forward	no
7682	ST-14	6/6	new	GPZ	fiberglass only	forward	no
7683	ST-10b	8/52	new	PM	harness	forward	no
7683A	ST-10b	8/52	new	PM	straps	forward	no
7684	ST-10b	8/52	new	PM	straps	forward	no
7685	ST-6	6/6	new	PM	straps	forward	yes
7698	ST-6	6/6	new	PAIS	harness	forward	no

Table 8. PTT deployment, transmission period, and dates captured before deployment.

PTT	Date deployed	Last transmission	Number	
			of days	Dates captured before deployment
7660	25 Sept. 1996	10 June 1997	258	16 July 1996, 12 Sept. 1996
7661	17 Sept. 1996	9 May 1997	234	-
7662	24 Oct. 1996	4 July 1997	253	-
7663	15 Nov. 1996	20 June 1997	217	13 Aug. 1996
7667	2 May 1995	1 June 1995	30	-
7668	14 Apr. 1995	3 July 1995	80	-
7669	14 Apr. 1995	5 June 1995	52	18 May 1993, 15 June 1993, 22 Oct. 1993, 16 Nov. 1993, 8 Dec. 1993
7670	14 Oct. 1995	25 Oct. 1995	11	-
7671	14 Oct. 1995	25 Feb. 1996	134	-
7671A	11 Oct. 1996	17 May 1997	218	-
7672	2 Dec. 1995	31 Jan. 1996	60	-
7672A	11 Oct. 1996	12 Feb. 1997	124	12 Sept. 1996

Table 8. Continued.

PTT	Date deployed	Last transmission	Number	
			of days	Dates captured before deployment
7673	11 Nov. 1995	11 July 1996	243	-
7674	1 Dec. 1995	13 May 1996	164	8 Nov. 1994, 21 Mar. 1995, 6 July 1995, 2 Nov. 1995
7674A	11 Oct. 1996	26 Oct. 1997	380	-
7675	17 May 1996	17 Nov. 1996	183	18 April 1996
7675A	17 Sept. 1997	23 Feb. 1998	159	-
7676	1 Dec. 1995	9 Dec. 1995	8	16 Sept. 1993, 13 Apr. 1994, 16 Aug. 1994, 18 Oct. 1994, 8 Nov. 1994
7676A	17 Sept. 1996	2 Jan. 1997	107	-
7677	11 Nov. 1995	18 Jan. 1997	434	-
7677A	3 Dec. 1997	4 July 1998	213	13 Apr. 1995, 2 May 1995, 8 Apr. 1997
7678	11 Nov. 1995	24 July 1996	256	-
7680	11 Nov. 1995	13 Sept. 1996	307	18 Oct. 1994

Table 8. Continued.

PTT	Number			
	Date deployed	Last transmission	of days	Dates captured before deployment
7681	11 Nov. 1995	18 Nov. 1996	373	-
7682	9 Feb. 1996	2 Sept. 1996	206	-
7683	14 Dec. 1995	29 Feb. 1996	77	-
7683A	25 Sept. 1996	23 Oct. 1996	28	-
7684	2 Dec. 1995	17 Aug. 1996	259	-
7685	5 Mar. 1997	31 May 1997	87	-
7698	19 July 1996	11 June 1997	327	-

Table 9. Recapture of PTT outfitted turtles or transmitters.

PTT	Number of			Comments
	Recapture date	Recapture method	days post-deployment	
7668	14 Sept. 1995	netted	153	transmitter gone
7669	8 Aug. 1985	netted	116	transmitter gone
7671	12 Jan. 1996	stranded	90	transmitter and straps in-tact
7671	12 March 1996	stranded	149	weak link deteriorated, antenna bent
7674	14 May 1996	netted	164	weak link gone, straps frayed
7675	21 May 1996	netted	4	weak link rusting
7675	12 Sept. 1996	netted	118	transmitter and harness lifted and moved posteriorly
7676A	23 Oct. 1996	netted	36	transmitter and straps in-tact
7683A	23 Oct. 1996	netted	28	transmitter and straps in-tact
7683A	8 July 1997	netted	286	transmitter gone
7685	18 June 1997	netted	105	transmitter gone
7685	4 July 1997	transmitter found	121	weak link and most straps gone, antenna coating abraded

The PTTs were applied to 18 females, six males, and six turtles for which sex was not identified. Sex of one male was determined by visual examination of gonads during necropsy. Sex of the females and other males was determined through analysis of serum testosterone assays of collected blood samples (see Chapter IV). Turtles for which sex was not identified included two individuals that were identified as both female and unknown through blood samples and four individuals from which no blood samples were analyzed.

Turtles were transported to various locations for PTT attachment, including the field team's lodging in Port Mansfield (n = 17), Padre Island National Seashore laboratory (n = 11), beach at the netting site (n = 1) and Gladys Porter Zoo (n = 1) (Table 7). Three of the PTTs were attached "backwards", with the antenna oriented posteriorly, and the remainder were attached "forwards", with the antenna oriented anteriorly (Table 7). PTTs were attached to turtles with thin layers of polyester resin and fiberglass cloth over the second neural scute of the carapace (Byles and Keinath, 1990; Renaud et al., 1993, 1996a; Balazs, 1994; Balazs et al., 1994, 1996; Plotkin, 1994, 1998; Plotkin et al., 1995). Four were attached with fiberglass only. The other 26 were also secured with harnesses constructed of neoprene cloth applied anteriorly and posteriorly (termed "harness", n = 5) or nylon strapping applied laterally (termed "straps", n = 21) (Table 7). These harnesses were patterned after those previously used on sea turtles (Standora et al., 1982; Stoneburner, 1982; Eckert and Eckert, 1986; Byles, 1989; Keinath et al., 1989; Byles and Keinath, 1990;

Keinath and Musick, 1993; Hughes et al., 1998). The nylon strapping and neoprene had breakaway or corrodible links (Eckert and Eckert, 1986; Byles and Keinath, 1990) that would deteriorate and allow the turtle to free itself from the material. Six of the ST-6 PTTs were applied with a posterior fairing, to decrease drag (Watson and Granger, 1998) (Table 7). Turtles were held from 3 h to 4 days for PTT attachment and subsequently were released at the capture ($n = 29$) and stranding ($n = 1$) sites.

Turtle movements were monitored via satellite until transmitters were removed or transmissions ceased due to transmitter detachment or failure. Transmitters were programmed with two different transmission (duty) cycles to extend the life of the battery; these two cycles were 6 h on/6 h off ($n = 22$) and 8 h on/52 h off ($n = 8$) (Table 7). A saltwater switch was used to determine dive parameters and suppress the transmissions while underwater to conserve battery life (Tomkiewicz, 1988; Keinath, 1993; Keinath and Musick, 1993; Beavers and Casano, 1996). Polar-orbiting NOAA Tiros-N satellites received transmissions, but only when the PTT was "on", a satellite was overhead, and the PTT was at the surface (Eckert, 1998; Plotkin, 1998). The locations of the turtles (latitude and longitude) were calculated by the Argos Data Collection and Location System from the Doppler shift in transmission frequency detected by a satellite as it approached and then moved away from the transmitter (Harris et al., 1990; Mate et al., 1992; Britten et al., 1995; Eckert, 1999). During each overpass, the satellite remained overhead an average of 10 min (Eckert, 1998).

Transmitters broadcasted data (messages) every 42 to 46 sec, at a frequency of 401.65 MHz, with transmission power outputs between 0.25-1.0 watts (Table 6). Data received by the satellites were distributed to ground stations and processed and disseminated by Argos (Argos, 1996).

For each transmission, Argos provided data on PTT identification number, latitude and longitude of the PTT, location quality, date and time of PTT transmission, number of messages used to calculate PTT location, and dive data. Additionally, for ST-6 and ST-14 PTTs, internal temperature of the PTT housing was reported, with an accuracy of ± 2 C.

For each location transmission, two points were reported as possible locations and typically one of those was obviously incorrect. The accuracy of latitude and longitude calculations was dependent on the number of messages received from a PTT during a satellite pass and the angle to the satellite from the PTT. Argos supplies location quality indices (LQ) for each calculated latitude and longitude; these include LQ 3, 2, 1, 0, A, B, or Z, with "3" the most accurate and "0" the least accurate (Eckert, 1999). Argos has estimated that accuracy in latitude and longitude for LQ 3 is less than 150 m, for LQ 2 is from 150-350 m, for LQ 1 is from 350-1000 m, and for LQ 0 is more than 1000 m (Argos, 1996). Argos provides no estimation of location accuracy for LQ A and LQ B, but this does not mean that locations are necessarily less accurate. LQ Z are rejected, invalid locations. Argos calculated LQ using two different pieces of software. The standard location feature (PRV[/A]) output was the primary

one used to identify LQ during this study; the diagnostics feature (DIAG) output was used to fill in gaps from the PRV[/A] output. When Argos did not provide a LQ for a transmission from either feature, the LQ U (unknown) was assigned.

Location data were reviewed and unrealistic locations were rejected (Keinath and Musick, 1993; Plotkin, 1994, 1998; Luschi et al., 1998; Eckert, 1999).

Locations were rejected for one or more of the following reasons: (1) only 2 transmissions were received from a transmitter during a satellite pass and transmissions were identical; (2) the location calculated for a transmitter was on land (discerned by zooming in on points using ESRI ArcView GIS software version 3.0a); and (3) the rate of movement (km/h) of a turtle between two consecutive locations exceeded 6 km/h (Plotkin, 1998). Sequence of movement was plotted for each turtle using locations that were not rejected. Graphs of latitude and temperature by date were graphed for each PTT with 10 or more accepted locations.

Analysis of data.—All means are followed by $\pm$ one standard deviation. The number of days from the date deployed to the date of the last transmission (D), number of transmissions received (T), number of hours “on” (T hours), transmission success rate (TSR), number of locations mapped (L), number of location hours (L hours), and location success rate (LSR) were calculated for each transmitter. L hours were the number of T hours minus the number of hours the transmitter/turtle was beached. TSR was calculated as T divided by T

hours, multiplied by 100. LSR was calculated as L divided by L hours, multiplied by 100.

Data were tested for normality and homogeneity of variance prior to using parametric procedures. When parametric assumptions were not met, equivalent non-parametric procedures were used. A t-test was used to compare the mean D from ST-6 PTTs and ST-10 PTTs. Mann-Whitney rank sum tests were used to compare the median T, median L, median TSR, and median LSR from ST-6 PTTs and ST-10 PTTs. The mean D from PTTs affixed to turtles that were recaptured during netting at the Mansfield Channel after PTT deployment and those that were not recaptured there were compared using a t-test. Mann-Whitney rank sum tests were used to compare the median T, median L, median TSR, and median LSR from turtles that were and were not recaptured. T-tests were used to compare the mean D, mean L, and mean LSR from females and males. Mann-Whitney rank sum tests were used to compare the median T and median TSR for females and males.

Results

Tracking duration and location quality.—Overall, 4,746 transmissions were received (Appendix IV). The numbers of transmissions for each LQ are as follows: 3 (n = 554), 2 (n = 255), 1 (n = 223), 0 (n = 793), A (n = 858), B (n = 1979), Z (n = 67), and U (n = 17) (Appendix V). Of these, 940 locations were mapped (Appendices IV, VI). The 940 mapped locations included LQ 3 (n =

60), 2 ($n = 37$), 1 ($n = 45$), 0 ($n = 165$), A ($n = 225$), and B ($n = 408$); all Z and U locations were rejected. The majority of the 3,806 transmissions that were not mapped were transmissions that failed to yield a location. However, approximately 800 were not mapped because the transmissions were after the transmitter/turtle was beached and approximately 300 locations were not mapped because the locations were rejected. For some PTTs (7672A, 7675, and 7682), the points with the highest accuracy (LQ 3) were in a cluster near the Mansfield Channel (Appendix VI). Also, more LQ 3 and 2 locations were documented during the colder months (October-March) than during warmer months.

For the 30 PTTs, D ranged from 8 to 434 days ($\bar{x} = 183 \pm 116$ days) (Table 8), T from 10 to 736 ($\bar{x} = 158 \pm 167$), TSR from 2.50 to 28.57 ($\bar{x} = 9.58 \pm 6.80$), L from 0 to 121 ($\bar{x} = 31 \pm 30$), and LSR from 0.00 to 11.43 ($\bar{x} = 2.16 \pm 2.27$) (Appendix IV).

The mean D from ST-6 PTTs ($\bar{x} = 217 \pm 110$, $n = 16$) was significantly larger than from ST-10 PTTs ($\bar{x} = 125 \pm 101$, $n = 11$) ($t = -2.187$, $df = 25$, $P = 0.038$). The median T from ST-6 PTTs was significantly larger than from ST-10 PTTs ($T = 76.500$, $n(\text{small}) = 11$, $n(\text{big}) = 16$, $P < 0.001$). The median L from ST-6 PTTs was significantly larger than from ST-10 PTTs ($T = 80.000$, $n(\text{small}) = 11$, $n(\text{big}) = 16$, $P < 0.001$). However, the median TSR for ST-6 and ST-10 PTTs did not differ ($T = 137.00$, $n(\text{small}) = 11$, $n(\text{big}) = 16$, $P = 0.416$) and the median LSR for ST-6 and ST-10 PTTs did not differ ($T = 138.00$, $n(\text{small}) = 11$, $n(\text{big}) = 16$, P

= 0.444). For the three ST-14 PTTs deployed, D ranged from 60-373 days ($\bar{x}$ = 213 $\pm$ 157 days).

The mean D from PTTs affixed to turtles that were not recaptured during netting at the Mansfield Channel after PTT deployment ($\bar{x}$ = 208 $\pm$ 121, n = 22) was significantly larger than the mean D from those that were recaptured there one or two times after deployment ($\bar{x}$ = 100 $\pm$ 56, n = 7) (t = 2.258, df = 27, P = 0.032). However, turtles that were and were not recaptured did not differ for the median T (T = 81.000, $n(\text{small})$ = 7, $n(\text{big})$ = 22, P = 0.231), median L (T = 74.500, $n(\text{small})$ = 7, $n(\text{big})$ = 22, P = 0.126), median TSR (T = 103.00, $n(\text{small})$ = 7, $n(\text{big})$ = 22, P = 0.939), and median LSR (T = 80.00, $n(\text{small})$ = 7, $n(\text{big})$ = 22, P = 0.212).

No major differences were noted in the movement patterns of females and males (Appendix VI). The mean D from females ($\bar{x}$ = 180 $\pm$ 112, n = 18) and males ($\bar{x}$ = 166 $\pm$ 72, n = 6) did not differ (t = 0.286, df = 22, P = 0.777). The median T received from females and males did not differ (T = 83.500, $n(\text{small})$ = 6, $n(\text{big})$ = 18, P = 0.594). The mean L gathered from females ($\bar{x}$ = 29 $\pm$ 27, n = 18) and males ($\bar{x}$ = 31 $\pm$ 26, n = 6) did not differ (t = -0.223, df = 22, P = 0.826). However, the median TSR for females was significantly less than the median TSR for males (T = 106.000, $n(\text{small})$ = 6, $n(\text{big})$ = 18, P = 0.042) and the mean LSR for females ($\bar{x}$ = 1.478 $\pm$ 1.002, n = 18) was significantly less than the mean LSR for males ($\bar{x}$ = 2.757 $\pm$ 1.910, n = 6) (t = -2.140, df = 22, P = 0.044).

The last transmission ranged from between 1 June 1995 and 4 July 1998 for

the various PTTs (Table 8). Some PTTs ceased transmitting location data, but continued to transmit other data for an additional 2-4 weeks. Transmitters were still attached to four individuals that were netted at the Mansfield Channel (Table 9). The transmitter was removed from one of those turtles (7674) on 14 May 1996 because it was thought that this PTT was no longer functioning. One transmitter (7685) was found washed ashore on 4 July 1997 (Table 9). This transmitter must have been shed from the turtle since it was missing when this turtle was captured on 18 June 1997. Three other turtles were recaptured (through netting at the Mansfield Channel or stranding) and found to have shed their transmitters (Table 9). The four PTTs were detected missing from 105-286 days ($\bar{x} = 165 \pm 83.2$ days) post-deployment.

One turtle (7671) outfitted with a PTT was later found stranded twice (Table 9). The first time it was found cold stunned alive on 9 January 1996, taken to a rehabilitation facility, and released on 13 January 1996. Locations for the 4 days in rehabilitation were included in the T (Appendix IV) and LQ (Appendix V) data, but not included in the tracking map (Appendix VI) or temperature graph (Appendix VII) for this turtle. The second time it was found stranded dead. Transmissions were intentionally terminated when the turtle was found dead on 25 February 1996, with the first day of eliminated data on 26 February 1996. The turtle was necropsied by Dr. Mike Hughes (Corpus Christi Animal Clinic, Corpus Christi, Texas). The clinical diagnosis was that there was a hole in the ventricle, from an unknown cause but possibly due to previous cold exposure

that caused blood sludging and a clotting embolism in the heart. This turtle was obviously weakened when the temperatures recorded by the PTT dropped to 12.75 C and then to 9.10 C on 23 December 1995. The average duration of dives and number of dives in the last 12 h both went to 0.0 on that date and remained at 0.0 until the turtle was found stranded on 9 January 1996.

Although the turtle was thought to be rehabilitated when it was released on 13 January 1996, it was probably still in a weakened condition. All mapped locations identified after release were LQ 3 whereas previous to that time no LQ 3 locations were mapped for this turtle. No other turtles exhibited a similar pattern of dive data falling to 0.0 for a period of time during the middle of the track, followed by resumption of dive data and increase in LQ for mapped locations.

Two transmitters (7663 and 7698) continued to transmit after they apparently washed ashore in Mexico. It is unknown whether the PTTs had detached from the turtles and washed ashore or if the turtles had stranded with the transmitters still attached. After 5 March 1997 (7663) and 19 March 1997 (7698), numerous transmissions were received, but the average duration of dives and number of dives in last 12 h were 0.0 and the length of the last dive was the same number as in the last message before the other dive data went to 0.0. It is assumed that the transmitters were beached beginning on 6 March 1997 (7663) and 20 March 1997 (7698); from these days forward the locations transmitted were not mapped (Appendix VI) and the transmissions were not included in L and L

hours. PTTs 7663 and 7698 continued to transmit through 20 June 1997 and 11 June 1997, respectively, and all transmissions (including those when the transmitters were assumed to be beached) were included in T, D, date of last transmission, and LQ summary data for these PTTs (Table 8, Appendices IV, V).

PTTs used in this study included 28 that were new and two that were refurbished. Two of the three PTTs that were recovered (7671 and 7674) were refurbished and deployed on other turtles tracked during this study (7671A and 7674A). Performance (D, T, L, and LQ) of these two refurbished ST-6 PTTs was equivalent to that of the new ST-6 PTTs deployed.

Spatial movements.—Tracking maps were prepared for the 28 PTTs with any L (Appendices IV, VI). No maps were prepared for PTTs 7676 and 7683A, which yielded no locations after screening for the rejection criteria. Virtually all tracked turtles were located in the vicinity of the Mansfield Channel on at least one occasion after PTT deployment and many were located there several times.

A variety of movements were documented. All mapped locations for two turtles (7667, 7669) were within 35 km of the Mansfield Channel jetties (Appendix VI). However, both were only tracked for 1-2 months. Turtles tracked for longer time periods dispersed to waters within the Lower Laguna Madre or Gulf of Mexico; some dispersed within a few days, while others were located in the vicinity of the Mansfield Channel for months. Collectively,

locations ranged from approximately 21°21' N (7674A) to 27°43' N (7663) and 90°06' W (7677) to 97°50' W (7674A). However, the vast majority of locations were within a much smaller area centered in south Texas.

Twenty-five of the tracked turtles (7660, 7662, 7663, 7668, 7669, 7870, 7671, 7671A, 7672, 7672A, 7673, 7674, 7674A, 7675, 7675A, 7677, 7677A, 7678, 7680, 7681, 7682, 7683, 7684, 7685, and 7698) entered the Laguna Madre (Appendix VI). Most of the located positions were within the Lower Laguna Madre, near the Mansfield Channel. However, some of the locations were in the Upper Laguna Madre and some in the Lower Laguna Madre near the Brazos Santiago Pass. Some turtles moved extensively within the Laguna Madre, while others made only brief excursions into the Laguna Madre from the pass areas. All 25 appeared to have used the Mansfield Channel as a passageway between the Gulf of Mexico and the Lower Laguna Madre. Movement both into and out of the channel was noted.

Eight of the tracked turtles (7663, 7671, 7671A, 7673, 7678, 7680, 7682, and 7683) were located at the Brazos Santiago Pass at some time during the tracking period. Only a few locations were noted at the Brazos Santiago Pass for some turtles, but for others numerous locations were noted there.

Twenty of the tracked turtles (7661, 7662, 7663, 7671, 7671A, 7672, 7672A, 7673, 7674, 7674A, 7675, 7677, 7677A, 7678, 7680, 7681, 7682, 7683, 7684, and 7698) traveled into waters off the coast of Mexico. Some traveled just a few km south of the U.S./Mexico border, while others traveled a few hundred km

south of the border. Of these, seven (7661, 7662, 7672, 7672A, 7674A, 7683, and 7698) remained south of the U.S./Mexico border through the end of the tracking period. However, the remaining 13 (7663, 7671, 7671A, 7673, 7674, 7675, 7677, 7677A, 7678, 7680, 7681, 7682, and 7684) later traveled northward and re-entered waters off the U.S. coast.

Sixteen of the tracked turtles (7663, 7670, 7671A, 7673, 7674, 7674A, 7675, 7677, 7678, 7680, 7681, 7682, 7683, 7684, 7685, and 7698) traveled more than 30 km north of the Mansfield Channel jetties. However, fewer locations were noted and less time was spent north of the Mansfield Channel than south of it.

Although netting personnel and the public reported a few visual observations of turtles with attached transmitters at the Mansfield Channel jetties, since 30 PTTs were deployed it is not possible to conclusively match these observations with specific individuals. On 6 June 1996, a fisherman caught a green turtle with a metal flipper tag, PTT, and green straps at the Fish Pass jetties on Mustang Island, Texas. Unfortunately, the fisherman failed to note the tag number. Green straps were used to help secure the PTTs on three turtles (7673, 7677, and 7678). Of these three PTTs and others that had been deployed by this date, PTT 7673 was located closest to the Fish Pass jetties then (Appendix VI). Although it is likely that the turtle caught was 7673, this cannot be proven conclusively. However, this record demonstrates usage of a third jetty system in south Texas by turtles tracked during the study period.

Seasonal movements.—Turtles displayed a higher degree of site fidelity to the Mansfield Channel area during the spring, summer, and fall than during the winter. Turtles were tracked during three winter periods (1995-1996, 1996-1997, and 1997-1998). Virtually all tracked turtles left the Mansfield Channel area at some point during the winter; some only left for a few days, while others were not detected returning during the tracking or netting periods.

Movements of turtles differed during these three winter periods. Movements were more erratic and variable during the winter of 1995-1996 than during the winter of 1996-1997 (Appendices VI, VII). The lowest temperatures recorded by PTTs (as low as 5 C) were recorded during the winter of 1995-1996 (Appendix VII). During the winter of 1996-1997, after temperatures dropped to 10-15 C, tracked turtles made more direct movements southward (Appendices VI, VII).

Nine turtles yielded locations from December 1995 through at least January 1996 (7671, 7672, 7673, 7674, 7677, 7678, 7680, 7681, and 7683).

Movements of the nine turtles differed. PTT 7674 remained in the vicinity of the Mansfield Channel throughout this time. However, all others left for a period of time; some entered the Lower Laguna Madre, some Gulf waters off the south Texas coast, and some Gulf waters off the coast of Mexico. PTTs 7671, 7677, 7678, and 7681 returned to the Mansfield Channel after temperatures warmed, but PTTs 7672, 7673, 7680, and 7683 did not return during the tracking period.

All seven turtles with locations from December 1996 through at least January 1997 (7661, 7662, 7663, 7671A, 7672A, 7674A, and 7698) left U.S.

waters and migrated southward along the Gulf coast of Mexico. All left U.S. waters at approximately the same time, roughly 12 January 1997, and traveled parallel to the coastline. All seven ventured at least 60 km south of the U.S./Mexico border and all but 7663 and 7671A remained in waters off the coast of Mexico until transmissions ceased.

The one turtle with locations from December 1997 through at least January 1998 (7677A) left the Mansfield Channel area, but returned there during April. No cold stunned turtles were located during this time (see Chapter II).

Discussion

Tracking duration and transmitter performance.—For the 30 PTTs deployed, the mean number of days that data were transmitted was 183 days, with a range of 8 to 434 days. In comparison to other studies in which several PTTs were deployed on sea turtles, this PTT longevity was longer than for some studies (Byles, 1989; Keinath et al., 1996), but shorter than for others (Plotkin, 1994). Tracking duration is a function of adherence of transmitter, transmitter damage due to abrasion or biofouling, battery life, and turtle survival. Renaud et al. (1993) hypothesized that the inshore environment is harsher than the offshore environment and that transmitters will not last as long on sea turtles inhabiting areas near rock groins or seagrass beds. Some PTTs were shed prematurely during this study. Wedging between rocks and swimming through grassbeds could have caused PTTs to become dislodged or damaged (Renaud et al.,

1993). Tracking duration was less for PTTs attached to turtles that were recaptured during netting at the Mansfield Channel than to turtles that were not. This disparity could be related to an increased number of opportunities for the transmitter to be dislodged during wedging between rocks at the Mansfield Channel for the recaptured turtles. The increased PTT longevity recorded by Plotkin (1994) could be related to the open sea habitat of the olive ridley turtles (*Lepidochelys olivacea* Eschscholtz, 1829) tracked.

The three PTTs that were attached with the antenna oriented posteriorly ceased to transmit earlier than PTTs with the antenna oriented anteriorly. However, these three PTTs were among the four attached without harnesses and two of the three were detected prematurely shed from the turtles. The fourth PTT attached without a harness was on a larger turtle (with a less flexible carapace than smaller turtles) and the transmission period was longer.

Satellite transmitters can be safely used to monitor the long-term and long-distance movements of sea turtles, but care must be taken to ensure that the transmitter is small enough to be supported by the turtle (Byles and Keinath, 1990; Renaud et al., 1993; Keinath et al., 1996). Due to the small size of the ST-10, it is the PTT model currently recommended for studies using satellite technology to track the movements of juvenile sea turtles (Watson and Granger, 1998). However, ST-6 and ST-14 PTTs transmitted for more days, provided more transmissions, and yielded more mapped locations than did ST-10 transmitters. This poorer performance for ST-10 PTTs could reflect overall

poorer performance of this PTT model. However, ST-10 PTTs may have performed more poorly during this study because of a higher level of dislodging and damage to ST-10 PTTs. Three ST-10 PTTs were detected shed, whereas only one ST-6 and no ST-14 PTTs were detected shed. However, even with those three shed ST-10 PTTs excluded, ST-6 and ST-14 PTTs outperformed ST-10 PTTs. ST-10 PTTs were attached to smaller turtles and these smaller turtles may have remained at the Mansfield Channel jetties more than larger turtles and thereby had more opportunity to dislodge or damage the PTTs by wedging between rocks there. Smaller green turtles travel less distance in the Lower Laguna Madre (Arms, 1996) and have more site fidelity to the Brazos Santiago Pass (Coyne, 1994) than do larger green turtles.

PTTs used in this study included 28 that were new and two that were refurbished. Performance of the two refurbished ST-6 PTTs was equivalent to (or better) than that of the new ST-6 PTTs deployed. Since refurbished transmitters are significantly less expensive than new transmitters, refurbishment is an economical means to re-cycle recovered transmitters.

Spatial movements.—Surface durations of juvenile green turtles in south Texas inshore waters are typically less than 20 sec (Arms, 1996) and this short surface time likely led to the large number of locations with lower LQ. After screening location data using the rejection criteria, there were no accepted locations that could be mapped for two PTTs. Locations mapped for the other

28 tracked turtles included data of LQ 3, 2, 1, 0, A, and B. If the tracking maps had been prepared using only LQ 3, 2, and 1 data, no maps would have been prepared for an additional 13 PTTs; all locations would have been eliminated for 12 PTTs and all but one location would have been eliminated for one PTT. All locations included in the 28 maps passed the rejection criteria. However, some of the locations mapped may have been inaccurate. Those movements that ventured far into the Gulf of Mexico were questionable, but possible. Green turtles may perform exploratory movements in different directions (Luschi et al., 1998). Those locations close to clusters of accepted locations and along directional pathways were probably more accurate.

Previous to this study, only two other juvenile green turtles were tracked on the Texas coast using satellite technology. For less than one year, Williams and Renaud (1998) studied the movements of two green turtles (35.0 and 36.3 SLCL) captured and released in Matagorda Bay in 1996. Both turtles remained on the central Texas coast until the passage of a cold front on 11 January 1997, at which time they both moved to the south Texas coast. In January 1997, transmissions ceased for one and in mid-February 1997 the other moved north and returned to the Matagorda Bay area by late March.

Three jettied passes in south Texas were used by turtles during this study, including a considerable number of tracked locations at both the Mansfield Channel and Brazos Santiago Pass and one visual observation at the Fish Pass. Virtually all tracked turtles were located in the vicinity of the Mansfield

Channel on at least one occasion after PTT deployment and several were located there several times over a period of months. However, relatively few were subsequently netted there, despite apparently remaining in the vicinity. Juvenile green turtle usage of and site fidelity to the Mansfield Channel (Shaver, 1994) and Brazos Santiago Pass (Williams and Manzella, 1992; Coyne, 1994; Renaud et al., 1994a; Williams et al., 1994; Renaud, 1995b; Renaud et al., 1995) have been documented previously and these areas serve as important developmental habitat for them.

Turtles at both the Mansfield Channel (Kaldy et al., 1995) and Brazos Santiago Pass (Coyne, 1994; Renaud et al., 1994a) jetties have an abundant food source of algae (available year-round) in proximity to resting sites. Also, sea grasses, another important food source for green turtles, are available nearby within the Laguna Madre (Quammen and Onuf, 1993; Renaud et al., 1994a). Renaud et al. (1994a) hypothesized that juvenile green turtles select for the south jetty over the north jetty at the Brazos Santiago Pass due to the higher human usage of the north jetty. Public usage of the Mansfield Channel jetties is less than at both jetties at the Brazos Santiago Pass and this could significantly increase the attractiveness of the Mansfield Channel to juvenile green turtles.

Twenty-five of the tracked turtles entered the Laguna Madre. Some turtles moved extensively within the Laguna Madre, while others made only brief excursions into and out of Laguna Madre from the Mansfield Channel and

Brazos Santiago Pass. The Laguna Madre is an important developmental habitat for juvenile green turtles (Coyne, 1994; Renaud, 1995b; Arms, 1996). All 25 appeared to have used the Mansfield Channel as a passageway between the Gulf of Mexico and the Lower Laguna Madre and movement both into and out of the channel was noted. This was the first documentation that juvenile green turtles use the Mansfield Channel as a passageway between the Lower Laguna Madre and Gulf of Mexico. Use of the Brazos Santiago Pass as a route of movement between the Lower Laguna Madre and Gulf of Mexico was documented previously (Manzella et al., 1990; Renaud et al., 1994a; Arms, 1996).

Tracked turtles moved extensively in the Gulf of Mexico. Sixteen of the tracked turtles traveled more than 30 km north of the Mansfield Channel jetties, but fewer locations were noted and less time was spent north of the Mansfield Channel than south of it. Twenty of the tracked turtles traveled southward into Gulf of Mexico waters off Mexico. Some traveled just a few km south of the U.S./Mexico border, while others traveled a few hundred km south of the border. Seven of the 20 remained south of the U.S./Mexico border through the end of the tracking period and 13 later traveled northward and re-entered waters off the Texas coast. Previous to this study, the presence of juvenile green turtles on the Gulf coast of Mexico was known (Hildebrand, 1982; Marquez, 1996), but virtually no data were available on their seasonality, distribution, and movements there. Results from this study provide the first documentation of

juvenile green turtles moving between Gulf of Mexico waters off Texas and Mexico. Based on the movement patterns documented and a tag return from a green turtle netted at the Mansfield Channel that was recovered in Mexico (see Chapter IV), many juvenile green turtles move between Texas and Mexico. In contrast, no green turtles were tracked to Florida during this study. Additionally, none tagged and released after hypothermic stunning in south Texas (see Chapter II) and netted and tagged at the Mansfield Channel (see Chapter IV) were later detected in Florida. Hence, the population of juvenile green turtles in the western Gulf of Mexico (off Texas and Tamaulipas, Mexico) may be distinct from the population in Florida. A lack of co-mingling of juveniles between the two areas would be consistent with the high level of fibropapillomatosis in Florida versus the lack of this affliction in Texas (see Chapter II, IV).

Seasonal movements.—Site fidelity to the Mansfield Channel area was higher during the spring, summer, and fall than during the winter. Virtually all tracked turtles left the Mansfield Channel area at some point during the winter; some only left for a few days, while others were not detected returning during the tracking and netting periods. Fall and winter migration of sea turtles southward in the U.S. (Byles, 1988; Keinath, 1993; Gitschlag, 1996; Keinath et al., 1996) may be related to the passage of winter storms rather than simply a decline of water temperatures (Byles, 1988; Gitschlag, 1996). A more gradual onset of winter and/or unseasonably warm winters may not be enough to trigger

movement southward or offshore, but may result in cold stunning if extreme cold fronts later occur. During the winter, water temperatures along the Gulf coast of Mexico are warmer than along the south Texas coast (Inoue and Welsh, 1997). Fall and winter movements of juvenile green turtles differ during different years and in different areas in south Texas. Some green turtles leave south Texas during the winter, while others overwinter (at least in the Lower Laguna Madre) during some years. Whether green turtles stay or leave is likely dependent on temperature parameters and the degree of access to the Gulf of Mexico. It would be easier for turtles at the Mansfield Channel jetties to escape cold temperatures by moving southward or offshore, than for turtles in the Laguna Madre, which has only two direct access points to the Gulf of Mexico. Most cold stunned turtles documented on the Texas coast in the last two decades have been found in the Laguna Madre (see Chapter II).

The lowest temperatures recorded by PTTs during this study (as low as 5 C) were during the winter of 1995-1996 and movements were erratic and variable during this winter. One of the tracked turtles remained at the Mansfield Channel throughout the winter, some entered the Lower Laguna Madre, some entered Gulf waters off the south Texas coast, and some entered Gulf waters off the coast of Mexico. Half of the turtles returned to the Mansfield Channel after temperatures warmed, but the others did not return during the tracking period. From 12 November 1995 to 15 February 1996, 54 cold stunned green turtles were found on the Texas coast (see Chapter II). In contrast, during the winter of

1996-1997, all tracked turtles made more direct movements southward after temperatures dropped to 10-15 C. All left U.S. waters at approximately the same time, roughly 12 January 1997, and traveled parallel to the coastline. All but two of the tracked turtles remained in waters off the coast of Mexico until transmissions ceased. From 6 January through 7 February 1997, 96 green turtles were found cold stunned on the Texas coast, during the worst cold stunning episode recorded there in at least two decades (see Chapter II).

A juvenile green turtle, released with radio and sonic transmitters in the Lower Laguna Madre on 24 August 1989, apparently left the Lower Laguna Madre via the Brazos Santiago Pass on 18 September 1989, shortly after the passage of two minor cold fronts, and entered the Gulf of Mexico (Manzella et al., 1990). Fourteen green turtles were found cold stunned in south Texas from December 1989 through mid-February 1990 (see Chapter II). However, Arms (1996) used sonic and radio telemetry to track nine juvenile green turtles in the Lower Laguna Madre from October 1992 to March 1993 and November 1993 to March 1994 and found that most of the tracked turtles overwintered there. During these months, the lowest monthly mean air temperature was 17.85 C and lowest mean water temperature 16.26 C (Arms, 1996). These relatively mild hydrographic conditions may have prevented seasonal offshore movement. No cold stunning was documented during any of these months (see Chapter II) and these observations demonstrate that during years with relatively mild hydrographic conditions juvenile green turtles can safely overwinter in the

Laguna Madre.

Juvenile green turtles tracked during this study swam both with and against currents. Mean along-shore current flows during the spring (March-May), fall (September-November), and winter (December-February) are westward and southward and during the summer (June-August) are more variable and generally eastward and northward along the south Texas coast (Dinnel et al., 1997; Inoue and Welsh, 1997).

Conclusions.—The Mansfield Channel is an important developmental habitat for juvenile green turtles and is used as a passageway to the Lower Laguna Madre. Green turtles tracked during this study dispersed to a variety of areas in south Texas and Mexico. Conservation measures undertaken to help restore this species in Texas must employ techniques to protect juvenile green turtles both in south Texas and Mexico. Satellite tracking data amassed during this study can be used to evaluate threats to juvenile green turtles in the marine ecosystem and develop appropriate protection strategies. These human-related (dredging, boating, recreational and commercial fishing, etc.) and natural (hypothermic stunning) threats vary temporally and spatially.

CHAPTER VII

SUMMARY

Data on residency, seasonality, yearly relative abundance, distribution, movements, migration, sex ratios, sizes, and mortality factors of green turtles in Texas were collected through investigation of nests, and stranded, netted, and satellite-tracked turtles.

Six hundred seven green turtles were located stranded along the Texas coast from 1980 to 1998, including 471 found from 1989 to 1997. Of the 607, 60% were located inshore (beaches or waters of passes and bays) and 40% offshore (beaches or waters of the Gulf or Mexico). Strandings were distributed throughout Texas. However, both inshore and offshore strandings were concentrated in south Texas, with the largest concentration in the Lower Laguna Madre, near Port Isabel. Possible stranding causes were identified for 298 of the 607 turtles found from 1980 to 1998. Hypothermic stunning was the likely stranding cause for 230 of the 298. Sixty-eight of the 298 stranded due to a variety of other causes. Hypothermic stunning is a significant threat to green turtles in Texas, particularly within south Texas inshore waters. The overall temporal and spatial distributions of green turtle strandings were dominated by hypothermic stunning.

Two hundred fifty-eight green turtles ($n = 383$ captures) were netted in the Mansfield Channel during 1149 h of effort (3.63 turtles/km-h) from June 1989

through December 1997. Seventy-three of the 258 individuals were recaptured.

Ninety-eight percent of the stranded and all of the netted green turtles were juveniles and, based on these analyses, the vast majority of green turtles occupying Texas waters are juveniles. Only six confirmed green turtle nests have been documented on the Texas coast, including one found in 1987 and five in 1998, although additional nesting may have occurred without being observed. The relatively large numbers found stranded and netted, high recapture rate, and movement patterns of tracked turtles demonstrate the importance of Texas waters to juvenile green turtles. The Mansfield Channel and other south Texas bays, passes, and jetty areas are important developmental habitats for juvenile green turtles. Juvenile green turtles use these areas for foraging and resting. They use the Mansfield Channel to move between the Gulf of Mexico and Laguna Madre and use Gulf of Mexico waters off the Texas coast to move between south Texas and Mexico.

Yearly numbers of stranded turtles and yearly CPUE followed similar trends and were correlated. Strandings generally increased from 1980 through 1998, but there was no clear trend of increase or decrease in yearly strandings and yearly CPUE from 1989 through 1997.

The monthly trends of stranding numbers and CPUE differed dramatically. Strandings were most numerous during the winter and CPUE was highest in the summer and fall. Water temperature varied seasonally and influenced strandings, CPUE, and movements. CPUE was positively correlated with water

temperature and no turtles were caught in January and when mean water temperatures were below 15.5 C. Most green turtles probably left the jetty area during colder periods, perhaps only temporarily, and entered warmer waters. Some netted and tracked turtles moved southward during periods of declining temperatures, but others overwintered in south Texas waters.

The sex ratio for stranded turtles (1980-1998:1.09F:1.00M; 1989-1997: 0.94F:1.00M) differed from the sex ratio for netted turtles (4.16F:1.0M). The size range for stranded turtles was larger than for netted turtles. Also, turtles found stranded ($\bar{x}$ = 37.8 cm SLCL) were larger than those netted ($\bar{x}$ = 32.4 cm SLCL). Turtles found stranded inshore were larger than turtles found stranded offshore and turtles netted, but turtles found stranded offshore and netted turtles did not differ in size.

Yearly CPUE at the Mansfield Channel may be a useful predictor for the yearly number of sea turtles found stranded on the Texas coast. However, monthly trend, sex ratio, and size data from Mansfield Channel cannot be used as a strict index of the overall green turtle population occurring within Texas waters.

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APPENDIX I

FREQUENCIES OF CODES IN DATA FIELDS NOTE1-NOTE6 FOR

***CHELONIA MYDAS* FOUND STRANDED ON THE TEXAS COAST FROM**

1980 TO 1998^a

Description [note codes]	Frequency
Hypothermic stun related [08]	230
Necropsied [27]	155
Released at later date [57]	129
Tagged after stranding [25]	124
Flipper damage (not totally missing) [53]	69
Carapace damage (unknown cause) [52]	47
See original data sheets for further information [14]	46
Observed floating dead or live in water, turtle recovered [10]	44
Some flipper combination missing [37]	37
Died at holding facility of on beach [04]	28
Final fate unknown [05]	28
Injuries/wounds described are healed/old [71]	26
Apparent propeller wounds, probable boat strike [18]	25
Carapace damage – marginals only (unknown cause) [79]	23
Injury to skull (unknown cause) [66]	22
Skull and some combination of flippers missing [20]	20
Neck region damage (unknown cause) [91]	20
Plastron damage (unknown cause) [74]	19

Description [note codes]	Frequency
Captured/stranded prior to this capture [AA]	17
Tar and/or oil on turtle [49]	15
Skull missing [17]	14
Entangled in fishing line [11]	13
Found trapped in jetty rocks [AX]	11
Released at same site [23]	10
Plastics/persistent marine debris found in digestive tract upon necropsy [16]	8
Entangled in a non-fishing gear medium [48]	8
Emaciated [36]	7
Probable dredge kill [96]	6
Hook in flipper or other soft body part (not in mouth) [AE]	6
Growth abnormality, does not appear to be damaged [77]	5
Possible boat collision (different from boat propeller damage) [88]	5
Large portion of body missing (unknown cause) [98]	5
Turtle previously released with a transmitter [89]	4
Necropsy report filed with stranding form [AL]	4
Entangled in fishing net [13]	3
Possible mutilation [26]	3

Description [note codes]	Frequency
Entangled in debris, entangled on reef (or submerged object) [28]	3
Throat or neck cut [69]	3
Paint mark/residue on carcass [19]	2
Hook in mouth [24]	2
Emaciated, covered with tiny barnacles [33]	2
Apparent tag scar [39]	2
Nature of wounds suggest gill net, net, trap line, or line entanglement [41]	2
Monofilament or steel line protruding from mouth or cloaca [95]	2
Additional tags applied this capture [99]	2
Caught in abandoned gear [AO]	2
Carcass tagged for identification purposes [AU]	2
Observed floating dead in water, carcass not recovered [9]	1
Turtle has a tag, number is unreadable [21]	1
Found in holding tank on shrimp trawl [22]	1
Apparent bullet wounds [30]	1
Some flipper combination missing (appears man-induced) [38]	1
Skull only [44]	1
Found alive and flipped on beach and stuck in sand [55]	1

Description [note codes]	Frequency
Caught in gill net [59]	1
Post-hatchling, young of the year [70]	1
Flipper(s) found on beach [72]	1
Found in association with red tide occurrence [86]	1
Constriction wounds/marks on flippers or neck [90]	1
Mud or mud stains on body [AB]	1
Tar and/or oil in digestive tract upon necropsy [AC]	1
Monofilament line found in digestive tract upon necropsy [AF]	1
Binary coded internal tag verified [AJ]	1
Balloons found in digestive tract upon necropsy [AK]	1
Entangled in rope (not deliberately tied) [AP]	1
Plastron missing [AQ]	1
Buoyancy problem – turtle unable to dive/submerge properly [BF]	1

^a Frequencies in this table represent the number of records bearing a particular code. Therefore, the frequencies do not sum to the total number of records.

APPENDIX II

**COMMENTS REGARDING TAGGING, TAG REPORTING, TAG LOSS, SEX
RATIO ANALYSIS, AND INJURIES FOR *CHELONIA MYDAS* NETTED AT
THE MANSFIELD CHANNEL JETTIES FROM JUNE 1989 TO DECEMBER
1997**

Comment	Number of individuals
Metal tag only applied to one front flipper (no other flippers)	27
Multiple blood samples analyzed; all classified as female	25
Two blood samples analyzed	21
No metal tag applied (released with only PIT tags)	10
Gashes on flesh, carapace, and/or plastron when netted	10
Three blood samples analyzed	10
Plastic tag applied to a front or a rear flipper	9
Matched by tag scars, photographs, descriptions, measurements	7
Found stranded and reported after being netted and tagged	7
Missing a front flipper	6
Rear flipper metal tag lost	6
Front and rear flipper metal tags lost	5
Front flipper metal tag lost	5
Mud on carapace when netted (July and August)	5
Multiple blood samples analyzed; all classified as male	5
Multiple blood samples analyzed; one classified as unknown	5
Caught by hook-and-line and reported after being netted and tagged	4

Comment	Number of individuals
Four blood samples analyzed	4
Missing a rear flipper	2
Both front flipper metal tags lost	1
Monofilament line around flippers when netted	1
Missing a tail	1
PIT tag lost	1
Tags from a different netting project found	1
Hook in flipper when netted	1

APPENDIX III

***CHELONIA MYDAS* NETTED AT THE MANSFIELD CHANNEL JETTIES
FROM 1989 TO 1997 AND LATER REPORTED STRANDED (S) OR CAUGHT
ON HOOK-AND-LINE (H)**

Turtle number	Date initial net capture	Report method	Report location	Report date
24	30 May 1990	S (dead)	South Padre Island, Gulf beach, (26°31'30"N, 97°15'36"W)	27 Dec. 1990 ^a
27	16 May 1991	H (alive)	Mansfield Channel jetties (26°33'50"N, 97°16'45"W)	25 May 1991 ^a
30	11 June 1991	H (alive)	Mansfield Channel jetties (26°33'50"N, 97°16'45"W)	15 June 1991 ^a
44	9 Feb. 1993	H (alive)	Mansfield Channel jetties (26°33'50"N, 97°16'45"W)	13 Aug. 1993 ^a
72	16 Aug. 1994	S (alive)	Lower Laguna Madre (26°23'N, 97°21'W)	22 July 1995 ^a
119	12 Oct. 1995	S (alive)	Lower Laguna Madre (26°05'12"N, 97°11'24"W)	9 Jan. 1996 ^b
129	30 Nov. 1995 ^c	S (dead)	North Padre Island, Gulf beach (26°34'34"N, 97°16'52"W)	5 Nov. 1997 ^a
191	12 Sept. 1996 ^d	S (alive)	North Padre Island, Gulf beach (26°44'26"N, 97°20'03"W)	2 Jan. 1997 ^a
194	24 Sept. 1996	S (dead)	Tamaulipas, Mexico, Gulf beach (23°50'N, 97°46'W)	16 March 1997 ^a
207	10 Oct. 1996	S (dead)	Lower Laguna Madre (26°04'30"N, 97°12'54"W)	21 Jan. 1997 ^a

Turtle number	Date initial net capture	Report method	Report location	Report date
242	20 March 1997 ^a H (alive)		Mansfield Channel jetties (26°33'50"N, 97°16'45"W)	6 Sept. 1998 ^a

^a Was not netted or reported again.

^b Was not netted again, but was found stranded again (dead) on 25 Feb. 1996 at Brazos Santiago Pass (26°03'42"N, 97°09'05"W).

^c Was also netted on 18 April 1996.

^d Was also netted on 23 Oct. 1996.

^e Was also netted on 8 April 1997.

APPENDIX IV
PTT TRANSMISSION SUCCESS RATES^a

PTT	T	T hours	TSR	L	L hours	LSR
7660	24	826	2.91	6	826	0.73
7661	24	749	3.20	7	749	0.93
7662	426	3036	14.03	79	3036	2.60
7663	736	2604	28.26	38	1320	2.88
7667	26	360	7.22	3	360	0.83
7668	24	960	2.50	3	960	0.31
7669	36	624	5.77	7	624	1.12
7670	10	35	28.57	4	35	11.43
7671	133	1608	8.27	30	1560	1.92
7671A	190	2616	7.26	67	2616	2.56
7672	57	720	7.92	21	720	2.92
7672A	107	1488	7.19	41	1488	2.76
7673	62	778	7.97	20	778	2.57
7674	162	1968	8.23	54	1968	2.74
7674A	252	4560	5.53	51	4560	1.12
7675	259	2196	11.79	39	2196	1.78
7675A	72	1908	3.77	31	1908	1.62
7676	11	96	11.46	0	96	0.00

PTT	T	T hours	TSR	L	L hours	LSR
7676A	25	342	7.31	4	342	1.17
7677	309	5208	5.93	40	5208	0.77
7677A	195	2556	7.63	36	2556	1.41
7678	219	3072	7.13	66	3072	2.15
7680	328	3684	8.90	95	3684	2.58
7681	145	4476	3.24	13	4476	0.29
7682	380	2472	15.37	121	2472	4.89
7683	36	246	14.63	16	246	6.50
7683A	22	90	24.44	0	90	0.00
7684	48	829	5.79	18	829	2.17
7685	62	1044	5.94	10	1044	0.96
7698	366	3924	9.33	20	2940	0.68

^a T = number of transmissions received, T hours = number of hours on, TSR = transmission success rate, L = number of locations mapped, L hours = number of location hours, and LSR = location success rate. $TSR = (T/T \text{ hours}) \times 100$, $L \text{ hours} = T \text{ hours} - \text{hours beached}$, and $LSR = (L/L \text{ hours}) \times 100$.

APPENDIX V
LOCATION QUALITY INDICES (LQ) OF PTT LOCATIONS*

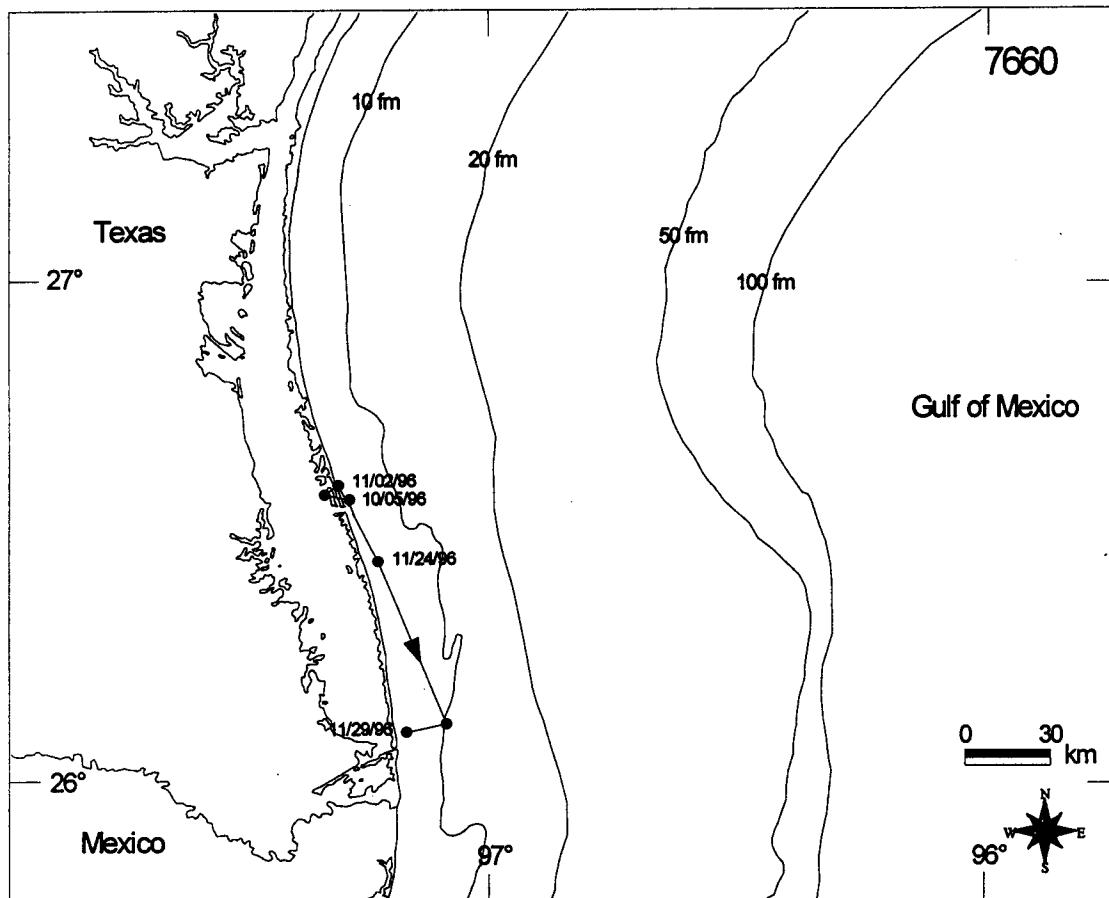
PTT	U	ZD	B	BD	A	AD	0	0D	1	1D	2	2D	3	3D
7660	0	0	1	0	5	0	6	0	1	0	11	0	0	0
7661	0	0	3	0	3	0	14	0	4	0	0	0	0	0
7662	0	0	333	0	26	0	54	0	13	0	0	0	0	0
7663	0	0	159	0	69	0	57	0	71	0	124	0	256	0
7667	0	0	3	0	23	0	0	0	0	0	0	0	0	0
7668	0	0	0	0	0	0	0	0	0	0	0	0	24	0
7669	0	0	35	0	0	0	1	0	0	0	0	0	0	0
7670	0	0	0	0	6	0	0	0	0	0	0	0	4	0
7671	0	3	71	1	2	0	24	0	4	0	0	0	28	0
7671A	0	0	96	0	46	0	35	0	9	0	4	0	0	0
7672	0	0	22	0	20	0	2	0	8	0	3	0	2	0
7672A	0	0	14	0	23	0	12	0	0	0	0	0	58	0

PTT	U	ZD	B	BD	A	AD	0	OD	1	1D	2	2D	3	3D
7673	0	2	2	0	32	1	24	0	0	0	0	0	1	0
7674	0	5	73	1	34	0	41	1	3	0	4	0	0	0
7674A	0	0	138	0	0	0	16	0	42	0	26	0	30	0
7675	10	8	126	0	94	0	0	0	0	0	0	0	21	0
7675A	0	0	39	0	24	0	9	0	0	0	0	0	0	0
7676	0	0	0	0	11	0	0	0	0	0	0	0	0	0
7676A	2	0	0	0	23	0	0	0	0	0	0	0	0	0
7677	4	11	211	1	31	1	50	0	0	0	0	0	0	0
7677A	0	0	147	0	0	0	48	0	0	0	0	0	0	0
7678	0	2	104	5	97	2	5	0	4	0	0	0	0	0
7680	0	17	183	2	100	1	15	1	9	0	0	0	0	0
7681	0	0	0	0	0	0	145	0	0	0	0	0	0	0

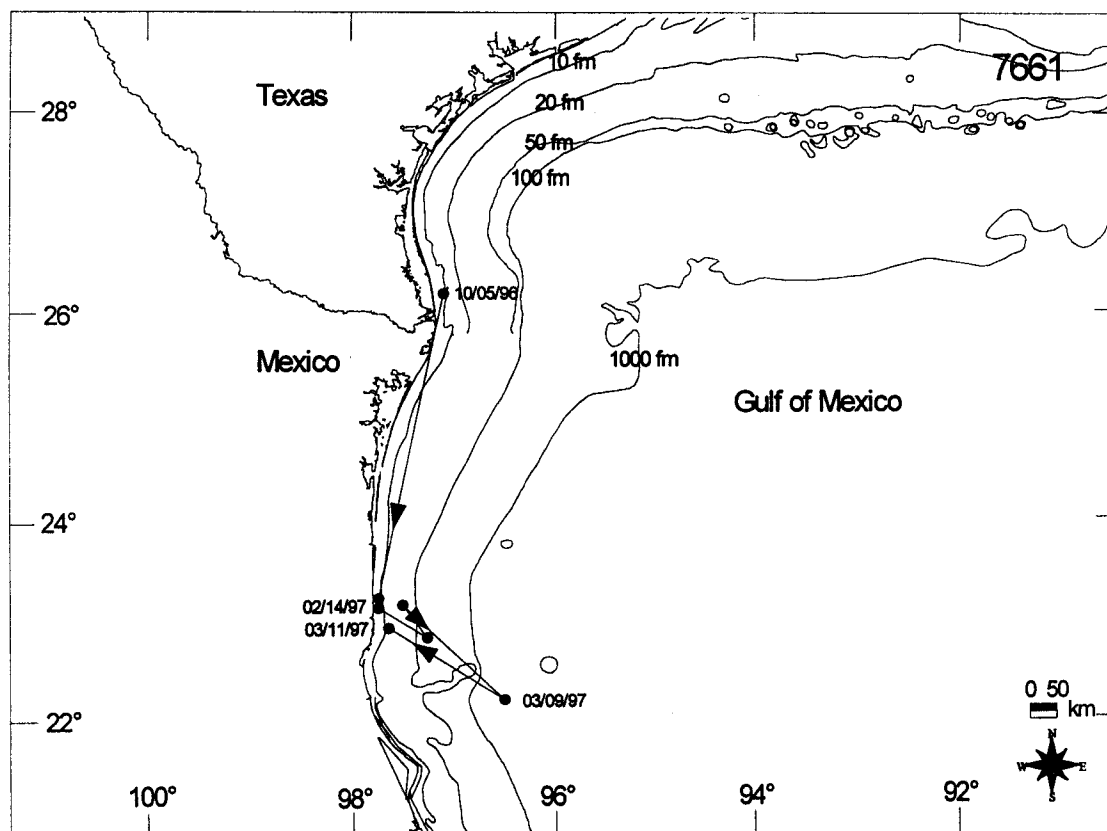
PTT	U	ZD	B	BD	A	AD	0	OD	1	1D	2	2D	3	3D
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7683	0	4	1	0	10	0	21	0	0	0	0	0	0	0
7683A	1	0	0	0	0	0	21	0	0	0	0	0	0	0
7684	0	0	0	0	8	0	27	0	11	0	2	0	0	0
7685	0	0	0	0	48	0	14	0	0	0	0	0	0	0
7698	0	8	31	0	21	0	127	0	31	0	47	0	101	0

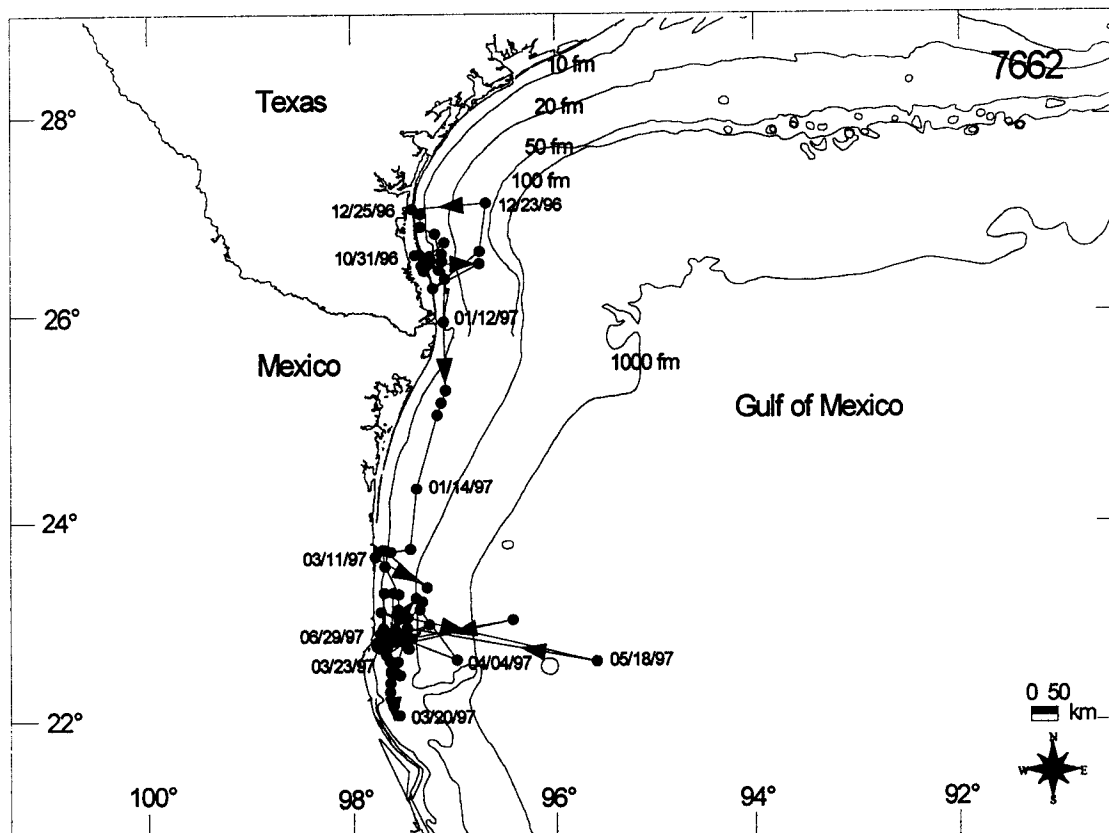
* Codes ending in D were obtained from the diagnostics feature of Argos and others were obtained from the standard location feature of Argos.

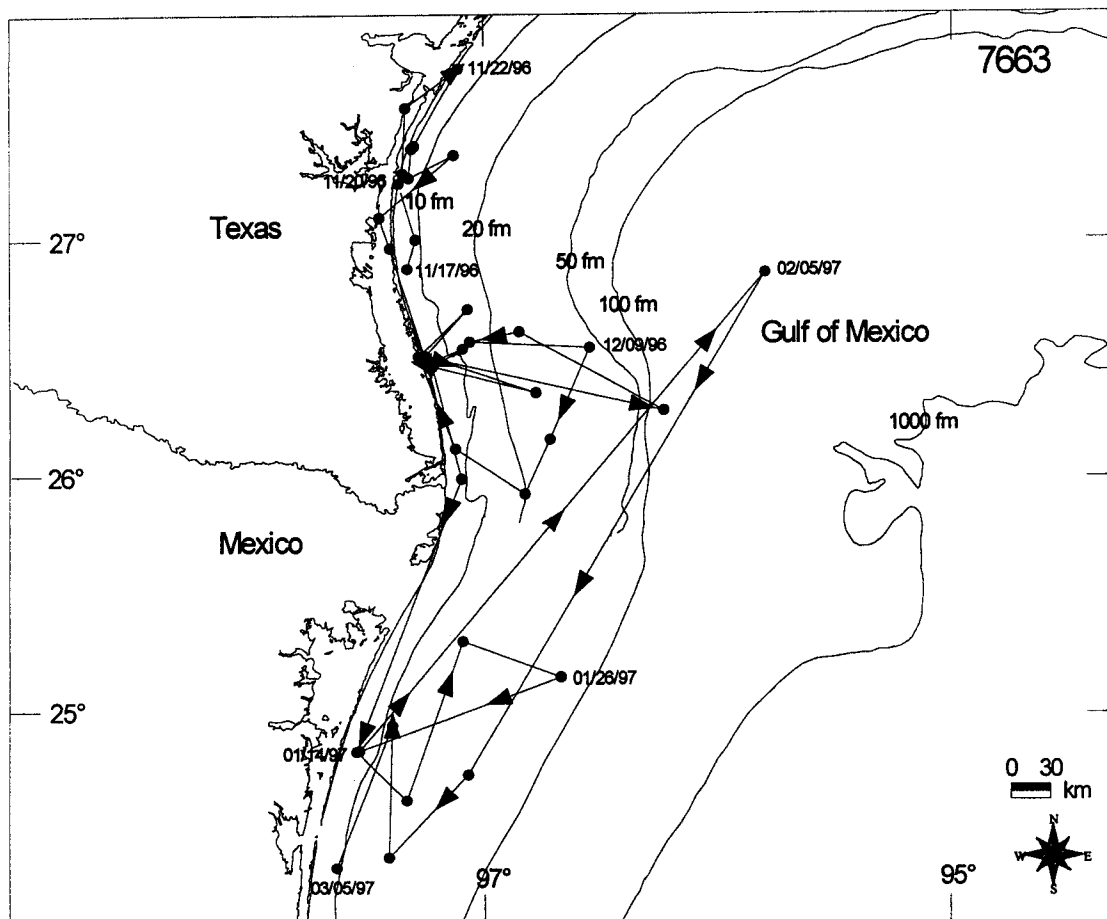
APPENDIX VI
MOVEMENTS OF TRACKED *CHELONIA MYDAS*

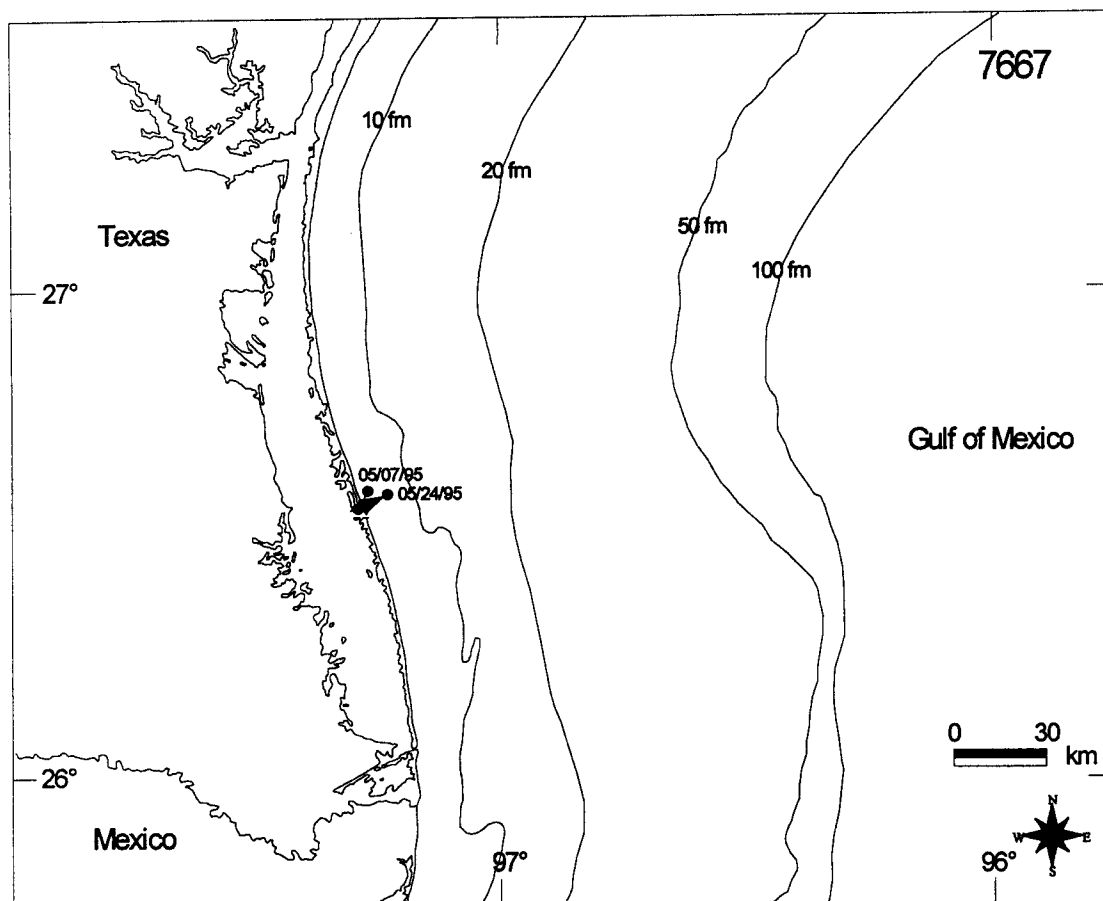


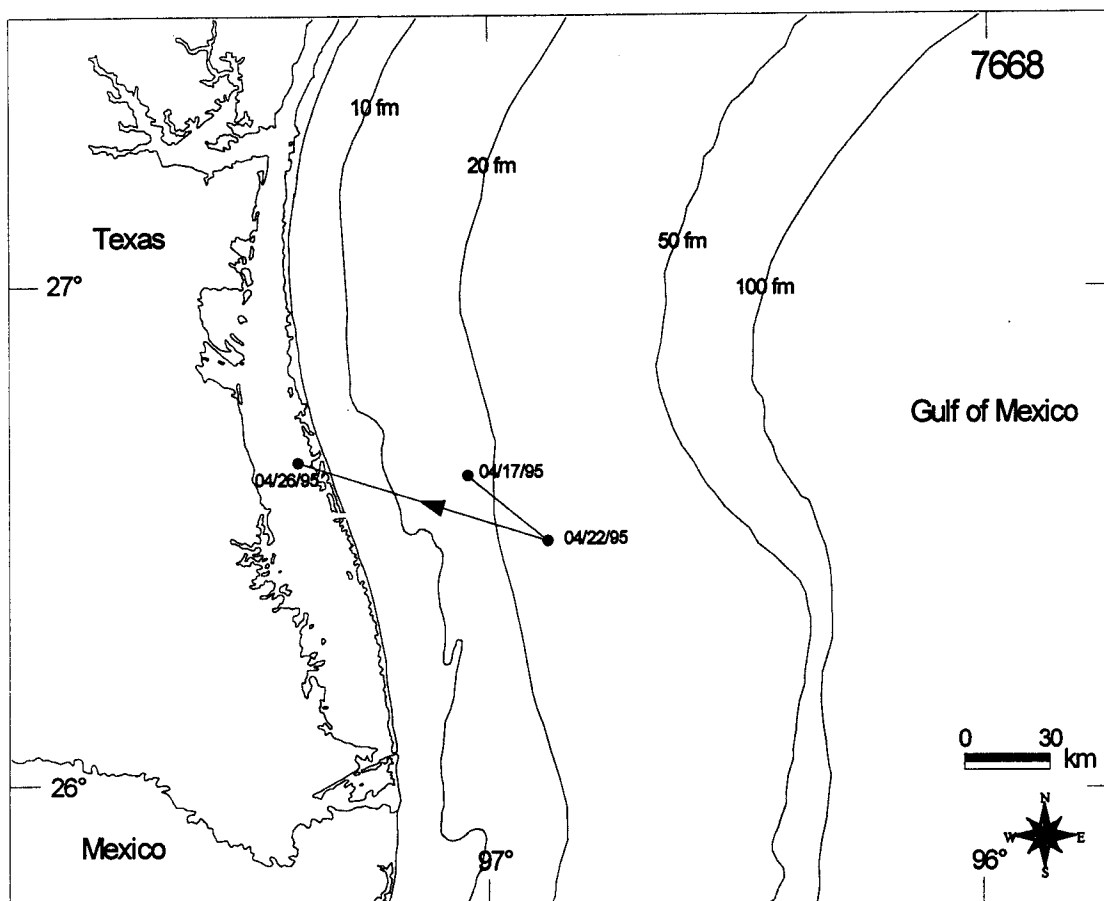


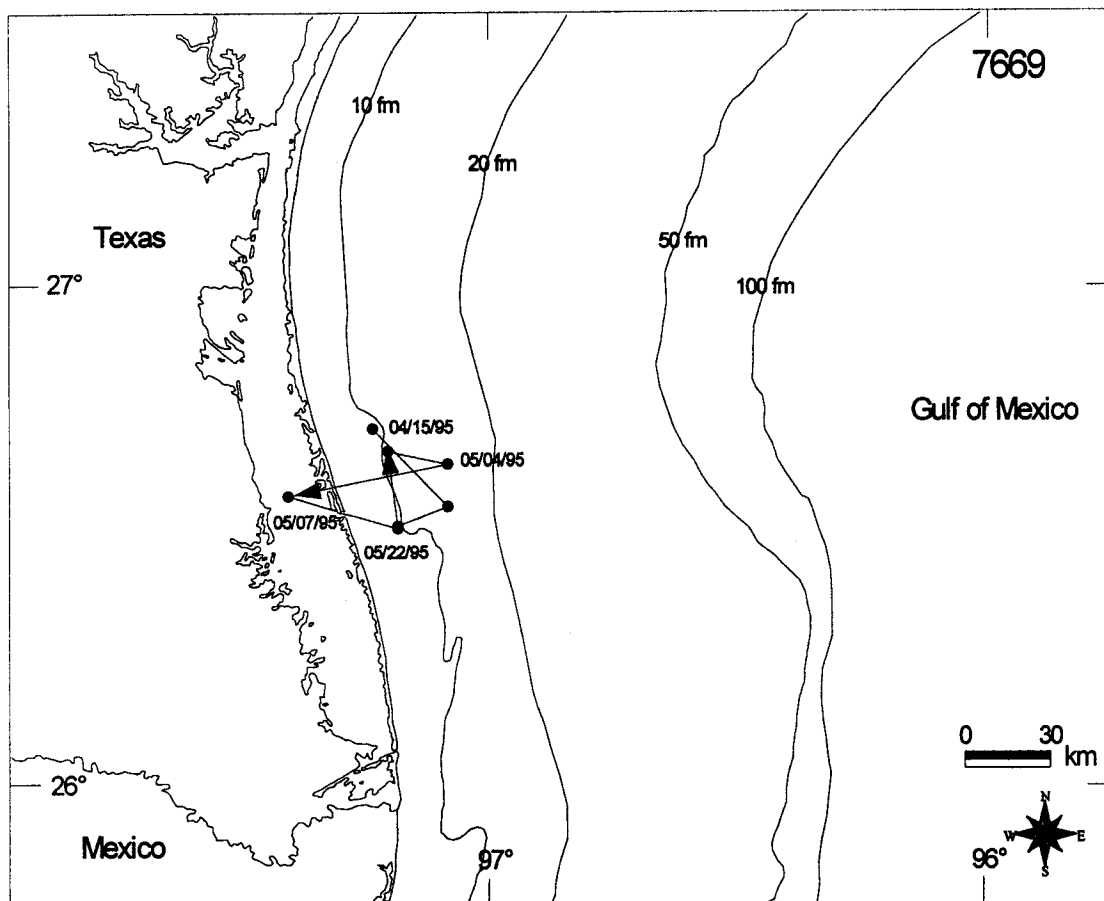


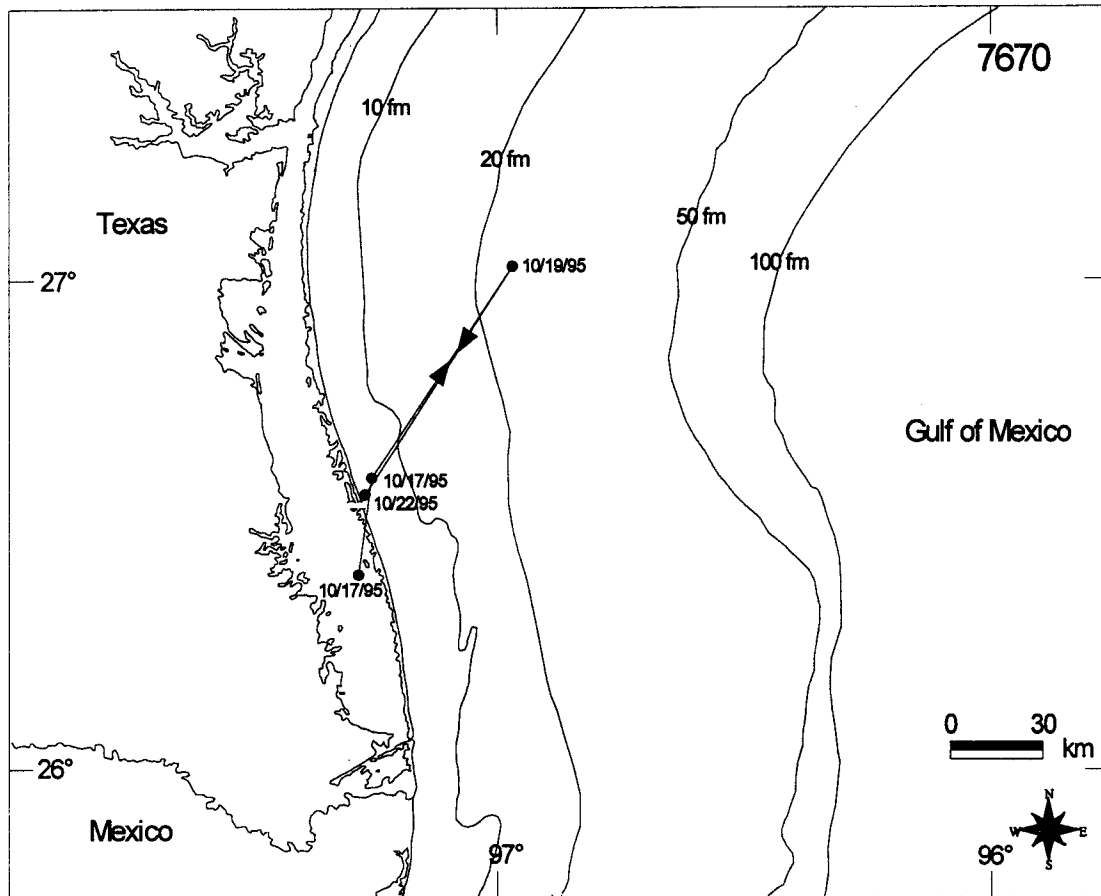


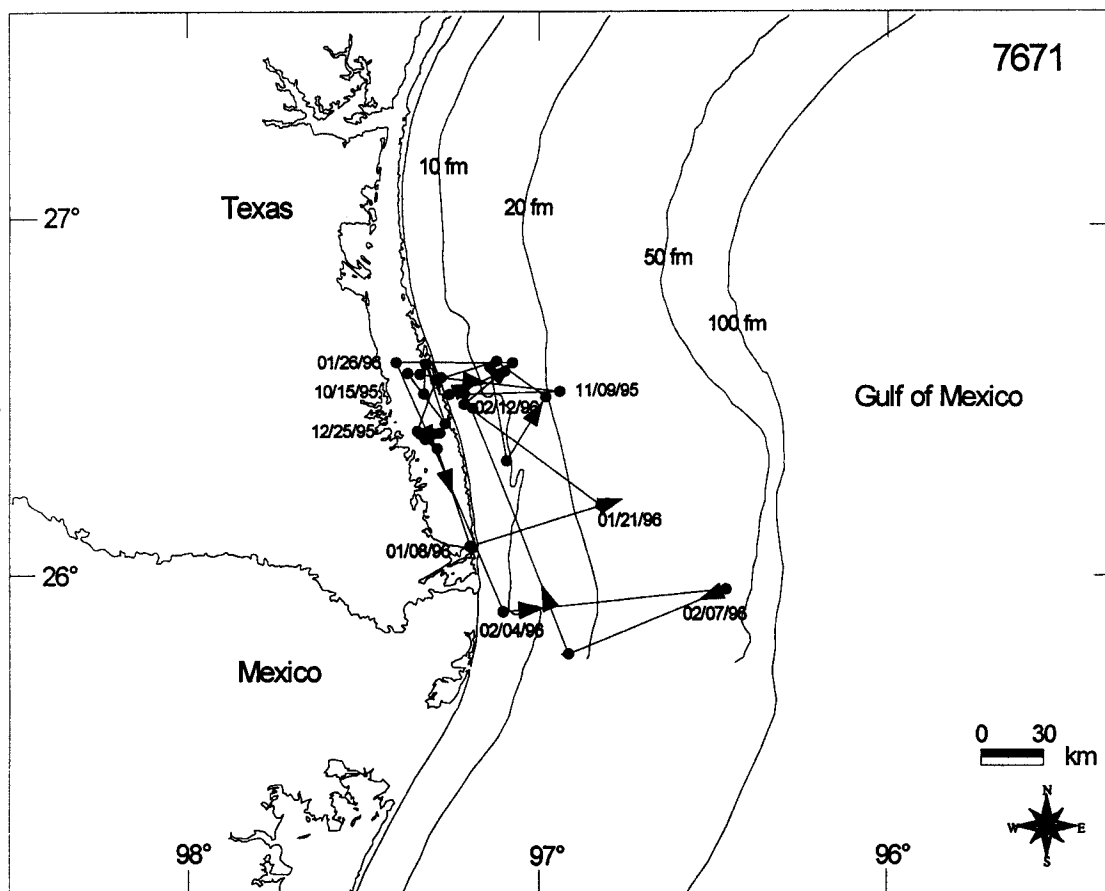


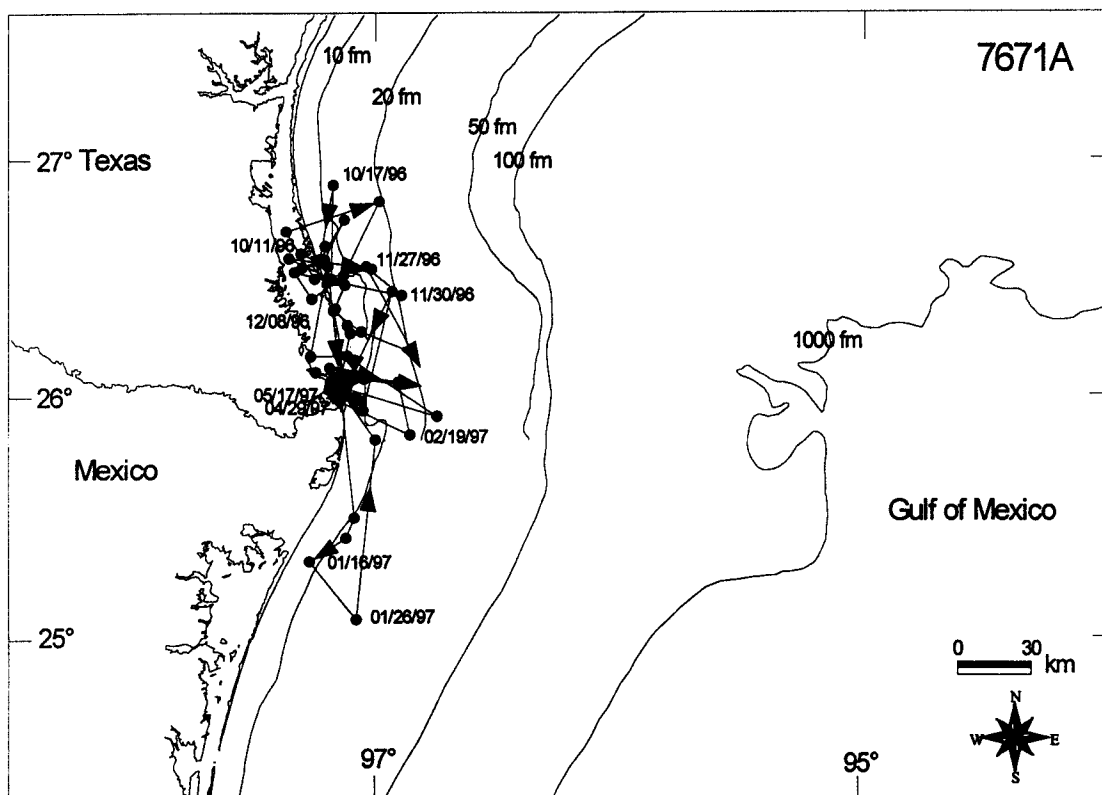


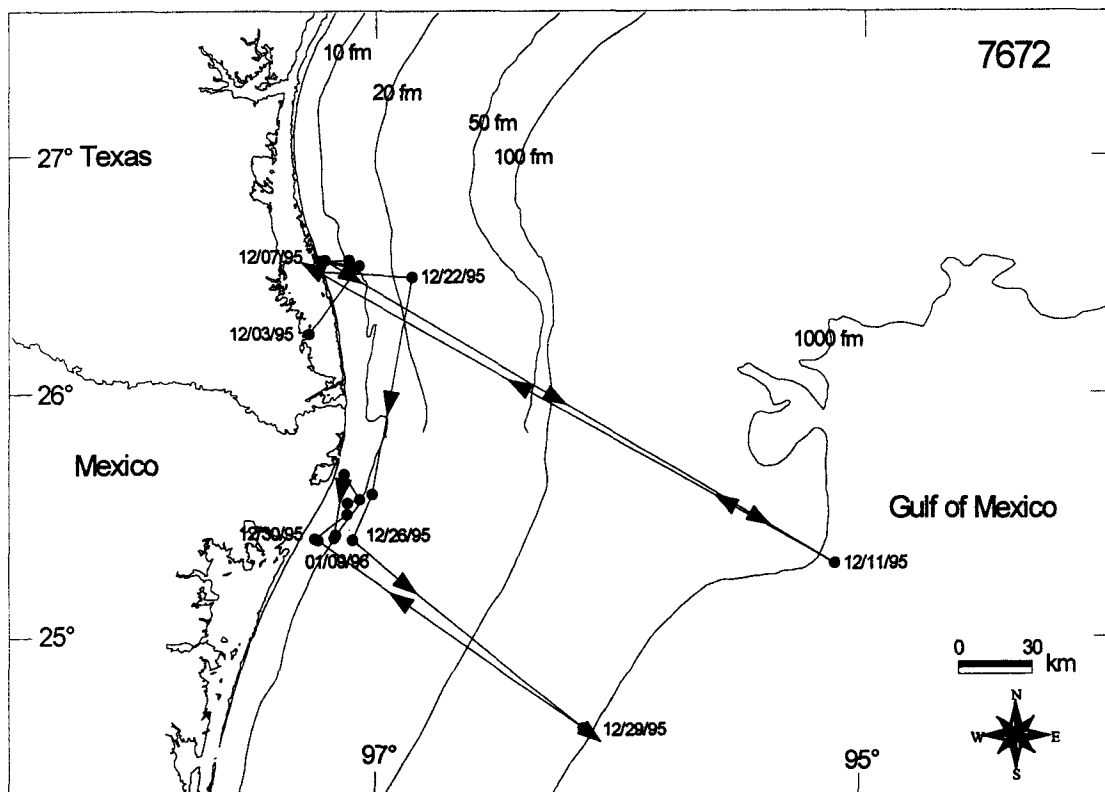


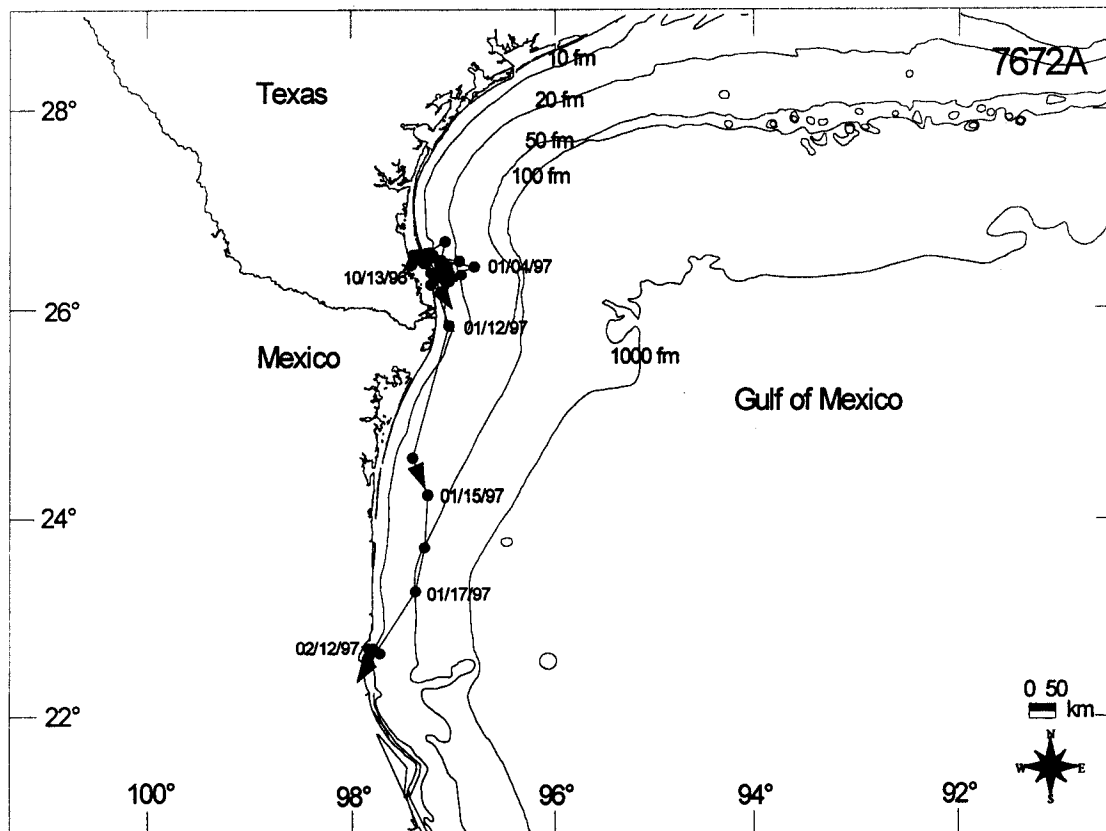


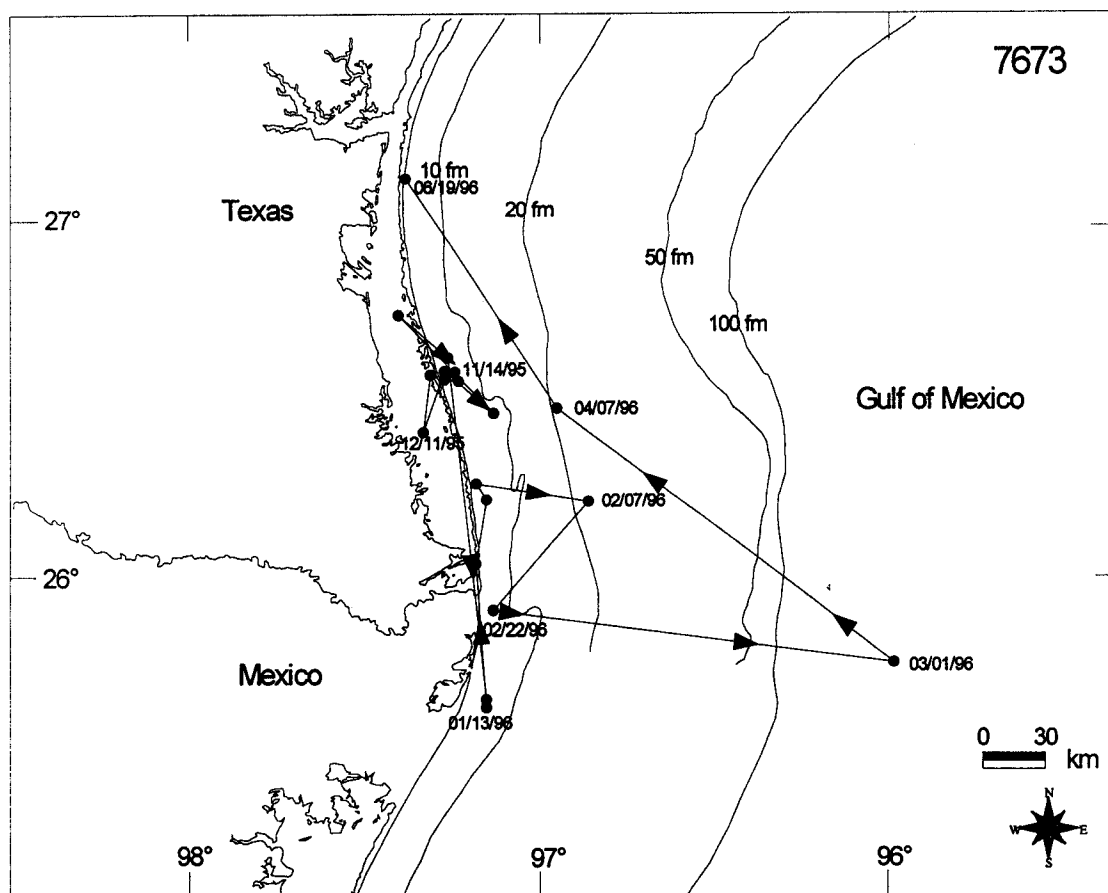


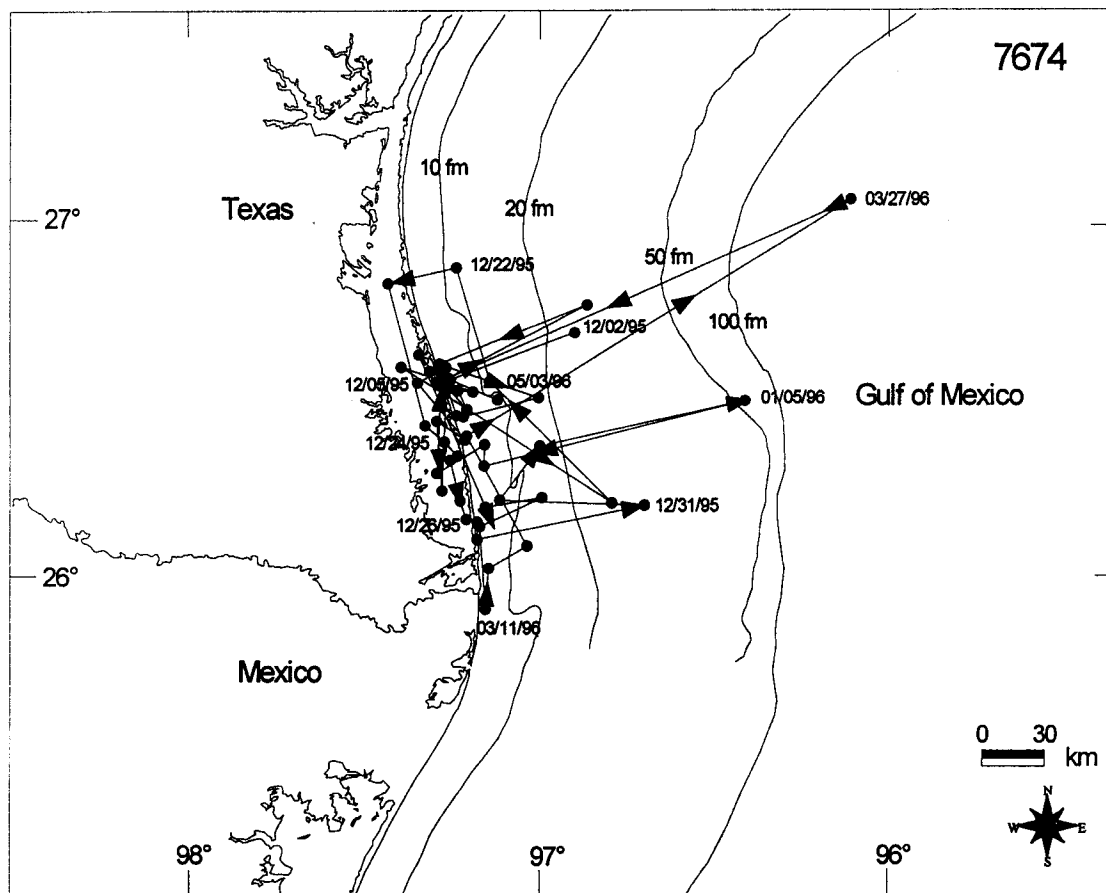


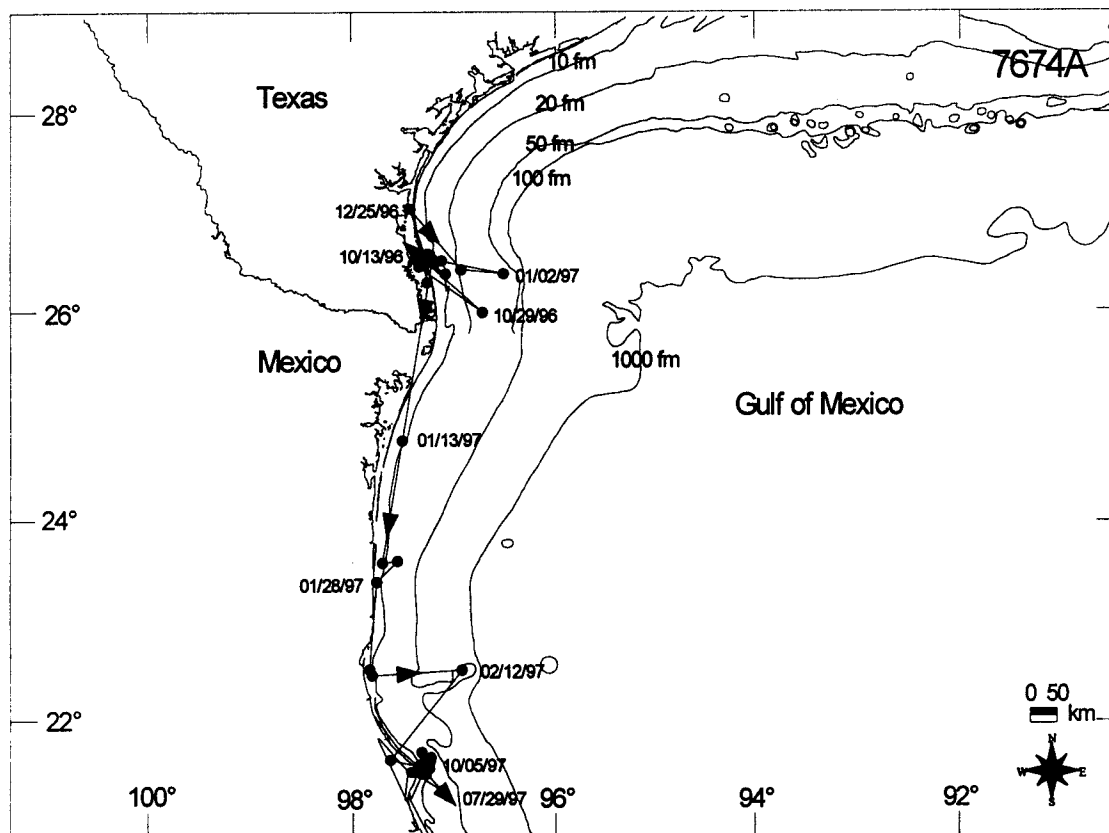


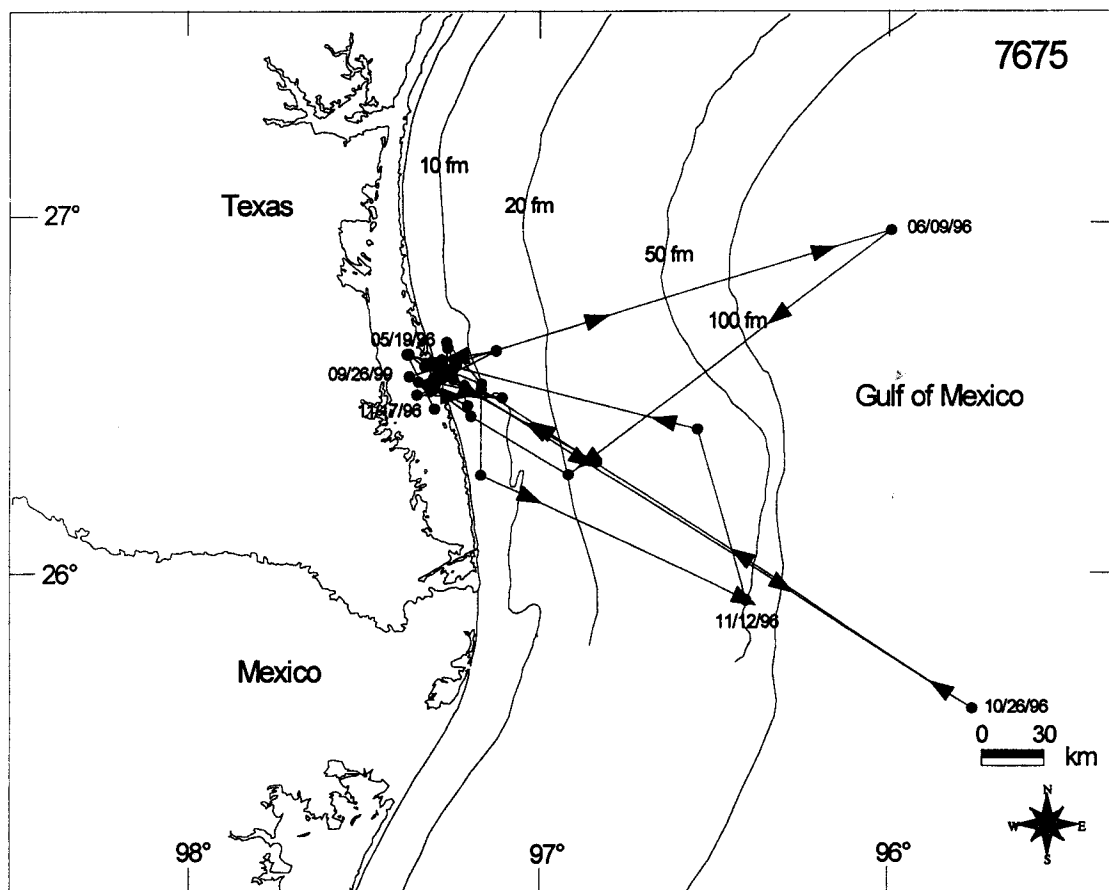


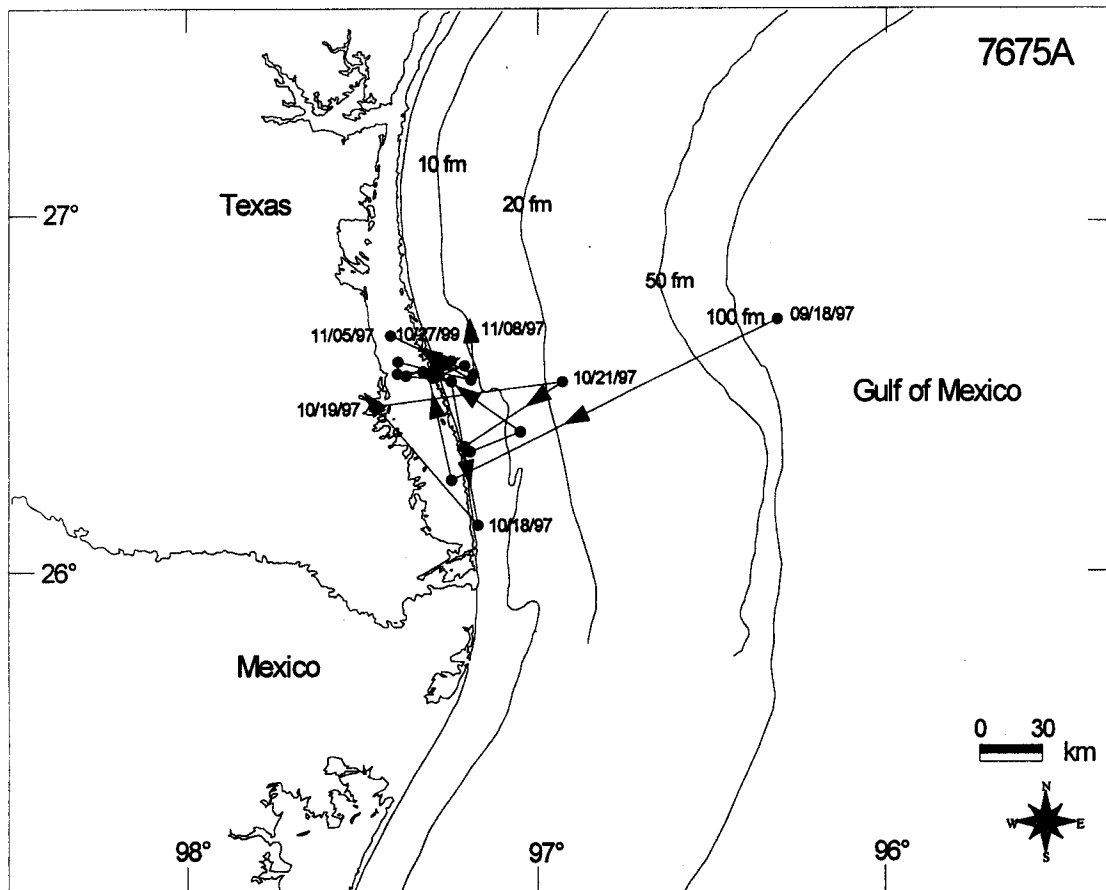


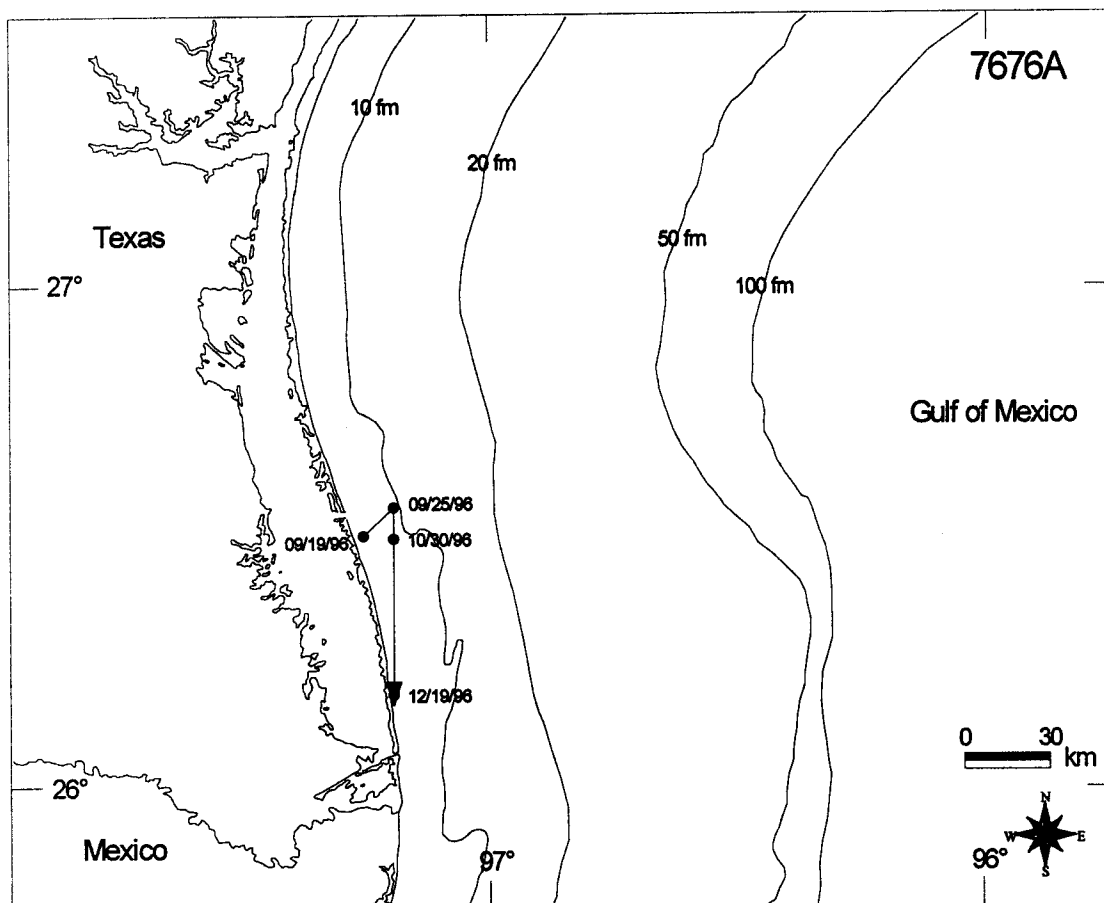


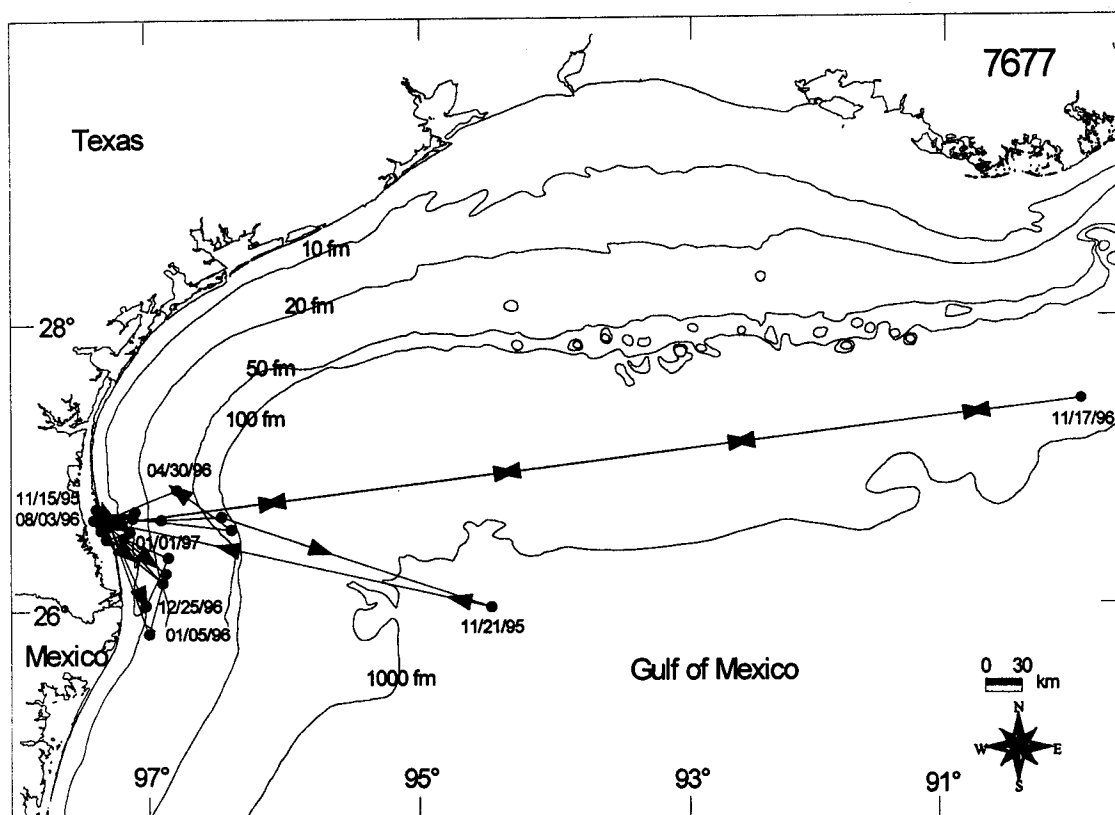


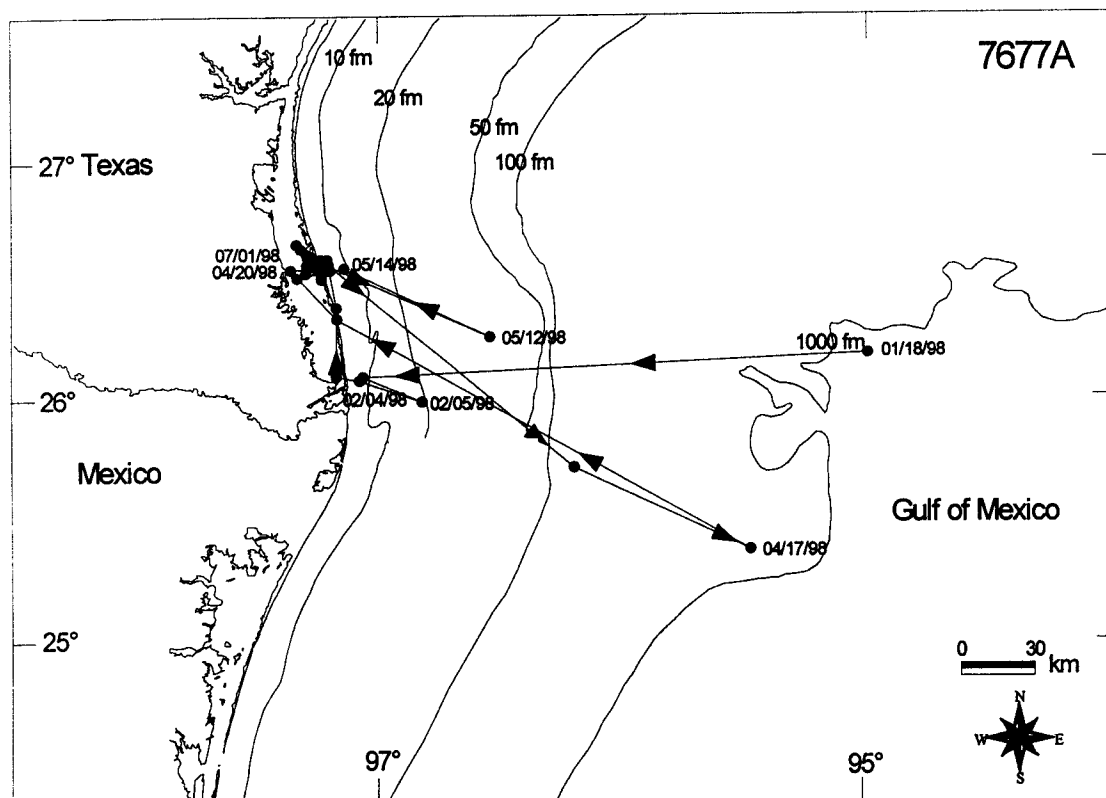


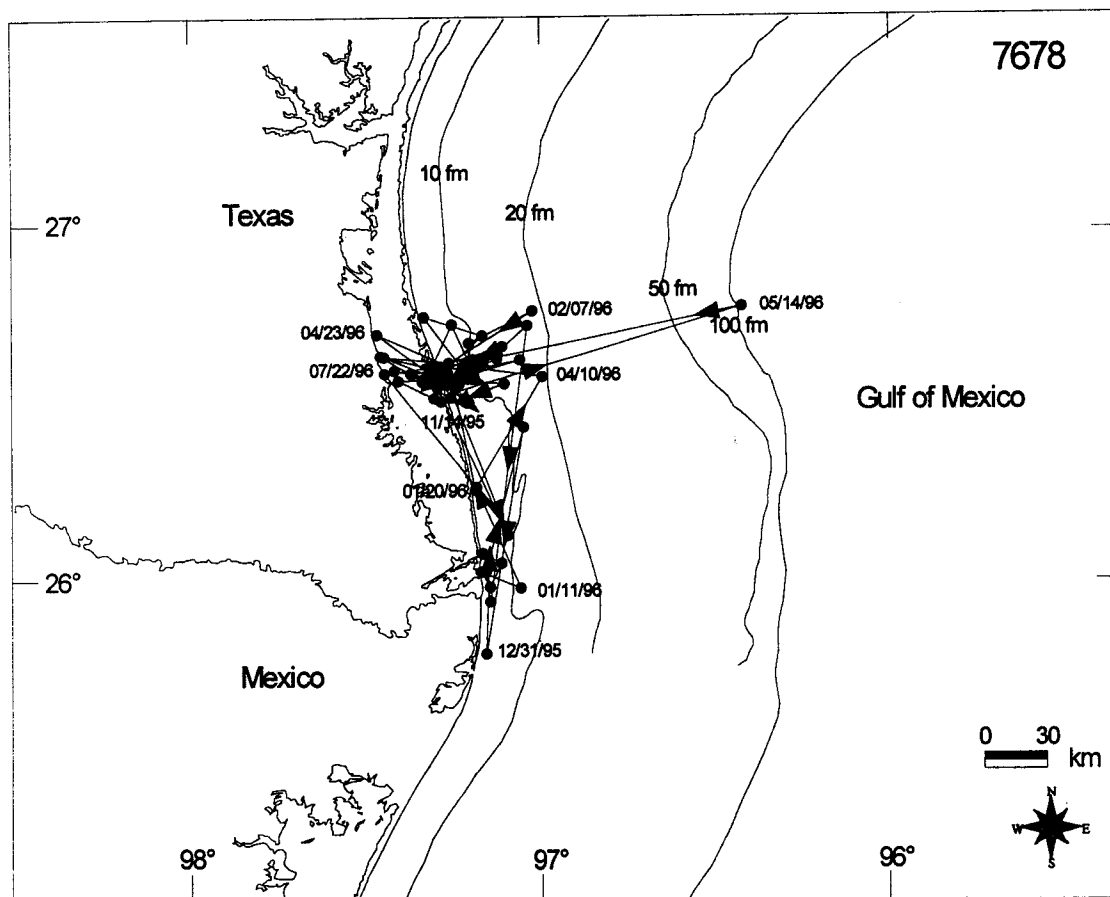


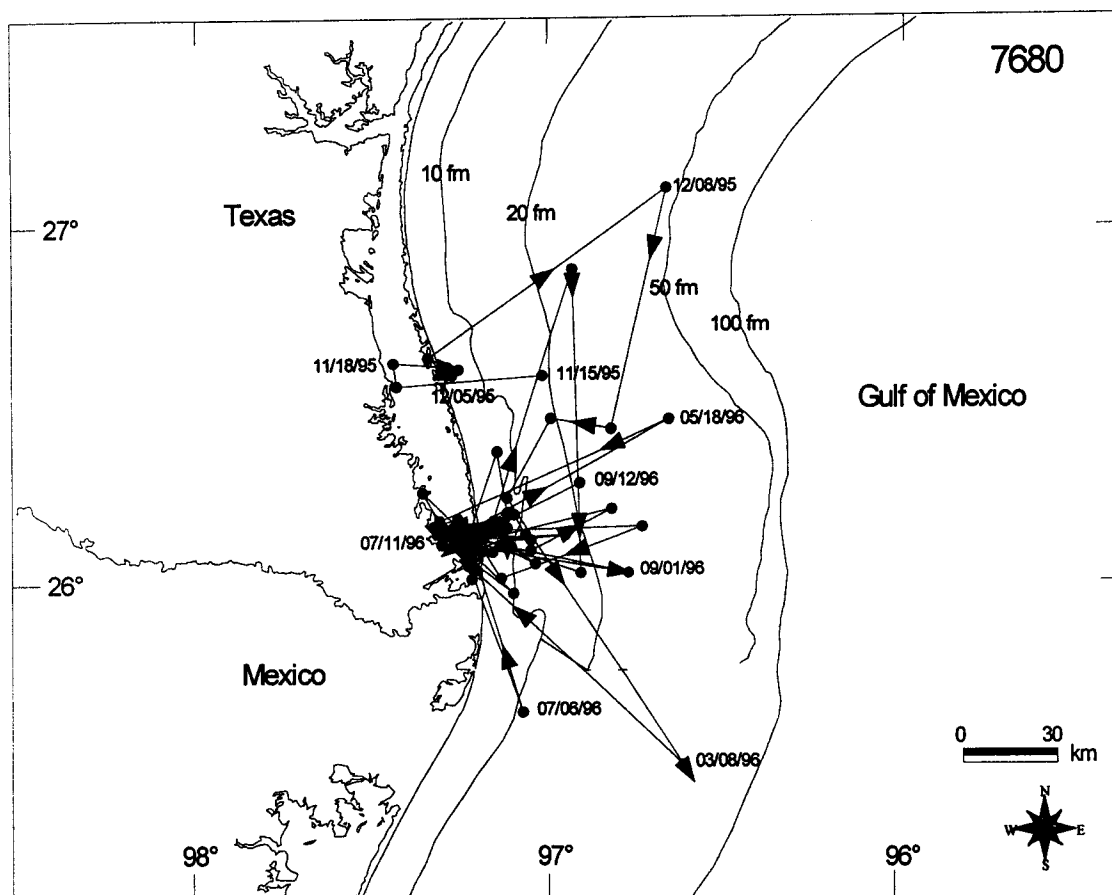


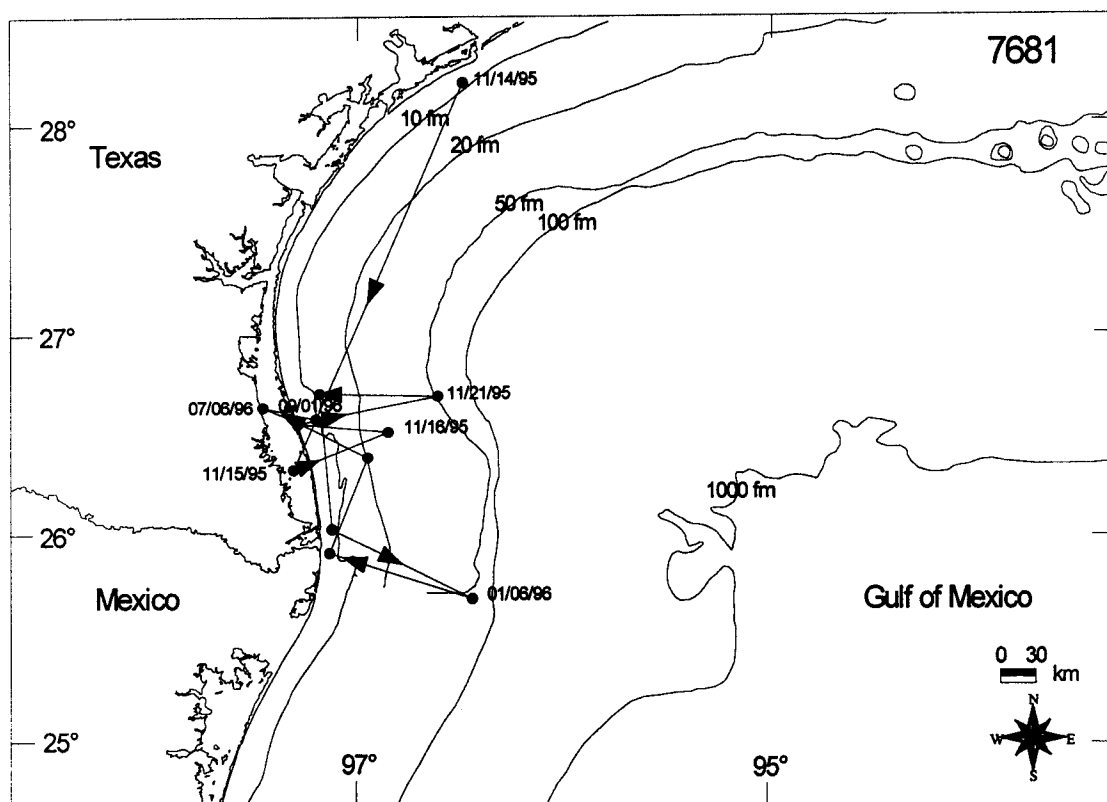


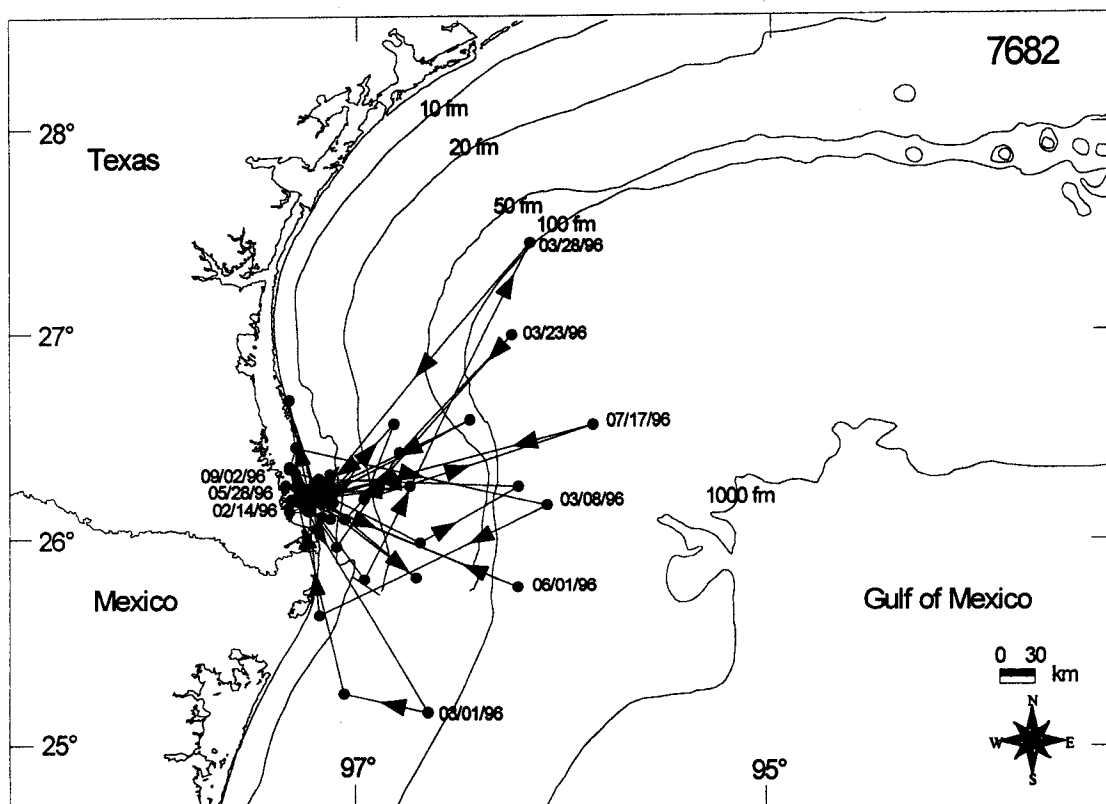


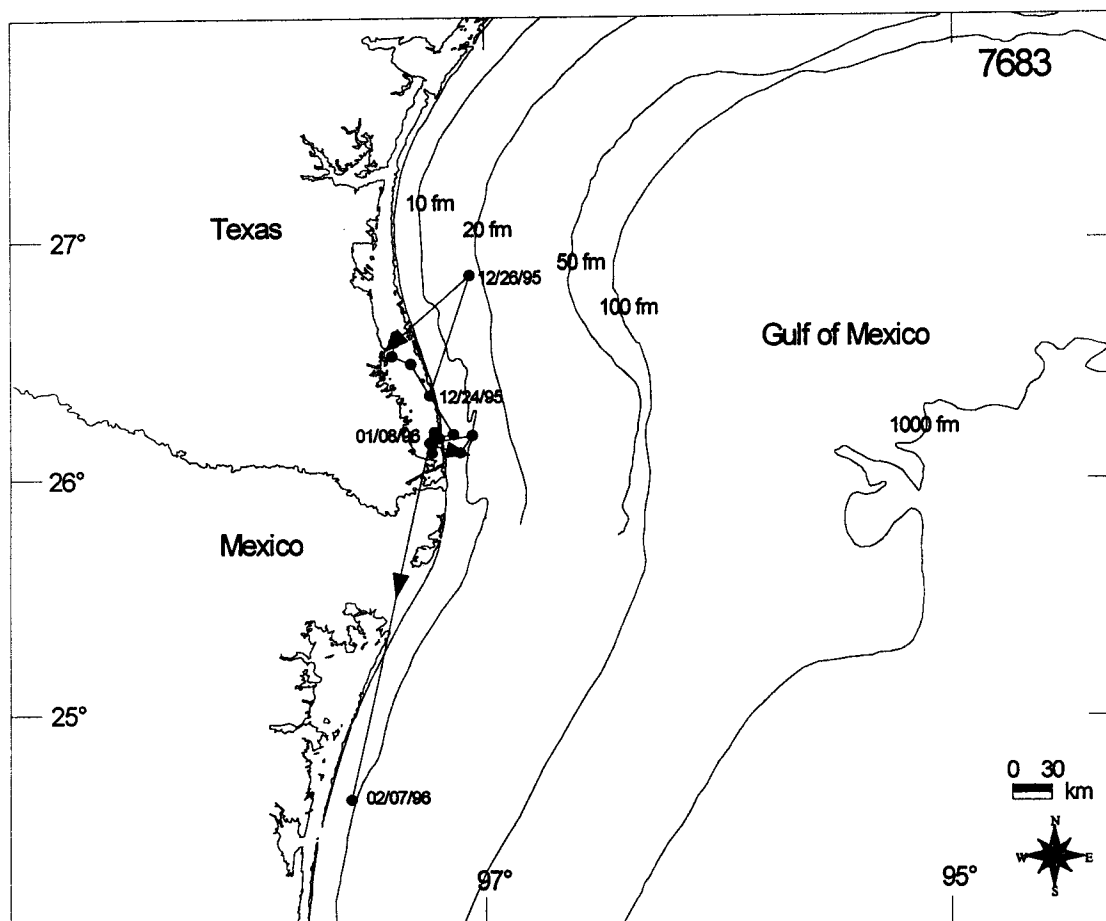


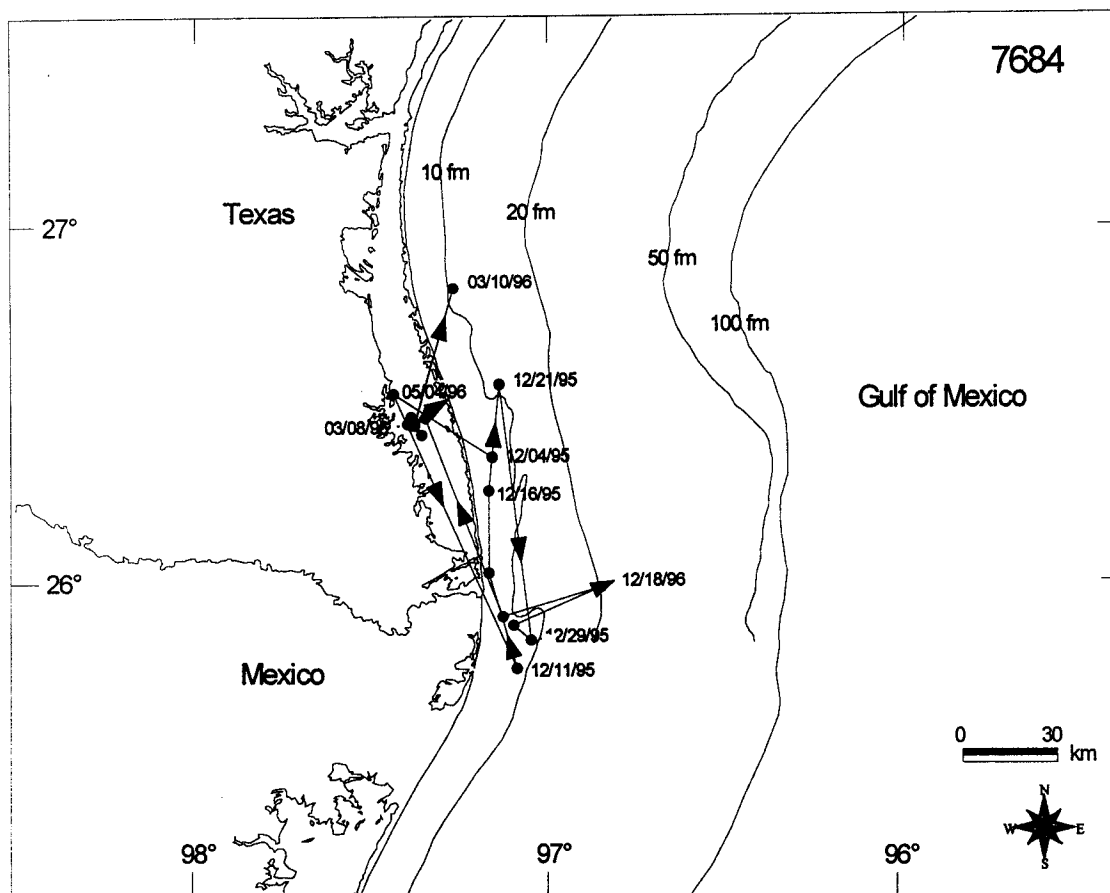


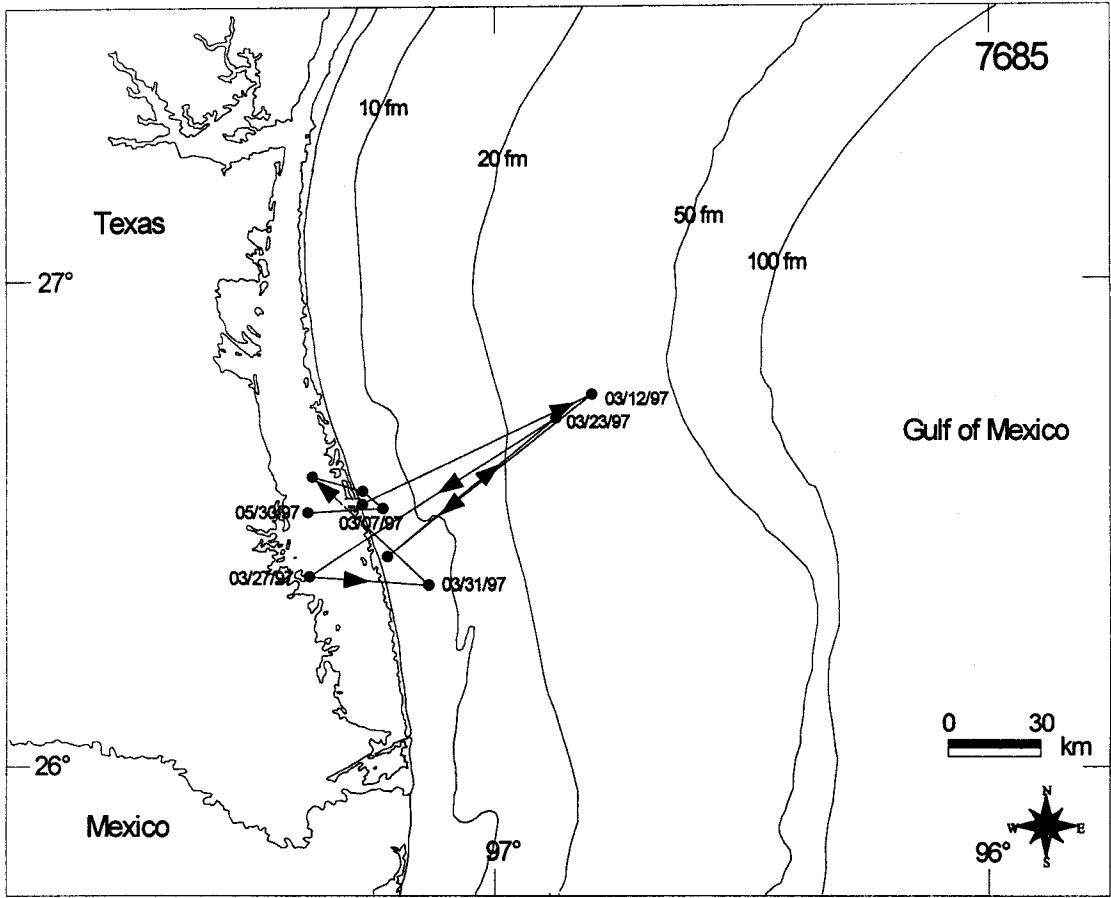


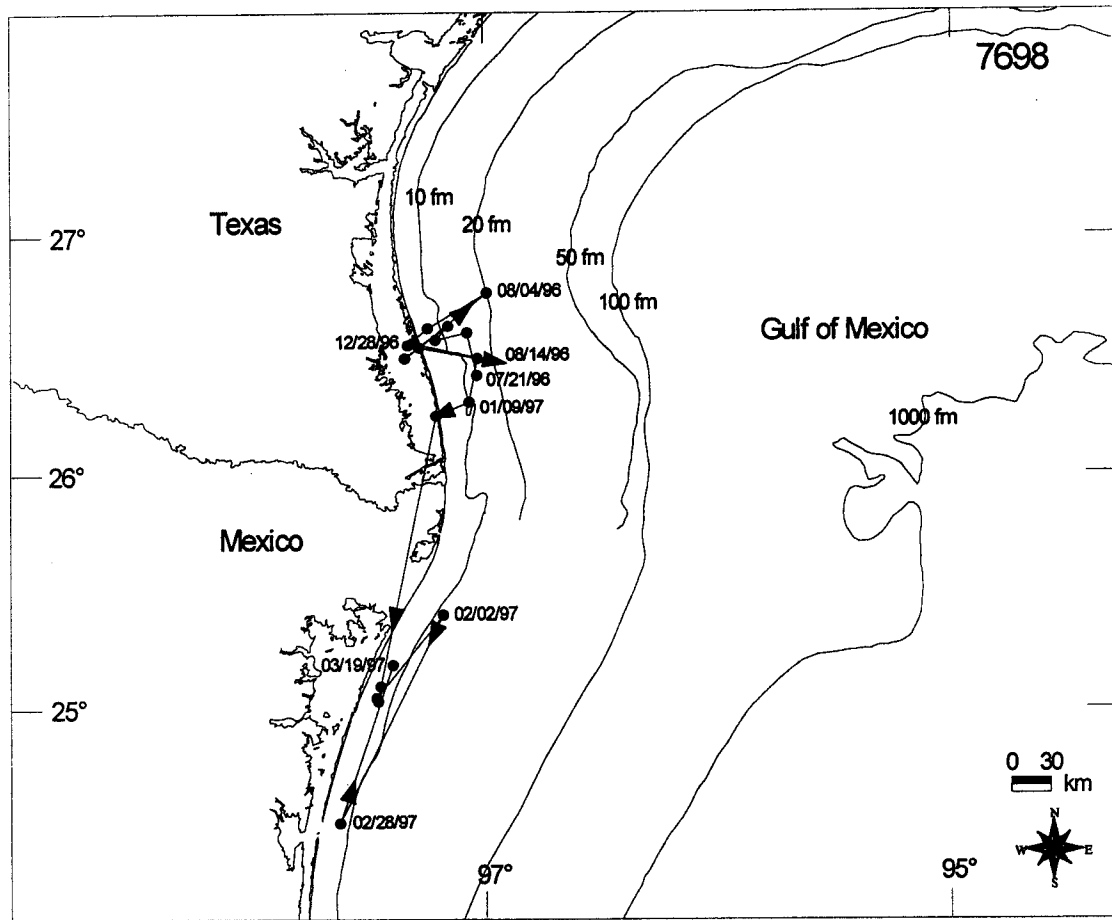




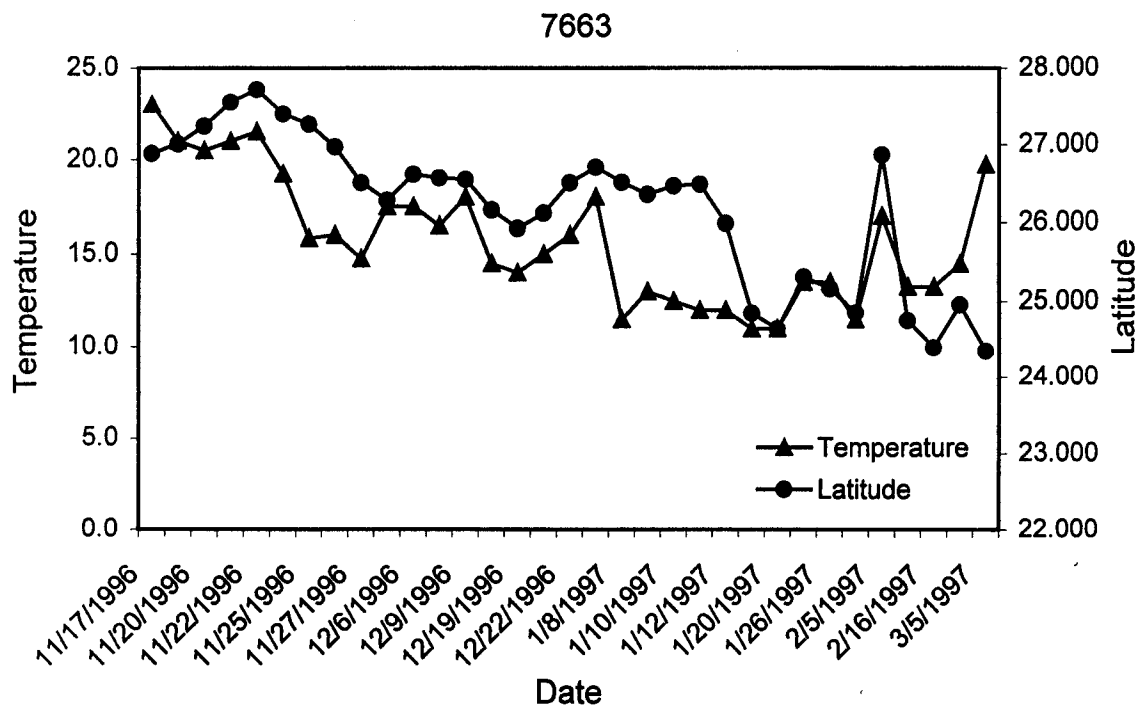
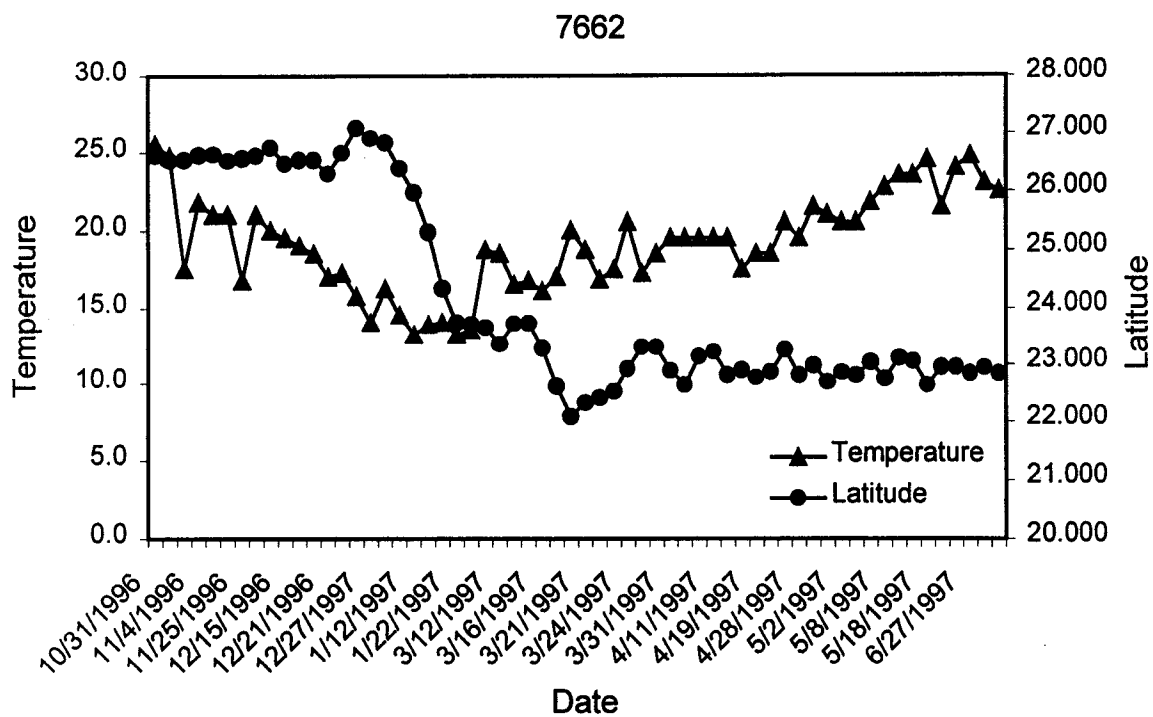


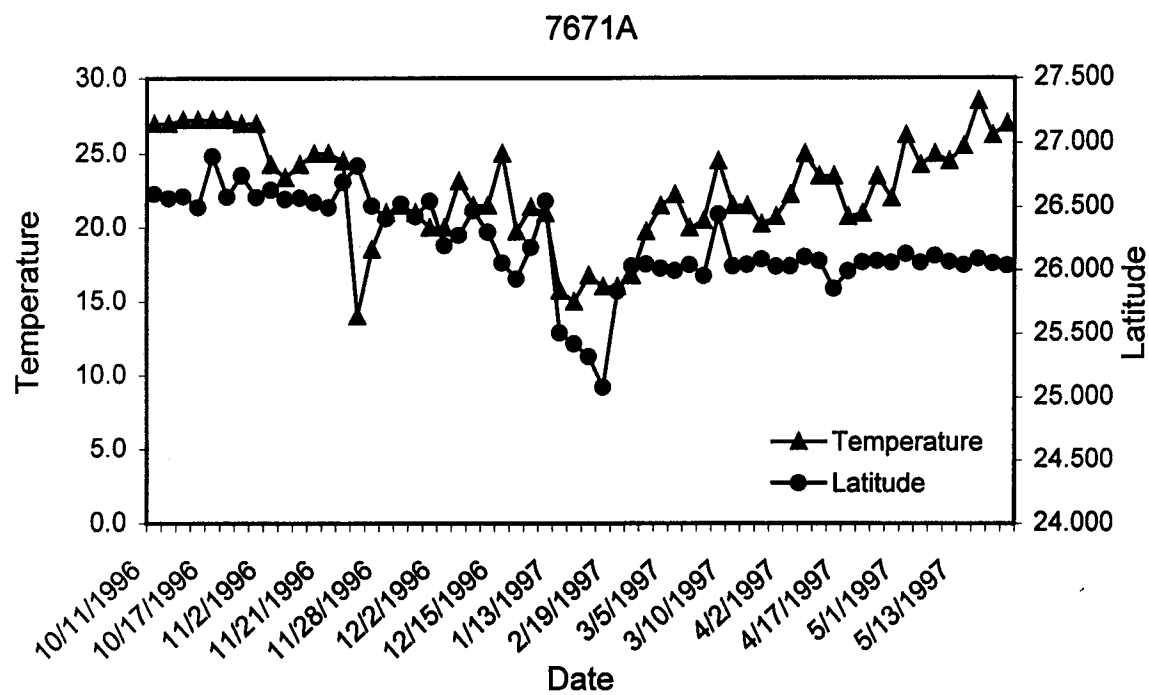
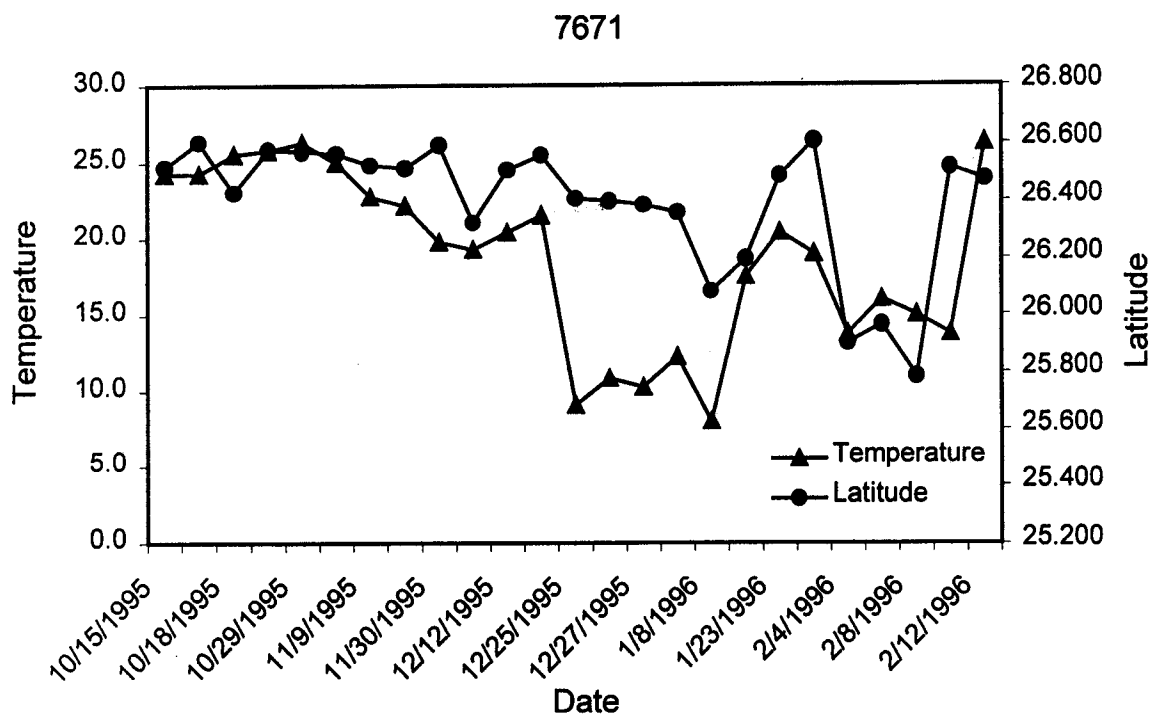


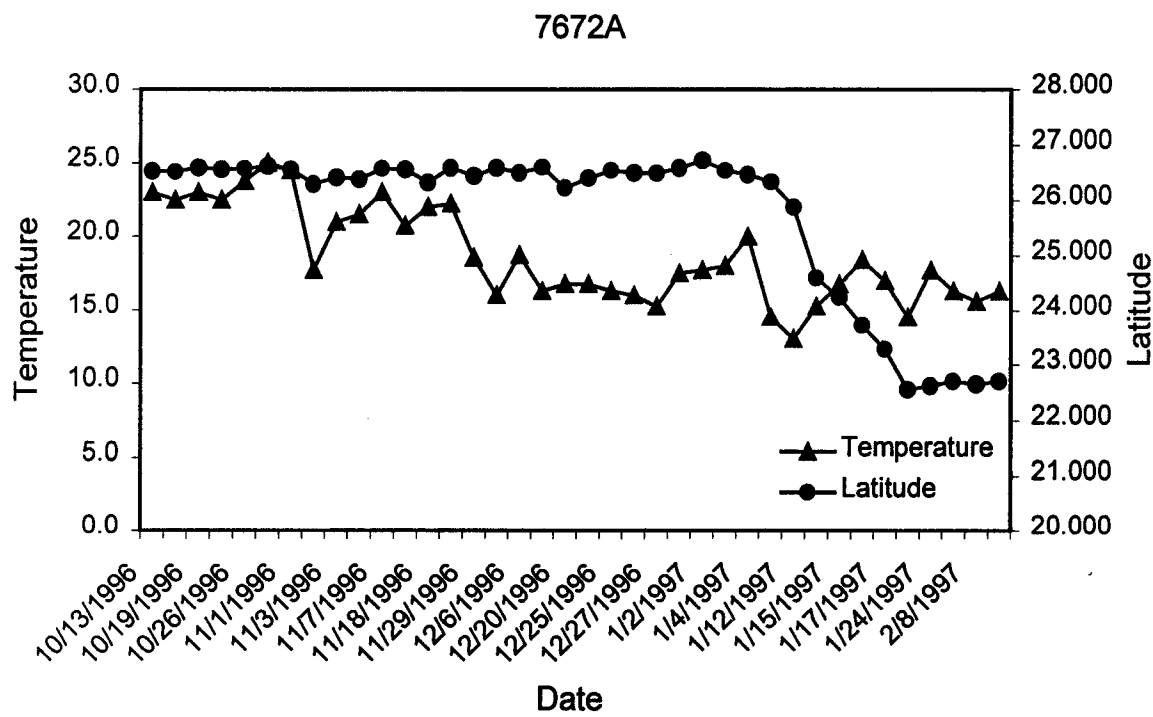
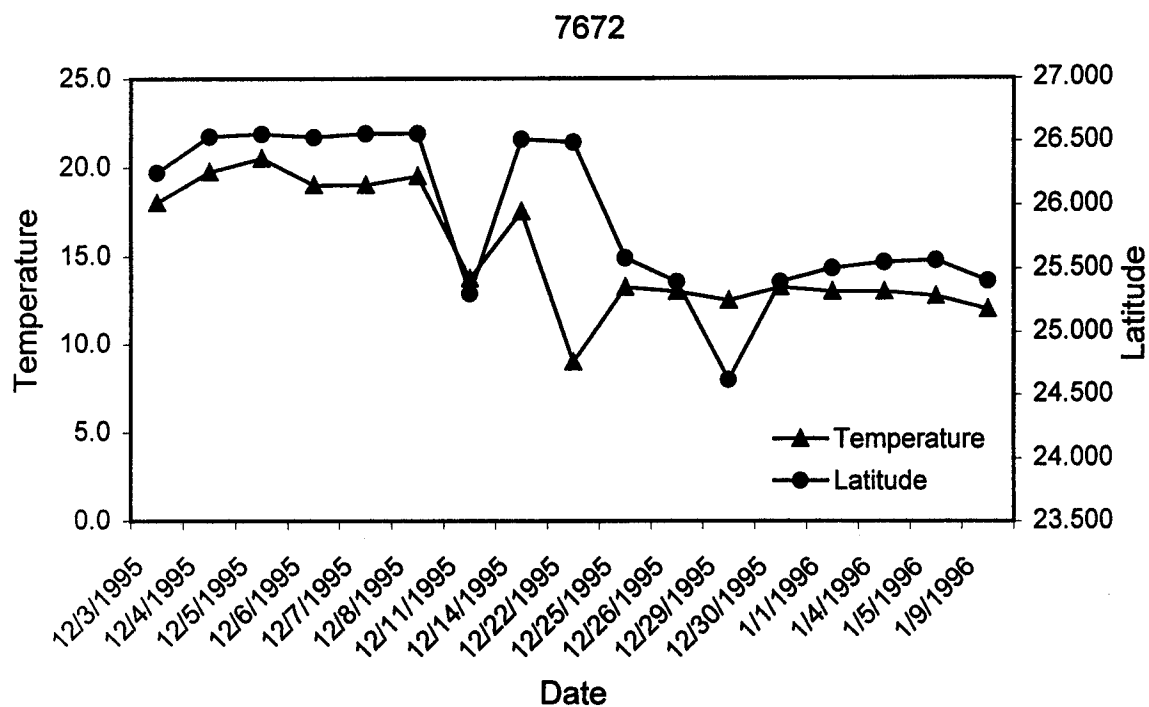


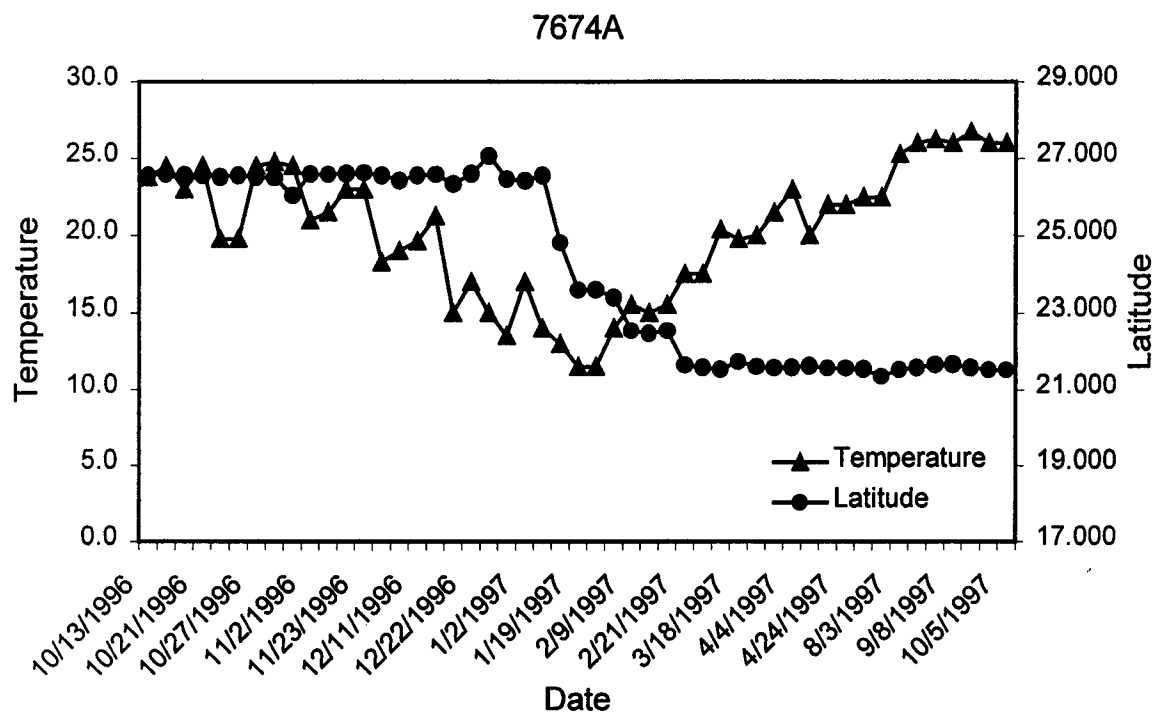
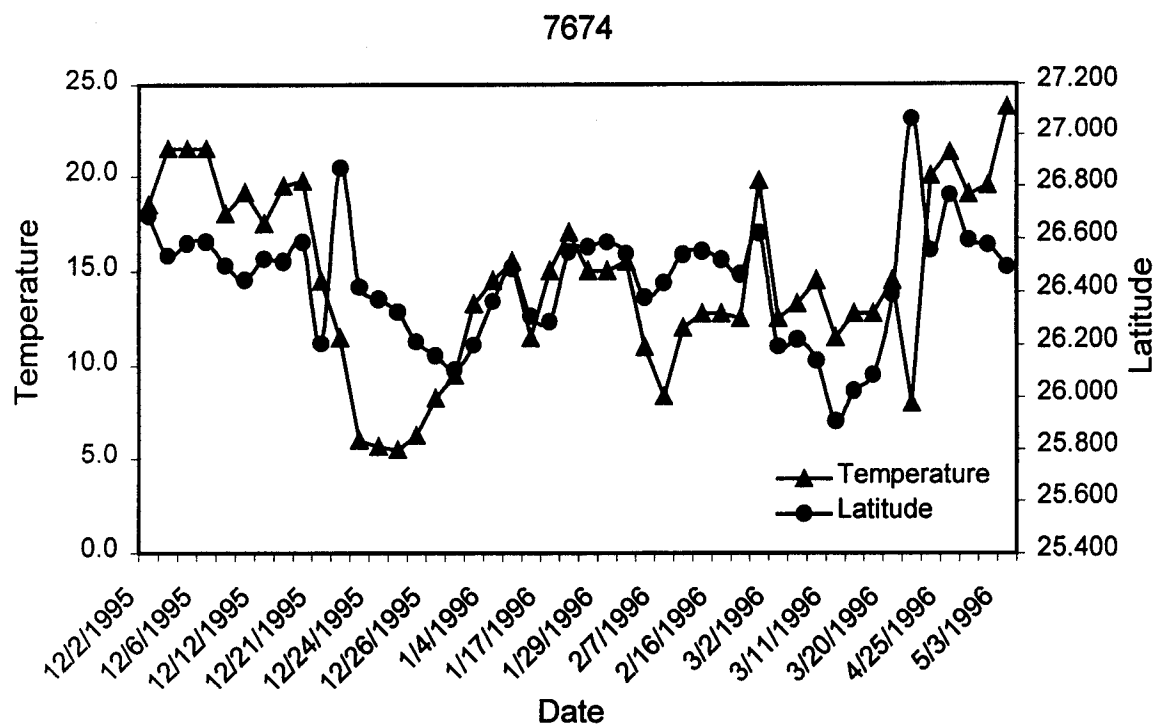


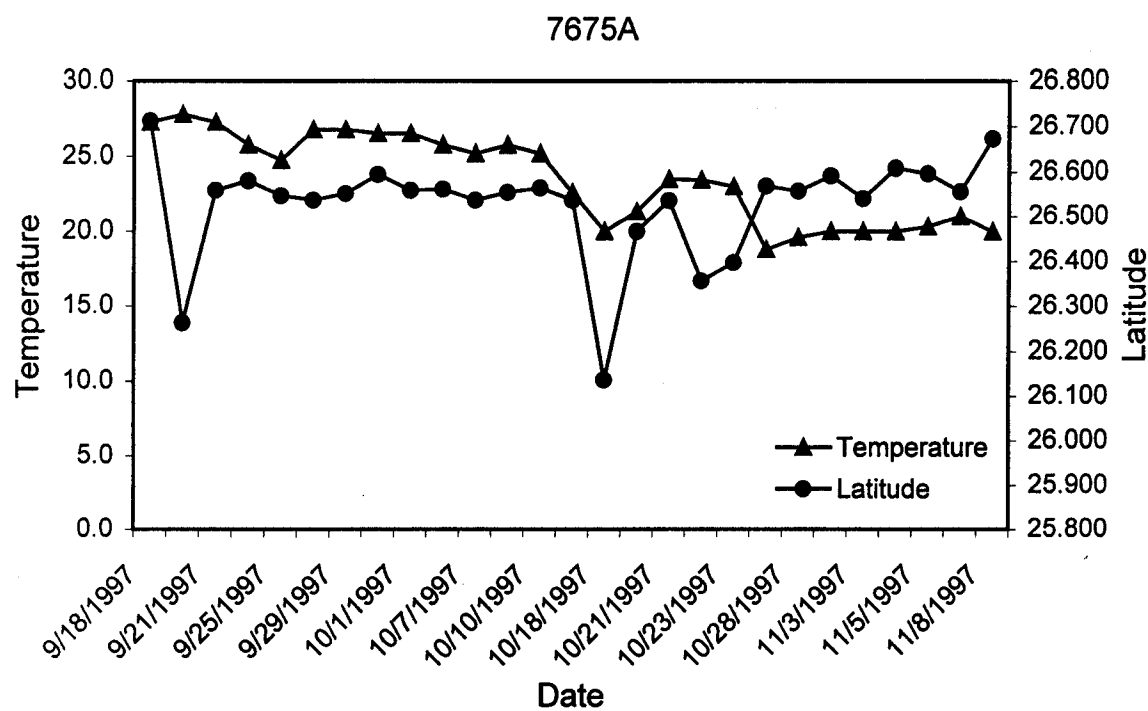
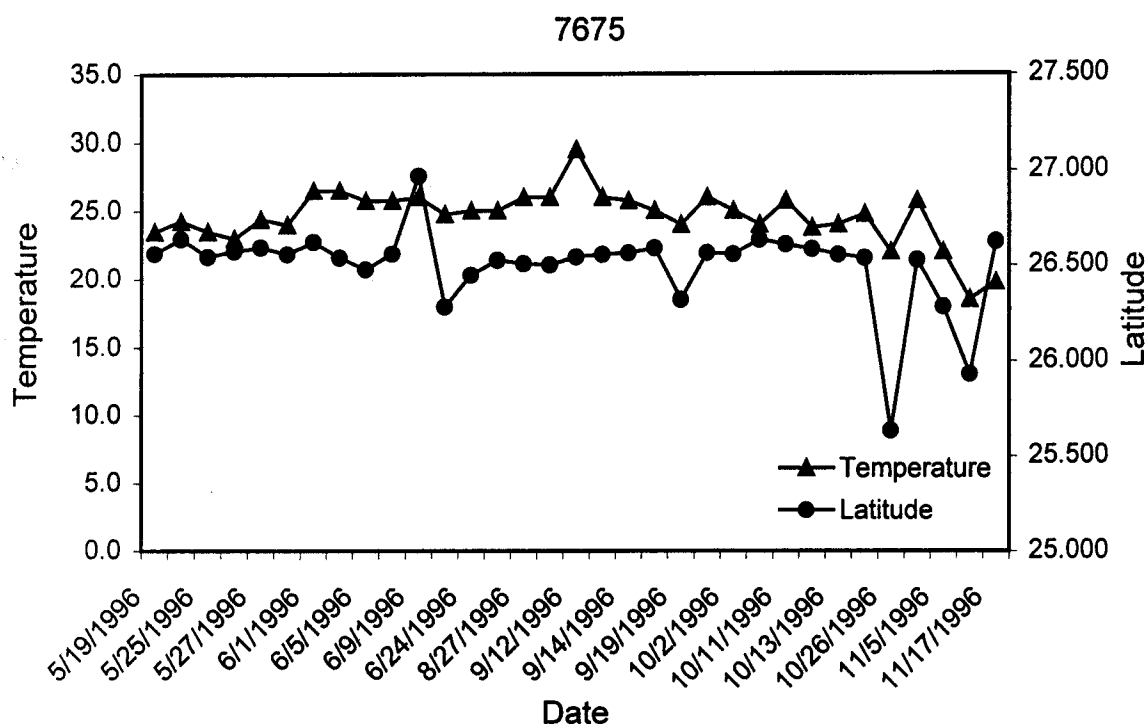
APPENDIX VII
LOCATIONS AND TEMPERATURES (C) FOR *CHELONIA MYDAS*
OUTFITTED WITH ST-6 AND ST-14 PTTS

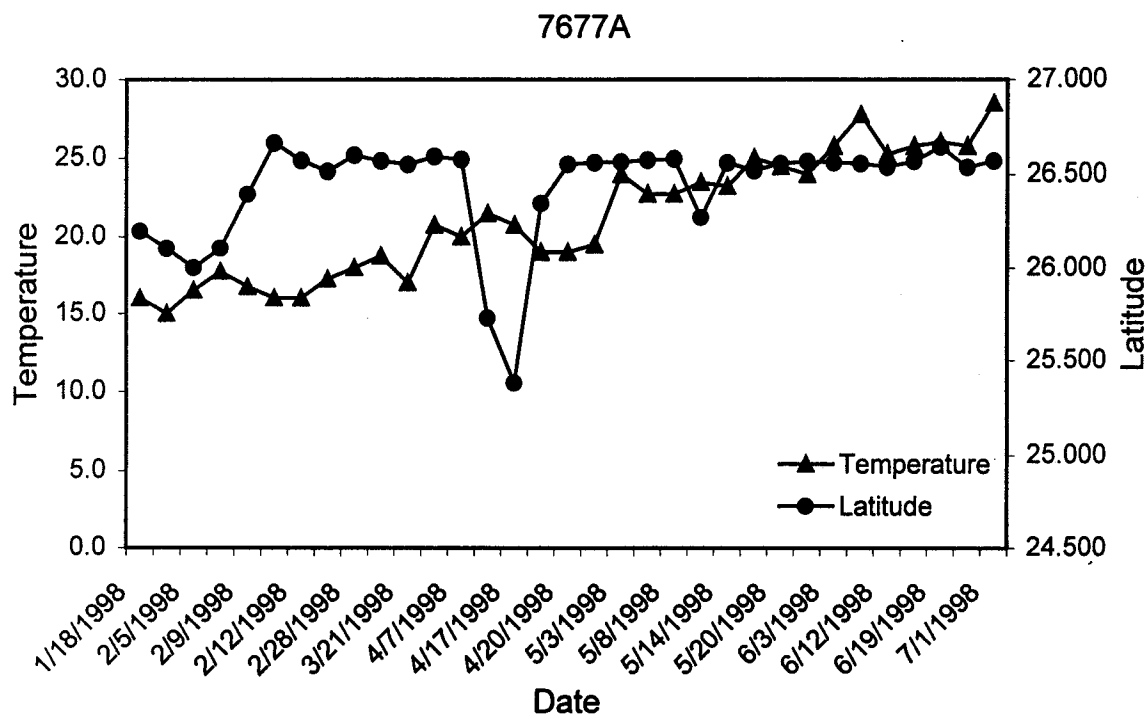
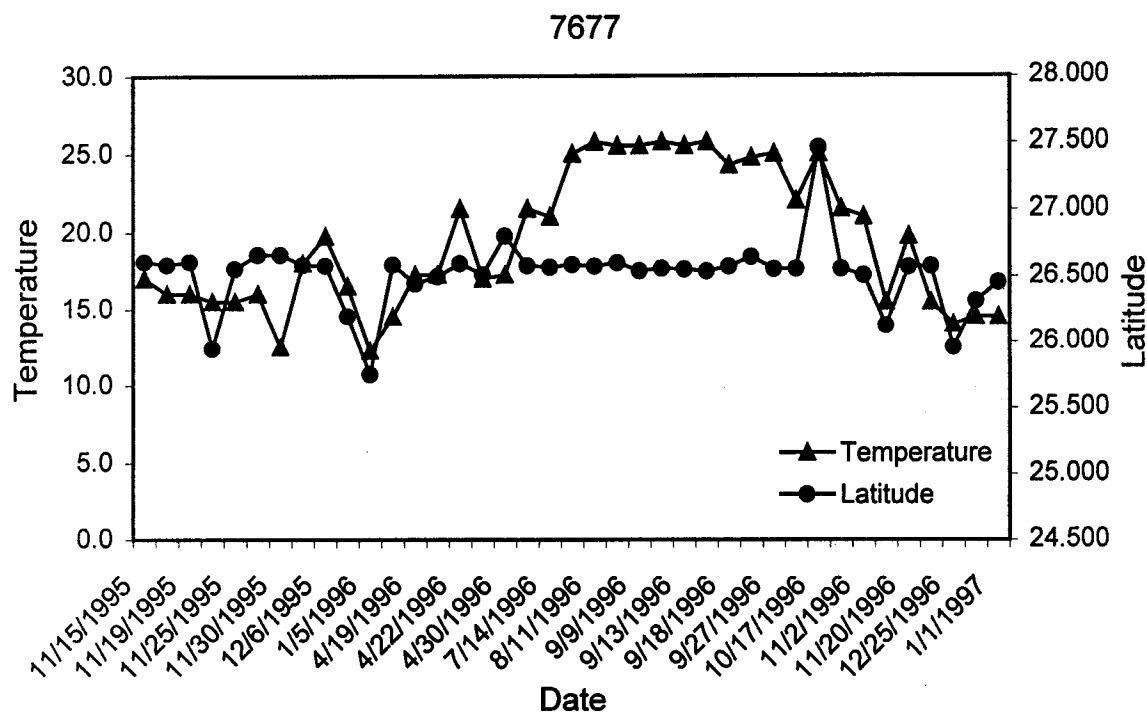


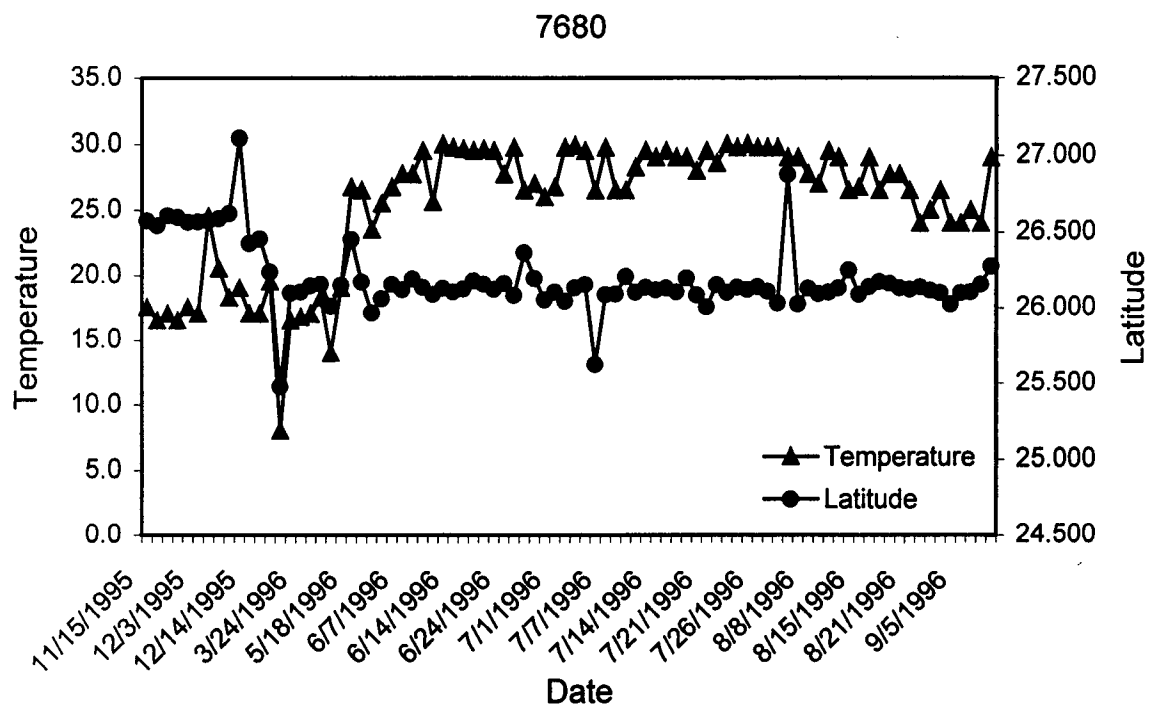
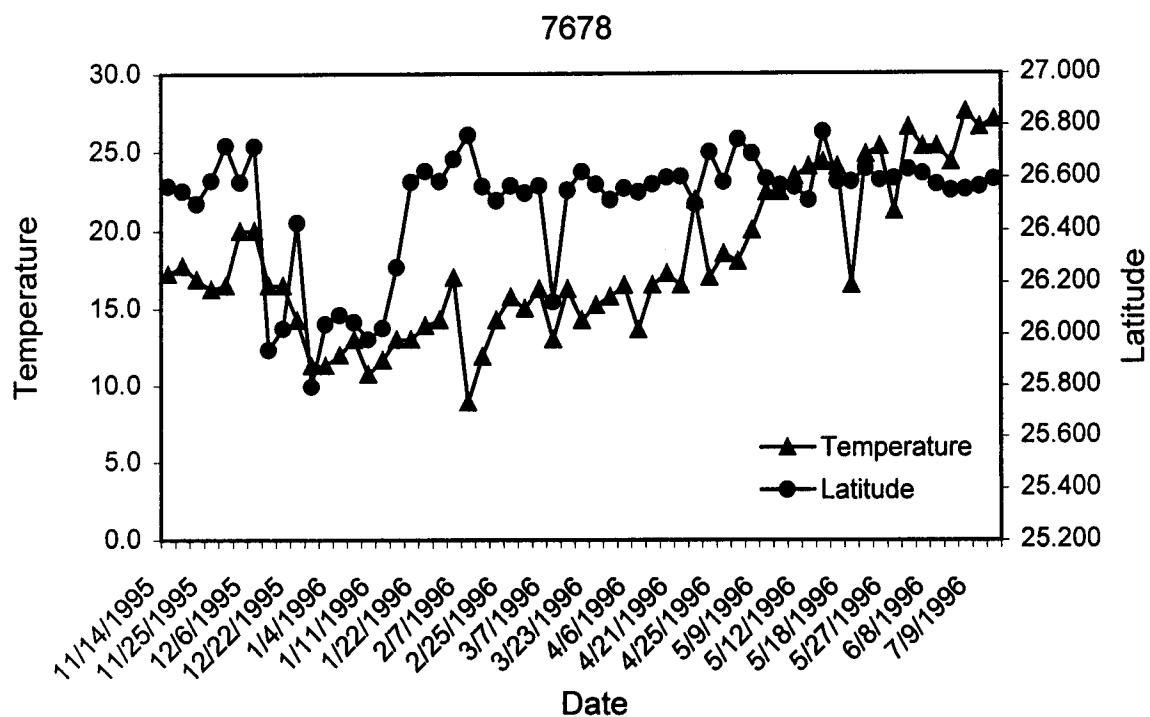


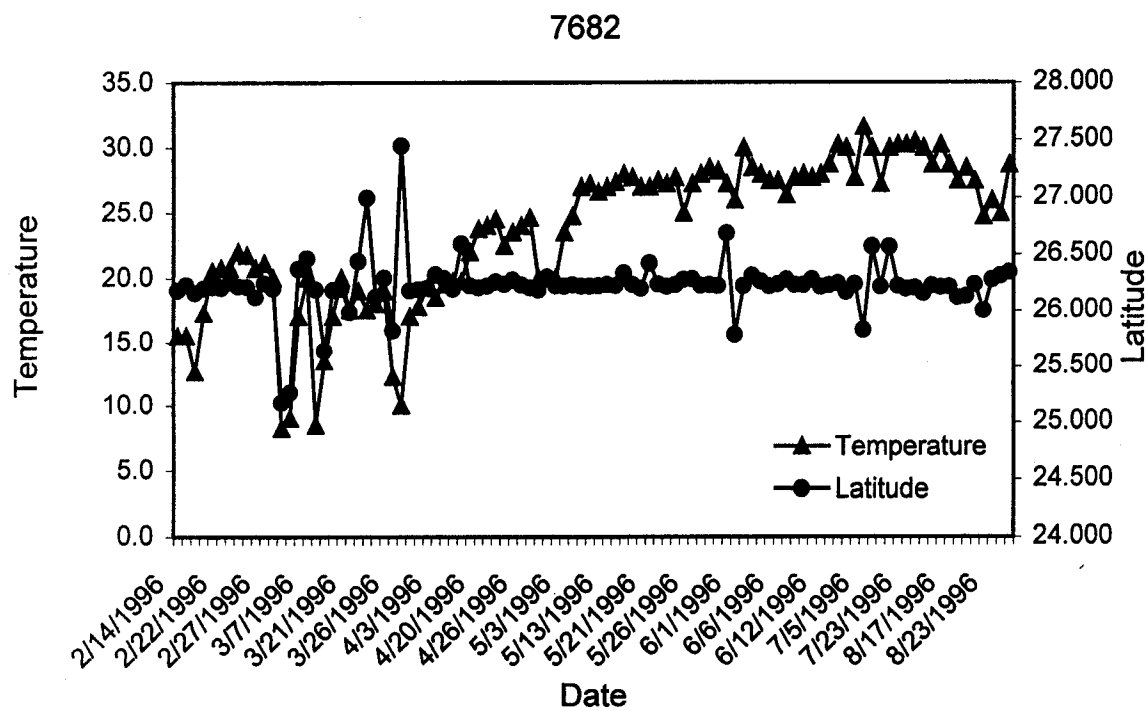
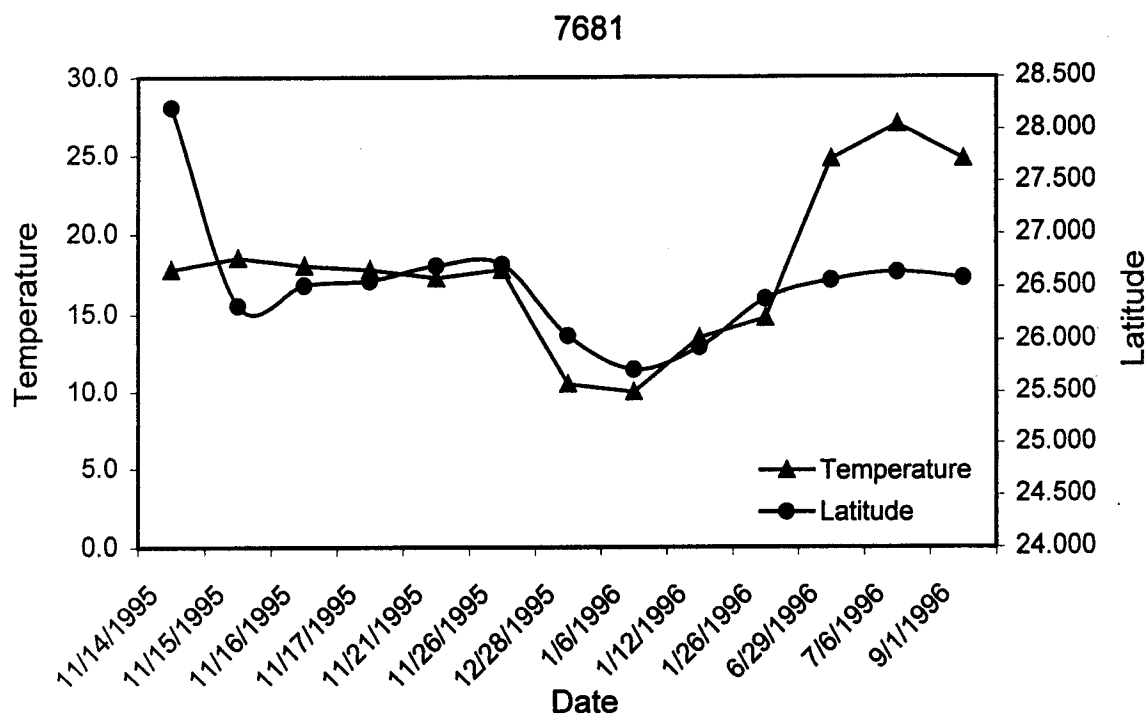


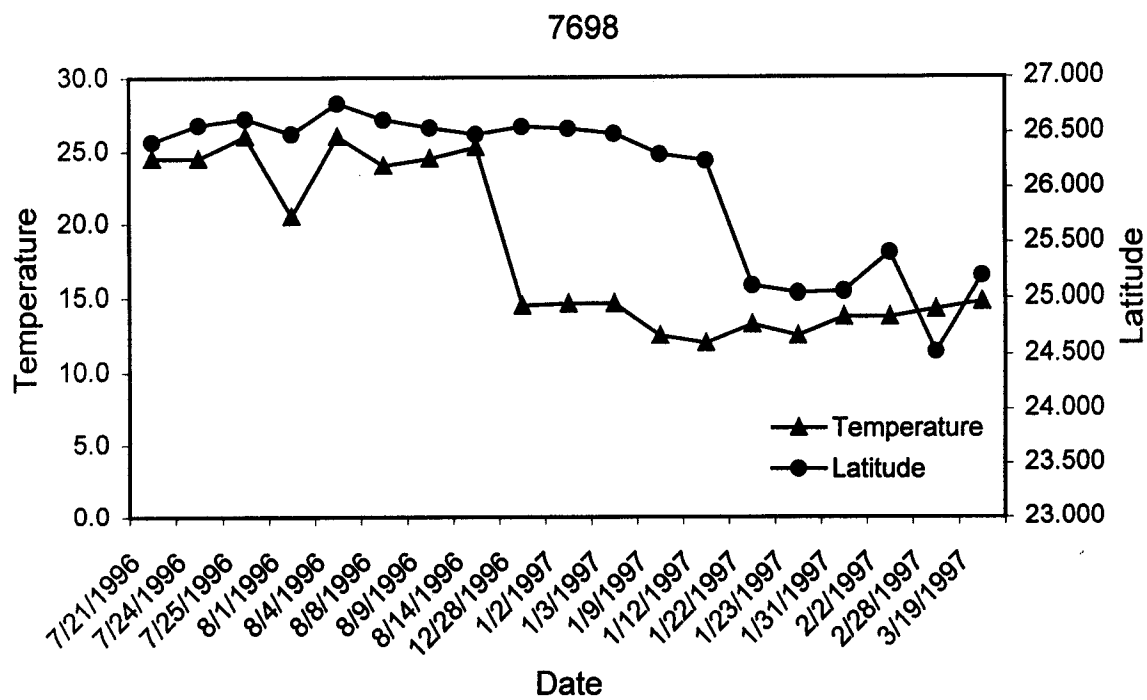
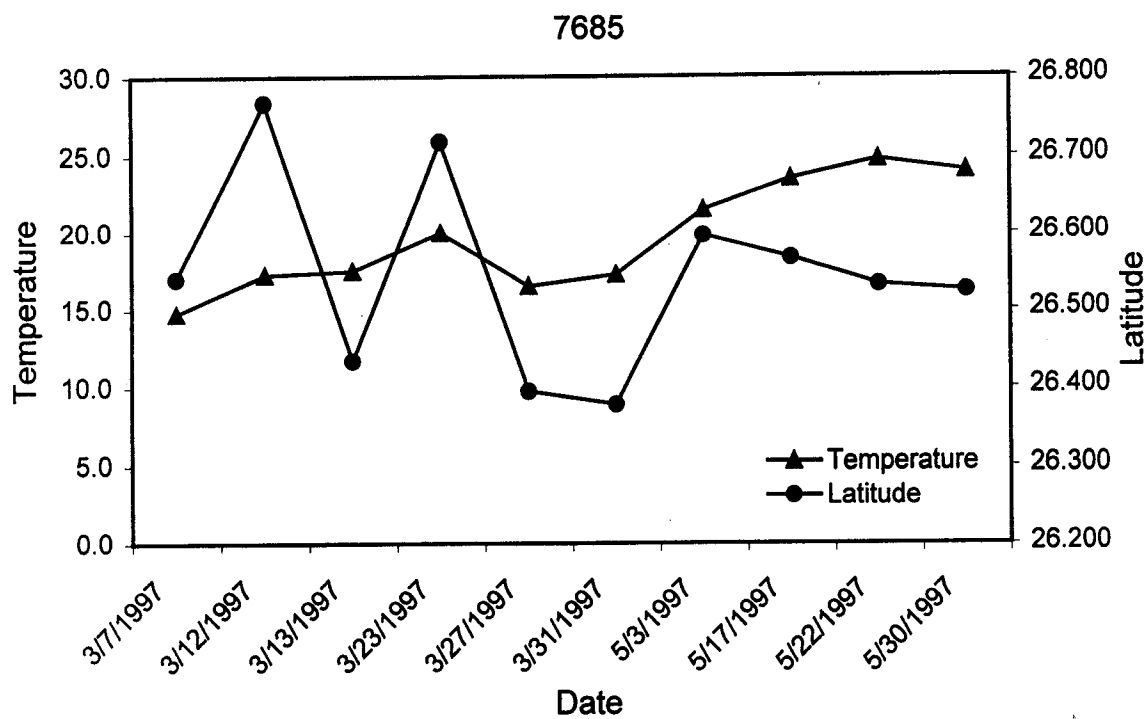












VITA

Donna Jill Shaver received her Bachelor of Science degree in Wildlife Biology from Cornell University, Ithaca, New York, in 1981 and her Master of Science degree in Biology from Texas A&I University, Kingsville, Texas, in 1984. The subject of her research was the surf zone fish fauna of Padre Island National Seashore. In 1995, she began her studies toward a Doctor of Philosophy degree in Zoology. On November 25, 1995, she was married to John E. Miller in Tully, New York. She began working with sea turtles at Padre Island National Seashore in 1980, gained permanent employment there in 1985, and became the Texas Coordinator of the Sea Turtle Stranding and Salvage Network in 1989. She is an employee of the U.S. Geological Survey, Biological Resources Division, and is the Station Leader of the Padre Island Field Station, located at Padre Island National Seashore. Her permanent address is Padre Island National Seashore, P.O. Box 181300, Corpus Christi, Texas 78480-1300.