REDUCING IMPACTS OF HOPPER DREDGING ON MARINE TURTLES IN THE NORTHWESTERN GULF OF MEXICO

by

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(Under the Direction of Sara H. Schweitzer)

ABSTRACT

Three species of threatened or endangered marine turtles are sometimes harmed or killed by hopper dredges in U.S. shipping channels: loggerhead (*Caretta caretta*), green (*Chelonia mydas*), and Kemp's ridley (*Lepidochelys kempii*). The U.S. Army Corps of Engineers manages dredging in these channels and works to monitor and mitigate negative impacts on turtles. I analyzed Corps of Engineers data to examine turtle behavior and relative abundance in shipping channels in the northwestern Gulf of Mexico, and provide information to reduce dredge-turtle interactions in the region. Turtles were taken by dredges and captured by trawls more frequently in southern channels relative to northern channels. Dredge take and trawl capture rates were greatest during March-June relative to other periods. Projects using relocation experienced fewer takes, on average, than projects without relocation trawling. Dredge hopper size and drag arm configuration, sea surface temperature, and period of day also affected rates of take and capture.

INDEX WORDS: *Caretta caretta, Chelonia mydas,* CPUE, Gulf of Mexico, hierarchical linear model, hopper dredge, incidental take, *Lepidochelys kempii,* relocation trawling, sea turtle, shipping channel, U.S. Army Corps of Engineers

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Five species of marine turtles inhabit U.S. coastal waters of the Atlantic and the Gulf of Mexico: loggerhead (*Caretta caretta*), green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), Kemp's ridley (*Lepidochelys kempii*), and hawksbill (*Eretmochelys imbricata*). Throughout their ranges, sea turtle populations have declined from historical levels (National Research Council 1990) and all species occurring in the U.S. are federally listed as endangered or threatened under the U.S. Endangered Species Act (ESA; CFR 1999).

Anthropogenic threats are largely responsible for the observed decline in marine turtle populations (National Research Council 1990). These threats include coastal development, marine pollution, commercial fishing, and hopper dredging. Development on nesting beaches reduces nesting habitat and artificial lighting disorients adult females and new hatchlings (National Research Council 1990). Turtles from all age classes are harmed or killed when they ingest plastic marine debris or when they become entangled in debris such as discarded fishing gear (National Research Council 1990). In U.S. waters, shrimp trawling causes greater turtle mortality than any other anthropogenic source (Henwood and Stuntz 1987, National Research Council 1990, Crowder et al. 1994), although other trawl fisheries also cause significant mortalities (Epperly et al. 1995).

Shipping channels are trenches in the sea floor, excavated to allow the passage of marine vessel traffic between deep ocean areas and inshore bays and harbors. The U.S. Army Corps of Engineers (USACE) is federally mandated to maintain navigable depths in U.S. shipping channels and sometimes uses hopper dredges for this purpose. Hopper dredges are self-contained ships that lower trailing suction dragheads to the sea floor to remove substrate. Turtles are harmed or killed when they are entrained in the hydraulic system of a hopper dredge. Although all resident species are potentially at risk from dredging (National Research Council 1990), only mortality of loggerhead, green, and Kemp's ridley turtles has been confirmed, and these species are considered at most risk (Dickerson et al. 1990, Dickerson et al. 2004). Hereafter, all discussion will concern these three species. Turtle entrainment events are referred to as incidental takes. Recovery plans prepared by the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) mandate efforts to study the abundance and behavior of turtles at dredge sites, and to reduce the mortality of turtles at dredge sites (NMFS and USFWS 1991a,b; USFWS and NMFS 1992). With continued increases in human populations and the economy, dredging activity will necessarily increase in coastal waters. To protect threatened and endangered marine turtles, it is important to reduce turtle mortality from this activity as much as possible while still allowing indispensable economic activities. Quantitative analysis of data from dredging activity and dredge-related turtle mortality may reduce the negative impacts of hopper dredging.

Most research on turtles in shipping channels has focused on channels of the southeastern Atlantic coast between Virginia and Florida (Henwood, 1987, Keinath et al. 1992, Van Dolah and Maier 1993, Standora et al. 1994, Dickerson et al. 1995, Nelson 1996). Although researchers have studied turtle behavior in Gulf of Mexico shipping channels (Renaud et al. 1994, Renaud et al. 1995), these channels have received substantially less attention than their Atlantic counterparts. Since 2000, several Gulf Coast dredging projects have been prematurely curtailed due to dredge-related turtle morality (personal observation). Aside from the potential risks to turtle populations posed by high dredge-related mortality, project shutdowns of this nature result in significant economic costs to private dredge companies, federal agencies, and U.S. taxpayers. The goal of this research was to examine data from Gulf of Mexico hopper dredge projects between 1995 and 2004 to provide information to reduce takes and provide management tools in the region.

NATURAL HISTORY

Loggerhead, green, and Kemp's ridley sea turtles occur in U.S. coastal waters from New England to Texas (Ruckdeschel and Shoop 2006). Adult and juvenile loggerheads and greens are found throughout this range (Dodd 1988, Hirth 1997). Juvenile Kemp's also occur throughout this range, but adults of the species are restricted primarily to the Gulf of Mexico (Marquez 1994). Of these species, loggerheads are the most abundant in U.S. waters (Maier et al. 2004, Ruckdeschel and Shoop 2006). Loggerheads in the U.S. represent at least three genetically distinct nesting subpopulations: the northern population nests on the Atlantic coast north of central Florida, the south Florida population nests in southeastern Florida, and the western population nests on beaches of the Gulf of Mexico (Plotkin and Spotila 2002). The northern and south Florida populations mix on foraging grounds on the Atlantic U.S. coast (Plotkin and Spotila 2002).

Generally, turtles are only abundant during spring and summer in the portion of this range north of Florida (Dickerson et al. 1995, Avens et al. 2003, Avens and Lohmann 2004). However, Epperly et al. (1995) found significant overwintering populations of loggerheads in coastal North Carolina near Cape Hatteras, and Kemp's were common in that area in November and December. Maier et al. (2004) found that loggerheads were the most commonly captured species in summer research trawls in the Atlantic, followed by Kemp's, and that greens were uncommon. Turtles are continuously present in southeastern Florida coastal areas (Henwood 1987, Gitschlag 1996). Turtles are present in the Gulf of Mexico throughout the year, although they are generally less abundant in the northern areas of the region during the winter, and may move south in response to decreasing water temperatures (Renaud et al. 1994, Renaud 1995).

In the U.S., marine turtles nest on sandy beaches from Virginia to Texas (Ruckdeschel and Shoop 2006). Loggerheads nest throughout this range (Dodd 1988) and greens nest primarily in Florida (Hirth 1997). Kemp's ridleys nest primarily in northeastern Mexico (Marquez 1994). Mating occurs in coastal waters near nesting beaches during a period shortly before nesting (Miller 1995, Frick 2000).

Gravid females emerge on sandy beaches at night, use their rear feet to excavate nest cavities in loose sand above the high tide line, and deposit between 50 and 180 soft-shelled eggs (Ehrhart 1982). Clutches laid by a single female sometimes exhibit multiple paternity (Kichler et al. 1999, Moore and Ball 2002, Ireland et al. 2003). Marine turtles, exhibit mean remigration intervals of 2-5 years, and lay several clutches during each year that they nest (Miller 1995). Nesting females show a high level of philopatry, returning to the same nesting beach on subsequent nesting seasons (Miller 1995).

Hatchling turtles emerge from the nest and disperse into pelagic environments where they remain for several years before recruiting into neritic habitats (Carr 1987, Bolten and Balazs 1995). This early pelagic hatchling stage was a mystery to researchers for many years and remains poorly understood. Carr (1987) presented evidence that hatchlings drift passively in ocean currents associated with debris-filled current drift lines and sargassum mats. Bjorndal et al. (2000) estimated that this stage lasted for 8.2 years for loggerheads.

In U.S. waters, juvenile turtles recruit from the pelagic stage into coastal habitats where they are believed to remain for the duration of their lives. There is much variation within and among species in the size at which individuals recruit into neritic habitats. Bjorndal et al. (2001) estimated that loggerheads recruit to neritic habitats between 46–64 cm curved carapace length (CCL); and greens, between 25–35 cm straight carapace length (SCL; Bjorndal et al. 2000). Less is known about the Kemp's ridley, but few individuals smaller than 20 cm SCL were found in foraging areas in U.S. waters (Marquez 1994). The longevity of sea turtles is not known. Bjorndal et al. (2001) estimated that loggerheads attained a length of 87 cm CCL at 26.5 years, noting that 87 cm is a very low estimate of size at sexual maturity and that the average age at sexual maturity is probably greater than 26.5 years. Growth models for green turtles estimate that individuals take 11.96 years to grow from 30 to 70 cm SCL (Bjorndal et al. 1995). Given a pelagic stage similar in length to loggerheads, and given that minimum size of nesting females is about 100 cm SCL (Bjorndal et al. 1995), green turtles are probably older than 20 years at sexual maturity. The average size of nesting female Kemp's is around 62.3–66 cm SCL, and this species has been observed nesting at ages as young as 5 years in captivity (Marquez 1994).

Juvenile and adult loggerhead and Kemp's ridley turtles are opportunistic benthic foragers that ingest a variety of marine invertebrates, especially mollusks and crustaceans (Bjorndal 1985, Dodd 1988, Marquez 1994). Juvenile and adult green turtles are primarily herbivorous, foraging on marine grasses and algae, although pelagic stage post hatchlings probably ingest marine invertebrates (Bjorndal 1985, Hirth 1997), and large green turtles readily eat fish or squid in captivity (personal observation).

The movement and behavior of turtles in marine environments are poorly understood, although research in recent years has helped to clarify them. In U.S. east coast waters, turtles make seasonal migrations, moving north in summer and south in winter (Gitschlag 1996, Avens and Lohmann 2004). Turtles are capable of directed long-distance movement across pelagic environments (Cheng 2000, Nichols et al. 2000, Luschi et al. 2003), but some researchers have suggested that turtles prefer to move along the coast instead of crossing open pelagic areas (Papi et al. 1997, Cheng 2000). Newly hatched turtles apparently use the inclination of the earth's magnetic fields to orient after entering the water (Witherington 1995). Larger juveniles and adults probably use redundant cues for orientation; Avens and Lohmann (2003) found that the orientation of juvenile loggerheads was changed when both vision and sensation of earth's magnetic field were disrupted, but was not affected by the disruption of either ability alone. Papi et al. (2000) found that adult green turtles with attached magnets were able to navigate comparably to un-disturbed turtles.

Adult and juvenile turtles home rapidly to specific areas following displacement (Standora et al. 1994, Avens et al. 2003), and sometimes return to the same areas after leaving on seasonal migrations (Van Dolah and Maier 1993, Avens et al. 2003). Turtles establish temporary home ranges and may occupy a series of foraging areas for extended periods (Renaud and Carpenter 1994, Renaud et al. 1995, and Avens et al. 2003).

THREATS AND CONSERVATION

Historically, the decline of turtles in the U.S. was due, in part, to direct harvest of turtles and their eggs (National Research Council 1990). Present threats include development on nesting beaches, commercial fishing nets, boat strikes, pollution, and marine construction and dredging (National Research Council 1990, Eckert 1995, Dickerson et al. 2004). The northern U.S. nesting subpopulation of loggerheads continues a slow decline and south Florida nesting populations have stabilized (Limpus 1995). Due to rigorous protection, the south Florida nesting populations of greens have recovered slightly, as has the nesting population of Kemp's (Limpus 1995). From an intensive trawl survey of turtles between Winyah Bay, South Carolina and St. Augustine, Florida, Maier et al. (2004) found that catch per unit of effort of turtles was greater than in most other reported literature and that most of the turtles were juvenile loggerheads, suggesting that conservation efforts may be successful.

In recent decades, the focus of protection has moved from turtle nests and eggs to protection of turtles in the marine environment. Crouse et al. (1987) estimated that protection of older juvenile and mature adult turtles in the marine environment was more important to conserving populations than was increasing production from nesting beaches. The most important current threat to turtles in U.S. waters is commercial fishing, primarily shrimp trawling (Henwood and Stuntz 1987, National Research Council 1990). Since the early 1990s, the U.S. has mandated the use of turtle excluder devices (TEDs) in shrimp trawls. Crowder et al. (1994) estimated that TED use could slow the decline of turtles but these researchers were unable to provide reliable forecasts of recovery, warning that any recovery would be slow. The NMFS continues to frequently modify the physical characteristics mandated for TEDs, as well as the areas and seasons of mandatory use in U.S. waters. Some researchers criticize the effectiveness of TEDs, pointing out that strandings on U.S. beaches have not decreased since instigation of TED use (Ruckdeschel and Shoop 2006).

DREDGING AND MARINE TURTLES

During dredging, dragarms are lowered to the sea floor within the channel, and hydraulic suction is used to carry a mixture of solid substrate and water into the internal hopper of the dredge. Within the hopper, solid material settles to the bottom, and water is allowed to overflow back into the sea. After filling the dredge hopper, or after a set period of work, dredge operators move to a designated disposal area and deposited the contents of the hopper. During agitation dredging, material is mobilized by the dredge using hydraulic suction and local currents passively remove the material from the site.

Since 71 turtle mortalities were observed at a Cape Canaveral, Florida dredge project during 1980-1981, the USACE, in cooperation with the NMFS and the USFWS, has monitored and reduced turtle mortality at hopper dredge sites (Dickerson et al. 1990, Dickerson et al. 2004). These efforts have included basic research, gear and operational modifications, and the institution of restrictive environmental windows, onboard observer programs, and mitigation trawling (Dickerson et al. 1995).

Several trawl surveys have been conducted in channels of the U.S. east coast. Data from five trawling surveys in Cape Canaveral, Florida showed that turtles were abundant during every month, although there were seasonal differences in relative abundance of juveniles and adults (Henwood 1987). Juvenile turtles were most abundant between August and March, suggesting that Cape Canaveral is an important winter foraging ground for juvenile turtles (Henwood 1987). Analysis of monthly trawl surveys in the Charleston, South Carolina entrance channel found that turtles were most abundant during July and absent during January through March (Van Dolah and Maier 1993). A USACE abundance trawl survey of six south Atlantic channels found that Charleston, South Carolina, Savannah, Georgia, Brunswick, Georgia, and Fernandina-St. Mary's, Florida exhibited similar trends in seasonal abundance to those found by Van Dolah and Maier (1993) and that Cape Canaveral had a significant year-round population of turtles.

The fine-scale behavior of turtles in Atlantic channels has been studied with telemetry. Telemetry of juvenile loggerheads in the Chesapeake Bay showed that turtles spent much of their time within the confines of the York River outlet channel (Byles 1988). Five loggerheads tracked in St. Simons Sound, Georgia spent most of their time on the bottom in the channel (Keinath et al. 1992). A similar study found that loggerheads in Charleston, South Carolina and Savannah, Georgia spent little time in the channel (Keinath et al. 1995). Juvenile loggerheads near St. Mary's Entrance Channel, Georgia spent most of their time on the bottom and most positions were outside the shipping channel (Nelson 1996). Turtles displaced from Cape Canaveral shipping channel were able to return to the channel from distances as great as 70 km (Standora et al. 1994).

Turtles resident in or near shipping channels of the Gulf of Mexico have received less study than their Atlantic counterparts. Telemetry studies found that several Kemp's ridley turtles spent prolonged periods near shipping channels, and that during this period, turtles spent as much as 24% of their time within the confines of the channel (Renaud et al. 1994). Juvenile green turtles occupied areas around jetties that protect shipping channels in southwest Texas (Renaud et al. 1992, Renaud et al. 1995). Loggerheads used shipping channels to move between inshore and offshore areas (Renaud et al. 1992).

To reduce turtle mortality at hopper dredge sites, the USACE tested and adopted several gear modifications. Most important of these was the rigid draghead deflector, attached to the end of the trailing suction apparatus used on hopper dredges (Dickerson et al. 2004). This deflector was designed to plow through the substrate and displace turtles from the path of the draghead, and to prohibit entrance of turtles into the hydraulic system of the dredge.

The USACE also institutes environmental windows, based on water temperature studies, restricting the time when dredging is permitted to times when turtles are least likely to be present (Dickerson et al. 1995). Such windows are most effective in Atlantic channels north of Florida, where turtle abundance is greatly reduced during winter months. In south Florida channels and in some Gulf of Mexico channels, environmental windows may not be effective because turtles are continually present.

Another important USACE effort to reduce mortality is relocation trawling. When this management technique is used, a trawler outfitted with specially designed nets conducts repeated, short-duration tows in the project site while dredging is underway (Dickerson et al. 2004). Captured turtles are tagged and released several kilometers from the dredge site. Although the effectiveness of relocation was difficult to evaluate, anecdotal evidence suggested that it was useful (Dickerson et al. 1995). In a 1991, Brunswick Harbor, Georgia project, 21 turtles were entrained during the first 66 days of dredging when no relocation was conducted, and one was entrained in the next 25 days during which relocation was conducted. In Savannah Harbor, Georgia, 17 entrainments were documented during 10 days of dredging without relocation, and none were reported in the 14 days with relocation (Dickerson et al. 1995). More recent studies, using USACE data, suggest that relocation trawling is effective at reducing incidental takes by dredges (Dickerson et al. *in press*). Although recaptures during relocation trawling are relatively rare, they occasionally occur (NMFS 2003, REMSA, Inc. unpublished data).

To monitor the mortality of marine turtles at dredge sites, the USACE instituted an observer program (Dickerson et al. 2004). Observers stay on board dredges and monitor each dredged load for the presence of marine turtles. Special screening at hopper inflow and overflow points allows sampling of dredge materials for fragments of entrained turtles. Although screening and data collection began in 1981 in Atlantic channels, these measures were not instituted in the Gulf of Mexico until 1995 (Dickerson et al. 2004). Observers record data on dredging activity and incidental takes. Although data collection has been similar through the years since it was instituted, there have been inconsistencies. The daily schedule for recording air and water temperature and other environmental data has not been standardized and is not typically reported (personal observation). Different methods of recording the location of dredging activity have included channel markers, channel miles, latitude and longitude, and several forms of industry-specific notation (personal observation). Despite these inconsistencies, the observer program has been successful at recording the timing and gross geographic location of incidental takes, the overall progress of dredging activity, and the identification and condition of entrained turtle specimens.

As evidenced by observer data, the efforts of the USACE, the NMFS, and the dredging industry have reduced turtle mortality at hopper dredge sites from previous levels (Dickerson et al. 2004). Dredging effects may be negligible from an overall turtle population standpoint, especially when compared to the high levels of mortality estimated from commercial trawling activities. Under ESA guidelines, the USACE is permitted a limited number of incidental takes of turtles, by species and by region each year (NMFS 2003, Dickerson et al. 2004). Within this regulatory framework, exceeding take limits is expensive and time consuming. When the number of incidental takes approaches or exceeds allowable limits, dredge operations may be suspended or abandoned, resulting in loss of production. Furthermore, the mitigation practices discussed above, though successful, are expensive and are paid by U.S. taxpayers. Therefore, USACE turtle management necessarily focuses on keeping takes within permitted parameters while using proven mitigation techniques as effectively as possible.

STUDY OVERVIEW

In this study, I examined a subset of available USACE data on dredging activity, incidental takes, relocation trawl activity, and trawl captures for the northwestern Gulf of

Mexico. My goals were to respond to the mandates of ESA recovery plans, to provide managers in the region with information that would further reduce incidental sea turtle takes at hopper dredge sites, and to further increase knowledge of turtle behavior in shipping channels. I used hierarchical linear models to analyze the subset of data. For incidental dredge take data, I used mean takes directly as the response variable. I analyzed dredge data with several objectives and these were as follows:

1. Discover the effect of location within the region on incidental takes. I hypothesized that channels at more southern latitudes would experience greater numbers of incidental takes relative to channels at more northern latitudes.

2. Examine the variation in incidental take rates among dredges with differing physical characteristics.

3. Determine periods of the year when takes were more or less likely to occur within different areas of the region. Based on information from the Gulf Coast and from other coastal regions, I suspected that more takes would be experienced during spring and summer months relative to fall and winter months.

4. Detect effects of relocation trawling on incidental dredge takes. Based on anecdotal evidence from projects where trawling was used, I hypothesized that projects where relocation trawling was used would experience statistically significant fewer takes than similar projects where trawling was not used.

For relocation trawl data, I used a standardized measure of catch per unit of effort (CPUE) as the response variable. I analyzed relocation trawl data with several objectives that were as follows:

1. Compile basic CPUE values for shipping channels to aid in monitoring relative turtle abundance in the region.

2. Discover the effect of location within the region on CPUE. I hypothesized that channels at more southern latitudes would exhibit greater average CPUE relative to channels at more northern latitudes.

3. Determine periods during the year when turtles were more or less abundant within the region. I suspected that turtles would be more abundant during spring and summer relative to fall and winter.

4. Determine the effect of water temperature on the CPUE of turtles within the region. I hypothesized that temperature would have a positive relationship with average CPUE and that greater relative abundance would be observed at relatively warmer temperatures.

5. Determine periods during the 24-hour day when turtles were more likely to be captured by trawl vessels. I expected that catch rates would be greater during daylight hours.

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CHAPTER 2

DREDGE-TURTLE INTERACTIONS IN SHIPPING CHANNELS OF THE NORTHWESTERN GULF OF MEXICO[1]

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ABSTRACT

Hopper dredges, used in U.S. shipping channels, sometimes harm or kill threatened or endangered marine turtles. The U.S. Army Corps of Engineers monitors turtle takes and works to mitigate dredge-turtle interactions. We used hierarchical linear models to examine a subset of Corps data for dredging projects in the northwestern Gulf of Mexico, 1995-2005, to determine the effects of latitude, season, dredge characteristics, and relocation trawling on incidental turtle takes by hopper dredges. Takes were more frequent in southern channels relative to northern channels, and more frequent in March-June than during other periods. Takes were less frequent on projects where relocation trawling was used. These results will help managers assign restrictive dredging windows and allocate mitigation efforts.

ADDITIONAL INDEX WORDS. *Caretta caretta, Chelonia mydas, dragarm, drag head, hierarchical linear model, hopper dredge, incidental take, Lepidochelys kempi, relocation trawling, sea turtle, U.S. Army Corps of Engineers*

INTRODUCTION

Five species of threatened or endangered marine turtles inhabit the coastal waters of the United States: loggerhead (Caretta caretta), green (Chelonia mydas), Kemp's ridley (Lepidochelys kempii), leatherback (Dermochelys coriacea), and hawksbill (Eretmochelys imbricata). Turtles in coastal environments face human-related threats including commercial and recreational boat traffic, commercial fishing, and hopper dredging. Much of this human activity is focused within entrance shipping channels. The U.S. Army Corps of Engineers (USACE) is mandated to maintain navigational depths in U.S. shipping channels. Hopper dredges are sometimes used for this purpose and are known to cause risk to marine turtles (DICKERSON *et al*., 1990). Hopper dredges are self-contained ships that remove material from the seabed with trailing suction drag heads. Turtles are injured or killed when they are entrained in the hydraulic system of a hopper dredge. The harming or killing of a marine turtle by entrainment in a hopper dredge is termed an incidental take.

After 71 turtle deaths were observed at a 1980-1981 hopper dredge project in Cape Canaveral, Florida, the USACE, National Marine Fisheries Service (NMFS), and U.S. Fish and Wildlife Service (USFWS) developed plans that resulted in restrictive environmental windows, gear and operational modifications, onboard observer programs, and mitigation trawling (DICKERSON *et al*., 1990). Restrictive windows prohibited dredging during specific periods of the years when managers believe the risk of dredge-turtle encounters is greatest. Turtle deflectors were developed for trailing suction drag heads, and screening of dredged material was initiated to allow sampling of fragments of entrained turtles. The onboard observer program placed trained observers aboard dredges to monitor incidental turtle takes during dredging operations. Mitigation trawling was used on some projects where higher levels of incidental take was expected due to higher occurrence of sea turtles or where higher incidental take was observed at any phase of the dredging project. Mitigation trawlers captured and relocated turtles away from channels during dredging operations. Subsequent research increased our understanding of turtle behavior, abundance, and seasonality in U.S. shipping channels.

Most research focused on channels of the southeastern Atlantic coast between Virginia and Florida (HENWOOD, 1987; KEINATH *et al*., 1992; VAN DOLAH and MAIER, 1993; STANDORA *et al*., 1994; DICKERSON *et al*. 1995; NELSON, 1996). Since mitigation measures were initiated, turtle mortality relative to dredging effort has decreased in Atlantic channels (DICKERSON *et al.,* 2004). Although some researchers had studied turtle behavior in the Gulf of Mexico, U.S.A. shipping channels (RENAUD *et al*., 1994), these channels had received substantially less attention than their Atlantic counterparts. This relative dearth of information on turtles in Gulf channels suggested the need for further study to inform dredging management decisions in the region. To decrease turtle mortality at dredge sites, managers needed information on locations and time periods when turtle mortality was less likely to occur, the relationship between turtle mortality and physical dredge characteristics, and the effectiveness of trawling as a mitigation technique.

The onboard observer programs have produced data on dredging activity and incidental turtle mortality since their initiation in the early 1980s. The USACE compiled much of these raw data and works to obtain more complete records from the parties involved. These data represented a valuable source of information about turtles in coastal channels. We used hierarchical linear models to examine a set of historical data for northwestern Gulf of Mexico shipping channels from dredge projects between 1995 and 2005, to explore the effects of location, season, dredge characteristics, and mitigation trawling efforts on incidental hopper dredge mortality of sea turtles. We hypothesized that dredge projects at southern latitudes would experience higher turtle mortality relative to projects at more northern latitudes and that greater mortality would occur during warmer months. We further hypothesized that dredges with larger hopper capacities and dredges using more suction drag heads would experience higher mortality. Finally, we hypothesized that the use of mitigation trawling would result in lower mortality at hopper dredge sites.

STUDY AREA

Data were analyzed from eight shipping entrance channels in the northwestern Gulf of Mexico, U.S.A. (Figure 2.1). Channels examined, from northernmost to southernmost, were Sabine, Texas (29.68 N -93.83 W); Mississippi River Gulf Outlet (MRGO), Louisiana (29.47 N -

89.08 W); Houston Galveston Navigation Channel (HGNC), Texas (29.34 N -94.68 W); Freeport, Texas (28.93 N -95.29 W); Matagorda, Texas (28.42 N -96.32 W); Corpus Christi, Texas (27.83 N -97.03 W); Port Mansfield, Texas (26.56 N -97.27 W); and Brownsville, Texas (26.07 N -97.14 W). Channels ranged in depth from approximately 10.8 m to 15.4 m. Length of dredged sections ranged from approximately 2 to 15 km. Each channel was bounded by navigational buoys, and each was protected at its coastal junction by rock jetties. Channels were located within two USACE management districts. The MRGO channel was managed by the New Orleans District; all others were managed by the Galveston District. The MRGO channel experienced heavy shoaling from Hurricane Katrina in August 2005, and was temporarily abandoned for shipping purposes. As of January 2007, it was not re-dredged and USACE managers suggested that it would be abandoned as a dredge-maintained shipping channel.

METHODS

Dredging

During dredging, dragarms were lowered to the sea floor within the channel, and hydraulic suction was used to carry a mixture of solid substrate and water into the internal hopper of the dredge. Within the hopper, solid materials settled and water was allowed to overflow back into the sea. All material entering the hopper passed through metal screens with 10.2 X 10.2-cm openings. In most cases, all overflow points were similarly screened. After filling the dredge hopper, or after a set period of work, dredge operators moved to a designated disposal area and deposited the contents of the hopper. During periods when active dredging was suspended, on-board observers checked drag heads, inflow screens, and overflow screens for turtles or fragments of turtles. In a few cases in the MRGO channel, agitation dredging was used. During agitation dredging, material was mobilized by the dredge using hydraulic suction and local currents passively removed the material from the site. Because the effort from this type of dredging was small relative to overall effort, and because endangered species observing activities were identical in agitation dredging, I included these projects in the data set.

Data

We obtained data on dredging and incidental marine turtle takes from the USACE Engineer Research and Development Center, Waterways Experiment Station in Vicksburg, Mississippi, U.S.A. Data were from observer records, dredge company documents, and USACE project reports for dredge projects occurring from 1995-2005. The majority of this data is now available online at the USACE Sea Turtle Data Warehouse (http://el.erdc.usace.army.mil/seaturtles/index.cfm).

We created a record for each dredge day, where a dredge day was defined as a single dredge operating for a single 24-hour day. For each record, we included observations of take, date, channel, dredge name, and mitigation trawl level. A take was defined as documented injured or killed marine turtle, attributed by NMFS managers to entrainment by a hopper dredge. We designated trawl levels as follows: level 0—no trawling occurred; level 1—one trawler operating 12 hours/day; level 2—one trawler operating 24 hours/day; and level 3—two trawlers operating 24 hours/day. We condensed these data by calculating the mean take per dredge day for each channel, during each month when observed dredging occurred in the channel, by each individual dredge operating during each month, and for each trawl level used by individual dredges.

Because data were collected from a variety of sources over a 10-year period, there was inconsistency in several types of data. Environmental data such as temperature, wind speed, and sea conditions were lacking for some efforts. Location data, other than channel name, were not included for many projects and were recorded in several different formats for projects where they were available. Similarly, records of the amount of material moved per load were not consistently available. Therefore, these types of data were not used in the analysis. For most dredge projects, multiple sources of information about dredging effort and incidental takes were available. Daily dredge observer records were available from all projects used in the analysis. For most projects, summary USACE reports and summary reports prepared by private observer companies were also available. Incidental takes were reported in the routine daily observer sheets and also in separate incidental take reports. Trawling data was recorded similarly in routine data sheets, in tagging reports, and in observer company summary reports. We checked for accuracy of date, dredge, and channel by comparing database records created from routine observer data to available summary reports. We checked the accuracy of take and trawl level by comparing our database records to separate take reports and relocation trawl reports. When inconsistencies were found among multiple records, and the source of the difference could not conclusively be identified and explained, these records were deleted from the data set. We used the resulting data set for all subsequent analyses.

Analysis

We used hierarchical linear models to explore the effects of predictor variables on dredge takes. We fit models using a two-level approach, with channel as level two and individual observations within channels as level one. Hierarchical modeling is appropriate for analysis of multi-level data, in which observations within a level are not independent (BRYK and RAUDENBUSH, 1992). Because the data consisted of repeated observations from each channel, hierarchical modeling was more appropriate than standard multiple regression. Furthermore, hierarchical models are useful for determining and estimating effects where observations are scant or absent within some of the groups of interest (BRYK and RAUDENBUSH, 1992).

We used mean take per dredge day as the response variable for all models. We used descriptions of location, time, dredge characteristics, and trawling effort for independent variables. Latitude was the only location variable. For ease of interpretation, we centered latitude around the mean latitude for the data set, creating a variable with a mean of 0. All other independent variables were categorical. In different models, we used different designations of time, dredge characteristics, and trawl effort. For time variables, we used either individual months or groupings of months that I hypothesized to have ecological significance. Therefore, months were grouped into categories roughly coinciding with seasons or periods when water temperatures may affect turtle movement and behavior. For dredge variables, we used either individual dredges or classifications of dredges based on hopper capacity. We also classified dredges by the number of dragarms they possessed. For trawl variables, we used either the levels as described above, or the presence of trawling (at any level) relative to the absence of trawling.

We fit an unconditional model, containing no predictor variables, to estimate the amount of variation occurring among and within channels. We used among channel variation (τ_{00}), and within channel variation (σ^2), to calculate interclass correlation (ρ), using the formula (SINGER, 1998):

$$\hat{\rho} = \frac{\hat{\tau}_{00}}{\hat{\tau}_{00} + \hat{\sigma}^2} \qquad \rho\text{-rho} \quad \tau\text{-tau} \quad \sigma\text{ - sigma} \qquad (1)$$

We constructed a global model using latitude, twelve individual months, sixteen individual dredges, three drag head classes, four trawl levels, and all possible two-way interactions. For ease of interpretation, we did not include any higher-level interactions in the global model. We plotted predicted versus residual values for the global model to examine data for normality. From the global model we constructed a subset of candidate models that we hypothesized to be ecologically meaningful and to have useful management interpretations for determining latitudes, dredge characteristics, time periods, and mitigation trawling levels where incidental takes were less likely to occur. We fit models to allow a single explicit random effect (τ_{00}) representing the remaining variation among channels, and the random variation (σ^2) implicit in all linear models, representing the remaining variation within channels (SINGER, 1998). Models were fit using Statistical Analysis Software (SAS) version 9.1 (SAS Institute, Inc., 2003).

We used Akaike's Information Criteria (AIC; AKAIKE, 1973) to evaluate the fit of each candidate model and to rank it in relation to other models in the set. We calculated AIC weights for this candidate model set. These weights represent the probability that a given model is the correct one, given the other models in the set (BURNHAM and ANDERSON, 1998). We used AIC weights to calculate a confidence set of models that had weights greater than 10% of the best-fitting model weight (BURNHAM and ANDERSON, 1998). For discussion purposes, we selected the five best fitting models from this set. We calculated parameter estimates and 90% confidence intervals for the best fitting models and used the parameter estimates from these models to explore the main effects and interaction effects of the independent variables.

RESULTS

The analysis data set included a total effort of 2633 dredge-days, completed with 15 dredges over the course of 50 dredge projects in northwestern Gulf of Mexico shipping channels from 1995-2005. The mean take level for the entire data set was 0.0251 takes·dredge-day^{-1}. Sixty-six marine turtle takes occurred during the studied projects. This data set did not include all dredging effort occurring in the region during the period of the study. In particular, data on several projects from the MRGO channel were not available. Effort, takes, and species composition of takes varied among channels and among months (Table 2.1). Within the study area, loggerheads were most frequently taken, followed by greens and Kemp's ridleys. Loggerheads and Kemp's were taken throughout the study area, but greens were only taken in the southernmost channels of the region with the greatest number of takes in Brownsville. Dredges varied in hopper size and in number of dragarms used, but most of dredges had two dragarms and had hopper capacities >2336 m^3 (Table 2.2). For models discussed here, dredges with hopper capacities >2336 m^3 were defined as large, and dredges with smaller hopper capacities were defined as small.

A plot of predicted versus residual values from the global model indicated the data did not violate assumptions of normality. From the unconditional model, containing no predictor variables, the interclass correlation (ρ) was 14.8%; hence, 14.8% of the variation in the data occurred among channels and 85.2% of the variation occurred within channels. Latitude alone accounted for 96.6% of the among channel variation.

From the candidate model set, 14 models had AIC weight values greater than 10% of the best fitting model's weight (APPENDIX C). All variables used in these 14 models had relatively high importance weights. From these, the five best fitting models were selected for discussion purposes (Table 2.3). Although the overall candidate model set contained multiple categorical variables for season, dredge characteristics, and trawl levels, the five best fitting models contained similar categorical variables for season, hopper, dragarm, and relocation trawling (Table 2.3).

The best fitting model contained latitude, March-June (spring), dredge hopper capacity >2336 m^3 (large), dredges with two dragarms , dredges with three dragarms, relocation trawling, and interaction terms for latitude* 2 dragarms, latitude*3 dragarms, and latitude*July-October (summer). This model was the least constrained of the best fitting models, and other models in this set contained subsets of these variables. All best fitting models contained parameters for spring, 2 dragarms, trawling, and the interaction terms latitude*2 dragarms, latitude*3 dragarms, and latitude*summer, and none of the best fitting models included other interactions. Two models in the set included parameters for latitude as a main effect, three models contained large dredges, and three models contained 3 dragarms.

The best fitting model accounted for 15.7% of the within-channel variation and 96% of the among channel variation. Therefore, it accounted for 28.2% of the explainable variation in the data. The model estimated that at a theoretical channel at 28.89 N latitude, during November-February, in the absence of mitigation trawling, a large dredge with one dragarm, would experience, on average, 0.12 takes·dredge-day^{-1} with a 90% confidence interval of 0.05 – 0.20 takes·dredge-day^{-1} (Table 2.5). Estimated takes for spring were 0.05 takes·dredge-day^{-1} greater than estimated takes for November-February for all dredge types and all latitudes. Estimated effects for small single dragarm dredges, and for large dredges had wide confidence intervals containing 0, implying that these estimates were unreliable. The latitude*2 dragarms and latitude*3 dragarms interactions indicated that takes for these dredges varied across latitude differently than single dragarm dredges. For dredges with two or three dragarms, during November-June inclusive, estimated takes decreased for each degree of latitude moved north in the study area (Figure 2.2). During summer, estimated takes increased with latitude for all dredge types (Figure 2.3). For all dredge types, during all seasons, and at all latitudes, estimated takes were 0.03 takes·dredge-day^{-1} lower when relocation trawling was used.

The other four models in the best fitting model set produced similar estimates (Table 2.5). In all models, estimated takes were higher during spring than during November-February for all dredges, at all latitudes. Estimated takes decreased with increasing latitude for dredges with two or three dragarms during all months except July-October. During summer latitude had a positive effect and estimated takes increased with increasing latitude for all dredges. The presence of relocation trawling had a negative effect in all best fitting models (Figure 2.4).

DISCUSSION

Our findings imply that incidental marine turtle takes by hopper dredges in shipping channels in the northwestern Gulf of Mexico are affected by latitude, season, dredge characteristics, and mitigation trawling efforts. Understanding these relationships may prove useful to managers as they plan and implement hopper dredging activities. Furthermore, these findings may provide insight into turtle behavior in the region. The unexplained variability may have been due, in part, to the presence of many zero values in the data set (CUNNINGHAM and LINDENHAYER 2005). However, the best fitting models produced parameter estimates that were fairly precise and that can be used to examine qualitative relationships. The USACE is mandated by Endangered Species Act (ESA) legislation to keep yearly incidental takes within specific limits by management districts (NMFS 2003). Surpassing set limits is potentially expensive and time consuming if dredging operations must be halted or abandoned resulting in lost production. Therefore, even small improvements in the ability to avoid incidental takes could potentially provide relatively great benefits.

Latitude was an important variable in the best fitting models. Latitude increases with northward movement, and one degree of latitude represents approximately 110 km. When only latitude was considered, northern channels in the study area were estimated to experience relatively fewer takes, on average, than southern channels. This was consistent with more randomly designed studies in which a trend of greater turtle density at lower latitudes was observed in the U.S. Atlantic (MAIER *et al*., 2004). However, the effect of latitude varied differently during different periods of the year and for different dredge types. Because only one dredge small single dragarm dredge was included in the data set (Table 2.2) estimated effects for this dredge cannot be applied generally . Furthermore, there were no samples from this dredge in the northern-most channels of the study area, and the estimated effect was relatively imprecise and likely unreliable.

Most hopper dredges used in U.S. shipping channels possess two dragarms. For these dredges, estimated takes decreased with increasing latitude during November-June inclusive, and increased with latitude during summer (Figure 2.3). The negative latitude effect during spring and November-February is consistent with a scenario of seasonal behavior in which turtles migrate north in the summer and south in the winter in response to water temperature or food availability. Turtles in the U.S. Atlantic make seasonal migrations across wide ranges of latitude (HENWOOD, 1987, AVENS and LOHMANN, 2004), and some evidence has suggested that turtles in the Gulf of Mexico make seasonal movements (RENAUD and CARPENTER, 1994). The positive latitude effect during July-October, and the low take estimates in southern channels during these months were unexpected (Figure 2.3). This may be due in part to the scant data from the southernmost channels during these months (Table 2.1). All dredging effort in this study occurred in shipping channels, and shipping channels are relatively short trenches located in or near the mouths of inlets. Turtles may be abundant in nearby non-channel habitat during these months. However, most of the turtles captured in the southernmost channel were greens, and greens are known to be present in Brownsville channel during July-October (RENAUD *et al.* 1995). Further study is needed to determine if takes are actually less common in summer and early autumn in southern channels relative to northern channels.

The period March-June had a positive additive effect on takes relative to the period November-February for all dredges at all latitudes, implying that this period may be especially important when managing turtles in this region. If turtles are moving north into the region during this time, they may be especially vulnerable because of different diving or swimming behavior, or the channels may act as bottlenecks, concentrating turtles in the area. Regardless of the cause of this effect, awareness of it may be useful for managers. The months March-June produced the highest take estimates of any period for most of the study area (Figure 2.3). Prohibiting hopper dredging in channels during certain time periods has been an established management tool for Atlantic channels (DICKERSON *et al*., 1990), and the most recent biological opinion for the Gulf of Mexico indicates that dredging should occur, when possible, between December-March (NMFS, 2003). Our results suggest that dredging only during this window will reduce takes relative to dredging throughout the year, but that dredging only during November-February might result in even fewer takes. Furthermore, our findings suggest that if dredging during this period is unavoidable, then the northernmost areas of the region may present the lowest risk of turtle takes.

Our models estimated differences among dredges with different hopper capacities and different dragarm configurations (Figure 2.2). However, this study did not quantify the differences among dredges in the number of dredge days necessary to complete a project.

Variation in takes among dredges may result from operational differences and from dredge characteristics not considered here. Our results suggest that some variation in the takes can be explained by dredge characteristics. Given the system under which companies bid for dredge contracts, the effects of physical dredge characteristics found in these models have little application in forming management strategies. However, the results suggest that a more detailed exploration of dredge characteristics may yield results with greater benefit.

The presence of relocation trawling reduced take estimates across all dredge types, during all seasons, and across all latitudes in all the best fitting models (Figure 2.4). This effect was similar among the models. DICKERSON *et al*. (1995) noted that although anecdotal evidence suggested that trawling reduced the takes experienced by dredges, the effect of the management technique was difficult to evaluate. More recent studies have suggested that relocation trawling is effective at reducing takes (DICKERSON *et al.*, *in* press). Our findings provide quantitative evidence suggestive that trawling does reduce the occurrence of incidental dredge takes, although the confidence interval is wide suggesting that the effect is weak. Trawling may have been initiated on projects when takes were observed in the early stages of dredging, or managers may have chosen to use trawling on projects where a high number of takes were expected. These factors could have resulted in trawling being used more frequently on projects where turtles were more abundant. Because this study did not control for these factors, the estimated trawling effect may be artificially low. However, even small reductions in takes can be important to managers. Coastal regions are permitted only a limiting number of incidental takes. A single take can result in expense and lost time if dredging operations must be stopped or paused because of the danger of exceeding set limits.

CONCLUSIONS

This was the first study to quantitatively examine a portion of the available dredge-related sea turtle data from Gulf of Mexico channels, and to provided insight into the effects of season, latitude, dredge characteristics, and relocation trawling on incidental takes by hopper dredges. In most of the study area, the period March-June was estimated to experience the highest rate of incidental takes. During this period, and during November-February, estimated takes were lower at more northern latitudes relative to more southern latitudes for most dredge types, implying that more northern channels in the region present lower risk of dredge takes. There were differences in takes among different dredges of different hopper size and dragarm configurations. Relocation trawling was estimated to reduce the numbers of incidental takes by hopper dredges. This result suggested that trawling is a valid technique for reducing incidental takes.

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Table 2.1. Dredging effort (in dredge days), and takes (number of turtles taken) by period and by species for hopper dredge projects in northwestern Gulf of Mexico shipping channels, conducted from 1995–2004. Species taken included loggerhead (*Caretta caretta*), green (*Chelonia mydas*), Kemp's ridley (*Lepidochelys kempii*), and unidentified sea turtles. Channels are arranged from northernmost (Sabine) to southernmost (Brownsville).

	Total	Total	Mar-June		July-Oct		Nov-Feb		Species			
Channel	**effort**	**takes**	**effort**	**takes**	**effort**	**takes**	**effort**	**takes**	**Loggerhead**	**Green**	**Kemp's**	**Unidentified**
Sabine	336	1	142	0	128	1	66	0	1	0	0	0
MRGO[a]	796	25	286	15	237	8	273	2	19	0	4	2
HGNC[b]	534	5	230	2	287	3	17	0	3	0	1	1
Freeport	598	8	24	1	322	7	252	0	8	0	0	0
Matagorda	65	2	0	0	45	1	20	1	1	1	0	0
Corpus Christi	150	9	94	8	56	1	0	0	8	0	1	0
Port Mansfield	17	2	17	2	0	0	0	0	0	2	0	0
Brownsville	137	14	76	5	0	0	61	9	1	11	2	0
Totals	**2633**	**66**	**869**	**33**	**1075**	**21**	**689**	**12**	**41**	**14**	**8**	**3**

[a] Mississippi River Gulf Outlet Channel
[b] Houston Galveston Navigation Channel

Table 2.2. Number of dredges, total effort (in dredge-days), number of channels worked, and number of turtles taken by dredges with different drag arm configurations and hopper capacities, 1995–2005. Fifteen dredges and 8 channels were included in the study data set.

Dredge characteristic	Number of dredges	Total effort	Number of channels	Number of turtles
1 drag arm, hopper <2336 m^3	1	206	4	8
2 drag arms, hopper <2336 m^3	2	125	4	4
2 drag arms, hopper >2336 m^3	11	2,140	7	48
3 drag arms, hopper >2336 m^3	1	162	4	6

Table 2.3. Five best fitting models estimating mean daily turtle take during hopper dredging in shipping channels in the northwestern Gulf of Mexico, 1995–2004, showing number of parameters (K), Akaike Information Criterion values (AIC), difference in AIC from the best fitting model (ΔAIC), and AIC weights (AIC *wt*) for each model.

Model	**K**	**AIC**	**ΔAIC**	**AIC *wt***
1) Latitude March-June Hopper>2336m^3 2-dragarms 3-dragarms trawling Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms	12	-265.1	0	0.16
2) March-June Hopper>2336m^3 2-dragarms trawling Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms	10	-264.6	0.5	0.13
3) March-June Hopper>2336m^3 2-dragarms 3-dragarms trawling Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms	11	-264.5	0.6	0.12
4) Latitude March-June 2-dragarms 3-dragarms trawling Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms	11	-264.4	0.7	0.11
5) March-June 2-dragarms trawling Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms	9	-263.9	1.2	0.09

Table 2.4. Parameters used in best fitting models estimating mean daily take of marine turtles during hopper dredge projects at shipping channels in the northwestern Gulf of Mexico. All variables except latitude were categorical. For categorical variables, effects were estimated relative to the baseline for each variable type.

Type	**Parameter**	**Description**
Location	**LAT**	latitude, continuous, centered on mean of 28.89° North
Season	**SP**	March-June
	SU	July-October
	(baseline)	November-February inclusive
Hopper	**DLG**	dredge hopper capacity > 2336 m^3
	(baseline)	dredge hopper capacity < 2336 m^3
Drag arm	**DAL**	dredge had 3 drag arms
	DAM	dredge had 2 drag arms
	(baseline)	dredge had 1 drag arm
Trawl	**TY**	relocation trawling used
	(baseline)	relocation trawling not used

Table 2.5. Parameter estimates for the five best fitting models estimating marine turtle takes during hopper dredging of shipping channels in the northwestern Gulf of Mexico. The estimated random effect (remaining variation among channels) was <0.0001 in all models. Estimates and confidence intervals are standardized in mean takes per dredge day. Estimates are relative to the baseline for each parameter. Parameters and baselines are described in Table 2.4.

Model	Parameter	Parameter estimate	90% Confidence Interval Lower	90% Confidence Interval Upper
LAT SP DLG DAM DAL TY LAT*SU LAT*DAM LAT*DAL				
	Intercept	0.1245	0.0499	0.1990
	Latitude	0.0380	-0.0012	0.0772
	March-June	0.0530	0.0237	0.0823
	Hopper >2336 M^3	0.0610	-0.0011	0.1231
	2 Dragarms	-0.1616	-0.2495	-0.0737
	3 Dragarms	-0.1219	-0.2243	-0.0195
	Trawling	-0.0304	-0.0605	-0.0003
	Latitude*July-October	0.0850	0.0424	0.1276
	Latitude*2 Dragarms	-0.0994	-0.1429	-0.0559
	Latitude*3 Dragarms	-0.1194	-0.2051	-0.0338
SP DLG DAM TY LAT*SU LAT*DAM LAT*DAL				
	Intercept	0.0616	0.0173	0.1059
	March-June	0.0488	0.0204	0.0773
	Hopper >2336 M^3	0.0233	-0.0212	0.0679
	2 Dragarms	-0.0650	-0.1085	-0.0215
	Trawling	-0.0204	-0.0496	0.0088
	Latitude*July-October	0.0810	0.0379	0.1241
	Latitude*2 Dragarms	-0.0568	-0.0742	-0.0394
	Latitude*3 Dragarms	-0.0872	-0.1616	-0.0128
SP DLG DAM DAL TY LAT*SU LAT*DAM LAT*DAL				
	Intercept	0.0802	0.0293	0.1311
	March-June	0.0457	0.0171	0.0743
	Hopper >2336 M^3	0.0600	-0.0026	0.1226
	2 Dragarms	-0.1147	-0.1887	-0.0407
	3 Dragarms	-0.0756	-0.1670	0.0157
	Trawling	-0.0272	-0.0574	0.0030
	Latitude*July-October	0.0817	0.0389	0.1246
	Latitude*2 Dragarms	-0.0610	-0.0791	-0.0430
	Latitude*3 Dragarms	-0.0779	-0.1527	-0.0031

Table 2.5 continued.

Model	Parameter	Parameter estimate	90% Confidence Interval Lower	Upper
LAT SP DAM DALTY LAT*SU LAT*DAM LAT*DAL				
	Intercept	0.1207	0.0457	0.1958
	Latitude	0.0374	-0.0022	0.0769
	March-June	0.0533	0.0237	0.0828
	2 Dragarms	-0.1026	-0.1672	-0.0379
	3 Dragarms	-0.0582	-0.1382	0.0217
	Trawling	-0.0260	-0.0560	0.0041
	Latitude*July-October	0.0804	0.0376	0.1231
	Latitude*2 Dragarms	-0.0913	-0.1344	-0.0482
	Latitude*3 Dragarms	-0.1159	-0.2022	-0.0296
SP DAM TY LAT*SU LAT*DAM LAT*DAL				
	Intercept	0.0710	0.0317	0.1103
	March-June	0.0471	0.0187	0.0755
	2 Dragarms	-0.0519	-0.0879	-0.0160
	Trawling	-0.0213	-0.0505	0.0080
	Latitude*July-October	0.0780	0.0352	0.1209
	Latitude*2 Dragarms	-0.0539	-0.0705	-0.0374
	Latitude*3 Dragarms	-0.0788	-0.1518	-0.0058

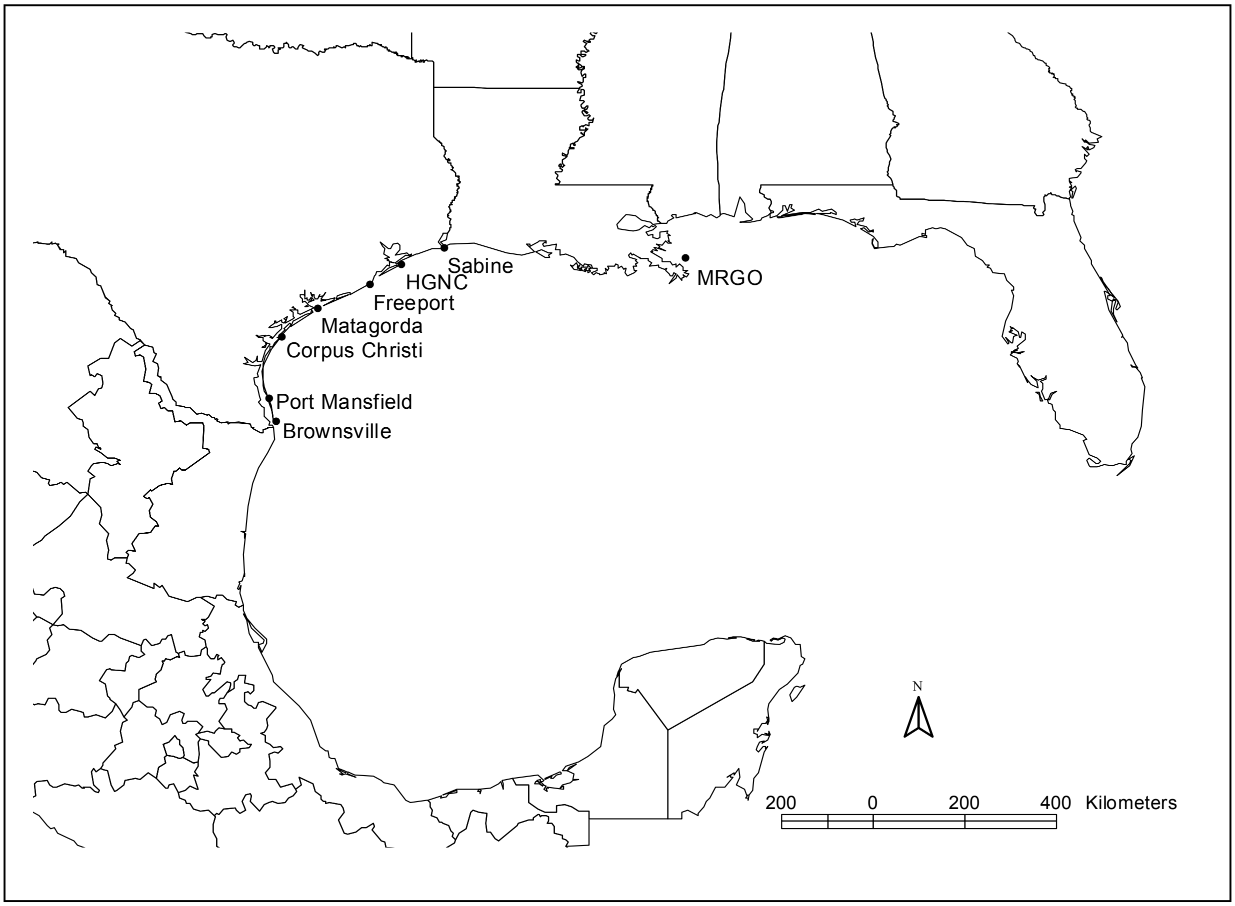

Figure 2.1. Eight shipping channels in the northwestern Gulf of Mexico from which data were used in a study of dredge-turtle interactions, 1995–2005. From north to south channels were: Mississippi River Gulf Outlet, Louisiana (MRGO); Sabine, Texas; Houston Galveston Navigation Channel, Texas (HGNC); Freeport, Texas; Matagorda, Texas; Corpus Christi, Texas; Port Mansfield, Texas; and Brownsville, Texas.

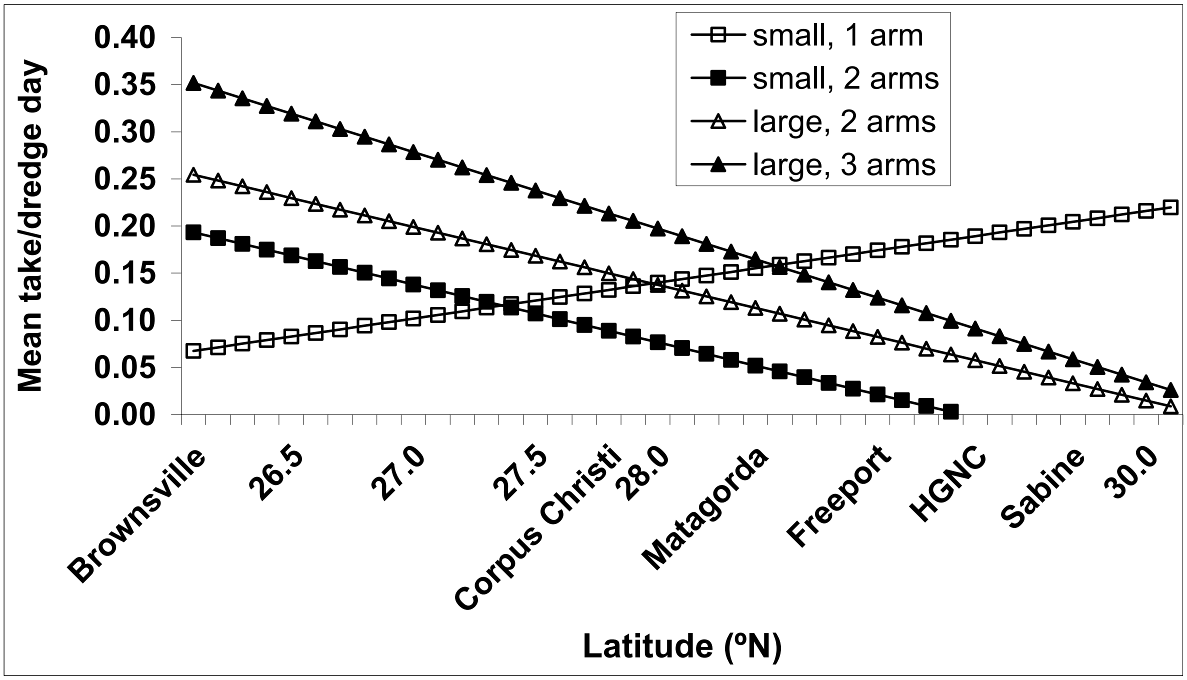

Figure 2.2. Relationship between latitude (in degrees north) and dredge takes of marine turtles (mean takes·dredge-day^{-1}) from the best fitting model, for small (< 2336 m^3 hopper capacity) and large (> 2336 m^3 hopper capacity) dredges with one, two, and three drag arms. Estimates are for the months March-June in the absence of relocation trawling, 1995-2004. Selected study channels are shown at their approximate latitude.

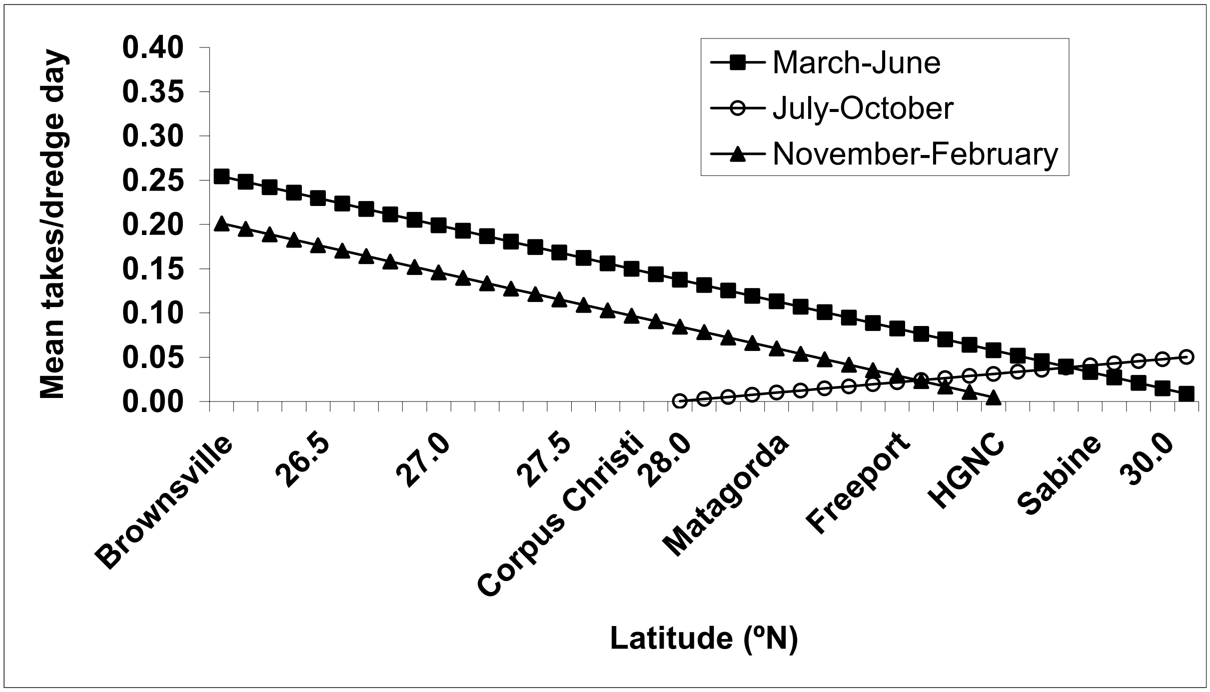

Figure 2.3. Relationship between latitude (in degrees north) and takes of marine turtles (mean takes·dredge-day^{-1}) during different periods of the year, 1995-2004. Estimates are from the best fitting model, for a dredge with >2336 m^3 hopper capacity, with two drag arms, in the absence of relocation trawling. Selected study channels are shown at their approximate latitude.

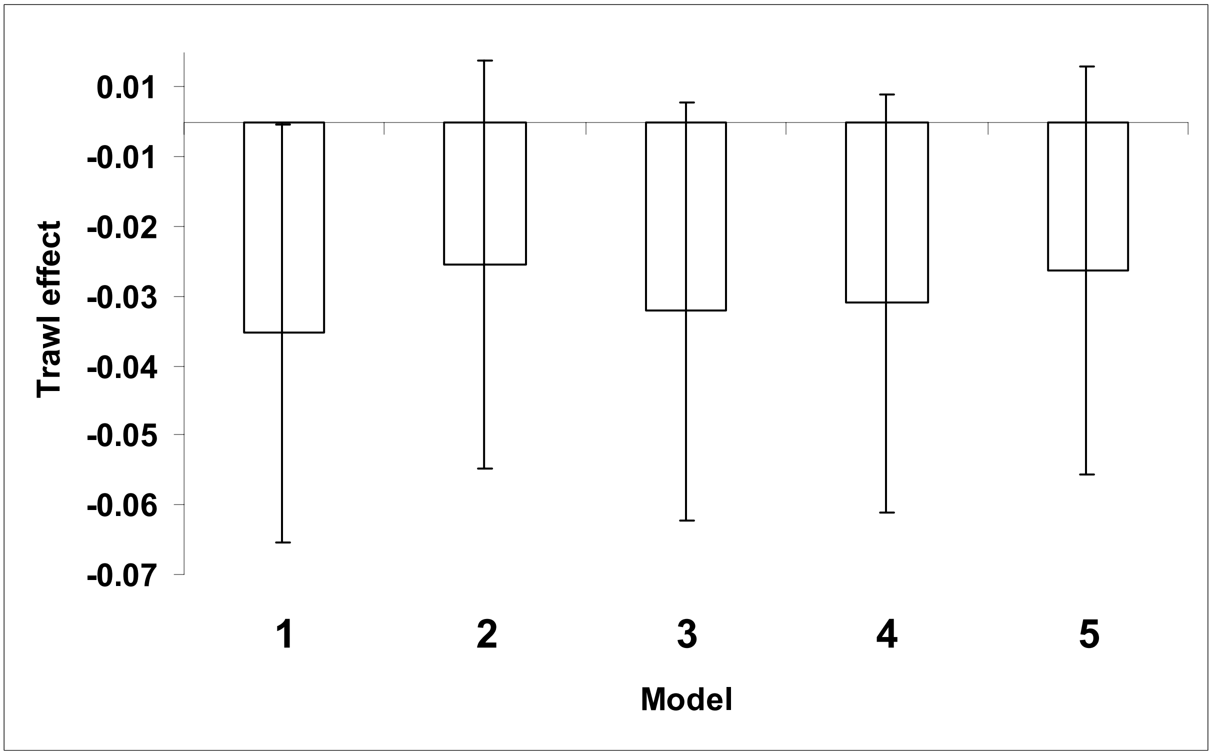

Figure 2.4. The effect (mean takes·dredge-day^{-1}) of relocation trawling on dredge takes of marine turtles in the northwestern Gulf of Mexico. Effects were estimated with model controlled for small dredges (<2336 m^3 hopper capacity) with a single drag arm during winter months, and are relative to takes in the absence of relocation trawling. Table 2.3 lists the best fitting models.

CHAPTER 3

BEHAVIOR AND RELATIVE ABUNDANCE OF MARINE TURTLES IN DREDGED SHIPPING CHANNELS IN THE NORTHWESTERN GULF OF MEXICO[1]

[1]Sundin, G. W., Schweitzer, S. H., Dickerson, D., Peterson, J. T., Theriot, C., and Wolters, M. To be submitted to *Journal of Coastal Research*

ABSTRACT

Hopper dredges, used in U.S. shipping channels, can injure or kill threatened or endangered marine turtles. To mitigate the impact of dredging on turtles, the U.S. Army Corps of Engineers commonly uses trawling to relocate turtles away from active dredge sites. We analyzed a subset of trawling data for dredging projects in the northwestern Gulf of Mexico, 2001-2005. We estimated catch per unit effort (CPUE) values by trimester. We used hierarchical linear models to determine the effects of latitude, season, day period, and sea temperature, on trawler catch per unit effort. Our CPUE estimates from relocation trawling were higher than fishery dependent estimates made 20 years ago. Green turtles only occurred in southern channels, while loggerheads and Kemp's ridleys occurred throughout the region. Captures were more frequent in southern channels relative to northern channels, and more frequent in spring than during other seasons. Time of day and temperature affected captures, but these effects were small. These results will improve understanding of turtle abundance and distribution in the area and help managers reduce the number of turtles injured or killed by dredging.
ADDITIONAL INDEX WORDS. *Caretta caretta, catch per unit effort, Chelonia mydas*, *CPUE*, *hierarchical linear model*, *hopper dredge*, *incidental take*, *Lepidochelys kempi*, *relocation trawling*, *sea turtle, U.S. Army Corps of Engineers*

INTRODUCTION

Five species of threatened or endangered marine turtles inhabit the coastal waters of the United States. Turtles in coastal environments face several anthropogenic threats, including commercial fishing, boat traffic, and hopper dredging (National Research Council 1990). Much of this activity occurs in shipping channels. The U.S. Army Corps of Engineers (USACE) is federally mandated to create and maintain navigable channels for vessel traffic in U.S. coastal waters. The USACE and contracted private companies sometimes use hopper dredges for this purpose. Hopper dredges are self-contained ships that remove substrate from the sea floor using trailing suction heads (drag heads) that are lowered from the vessel. Marine turtles are injured or killed when they are entrained in the powerful hydraulic system of a hopper dredge (DICKERSON *et al*., 1990).

After 71 turtle deaths were observed at a 1980-1981 hopper dredge project in Cape Canaveral, Florida, the USACE, National Marine Fisheries Service (NMFS), and U.S. Fish and Wildlife Service (USFWS) developed plans to reduce the impact of hopper dredging on marine turtle populations (DICKERSON *et al*., 1990). One of the mitigating techniques instituted was relocation trawling. Relocation trawling is used to temporarily remove turtles from dredge sites to reduce the risk of takes by dredges. Relocation trawling is used during Gulf of Mexico projects where two or more turtles are taken by dredges in a 24-hour period, when four turtles are taken on a project, or when the USACE district where the work occurs has experienced 75% of its permitted incidental takes (NMFS, 2003). However, regional managers may choose to use relocation trawling on any project where high turtle densities are expected.

Trawling is a valuable method of sampling turtles in the marine environment. Researchers have used trawling data from the U.S. Atlantic coast to obtain knowledge of behavior and abundance in shipping channels (HENWOOD, 1987; VAN DOLAH and MAIER, 1993; DICKERSON *et al*., 1995), to examine fishery interactions (EPPERLY *et al.*, 1995), and to provide regional indices of abundance (MAIER *et al.,* 2004). The Gulf of Mexico has received substantially less trawl sampling research than the Atlantic, but researchers have used fishery-dependant trawl data to estimate simple abundance indices (Gulf and South Atlantic Fisheries Development Foundation, GSAFDF, 1998; JAMIR, 1999).

Data collected from relocation trawling efforts represent a valuable source of information about turtle abundance and behavior in shipping channels and in shallow coastal waters generally. Managers need such information to manage turtles effectively in dredged channels and other coastal areas. Dredge projects may be forced to shut down prematurely when they are in danger of causing incidental takes in excess of those permitted under Endangered Species Act (ESA) legislation (NMFS, 2003). Such shutdowns are costly to private companies and to U.S. taxpayers. Due to the relative dearth of information from the Gulf of Mexico shipping channels, the need for management tools in this region is especially acute.

In this study, we analyzed a set of historical data from USACE-directed relocation trawling activities in the Gulf of Mexico from 2001-2005. Our objectives were to provide information that would help regional managers schedule dredging activities and mitigation efforts to reduce mortality of turtles at dredged channels, and add to our understanding of turtle abundance and behavior in coastal waters. We used catch per unit effort (CPUE) values to provide abundance indices for comparison with previous estimates and to provide baseline values for further monitoring. Based upon observed increases in CPUE noted by other researchers (VAN DOLAH and MAIER, 1993; GSAFDF, 1998; JAMIR, 1999) in both the Gulf and Atlantic U.S. waters, we hypothesized that our CPUE estimates would be higher than estimates from previous studies in the region. We also used hierarchical linear models to explore the effects of latitude, water temperature, season, and daily time periods on CPUE. We hypothesized that CPUE values would be higher in the southern areas of the region, relative to the northern areas and suspected that CPUE would be greater in warmer waters. Further, we hypothesized that CPUE would be greater during the spring and summer months. Finally, we expected that CPUE would be greater during daylight hours than during hours of darkness.

STUDY AREA

Data were analyzed from seven shipping channels in the northwestern Gulf of Mexico, U.S.A. (Figure 3.1). Channels examined, from northernmost to southernmost, were Sabine, Texas (29.68 N -93.83 W); Mississippi River Gulf Outlet (MRGO), Louisiana (29.47 N -89.08 W); Houston Galveston Navigation Channel (HGNC), Texas (29.34 N -94.68 W); Freeport, Texas (28.93 N -95.29 W); Matagorda, Texas (28.42 N -96.32 W); Corpus Christi, Texas (27.83 N -97.03 W); and Brownsville, Texas (26.07 N -97.14 W). Trawled areas ranged in depth from approximately 9.1 m to 18.3 m. Each channel was bounded by navigational buoys, and each was protected at its coastal junction by rock jetties.

Channels were located within two USACE management districts. The MRGO channel was managed by the New Orleans District; all others were managed by the Galveston District. The MRGO channel experienced heavy shoaling from Hurricane Katrina in August 2005, and was temporarily abandoned for shipping purposes. As of January 2007, it was not re-dredged and USACE managers suggested that it would be abandoned as a dredge-maintained shipping channel.

METHODS

Trawling

Relocation trawling was conducted with standard shrimp trawling vessels outfitted with two specially designed nets. There were slight variations in power and length among vessels, but nets, tow times, and tow speeds were similar for all projects. Nets were similar to standard shrimp nets in gross design, but were constructed with large-mesh webbing to decrease bycatch and did not contain the turtle excluder devices (TEDs) that are mandatory for commercial shrimp trawling vessels. Tow times were restricted to durations <42 min to minimize risk of drowning turtles. Tows occurred at depths ranging from 4-18 meters. Depths were recorded in shipping channels. Because shipping channels are excavations in the sea floor, surrounding water depths are generally shallower than the depth in the channel. During relocation operations, trawlers made repeated tows in the project site while dredging operations were underway. Turtles were captured alive and displaced several kilometers from the dredged area. Release sites varied, but turtles typically were removed parallel to the coast from 2-22 km from the capture site. Vessel traffic and physical characteristics of the project site limited the activity of the trawler, but trawl operators generally tried to work as closely as possible to the dredges. Sometimes, trawlers towed directly in front of a dredge as it worked, attempting to sweep turtles from the immediate path of the drag arms. When this was not feasible, trawlers attempted to cover the active work site in a comprehensive manner to remove turtles from areas where dredging was immanent. Some tows followed straight paths along the channel length for distances ranging from approximately 1.8 to 4.6 km. During some tows, trawlers made a 180-degree turn and moved back along the length of the channel during a single tow. Relocation trawling effort ranged from a single trawler operating during 12 hours of the day to two trawlers operating continuously. The most common configuration was a single trawler operating continuously.

Data

We obtained relocation trawl data from the USACE Engineer Research and Development Center, Waterways Experiment Station in Vicksburg, Mississippi, U.S.A. Data were collected from relocation records, USACE district project reports, contractor final trawl reports, and tagging reports. We created a record for each trawl that contained date and location data, environmental data, tow start and end times, and turtle captures. We standardized trawl effort for individual trawls in 30.5-m net hours (HENWOOD and STUNTZ 1987). One 30.5-m net hour is equivalent to a tow of exactly one hour by a single net with a head rope length of 30.5 m. The head rope extends across the mouth of the net. This method assumes that there is a direct proportional relationship between head rope length and captures (JAMIR 1999). We summarized these data by calculating the mean effort, captures, and temperature for each channel, during each month when trawling occurred, and by "watch". Watches were 6-hour periods defined as follows: AM1—00:01 to 06:00; AM2—06:01 to 12:00; PM1— 12:01 to 18:00; and PM2—18:00 to 00:00. Individual tows were classified into watches based on the start time of the tow and summarized over the entire month for each channel. From this summarized data set, we calculated CPUE using the equation (JAMIR, 1999):

$$\hat{C} = \frac{\sum s_i}{\sum e_i} = \frac{\bar{s}}{\bar{e}}$$

Where i = 1, 2 ..., n number of tows

$\hat{C}$ = estimated sample CPUE

s_i = number of turtles per tow

e_i = standardized effort per tow

$\bar{s}$ = mean value of s

$\bar{e}$ = mean value of e

The CPUE values thus derived were used in all subsequent analyses.

Analysis

From the data set described above, we calculated mean CPUE values for appropriate regions and seasons for comparison with the results of earlier studies that estimated CPUE of turtles while trawling for shrimp in the Gulf of Mexico (HENWOOD and STUNTZ, 1987; Gulf and South Atlantic Fisheries Development Foundation, 1998; JAMIR, 1999). Confidence intervals of the estimates were calculated using the methods of JAMIR (1999). We also used hierarchical linear models to explore the effects of predictor variables on CPUE. We fit models using a two level approach, with channel as level two and observations within channels as level one. Hierarchical modeling is appropriate for analysis of multi-level data, in which observations within a level are not independent (BRYK and RAUDENBUSH, 1992). Because our data consisted of repeated observations from each channel, hierarchical modeling was more appropriate than standard multiple regression. Furthermore, hierarchical models are useful for determining and estimating effects where observations are scant or absent within some of the groups of interest (BRYK and RAUDENBUSH, 1992).

We used mean CPUE as the response variable for all models. We assumed that there was a linear relationship between effort and captures within the data used to calculate the means. We examined the validity of this assumption by plotting cumulative catch versus cumulative effort for each trawler on each project where at least two turtles were captured by the trawler (APPENDIX D). We found that the assumption of linearity was not violated. We created a model set for combined species, all turtles captured of any species, another for loggerhead (Caretta caretta), and another for Kemp's ridley (Lepidochelys kempi) turtles. We used latitude, temperature, and designations of time as independent variables (Table 3.1). Latitude was the only level-2 variable. For ease of interpretation, we scaled latitude from Brownsville, Texas, the southernmost channel in the study area. All time variables were categorical and were of two basic types. "Seasonal" variables were individual months, or groupings of months, and "period" variables were created by dividing the 24-hour day into segments.

We fit an unconditional model, containing no predictor variables, to estimate the amount of variation occurring among and within channels. We used among channel variation (τ_{00}), and within channel variation (σ^2) from this model, to calculate interclass correlation (ρ), using the formula (SINGER, 1998):

$$\hat{\rho} = \frac{\hat{\tau}_{00}}{\hat{\tau}_{00} + \hat{\sigma}^2} \qquad \rho\text{-rho} \quad \tau\text{-tau} \quad \sigma\text{ - sigma} \qquad (1)$$

We fit a global model containing latitude, temperature, 12 individual months, four 6-hour watches, and all possible 2-way interactions except the interaction between month and watch. For ease of interpretation we did not include any higher-level interactions in the global model. We plotted the predicted versus the residual values from the global model to examine normality of data. From the global model, we constructed a subset of candidate models that we hypothesized to be ecologically meaningful and to have useful management interpretations for determining locations, times, and water temperatures where turtles were less likely to occur. We fit models to allow a single explicit random effect (τ_{00} ; the remaining variation among channels) and the single random effect implicit in all linear models (σ^2 ; the remaining variation within channels; SINGER, 1998). We fit models using Statistical Analysis Software (SAS) version 9.1 (SAS Institute 2003). Models were fit using the PROC MIXED procedure.

We used Akaike's Information Criteria (AIC; AKAIKE, 1973) to evaluate the fit of each candidate model and to rank each in relation to other models in the set. We calculated AIC weights for this candidate model set that represented the probability that a given model was the correct one, given the other models in the set (BURNHAM and ANDERSON, 1998). We used AIC weights to calculate a confidence set of models that had weights greater than 10% of the best-fitting model weight. We calculated importance weights for individual variables by summing the

AIC weights for each model in which they occurred, and removed models containing variables with relatively low importance weights from the confidence model set (BURNHAM and ANDERSON, 1998). For discussion purposes, we selected the top five best fitting models from this set. We calculated parameter estimates and 90% confidence intervals for models in the inference set and used parameter estimates from these models to explore main effects and interactions.

RESULTS

The analysis data set represented 133 turtle captures in 14,514 individual tows, and 10,126 standardized 30.5-m net-hours from seven study channels (Table 3.2). Effort and catch varied among seasons and channels. Turtles were captured in all channels except Matagorda. Loggerhead and Kemp's ridley turtles were captured throughout the study area, but green turtles (Chelonia mydas) were only captured in Brownsville, the southernmost channel in the study area. Eighty-eight loggerheads, 26 Kemp's ridley, and 18 greens turtles were captured.. Two loggerheads were recaptured during the same project in Corpus Christi channel in June 2003 and were included in the data set. One leatherback (Dermochelys coriacea) was captured in the Corpus Christi channel in April 2003 and was also included in the data set. Leatherbacks are rarely captured during relocation trawling in shipping channels. This may be due to large size, low density in these areas, or other behavioral factors.

Catch Per Unit Effort

Estimated mean CPUE for the study area, for all months combined, was 0.0131 turtles·30.5-m net-hour^{-1}, with a 95% confidence interval of 0.0109 to 0.0154 turtles·30.5-m net-hour^{-1} (Table 3.3). Estimated CPUE values from this study were similar for January-April and May-August, and lower for September-December, as evidenced by the confidence intervals for estimates from these periods (Table 3.3). Previous trawl studies stratified results by depth and yearly trimester (Table 3.3; HENWOOD and STUNTZ, 1987; Gulf and South Atlantic Fisheries Development Foundation, 1998; JAMIR, 1999). In our study, 99% of tows occurred in depths between 9-18 m. However, most depths in our study were recorded in shipping channels, and nearby depths outside the channel were shallower. Therefore, we compared our results to previous results from both 0-9 and 9-18-m strata. General trends in season were similar, but estimated CPUE values from our study were higher than values from HENWOOD and STUNTZ (1987) for all trimesters in all depths, and generally lower than values from the Gulf and South Atlantic Fisheries Development Foundation (1998) study.

Modeling

For each of the three candidate model sets, the plotted predicted values versus residual values did not indicate violations of normality assumptions within the data. The candidate model set predicting CPUE of combined species contained 104 models. The interclass correlation (ρ) from the unconditional model was 3%; hence, 97% of the variation in the data occurred within channels. The best fitting model (Table 3.4) accounted for 92% of explainable within-channel variation. It estimated that in Brownsville Channel, at a water temperature of 24.2°C, during the months of July-March, and during the 18-hour period between 18:00 and 12:00, the mean CPUE would be 0.0350 turtles·30.5-m net-hour^{-1} (Table 3.5). As temperature increased, CPUE increased. During the hours of 12:00 and 18:00, CPUE was higher than at other periods of the day. CPUE was lower at more northerly latitudes. Within the study area, CPUE was generally higher during April-June, but the difference in CPUE between this period and the July-March period was smaller in the more northern latitudes (Figure 3.2). Controlled as described, other models in the inference set produced similar estimates of mean CPUE (intercept), and of the effects of temperature, watch5, and of the latitude*seas6 interaction. Two models contained latitude*watch5 interactions, and one contained temperature*seas6 interaction parameter. However, 90% confidence intervals for these estimates contained 0, and the nature of the effects was difficult to determine. The fifth best fitting model contained watch2. From this model, the effect of watch2 was negative, estimating lower CPUE values during the hours between 00:01 and 12:00.

The candidate model set predicting CPUE of loggerhead turtles contained 75 models. The interclass correlation (ρ) from the unconditional model was 4%; therefore 96% of the variation in the data occurred within channels. The best fitting model contained latitude, temperature, watch5, seas6, and a latitude*seas6 interaction (Table 3.6), and accounted for 96% of the explainable within channel variation. It estimated that in Brownsville Channel, at a water temperature of 24.2°C, during the months of July-March, and during the 18-hour period between 18:00 and 12:00, the mean CPUE would be 0.0057 loggerheads·30.5-m net-hour^{-1} (Table 3.7). The 90% confidence interval for this estimate included 0, suggesting that, under the controls described, estimated CPUE could not be reliably distinguished from 0. Latitude had a negative effect, but the 90% confidence interval for the estimate of this effect also contained 0. Latitude related negatively with the months April-June (Figure 3.3) in all models. Within the study area, estimated CPUE of loggerhead turtles was nearly constant across latitudes during July-March, but was higher in the southern latitudes during April-June. Temperature and watch5 both had positive additive effects on CPUE of loggerhead turtles; at higher temperatures and during the 6-hour period between 12:00 and 18:00, CPUE was higher. Other best fitting models produced similar estimates. Temperature generally had a positive additive effect on CPUE. Two models contained a latitude*temperature interaction, but the 90% confidence interval for this effect contained 0. Other best fitting models also contained negative effects for both watch2 and watch3. During the period between 00:01 and 12:00 (watch2) and the between 00:01 and 06:00 (watch3), estimated CPUE of loggerhead turtles was lower.

The candidate model set predicting CPUE of Kemp's ridley turtles contained 94 models. The interclass correlation (ρ) from the unconditional model was 17%; therefore 83% of the variation in the data occurred within channels. The best fitting model contained watch2, the seas1 periods spring and summer (Table 3.8), a latitude*spring interaction, and a watch2*spring interaction. This model accounted for 21% of the within channel variation, and estimated that in Brownsville channel, at a water temperature of 24.2°C, during the months of December-February, and during the 12-hour period between 12:01 and 24:00, the mean CPUE of Kemp's ridley turtles was 0.0026 Kemp's·30.5-m net-hour^{-1} (Table 3.9). The 90% confidence interval for this estimate was wide and contained 0, indicating that when controlled as described, the estimated CPUE of Kemp's ridley turtles could not be reliably distinguished from 0. The months, June-August (SU), had a small positive additive effect on CPUE. During March-May, estimated CPUE decreased at more northerly latitudes (Figure 3.4). Although other best fitting models parameterized latitude as a main effect, all estimates of this effect had wide confidence intervals containing 0, indicating that latitude had no easily distinguishable effect on CPUE except during March-May. The watch2*spring interaction indicated that during the months, March-May, estimated CPUE varied differently across the 24-hour period compared to other months of the year. During March-May, estimated CPUE of Kemp's ridley turtle was relatively greater during the hours 00:01-12:00, but during June-February it was relatively lower during those hours, with slight additive differences between June-August and September-February. All other best fitting models contained parameters for spring, summer, watch2*spring, and latitude*spring that produced similar estimates. Three of the best fitting models contained a negative latitude*watch interaction (Figure 3.5), indicating that CPUE varied differently across latitude during different periods of the day. During the hours 00:01 to 12:00, CPUE decreased with increasing latitude, and during the hours 12:01-24:00, it increased with increasing latitude. Other best fitting models contained a positive additive effect for fall, and a negative latitude*summer interaction. Both of these estimates were small, and their 90% confidence intervals contained 0.

DISCUSSION

Turtles are relatively abundant within the channels of the northwestern Gulf of Mexico and their abundance or catchability is affected by temperature, latitude, season, and time of day. Our objectives were to discover patterns in turtle CPUE in shipping channels in the northwestern Gulf of Mexico to assist managers in the region and to increase our understanding of basic behavior. We found that specific seasons and times of day, and specific locations within the region, may present lower risk of dredge-turtle interactions than other times and locations. Furthermore, our findings suggest a pattern of spring migratory behavior for loggerhead and Kemp's ridley turtles.

Our combined and trimester CPUE values were higher in all cases than those calculated for the same periods and similar depths from the HENWOOD and STUNTZ (1987) NMFS data set (Table 3.1) by JAMIR (1999). However, our CPUE results were lower in most cases than those calculated from the more recent GSAFDF dataset (JAMIR, 1999). The results from both the NMFS and the GSAFDF data sets were calculated for Gulf regions west of 91 degrees latitude, matching our study area closely. However, caution is necessary when comparing our results with the results of previous studies. Both the NMFS and the GSAFDF values presented for comparison were calculated from fishery-dependant survey data that may be biased toward areas where shrimp may be abundant, while our data were collected solely from shipping channels with intensive trawling concurrent with active dredging. Because our results were calculated from a data set representing a large sampling effort, in the same region at similar depths, and standardized using the same method, it is reasonable to compare the results of these studies for discussion purposes. The larger CPUE values from more recent studies relative to the NMFS study may reflect an increasing density of turtles, or it may reflect a greater turtle density within shipping channels relative to coastal areas, generally. MAIER *et al.* (2004) found that CPUE values from a study in the U.S. South Atlantic were greater than values from previous studies in the region. Similarly, the GSAFDF CPUE results for the Atlantic were higher than the earlier NMFS values for the region (JAMIR, 1999). Results from telemetry studies suggest that some turtles spend more time within channels than in surrounding areas (KEINATH *et al.,* 1992). Similarly, results from a study in the Charleston Entrance Channel, South Carolina, suggest that the CPUE within the channel was higher than CPUE from surrounding coastal areas (VAN DOLAH and MAIER, 1993).

In this study, the two species captured in trawls most frequently were loggerhead and Kemp's ridley turtles. The nesting population of Kemp's in the western Gulf increased between the period when the NMFS study data were collected (1973-1984) and 2000 (HENWOOD and STUNTZ, 1987; Turtle Expert Working Group, 2000). The higher CPUE results from our study (2001-2005) may be due in part to a continuing increase in abundance of this species. While relatively little is known about population trends of loggerheads in the Gulf of Mexico, the South Florida nesting population increased from the late 1980s to 2000 (Turtle Expert Working Group, 2000). Although data from this study cannot be used to support a trend in turtle density in the region, that the CPUE values are more than two times greater than the HENWOOD and STUNTZ values (GSAFDF, 1998) in most depths during most time periods is consistent with increased abundance. Furthermore, these data suggest that if relocation trawling continues, it may be useful as a monitoring tool for the region using this study's results as a baseline.

Models developed from these data indicated that water temperature and latitude affect the CPUE of sea turtles in the northwestern Gulf of Mexico, and that CPUE differs during different times of the year, during different times of the day, and between species. For CPUE of combined species (Table 3.5) and loggerheads (Table 3.7), the positive effect of temperature was small and similar among all best fitting models. The temperature effect of 0.0008 translates into approximately two turtles more during a typical week of relocation trawling at a temperature of 30.0°C, relative to the same effort at a temperature of 15°C. This linear relationship can only apply over a relatively small temperature range because turtles are rarely found in waters colder than 15°C (DICKERSON *et al.,* 1995, EPPERLY *et al.*, 1995). Within our data set, 759 tows occurred at temps below 15°C, and all captures occurred at temperatures between 16.1-32.0°C. For the CPUE of Kemp's ridley turtles (Table 3.9), temperature was not included in any of the best fitting models. The lack of temperature in the best fitting models for Kemp's, and the small size of the effect in other best fitting models was probably partially due to the correlation between temperature and season. Therefore, managers may find it more effective to focus on season, and consider only threshold temperatures when making decisions regarding the timing and location of dredging activities.

Season and latitude affected CPUE and were interrelated. The relationship between latitude and the spring and early summer months was similar for loggerhead and Kemp's ridley (Figures 3.3, 3.4) and implied that within the study area, turtles were either more abundant or were more susceptible to trawling in channels during these months. The difference in CPUE across latitude during spring is consistent with a northward movement of turtles into these channels during the spring months, with the surge of turtles arriving earlier in southern latitudes and continuing throughout the period. This hypothesis is reasonably consistent with findings from other research. The CPUE of Kemp's and loggerheads from tangle netting near the Sabine Channel jetties between May-October was highest in May, with no captures in September or October (LANDRY *et al.*, 1996). A similar effort in Matagorda Bay found the highest catch rates of Kemp's in May-July with none captured in August-October (LANDRY *et al.*, 1997). Loggerhead turtles are known to have a magnetic compass sense and exhibit consistent directional orientations during certain seasons even under laboratory conditions (AVENS and LOHMANN, 2004). Furthermore, evidence suggests that turtles use visual cues as well as internal compass cues for navigation and migratory movement (AVENS and LOHMANN, 2003). The northward movements of turtles in this region may be triggered by temperature or photoperiod changes, changes in prey abundance, or other cues.

The finding of no differences in CPUE of loggerheads among summer, fall, and winter months, and the small effect of summer on CPUE of Kemp's, were unexpected. The northernmost channel in the study area is within 75 km of the northernmost extent of the Gulf of Mexico. If turtles are actively moving north into the study area in increasing numbers during spring in response to rising water temperatures or prey movement, it is logical to assume they will remain similarly abundant in the area during summer. It is important to note that the precise area sampled by relocation trawling was a series of narrow transects located in or near the open Gulf, at the mouths of bays and inlets. Kemp's and loggerheads are present inshore of these transects in bays and inlets during the spring and summer months (LANDRY *et al.*, 1996;

LANDRY *et al.*, 1997). Turtles may be particularly vulnerable to capture as they arrive from the south and pass through these bottleneck areas in large numbers to reach inshore foraging grounds. If turtles arrive in a pulse and leave at a steady rate over several months, CPUE will be greater during the arrival period relative to the departure. A telemetry study of four loggerheads off the Texas coast, found that all turtles over-wintered in the northern Gulf, offshore of the coastal areas containing shipping channels, but well within the northern latitudes of our study area (RENAUD and CARPENTER, 1994). Therefore, although turtles may be caught less frequently during relocation trawling in fall and winter months, they may be in nearby offshore waters.

Regardless of the underlying behavior causing the relatively high CPUE values during spring months, knowledge of this effect can be used by managers of dredging operations. Relocation trawling occurs in shipping channels, concurrently with active dredging; hence, samples of turtles from trawling are from the sea floor where dredging occurs. Therefore, vulnerability to capture by a trawl net or a drag head are correlated. Consequently, the months, March-June present a greater risk of dredge-turtle interactions than any other period of the year in most of the study area. If dredging is conducted during these months, the lowest risk will be in the northernmost area of the region.

In this study, green sea turtles were only captured in Brownsville Channel during winter months (Table 3.2). For loggerhead and Kemp's turtles analyzed separately, the negative effect of latitude during non-spring months was negligible or nonexistent (Table 3.7, Table 3.9), implying that the non-spring latitude effect in the combined species models is caused by green turtles. All but one of the green sea turtles captured were relatively small juveniles. Studies of movement using telemetry found that juvenile green turtles exhibited strong site fidelity along the jetties of the Brownsville Channel, often staying within meters of release sites for days, foraging on algal growth along the jetty rocks (RENAUD *et al.*, 1992; RENAUD *et al.*, 1995). Greens are also found farther north within the study area, at least to Matagorda Bay (LANDRY *et al.*, 1997), although they were not captured outside Brownsville for this study. The low incidence of loggerhead and Kemp's captures in Brownsville during the winter is consistent with the latitude effect observed in the models for these species, and suggests that greens behave differently. Because our study did not contain samples from Brownsville Channel for any non-winter months, and because the species assemblage there is unique among the channels of this study, further data are needed to make strong management recommendations for this channel. In the absence of other information, managers may attempt to schedule dredging activities there during months with coldest water temperatures.

Estimated CPUE for combined species and for loggerheads generally were greater during the afternoon (12:01-18:00) relative to all other hours of the day during all seasons at all latitudes (Tables 3.5, 3.7). The CPUE for Kemp's was generally higher during the morning (00:01-12:00) relative to other hours during spring, and lower during these hours relative to other hours during all other months (Table 3.9). Furthermore, with other variables constant, CPUE for Kemp's increased during the afternoon and evening hours (12:01-24:00), while decreasing during the morning hours as latitude increased (Figure 3.5). These differences may be related to diving behavior. While the percentage of time turtles spend underwater remains relatively constant across days and seasons, turtles tend to make less frequent, longer duration dives at night relative to the day (RENAUD and CARPENTER, 1994; RENAUD *et al.*, 1995). It is not well known what portion of their underwater time turtles in this region spend foraging actively on the bottom, holding or swimming at constant depths in the water column, or resting stationary on the bottom.

Turtles are most vulnerable to trawlers and dredges when they are near the bottom, and may be more vulnerable if they are in a resting state, although there is no evidence to support this theory. Our results simply indicate that loggerheads are generally more vulnerable to trawling in shipping channels during the afternoon hours.

CONCLUSIONS

This study presents quantitative and qualitative findings that are potentially useful to dredging operation managers and increase our understanding of turtle abundance and behavior in the northwestern Gulf of Mexico. Our study indicated that the months, March-June present the greatest risk of dredge-turtle encounters in most of the region. If managers have the option of foregoing dredging throughout the region for several months, March-June would be an appropriate closure period. If it is necessary to dredge during these months, the northernmost channels in the region present the lowest risk of turtle encounters. Similarly, if relocation trawling or other mitigation efforts are not feasible to use for all the dredging effort in the region, then these mitigation tools should be used preferentially during projects in the spring months and at projects in the southernmost area of the region. Under ESA guidelines, USACE districts in the Gulf of Mexico are permitted fewer Kemp's takes than any other species (NMFS, 2003). Because summer estimates of CPUE are higher than fall and winter months, the period of September-February may provide the lowest risk of Kemp's mortality. In general season is more useful than temperature as a predictor of turtle relative abundance. However, any time that water temperatures are below 15°C, the risk of turtle encounters is low.

The southernmost channels in the region may be unique because green turtles are abundant there during the early winter. More study is needed to examine populations of turtles in these channels during other months, although models predict that both loggerheads and

Kemp's will be abundant there during the spring. Our results are consistent with northward migratory movement by loggerheads and Kemp's during the spring months, with turtles arriving earlier in the southernmost regions and continuing to arrive throughout the period. Further study is needed to determine whether temperature, photoperiod, prey abundance, or other cues are responsible for triggering this northward movement.

In addition to being a valuable tool for reducing the mortality of marine turtles at hopper dredge sites, relocation trawling provides data for monitoring relative abundance and behavior of marine turtles. Because trawling is an expensive sampling method, managers should standardize the collection and maximize the use of trawling data.

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Table 3.1. Parameters used in models estimating CPUE of marine turtles in northwestern Gulf of Mexico shipping channels. Season variables and watch variables were categorical and were created by dividing the year into periods (season) or the 24-hour day into periods (watch). All effects were estimated relative to the baseline level of each variable.

Type	Parameter	Levels	Description
Location	**LAT**	continuous	latitude scaled from Brownsville Channel
Temperature	**TEMP**	continuous	temperature, centered on the mean
Season	**S1**	SP	March-May
		SU	June-August
		FA	September-November
		(baseline)	December-February
	S6	SP	April-June
		(baseline)	July-March inclusive
Watch	**W2**	A	hours 00:01-12:00
		(baseline)	hours 12:01-24:00
	W3	A	hours 00:01-06:00
		(baseline)	hours 06:01-24:00
	W5	A	hours 12:01-18:00
		(baseline)	hours 18:01-12:00 inclusive

Table 3.2. Trawl effort (30.5-m net-hour units) and turtle capture data from relocation trawling in seven study channels in the northwestern Gulf of Mexico, 2001-2005, summarized by yearly trimester. Captures are summarized by species: loggerhead, green, Kemp's ridley, and leatherback. Channels are arranged from northernmost (top) to southernmost (bottom).

Channel	Total effort	Jan-Apr effort	May-Aug effort	Sep-Dec effort	Total # turtles	Species: loggerhead	green	Kemp's	leatherback
Sabine	1,591.6	177.0	630.4	784.2	11	6	0	5	0
MRGO[a]	255.0	0.0	255.0	0.0	9	9	0	0	0
HGNC[b]	3,092.3	237.3	2,642.5	212.4	15	11	0	4	0
Freeport	2,806.1	0.0	631.8	2,174.3	7	5	0	2	0
Matagorda	199.8	199.8	0.0	0.0	0	0	0	0	0
Corpus Christi	1,691.7	311.3	1,380.4	0.0	72	56	0	15	1
Brownsville	489.4	0.0	0.0	489.4	19	1	18	0	0
TOTAL	**10,125.8**	**925.4**	**5,540.1**	**3,660.3**	**133**	**88**	**18**	**26**	**1**

[a] Mississippi River Gulf Outlet Channel
[b] Houston Galveston Navigation Channel

Table 3.3. Comparison of trawl effort and catch results from this study (USACE), to results from previous studies in the western Gulf of Mexico. Data[1] were from studies by Henwood and Stuntz (1987; NMFS), and by the Gulf and South Atlantic Fisheries Development Foundation (1998; GSAFDF). Results are presented by all months combined and by yearly trimester. Because previous studies were stratified by depth (m), data for the depth categories most similar to those in the current study were presented. Total effort and mean effort per tow are in standardized 30.5-m net hours, and CPUE and associated confidence intervals are in turtles·30.5-m net-hour^{-1}.

		Total #	Total	Mean	Total #	Mean #	Confidence Interval		
All Months	**Depth**	**tows**	**effort**	**effort**	**turtles**	**turtles**	**Lower 95%**	**CPUE**	**Upper 95%**
USACE		14,514	10125.8	0.6977	133	0.0092	0.0109	0.0131	0.0154
GSAFDF	00-09	362	321.0	0.8867	20	0.0553	0.0325	0.0623	0.0921
	09-18	59	76.9	1.3032	1	0.0170	-0.0124	0.0130	0.0385
NMFS	00-09	1029	2827.7	2.7480	12	0.0117	0.0019	0.0042	0.0066
	09-18	1289	4614.2	3.5797	13	0.0101	0.0013	0.0028	0.0043
January-April									
USACE		1308	925.4	0.7075	16	0.0122	0.0089	0.0173	0.0257
GSAFDF	00-09	89	79.4	0.8923	5	0.0562	0.0088	0.0630	0.1171
	09-18	17	23.4	1.3756	1	0.0588	-0.0408	0.0428	0.1264
NMFS	00-09	56	382.3	6.8275	0	0	0	0	0
	09-18	22	243.4	11.0621	0	0	0	0	0
May-August									
USACE		8103	5540.1	0.6837	91	0.0112	0.0130	0.0164	0.0199
GSAFDF	00-09	48	29.8	0.6217	4	0.0833	-0.0162	0.1341	0.2843
	09-18	12	14.8	1.2359	0	0	0	0	0
NMFS	00-09	101	223.3	2.2108	3	0.0297	-0.0010	0.0134	0.0279
	09-18	192	507.5	2.6431	2	0.0104	-0.0015	0.0039	0.0090
September-December									
USACE		5103	3660.3	0.7174	26	0.0051	0.0044	0.0071	0.0098
GSAFDF	00-09	225	211.7	0.9410	11	0.0489	0.0163	0.0520	0.0876
	09-18	30	38.7	1.2892	0	0	0	0	0
NMFS	00-09	872	2222.1	2.5483	9	0.0103	0.0014	0.0041	0.0067
	09-18	1075	3863.3	3.5938	11	0.0102	0.0012	0.0029	0.0045

[1] All values taken from Jamir (1999)

Table 3.4. Top 5 best fitting models estimating the CPUE of combined turtle species (loggerhead, Kemp's, Green, and leatherback) from shipping channels in the northwestern Gulf of Mexico, and number of parameters (K), Akaike Information Criterion values (AIC), difference in AIC from the best fitting model (ΔAIC), and AIC weights (AIC *wt*) for each model.

Model	K	AIC	ΔAIC	AIC *wt*
Latitude Temperature 12:01-1800 April-June Latitude*April-June	8	-466.6	0	0.103
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Latitude*12:01-18:00	9	-466.6	0	0.103
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Temperature*April-June	9	-465.7	0.9	0.066
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Latitude*12:01-18:01 Temperature*April-June	10	-465.7	0.9	0.066
Latitude Temperature 00:01-12:00 April-June Latitude*April-June	8	-465.4	1.2	0.057

Table 3.5. The top 5 best fitting models that estimate the CPUE of combined turtle species (loggerhead, Kemp's, green, and leatherback) in shipping channels in the northwestern Gulf of Mexico. The estimated random effect (remaining variation among channels) was <0.0001 in all models. Parameter estimates and confidence interval values are in turtles·30.5-m net-hour^{-1}. . Estimates are relative to the baseline for each parameter. Parameters are described in Table 3.1

			90% Confidence Interval	
Model	**Parameter**	**estimate**	**Lower**	**Upper**
LAT TEMP W5 S6 LAT*S6				
	Intercept	0.0350	0.0165	0.0535
	Latitude	-0.0098	-0.0151	-0.0045
	Temperature	0.0008	0.0002	0.0014
	12:01-18:00	0.0108	0.0036	0.0180
	April-June	0.0509	0.0222	0.0796
	Latitude*April-June	-0.0142	-0.0244	-0.0041
LAT TEMP W5 S6 LAT*S6 LAT*W5				
	Intercept	0.0303	0.0107	0.0500
	Latitude	-0.0081	-0.0137	-0.0025
	Temperature	0.0008	-0.0002	0.0014
	12:01-18:00	0.0300	0.0060	0.0539
	April-June	0.0510	0.0225	0.0795
	Latitude*April-June	-0.0143	-0.0244	-0.0043
	Latitude*12:01-18:00	-0.0069	-0.0151	0.0013
LAT TEMP W5 S6 LAT*S6 TEMP*S6				
	Intercept	0.0358	0.0172	0.0544
	Latitude	-0.0101	-0.0154	-0.0047
	Temperature	0.0009	0.0003	0.0015
	12:01-18:00	0.0108	0.0036	0.0180
	April-June	0.0498	0.0210	0.0787
	Latitude*April-June	-0.0134	-0.0236	-0.0032
	Temperature*April-June	-0.0014	-0.0036	0.0008
LAT TEMP W5 S6 LAT*S6 LAT*W5 TEMP*S6				
	Intercept	0.0311	0.0113	0.0508
	Latitude	-0.0084	-0.0140	-0.0027
	Temperature	0.0009	0.0003	0.0015
	12:01-18:00	0.0300	0.0063	0.0538
	April-June	0.0499	0.0213	0.0786
	Latitude*April-June	-0.0135	-0.0236	-0.0033
	Latitude*12:01-18:00	-0.0069	-0.0151	0.0012
	Temperature*April-June	-0.0014	-0.0035	0.0008
LAT TEMP W2 S6 LAT*S6				
	Intercept	0.0419	0.0230	0.0607
	Latitude	-0.0098	-0.0151	-0.0045
	Temperature	0.0008	0.0002	0.0014
	00:01-1200	-0.0083	-0.0146	-0.0021
	April-June	0.0507	0.0218	0.0796
	Latitude*April-June	-0.0141	-0.0243	-0.0039

Table 3.6. Top 5 best fitting models estimating the CPUE of loggerhead turtles in shipping channels in the northwestern Gulf of Mexico, number of parameters (K), Akaike Information Criterion values (AIC), difference in AIC from the best fitting model (ΔAIC), and AIC weights (AIC *wt*) for each model.

Model	K	AIC	ΔAIC	AIC *wt*
Latitude Temperature 12:01-18:00 April-June Latitude*April-June	8	-531.1	0	0.074
Latitude Temperature 00:01-06:00 April-June Latitude*April-June	8	-531.0	0.1	0.071
Latitude Temperature 00:01-12:00 April-June Latitude*April-June	8	-530.7	0.4	0.061
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Latitude*Temperature	9	-530.7	0.4	0.061
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Temperature*April-June	9	-530.6	0.5	0.058

Table 3.7. The top 5 best fitting models that estimate the CPUE of loggerhead turtles in shipping channels in the northwestern Gulf of Mexico. The estimated random effect (remaining variation among channels) was <0.0001 in all models. Estimates and confidence interval values are in loggerheads·30.5-m net-hour^{-1}. Parameters are described in Table 3.1.

			90% Confidence Interval	
Model	**Parameter**	**Parameter estimate**	**Lower**	**Upper**
LAT TEMP W5 S6 LAT*S6				
	Intercept	0.0057	-0.0064	0.0178
	Latitude	-0.0009	-0.0043	0.0025
	Temperature	0.0006	0.0002	0.0010
	12:01-18:00	0.0064	0.0012	0.0116
	April-June	0.0497	0.0308	0.0686
	Latitude*April-June	-0.0139	-0.0205	-0.0072
LAT TEMP W3 S6 LAT*S6				
	Intercept	0.0089	-0.0033	0.0210
	Latitude	-0.0009	-0.0043	0.0025
	Temperature	0.0006	0.0002	0.0010
	00:01-06:00	-0.0062	-0.0114	-0.0011
	April-June	0.0497	0.0308	0.0686
	Latitude*April-June	-0.0139	-0.0205	-0.0072
LAT TEMP W5 S6 LAT*S6 LAT*TEMP				
	INT	0.0116	-0.0036	0.0268
	Latitude	-0.0027	-0.0069	0.0015
	Temperature	0.0019	0.0001	0.0037
	12:01-18:00	0.0065	0.0013	0.0116
	April-June	0.0441	0.0240	0.0642
	Latitude*April-June	-0.0121	-0.0191	-0.0051
	Latitude*Temperature	-0.0005	-0.0010	0.0001
LAT TEMP W2 S6 LAT*S6				
	INT	0.0099	-0.0024	0.0223
	Latitude	-0.0009	-0.0043	0.0025
	Temperature	0.0006	0.0002	0.0010
	00:01-12:00	-0.0052	-0.0097	-0.0008
	April-June	0.0494	0.0304	0.0684
	Latitude*April-June	-0.0137	-0.0204	-0.0070
LAT TEMP W5 S6 LAT*S6 LAT*TEMP				
	INT	0.0051	-0.0067	0.0170
	Latitude	-0.0007	-0.0040	0.0026
	Temperature	0.0005	0.0001	0.0009
	12:01-18:00	0.0064	0.0013	0.0116
	April-June	0.0512	0.0327	0.0697
	Latitude*April-June	-0.0147	-0.0213	-0.0082
	Latitude*temperature	0.0012	-0.0004	0.0027

Table 3.8. Top 5 best fitting models estimating the CPUE of Kemp's ridley turtles in shipping channels in the northwestern Gulf of Mexico, number of parameters (K), Akaike Information Criterion values (AIC), difference in AIC from the best fitting model (ΔAIC), and AIC weights (AIC *wt*) for each model. Parameters are described in Table 3.1.

Model	K	AIC	ΔAIC	AIC *wt*
00:01-12:00 March-May June-August Latitude*March-May 00:01-12:00*March-May	8	-703.9	0	0.209
Latitude 00:01-12:00 March-May June-August Latitude*00:01-12:00 Latitude*March-May 00:01-12:00*March-May	10	-703.3	0.6	0.155
Latitude 00:01-12:00 March-May June-August Latitude*March-May 00:01-12:00*March-May	9	-702.0	1.9	0.081
Latitude 00:01-12:00 March-May June-August Latitude*00:01-12:00 Latitude*March-May Latitude*June-August 00:01-12:00*March-May	11	-701.4	2.5	0.060
Latitude 00:01-12:00 March-May June-August September-November Latitude*00:01-12:00 Latitude*March-May 00:01-12:00*March-May	11	-701.4	2.5	0.060

Table 3.9. The top 5 best fitting models that estimated the CPUE of Kemp's ridley turtles in shipping channels in the northwestern Gulf of Mexico. The estimated random effect (remaining variation among channels) was <0.0001 in all models. Estimates and confidence interval values are in Kemp's·30.5-m net-hour^{-1}. Parameters are described in Table 3.1.

Model	Parameter	Parameter estimate	90% Confidence Interval Lower	90% Confidence Interval Upper
W2 SP SU LAT*SP W2*SP				
	Intercept	0.0026	-0.0003	0.0055
	00:01-12:00	-0.0044	-0.0072	-0.0015
	March-May	0.0357	0.0248	0.0466
	June-August	0.0035	0.0007	0.0063
	Latitude*March-May	-0.0120	-0.0156	-0.0084
	00:01-12:00*March-May	0.0099	0.0038	0.0160
LAT W2 SP SU LAT*W2 LAT*SP W2*SP				
	Intercept	-0.0029	-0.0109	0.0051
	Latitude	0.0019	-0.0003	0.0041
	00:01-12:00	0.0050	-0.0038	0.0139
	March-May	0.0367	0.0250	0.0483
	June-August	0.0035	0.0007	0.0003
	Latitude*00:01-12:00	-0.0062	-0.0033	-0.0003
	Latitude*March-May	-0.0123	-0.0162	-0.0084
	00:01-12:00*March-May	0.0095	0.0035	0.0156
LAT W2 SP SU LAT*SP W2*SP				
	Intercept	0.0018	-0.0044	0.0081
	Latitude	0.0003	-0.0014	0.0019
	00:01-12:00	-0.0044	-0.0072	-0.0016
	March-May	0.0364	0.0246	0.0483
	June-August	0.0034	0.0006	0.0063
	Latitude*March-May	-0.0123	-0.0163	-0.0083
	00:01-12:00*March-May	0.0099	0.0038	0.0160
LAT W2 SP SU LAT*W2 LAT*SP LAT*SU W2*SP				
	Intercept	-0.0026	-0.0114	0.0061
	Latitude	0.0018	-0.0006	0.0043
	00:01-12:00	0.0050	-0.0038	0.0139
	March-May	0.0364	0.0244	0.0484
	June-August	0.0026	-0.0082	0.0134
	Latitude*00:01-12:00	-0.0033	-0.0062	-0.0003
	Latitude*March-May	-0.0122	-0.0163	-0.0082
	Latitude*June-August	0.0003	-0.0033	0.0039
	00:01-12:00*March-May	0.0095	0.0035	0.0156

Table 3.9 (Continued)

Model	Parameter	Parameter estimate	90% Confidence Interval Lower	Upper
LAT W2 SP SU FA LAT*W2 LAT*SP W2*SP				
	Intercept	-0.0030	-0.0111	0.0051
	Latitude	0.0018	-0.0004	0.0041
	00:01-12:00	0.0050	-0.0038	0.0139
	March-May	0.0368	0.0251	0.0484
	June-August	0.0039	0.0003	0.0074
	September-November	0.0007	-0.0034	0.0048
	Latitude*00:01-12:00	-0.0033	-0.0062	-0.0003
	Latitude*March-May	-0.0122	-0.0162	-0.0083
	00:01-12:00*March-May	0.0095	0.0035	0.0156

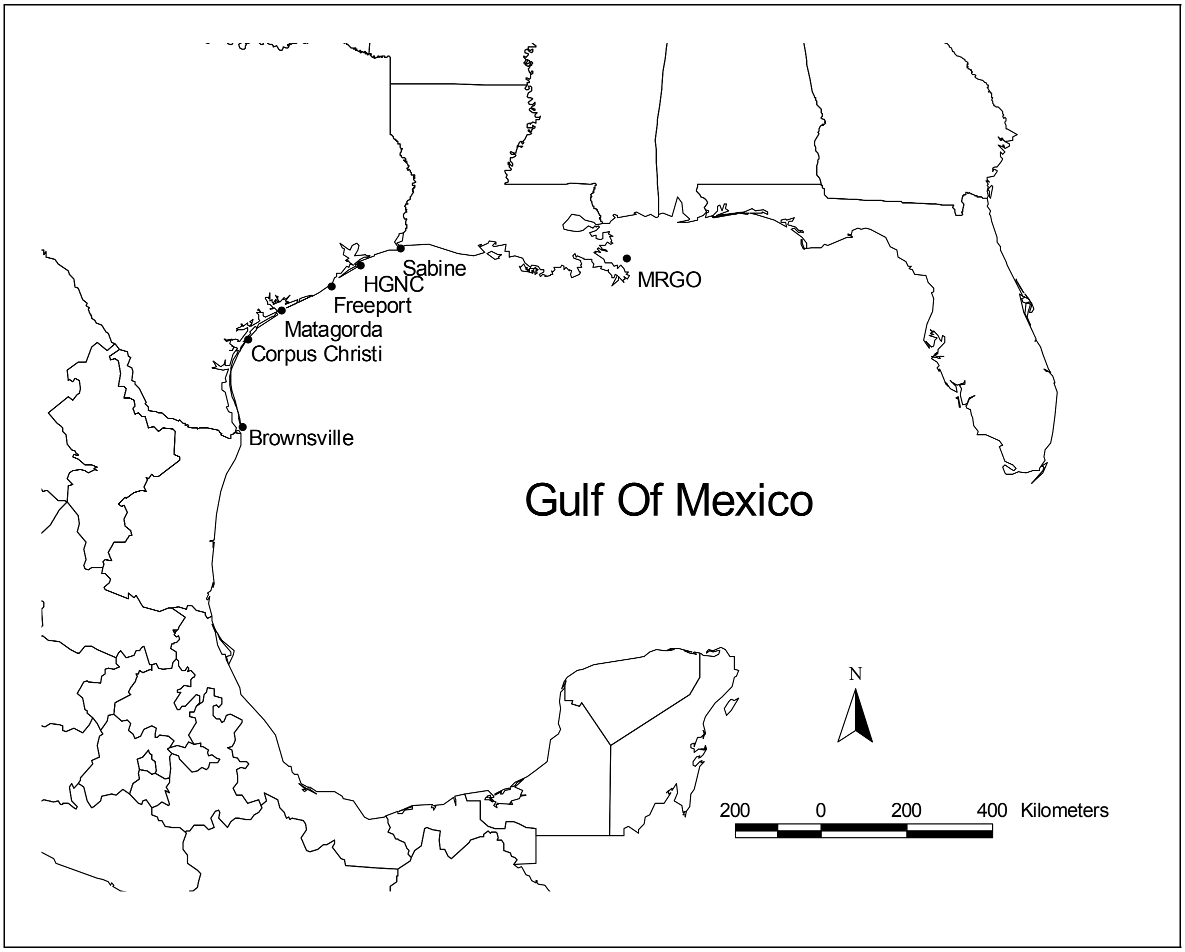

Figure 3.1. Study area in northwestern Gulf of Mexico, U.S.A, showing locations of seven shipping channels from which data were obtained for this study. From north to south, the channels were Sabine, Texas; Mississippi River Gulf Outlet (MRGO), Louisiana; Houston Galveston Navigation Channel (HGNC), Texas; Freeport, Texas; Matagorda, Texas; Corpus Christi, Texas; and Brownsville, Texas.

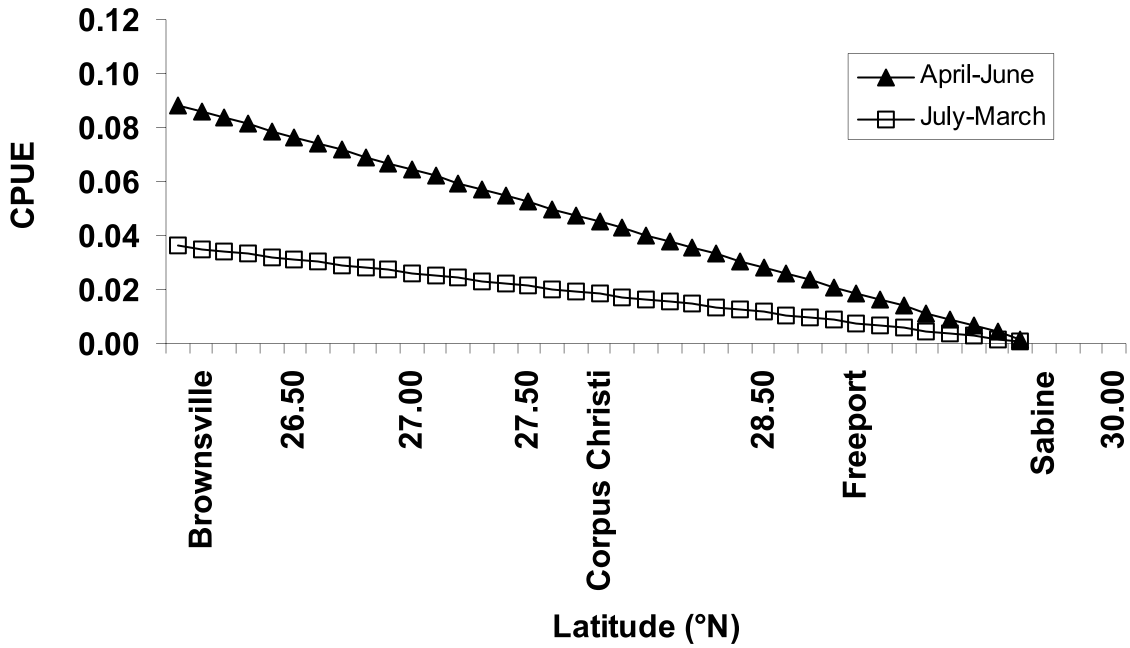

Figure 3.2. The relationship between latitude (ºN) and CPUE (turtles·30.5-m net-hours^{-1}) of all species of marine turtles during different periods of the year, 2001-2005, in shipping channels of the northwestern Gulf of Mexico. Estimates were from the best fitting model controlled for the 36-hour period 18:00-12:00 inclusive, and a mean water temperature of 24.2°C.

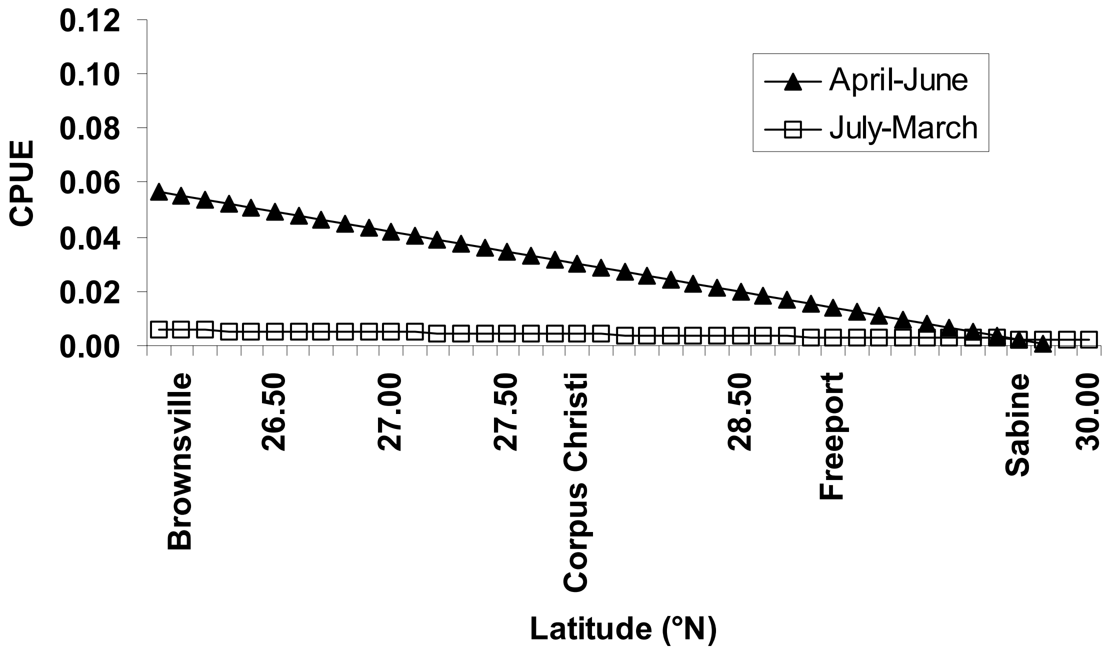

Figure 3.3. The relationship between latitude (°N) and CPUE (turtles·30.5-meter net-hours^{-1}) of loggerhead turtles during different periods of the year, 2001-2005, in shipping channels of the northwestern Gulf of Mexico. Estimates were from the best fitting model controlled for the 36-hour period 18:00-12:00 inclusive and a mean water temperature of 24.2°C.

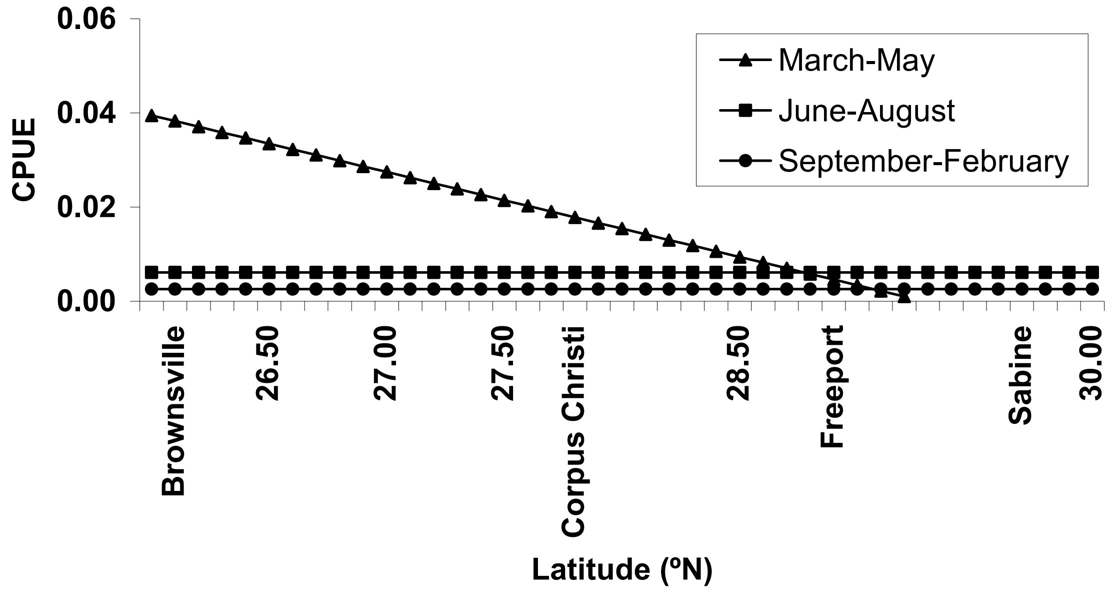

Figure 3.4. The relationship between latitude (ºN) and CPUE (turtles·30.5-m net-hours^{-1}) of Kemp's ridley turtles during different periods of the year, 2001-2005, in shipping channels of the northwestern Gulf of Mexico. Estimates were from the best fitting model controlled for the 12-hour period 12:01-24:00 inclusive and a mean water temperature of 24.2°C.

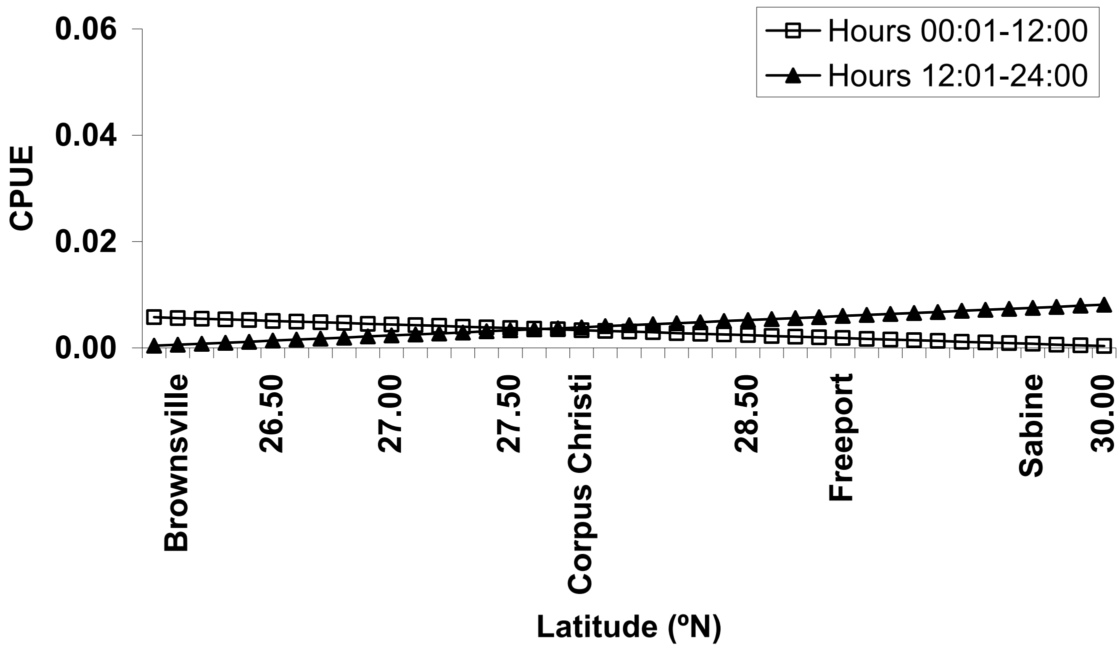

Figure 3.5. Relationship between latitude (ºN) and the CPUE (turtles·30.5-m net-hours^{-1}) of Kemp's ridley turtles during different periods of the day for shipping channels in the northwestern Gulf of Mexico. Estimates were made from the second best fitting model controlled for the months March-May and a mean water temperature of 24.2°C.

CHAPTER 4

CONCLUSIONS

Marine turtles were present in shipping channels of the northwestern Gulf of Mexico between 1995 and 2005, as evidenced by incidental takes by hopper dredges and from captures during relocation trawling. The rate of incidental takes by hopper dredges was affected by latitude, season, and by physical characteristics of the dredges used. The rate of capture by relocation trawling vessels was affected by latitude, surface water temperature, season, time of day, and species of turtle. These findings will be useful to managers in the region who strive to reduce takes by dredges and to allocate dredging and relocation trawling efforts most effectively.

RELATIVE ABUNDANCE

The analyzed sets of U.S. Army Corps of Engineers (USACE) data included 66 turtles taken by dredges and 133 turtles captured during relocation trawling. Loggerhead sea turtles (*Caretta caretta*) were taken by dredges and captured by trawlers most frequently. Forty-one loggerheads were taken by dredges and 88 were captured during relocation trawling. This predominance of loggerheads has also been seen during other trawl sampling efforts in the Gulf of Mexico (Henwood and Stuntz 1987; GSAFDF 1998). Loggerheads were caught throughout the study region. Fourteen green turtles (*Chelonia mydas*) were taken by dredges, and 18 were captured during relocation trawling. Of these 32 green turtles, 29 were taken or captured in Brownsville Channel, the southernmost channel in the study area, and none were captured north of Matagorda, near the latitudinal center of the study area. The higher density of greens in southern channels of the region, relative to northern channels, is consistent with findings of other research (Renaud et al. 1994; Renaud et al. 1995; Landry et al. 1996; Landry et al. 1997) and suggests that the risk of taking green turtles while dredging is primarily confined to the southern half of the region. Eight Kemp's ridley turtles (*Lepidochelys kempii*) were taken by dredges, and 26 were captured during relocation trawling. Kemp's were caught throughout the study region.

The mean dredge take for the region, 1995–2004, was 0.0251 turtles per dredge-day (SD ± 0.1564). Mean catch per unit effort (CPUE) for relocation trawling for the study area during 2001-2005 was 0.0131 turtles·30.5-m net-hour^{-1} (95% CI = 0.0109—0.0154). Estimated CPUE was 0.0173 turtles·30.5-m net-hour^{-1} (95% CI = 0.0089—0.0257) for January-April, 0.0164 (95% CI = 0.0130—0.0199) for May-August, and 0.0071 turtles·30.5-m net-hour^{-1} (95% CI = 0.0044—0.0098) for September-December. Ninety-nine percent of this effort occurred in water <18 m deep.

Henwood and Stuntz (1987) estimated CPUE values from National Marine Fisheries Service (NMFS) data collected during fishery dependent trawl sampling in the northwestern Gulf of Mexico, 1973–1984. The Gulf and South Atlantic Fisheries Development Foundation (GSAFDF; 1998) estimated similar CPUE values from fishery dependent data collected in the late 1990s. Jamir (1999) revised the GSAFDF estimates and compared them to reconstructed estimates from the earlier NMFS database. For discussion purposes, I compared my CPUE estimates to the results of these previous studies for depths <18 m. The USACE estimates were higher than estimates from the NMFS data for all depths and trimesters, and lower than those from the GSAFDF data except in strata where GSAFDF sample strata contained low effort. Because I analyzed samples collected only in shipping channels while these fishery dependant surveys analyzed samples collected from commercial shrimp trawling vessels, results of these studies cannot be compared to make unambiguous conclusions. However, the results are consistent with an increase of turtle density in the region over a 20-year period. The number of Kemp's ridleys nesting in the western Gulf increased between 1987 and 1999 (TEWG 2000) and the continued recovery of this species may account for some of the observed CPUE increase. Turtle managers suggest turtle populations appear to be stable or increasing in the region (NMFS 2003).

The USACE trawling effort represented greater trawl sampling effort in water <18 m than either of the previous trawl studies in the northwestern Gulf of Mexico (Henwood and Stuntz 1987; Jamir 1999). This substantial effort has important implications for management. Because relocation trawling evidently represents the largest source of in-water turtle sampling in the region, and because trawling is an expensive and difficult sampling method, managers should capitalize on this data source. These results may be useful as a baseline for monitoring changes in relative abundance in the area using ongoing relocation trawling.

LATITUDE AND SEASON

Latitude affected both dredge takes and trawl captures and was related to season. In the absence of other predictors, the effect of latitude was negative and estimates of both dredge takes and trawl captures were higher in the southern portion of the study area. This is consistent with studies in the southeastern U.S. Atlantic in which turtles were generally more abundant in trawl samples at southern latitudes (Maier et al. 2004). In best fitting models for both dredge takes and trawl captures, estimated mean take or estimated CPUE decreased with increasing latitude during spring months (March-June). On the U.S. Atlantic coast, turtles move north along the coast in spring and return south in late fall (Van Dolah and Maier 1993; Dickerson et al. 1995; Avens and Lohmann 2004). There is evidence that turtles in the Gulf of Mexico respond to decreasing water temperatures by moving south (Renaud and Carpenter 1994). The lower take rates and

CPUE during spring in northern channels relative to southern channels may result from migratory behavior. Turtles may move into the area in the spring months in response to warming water, photoperiod changes, or changes in prey distribution, arriving earlier in the southern channels.

Estimated dredge takes and trawl captures were greater during spring months than during any other period across most of the study area. Other studies near Sabine and Matagorda found that CPUE rates were greatest in spring and early summer, with few captures in fall months (Landry et al. 1996; Landry et al. 1997). The higher take and capture rates that I estimated for the spring months, relative to all other months, may result from actual differences in turtle density in the general region, from differences in density within shipping channels relative to other nearby habitats, or from differences in catchability during these months.

Estimated dredge takes increased with increasing latitude during the summer months (July-October). Furthermore, no takes were estimated for the southern portion of the study area during these months. This result was unexpected; if turtles arrive in the area in the spring, it is expected that they will remain in the region throughout the warm summer months. Turtles are known to be present in the northern latitudes of my study area during July-August (Renaud and Carpenter 1994; Landry et al. 1996). Shipping channels represent narrow transects in or near the open Gulf, and lead into inshore bays and inlets. Turtles may be uniquely vulnerable during their initial arrival in these areas, or turtles may be concentrated at these bottlenecks as they pass through into inshore bays and harbors where they are not susceptible to dredges and trawlers. Turtles are known to occur in these inshore waters during the summer months (Landry et al. 1996; Landry et al. 1997). Furthermore, there was relatively little effort in southern channels during summer months, suggesting that further data are needed to adequately examine the relative abundance of turtles in the southern areas during these months.

For trawl sampling, there was no meaningful effect of latitude during non-spring months for loggerhead and Kemp's ridley turtles. For loggerheads, no difference in CPUE could be distinguished between summer, fall, and winter months. For Kemps, CPUE estimates for June-August were slightly greater than estimates for September-February.

TRAWLING

Trawling had a negative effect on dredge takes in the best fitting models analyzing the dredge data set. The best fitting model estimated that projects using relocation trawling experienced, on average, 0.0304 turtles per dredge-day fewer takes (90% CI: -0.0605 to -0.0003). This translates into approximately one fewer take per month on projects where trawling is used relative to projects where trawling is not used. The confidence interval was wide, suggesting that while there is evidence of a reduction, the effect is weak. Trawling may have been initiated on projects when takes were observed in the early stages of dredging, or managers may have chosen to use trawling on projects where a high number of takes were expected. These factors could have resulted in trawling being used preferentially on projects where turtles were more abundant and caused the estimated trawling effect to be artificially low. However, even small reductions in takes can be important to managers. Regions are permitted only a limiting number of incidental takes. A single take can result in expense and lost time if dredging operations must be stopped or paused because of the danger of exceeding set limits. Managers believe that relocation trawling reduces turtle mortality by dredges (NMFS 2003). Prior to 2007, the belief in the effectiveness of trawling was based largely upon anecdotal evidence (Dickerson et al. *in* press). This study provides quantitative evidence that relocation trawling does reduce turtle takes by hopper dredges. This finding is consistent with other recent work that suggests that trawling can be effective at reducing incidental takes (Dickerson et al. *in press*).

DREDGE CHARACTERISTICS

Dredges with different hopper sizes and different numbers of drag arms experienced different levels of takes. Most hopper dredges used in the U.S. have two drag arms and hopper capacities >2336 m^2. My data set included only a single dredge with one drag arm. For dredges with two or more drag arms (n = 16), estimated takes were as expected. That is, the highest take level was estimated for a dredge with hopper capacity >2336 m^2 and three drag arms (n = 1); the next highest take level was estimated for dredges with hopper capacities >2336 m^2 and two drag arms (n = 11); and the next highest takes were estimated for dredges with hopper capacities <2336 m^2 and two drag arms (n = 2). This general relationship among these dredges was similar for all seasons, with a negative latitude effect in the spring, fall, and winter, and a positive latitude effect during the summer. However, estimated take rate for dredges with one drag arm (n = 1) increased with latitude for all seasons. Because only a single dredge of this configuration was used, any effect of general dredge characteristics was confounded with individual dredge effects.

That larger dredges experienced higher take rates was not unexpected. However, managers must be aware that larger dredges may complete a project quicker than smaller dredges and that the expected overall take may be similar for a given project. My results suggest that variability in dredge characteristics may be important in how likely dredges are to cause incidental takes. Hopper dredges are each unique in physical design and in how they are operated. Other characteristics related to use, horsepower, hydraulic pump strength, or pump configuration may be more useful in predicting incidental turtle takes.

WATCH

Trawler CPUE of loggerheads and Kemp's was affected by time of day. For loggerheads, CPUE was generally greater during afternoon hours (12:01-18:00) relative to other periods during all seasons at all latitudes. Kemp's CPUE was generally greater during 00:01-12:00 during spring, and lower during these hours during all other months. These effects may be related to diving behavior (Renaud and Carpenter 1994; Renaud et al. 1994). However, because different species occurring in the same channels are more likely to be captured at different times, there are few valid management recommendations to be made from this result. During winter months, the greatest risk appears to occur during the daylight hours (06:01-18:00). However, I suggest that turtles are generally present throughout the 24-hour period and that operators should continue to use all mitigating measures available throughout the day.

TEMPERATURE

Temperature affected trawler CPUE for combined species and loggerheads, but the effect was very small at 0.0008 turtles·30.5-m net-hour^{-1} more for each degree of temperature increase. Turtles are known to occur rarely in temperatures <15ºC, although they have been taken in trawls on the east coast at temperatures below this threshold (Dickerson et al. 1995; Epperly et al. 1995; NMFS 2003). In my data sets, two turtles were taken during 152 dredge days at water temperatures <15ºC, and none were captured in 759 trawls occurring at temperatures <15ºC. This suggests that turtles in the northwestern Gulf of Mexico occur only rarely at temperatures <15ºC

MANAGEMENT RECOMMENDATIONS

ENVIRONMENTAL WINDOWS

Managers are concerned with reducing takes by hopper dredges to protect marine turtle populations and to conduct necessary hopper dredging operations within ESA guidelines to avoid extra cost and loss of efficiency. Environmental windows have been used with success in the U.S. Atlantic (Dickerson et al. 2004). My findings suggest that limiting dredging to November-February might provide a reduction in takes in the northwestern Gulf, relative to dredging throughout the year. Therefore I recommend that dredging in the USACE Galveston District be conducted, when possible, during November-February. Currently, the entire Gulf is managed under similar dredge windows. However, my results suggest that there are substantial differences in relative abundance within the study area during the closed time period. I found that even during spring months, the most northern channels in the USACE Galveston District present lower risk than the southernmost channels. Therefore, I further recommend that if dredging must occur during this high-risk period, that this effort be allocated to the northernmost channels as much as possible. I further suggest that the months November-February present the lowest risk of dredge takes for all channels north of Corpus Christi. This period may also present lower risk for more southern channels, but data are lacking for these channels.

TRAWLING

My results imply that relocation trawling reduces incidental dredge takes in the region. I recommend that trawling be used in the region to reduce incidental takes, but suggest that the benefits of trawling may not be worth its considerable cost in situations where estimated dredge takes are low. For example, there may be little to gain by using relocation trawling in channels north of HGNC during November-February when dredge takes are predicted to be low.

Although they are not mandated to do so, managers in the Galveston USACE district generally use relocation trawling during all hopper dredge projects in the channels of this study (NMFS 2003). This represents a great source of information on trends and changes in relative abundance in shipping channels. Therefore, I recommend that relocation trawling data should be summarized every 3-5 years and used to calculate CPUE estimates for regions and for specific time periods.

DREDGE DATA COLLECTION

Observers onboard dredges serve the purpose of identifying and reporting incidental takes. Onboard dredge observers collect data of great potential use to managers. Therefore, observers should be trained to collect data using specific standardized methods. I recommend that the USACE continue its efforts to get observer dredge data into electronic media as soon as possible. I recommend that all observers on all projects use a single standard method of reporting the location of dredge activities. Dredge station notation would be suitable for this purpose and I recommend that observers are trained to record this for each load. I recommend that reporting of temperatures, wind speeds, and other environmental data be qualified with the time and the source of the information.

RECOMMENDATIONS FOR FURTHER RESEARCH

- To better understand turtle abundance and seasonality in the region, randomized trawling surveys should be conducted in shallow waters of the Gulf of Mexico. Ideally, surveys should be independent of fishery or relocation trawling activity. The need for trawl sampling data for the Brownsville and Port Mansfield channels during the spring and summer months is especially acute because there is little information on species abundance during these months, although the existing data suggest turtles may be abundant there year round.

- Relocation trawl data should be collected with specific research and monitoring goals in mind. In particular, a summary of basic CPUE data by channels and season every five years will be useful in determining trends in turtle abundance and population composition in the region.
- The great variation in takes by different dredge types suggests that physical dredge factors may be affecting turtle takes. Therefore, different physical aspects of dredges should be considered, as well as different operational methods. Because these data are not readily available or are difficult to gather after the fact under the current system, onboard dredge observers should be trained to collect these data regularly, based on specific research questions.
- Variation in takes also may be related to location within the channel and to progress of dredge excavation. I recommend that a standardized method of recording dredge project progress and the location of dredging activities be mandated for all observers with the goal of answering these questions with future research. I recommend that observers be taught to use "dredge station" notation or similar for this purpose.

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APPENDIX A. Dredging effort (dredge days) and incidental dredge takes of marine turtles (*Caretta caretta, Chelonia mydas, Lepidochelys kempii*, and unidentified species) by channel and by month for selected dredge projects in shipping channels of the northwestern Gulf of Mexico, 1995-2005.

Channel	**Months**											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sabine												
Effort	29	22	50	52	22	18	5	66	53	4		15
Takes	0	0	0	0	0	0	0	1	0	0		0
MRGO[a]												
Effort		24	27	128	66	65	49	29	34	125	192	57
Takes		0	0	7	3	5	2	0	0	6	1	1
HGNC[b]												
Effort				16	74	140	113	87	58	29	8	9
Takes				0	0	2	1	2	0	0	0	0
Freeport												
Effort	55	22		20		4	60	101	62	99	114	61
Takes	0	0		0		1	3	2	0	2	0	0
Matagorda												
Effort	14	6					16	3		26		
Takes	1	0					0	0		1		
Corpus Christi												
Effort				21	25	48	18	23	15			
Takes				1	4	3	0	0	1			
Port Mansfield												
Effort			17									
Takes			2									
Brownsville												
Effort	1	35	14	26	26	10						25
Takes	0	4	3	1	0	1						5
TOTAL												
Effort	99	109	108	263	213	285	261	309	222	283	314	167
Takes	1	4	5	9	7	12	6	5	1	9	1	6

[a]MRGO = Mississippi River Gulf Outlet [b]HGNC = Houston Galveston Navigation Channel

APPENDIX B. Trawling effort (30.5-m net-hours), number of turtles captured (*Caretta caretta, Chelonia mydas, Lepidochelys kempii*, *Dermochelys coriacea*), and estimated catch per unit effort (CPUE; turtles·30.5-m net hour^{-1}), with standard error[a] (SE) by month and by channel for selected dredge projects in the northwestern Gulf of Mexico, 1995-2005.

Channel	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sabine												
Effort	177.0						99.0	531.4	469.0			315.1
Turtles	0						4	6	1			0
CPUE	0						0.0404	0.0113	0.0021			0
CPUE SE	0						0.0200	0.0053	0.0021			0
MRGO[b]												
Effort					179.5	9.7		65.7				
Turtles					7	0		2				
CPUE					0.0390	0		0.0304				
CPUE SE					0.0145	0		0.0214				
HGNC[c]												
Effort				237.3	812.8	959.9	361.5	508.3	212.4			
Turtles				3	3	7	2	0	0			
CPUE				0.0126	0.0037	0.0073	0.0055	0	0			
CPUE SE				0.0073	0.0021	0.0028	0.0039	0	0			
Freeport												
Effort							220.1	411.7	1062.1	866.2	246.1	
Turtles							0	1	4	2	0	
CPUE							0	0.0024	0.0038	0.0023	0	
CPUE SE							0	0.0024	0.0019	0 .0016	0	
Matagorda												
Effort	114.5	85.3										
Turtles	0	0										
CPUE	0	0										
CPUE SE	0	0										

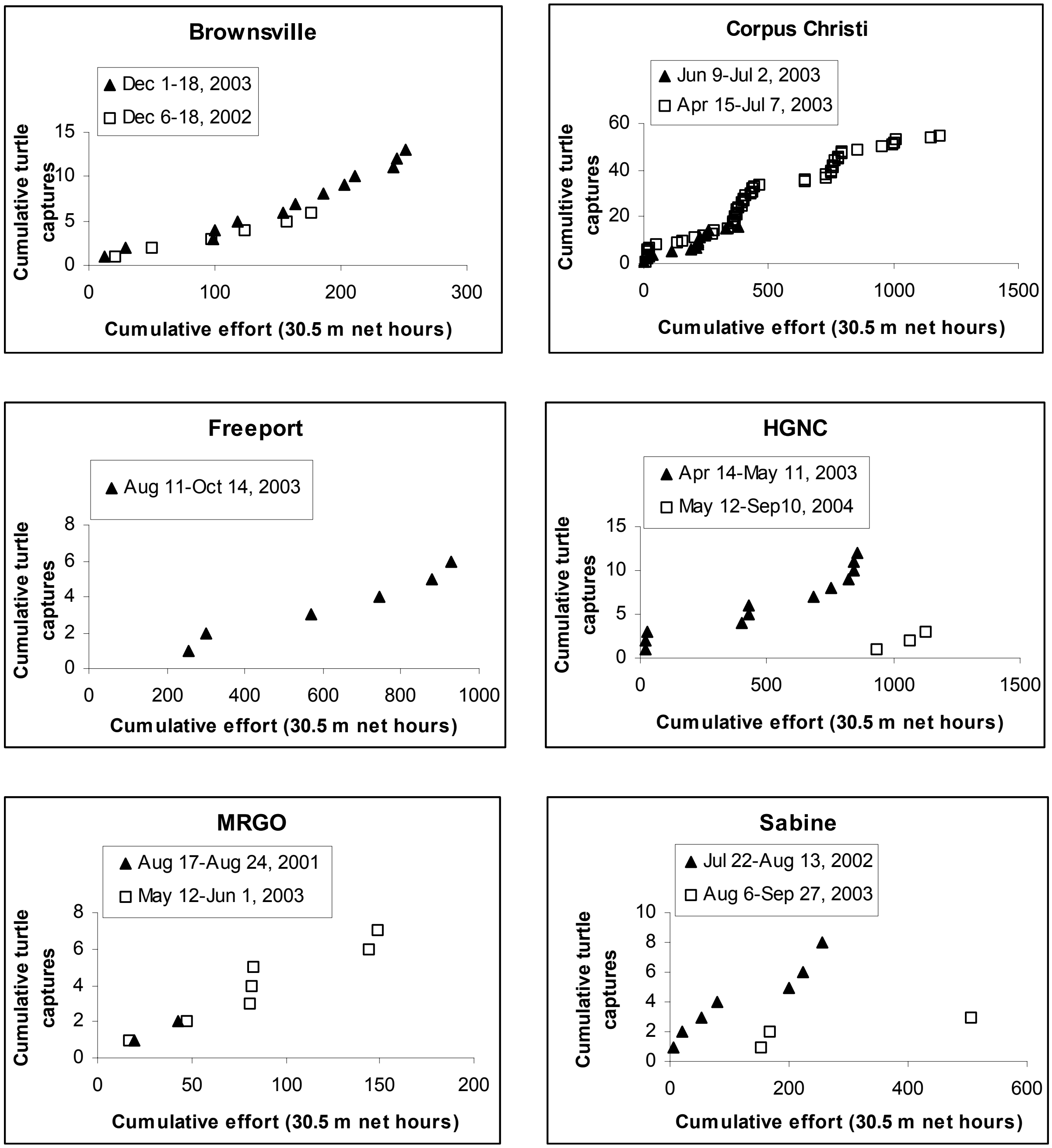
APPENDIX B continued.

Channel	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Corpus Christi												
Effort				311.3	415.5	821.4	143.6					
Turtles				13	24	32	3					
CPUE				0.0418	0.0578	0.0390	0.0209					
CPUE SE				0.0114	0.0115	0.0070	0.0120					
Brownsville												
Effort												489.4
Turtles												19
CPUE												0.0388
CPUE SE												0.0088

[a] Standard error calculated using the method of JAMIR (1999).
[b] Mississippi River Gulf Outlet
[c] Houston Galveston Navigation Channel

APPENDIX C. Confidence set of models estimating mean daily turtle take during hopper dredging in shipping channels in the northwestern Gulf of Mexico, 1995–2004, showing number of parameters (K), Akaike Information Criterion values (AIC), difference in AIC from the best fitting model (ΔAIC), and percentage of the best fitting model weight represented by each individual model weight (% wt). The confidence set contained all models with AIC weights greater than 10% of the best fitting model AIC weight.

Model	**K**	**AIC**	**ΔAIC**	**% *wt***
Latitude March-June Hopper>2336m^3 2-dragarms 3-dragarms Trawling Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms	12	-265.1	0	100.0
March-June Hopper>2336m^3 2-dragarms Trawling Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms	10	-264.6	0.5	77.9
March-June Hopper>2336m^3 2-dragarms 3-dragarms Trawling Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms	11	-264.5	0.6	74.1
Latitude March-June 2-dragarms 3-dragarms Trawling Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms	11	-264.4	0.7	70.5
March-June 2-dragarms Trawling Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms	9	-263.9	1.2	54.9
Latitude March-June July-October Hopper>2336m^3 2-dragarms 3-dragarms Trawling Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms	13	-263.1	2.0	36.8
Latitude March-June Hopper>2336m^3 2-dragarms 3-dragarmsl Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms	11	-262.3	2.8	24.7
Latitude March-June 2-dragarms Latitude*July-October Latitude*2-dragarms	8	-262.0	3.1	21.2
Latitude March-June July-October Hopper>2336m^3 2-dragarms 3-dragarms Level-1-trawl Level-2-trawl Level-3-trawl Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms Latitude*Level-1-trawl Latitude*Level-2-trawl Latitude*Level-3-trawl	18	-261.5	3.6	16.5
Latitude March-June July-October Hopper>2336m^3 2-dragarms 3-dragarms Trawling Latitude*March-June Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms	14	-261.3	3.8	15.0
Latitude March-June July-October 2-dragarms 3-dragarms Level-1-trawl Level-2-trawl Level-3-trawl Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms Latitude*Level-1-trawl Latitude*Level-2-trawl Latitude*Level-3-trawl	17	-261.1	4.0	13.5
Latitude March-June 2-dragarms Trawling Latitude*July-October Latitude*2-dragarms	9	-261.0	4.1	12.9
Latitude March-June July-October Hopper>2336m^3 2-dragarms 3-dragarms Level-2-trawl Level-3-trawl Trawling Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms Latitude*Level-2-trawl Latitude*Level-3-trawl	17	-261.0	4.1	12.9
Latitude March-June July-October 2-dragarms 3-dragarms Level-2-trawl Level-3-trawl Latitude*July-October Latitude*2-dragarms Latitude*3-dragarms Latitude*Level-2-trawl Latitude*Level-3-trawl	15	-260.6	4.5	10.5



APPENDIX D. Cumulative turtle captures, cumulative trawling effort, and dates worked by individual trawlers for each channel and for each project from the study data set in which >2 turtles were captured, 2001-2005.

APPENDIX E. Confidence set of models estimating CPUE of combined turtle species (loggerhead, Kemp's, Green, and leatherback) from shipping channels in the northwestern Gulf of Mexico, 2001–2005, showing number of parameters (K), Akaike Information Criterion values (AIC), difference in AIC from the best fitting model (ΔAIC), and percentage of the best fitting model weight represented by each individual model weight (% wt). The confidence set contained all models with AIC weights greater than 10% of the best fitting model AIC weight.

Model	**K**	**AIC**	**ΔAIC**	**% *wt***
Latitude Temperature 12:01-1800 April-June Latitude*April-June	8	-466.6	0	100.0
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Latitude*12:01-18:00	9	-466.6	0	100.0
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Temperature*April-June	9	-465.7	0.9	63.8
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Latitude*12:01-18:01 Temperature*April-June	10	-465.7	0.9	63.8
Latitude Temperature 00:01-12:00 April-June Latitude*April-June	8	-465.4	1.2	54.9
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Latitude*Temperature	9	-465.1	1.5	47.2
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Latitude*Temperature Latitude*12:01-18:01	10	-465.1	1.5	47.2
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Latitude*Temperature	10	-463.9	2.7	25.9
Latitude Temperature 12:01-18:00 April-June	7	-463.8	2.8	24.7
Latitude Temperature 00:01-12:00 April-June Latitude*April-June 00:01*April-June	9	-463.5	3.1	21.2
Latitude Temperature 00:01-06:00 06:01-12:00 12:01-18:00 18:01-00:00 April-June Latitude*April-June	5	-463.4	3.2	20.2
Latitude Temperature 00:01-12:00 April-June	7	-462.7	3.9	14.2
Latitude Temperature April-June Latitude*April-June	7	-462.6	4.0	13.5

APPENDIX F. Confidence set of models estimating CPUE of loggerhead turtles from shipping channels in the northwestern Gulf of Mexico, 2001–2005, showing number of parameters (K), Akaike Information Criterion values (AIC), difference in AIC from the best fitting model (ΔAIC), and percentage of the best fitting model weight represented by each individual model weight (% wt). The confidence set contained all models with AIC weights greater than 10% of the best fitting model AIC weight.

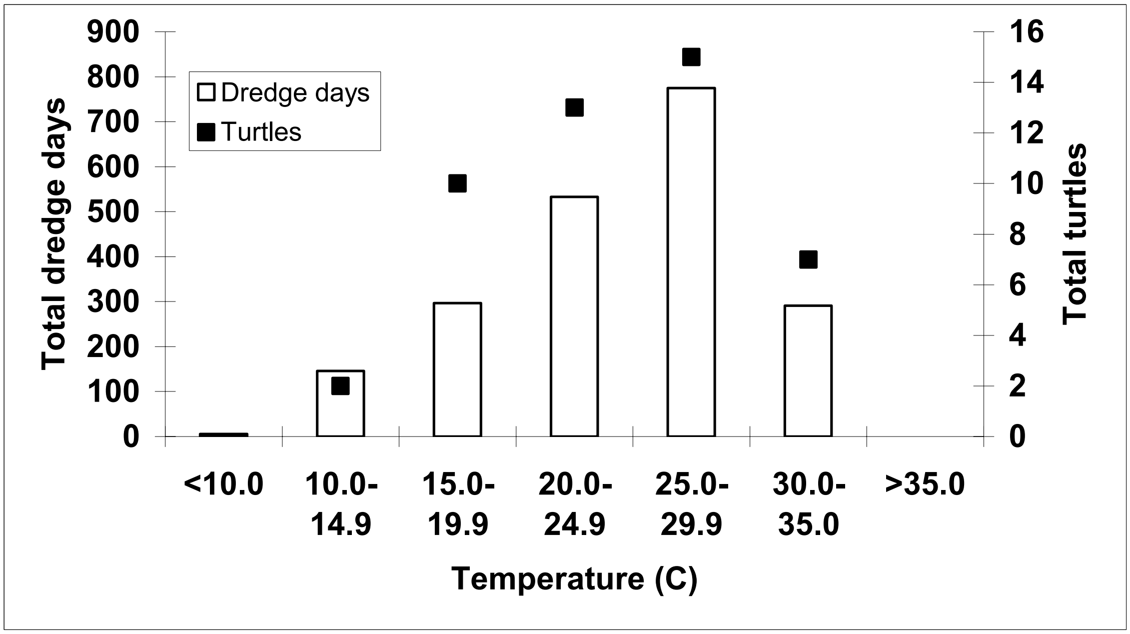
Model	**K**	**AIC**	**ΔAIC**	**% *wt***
Latitude Temperature 12:01-18:00 April-June Latitude*April-June	8	-531.1	0	100.0
Latitude Temperature 00:01-06:00 April-June Latitude*April-June	8	-531.0	0.1	95.1
Latitude Temperature 00:01-12:00 April-June Latitude*April-June	8	-530.7	0.4	81.9
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Latitude*Temperature	9	-530.7	0.4	81.9
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Temperature*April-June	9	-530.6	0.5	77.9
Latitude Temperature 00:01-06:00 April-June Latitude*April-June Temperature*April-June	9	-530.5	0.6	74.1
Latitude Temperature 00:01-12:00 April-June Latitude*April-June Temperature*April-June	9	-530.1	1.0	60.7
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Temperature*April-June Latitude*Temperature	10	-529.7	1.4	49.7
Latitude Temperature 00:01-06:00 April-June Latitude*April-June 00:01*April-June	9	-529.6	1.5	47.2
Latitude Temperature 00:01-12:00 April-June Latitude*April-June 00:01-12:00 *April-June	9	-529.6	1.5	47.2
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Latitude*12:01-18:01	9	-529.2	1.9	38.7
Latitude Temperature 00:01-06:00 April-June Latitude*April-June Temperature*April-June 00:01-06:00*April-June	10	-529.1	2	36.8
Latitude Temperature April-June Latitude*April-June	7	-529.0	2.1	35.0
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Latitude*Temperature Latitude*12:01-18:00	10	-528.8	2.3	31.7
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Temperature*April-June Latitude*12:01-18:00	10	-528.7	2.4	30.1
Latitude Temperature 12:01-18:00 April-June Latitude*April-June Temperature*April-June12:01-18:00*April-June	10	-528.6	2.5	28.7
Latitude Temperature April-June Latitude*April-June Temperature*April-June	8	-528.4	2.7	25.9

APPENDIX F continued.

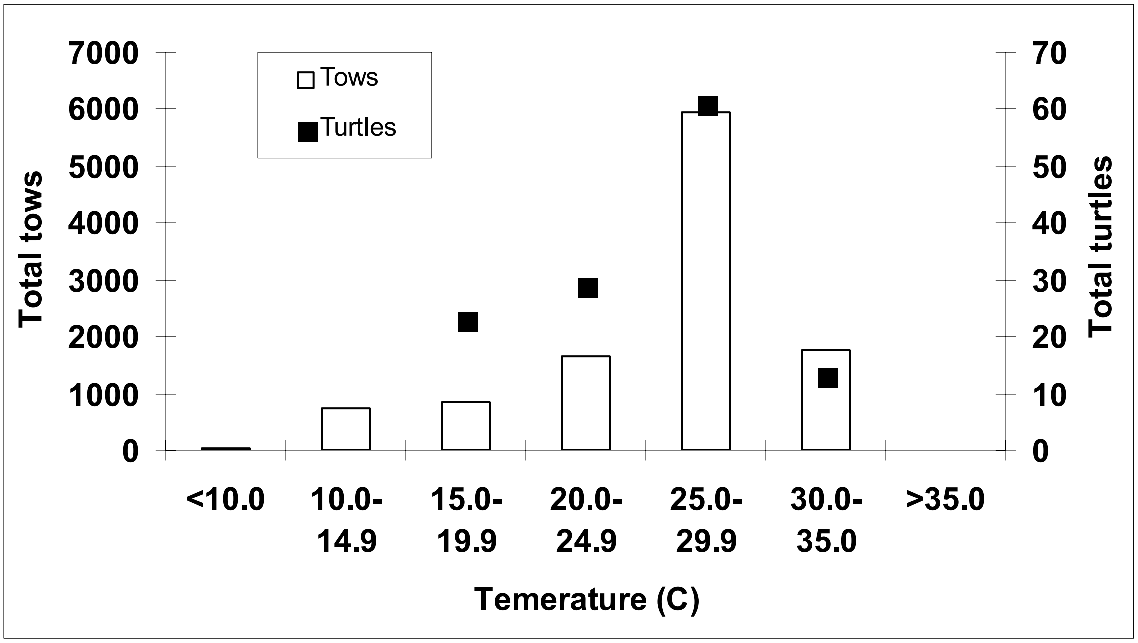
Model	**K**	**AIC**	**ΔAIC**	**% *wt***
Latitude Temperature 00:01-12:00 April-June Latitude*April-June 00:01-12:00*April-June Latitude*00:01-12:00	10	-527.6	3.5	17.4

APPENDIX G. Confidence set of models estimating CPUE of Kemp's ridley turtles from shipping channels in the northwestern Gulf of Mexico, 2001–2005, showing number of parameters (K), Akaike Information Criterion values (AIC), difference in AIC from the best fitting model (ΔAIC), and percentage of the best fitting model weight represented by each individual model weight (% wt). The confidence set contained all models with AIC weights greater than 10% of the best fitting model AIC weight.

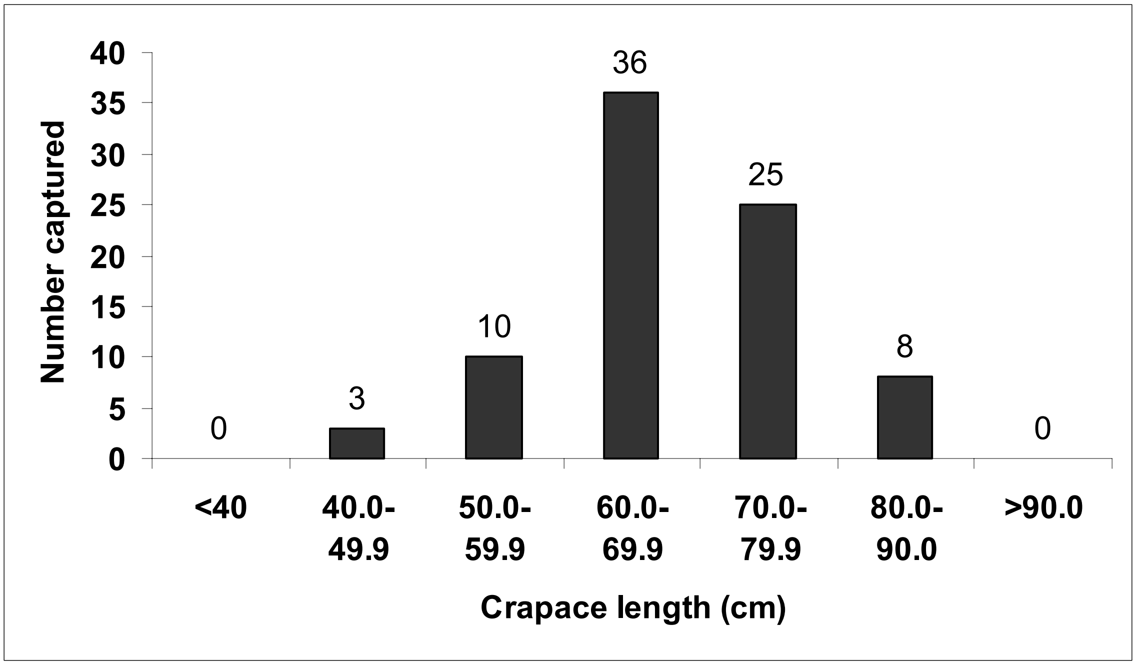
Model	**K**	**AIC**	**ΔAIC**	**% wt**
00:01-12:00 March-May June-August Latitude*March-May 00:01-12:00*March-May	8	-703.9	0	100.0
Latitude 00:01-12:00 March-May June-August Latitude*00:01-12:00 Latitude*March-May 00:01-12:00*March-May	10	-703.3	0.6	74.1
Latitude 00:01-12:00 March-May June-August Latitude*March-May 00:01-12:00*March-May	9	-702.0	1.9	38.7
Latitude 00:01-12:00 March-May June-August Latitude*00:01-12:00 Latitude*March-May Latitude*June-August 00:01-12:00*March-May	11	-701.4	2.5	28.7
Latitude 00:01-12:00 March-May June-August September-November Latitude*00:01-12:00 Latitude*March-May 00:01-12:00*March-May	11	-701.4	2.5	28.7
00:01-12:00 March-May Latitude*00:01-12:00 Latitude*March-May 00:01-12:00*March-May	8	-701.2	2.7	25.9
Latitude 00:01-12:00 March-May s Latitude*00:01-12:00 Latitude*March-May 00:01-12:00*March-May	9	-701.2	2.7	25.9
00:01-12:00 May-July Latitude*00:01-12:00 Latitude*May-July 00:01-12:00*May-July	8	-700.7	3.2	20.2
00:01-12:00 March-May September-November Latitude*00:01-12:00 Latitude*March-May 00:01-12:00*March-May	9	-700.2	3.7	15.7
Latitude 00:01-12:00 March-May September-November Latitude*00:01-12:00 Latitude*March-May 00:01-12:00*March-May	10	-700.2	3.7	15.7



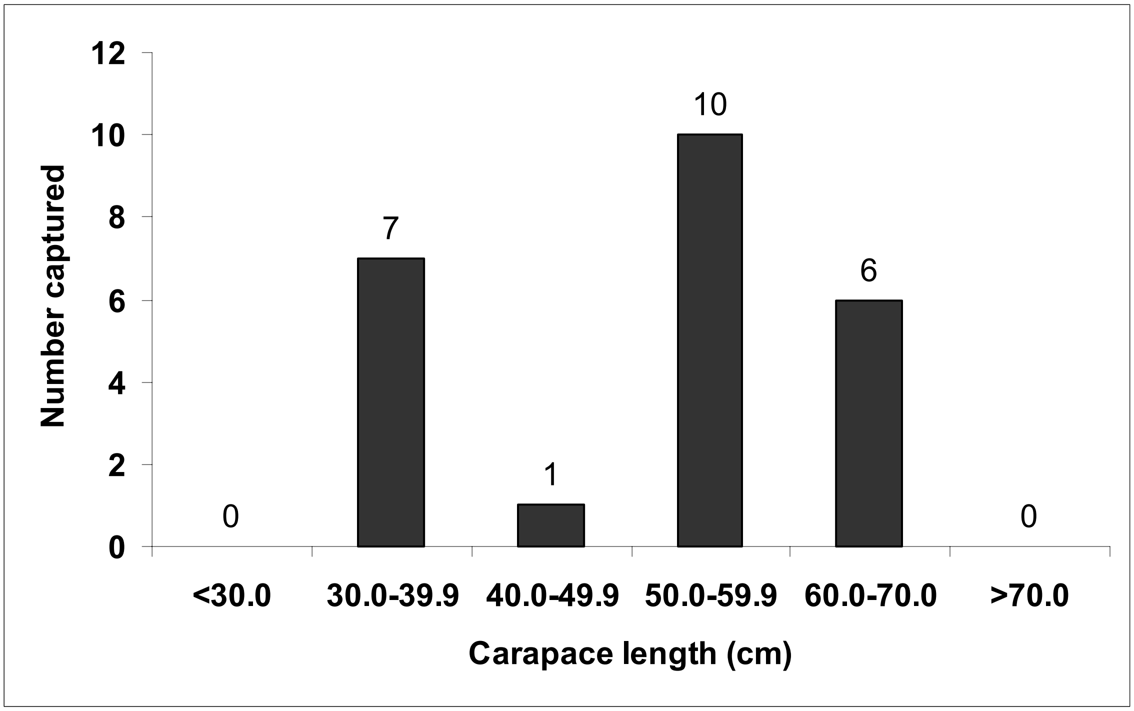
APPENDIX H. Number of dredge days and number of incidental turtle dredge takes at different sea surface temperatures (C) during dredge projects in shipping channels in the northwestern Gulf of Mexico, 1995-2005.



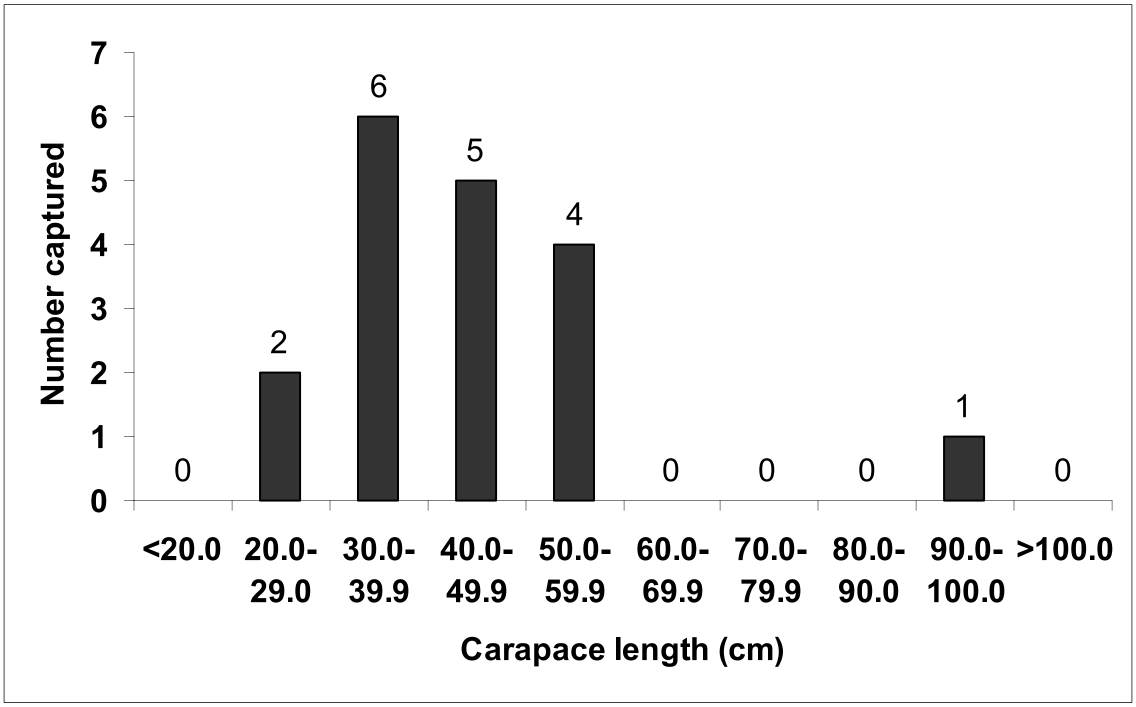
APPENDIX I. Number of tows and number of turtles captured at different sea surface temperatures (C) during relocation trawling at dredge projects in shipping channels in the northwestern Gulf of Mexico, 2001-2005.



APPENDIX J. Distribution of carapace lengths (straight length) of loggerhead turtles captured during relocation trawling in shipping channels in the northwestern Gulf of Mexico, 2001-2005.



APPENDIX K. Distribution of carapace lengths (straight length) of Kemp's ridley turtles captured during relocation trawling in shipping channels in the northwestern Gulf of Mexico, 2001-2005.



APPENDIX L. Distribution of carapace lengths (straight length) of green turtles captured during relocation trawling in shipping channels in the northwestern Gulf of Mexico, 2001-2005.

APPENDIX M. Example of suggested marine endangered species observer dredge load data form. Example presented on page 113. Form is based on existing form available for viewing at: http://el.erdc.usace.army.mil/seaturtles/docs/observerforms.pdf

ENDANGERED SPECIES OBSERVER PROGRAM

LOAD DATA FORM

USACE DISTRICT:____________________ CHANNEL:________________________
CONTRACT #:______________ Maintenance___New Work___ Project start date__________
PROJECT NAME:___________________________
DREDGE NAME:____________________ DREDGE COMPANY:________________

LOAD #:______ LOAD start date:________ LOAD times (24 hr): Start_________ END________
LOAD LOCATION (Dredge station): Start:______+____ End:______+____

TURTLES OR TURTLE PARTS FOUND: YES_____ NO_____
SPECIES OF TURTLE: unknown loggerhead Kemp's ridley green hawksbill leatherback

Description of dredged material:____
Volume of material dredged (cubic yards):_____________

SCREENING:		**Condition:**	**Coverage**				
	Port inflow:	_________	**None**	**25%**	**50%**	**75%**	**100%**
	Starboard inflow:	_________	**None**	**25%**	**50%**	**75%**	**100%**
	Overflow:	_________	**None**	**25%**	**50%**	**75%**	**100%**
	Other:	_________	**None**	**25%**	**50%**	**75%**	**100%**

Number of dragheads used:_______ Type of dragheads:_______ Size of dragheads:_______
Draghead deflector: Yes_____ No_____ Condition of deflector:__________________________

Skies: Clear___ Scattered clouds___ Mostly cloudy___ Overcast___ **Precipitation:** Yes___ No___
Tide: Ebb___ Slack ebb___ Flood___ Slack flood___ Unknown___
Wave ht:______ft Source: Buoy report/VHF weather___ Visual estimate___
Wind sp/direction:___/___ Source: Vessel instruments___ Visual estimate___
Air temp:___ °C/°F Source: Observer instrument___Vessel instrument___ Other_____

WATER TEMP: Surface___ °C/°F Mid depth___ °C/°F Date/time taken:________/_________
Water temp source: Observer instrument____ Vessel Instrument____ Other__________

Count or estimate number:	**Port Screens**	**Starboard Screens**	**Overflow Screens**
Sturgeon (any species)	____________________	____________________	____________________
Fin fish (any species)	____________________	____________________	____________________
Sharks (any species)	____________________	____________________	____________________
Horseshoe crabs	____________________	____________________	____________________
Blue crabs	____________________	____________________	____________________
Other	____________________	____________________	____________________

COMMENTS:____
____
____
____

% Observer coverage: 50%_____ 100%_____
Observer name:______________________
Observer company:___________________ Observer signature:________________________